ADEQ
Arizona Department of Environmental Quality
Janice K. Brewer, Governor
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Little Colorado River

Silver Creek to Carr Lake Draw
Reach # 15020002-004

Suspended Sediment Concentration TMDL

Little Colorado River Watershed
Apache and Navajo Counties, Arizona

June 2013

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LIST OF ABBREVIATIONS

A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AgI	Agricultural-Irrigation
AgL	Agricultural-Livestock watering
A.R.S.	Arizona Revised Statutes
ASTM	American Society for Testing and Materials
AUM	Animal Unit Month
AZPDES	Arizona Pollution Discharge Elimination System
A-S NF	Apache-Sitgreaves National Forests
A&Wc	Aquatic and Wildlife-cold water
A&Ww	Aquatic and Wildlife-warm water
BLM	Bureau of Land Management
BMP	Best Management Practice
cfs	cubic feet per second
CGP	Construction General Permit
CWA	Clean Water Act
DWS	Domestic Water Source
EPA	United States Environmental Protection Agency
ft.	feet
FC	Fish consumption
FBC	Full Body Contact
GNF	Gila National Forest
LA	Load Allocation
LCR	Little Colorado River
mg/l	milligrams per liter
mgd	million gallons per day
mi.	miles
MOS	Margin of Safety
MSGP	Multi-sector General Permit
NB	Natural background
NEMO	Nonpoint Source Education for Municipal Officials
NEPA	National Environmental Policy Act
NM	New Mexico
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
POR	Period of Record
SSC	Suspended sediment concentration
SWPPP	Storm Water Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
WLA	Waste Load Allocation
WRCC	Western Regional Climate Center
WWTP	Wastewater Treatment Plant

1.0 EXECUTIVE SUMMARY

The Arizona Department of Environmental Quality (ADEQ) 2004 Clean Water Act (CWA) 303[d] List classified the Little Colorado River (LCR) (HUC #15020002-004: from Silver Creek to Carr Wash) as impaired for the aquatic and wildlife - cold water (A&Wc) designated use based on EPA's assessment of turbidity exceedances (eight exceedances in eight assessed events) as evidence of narrative bottom deposits violations. The 2006/2008 ADEQ Water Quality Assessment formally classified the reach as impaired for suspended sediment concentration (SSC) with five of nine rolling geomean determinations exceeding the 80 mg/l criteria in the five-year assessment window. The SSC standard for the aquatic and wildlife cold-water designated use has since been lowered to a 25 mg/l median. Impairment listings result in a total maximum daily load (TMDL) study and report detailing how the impaired waterbody may be brought into attainment of state water quality standards through identification of nonpoint source areas, critical conditions, and percent reductions necessary.

Sampling commenced in 2007 for this TMDL project. Sampling sites were located to take advantage of the presence of a USGS gauge on the LCR at Woodruff, Arizona, and to isolate contributions from the two major subwatersheds feeding the LCR mainstem in the Woodruff vicinity. Seasonality was addressed through sampling at baseflow, spring runoff and storms. All sampling was done via grab sampling methods. TMDL sampling included a minimum of two baseflow, four storm, and one spring melt events. Water samples were analyzed for SSC using Method ASTM D3977C, which reported results in concentrations split between the fine fraction (particles less than 2 mm diameter) and the coarse fraction (particles greater than 2 mm diameter).

Load duration curves were used for modeling SSC loads and calculating the TMDL target values for Reach 15020002-004. The load duration curve approach was chosen for its flexibility, its capacity to identify and address flow-dependent conditions, and the ability to classify and analyze various data points individually in accordance with the requirements of Arizona's water quality standard for SSC. Long-term USGS streamflow gauges in the watershed permitted an in-depth examination of flow history.

The cumulative data for the LCR at Woodruff indicates that reductions are called for in all five flow classes, though insufficient nonstorm data is available to quantify reductions for the upper three flow classes. Specific load allocation reductions necessary are 99.8 percent and 93.1 percent for the dry condition and low flow classes respectively. In neither of these classes were any contributions from the LCR above the Silver Creek confluence present; all necessary quantifiable reductions are attributable to the Silver Creek watershed alone.

Loads are exceeding the system's assimilation capacity in nonstorm conditions (outside of a 48 hour exclusion window) due almost entirely to contributions from the perennial Silver Creek watershed. Loading is further exacerbated by contributions from the LCR subwatershed above the Silver Creek confluence in those few events where the LCR above Silver Creek is flowing in nonstorm - stable flow conditions; however, these are rare occasions accounting for only a small proportion of time. The 48 hour exclusion window for storm events in the SSC water quality standard greatly reduces the sample population available for evaluation in the upper three flow classes; consequently, sources that contribute on a local basis absent overland flows are implicated in the need for nonpoint source loading improvement. Load duration analysis suggests that local point sources are an issue for the impairment, since low flow categories show problems. Additionally, a mix of run-off from impervious developed areas, and riparian zone/floodplain contributions are contributing stressors. Promise is shown for the improvement of riparian buffers and implementation of filter strips and additional local controls for the areas identified as particular problems. Field reconnaissance, field data, and desktop GIS analyses pinpoint the Shumway-Taylor-Snowflake corridor with its extensive farmland and pasture areas adjacent to Silver Creek, along with urban contributions from the towns in the proximity as being the areas where the most improvement in nonpoint source sediment pollution may be achieved.

2.0 BACKGROUND INFORMATION

2.1 Water Quality Standards

Water quality standards for a stream reach are based upon the designated uses assigned to it according to the Arizona Administrative Code Title 18, Chapter 11 (18 A.A.C. 11). This project addresses the segment of the LCR from Silver Creek to Carr Wash [15020002-004] first identified as impaired on the 2004 303[d] list. Table 1 lists the segment, HUC number, and related designated uses.

Segment Description	HUC Number	Designated Uses
Silver Creek to Carr Wash	15020002-004	Aquatic and Wildlife Cold, Fish Consumption, Full Body Contact, Domestic Water Source, Agriculture-Irrigation, Agriculture - Livestock Watering

Table 1. Segment of the LCR with HUC number and designated uses

The segment includes approximately six miles of the LCR from Silver Creek to Carr Wash [15020002-004] listed as impaired for A&Wc designated uses due to SSC exceedances. The watershed above the impaired reach includes the major tributaries of Silver Creek, the LCR main-stem, and the Zuni River.

The applicable SSC standard is a median of 25 mg/l for a four-sample minimum. Prior to January 2009, the SSC water quality standard adopted in 2002 was measured as a geometric mean and set at 80 mg/l for the A&Wc designated use.

2.2 Physiographic Setting

The LCR is located in Apache and Navajo counties in northeastern Arizona (Figure 1). The headwaters originate in the White Mountains along the northern and eastern slopes of Mt. Baldy.

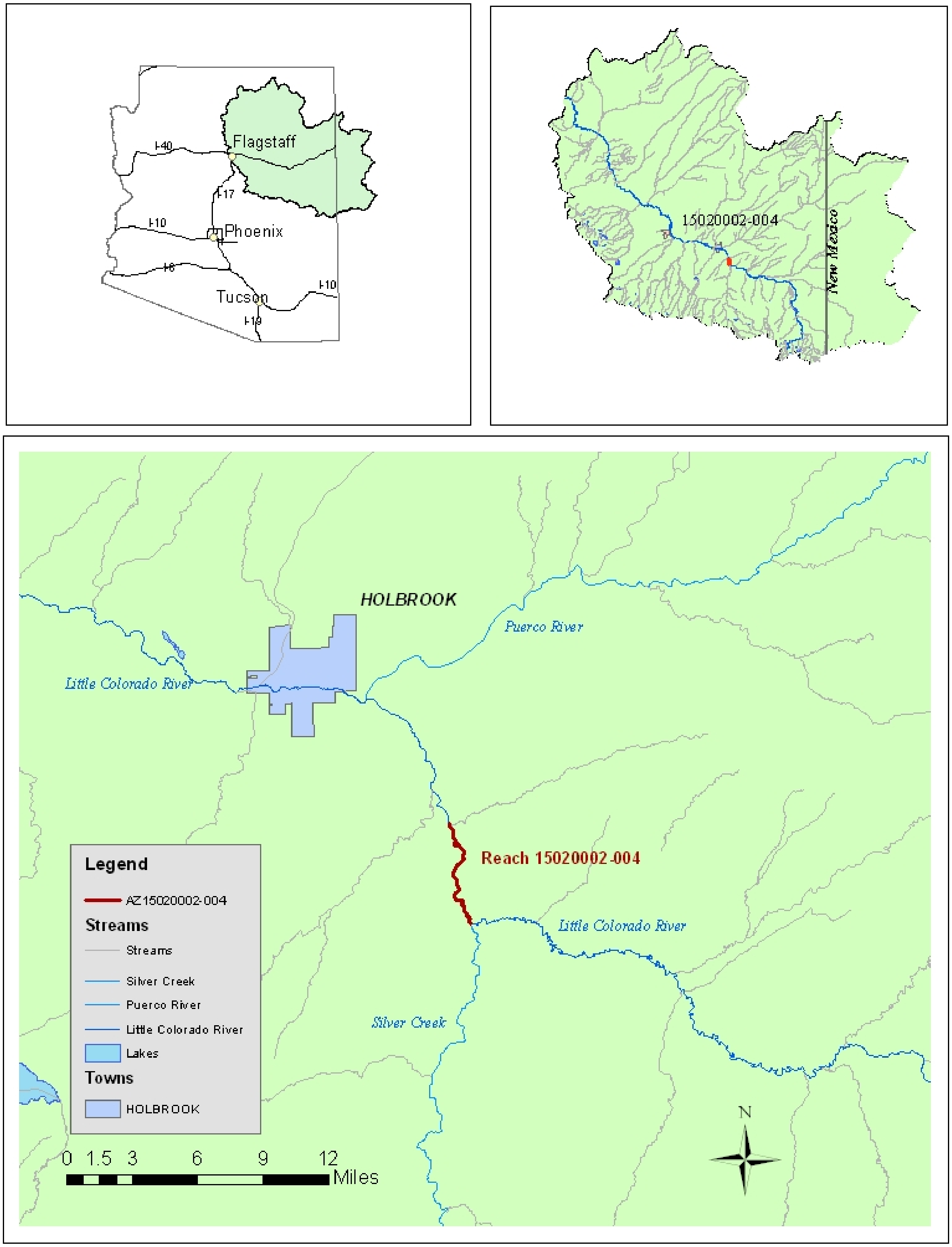

Figure 1. LCR Location Map

It flows to the northwest leaving the basin near Cameron, Arizona and joining the Colorado River in the Grand Canyon.

Elevations in the LCR-San Juan Basin vary from 12,600 feet at Humphrey's Peak, near Flagstaff, to 4,200 feet where the LCR flows out of the basin near Cameron, Arizona (ADWR, 2006). Within the study areas, elevations range from 5,180 feet near the confluence with Silver Creek to over 9,000 feet in the White Mountains. Most of the study area consists of desert highland flora and fauna, with coldwater aquatic communities in the upper reaches of Silver Creek and the LCR where perennial waters exist.

The LCR basin has a drainage area of approximately 26,459 miles upstream from the United States Geological Survey (USGS) gauging station near Cameron, Arizona (09402000), which is 42 miles upstream from its confluence with the Colorado River.

LCR basin land ownership within Arizona is divided among tribal (60 percent), private (15 percent) federal (20 percent) and state (5 percent) lands (Figure 3). Land use is primarily open grazing, forestry, and recreation. The largest communities in the region are Holbrook (pop. 5,053) and Winslow (pop. 9,655) based on the 2010 U.S. Census.

2.3 Climatic Setting

Warm summers and mild winters characterize the general climate of the LCR. Average high temperatures range from the mid 70s to 80s with the highest temperatures starting in late June through early September. Average precipitation in the basin ranges from eight to 12 inches (WRCC, 2003). Much of the rainfall in the basin occurs in June to September as a result of high intensity, short duration storms associated with the summer monsoon season. The basin picks up additional precipitation during the winter months from rain and snow storms.

2.4 Hydrology

Streamflow in the LCR generally is perennial upstream of Woodruff along the Silver Creek stream network and intermittent along the LCR stream network above the Silver Creek confluence. Major tributaries include Silver Creek, Brown Creek, Cottonwood Wash, Zuni River, and Carrizo Wash. Silver Creek, the largest tributary in the watershed in terms of discharge, is characterized by perennial flow. Peak flows in the basin occur between March and April from snowmelt and from July to August from monsoon rainfall.

The mix of essentially perennial waters and intermittent / ephemeral waters, with a large percentage of the watershed drained by the ephemeral waters, and the spatial segregation and interruption of hydrologic continuity at Lyman Lake Dam in the upper portions of the ephemeral regions carries implications for TMDL development. Sizable proportions of stream loading occur as a result of monsoon storms and prolonged winter storms causing intermittent water courses to flow and water quality standards for SSC to be exceeded.

2.5 Geology and Soils

Much of the study area is underlain by Triassic sandstone and mudstone deposits with traces of Pliocene to Mid-Miocene conglomerates and sandstones (Kamilli and Richards, 1998). The LCR and Puerco River channels are cut into older alluvium that fills valleys eroded in the Quaternary Period (Leopold and Snyder, 1951; Mann and Nemecek, 1983). The valley fill varies in thickness from zero to about 148 feet and in width from about 328 feet to about 3.7 miles (Mann and Nemecek, 1983). The headwaters originate south of Springerville, Arizona in the White Mountains, and flow north through Quaternary and Upper Tertiary volcanic rock.

The LCR Basin is home to the Painted Desert and Petrified Forest National Park in the general region of the impaired reach. The landforms comprising these scenic wonders consist of badlands, buttes, and mesas in colorful arrays similar to the Grand Canyon region to the northwest. As such, these formations and landforms are largely exposed soils. Soils in the LCR Basin are highly erosive and fine-grained, with weighted erosivity values in the evaluated subwatersheds of 0.18 to 0.23. Erosivity [K] values range from 0.01 (less erosive) to 0.69 (highly erosive) based on a unit plot tested by the NRCS/SCS. When evaluated by 12 digit HUCs within the study area boundary, the maximum average K value rises to 0.33 (The areal average K value limit for 12 digit HUCs in Arizona is 0.44). RUSLE model results show percentages of fine-grained sediments (< 2 mm) ranging from 39 to 58 percent in the study area subwatersheds.

The high erosivity of the landscape in the study area has implications for sediment loading of the watercourses. Higher erosivity vales can expect to be found in tandem with higher SSC loads in watercourses, regardless of other possible nonpoint source pollution contributions. In short, a higher average K value for a watershed indicates a higher percentage of the SSC contribution considered as natural background in the water column. The main mechanism of loading on southwestern landscapes with limited ground cover is overland flow in short and flashy pulses due to storms that wash sediment into watercourses. Additional discussion regarding soil erodibility is presented in Section 5.1.

2.6 Land Cover and Vegetation

Land cover distribution in the LCR basin reflects its status as a largely rural watershed with arid climate characteristics. Most of the land is characterized by desert scrub in the lower elevations with conifer forests comprising the higher elevations adjacent to the Mogollon Rim. Pinyon-juniper woodland communities occupy an intermediate habitat between the two. Table 2 tabulates the percentages of land cover based on the National Land Cover Dataset of 1992.

The two primary mapped vegetative communities within the LCR watershed above Woodruff are the Plains and Great Basin Grassland (41 percent of the watershed), and Great Basin Conifer Woodland (29 percent of the watershed area) (Figure 2). However, field reconnaissance suggests that mapped units of grasslands have in many cases deteriorated over the years and are now more accurately characterized as desert scrub. Where grasslands exist, they tend to be widely scattered and thinly vegetated, unlike the robust grasslands found in southern Arizona. The relative lack of robustness of the grasslands and the arid climatic regime limiting any improvement in grassland health carries implications for heavier erosive potentials during storm events with overland flow.

Land Cover	Area, sq, mi.	Percent Cover
Shrubland	4346.56	51.32%
Evergreen Forest	3264.49	38.55%
Grasslands/Herbaceous	733.86	8.67%
Bare Rock/Sand/Clay	42.90	0.51%
Pasture/hay	26.96	0.32%
Open Water	13.73	0.16%
Mixed Forest	9.24	0.11%
Commercial/Industrial	7.59	0.09%
Small Grains	6.81	0.08%
Low Intensity Residential	5.78	0.07%
Quarries/Strip Mines/ Gravel Pits	4.36	0.05%
Row Crops	2.27	0.03%
Emergent Herbaceous Wetlands	1.68	0.02%
Urban/Recreational Grasses	1.31	0.02%
Woody Wetlands	1.07	0.01%
Orchards/Vineyards/Others	0.20	<0.01%
Deciduous Forest	0.07	<0.01%

Table 2. Percentages Land Cover, LCR Basin

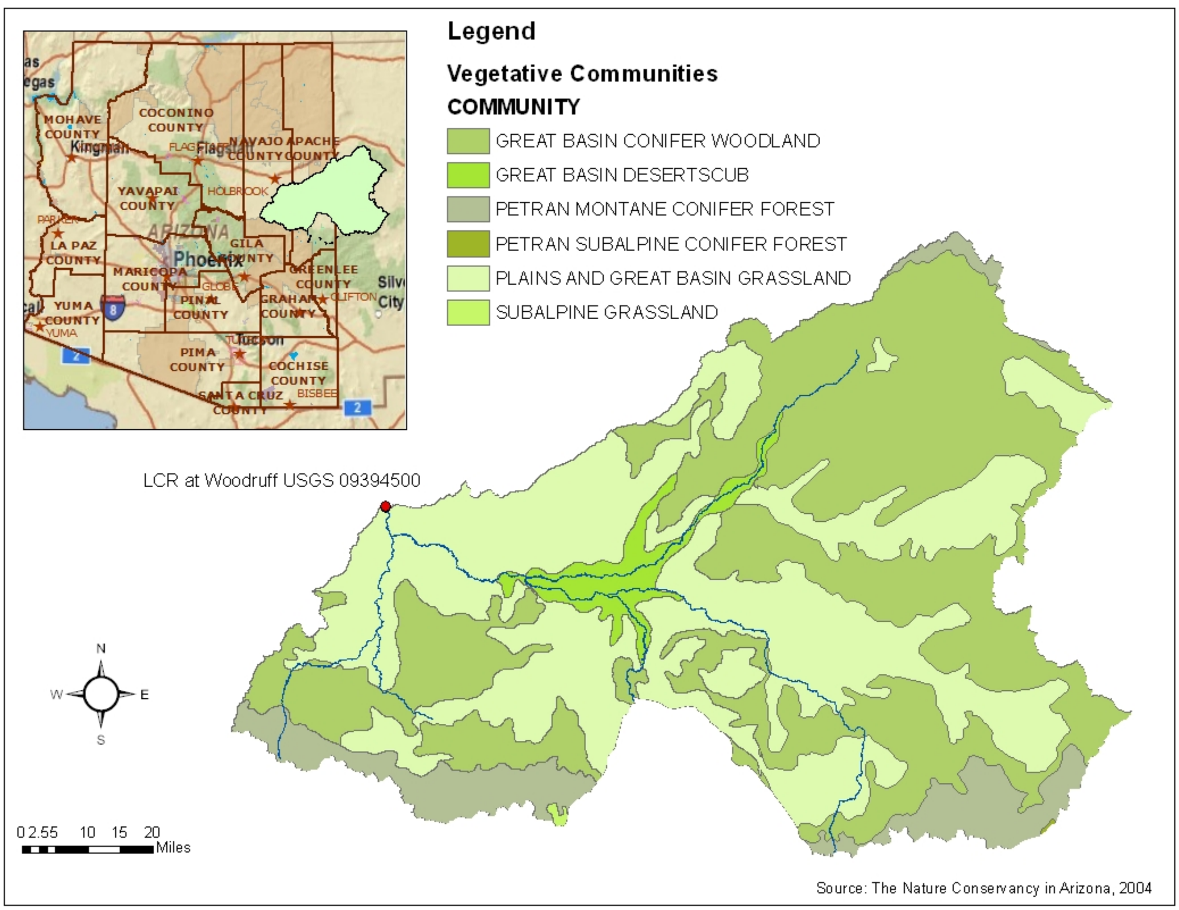

Figure 2. Southwestern Biotic Communities in the LCR Basin above Woodruff

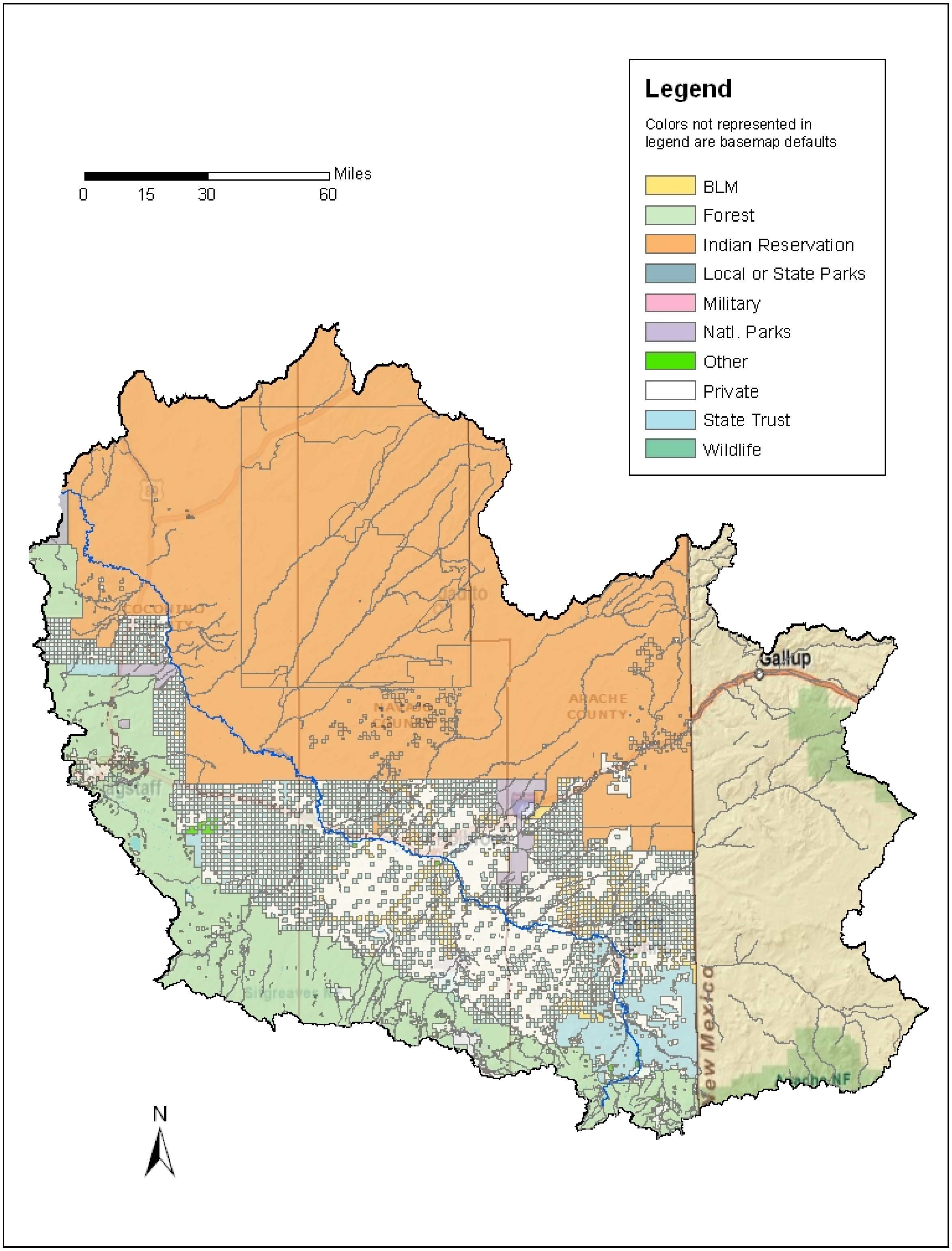

Figure 3. Arizona Land Ownership, LCR Basin

3.0 EXISTING DATA SOURCES

3.1 Existing Water Quality Data and Limitations

Water quality data has been collected from sites within the study area since 1954 by the USGS. Additional sampling has occurred since 1993 by ADEQ. Analytical parameters have included metals, bacteria, nutrients, radiochemicals, inorganics, and suspended sediments.

3.2 Existing Discharge Data

The USGS currently maintains an active real-time gauging station within the study area. A gauge on the Woodruff Road Bridge at Woodruff, Arizona (USGS Site #09394500) provides real time discharge, stage and precipitation data. It also includes historic discharge from 1906 with a continuous record starting in 1935. Some water quality data is also available for this site.

Additional gauges in the area include a gauge on Silver Creek near the confluence with the LCR (09394000), which collected discharge measurements from 1929 to 1952 before its use was discontinued. There are three additional historic gauges on Silver Creek upstream of the study area, including a gauge near Shumway, Arizona (09390000) that includes discharge data from November 1944 to June 1955, a gauge at Snowflake, Arizona (09393000) that includes discharge data from May 1906 to December 1906, and a gauge below Snowflake, Arizona (09393500) that includes discharge from December 1919 to February 1995 and analytical data from May 1971 to May 1974.

Several active gauges cluster on the LCR around St. Johns, Arizona approximately 60-70 miles upstream of the LCR-Silver Creek confluence, including USGS 09386300, 09386030, 09386250, and 09385700, all of which are below Lyman Lake. These gauges are of limited utility due to the intermittent nature of the LCR below St. Johns.

3.3 Existing Precipitation Data

In addition to the precipitation data collected by the USGS, data is also available from five National Weather service (NWS) gauging stations near the study area (Table 3) (WRCC, 2003).

Station Name	Co-op ID	Period of Record[1]
Holbrook	024089	01/01/1893-12/30/2005
Petrified Forest National Park	026468	07/01/1948-12/31/2005
Winslow	029439	10/01/1898-12/31/2005
Snowflake	028012	06/01/1897-12/31/2005
Snowflake 15W[2]	028018	05/01/1965-02/28/1998

Table 3. National Weather Service Stations in the LCR Basin

1 – Period of Record includes historical data for each station, current conditions and observations are available at http://www.wrcc.dri.edu/currentobs.html

2 -- Station is no longer active.

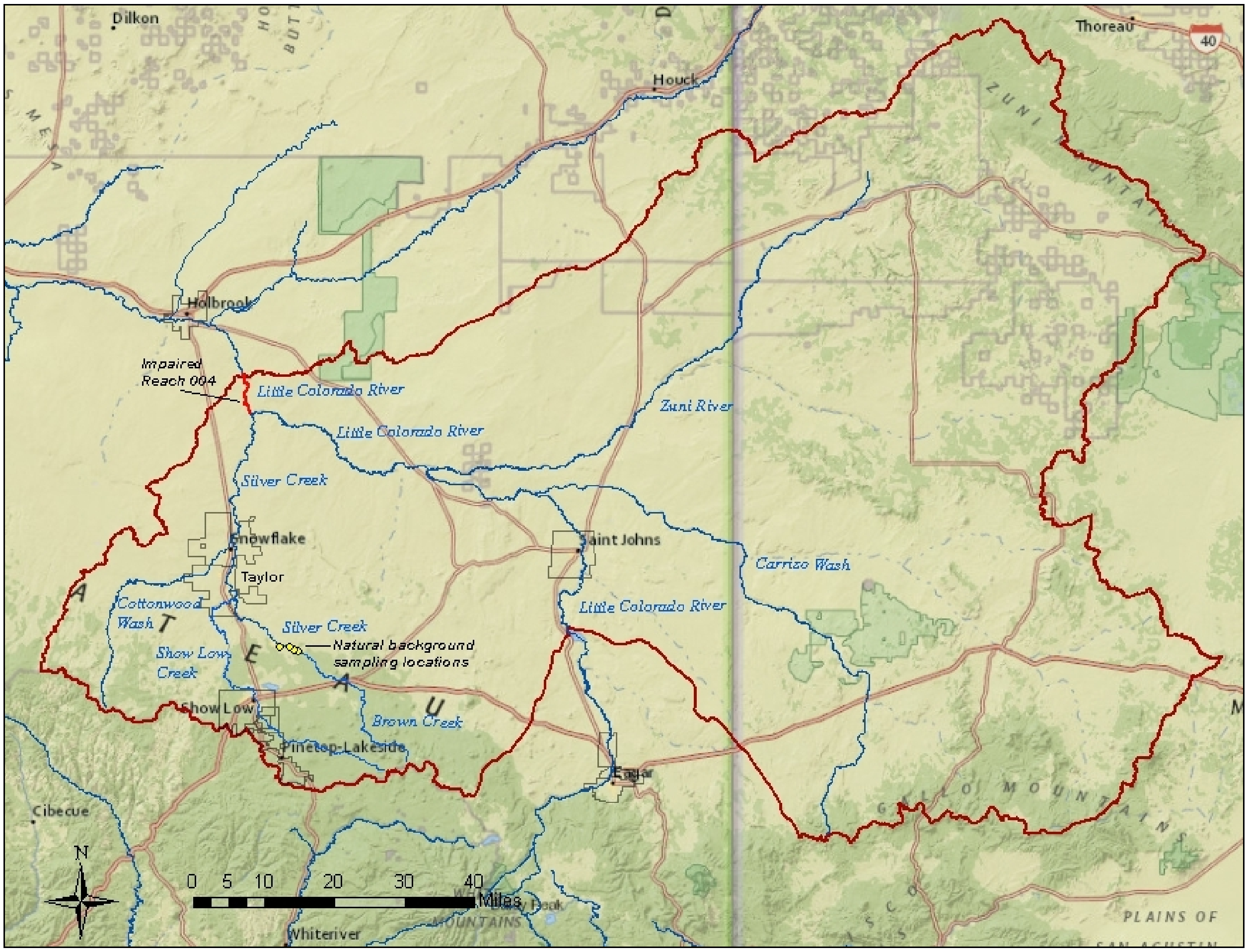

Figure 4. Watershed of the TMDL analysis and natural background sites

4.0 SOURCE ASSESSMENT

The TMDL watershed for analysis is shown in Figure 4. As discussed in Section 5.2, the portion of the LCR watershed above the dam at Lyman Lake Reservoir is excluded from the TMDL analysis. Discussion of the following point sources and nonpoint sources is developed from facilities and land use activities occurring within the watershed boundary.

4.1 Summary of Point Sources

4.1.1 AZPDES and NPDES Permits

The Town of Snowflake Wastewater Treatment Plant (WWTP) (Figure 5) in southern Navajo County formerly held AZPDES permit AZ0024287 allowing discharge to an unnamed tributary of Silver Creek above Reach 15020002-004. The design capacity of the plant was 0.6 MGD (equivalent to a steady discharge of 0.93 cfs). Permit AZ0024287 was allowed to expire on December 21, 2009. The WWTP was not authorized to discharge effluent to the waters of the

United States until a renewal permit could be issued. A new permit (AZ0026034) was issued with generally the same terms effective in February 2012. A new outfall discharging directly to Cottonwood Wash, an intermittent tributary feeding Silver Creek directly, has been constructed. The plant formerly discharged through Outfall 001 to an unnamed dry wash, tributary to Cottonwood Wash, thence tributary to Silver Creek. The design capacity of the plant is unchanged at 0.6 MGD. See Section 7.3 for further discussion of Snowflake's permit status and numeric WLA.

The AZPDES permit for the Pinetop-Lakeside WWTP, also in Navajo County (AZ0025437) which authorized discharges to an unlisted wash, tributary to Show Low Creek, had an expiration date of January 22, 2012, but was administratively continued while the renewal application was processed.. The permit was renewed with the same number effective September 5, 2012 but is restricted to only biosolid operations. No discharges to waters of the United States are authorized in the renewal permit.

AZPDES permit AZ0023841 for the Show Low WWTP sets a TSS monthly concentration limit for effluent of 90 mg/l with a maximum daily reported value of 110 mg/l incorporated. Mass limits of 477 kg/day are given in the terms of the permit. No specific criteria for suspended sediment are listed in the permit. The design capacity of the plant is 2.46 MGD (equivalent to a steady discharge of 3.806 cfs). The plant discharges through Outfall 001 to Telephone Lake and Pintail Lake, constructed wetlands within hydrologically closed sub-basins. The lakes do not discharge to Silver Creek or the LCR hydrologic network. Monitoring is required two times per month, and sampling is by composite samples.

There are no other individual AZPDES permits addressing discharges where suspended sediment is a constituent of concern in Navajo or Apache counties above the LCR–Carr Lake Draw confluence apart from the ones discussed in this section, and no Superfund sites within the delineated watershed in Arizona. Refer to Figure 5 for an overview of contributing individual permittees in the Silver Creek basin.

The Arizona Department of Transportation (ADOT) has state-wide Municipal Separate Storm Sewer System (MS4) permit coverage as a Medium-to-Large municipal operation for its facilities and infrastructure. ADOT operates its stormwater program under a separate individual permit (AZS000018-2008) and program known as the Statewide Stormwater Management Plan (SSWMP). Arizona has several state highways that transit the TMDL watershed, including Highways 77, 277, 260, 180, and 61. ADOT's SSWMP states:

ADOT is considered a large MS4 by virtue of ADOT-owned conveyances or systems of conveyances used for collecting and conveying stormwater. These include drainage systems, catch basins, curbs, gutters, ditches, man-made channels or storm drains associated with roads and highways constructed, maintained, or operated by ADOT. The Arizona Department of Environmental Quality (ADEQ) determined ADOT is required to meet the Phase II MS4 community requirements in addition to the Phase I requirements.
…

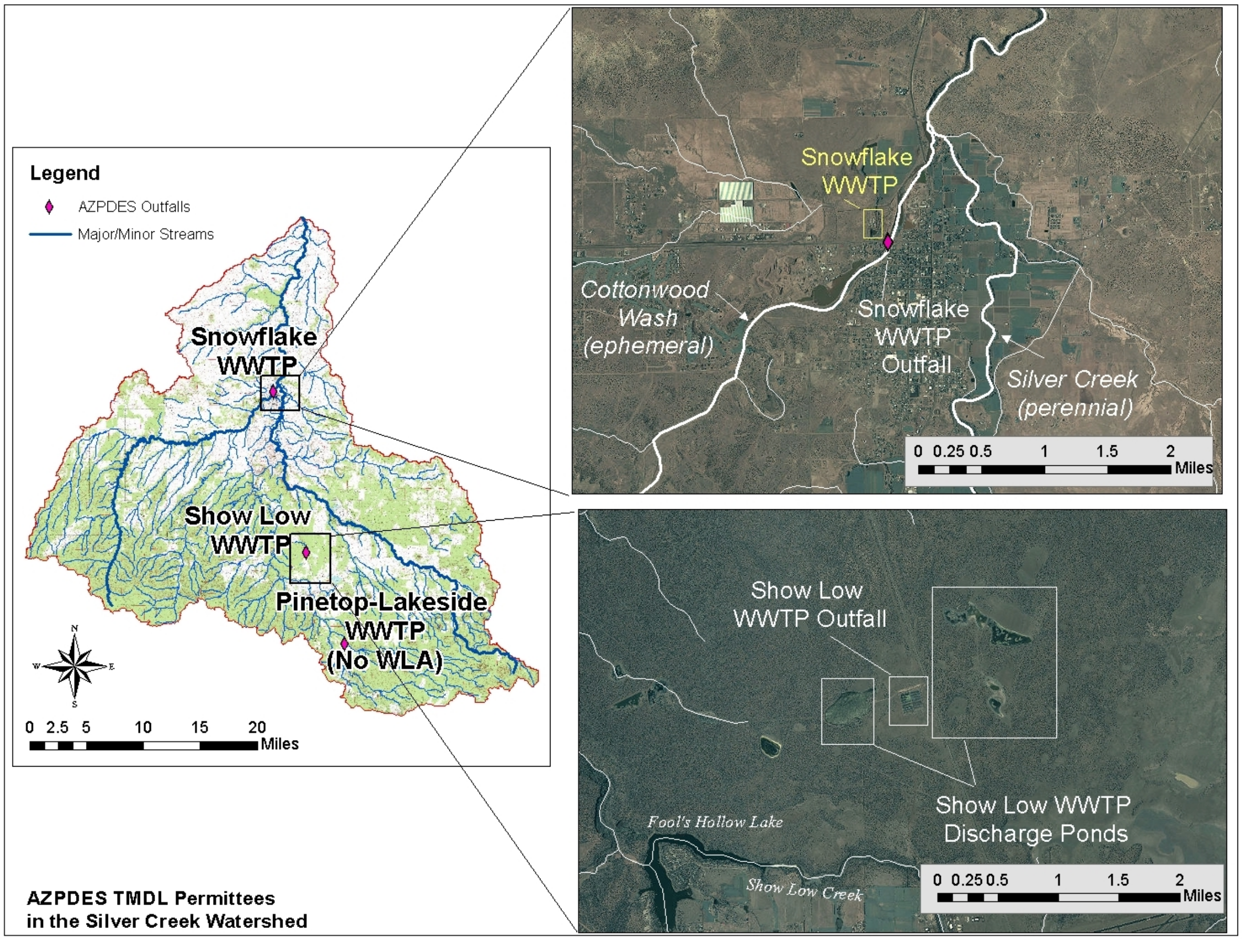

Figure 5. Locations of AZPDES individual permittees in the Silver Creek watershed

ADOT's current AZPDES Permit was issued on September 19, 2008 by ADEQ. This Permit replaces the original National Pollutant Discharge Elimination System (NPDES) Permit issued by USEPA on September 30, 1999. The scope of the current Permit includes all stormwater discharges associated with construction sites, industrial facilities, and MS4s under ADOT's control.

There are no NPDES facilities within the LCR watershed boundary in the State of New Mexico. Additional discussion pertaining to waste load allocations is presented in the following section and Section 7.3.

4.1.2 General Permits, Current and Future Permittees

The purpose of Arizona's multi-sector general permit (MSGP) and construction general permit (CGP) is to protect the quality and beneficial uses of Arizona's surface water resources from pollution in stormwater runoff resulting from mining, non-mining, and construction operations and activities. Under the Clean Water Act and Arizona Revised Statutes, it is illegal to have a point source discharge of pollutants that is not authorized by a permit, including stormwater runoff from industrial or construction sites to a water of the United States. To protect water quality, general permits require operators to plan and implement appropriate pollution prevention and control practices for stormwater runoff.

As of fall 2012, 40 permittees were covered under the CGP in the Little Colorado River watershed in Navajo and Apache Counties. The CGP expires for all permittees on February 28, 2013, but it will be renewed for another term at that date. CGP permittees typically operate for short durations of time under permit coverage, and the number of permittees can fluctuate widely over any given period of time. Consequently, CGP permittees will not be itemized in this TMDL.

As of fall 2012, MSGP permittees in the LCR basin in Navajo and Apache counties numbered 17. MSGP activities and facilities are typically ongoing and of longer durations than CGP operations. Details for MSGP permittees are presented in Table 4.

A concentration-based WLA equivalent to the 2009 A&Wc water quality standard for suspended sediment concentration (25 mg/l) is established for existing and future permittees covered under all sectors of the MSGP, CGP, and MS4s.

ADEQ will require permittees to meet the terms of the WLA in one of the following ways:

- The SSC numeric standard for cold water streams (25 mg/l) shall be met as a concentration-based wasteload allocation for each of the individual stormwater outfalls or other points of discharge as identified in the permittee’s approved SWPPP or
- Permittees can demonstrate through monitoring and reporting that discharges reaching waters with an A&Wc designated use are not causing or contributing to exceedances of the 2009 SSC water quality standard in the receiving waters with the A&Wc use.

The permitting agency may impose additional monitoring requirements to determine compliance in context with the general permit. Specific monitoring requirements and BMP requirements will be addressed in SWPPPs to be reviewed by the ADEQ Stormwater and General Permits Unit, as required in Sections 2.2.2 and 3.1.1 of the 2010 ADEQ Mineral Industry and Industrial MSGPs and pertinent sections of the 2008 ADEQ CGP.

FACILITY_NAME	***CITY***	***LATITUDE***	***LONGITUDE***	***TYPE***	***EXPIRATION DATE***
TAYLOR PIT	TAYLOR	34 28 50.00	110 06 40.18	MINING	JANUARY 31, 2016
CEMEX - SHOW LOW PLANT	SHOW LOW	34 15 39	110 01 13	NONMINING	JANUARY 31, 2016
COOLEY KNOLL CINDER PIT	WHITE MTN LAKE	34 19 49	109 57 48	NONMINING	JANUARY 31, 2016
ERGON ASPHALT & EMULSIONS - SNOWFLAKE	SNOWFLAKE	34 30 50	110 06 17	NONMINING	JANUARY 31, 2016
FIRST STUDENT INC #20987	SNOWFLAKE	34 30 19.69	110 05 24.46	NONMINING	JANUARY 31, 2016
GERNIMO BRIMHALL SAND MTLS	SNOWFLAKE	34 55 59	110 14 24	NONMINING	JANUARY 31, 2016
LONE PINE TRANSFER	SHOW LOW	34 21 25.45	110 03 24.44	NONMINING	JANUARY 31, 2016
SHOW LOW AUTO SALES & WRECKING, INC.	SHOW LOW	34 15 33	110 00 19	NONMINING	JANUARY 31, 2016
SHOW LOW AUTO SALES & WRECKING, INC.	SHOW LOW	34 15 33	110 00 19	NONMINING	JANUARY 31, 2016
SHOW LOW REGIONAL AIRPORT	SHOW LOW	34 15 54	110 00 02	NONMINING	JANUARY 31, 2016
SNOWFLAKE COTTONWOOD DECKER PLANT 2	SNOWFLAKE	34 30 37	110 05 45	NONMINING	JANUARY 31, 2016
SNOWFLAKE COTTONWOOD NORTH PLANT 1	SNOWFLAKE	34 31 05	110 04 49	NONMINING	JANUARY 31, 2016
WHITE MOUNTAIN REDI MIX	SHOW LOW	34 15 30.88	110 00 10.30	NONMINING	JANUARY 31, 2016
JOE'S PIT	TAYLOR	34 27 55.09	110 09 30.62	MINING AND NONMINING	JANUARY 31, 2016
PERKINS CINDERS INC - LINDEN PIT	SHOWLOW	34 17 10.03	110 07 15.52	MINING AND NONMINING	JANUARY 31, 2016
PERKINS CINDERS INC - LINDEN PIT	SHOWLOW	34 17 10.03	110 07 15.52	MINING AND NONMINING	JANUARY 31, 2016
PERKINS CINDERS INC - LINDEN PIT	SHOWLOW	34 17 10.03	110 07 15.52	MINING AND NONMINING	JANUARY 31, 2016

Table 4. MSGP permittees in LCR TMDL watershed

4.2 Summary of Nonpoint Sources

4.2.1 Forests

Forest areas comprise a little more than 38 percent of watershed area. Much of this land is under the management of the U.S. Forest Service. USFS Region Three Forests within the watershed boundary include the Apache-Sitgreaves National Forest (A-S NF) and the Gila National Forest (GNF).

Generally, forest lands protect against excessive erosion of soils by a higher organic content binding the soil together, and by providing a floor layer of litter and duff covers to shield soils from separation and transport due to rainfall. Logging practices and grazing on public lands are examples of sanctioned public land uses that have a potential for contributing to increased sediment loading of streams and rivers. Each of these activities will be addressed separately.

4.2.2 Erosion and Sedimentation

As in all river systems, natural erosive processes contribute nonpoint source sediment loads in the LCR watershed. Detachment of soil particles from uplands by wind or precipitation events, transport of detached particles overland into watercourses, and the conveyance of sediment within the watercourse are all integral parts of and closely partnered with processes of the hydrologic cycle. A stream’s hydrologic function consists not only of conveying water through the hydrologic network, but also of transporting sediment loads. Excessive sediment loads can create aggradation or deposition within the stream channel network. Additionally, excessively exposed or vulnerable soils can provide loads through erosion of the uplands, and sediments within the hydrologic system coupled with the hydraulic force of water in the system contribute to erosion along stream banks and down-cutting within the stream channel proper. These conditions and functions can be attributed to natural conditions, adverse anthropogenic influence, or to various combinations of the two. Although natural processes contribute to the overall sediment load, they alone do not cause exceedances of the applicable SSC water quality standard.

4.2.3 Channel Storage

A significant percentage of in-stream sediment loads results from prior deposition of sediments in the river network upstream. This channel storage is entrained and moved through the stream network in high-intensity precipitation events, as is apparent in observing the distribution of data points in the load duration curve used to analyze sediment loads. Cleland (EPA, 2007a) noted in a load duration analysis that the category consisting of the highest 10 percent of flows recorded in the flow distribution is largely comprised of data points where sediment or other pollutants are being mobilized from in-channel storage. Additional sediment loads in the moist conditions category of the flow distribution can likely be attributed to the same process. A measure of the amount of sediment exiting the watershed from a pour point compared to the amount of sediment modeled as entering the hydrologic cycle off the land surface is termed the sediment delivery ratio, and is used as a standard part of engineering sedimentation analysis. Sediment delivery ratios for the watershed being analyzed were determined by the RUSLE model used in this study to be uniformly low for all subwatersheds modeled, ranging from 9.3 percent for the LCR above Silver Creek to Lyman Lake Dam to 18.8 percent for the small subwatershed of the LCR extending from the Silver Creek confluence to Carr Lake Draw. In part, these low sediment delivery rates are attributable to large subwatershed areas and low gradients limiting the energy available to transport sediment, as well as the sheer volume of sediment entering the system in more than 8,000 square miles, but an additional factor is the intermittent / ephemeral flow regime character of the hydrologic network. Sediment is not continually exported from the watershed where the hydrologic network is intermittent, thus leading to more loading in storm events than otherwise would be the case. While channel storage can be considered a largely natural contributor to sediment problems in the water column, focus on channel storage as a problematic process is misplaced, as channel storage ultimately serves as a repository and indicator for upland erosion problems of a more anthropogenic origin.

4.2.4 Urban/Developed

Urban or developed areas can contribute to excessive sediment loading by stormwater run-off from impervious areas, and by concentrations of stormflow in engineered drainage systems feeding into natural watercourses. Run-off from such sources typically gathers much more velocity and erosive power, with reduced chance of infiltration and interception, than run-off from natural settings. Minimal impact from lightly developed areas in the LCR watershed is observed. Development footprint in the LCR basin is 13.36 square miles, comprising 0.16 percent of watershed area. However, the concentration of towns along the perennial Silver Creek in the western part of the watershed, including the towns of Taylor, Snowflake, Show Low, and Pinetop-Lakeside, carries the potential of amplifying development effects on nonpoint source loadings.

4.2.5 Logging

While logging activities do occur in the Forests within the LCR watershed, activity is light and total sediment contribution from these activities is likely low. The Gila National Forest (GNF) reports that logging has been light since the closure of a mill near Reserve, N.M. in the early 1990s. GNF's annual timber target ranged from 6,000 CCF (hundred cubic feet) to 9,000 CCF from 2002 to the present (Hernandez, 2008) with approximately 4,000 CCF allotted to personal use products such as firewood annually. One operator in the Forest makes bids on opened timber sales, and several sales prior to 2005 received no bids. GNF reports that no new roads have been constructed to access logging areas in recent years.

Through the USDA Forest Service's Southwest Region, GNF participates in an agreement with the New Mexico Environment Department that seeks to implement a host of Best Management Practices pertaining to logging to support Clean Water Act objectives. The two agencies have agreed to develop preventative or mitigative land management practices to improve or protect water quality on National Forest System Lands. Though not an exhaustive compilation, areas of specific measures for the GNF include the following:

- Limitations on Operating Season
- Stream Course Protection
- Riparian Treatment Areas
- Treatment of Ephemeral Drainages
- Streamside Management Zone Designations
- Log Landing Stipulations
- Skid Trail Controls and Design
- Road Construction, Closure, and Maintenance Measures

The agreement was based upon mitigative measures outlined in the Clean Water Act and expanded where necessary to accommodate additional facets of logging practices. Site-specific BMPs are drafted and implemented where necessary to protect the resource and water quality. Additional guidelines were informed by the content of soil inventories on Forest lands, Forest Service Handbook 2209.18, and the experience of Forest personnel.

Logging on the Apache-Sitgreaves National Forests (A-S NF) is relatively light, as well, though heavier than found on the GNF. Logging on a wide scale was essentially ceased in 1998 by environmental appeals (Nedrow, 2008). The Rodeo-Chedeski fire of 2002, which covered some 468,000 acres, resulted in a salvage operation afterwards lasting for four years. However, since then only one project, the White Mountain Stewardship Project (WMSP), has been opened to bid, though older on-going projects continue. WMSP is outside of LCR watershed boundaries. Target volume for logging across the A-S NF has been consistent at approximately 50,000 CCF over the past five years and is expected to hold at this level for the next few years. The A-S NF logs about 10,000 CCF per year for fuel wood and personal use sales across the Forest.

Most logging on the A-S NF is now mechanized, and standard BMPs are followed with all mechanized equipment. One BMP of note is a requirement for straight in-out accessing of timber in ecologically sensitive areas where fallers or other mechanized equipment are used. Filter strips are utilized to protect riparian channels with widths determined by the grade of local topography. Streamside Management Zones are designated with the intention of providing sufficient sediment buffering capacity to protect water quality. Percentage of ground coverage is monitored to reduce the potential of erosive processes.

4.2.6 Grazing

Semi-arid regions with sparse ground cover, such as those found along the LCR main-stem, are particularly vulnerable to increased sediment loading rates due to the flashy nature of overland flow and the possibility of flash flooding in gullies and ephemeral drainages feeding into the main channel as a result of intense, short-lived monsoon storms. Grazing activities, where not properly managed, can add to sedimentation problems in watercourses. This can occur due to multiple factors contributing to increased overland flow velocities and the resulting higher carrying capacity of run-off, including the reduction of vegetative cover shielding the surface from rainfall, the depletion of a litter layer acting to reduce run-off velocities, and the compaction of soil contributing to lower infiltration rates. Cattle hoof chiseling along riverbanks also contributes to sedimentation of waterways.

Grazing activities in the LCR basin above Carr Lake Draw can be largely attributed to four different sectors: U.S. Forest Service lands, Bureau of Land Management lands, Arizona State Trust Land, and privately-held lands. Within the defined LCR watershed delineated above Carr Lake Draw, N.M. acreage accounts for 48.7 percent of watershed area. On the remaining Arizona lands, the four classes of land owners that own or administer more than two percent of watershed area and pursue or allow grazing activities are detailed in Table 5. Additional discussion on each will follow.

Land Ownership/Administration, LCR Watershed above Carr Lake Draw	**Area, sq. mi**	**Percent**
New Mexico	3956.93	48.7%
Private Lands	1793.87	22.1%
State Trust Lands	1078.92	13.3%
Apache-Sitgreaves National Forest	847.59	10.4%
Bureau of Land Management	180.30	2.2%
Others	263.74	3.3%

Table 5. Land Ownership, LCR Watershed above Carr Lake Draw

The A-S NF administers more than 2 million acres of National Forest land. Statistics and summaries subsequently presented from the A-S NF on its grazing program account for all Forest acreage, and are not specific to the portions of the Forest within the LCR watershed boundary. There were a total of 96 active allotments on the A-S NF in 2007 (D. Jevons, Apache-Sitgreaves National Forest, Acting Forest Supervisor, written communication, 7-14-2008). The trend on numbers of active grazing allotments has been decreasing in recent years. In 1983, a total of 128 grazing allotments existed; in 2000 the number had declined to 115 being analyzed and having management practices updated under NEPA. The Forest Service has concentrated in recent years on maintaining satisfactory conditions for wildlife habitat and watershed, riparian and forage vegetation, while recovering from recent major fires and still contending with ongoing drought conditions. Thirteen allotments in 2007 were not used for various reasons. The authorized number of animal unit months (AUMs) in 2007 was 127,509. Recent years have seen some fluctuation of authorized numbers, ranging from a high of 187,035 in 2003 to a low of 89,603 in 2004. Active range condition and trend studies are ongoing. Six allotments were consolidated for more effective resource management under NEPA in 2007. Grazing is permitted for cattle, horse, sheep, and burros.

A large portion of watershed area is Arizona State Trust Land, where grazing allotments are set aside and grazing is actively pursued. Rangeland management on Arizona’s State Trust land is a mutual effort between the Land Department and its grazing lessees. Livestock grazing takes place on more acres of State Trust land than any other use. This is due to the remoteness, aridity and lack of infrastructure, such a waterlines, roads, sewers and utilities that make land attractive for development. This reality is not expected to change to any great degree in the near future.

The Arizona Legislature does not provide any funding for the Land Department to institute any agency initiated management practices on State Trust rangeland. The Land Department relies on its grazing lessees to expend their own money to initiate management practices on their leases. Such management practices are water sources (such as wells and stock tanks), water distribution systems (pipelines), handling facilities (corrals), livestock control measures (fencing), and various types of land treatments to remove undesirable vegetation species or to plant desired vegetation species (prescribed fire, grubbing, agra-axe, root plowing, chaining, herbicides, reseeding) (Arizona State Land Dept., 2010).

The State Lands Department offers grazing leases for up to a maximum of 10 years. Generally, Rangeland Health Assessments are not required on State Trust Land, though a few may be associated with USFS grazing management plans if USFS lands are on adjacent parcels. Leasees can be reimbursed for the cost of range improvements, such as the installation of fences or watering tanks, if the application for such improvements is approved by the Arizona State Land Department (S. Miller, ASLD, personal communication, 6-15-09).

A small percentage of BLM lands exist within the watershed boundary. These land parcels are interspersed with private lands and State Trust Lands throughout the middle and lower elevations of the watershed in a checkerboard distribution where parcel boundaries date from the first days of surveyed townships, ranges, and sections and original land grants made in the 1800s (refer to Figure 3). The parcels are administered out of the Safford District BLM Office in eastern Arizona. Grazing allotments are affiliated with these parcels; in most cases, these allotments extend beyond individual parcel boundaries to include a mix of private, state, and federal lands. Coordinated land management practices in such a fragmented ownership pattern have proven to be difficult. BLM lands comprise only 2.2 percent of watershed area. Numbers on cattle run on BLM allotments are not readily available (C. Morris, BLM-Safford, personal communication, 7-15-10).

Private land grazing in the LCR watershed is tightly interdependent with State Trust Land grazing leases. The checkerboard land ownership pattern established from land originally deeded to railroads in the late 1800s (see Figure 3) shows today that adjacent sectional ownership alternates between state land and private lands. Much of this land has become adverse-deeded over the years as a consequence of further subdivision. Many of the subdivided parcels are either not fenced in or lived upon, thus in practice establishing open range country. Two large private companies still own and graze on a substantial amount of land in the area and sub-lease their lands out to other private parties for grazing as well. These entities are the Aztec Land and Cattle Company, with a long history in the region, and the NZ Legacy Cattle Company.

Actual stocking rates are dependent upon the health of the lands and the abundance of forage available. Most of the area where private lands exist falls in a range of expected rainfall from 6 to 14 inches per year with widely differing forage conditions as a result. AUMs have declined in recent years due to a persisting lack of forage attributable to drought. General rules of thumb for actual carrying capacity and usage are typically 4-5 animals per section where precipitation is lighter and forage sparse to 6-8 animals per section in better conditions. Grazing rotation is the preferred management method used on private lands in the region (R. Murph, NRCS-Holbrook, personal communication, 9-3-10).

4.2.7 Agriculture

Agriculture in the area can broadly be broken down into two classes: irrigated seasonal cropland, and pasture or forage land. Agricultural areas are generally found around the towns of the LCR Basin and along the watercourses and thus are considered possible nonpoint source contributors to sediment loading. These areas have the potential to add to SSC loading rates for stream networks due to the turning of earth for planting in ways that do not prevent excessive erosion. Due to the sparse nature of rainfall and the intermittency of the LCR, agriculture is likely a minor contributor to SSC problems in the basin; total area used for agricultural purposes in the basin is 93.8 square kilometers or 0.44 percent of basin area.

4.2.8 Roads

Unpaved roads have the potential to add to sediment loading rates for stream networks in at least two substantive ways. Improper siting and design of unimproved roads, particularly in rugged terrain, has the potential to create channelizing of runoff, greater runoff velocities, and greater erosive potential, which could eventually find its way into streams and natural waterways. Activities associated with road construction, such as cut-and-fill earth-moving practices, leave greater portions of disturbed soils exposed to the elements, which create an ongoing possibility of future erosion. Additionally, the potential is amplified by the removal of native cover necessary to construct the road. Unimproved road crossings over intermittent or perennial stream waters also carry a higher possibility of adding to the sediment load of natural waterways.

5.0 LINKAGE ANALYSIS

5.1 Soil Erodibility

Three geologic units comprise the majority of the Silver Creek watershed contributing area in nonstorm flow conditions. These units include Kaibab Limestone of Permian age, the Moenkopi Formation (upper Triassic), and Quaternary/Upper Tertiary Basalts originating with White Mountain volcanism. Chuska and Dakota sandstone units, with minor areal coverage of the watershed, outcrop along the southwestern rim of the Silver Creek watershed.

The Moenkopi Formation, stretching across the Four Corners region, is comprised of several members of siltstone and sandstone, and has a characteristic bright red color. This formation, coupled with the Chinle Formation found elsewhere in the LCR Basin, makes up most of the areas known as the Painted Desert and the Petrified Forest in northern Arizona. Its native erosivity is high, and soils derived from this unit are likely primary contributors to SSC exceedances. Further compounding the sediment loading problem is that extensive agricultural and pasture lands near the towns of Taylor and Snowflake have been established in these soils along the Silver Creek watercourse.

Soils derived from these units form the basis for suspended sediment that winds up in the water column as a result of natural background erosion and aggravated nonpoint source loadings.

National Resource Conservation Service STATSGO soil information is summarized for the Silver Creek watershed in Table 6.

Map unit ID	*Map Unit Name*
AZ120	ROCK OUTCROP-KECH-BISOODI (AZ120)
AZ119	CERRILLOS-BARX-UBANK (AZ119)
AZ085	PURGATORY-CLAYSPRINGS-BADLAND (AZ085)
AZ130	TYPIC HAPLUSTALFS (AZ130)
AZ122	DEAMA-ROCK OUTCROP-ARABRAB (AZ122)
AZ160	TYPIC EUTROBORALFS (AZ160)
AZ193	DERECHO-MIRAND (AZ193)
AZ142	SPONSELLER-ESS (AZ142)
AZ121	SILKIE-CUATE (AZ121)
AZ196	MOLLIC EUTROBORALFS-TYPIC HAPLUSTALFS (AZ196)
AZ105	EPIKOM-TOURS-PURGATORY (AZ105)

Table 6. Soil map units within the Silver Creek watershed

Soil erodibility for each surface soil layer represented in the Silver Creek subwatershed's perennial flow to its confluence with the LCR and then on to the Woodruff gauging site is derived from STATSGO data in the form of K factors. The K factor is a standard index value applied to soils across the United States representing the susceptibility to erosion under standard conditions. The standard conditions consist of a 72.6 foot long unit plot at a 9 percent grade maintained in continuous fallow and tilled up and down periodically to control weeds. Values of K factor range from 0.02 for soils like clay which are highly resistant to detachment and erosion up to a maximum of 0.69 for silts highly susceptible to detachment and erosion. In practice, highly erosive K factors are local in nature, and when aggregated in the components and map units that form the spatial basis for consideration in STATSGO, the highest areal average erosivity represented in Arizona for a surface layer is 0.474. Typically, areal averages in excess of 0.2 are considered moderately to highly erosive for Arizona surface soils.

Erodibility values along the Silver Creek subwatershed's perennial watercourse are itemized in Table 7.

Map Unit Name	***Upper Layer K Factor***
ROCK OUTCROP-KECH-BISOODI (AZ120)	0.112
DEAMA-ROCK OUTCROP-ARABRAB (AZ122)	0.078
DERECHO-MIRAND (AZ193)	0.180
SILKIE-CUATE (AZ121)	0.254
MOLLIC EUTROBORALFS-TYPIC HAPLUSTALFS (AZ196)	0.268
EPIKOM-TOURS-PURGATORY (AZ105)	0.214

Table 7. Silver Creek Subwatershed Soil Erodibility

Units attributed to K factors are related to the mass of soil eroded from the landscape and are expressed (English) as tons per acre per erosion index unit where the erosion index (also defined as R in the USLE equation) is the product of total rainfall storm energy and maximum 30 minute rainfall intensity. Higher values of soil erodibility equate to higher rates of soil mass eroded in a given soil type with other factors considered equally. Test have shown that for soils generally, nomograph solutions of K factor differ from actual measured erosion by 0.02 in 65 percent of cases, while 95 percent of cases differ by less than 0.04 K factor units (USDA, 1978).

Using upper Silver Creek SSC measurements as a baseline and the determination of a weighted average K value as the percentage sums of the products of K factors and stream mileage through the various soil units serves as the linkage between soil condition and erosion susceptibility metrics within the watershed and SSC values found in the water column. The evaluation was carried out only for the Silver Creek watercourse, as the data set demonstrated fairly conclusively that the intermittent LCR contributes loads that may be considered under the 48 hour window exclusion written in the SSC standard only in exceptional circumstances. One data point in the entirety of the data set used in this TMDL evaluation consisted of a load contribution from the LCR subbasin (See Section 7.1). This approach also forms the foundation of the natural background determination, which is discussed more extensively in Section 6.2.

SSC values were converted to their associated daily loads (i.e. multiplied by discharge and the conversion factor 2.446) and plotted against a standard target load value in a load duration curve. As mentioned above, load allocations for subwatersheds were determined by the relative percentages of contributing tributary average daily discharge. Percentages were applied to the total suspended sediment loads, and the loads as broken down by the standard classes of a load duration analysis (<10 percent exceeds flows (high flows), 10 percent-40 percent exceeds flows (moist conditions), 40-60 percent exceeds flows (mid-range flows), 60-90 percent exceeds flows (dry conditions), >90 percent exceeds flows (low flows)). Using this empirical linking approach, the sum of the total load allocations of the various subwatersheds is targeted to meet the load allocation necessary to attain the water quality standard at the base of the impaired reach. An additional 2 percent was added to the margin of safety to account for the small subwatershed (0.56 percent area) below the LCR-Silver Creek confluence to the lowest point in the impaired reach.

The SSC standard of 25 mg/l was converted into a set of corresponding load allocation thresholds after limiting for natural background contributions and established waste load allocations. The 90th percentile value of existing loads was compared against the threshold values for subwatersheds where such analysis was possible. ADEQ has elected to use the 90th percentile value of existing loads in keeping with the manner in which the agency evaluates acute exceedances of other water quality parameters using a binomial distribution based upon a 10 percent exceedance frequency.

Figure 6 details the hydrologic network in the vicinity of the impaired reach and exhibits sites selected to characterize the watershed.

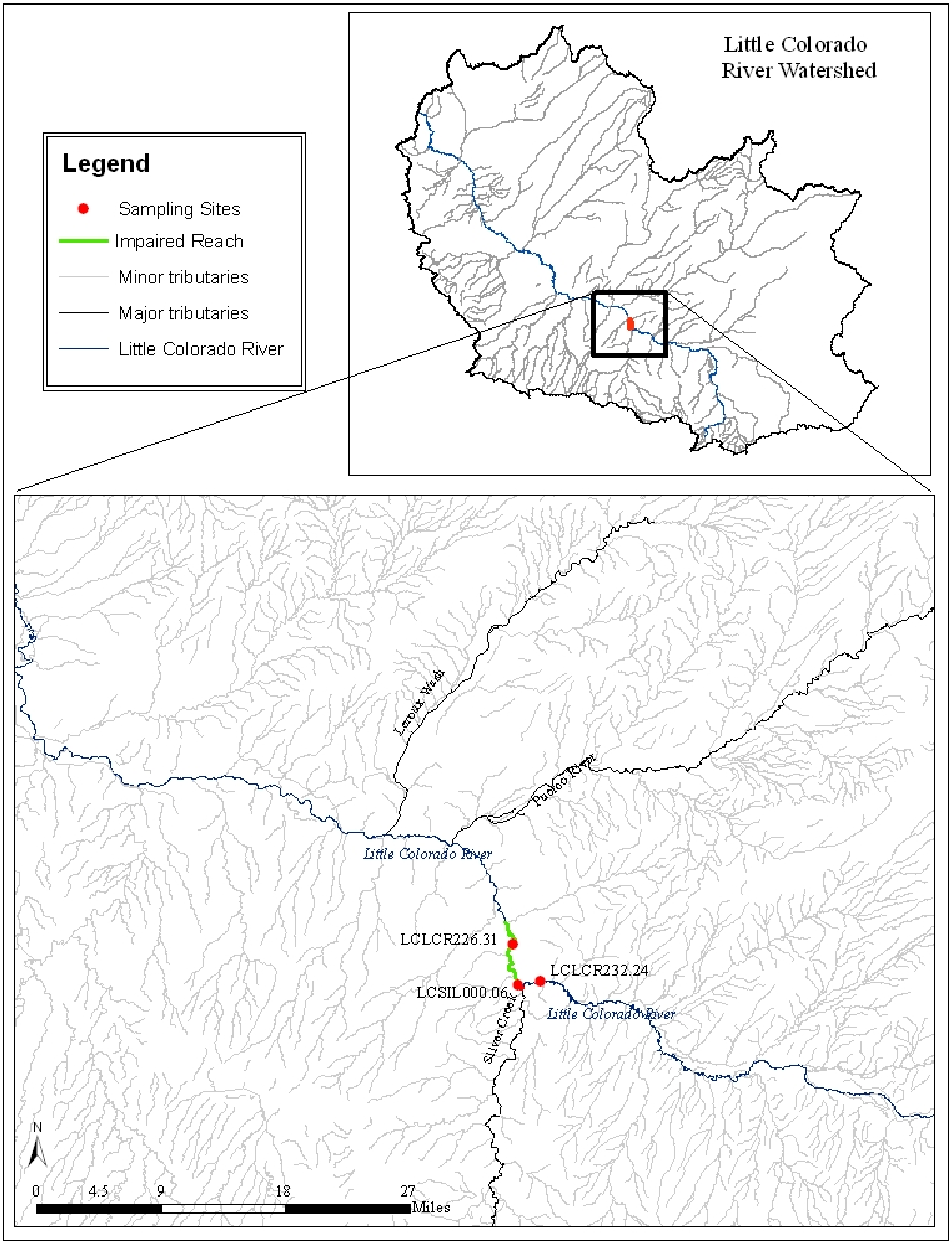

Figure 6. LCR TMDL Sample Sites

5.2 Watershed Definition and Delineation

The flow of the LCR is spatially interrupted by the existence of the Lyman Lake Dam, which creates Lyman Lake, a unit of the Arizona State Parks system used for recreation and irrigation storage. Above Lyman Lake, the LCR is perennial for its entire run to the White Mountains, where it headwaters in several significant tributaries. Water is routinely released from the dam during the irrigation season of April-October. Dam releases flow northward several miles toward the town of St. Johns, Arizona. The river is subject to agricultural diversions for local use during its entire run below the dam. Between diversions and infiltration, the LCR is typically exhausted with no flow remaining in the vicinity of the St Johns WWTP. The Lyman Lake dam is approximately 87 river miles upstream of the Silver Creek/LCR confluence. The LCR flows past the eastern edge of St. Johns near its lowest point of infiltration; this stretch of the river is 71 river miles above the LCR-Silver Creek confluence. The LCR is intermittent / ephemeral below this point to the confluence with Silver Creek. Due to this hydrologic character and the 48 hour storm exclusion provision of the SSC standard, the LCR subbasin does not typically contribute to exceedances during the time it is flowing; however, loads transported by the LCR in stormflow events are reflected in exceedances logged at Woodruff when only Silver Creek is flowing. Aggradation and deposition followed by re-suspension in the impaired reach by Silver Creek waters reflects contributions from both the LCR and Silver Creek subbasins in the lower flow categories,

Due to the spatially interrupted nature of the river, the differing hydrologic regimes above and below the dam, the residence time in the reservoir (approximately 228 days, based on a median storage volume of 11,300 acre-feet for the previous year and the USGS discharge statistics for the LCR below Lyman) and the distance of the reservoir from the project area, the possibility of suspended sediment loading attributable to the region above Lyman dam was considered miniscule if existent at all. Contributions from the LCR watershed above Lyman Lake were not considered in the analysis. Delineations and watershed definitions were generated and developed excluding the 790 square miles above Lyman Lake Dam. Source contributions above Lyman Lake were disregarded. The watershed area excluded constitutes approximately 10 percent of total watershed area.

6.0 MODELING AND ANALYTIC APPROACHES

Load duration curves were used for modeling suspended sediment loads and calculating the TMDL for Reach 15020002-004. The load duration curve approach was chosen for its flexibility, its capacity to identify and address flow-dependent conditions, and the ability to classify and analyze various data points individually in accordance with the requirements of Arizona’s water quality standard for SSC. Long-term USGS streamflow gauges in the watershed permitted an in-depth examination of flow history.

6.1 Flow and Load Duration Curves

ADEQ has chosen to employ a flow and load duration curve approach in order to determine total maximum daily loads and calculate necessary reductions. Cleland (2003) provides the following discussion on the elements and merits of a load duration curve method:

> *The percentage of time during which specified flows are equaled or exceeded may be evaluated using a flow duration curve (Leopold, 1994). Flow duration analysis looks at the cumulative frequency of historic flow data over a specified period. The duration analysis results in a curve, which relates flow values to the percent of time those values have been met or exceeded. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, whereas floods are exceeded infrequently. …*
>
> *The development of a flow duration curve typically uses daily average discharge rates, which are sorted from the highest value to the lowest. Using this convention, flow duration intervals are expressed as percentages, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). Thus, a flow duration interval of sixty associated with a stream discharge of 82 cubic feet per second (cfs) implies that sixty percent of all observed stream discharge values equal or exceed 82 cfs…*
>
> *…A duration curve framework is particularly useful in providing a simple display that describes the flow conditions under which water quality criteria are exceeded. Stiles (2002) describes the development of a load duration curve using the flow duration curve, the applicable water quality criterion, and the appropriate conversion factor. Ambient water quality data, taken with some measure or estimate of flow at the time of sampling, can be used to compute an instantaneous load. Using the relative percent exceedance from the flow duration curve that corresponds to the stream discharge at the time the water quality sample was taken, the computed load can be plotted in a duration curve format (*Figure 7*).*
>
> *By displaying instantaneous loads calculated from ambient water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval), a pattern develops, which describes the characteristics of the impairment. Loads that plot above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show attainment. The pattern of impairment can be examined to see if it occurs across all flow conditions, corresponds strictly to high flow events, or conversely, only to low flow conditions.*
>
> ***Duration Curve Zones***
> *Flow duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into five zones: one representing high flows, another for moist conditions, one covering median or mid-range*

flows, another for dry conditions, and one representing low flows. Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left generally reflect potential nonpoint source contributions. This concept is illustrated in Figure 7. Data may also be separated by season (e.g. spring runoff versus summer base flow). For example, Figure 7 uses a "+" to identify those ambient samples collected during primary contact recreation season (April – October).

Runoff Events and Storm Flows
The utility of duration curve zones for pattern analysis can be further enhanced to characterize wet-weather concerns. Some measure or estimate of flow is available to develop the duration curves. As a result, stream discharge measurements on days preceding collection of the ambient water quality sample may also be examined. This concept is illustrated in Figure 7 by comparing the flow on the day the sample was collected with the flow on the preceding day. Any one-day increase in flow (above some designated minimum threshold) is assumed to be the result of surface runoff (unless the stream is regulated by an upstream reservoir). In Figure 5, these samples are identified with a red shaded diamond.

Similarly, stream discharge data can also be examined using hydrograph separation techniques to identify storm flows. This is also illustrated in Figure 7. Water quality samples associated with storm flows (SF) greater than half of the total flow (SF>50%) are uniquely identified on the load duration curve, again with a red shaded diamond.

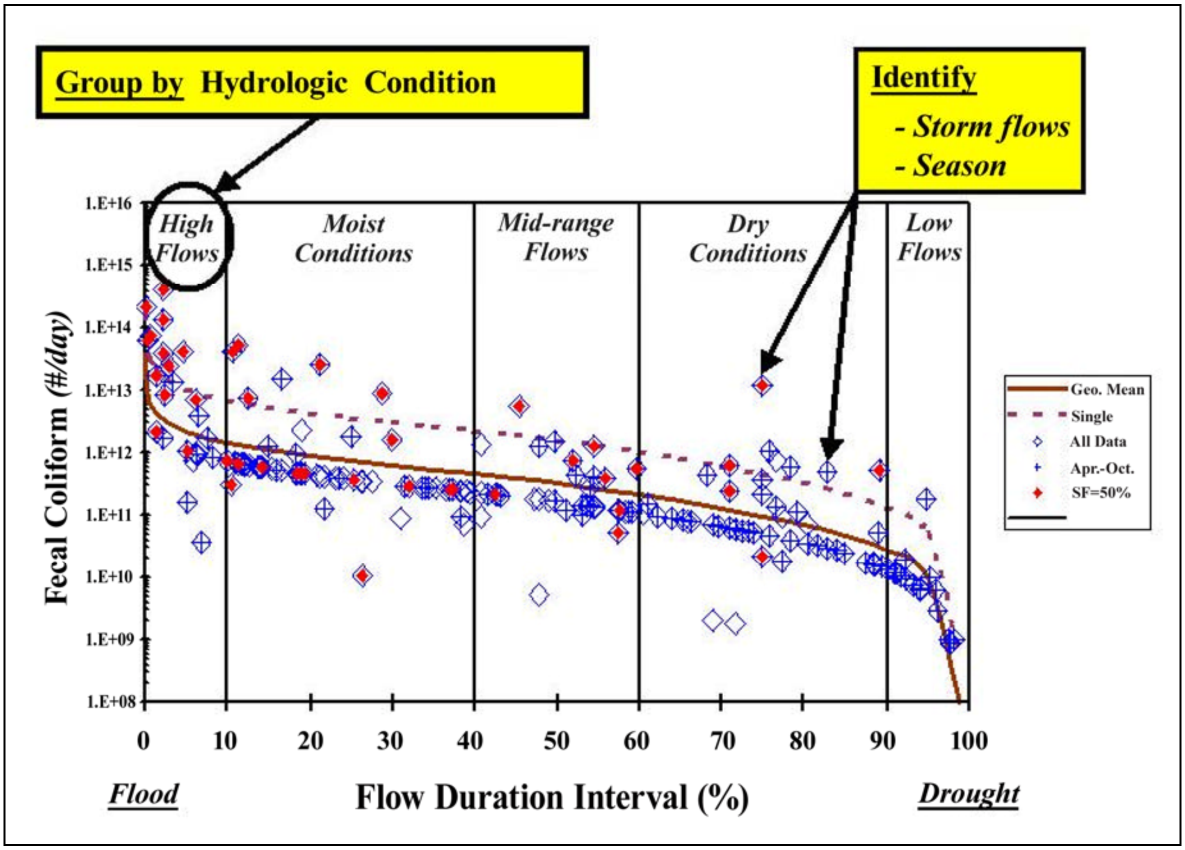

Figure 7. Sample Load Duration Curve
(Illustration from Cleland 2003).

As outlined above (Cleland, 2003), the subdivision of the flow frequency curve into five zones corresponding to high flows (0-10 percent flows exceed), moist conditions (10-40 percent flows exceed), mid-range flows (40-60 percent flows exceed), dry conditions (60-90 percent flows exceed), and low flows (>90 percent flows exceed) was executed for analysis and TMDL calculations.

Refer to Figure 8 for load duration data for the LCR at Woodruff. Flows have been graphed by percentage flow exceeded on the x-axis (the LCR at Woodruff flows approximately 95 percent of the time), and SSC loads in kg/day are graphed along the logarithmic y-axis. For the purposes of illustration, data was grouped into two categories: storm flow data and nonstorm flow (base flow) data. Samples collected within 48 hours of the hydrologic response to a precipitation event or when the LCR above Silver Creek added inputs constituted stormflow. Because most of the plotted data is historic data collected before tributary contributions were sampled and analyzed, it is not possible to further classify the exceedances based upon LCR subbasin contributions and Silver Creek subbasin contributions. Insufficient numbers of samples were collected on the tributaries to productively plot load duration curves for each subbasin.

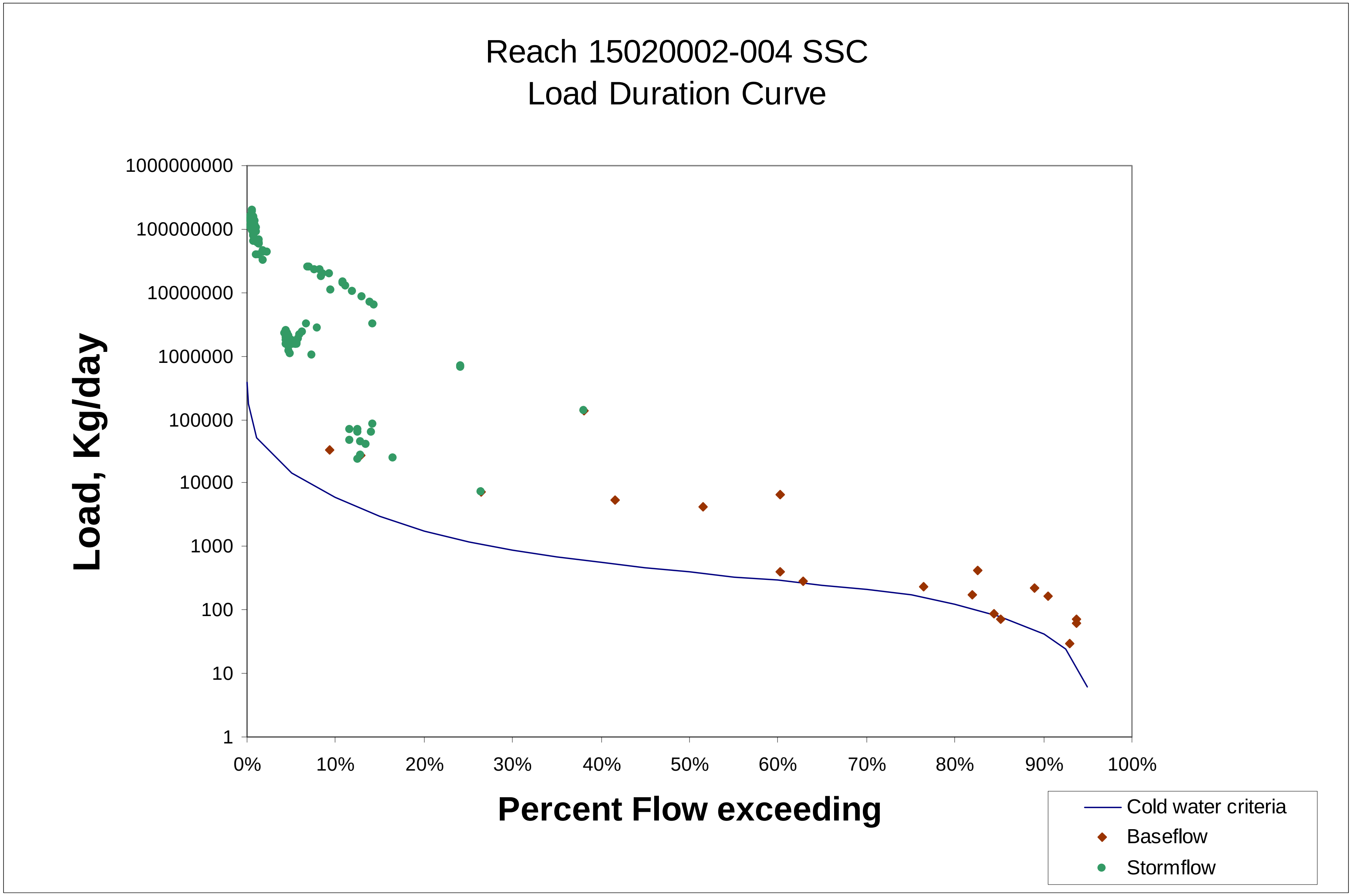

Figure 8. LCR at Woodruff Load Duration Curve

6.2 Natural Background Determination

TMDL establishment includes a provision for natural background loads in the waterbody being evaluated. Load allocations and waste load allocations are reduced proportionately to accommodate natural background loading. The term "natural background" is normally applied to those areas where no effects due to human activities (urban development, mining, agriculture, ranching, heavy recreational usage, etc.) are known to occur upstream. Care must be taken in selecting natural background sites to select sites principally to eliminate or minimize anthropogenic influence.

Unlike the evaluation of naturally-inherent chemical constituents that may occur in spring water, analysis of SSC values requires that some degree of hydrologic process be permitted to operate in the watershed before natural loading can be evaluated. Natural background sites were chosen with this secondary criterion in mind.

The choice of Silver Creek as the natural background for the project ensued from the extremely limited options available in the LCR basin to gather representative streamflow data from perennial waters relatively unimpacted by anthropogenic activities. The majority of the watershed above Woodruff (87 percent of land area) consists of areas either hydrologically discontinuous from the rest of the basin by virtue of dams or areas of only intermittent or ephemeral flow. Since the SSC standard excludes stormflow inputs within 48 hours of a local precipitation event from consideration, Silver Creek with its perennial flows, relatively low anthropogenic impacts in its upper reaches, and soil characteristics held in common with the remainder of the basin constituted the only viable option for the determination of natural background loading. Natural background sites are located within the watershed boundaries in Figure 4 (previously referenced).

The approach adopted to determine natural background SSC percentages for the impaired reach consisted of identifying and sampling locations in the upper Silver Creek watershed near Arizona Game and Fish's Silver Creek Fish Hatchery. These locations represented one of the three geologic units and three of the six different values of soil erodibility (K factor) that Silver Creek flows through to its confluence with the LCR and its subsequent passage as the LCR to the Woodruff gauge site. Baseflow conditions alone were used to evaluate natural loading. The mean value of SSC collected at these Silver Creek locations was determined. The mean concentration was adjusted to account for more erosive soils found in the Shumway-Taylor-Snowflake corridor by determining the ratio of the distance-weighted K (erodibility) factor for the entire perennial stretch of Silver Creek/LCR to Woodruff to the distance-weighted soil K factor from the natural background sites to the headwaters. Pertinent values are presented in Table 8.

Natural Background Sites	*Average SSC Value, mg/l*	*Weighted Avg. K Factor, above NB sites*	*Weighted Avg. K Factor, Perennial length*	*Ratio, K factor, Total : Upstream*	*Modeled NB SSC Value, mg/l*
LCSIL041.04, LCSIL042.58, LCSIL043.30, LCSIL043.84	10.6	0.1252	0.1557	1.244	13.1

Table 8. Natural background metrics

7.0 TMDL CALCULATIONS

7.1 Flow Characteristics and Critical Conditions

Due to the stated provision in Arizona's SSC water quality standard excluding standard application within 48 hours of a stormflow event, critical conditions for SSC exceedances for the impaired reach exist across all flow categories when Silver Creek is flowing, but particularly in the mid-range flows, dry conditions, and low-flow categories. Flows in the upper two categories are almost entirely excluded from consideration by the stormflow screening criteria in the standard. Consequently, the LCR above Silver Creek is generally not an active contributor in baseflow and mid-range flow conditions. However, loads suspended in the LCR subbasin above Silver Creek during stormflow events are likely to fall out of suspension as flow decreases, and some of this suspended sediment load is deposited in the impaired reach at the tail end of storm events, subject to re-suspension by only marginally higher flows from Silver Creek in nonstorm flow conditions. Thus, sustaining flow from Silver Creek is more likely to show exceedances in the low-flow categories, and these are considered the critical conditions. See the load duration curve in Appendix A for a graphic representation of this phenomenon.

While flow from Silver Creek approaches true perennial status, and the USGS site at Woodruff four miles downstream of the confluence reflects this with approximately 95 percent of days showing flow, flow contributions from the LCR above the Silver Creek confluence are much more intermittent and erratic in nature. This segment of the LCR flows only in direct response to precipitation events or prolonged snowmelts. Flow durations from this segment are estimated at 20 to 30 percent relative to a complete perennial flow history. Some flow may persist due to interflow contributions from the water table for periods exceeding the defined storm windows ADEQ employs to characterize discharge, but all contributions from the LCR above the Silver Creek confluence are either directly or indirectly related to recent precipitation events.

After screening for data points where SSC samples were collected and applying the 48 hour criterion to the USGS flow history at Woodruff, a selection of 19 data points from 1988 to 2010 was made. The majority of these data points were recorded before the TMDL project began in

2007 and thus before a site was established to characterize contributions from the LCR above Silver Creek. Of the seven data points remaining within the project time frame where the storm window criterion was applied, flow from the LCR above the Silver Creek confluence was present for only one. The discharge value for the one data point was 1.9 cfs. All other data points had either no flow (0 cfs) or no record of a site visit on the date when an SSC sample was collected at Woodruff., The 48 hour exclusion requirement in the water quality standard has essentially screened almost all of the highest critical condition data from the dataset. Consequently, it is of little value to allocate sediment loads by respective subwatershed contributions, since only one data point of the 19 considered had a load contribution from the LCR subwatershed above Silver Creek.

Having screened 48 hour stormflows from the dataset, however, it is evident that exceedances still exist transported almost entirely by the flows of Silver Creek alone across all flow classes. Unfortunately, the upper three classes of the load duration analysis had fewer than four samples to evaluate and therefore cannot be quantified at this juncture with any degree of reliability. The TMDL is targeted across all conditions showing exceedances and applied for the entire delineated watershed above the impaired reach (excluding Lyman Lake, as noted previously), as Silver Creek flows in nonstorm conditions are carrying portions of the LCR’s load transported into the impaired reach by stormflow.

7.2 Load Allocations

A standard load duration curve analysis was employed on data from the principal site in the impaired reach to determine load allocations and reductions necessary to attain the TMDL values. Load allocations were developed for the watershed as a whole and relied upon the temporal classification of flows showing exceedances for identification of likely source contributions and differentiation of the amount and frequency of those source contributors. As discussed in the previous section, a subwatershed analysis was not undertaken as screening criteria eliminated almost all load contributions from the LCR subwatershed above Silver Creek. Thus, the analysis was made solely on a temporal basis without further spatial segmentation.

Urban runoffs from the towns of Snowflake, Taylor, Show Low, Pinetop-Lakeside, and St. Johns were allocated a portion of the total load allocation based upon urban area footprints within the delineated TMDL watershed. The total urban area for these five communities is 127.35 square miles. The total delineated TMDL watershed area is 7342.21 square miles. The percentage urban area relative to the total watershed area is 1.73%. This proportion was applied to the total allocation and recorded as a sub-allocation in Table 12. It is noted that no data is available for assessing urban runoff sediment loads or determining any necessary reductions in the TMDL analysis. If any source’s currently assigned load allocations are later determined to be point sources requiring NPDES permits, the portion of the load allocations accruing to those sources are to be treated as wasteload allocations for purposes of determining appropriate water quality based effluent limitations pursuant to 40 CFR 122.44(d)(1).

See Section 6.1 for a thorough discussion of the load duration methodology and interpretation of results.

7.3 Waste Load Allocations

As outlined in Section 4.1.1, three AZPDES-permitted facilities exist in the LCR basin upstream of the Carr Lake Draw confluence, though Pinetop-Lakeside's discharge permit expired on January 22, 2012 (the town retains a biosolids operations AZPDES permit). Terms of Permit AZ0026034 (previously Permit AZ0024287) for the Snowflake WWTP present limits for TSS, but SSC is not explicitly addressed in the permit. The terms of the permit fact sheet acknowledge that discharge may reach or affect Silver Creek, and thus the permit was written to protect Silver Creek designated uses. Snowflake WWTP's permit to discharge expired in October of 2009, and Snowflake was granted a renewal of the permit under a new permit number (AZ0026034) in February 2012. Based upon Snowflake WWTP's maximum daily discharge of 0.6 mgd (equivalent to 0.928 cfs), the Snowflake WWTP is assigned a numeric SSC waste load allocation of 56.75 kg/day in the TMDL calculation where flow categories permit, as discussed below.

The Show Low Municipal WWTP (AZ0023841) discharges to constructed wetlands in former playa wetlands (Pintail Lake and Telephone Lake), with provisions made for excess discharges to be diverted or allowed by overland flow to an additional wetland (Ned Lake). The discharges are not expected to enter the hydrologic network and impact the water quality of Silver Creek or the LCR. While the permit lists criteria to be applied to TSS, the suspended sediment concentration water quality standard is not specifically addressed in the permit. Therefore, an SSC concentration-based waste load allocation of 25 mg/l consistent with the criteria of the A&Wc SSC water quality standard is assigned.

The Pinetop-Lakeside Sanitary District WWTP (AZ0025437) formerly discharged to a series of constructed pond wetlands adjacent to an ephemeral tributary of Show Low Creek. Two additional wetlands (Instream Wetland A and Instream Wetland B) were planned at the previous permit renewal to be constructed within the channel of the ephemeral drainage to handle overflow conditions during storm events and to provide additional capacity during the months of April-October. The additional wetlands were designed to allow assimilation of the entire two million gallon per day capacity of the WWTP if necessary. However, Pinetop-Lakeside never constructed the planned overflow wetlands and allowed their discharge permit to expire effective January 22, 2012. The permit was subsequently reissued under the same number effective September 5, 2012 for biosolid operations only with no discharges to waters of the United States authorized. Consequently, no wasteload allocation for AZPDES Permit AZ0025437 is granted or assigned.

Flows in the LCR at Woodruff are generally low and pose a problem in a load duration analysis incorporating numeric mass-limit based waste load allocations in the low flow (Category 5) classification. The median flow of the low flow category at Woodruff is 0.4 cfs. With a design capacity of 0.6 MGD for the Snowflake WWTP (equivalent to a steady state flow of 0.93 cfs), a potential exists with a numeric mass limit-based WLA for a discharge impacting the impaired reach to exceed the calculated WLA in the lowest flow class at Woodruff if the Snowflake WWTP is discharging at plant capacity. Consequently, a numeric mass limit WLA will only be applied to the upper four flow classes. A concentration-based WLA equivalent to the water quality standard (25 mg/l) for Snowflake will be applied to the low flow class. Since the load duration curve is predicated on the product of discharge and concentration, it can safely be surmised that in these flow categories, if the water quality standard is being met at the Snowflake WWTP outfall, waste loads for the LCR at Woodruff should be in accordance with the TMDL. The bifurcation between mass-based and load-based class targets in the TMDL analysis is not indicative of any inconsistency when considering existing permit limitations for TMDL implementation purposes, since concentration-based values as stated in Arizona's water quality standards are implicitly in effect for all discharges of WWTPs to receiving waters with an A&Wc designated use, from plant low flow up to maximum discharge capacity.

Wasteload allocations were developed and applied for the watershed as a whole in keeping with the manner by which load allocations were developed. The TMDL analysis included all subwatersheds and tributaries above the confluence of Carr Lake Draw at the base of the impaired reach; however, the analysis was made without spatial segmentation by subwatershed.

The point of compliance for WLAs for all discharges from individual AZPDES permit operations shall be the designated point(s) of discharge from the regulated facility prior to mixing with a stream reach carrying an A&Wc designated use.

For MS4, MSGP, and CGP permitted operations, the point of compliance with the WLA established in Section 4.1 will be determined as specified in the SWPPP or SWMP reviewed and approved by ADEQ.

7.4 Margin of Safety

A baseline margin of safety of 10 percent is subtracted from the TMDL allowance for each flow class to buffer against uncertainties in the study, including variability of sample concentrations, variability and error associated with flow measurement, and other uncertainties associated with sampling and analysis. An additional 2 percent margin of safety is applied to account for contributions from the LCR Silver-Carr Lake Draw subwatershed that cannot be isolated from the cumulative SSC values determined at the Woodruff site. The subwatershed is being accounted for in an areal comparison relative to the size of the entire contributing watershed; its area comprises 0.56 percent of total watershed area. The additional 2 percent allowance permits this subwatershed's contributions to be assimilated in the TMDL value without explicit numeric values and adds an additional implicit margin of safety beyond the subwatershed's expected contribution.

7.5 Results and Discussion

Sampling for the TMDL commenced in February 2007 and covered all phases of the hydrologic regime over a three year period. Existing Woodruff data included more than 20 years of data; however, source identification efforts with additional sampling on the tributaries did not begin until relatively late in the period. The intermittent / ephemeral nature of the LCR above the Silver Creek confluence coupled with the 48 hour stormflow exclusion stated in the water quality standard for suspended sediment samples precluded the collection and analysis of many samples from this subwatershed. Table 9 details the number, period, and type of samples used in the analysis effort. Table 10 itemizes exceedances considered for reductions in the TMDL analysis.

Subwatershed/Watershed	*Number Sampling Visits*	*Total Number Samples*	*Number Samples After Stormflow Exclusion*	*Sample Data Window*	*Type*
LCR-Silver-CLD/Cumulative	31	124	19	30-Sep-1988 to 10-Sept-2010	Baseflow, Snowmelt,
Silver Creek	12	9	5	27-Feb-2007 to 10-Sept-2010	Baseflow, Snowmelt,
LCR above Silver Creek	11	5*	1	15-Jul-2008 to 10-Sept-2010	Snowmelt

Table 9. Sample Population.

* Sample totals limited by intermittent character of the watercourse

Site	*Description*	*Sample Date*	*SSC (mg/l)*	*Flow (CFS)*	*Percent Flows exceeding*	*Flow Category*	*Load (Kg/day)*
LCLCR226.31	Little Colorado River near Woodruff, AZ	3/17/2010	127	108	0.094	1	33,549.34
LCLCR226.31	Little Colorado River near Woodruff, AZ	1/28/2009	171.86	66	0.128	2	27,744.39
LCLCR226.31	Little Colorado River near Woodruff, AZ	8/12/2003	162.5	18	0.264	2	7,154.55
LCLCR226.31	Little Colorado River near Woodruff, AZ	2/2/2010	5802	9.7	0.381	2	137,659.41
LCLCR226.31	Little Colorado River near Woodruff, AZ	9/30/1988	264	8.3	0.416	3	5,359.68
LCLCR226.31	Little Colorado River near Woodruff, AZ	3/3/2009	289.05	6.1	0.515	3	4,312.80
LCLCR226.31	Little Colorado River near Woodruff, AZ	8/7/2003	562.5	4.8	0.603	4	6,604.20
LCLCR226.31	Little Colorado River near Woodruff, AZ	1/9/2003	33.5	4.8	0.603	4	393.32
LCLCR226.31	Little Colorado River near Woodruff, AZ	2/26/2007	26.5	4.31	0.629	4	279.37
LCLCR226.31	Little Colorado River near Woodruff, AZ	3/23/2005	35.5	2.7	0.764	4	234.45
LCLCR226.31	Little Colorado River near Woodruff, AZ	11/28/2006	36.5	1.9	0.82	4	169.63
LCLCR226.31	Little Colorado River near Woodruff, AZ	9/24/2003	100.5	1.75	0.826	4	430.19
LCLCR226.31	Little Colorado River near Woodruff, AZ	4/1/2003	106.5	0.85	0.89	4	221.42
LCLCR226.31	Little Colorado River near Woodruff, AZ	10/1/2002	97.5	0.7	0.905	5	166.94
LCLCR226.31	Little Colorado River near Woodruff, AZ	6/7/2005	32.5	0.37	0.93	5	29.41
LCLCR226.31	Little Colorado River near Woodruff, AZ	5/17/2007	119	0.25	0.937	5	72.77
LCLCR226.31	Little Colorado River near Woodruff, AZ	7/7/2004	119	0.21	0.938	5	61.13
LCLCR232.24	LCR below Mexican Hollow Wash	2/2/2010	9103	1.9	N.A.	2*	42,305.28
LCSIL000.06	Silver Creek above LCR Confluence	3/17/2010	130	104	N.A.	1*	33,069.92
LCSIL000.06	Silver Creek above LCR Confluence	1/28/2009	179.05	63	N.A.	2*	27,591.25
LCSIL000.06	Silver Creek above LCR Confluence	2/2/2010	45	7.7	N.A.	2*	847.54
LCSIL000.06	Silver Creek above LCR Confluence	3/3/2009	91.4	6.1	N.A.	3*	1,363.74
LCSIL000.06	Silver Creek above LCR Confluence	2/26/2007	46	5	N.A.	4*	562.58

* - No independent flow history available. Associated with Woodruff flow category of the same date.

Table 10. SSC median value exceedances in the TMDL analysis

Table 11 outlines the TMDL targets, the margin of safety, load allocations, natural background and wasteload allocations for the impaired reach. Table 12 compares existing data to the TMDL targets and determines the percentage reductions necessary to attain the TMDL in each of the defined flow categories. Calculations for reductions are based on the 90th percentile value of existing data in each flow classification as compared to the water quality standard-derived target load value for the mid-point of each flow category. It should be noted that the tributary loads were classified according to the category of the combined flows as represented by the Woodruff flow history due to the lack of flow histories available for tributary discharges. The disparity in numbers of samples cumulatively presented for the impaired reach at the Woodruff site versus the tributary samples are a function of the long sampling history at Woodruff prior to the beginning of the TMDL study, the relatively short sampling history for Silver Creek, and the intermittent nature of the LCR above Silver Creek

The cumulative data for the LCR at Woodruff indicates that reductions are called for in all five flow classes, though insufficient nonstorm data is available to quantify reductions for the upper three flow classes. Specific load allocation reductions necessary are 99.8 percent and 93.1 percent for the dry condition and low flow classes respectively. In neither of these classes were any contributions from the LCR above the Silver Creek confluence present; all necessary quantifiable reductions are attributable to the Silver Creek watershed alone.

In summary, loads are exceeding the system’s assimilation capacity in nonstorm conditions (outside of a 48 hour exclusion window) due almost entirely to contributions from the perennial Silver Creek watershed. Loading is further exacerbated by contributions from the LCR subwatershed above the Silver Creek confluence in those few events where the LCR above Silver Creek is flowing in nonstorm - stable flow conditions; however, these are rare occasions accounting for only a small proportion of time. The 48 hour exclusion window for storm events in the SSC water quality standard greatly reduces the sample population available for evaluation in the upper three flow classes (Figure 6, note circular data points excluded versus diamond points considered); consequently, sources that contribute on a local basis absent overland flows are implicated in the need for nonpoint source loading improvement. Load duration analysis suggests that local point sources are an issue for the impairment, since low flow categories show problems. Additionally, a mix of run-off from impervious developed areas, and riparian zone/floodplain contributions are contributing stressors. Promise is shown for the improvement of riparian buffers and implementation of filter strips and additional local controls for the areas identified as particular problems. Field reconnaissance, field data, and desktop GIS analyses pinpoint the Shumway-Taylor-Snowflake corridor with its extensive farmland and pasture areas adjacent to Silver Creek, along with urban contributions from the towns in the proximity as being the areas where the most improvement in nonpoint source sediment pollution may be achieved. Additional information on specific implementation measures will follow in the subsequent section.

Reach 15020002-004: Little Colorado River, Carr Lake Draw - Silver Creek
TMDL calculations, Kg/day

			Category 1	*Category 2*	*Category 3*	*Category 4*	*Category 5*
	90th percentile values		*High Flows*	*Moist Conditions*	*Mid-Range Flows*	*Dry Conditions*	*Low Flows* $
Cumulative	Reach 15020002-004						
	TMDL (Kg/day):		14,370	1,162	391	171	24.5
	Margin of Safety	(12%)	1,724	139	47	21	2.9
	TMDL - MOS (Kg/day)		12,646	1,022	344	151	21.5
			Little Colorado and Silver Creek Hydrologic Inputs				
	Natural Background*		7,553	611	206	90	12.9
	Waste Load Allocation		56.75	56.75	56.75	56.75	**
	Total Load Allocation		5,036	355	82	3.9	8.7
	Sum		12,646	1,022	344	151	21.5

$ - Low flow category uses 92.5 percentile flow to determine target values; Flow class extends only to the 95th percentile before discharge is 0.
** - Concentration based WLA for Snowflake WWTP in Class 5. See discussion in Section 7.3.

Table 11. 15020002-004 TMDL Targets, Load Allocations, and Waste Load Allocations.

Reach 15020002-004: Little Colorado, Silver Creek to Carr Lake Draw
TMDL Cumulative Reductions
SSC, Kg/day
90th P-tile

		Category 1 *High Flows*	*Category 2* *Moist Conditions*	*Category 3* *Mid-Range Flows*	*Category 4* *Dry Conditions*	*Category 5* *Low Flows* $
TMDL (Kg/day):		**14,370**	**1162**	**391**	**171**	**24.5**
Margin of Safety	(12%)	1724	139	47	21	3
TMDL - MOS (Kg/day)		**12,646**	**1022**	**344**	**151**	**21.5**
Reach 15020002-004 Existing		**33,549** *	**115,676 ***	**5,255 ***	**1,665**	**139**
Total Load Allocation		5,036	355	82	3.9	8.7
Urban Load Allocation		87	6.14	1.42	0.07	0.15
Waste Load Allocation		56.75	56.75	56.75	56.75	**
Natural Background		7,553	611	206	90	12.9
Load Allocation Reductions Needed		*****	*****	*****	**99.8%**	**93.1%**

$ - Low flow category uses 92.5 percentile flow to determine target values; Flow class extends only to the 95th percentile before discharge is 0.

** - Concentration-based WLA for Snowflake WWTP in Class 5. See discussion in Section 7.3.

* - Fewer than four data points in category. Reductions not quantified.

Table 12. Reduction Determinations

8.0 IMPLEMENTATION PLAN

A basin as large as the LCR watershed, consisting of more than 8,000 square miles above the USGS gauge site 09394500 (LCR at Woodruff, AZ) and presenting multi-state jurisdictional issues, poses special challenges in the development of a TMDL implementation plan. Actual on-the-ground improvements in water quality will rely upon the voluntary initiative and actions of stakeholder groups and interested individuals employing standard BMPs at a local scale throughout the entire watershed. The scope of the cumulative problem is large enough that ongoing cooperation amongst many stakeholders working within the framework of this TMDL will be necessary to effect long-term improvements over several years. Water quality improvement for the LCR will ultimately come in incremental steps from many different directions and many different benefactors. Consequently, ADEQ's implementation plan consists of providing a general framework in this TMDL for addressing the problem with broad-brush guidance and subsequently providing more focused and region-specific recommendations and guidance for the implementation of more specific improvement measures on a sub-basin scale as stakeholders and interested parties come forward with proposals.

Sample results and TMDL calculations indicate that the critical conditions causing suspended sediment exceedances in the LCR watershed occur across all flow duration classes and include both the Silver Creek and LCR subwatersheds. However, the nature of the analysis focuses predominately on Silver Creek's contribution to the sediment problem by virtue of the fact that LCR subwatershed contributions were almost entirely screened from the dataset by the stormflow exclusion window of the standard. Broad scale and landscape-wide BMPs directed towards protecting water quality in these areas hold the most promise for mitigating suspended sediment impacts seen at Woodruff. General classes of activity identified for special consideration in the implementation plan include grazing and livestock management, urban stormwater runoff, agricultural practices to reduce erosion and sediment transport, logging and road management related to forestry activities, and mining.

8.1 Grazing Management BMPs and Improvements

The EPA's *Management Measures for NPS Pollution* manual offers a generally comprehensive menu of actions and BMPs applicable for grazing and livestock management to reduce the impacts of suspended sediment loading. Measures suggested include the following:

- Provide stream crossings or hardened watering access for drinking
- Provide alternative drinking water locations
- Locate salt and additional shade, if needed, away from sensitive areas, or
- Use improved grazing management (e.g., herding and rest-rotation grazing strategies) to reduce the physical disturbance and reduce direct loading of animal waste and sediment caused by livestock
- Exclude livestock from riparian zones and watercourses where necessary

Excerpts from the NPS Pollution Manual pertaining to grazing are presented in Appendix A.

8.2 Urban Stormwater Runoff

Urban stormflow run off is likely a contributing factor to excessive suspended sediment loading from the towns of Taylor, Snowflake, and Show Low. Pinetop-Lakeside may also contribute to problems in the largest hydrologic events. However, these conditions must be considered with the caveat that all stormflow within 48 hours of the onset or peak of the hydrologic response to a local precipitation event is screened from consideration of the percent reductions required for attainment of the water quality standard.

Urban stormflow BMPs hold promise for the amelioration of excessive sediment loading originating in the Silver Creek watershed. Excerpts from EPA's *Management Measures for NPS Pollution* manual with suggestions for broad scale BMPs applicable for urban stormwater mitigation to reduce the impacts of suspended sediment loading are presented in Appendix B. For the purposes of this implementation plan, urban stormwater will be treated in three separate classifications: existing development measures, septic systems, and pet waste.

Existing development measures to improve the quality of stormwater discharges include the following:

- Identify priority local and/or regional watershed pollutant reduction opportunities, e.g., improvements to existing urban runoff control structures;
- Contain a schedule for implementing appropriate controls;
- Limit destruction of natural conveyance systems; and
- Where appropriate, preserve, enhance, or establish buffers along surface waterbodies and their tributaries.

8.3 Agricultural BMPs

Though agriculture is limited in the LCR basin above Woodruff, the possibilities exist for nonpoint source suspended sediment loading from agricultural practices. Though most BMPs for agricultural practices are focused on the primary objective of reducing erosion and sediment transport, they have the secondary effect of allowing for slower run off and greater infiltration. Excerpts from EPA's *Management Measures for NPS Pollution* manual with suggestions for broad scale BMPs applicable for agriculture to reduce the impacts of erosion and consequent suspended sediment loading are presented in Appendix C.

8.4 Forestry, Logging, and Road Management BMPs

While forestry activities are light in the watershed, logging and erosion problems attributable to forest roads nevertheless constitute a possible source that must be addressed. EPA's management measures for Forestry, Logging, and Road Management BMPs are presented in Appendix D in four separate categories: logging operations within streamside management areas, road construction/reconstruction measures; road management operations; and timber harvesting in areas outside of streamside management areas. Each category has recommendations specific to the activities covered by the section. See Appendix D for specifics on each activity.

8.5 Mining and Abandoned Mine BMPs

Mining operations that do not adhere to BMPs in reducing the possibilities of erosion and sedimentation of waterways pose a larger danger of excessive nonpoint source contributions than several other land uses due to their activities directly related to earth-moving. Appendix F presents excerpts from EPA's *Coal Mining Proposed Best Management Practices Guidance Manual 03-24-2009.* Though coal is not mined in the TMDL study area, the BMPs presented are applicable to open-pit surface mines of many types. Quoting directly from the introduction:

Erosion and sediment deposition caused by weathering and precipitation are natural processes that can be accelerated in disturbed watersheds. Disturbances such as surface coal mining involve the removal of vegetation, soil, and rock. Spoil or highwall surfaces create conditions highly vulnerable to erosion and result in adverse sediment deposition that can clog streams, increase the risk of flooding, damage irrigation systems, and destroy aquatic habitats. Sediment deposition in downslope areas can have adverse environmental impacts on watershed soil and vegetation. Abandoned surface mine land, spoil refuse and gob piles often have exposed surfaces that are vulnerable to erosion or conducive to high rates of storm water runoff resulting in increased problems of sedimentation in receiving streams. Re-exposing these abandoned sites during remining operations without concern for sediment control can cause serious solids loading and hydrologic imbalance. Successful implementation of erosion and sediment control BMPs are critical for ultimate landscape stability and receiving stream protection.

The LCR Basin is not generally known for its mining industry due to its largely sedimentary character, but a number of mines dealing primarily with sand and gravel, uranium, and pumice are present and active within the basin. Section 4.2.5 provides additional facts regarding mining activity within the basin. As mentioned previously, Appendix E presents specific BMPs related to mining for consideration.

9.0 PUBLIC PARTICIPATION

Stakeholder and public participation was encouraged and received throughout the development of this TMDL. ADEQ participated in a LCR Watershed Coordinating Council meeting in early 2007 in Show Low, where the TMDL project was introduced; subsequently, ADEQ held another public meeting in Holbrook near the conclusion of the project to present findings and results after sampling and analysis was complete. Stakeholders and interested parties contacted throughout the project duration included the Town of Taylor, the Town of Pinetop-Lakeside, Navajo County, the Natural Resource Conservation Service, the Arizona Game and Fish Department, and Arizona NEMO. Public comment was invited for a 30 day period after the public meeting, and the TMDL was subsequently submitted to the Arizona Administrative Review for a 45 day notice period. Copies of the final TMDL will be provided to land management agencies including the A-S NF and the Bureau of Land Management.

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Appendix A – Grazing Management BMPs
Excerpts from EPA's Management Measures for NPS Pollution Manual

GRAZING MANAGEMENT

Protect range, pasture and other grazing lands:

By implementing one or more of the following to protect sensitive areas (such as streambanks, wetlands, estuaries, ponds, lake shores, and riparian zones):

- Exclude livestock,
- Provide stream crossings or hardened watering access for drinking,
- Provide alternative drinking water locations,
- Locate salt and additional shade, if needed, away from sensitive areas, or
- Use improved grazing management (e.g., herding) to reduce the physical disturbance and reduce direct loading of animal waste and sediment caused by livestock; and

By achieving either of the following on all range, pasture, and other grazing lands not addressed under (1):

- Implement the range and pasture components of a Conservation Management System (CMS) as defined in the Field Office Technical Guide of the USDA-SCS (see Appendix 2A of this chapter) by applying the progressive planning approach of the USDA-Soil Conservation Service (SCS) to reduce erosion, or
- Maintain range, pasture, and other grazing lands in accordance with activity plans established by either the Bureau of Land Management of the U.S. Department of the Interior or the Forest Service of USDA.

1. Applicability

The management measure is intended to be applied by States to activities on range, irrigated and nonirrigated pasture, and other grazing lands used by domestic livestock.

[EPA discussion continues; excerpt resumed below…]

Range is those lands on which the native vegetation (climax or natural potential plant community) is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing or browsing use. Range includes natural grassland, savannas, many wetlands, some deserts, tundra, and certain forb and shrub communities. Pastures are those lands that are primarily used for the production of adapted, domesticated forage plants for livestock. Other grazing lands include woodlands, native pastures, and croplands producing forages.

The major differences between range and pasture are the kind of vegetation and level of management that each land area receives. In most cases, range supports native vegetation that is extensively managed through the control of livestock rather than by agronomy practices, such as fertilization, mowing, irrigation, etc. Range also includes areas that have been seeded to introduced species (e.g., crested wheatgrass), but which are extensively managed like native range. Pastures are represented by those lands that have been seeded, usually to introduced species (e.g., tall fescue) or in some cases to native plants (e.g., switchgrass), and which are intensively managed using agronomy practices and control of livestock.

2. Description

The focus of the grazing management measure is on the riparian zone, yet the control of erosion from range, pasture, and other grazing lands above the riparian zone is also encouraged. Application of this management measure will reduce the physical disturbance to sensitive areas and reduce the discharge of sediment, animal waste, nutrients, and chemicals to surface waters. For information regarding potential problems caused by grazing, see Sections I.F.2 and I.F.6 of this chapter.

The key options to consider (all are not required by this management measure) when developing a comprehensive grazing management approach at a particular location include the development of one or more of the following:

Grazing management systems. These systems ensure proper grazing use through:

- Grazing frequency (includes complete rest);
- Livestock stocking rates;
- Livestock distribution;
- Timing (season of forage use) and duration of each rest and grazing period;
- Livestock kind and class; and
- Forage use allocation for livestock and wildlife.
- Proper water and salt supplement facilities.
- Livestock access control.
- Range or pasture rehabilitation.

For any grazing management system to work, it must be tailored to fit the needs of the vegetation, terrain, class or kind of livestock, and particular operation involved. For both pasture and range, areas should be provided for livestock watering, salting, and shade that are located away from streambanks and riparian zones where necessary and practical. This will be accomplished by managing livestock grazing and providing facilities for water, salt, and shade as needed. Special attention must be given to grazing management in riparian and wetland areas if management measure objectives are to be met. For purposes of this guidance, riparian areas are defined (Mitsch and Gosselink, 1986; Lowrance et al., 1988) as:

Vegetated ecosystems along a waterbody through which energy, materials, and water pass. Riparian areas characteristically have a high water table and are subject to periodic flooding and influence from the adjacent waterbody.
The health of the riparian system, and thus the quality of water, is dependent on the use, management, and condition of the related uplands. Therefore, the proper

management of riparian and wetland ecosystems will involve the correct management of livestock grazing and other land uses in the total watershed.

Conservation management systems (CMS) include any combination of conservation practices and management that achieves a level of treatment of the five natural resources (i.e., soil, water, air, plants, and animals) that satisfies criteria contained in the Soil Conservation Service (SCS) Field Office Technical Guide (FOTG), such as a resource management system (RMS) or an acceptable management system (AMS). These criteria are developed at the State level, with concurrence by the appropriate SCS National Technical Center (NTC). The criteria are then applied in the provision of field office technical assistance, under the direction of the District Conservationist of SCS. In-state coordination of FOTG use is provided by the Area Conservationist and State Conservationist of SCS.

The range and pasture components of a CMS address erosion control, proper grazing, adequate pasture stand density, and range condition. National (minimum) criteria pertaining to range and pasture under an RMS are applied to achieve environmental objectives, conserve natural resources, and prevent soil degradation.

[EPA discussion continues; excerpt resumed below…]

3. Management Measure Selection

This management measure was selected based on an evaluation of available information that documents the beneficial effects of improved grazing management (see "Effectiveness Information" below). Specifically, the available information shows that (1) aquatic habitat conditions are improved with proper livestock management; (2) pollution from livestock is decreased by reducing the amount of time spent in the stream through the provision of supplemental water; and (3) sediment delivery is reduced through the proper use of vegetation, streambank protection, planned grazing systems, and livestock management.

4. Effectiveness Information

…Miner et al. (1991) showed that the provision of supplemental water facilities reduced the time each cow spent in the stream within 4 hours of feeding from 14.5 minutes to 0.17 minutes (8-day average). This pasture study in Oregon showed that the 90 cows without supplemental water spent a daily average of 25.6 minutes per cow in the stream. For the 60 cows that were provided a supplemental water tank, the average daily time in the stream was 1.6 minutes per cow, while 11.6 minutes were spent at the water tank. Based on this study, the authors expect that decreased time spent in the stream will decrease bacterial loading from the cows.

Tiedemann et al. (1988) studied the effects of four grazing strategies on bacteria levels in 13 Oregon watersheds in the summer of 1984. Results indicate that lower fecal coliform levels can be achieved at stocking rates of about 20 ac/AUM if management for livestock distribution, fencing, and water developments are used. The study also indicates that, even with various management practices, the highest fecal coliform levels were associated with the higher stocking rates (6.9 ac/AUM) employed in strategy D.

[EPA discussion continues; excerpt resumed below…]

5. Range and Pasture Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

The U.S. Soil Conservation Service practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988.)

Grazing Management System Practices

Appropriate grazing management systems ensure proper grazing use by adjusting grazing intensity and duration to reflect the availability of forage and feed designated for livestock uses, and by controlling animal movement through the operating unit of range or pasture. Proper grazing use will maintain enough live vegetation and litter cover to protect the soil from erosion; will achieve riparian and other resource objectives; and will maintain or improve the quality, quantity, and age distribution of desirable vegetation. Practices that accomplish this are:

a. *Deferred grazing (352): Postponing grazing or resting grazing land for prescribed period.*

In areas with bare ground or low percent ground cover, deferred grazing will reduce sediment yield because of increased ground cover, less ground surface disturbance, improved soil bulk density characteristics, and greater infiltration rates. Areas mechanically treated will have less sediment yield when deferred to encourage re-vegetation. Animal waste would not be available to the area during the time of deferred grazing and there would be less opportunity for adverse runoff effects on surface or aquifer water quality. As vegetative cover increases, the filtering processes are enhanced, thus trapping more silt and nutrients as well as snow if climatic conditions for snow exist. Increased plant cover results in a greater uptake and utilization of plant nutrients.

b. *Planned grazing system (556): A practice in which two or more grazing units are alternately rested and grazed in a planned sequence for a period of years, and rest periods may be throughout the year or during the growing season of key plants.*

Planned grazing systems normally reduce the system time livestock spend in each pasture. This increases quality and quantity of vegetation. As vegetation quality increases, fiber content in manure decreases which speeds manure decomposition and reduces pollution potential. Freeze-thaw, shrink-swell, and other natural soil mechanisms can reduce compacted layers during the absence of grazing animals. This increases infiltration, increases vegetative growth, slows runoff, and improves the nutrient and moisture filtering and trapping ability of the area.
Decreased runoff will reduce the rate of erosion and movement of sediment and dissolved and sediment-attached substances to downstream water courses. No increase in ground water pollution hazard would be anticipated from the use of this practice.

c. *Proper grazing use (528): Grazing at an intensity that will maintain enough cover to protect the soil and maintain or improve the quantity and quality of desirable vegetation.*

Increased vegetation slows runoff and acts as a sediment filter for sediments and sediment attached substances, uses more nutrients, and reduces raindrop splash. Adverse chemical effects should not be anticipated from the use of this practice.

d. *Proper woodland grazing (530): Grazing wooded areas at an intensity that will maintain adequate cover for soil protection and maintain or improve the quantity and quality of trees and forage vegetation.*

This practice is applicable on wooded areas producing a significant amount of forage that can be harvested without damage to other values. In these areas there should be no detrimental effects on the quality of surface and ground water. Any time this practice is applied there must be a detailed management and grazing plan.

[EPA discussion continues; excerpt resumed below…]

Alternate Water Supply Practices

Providing water and salt supplement facilities away from streams will help keep livestock away from streambanks and riparian zones. The establishment of alternate water supplies for livestock is an essential component of this measure when problems related to the distribution of livestock occur in a grazing unit. In most western states, securing water rights may be necessary. Access to a developed or natural water supply that is protective of streambank and riparian zones can be provided by using the stream crossing (interim) technology to build a watering site. In some locations, artificial shade may be constructed to encourage use of upland sites for shading and loafing. Providing water can be accomplished through the following Soil Conservation Service practices and the stream crossing (interim) practice (practice "m") of the following section. Descriptions have been modified to meet CZM needs:

f. *Pipeline (516): Pipeline installed for conveying water for livestock or for recreation.*

Pipelines may decrease sediment, nutrient, organic, and bacteria pollution from livestock. Pipelines may afford the opportunity for alternative water sources other than streams and lakes, possibly keeping the animals away from the stream or impoundment. This will prevent bank destruction with resulting sedimentation, and will reduce animal waste deposition directly in the water. The reduction of concentrated livestock areas will reduce manure solids, nutrients, and bacteria that accompany surface runoff.

g. *Pond (378): A water impoundment made by constructing a dam or an embankment or by excavation of a pit or dugout.*

Ponds may trap nutrients and sediment which wash into the basin. This removes these substances from downstream. Chemical concentrations in the pond may be higher during the summer months. By reducing the amount of water that flows in the channel downstream, the frequency of flushing of the stream is reduced and there is a collection of substances held temporarily within the channel. A pond may cause more leachable substance to be carried into the ground water.

h. *Trough or tank (614): A trough or tank, with needed devices for water control and waste water disposal, installed to provide drinking water for livestock.*

By the installation of a trough or tank, livestock may be better distributed over the pasture, grazing can be better controlled, and surface runoff reduced, thus reducing erosion. By itself this practice will have only a minor effect on water quality; however when coupled with other conservation practices, the beneficial effects of the combined practices may be large. Each site and application should be evaluated on their own merits.

i. *Well (642): A well constructed or improved to provide water for irrigation, livestock, wildlife, or recreation.*

When water is obtained, if it has poor quality because of dissolved substances, its use in the surface environment or its discharge to downstream water courses the surface water will be degraded. The location of the well must consider the natural water quality and the hazards of its use in the potential contamination of the environment. Hazard exists during well development and its operation and maintenance to prevent aquifer quality damage from the pollutants through the well itself by back flushing, or accident, or flow down the annular spacing between the well casing and the bore hole.

j. *Spring development (574): Improving springs and seeps by excavating, cleaning, capping, or providing collection and storage facilities.*

There will be negligible long-term water quality impacts with spring developments. Erosion and sedimentation may occur from any disturbed areas during and immediately after construction, but should be short-lived. These sediments will have minor amounts of adsorbed nutrients from soil organic matter.

Livestock Access Limitation Practices

It may be necessary to minimize livestock access to streambanks, ponds or lakeshores, and riparian zones to protect these areas from physical disturbance. This could also be accomplished by establishing special use pastures to manage livestock in areas of concentration. Practices include:

k. *Fencing (382): Enclosing or dividing an area of land with a suitable permanent structure that acts as a barrier to livestock, big game, or people (does not include temporary fences).*

Fencing is a practice that can be on the contour or up and down slope. Often a fence line has grass and some shrubs in it. When a fence is built across the slope it will slow down runoff, and cause deposition of coarser grained materials reducing the amount of sediment delivered downslope. Fencing may protect riparian areas which act as sediment traps and filters along water channels and impoundments.
Livestock have a tendency to walk along fences. The paths become bare channels which concentrate and accelerate runoff causing a greater amount of erosion within the path and where the path/channel outlets into another channel. This can deliver more sediment and associated pollutants to surface waters. Fencing can have the effect of concentrating livestock in small areas, causing a concentration of manure which may wash off into the stream, thus causing surface water pollution.

l. *Livestock exclusion (472): Excluding livestock from an area not intended for grazing.*

Livestock exclusion may improve water quality by preventing livestock from being in the water or walking down the banks, and by preventing manure deposition in the stream. The amount of sediment and manure may be reduced in the surface water. This practice prevents compaction of the soil by livestock and prevents losses of vegetation and undergrowth. This may maintain or increase evapotranspiration. Increased permeability may reduce erosion and lower sediment and substance transportation to the surface waters. Shading along streams and channels resulting from the application of this practice may reduce surface water temperature.

m. *Stream crossing (interim): A stabilized area to provide access across a stream for livestock and farm machinery.*

The purpose is to provide a controlled crossing or watering access point for livestock along with access for farm equipment, control bank and streambed erosion, reduce sediment and enhance water quality, and maintain or improve wildlife habitat.

[EPA discussion continues; excerpt resumed below…]

Selection of Practices

The selection of management practices for this measure should be based on an evaluation of current conditions, problems identified, quality criteria, and management goals. Successful resource management on range and pasture includes appropriate application of a combination of practices that will meet the needs of the range and pasture ecosystem (i.e., the soil, water, air, plant, and animal (including fish and shellfish) resources) and the objectives of the land user.

For a sound grazing land management system to function properly and to provide for a sustained level of productivity, the following should be considered:

- Know the key factors of plant species management, their growth habits, and their response to different seasons and degrees of use by various kinds and classes of livestock.
- Know the demand for, and seasons of use of, forage and browse by wildlife species.
- Know the amount of plant residue or grazing height that should be left to protect grazing land soils from wind and water erosion, provide for plant regrowth, and provide the riparian vegetation height desired to trap sediment or other pollutants.
- Know the range site production capabilities and the pasture suitability group capabilities so an initial stocking rate can be established.
- Know how to use livestock as a tool in the management of the range ecosystems and pastures to ensure the health and vigor of the plants, soil tilth, proper nutrient cycling, erosion control, and riparian area management, while at the same time meeting livestock nutritional requirements.

- Establish grazing unit sizes, watering, shade and salt locations, etc. to secure optimum livestock distribution and proper vegetation use.
- Provide for livestock herding, as needed, to protect sensitive areas from excessive use at critical times.
- Encourage proper wildlife harvesting to ensure proper population densities and forage balances.
- Know the livestock diet requirements in terms of quantity and quality to ensure that there are enough grazing units to provide adequate livestock nutrition for the season and the kind and classes of animals on the farm/ranch.
- Maintain a flexible grazing system to adjust for unexpected environmentally and economically generated problems.

[EPA excerpts concluded]

Appendix B – Urban Stormwater Runoff BMPs
Excerpts from EPA's Management Measures for NPS Pollution Manual

Part A. Existing Development Management

Develop and implement watershed management programs to reduce runoff pollutant concentrations and volumes from existing development:

- Identify priority local and/or regional watershed pollutant reduction opportunities, e.g., improvements to existing urban runoff control structures;
- Contain a schedule for implementing appropriate controls;
- Limit destruction of natural conveyance systems; and
- Where appropriate, preserve, enhance, or establish buffers along surface waterbodies and their tributaries.

1. Applicability

This management measure is intended to be applied by States to all urban areas and existing development in order to reduce surface water runoff pollutant loadings from such areas. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal NPS programs in conformity with this management measure and will have flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).

2. Description

The purpose of this management measure is to protect or improve surface water quality by the development and implementation of watershed management programs that pursue the following objectives:

1. Reduce surface water runoff pollution loadings from areas where development has already occurred;
2. Limit surface water runoff volumes in order to minimize sediment loadings resulting from the erosion of streambanks and other natural conveyance systems; and
3. Preserve, enhance, or establish buffers that provide water quality benefits along waterbodies and their tributaries.

Maintenance of water quality becomes increasingly difficult as areas of impervious surface increase and urbanization occurs. For the purpose of this guidance, urbanized areas are those areas where the presence of "man-made" impervious surfaces results in increased peak runoff volumes and pollutant loadings that permanently alter one or more of the following: stream channels, natural drainageways, and in-stream and adjacent riparian habitat so that predevelopment aquatic flora and fauna are eliminated or reduced to unsustainable levels and predevelopment water quality has been degraded. Increased bank cutting, streambed scouring, siltation damaging to aquatic flora and fauna, increases in water temperature, decreases in dissolved oxygen, changes to the natural structure and flow of the stream or river, and the presence of anthropogenic pollutants that are not generated from agricultural activities, in general, are indications of urbanization.

The effects of urbanization have been well described in the introduction to this chapter. Protection of water quality in urbanized areas is difficult because of a range of factors. These factors include diverse pollutant loadings, large runoff volumes, limited areas suitable for surface water runoff treatment systems, high implementation costs associated with structural controls, and the destruction or absence of buffer zones that can filter pollutants and prevent the destabilization of streambanks and shorelines.

As discussed in Section II.B of this chapter, comprehensive watershed planning facilitates integration of source reduction activities and treatment strategies to mitigate the effects of urban runoff. Through the use of watershed management, States and local governments can identify local water quality objectives and focus resources on control of specific pollutants and sources. Watershed plans typically incorporate a combination of nonstructural and structural practices.

An important nonstructural component of many watershed management plans is the identification and preservation of buffers and natural systems. These areas help to maintain and improve surface water quality by filtering and infiltrating urban runoff. In areas of existing development, natural buffers and conveyance systems may have been altered as urbanization occurred. Where possible and appropriate, additional impacts to these areas should be minimized and if degraded, the functions of these areas restored. The preservation, enhancement, or establishment of buffers along waterbodies is generally recommended throughout the section 6217 management area as an important tool for reducing NPS impacts. The establishment and protection of buffers, however, is most appropriate along surface waterbodies and their tributaries where water quality and the biological integrity of the waterbody is dependent on the presence of an adequate buffer/riparian area. Buffers may be necessary where the buffer/riparian area (1) reduces significant NPS pollutant loadings, (2) provides habitat necessary to maintain the biological integrity of the receiving water, and (3) reduces undesirable thermal impacts to the waterbody. ….

Institutional controls, such as permits, inspection, and operation and maintenance requirements, are also essential components of a watershed management program. The effectiveness of many of the practices described in this chapter is dependent on administrative controls such as inspections. Without effective compliance mechanisms and operation and maintenance requirements, many of these practices will not perform satisfactorily.

Where existing development precludes the use of effective nonstructural controls, structural practices may be the only suitable option to decrease the NPS pollution loads generated from developed areas. In such situations, a watershed plan can be used to integrate the construction of new surface water runoff treatment structures and the retrofit of existing surface water runoff management systems.

Retrofitting is a process that involves the modification of existing surface water runoff control structures or surface water runoff conveyance systems, which were initially designed to control flooding, not to serve a water quality improvement function. By enlarging existing surface water runoff structures, changing the inflow and outflow characteristics of the device, and increasing detention times of the runoff, sediment and associated pollutants can be removed from the runoff. Retrofit of structural controls, however, is often the only feasible alternative for improving water quality in developed areas. Where the presence of existing development or financial constraints limits treatment options, targeting may be necessary to identify priority pollutants and select the most appropriate retrofits.

Once key pollutants have been identified, an achievable water quality target for the receiving water should be set to improve current levels based on an identified objective or to prevent degradation of current water quality. Extensive site evaluations should then be performed to assess the performance of existing surface water runoff management systems and to pinpoint low-cost structural changes or maintenance programs for improving pollutant-removal efficiency. Where flooding problems exist, water quality controls should be incorporated into the design of surface water runoff controls. Available land area is often limited in urban areas, and the lack of suitable areas will frequently restrict the use of conventional pond systems. In heavily urbanized areas, sand filters or water quality inlets with oil/grit separators may be appropriate for retrofits because they do not limit land usage.

3. Management Measure Selection

Components (1) and (2) of this management measure were selected so that local communities develop and implement watershed management programs. Watershed management programs are used throughout the 6217 management area although coverage is inconsistent among States and local governments (Puget Sound Water Quality Authority, 1986).

Local conditions, availability of funding, and problem pollutants vary widely in developed communities. Watershed management programs allow these communities to select and implement practices that best address local needs. The identification of priority and/or local regional pollutant reduction opportunities and schedules for implementing appropriate controls were selected as logical starting points in the process of instituting an institutional framework to address nonpoint source pollutant reductions.

Cost was also a major factor in the selection of this management measure. EPA acknowledges the high costs and other limitations inherent in treating existing sources to levels consistent with the standards set for developing areas. Suitable areas are often unavailable for structural treatment systems that can adequately protect receiving waters. The lack of universal cost-effective treatment options was a major factor in the selection of this management measure. EPA was also influenced by the frequent lack of funding for mandatory retrofitting and the extraordinarily high costs associated with the implementation of retention ponds and exfiltration systems in developed areas.

The use of retrofits has been encouraged because of proven water quality benefits. … Retrofits are currently being used by a number of States and local governments in the 6217 management area, including Maryland, Delaware, and South Carolina. Management measure components (3) and (4) were selected to preserve, enhance, and establish areas within existing development that provide positive water quality benefits. Refer to the New Development and Site Planning Management Measures for the rationale used in selecting components (3) and (4) of this management measure.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Priority NPS pollutants should be targeted, and implementation strategies for mitigating the effects of NPS pollutants should be developed.
b. Policies, plans, and organizational structures that ensure that all surface water runoff management facilities are properly operated and maintained should be developed. Periodic monitoring and maintenance may be necessary to ensure proper operation and maintenance.
c. Remnant pervious areas in already-built areas should be subject to enforceable preservation requirements. For example, set green space goals to promote tree plantings and pavement reclamation projects.
d. Developed areas in need of local or regional structural solutions should be identified and put in priority order.
e. Regional structural solutions, retrofit opportunities, and nonstructural alternatives should be identified, inventoried, and put in priority order.
f. Where possible, modify existing surface water runoff management structures to address water quality.
g. As capital resources allow, implement [appropriate] practices.

. [EPA excerpts concluded]

Appendix C – Agricultural Erosion and Sediment Control BMPs
Excerpts from EPA's Management Measures for NPS Pollution Manual

Erosion and Sediment Control Management Measure

Combinations of the following practices can be used to satisfy the requirements of this management measure. The SCS practice number and definitions are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

a. Conservation cover (327): Establishing and maintaining perennial vegetative cover to protect soil and water resources on land retired from agricultural production.

Agricultural chemicals are usually not applied to this cover in large quantities and surface and ground water quality may improve where these material are not used. Ground cover and crop residue will be increased with this practice. Erosion and yields of sediment and sediment related stream pollutants should decrease. Temperatures of the soil surface runoff and receiving water may be reduced. Effects will vary during the establishment period and include increases in runoff, erosion and sediment yield. Due to the reduction of deep percolation, the leaching of soluble material will be reduced, as will be the potential for causing saline seeps. Long-term effects of the practice would reduce agricultural nonpoint sources of pollution to all water resources.

b. Conservation cropping sequence (328): An adapted sequence of crops designed to provide adequate organic residue for maintenance or improvement of soil tilth.

This practice reduces erosion by increasing organic matter, resulting in a reduction of sediment and associated pollutants to surface waters. Crop rotations that improve soil tilth may also disrupt disease, insect and weed reproduction cycles, reducing the need for pesticides. This removes or reduces the availability of some pollutants in the watershed. Deep percolation may carry soluble nutrients and pesticides to the ground water. Underlying soil layers, rock and unconsolidated parent material may block, delay, or enhance the delivery of these pollutants to ground water. The fate of these pollutants will be site specific, depending on the crop management, the soil and geologic conditions.

c. Conservation tillage (329): Any tillage or planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water; or, where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small-grain residue equivalent on the surface during the critical erosion period.

This practice reduces soil erosion, detachment and sediment transport by providing soil cover during critical times in the cropping cycle. Surface residues reduce soil compaction from raindrops, preventing soil sealing and increasing infiltration. This action may increase the leaching of agricultural chemicals into the ground water.

In order to maintain the crop residue on the surface it is difficult to incorporate fertilizers and pesticides. This may increase the amount of these chemicals in the runoff and cause more surface water pollution.

The additional organic material on the surface may increase the bacterial action on and near the soil surface. This may tie-up and then breakdown many pesticides which are surface applied, resulting in less pesticide leaving the field. This practice is more effective in humid regions.

With a no-till operation the only soil disturbance is the planter shoe and the compaction from the wheels. The surface applied fertilizers and chemicals are not incorporated and often are not in direct contact with the soil surface. This condition may result in a high surface runoff of pollutants (nutrient and pesticides). Macropores develop under a no-till system. They permit deep percolation and the transmittal of pollutants, both soluble and insoluble to be carried into the deeper soil horizons and into the ground water.
Reduced tillage systems disrupt or break down the macropores, incidentally incorporate some of the materials applied to the soil surface, and reduce the effects of wheeltrack compaction. The results are less runoff and less pollutants in the runoff.

d. Contour farming (330): Farming sloping land in such a way that preparing land, planting, and cultivating are done on the contour. This includes following established grades of terraces or diversions.

This practice reduces erosion and sediment production. Less sediment and related pollutants may be transported to the receiving waters.
Increased infiltration may increase the transportation potential for soluble substances to the ground water.

e. Contour orchard and other fruit area (331): Planting orchards, vineyards, or small fruits so that all cultural operations are done on the contour.

Contour orchards and fruit areas may reduce erosion, sediment yield, and pesticide concentration in the water lost. Where inward sloping benches are used, the sediment and chemicals will be trapped against the slope. With annual events, the bench may provide 100 percent trap efficiency. Outward sloping benches may allow greater sediment and chemical loss. The amount of retention depends on the slope of the bench and the amount of cover. In addition, outward sloping benches are subject to erosion form runoff from benches immediately above them. Contouring allows better access to rills, permitting maintenance that reduces additional erosion. Immediately after establishment, contour orchards may be subject to erosion and sedimentation in excess of the now contoured orchard. Contour orchards require more fertilization and pesticide application than did the native grasses that frequently covered the slopes before orchards were started. Sediment leaving the site may carry more adsorbed nutrients and pesticides than did the sediment before the benches were established from uncultivated slopes. If contoured orchards replace other crop or intensive land use, the increase or decrease in chemical transport from the site may be determined by examining the types and amounts of chemicals used on the prior land use as compared to the contour orchard condition. Soluble pesticides and nutrients may be delivered to and possibly through the root zone in an amount proportional to the amount of soluble pesticides applied, the increase in infiltration, the chemistry of the pesticides, organic and clay content of the soil, and amounts of surface residues. Percolating water below the root zone may carry excess solutes or may dissolve potential pollutants as they move. In either case, these solutes could reach ground water supplies and/or surface downslope from the contour orchard area. The amount depends on soil type, surface water quality, and the availability of soluble material (natural or applied).

f. Cover and green manure crop (340): A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. It usually is grown for 1 year or less, except where there is permanent cover as in orchards.

Erosion, sediment and adsorbed chemical yields could be decreased in conventional tillage systems because of the increased period of vegetal cover. Plants will take up available nitrogen and prevent its undesired movement. Organic nutrients may be added to the nutrient budget reducing the need to supply more soluble forms. Overall volume of chemical application may decrease because the vegetation will supply nutrients and there may be allelopathic effects of some of the types of cover vegetation on weeds. Temperatures of ground and surface waters could slightly decrease.

g. Critical area planting (342): Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible or critically eroding areas (does not include tree planting mainly for wood products).

This practice may reduce soil erosion and sediment delivery to surface waters. Plants may take up more of the nutrients in the soil, reducing the amount that can be washed into surface waters or leached into ground water.
During grading, seedbed preparation, seeding, and mulching, large quantities of sediment and associated chemicals may be washed into surface waters prior to plant establishment.

h. Crop residue use (344): Using plant residues to protect cultivated fields during critical erosion periods.

When this practice is employed, raindrops are intercepted by the residue reducing detachment, soil dispersion, and soil compaction. Erosion may be reduced and the delivery of sediment and associated pollutants to surface water may be reduced. Reduced soil sealing, crusting and compaction allows more water to infiltrate, resulting in an increased potential for leaching of dissolved pollutants into the ground water.
Crop residues on the surface increase the microbial and bacterial action on or near the surface. Nitrates and surface-applied pesticides may be tied-up and less available to be delivered to surface and ground water. Residues trap sediment and reduce the amount carried to surface water. Crop residues promote soil aggregation and improve soil tilth.

i. Delayed seed bed preparation (354): Any cropping system in which all of the crop residue and volunteer vegetation are maintained on the soil surface until approximately 3 weeks before the succeeding crop is planted, thus shortening the bare seedbed period on fields during critical erosion periods.

The purpose is to reduce soil erosion by maintaining soil cover as long as practical to minimize raindrop splash and runoff during the spring erosion period. Other purposes include moisture conservation, improved water quality, increased soil infiltration, improved soil tilth, and food and cover for wildlife.

j. Diversion (362): A channel constructed across the slope with a supporting ridge on the lower side (Figure 2-3).

This practice will assist in the stabilization of a watershed, resulting in the reduction of sheet and rill erosion by reducing the length of slope. Sediment may be reduced by the elimination of ephemeral and large gullies. This may reduce the amount of sediment and related pollutants delivered to the surface waters.

k. Field border (386): A strip of perennial vegetation established at the edge of a field by planting or by converting it from trees to herbaceous vegetation or shrubs.

This practice reduces erosion by having perennial vegetation on an area of the field. Field borders serve as "anchoring points" for contour rows, terraces, diversions, and contour strip cropping. By elimination of the practice of tilling and planting the ends up and down slopes, erosion from concentrated flow in furrows and long rows may be reduced. This use may reduce the quantity of sediment and related pollutants transported to the surface waters.

l. Filter strip (393): A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.

Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials. When a storm causes runoff in excess When the field borders are located such that runoff flows across them in sheet flow, they may cause the deposition of sediment and prevent it from entering the surface water. Where these practice are between cropland and a stream or water body, the practice may reduce the amount of pesticide application drift from entering the surface water of the design runoff, the filter may be flooded and may cause large loads of pollutants to be released to the surface water. This type of filter requires high maintenance and has a relatively short service life and is effective only as long as the flow through the filter is shallow sheet flow.

Filter strips for runoff from concentrated livestock areas may trap organic material, solids, materials which become adsorbed to the vegetation or the soil within the filter. Often they will not filter out soluble materials. This type of filter is often wet and is difficult to maintain. Filter strips for controlled overland flow treatment of liquid wastes may effectively filter out pollutants. The filter must be properly managed and maintained, including the proper resting time. Filter strips on forest land may trap coarse sediment, timbering debris, and other deleterious material being transported by runoff. This may improve the quality of surface water and has little effect on soluble material in runoff or on the quality of ground water. All types of filters may reduce erosion on the area on which they are constructed. Filter strips trap solids from the runoff flowing in sheet flow through the filter. Coarse-grained and fibrous materials are filtered more efficiently than fine-grained and soluble substances. Filter strips work for design conditions, but when flooded or overloaded they may release a slug load of pollutants into the surface water.

m. Grade stabilization structure (410): A structure used to control the grade and head cutting in natural or artificial channels.

Where reduced stream velocities occur upstream and downstream from the structure, streambank and streambed erosion will be reduced. This will decrease the yield of sediment and sediment-attached substances. Structures that trap sediment will improve downstream water quality. The sediment yield change will be a function of the sediment yield to the structure, reservoir trap efficiency and of velocities of released water. Ground water recharge may affect aquifer quality depending on the quality of the recharging water. If the stored water contains only sediment and chemical with low water solubility, the ground water quality should not be affected.

n. Grassed waterway (412): A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.

This practice may reduce the erosion in a concentrated flow area, such as in a gully or in ephemeral gullies. This may result in the reduction of sediment and substances delivered to receiving waters. Vegetation may act as a filter in removing some of the sediment delivered to the waterway, although this is not the primary function of a grassed waterway.

Any chemicals applied to the waterway in the course of treatment of the adjacent cropland may wash directly into the surface waters in the case where there is a runoff event shortly after spraying.

When used as a stable outlet for another practice, waterways may increase the likelihood of dissolved and suspended pollutants being transported to surface waters when these pollutants are delivered to the waterway.

o. Grasses and legumes in rotation (411): Establishing grasses and legumes or a mixture of them and maintaining the stand for a definite number of years as part of a conservation cropping system.

Reduced runoff and increased vegetation may lower erosion rates and subsequent yields of sediment and sediment-attached substances. Less applied nitrogen may be required to grow crops because grasses and legumes will supply organic nitrogen. During the period of the rotation when the grasses and legumes are growing, they will take up more phosphorus. Less pesticides may similarly be required with this practice. Downstream water temperatures may be lower depending on the season when this practice is applied. There will be a greater opportunity for animal waste management on grasslands because manures and other wastes may be applied for a longer part of the crop year.

p. Sediment basins (350): Basins constructed to collect and store debris or sediment.

Sediment basins will remove sediment, sediment associated materials and other debris from the water which is passed on downstream. Due to the detention of the runoff in the basin, there is an increased opportunity for soluble materials to be leached toward the ground water.

q. Contour stripcropping (585): Growing crops in a systematic arrangement of strips or bands on the contour to reduce water erosion.

The crops are arranged so that a strip of grass or close-growing crop is alternated with a strip of clean-tilled crop or fallow or a strip of grass is alternated with a close-growing crop (Figure 2-4). This practice may reduce erosion and the amount of sediment and related substances delivered to the surface waters. The practice may increase the amount of water which infiltrates into the root zone, and, at the time there is an overabundance of soil water, this water may percolate and leach soluble substances into the ground water.

r. Field strip-cropping (586): Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion.

The crops are arranged so that a strip of grass or a close-growing crop is alternated with a clean-tilled crop or fallow. This practice may reduce erosion and the delivery of sediment and related substances to the surface waters. The practice may increase infiltration and, when there is sufficient water available, may increase the amount of leachable pollutants moved toward the ground water. Since this practice is not on the contour there will be areas of concentrated flow, from which detached sediment, adsorbed chemicals and dissolved substances will be delivered more rapidly to the receiving waters. The sod strips will not be efficient filter areas in these areas of concentrated flow.

s. Terrace (600): An earthen embankment, a channel, or combination ridge and channel constructed across the slope (Figures 2-5 and 2-6).

This practice reduces the slope length and the amount of surface runoff which passes over the area downslope from an individual terrace. This may reduce the erosion rate and production of sediment within the terrace interval. Terraces trap sediment and reduce the sediment and associated pollutant content in the runoff water which enhance surface water quality. Terraces may intercept and conduct surface runoff at a nonerosive velocity to stable outlets, thus, reducing the occurrence of ephemeral and classic gullies and the resulting sediment. Increases in infiltration can cause a greater amount of soluble nutrients and pesticides to be leached into the soil. Underground outlets may collect highly soluble nutrient and pesticide leachates and convey runoff and conveying it directly to an outlet, terraces may increase the delivery of pollutants to surface waters. Terraces increase the opportunity to leach salts below the root zone in the soil. Terraces may have a detrimental effect on water quality if they concentrate and accelerate delivery of dissolved or suspended nutrient, salt, and pesticide pollutants to surface or ground waters.

t. Water and sediment control basin (638): An earthen embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin.

The practice traps and removes sediment and sediment-attached substances from runoff. Trap control efficiencies for sediment and total phosphorus, that are transported by runoff, may exceed 90 percent in silt loam soils. Dissolved substances, such as nitrates, may be removed from discharge to downstream areas because of the increased infiltration. Where geologic condition permit, the practice will lead to increased loadings of dissolved substances toward ground water. Water temperatures of surface runoff, released through underground outlets, may increase slightly because of longer exposure to warming during its impoundment.

u. Wetland and riparian zone protection

Wetland and riparian zone protection practices are described in Chapter 7.

[EPA excerpts concluded]

Appendix D – Forestry, Logging, and Road Management BMPs
Excerpts from EPA's Management Measures for NPS Pollution Manual

Streamside Management Areas (SMAs)

Establish and maintain a streamside management area along surface waters, which is sufficiently wide and which includes a sufficient number of canopy species to buffer against detrimental changes in the temperature regime of the waterbody, to provide bank stability, and to withstand wind damage. Manage the SMA in such a way as to protect against soil disturbance in the SMA and delivery to the stream of sediments and nutrients generated by forestry activities, including harvesting. Manage the SMA canopy species to provide a sustainable source of large woody debris needed for instream channel structure and aquatic species habitat.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to surface waters bordering or within the area of operations. SMAs should be established for perennial waterbodies as well as for intermittent streams that are flowing during the time of operation. For winter logging, SMAs are also needed for intermittent streams since spring breakup is both the time of maximum transport of sediments from the harvest unit and the time when highest flows are present in intermittent streams.
Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The streamside management area (SMA) is also commonly referred to as a streamside management zone (SMZ) or as a riparian management area or zone. SMAs are widely recognized to be highly beneficial to water quality and aquatic habitat. Vegetation in SMAs reduces runoff and traps sediments generated from upslope activities, and reduces nutrients in runoff before it reaches surface waters (Figure 3-9, Kundt and Hall, 1988). Canopy species provide shading to surface waters, which moderates water temperature and provides the detritus that serves as an energy source for stream ecosystems. Trees in the SMA also provide a source of large woody debris to surface waters. SMAs provide important habitat for aquatic organisms (and terrestrial species) while preventing excessive logging-generated slash and debris from reaching waterbodies (Corbett and Lynch, 1985).

SMAs need to be of sufficient width to prevent delivery of sediments and nutrients generated from forestry activities (harvest, site preparation, or roads) in upland areas to the waterbody being protected. Widths for SMAs are established by considering the slope, soil type, precipitation, canopy, and waterbody characteristics. To avoid failure of SMAs, zones of preferential drainage such as intermittent channels, ephemeral channels and depressions need to be addressed when determining widths and laying out SMAs. SMAs should be designed to withstand wind damage or blowdown. For example, a single rank of canopy trees is not likely to withstand blowdown and maintain the functions of the SMA.

SMAs should be managed to maintain a sufficient number of large trees to provide for bank stability and a sustainable source of large woody debris. Large woody debris is naturally occurring dead and down woody materials and should not be confused with logging slash or debris. Trees to be maintained or managed in the SMA should provide for large woody debris recruitment to the stream at a rate that maintains beneficial uses associated with fish habitat and stream structure at the site and downstream. This should be sustainable over a time period that is equivalent to that needed for the tree species in the SMA to grow to the size needed to provide large woody debris.

A sufficient number of canopy species should also be maintained to provide shading to the stream water surface needed to prevent changes in temperature regime for the waterbody and to prevent deleterious temperature- or sunlight-related impacts on the aquatic biota. If the existing shading conditions for the waterbody prior to activity are known to be less than optimal for the stream, then SMAs should be managed to increase shading of the waterbody.
To preserve SMA integrity for water quality protection, some States limit the type of harvesting, timing of operations, amount harvested, or reforestation methods used. SMAs are managed to use only harvest and silvicultural methods that will prevent soil disturbance within the SMA. Additional operational considerations for SMAs are addressed in subsequent management measures. Practices for SMA applications to wetlands are described in Management Measure J.

3. Management Measure Selection

a. Effectiveness Information

The effectiveness of SMAs in protecting streams from temperature increases, large increases in sediment load, and reduced dissolved oxygen was demonstrated by Hall and others (1987). Lantz (1971) …. A comparison of physical changes associated with logging using three streamside treatments was made by Hartman and others (1987). This study was performed to observe the impact of these SMAs on the supply of woody debris essential to the fish population and channel structure. The volume and stability of large woody debris decreased immediately in the most intensive treatment area, decreased a few years after logging in the careful treatment area, and remained stable where streamside trees and other vegetation remained.

Other experimental forest studies have found that average monthly maximum water temperature increases from 3.3 to 10.5 øC following clearcutting (Lynch et. al., 1985). Increases in stream temperature result from increased direct solar radiation to the water surface from the removal of vegetative cover or shading in the streamside area. Stream temperature change depends on the height and density of trees, the width of the waterbody, and the volume of water (stream discharge), with small streams heating up faster than large streams per unit of increased solar radiation (Megahan, 1980). Increased direct solar radiation also shifts the energy sources for stream ecosystems from outside the stream sources, allochthonous organic matter, to instream producers, autochthonous aquatic plants such as algae.

Brown and Krygier (1970) report the greatest long-term average temperature response following clearcutting and slash disposal on a small watershed in Oregon. The average monthly temperature increased 14 øF compared to no increase on an adjacent, larger watershed that was clearcut in patches with 50- to 100-foot-wide buffer strips between the logging units and the perennial streams. Lynch and Corbett (1990) report less than a 3 øF mean temperature increase following harvesting, with 100-foot buffer strips along perennial streams. They attribute the increase to an intermittent stream with no protective vegetation that became perennial after harvesting due to increased flow. As a result of this BMP evaluation study, Pennsylvania modified its BMPs to require SMAs along both perennial and intermittent streams.
Another benefit of streamside management areas is control of suspended sediment and turbidity levels. Lynch and others (1985) documented the effectiveness of SMAs in controlling these pollutants. A combination of practices was applied, including buffer strips and prohibitions for skidding, slash disposal, and road layout in or near streams. Average stormwater-suspended sediment and turbidity levels for the treatment without these practices increased significantly compared to the control and SMA/BMP sites.

Practices such as directional felling are designed to minimize stream and streambank damage associated with increased logging debris in SMAs. Froehlich (1973) provides data on how effective different cutting practices and buffer strips are in preventing debris from entering the stream channel. Buffer strips were the most effective debris barriers. Narver (1971) investigated the impacts of logging debris in streams on salmonid production and describes threats to fish embryo survival from low dissolved oxygen concentrations and decreased flow velocities in intragravel waters. Erman and others (1977) studied the effectiveness of buffer strips in protecting aquatic organisms and found significant differences in benthic invertebrate communities when logging occurred with buffer strips less than 30 meters wide.

b. Cost Information

In 4 of the 10 areas in Oregon studied by Dykstra and Froelich (1976a), the 55-foot buffer strip was the least costly alternative, yet these researchers concluded that no single alternative is preferable for all sites in terms of costs and that cost analysis alone cannot resolve the question of best stream protection method

Dykstra and Froehlich (1976b) also found that increased cable-assisted directional felling costs (68 to 108 percent increase) were offset by savings in channel clean-up costs (only 27 percent as much large debris and 39 percent small debris accumulated in the stream for cable-assisted felling), increased yield from reduced breakage, and reduced yarding costs. They also estimated costs for debris removal from streams to be $300 to clean 5 tons of debris from a 100-foot segment, or about $60 per ton of residue removed.

Lickwar (1989) examined the costs of SMAs as determined by varying slope steepness in different regions in the Southeast and compared them to road construction and revegetation practice costs. He found SMAs to be the least expensive practice, in general, and to cost roughly the same independent of slope.

The costs associated with use of alternative buffer and filter strips were also analyzed in an Oregon case study (Olsen, 1987) and by Ellefson and Weible (1980). In the Oregon case study, increasing the buffer width from 35 feet on each side of a stream to 50 feet was shown to reduce the value per acre by $103 undiscounted and $75 discounted costs, approximately a 2 percent increase on a harvesting cost per acre of $5,163 undiscounted and $3,237 discounted. Doubling the buffer width from 35 to 70 feet on each side reduced the dollar value per acre by approximately 3 times more, adding approximately 8 percent to the discounted harvesting costs. Ellefson and Weible also analyzed the added cost and rate of return associated with various filter and buffer strip widths. Doubling the width of a filter strip from 30 to 60 feet increases the cost from $12 to $44 per sale and reduces the rate of return by 0.4 percent. Doubling the width of the buffer strip from 30 to 60 feet doubles the cost and reduces the rate of return by 1 percent. Increasing the width of the buffer strip from 30 to 100 feet triples the cost and reduces the rate of return by 2.3 percent.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure discussed above.

Generally, SMAs should have a minimum width of 35 to 50 feet. SMA width should also increase according to site-specific factors. The primary factors that determine the extension of SMA width are slope, class of watercourse, depth to water table, soil type, type of vegetation, and intensity of management.

Many States use SMAs. Examples of SMA designation strategies from Florida, North Carolina, Maine, and Washington are presented. Figure 3-10 depicts Florida's streamside management zone (SMZ) designations. Florida's SMZs are divided into a fixed-width primary zone and a variable secondary zone, each of which has its own special management criteria. …. Maine's recommended filter strip widths are dependent on the land slope between the road and waterbody. Washington State requires a riparian management zone (RMZ) around all Type 1, 2, and 3 waters where the adjacent harvest cutting is a regeneration cut or a clearcut. A guide for calculating the average width of the RMZ is provided in the Forest Practices Board manual (Washington State Forest Practices Board, 1988)(Figure 3-11).

- Minimize disturbances that would expose the mineral soil of the SMA forest floor. Do not operate skidders or other heavy machinery in the SMA.

- Locate all landings, portable sawmills, and roads outside the SMA.

- Restrict mechanical site preparation in the SMA, and encourage natural revegetation, seeding, and handplanting.

- Limit pesticide and fertilizer usage in the SMA. Buffers for pesticide application should be established for all flowing streams.

- Directionally fell trees away from streams to prevent logging slash and organic debris from entering the waterbody.

- Apply harvesting restrictions in the SMA to maintain its integrity.

Enough trees should be left to maintain shading and bank stability and to provide woody debris. This provision for leaving residual trees can be accomplished in a variety of ways. For example, the Maine Forestry Service (1991) specifies that no more than 40 percent of the total volume of timber 6 inches DBH and greater should be removed in a 10-year period, and the trees removed should be reasonably distributed within the SMA. Florida (1991) recommends leaving a volume equal to or exceeding one-half the volume of a fully stocked stand. The number of residual trees varies inversely with their average diameter. A shading requirement independent of the volume of timber may be necessary for streams where temperature changes could alter aquatic habitat.

Studies by Brazier and Brown (1973) demonstrated that the effectiveness of the SMA in controlling temperature changes is independent of timber volume; it is a complex interrelationship between canopy density, canopy height, stream width, and stream discharge. The Washington State Forest Practices Board (1988) incorporates leave tree and shade requirements in its regulations (Figure 3-12). Shade requirements within the SMA are to leave all nonmerchantable timber that provides midsummer and midday shade to the water surface, and to leave sufficient merchantable timber necessary to retain 50 percent of the summer midday shade. Shade cover is preferably left distributed evenly within the SMA (Figure 3-13). If a threat of blowdown exists, then clumping and clustering of leave trees may be used as long as the shade requirement is met (Figure 3-14).

Road Construction/Reconstruction Management Measure

- Follow preharvest planning (as described under Management Measure A) when constructing or reconstructing the roadway.
- Follow designs planned under Management Measure A for road surfacing and shaping.
- Install road drainage structures according to designs planned under Management Measure A and regional storm return period and installation specifications. Match these drainage structures with terrain features and with road surface and prism designs.
- Guard against the production of sediment when installing stream crossings.
- Protect surface waters from slash and debris material from roadway clearing.
- Use straw bales, silt fences, mulching, or other favorable practices on disturbed soils on unstable cuts, fills, etc.
- Avoid constructing new roads in SMAs to the extent practicable.

1. Applicability

This management measure is intended for application by States on lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to road construction/reconstruction operations for silvicultural purposes, including:

The clearing phase: clearing to remove trees and woody vegetation from the road right-of-way;

The pioneering phase: excavating and filling the slope to establish the road centerline and approximate grade;

The construction phase: final grade and road prism construction and bridge, culvert, and road drainage installation; and

The surfacing phase: placement and compaction of the roadbed, road fill compaction, and surface placement and compaction (if applicable).

Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize delivery of sediment to surface waters during road construction/reconstruction projects. Figure 3-15 depicts various road structures addressed by this management measure. Disturbance of soil and rock during road construction/reconstruction creates a significant potential for erosion and sedimentation of nearby streams and coastal waters. Some roads are temporary or seasonal-use roads, and their construction does not involve the high level of disturbance generated by permanent, high-standard roads. However, temporary or low-standard roads still need to be constructed in such a way as to prevent disturbance and sedimentation. Brown (1972) stated that road construction is the largest source of silviculture-produced sediment in the Pacific Northwest. It is also a significant source in other regions of the country. Therefore, proper road and drainage crossing construction practices are necessary to minimize sediment delivery to surface waters. Proper road design and construction can prevent road fill and road backslope failure, which can result in mass movements and severe sedimentation. Proper road drainage prevents concentration of water on road surfaces, thereby preventing road saturation that can lead to rutting, road slumping, and channel washout (Dyrness, 1967; Golden et al., 1984). Proper road drainage during logging operations is especially important because that is the time when erosion is greatly accelerated by continuous road use (Kochenderfer, 1970). Figure 3-16 presents various erosion and sediment control practices.

Surface protection of the roadbed and cut-and-fill slopes can:

Minimize soil losses during storms;
Reduce frost heave erosion production;
Restrain downslope movement of soil slumps; and
Minimize erosion from softened roadbeds (Swift, 1984).
Although there are many commonly practiced techniques to minimize erosion during the construction process, the most meaningful are related to how well the work is planned, scheduled, and controlled by the road builder and those responsible for determining that work satisfies design requirements and land management resource objectives (Larse, 1971).

3. Management Measure Selection

Most erosion from road construction occurs within a few years of disturbance (Megahan, 1980). Therefore, erosion control practices that provide immediate results (such as mulching or hay bales) should be applied as soon as possible to minimize potential erosion (Megahan, 1980). King (1984) found that the amount of sediment produced by road construction was directly related to the percent of the area taken by roads, the amount of protection given to the seeded slopes, and whether the road is given a protective surface.

a. Effectiveness Information

The effectiveness of road surfacing in controlling erosion was demonstrated by Kochenderfer and Helvey (1984). The data show that using 1-inch crusher-run gravel or 3-inch clean gravel can reduce erosion to less than one-half that of using 3-inch crusher run gravel and to 12 percent that of an ungraveled road surface.

According to Swift (1984b), road cuts and fills are the largest source of sediment once a logging road is constructed. His research showed that planting grass on cut-and-fill slopes of new roads effectively reduced erosion in the southern Appalachians. The combined effectiveness of grass establishment and roadbed graveling was a 97-99 percent reduction in soil loss.

Swift (1986) measured the extent of downslope soil movement for various categories of roadway and slope conditions. He found that grassed fill was more effective than mulched fill or bare fill in reducing the downslope movement of soil from newly constructed roads. The author determined grass, forest floor litter, and brush barriers to be effective management practices for reducing downslope sediment.

Megahan (1980, 1987) summarized the results of several studies that echo Swift's conclusions. The combination of straw mulch with some type of netting to hold it in place reduces erosion by more than 90 percent and has the added benefits of providing immediate erosion control and promoting revegetation. Treating the road surface reduced erosion 70 to 99 percent. Grass seeding alone can control erosion in moist climates, as confirmed by Swift (1984b).

b. Cost Information

The costs associated with construction of rolling dips on roads were estimated by Dubensky (1991) as $19.75 each, with more dips needed as the slope of the road increases.

Ellefson and Miles (1984) determined the decline in net revenue associated with culvert construction, water bar construction, and construction of broad-based dips to be 3.8 percent, 2.3 percent, and 2.4 percent, respectively, for a timber sale with net revenue of $124,340 without these practices. Kochenderfer and Wendel (1980) examined road costs, including bulldozing, construction of drainage dips, culvert installation, and graveling. They concluded that:

Cost to reconstruct a road (including 600 tons of 3-inch clean stone surfacing at $5.74/ton) = $5,855 per mile. Cost also included 20.5 hours (25 hours/mile) of D-6 tractor time (for road construction and construction of broad-based drainage dips), 23 hours (28 hours/mile) of JD 450 tractor time to spread gravel and do final dip shaping, and installation of two culverts. Road construction without the stone would have cost $1,061/mile.

Cost for a newly constructed road was $3,673 per mile, including 200 tons of gravel. Costs included 46.5 hours (57 hours/mile) of D-6 tractor time to bulldoze the road and construct 22 drainage dips. Spreading gravel and final dip shaping required 7.5 hours of JD tractor time. This road, constructed without stone, would have cost $2,078 per mile.

The study concluded that road construction costs in terrain similar to the West Virginia mountain area would range from about $2,000/mile with no gravel and few culverts to about $10,000/mile with complete graveling and more frequent use of culverts.

Kochenderfer, Wendel, and Smith (1984) examined the costs associated with road construction of four minimum standard roads in the Appalachians. Excavation costs varied according to site-specific factors (soil type, rock outcrop extent, topography) and increased as the amount of rock needing blasting and the number of large trees to be removed increased. Culvert costs varied according to the size and type of culvert used.

Lickwar (1989) studied the costs of various forestry practices in the Southeast. He determined that practices associated with road construction were generally the most expensive, regardless of terrain. The costs for broad-based dips and water bars increased as the terrain steepened, indicating increased implementation of erosion and runoff control practices as slopes increased. Steeper areas also required additional (nonspecified) road costs that were not necessary in moderate to flat areas. Unit cost comparisons for surfacing practices (Swift, 1984a) reveal that grass is the least expensive alternative, at $174 per kilometer of road. Five-centimeter crushed rock cost almost $2000 per kilometer, 15-centimeter gravel cost about $6000, and 20-centimeter gravel cost almost $9000. The author cautions, however, that material costs alone are misleading because an adequate road surface might endure several years of use, whereas a grassed or thinly-graveled surface would need replenishing. Even so, multiple grass plantings may be cheaper and more effective than gravel spread thinly over the roadbed, depending on climate, growing conditions, soil type, and road use (Swift, 1984b). Megahan (1987) found that dry seeding alone cost significantly less than seeding in conjunction with plastic netting.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

- Follow the design developed during preharvest planning to minimize erosion by properly timing and limiting ground disturbance operations.

- Construct bridges and install culverts during periods when streamflow is low.

- Avoid construction during egg incubation periods on streams with important spawning areas.

- Practice careful equipment operation during road construction to minimize the movement of excavated material downslope as unintentional sidecast.

- Compact the road base at the proper moisture content, surfacing, and grading to give the designed road surface drainage shaping.

- Use straw bales, straw mulch, grass-seeding, hydromulch, and other erosion control and revegetation techniques to complete the construction project. These methods are used to protect freshly disturbed soils until vegetation can be established.

- Prevent slash from entering streams or promptly remove slash that accidentally enters streams to prevent problems related to slash accumulations.
- Slash can be useful if placed as windrows along the base of the fill slope. Right-of-way material that is merchantable can also be used by the operator.

- Use turnouts, wing ditches, and dips to disperse runoff and reduce road surface drainage from flowing directly into watercourses.

- Install surface drainage controls to remove stormwater from the roadbed before the flow gains enough volume and velocity to erode the surface. Route discharge from drainage structures onto the forest floor so that water will disperse and infiltrate (Swift, 1985).

Methods of road surface drainage include:

<u>Broad-based Dip Construction</u>. A broad-based dip is a gentle roll in the centerline profile of a road that is designed to be a relatively permanent and self-maintaining water diversion structure and can be traversed by any vehicle (Swift, 1985, 1988) (See Figure 3-17). The dip should be outsloped 3 percent to divert stormwater off the roadbed and onto the forest floor, where transported soil can be trapped by forest litter (Swift, 1988). Broad-based dips should be used on roads having a gradient of 10 percent or less. Proper construction requires an experienced bulldozer operator (Kochenderfer, 1970).

Installation of Pole Culverts and/or Ditch Relief Culverts. Culverts are placed at varying intervals in a road to safely conduct water from the ditch to the outside portion of the road. Figures 3-18 and 3-19 highlight the design and installation of pole and pipe culverts, respectively. Culverts often need outlet and inlet protection to keep water from scouring away supporting material and to keep debris from plugging the culvert. Energy dissipators, such as riprap and slash, should be installed at culvert outlets (Rothwell, 1978). Culvert spacing depends on rainfall intensity, soil type, and road grade. Culvert size selection should be based on drainage area size and should be able to handle large flows. Open-top or pole culverts are temporary drainage structures that are most useful for intercepting runoff flowing down road surfaces (Kochenderfer, 1970). They can also be used as a substitute for pipe culverts on roads of smaller operations, if properly built and maintained, but they should not be used for handling intermittent or live streams. Open-top culverts should be placed at angles across a road to provide gradient to the culvert and to ensure that no two wheels of a vehicle hit the ditch at once.

Road Outsloping and Grading. Grade and outslope roadbeds to minimize water accumulation on road surfaces (Kochenderfer, 1970). This practice minimizes erosion and road failure potential. Outsloping involves grading the road so that it slopes downward from the toe of the road cut to the shoulder. The slope should be about 3-4 percent (Rothwell, 1978). Outsloping the roadbed keeps water from flowing next to and undermining the cut bank, and is intended to spill water off the road in small volumes at many random sites. In addition to outsloping the roadbed, a short reverse grade should be constructed to turn water off the surface. Providing a berm on the outside edge of an outsloped road during construction, and until loose fill material is protected by vegetation, can eliminate fill erosion (Swift, 1985). The effectiveness of outsloping is limited by roadbed rutting during wet conditions. Also, berms may form along the edge of older roadbeds and block drainage (Swift, 1985). Therefore, proper maintenance of these structures is necessary.

Ditch and Turnout Construction. Ditches should be used only where necessary and should discharge water into vegetated areas through the use of turnouts. The less water ditches carry and the more frequently water is discharged, the better. Construct wide, gently sloping ditches, especially in areas with highly erodible soils. Ditches should be stabilized with rock and/or vegetation (Yoho, 1980) and outfalls protected with rock, brush barriers, live vegetation, or other means. Roadside ditches should be large enough to carry runoff from moderate storms. A standard ditch used on secondary logging roads is a triangular section 45 cm deep, 90 cm wide on the roadway side, and 30 cm wide on the cut bank side. Minimum ditch gradient should be 0.5 percent, but 2 percent is preferred to ensure good drainage. Runoff should be frequently diverted into culverts to prevent erosion or overflow (Rothwell, 1978).

Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into the aquatic environment.
Methods to trap sediment include:

Brush Barriers. Brush barriers are slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars. Brush barriers should be installed at the toe of fills if the fills are located within 150 feet of a defined stream channel (Swift, 1988). Figure 3-20 shows the use of a brush barrier at the toe of fill. Proper installation is important because if the brush barrier is not firmly anchored and embedded in the slope, brush material may be ineffective for sediment removal and may detach to block ditches or culverts (Ontario Ministry of Natural

Resources, 1988). In addition to use as brush barriers, slash can be spread over exposed mineral soils to reduce the impact of precipitation events and surface flow.

Silt Fences. Silt fences are temporary barriers used to intercept sediment- laden runoff from small areas. They act as a strainer: silt and sand are trapped on the surface of the fence while water passes through. They may consist of woven geotextile filter fabric or straw bales. Silt fences should be installed prior to earthmoving operations and should be placed as close to the contour as possible.

Riprap. Riprap is a layer of rocks or rock fragments placed over exposed soil to protect it from erosive forces. Riprap is generally used only in areas where the velocity of water flow, seriousness of erosion, steepness of slope, or material type prevents satisfactory establishment of vegetation. Stones of suitable size are fitted and implanted in the slope to form a contiguous cover. When used near streams, riprap should be extended below the stream channel scour depth and above the high water line. Commonly, a filter cloth or graded filter blanket of small gravel is laid beneath the riprap. Riprap should not be used on slopes that are naturally subject to deep-seated or avalanche-type slide failure. Riprap should be used in conjunction with other slope stabilization techniques and then only if these techniques are ineffective alone. Riprap is not recommended for very steep slopes or fine-grained soils (Hynson et al., 1982).

Filter Strips. Sediment control is achieved by providing a filter or buffer strip between streams and construction activities in order to use the natural filtering capabilities of the forest floor and litter. The Streamside Management Area management measure requires the presence of a filter or buffer strip around all waterbodies.

Revegetate or stabilize disturbed areas, especially at stream crossings.
Cutbanks and fillslopes along forest roads are often difficult to revegetate (Berglund, 1978). Properly condition slopes to provide a seedbed, including rolling of embankments and scarifying of cut slopes. The rough soil surfaces will provide niches for seeds to lodge and germinate. Seed as soon as possible after disturbance, preferably during road construction or immediately following completion and within the same season (Larse, 1971). Early grassing and spreading of brush or erosion-resisting fabrics on exposed soils at stream crossings are imperative (Swift, 1985). See the Revegetation of Disturbed Areas management measure for a more detailed discussion.

Protect access points to the site that lead from a paved public right-of-way with stone, wood chips, corduroy logs, wooden mats, or other material to prevent soil or mud from being tracked onto the paved road.

This will prevent tracking of sediment onto roadways, thereby preventing the subsequent washoff of that sediment during storm events. When necessary, clean truck wheels to remove sediment prior to entering a public right-of-way.

Construct stream crossings to minimize erosion and sedimentation.

Avoid operating machinery in waterbodies. Work within or adjacent to live streams and water channels should not be attempted during periods of high streamflow, intense rainfall, or migratory fish spawning. Avoid channel changes and protect embankments with riprap, masonry headwalls, or other retaining structures (Larse, 1971).

If possible, culverts should be installed within the natural streambeds. The inlet should be on or below the streambed to minimize flooding upstream and to facilitate fish passage. Culverts should be firmly anchored and the earth compacted at least halfway up the side of the pipe to prevent water from leaking around it (Figure 3-22). Both ends of the culvert should protrude at least 1 foot beyond the fill (Hynson et al., 1982). Large culverts should be aligned with the natural course and gradient of the stream unless the inlet condition can be improved and the erosion potential reduced with some channel improvement (Larse, 1971). Use energy dissipators at the downstream end of the culverts to reduce the erosion energy of emerging water. Armor inlets to prevent undercutting and armor outlets to prevent erosion of fill or cut slopes.

Excavation for a bridge or a large culvert should not be performed in flowing water. The water should be diverted around the work site during construction with a cofferdam or stream diversion.
Isolating the work site from the flow of water is necessary to minimize the release of soil into the watercourse and to ensure a satisfactory installation in a dry environment. Limit the duration of construction to minimize environmental impacts by establishing disturbance limits, equipment limitations, the operational time period when disturbance can most easily be limited, and the use of erosion and sediment controls, such as silt fences and sediment catch basins. Diversions should be used only where constructing the stream crossing structure without diverting the stream would result in instream disturbance greater than the disturbance from diverting the stream. Figure 3-23 portrays a procedure for installing a large culvert when excavation in the channel of the stream would cause sedimentation and increase turbidity.

- Compact the fill to minimize erosion and ensure road stability (Hynson et al., 1982).
- During construction, fills or embankments are built up by gradual layering. Compact the entire surface of each layer with a tractor or other construction equipment. If the road is to be grassed, the final layer should not be compacted in order to provide an acceptable seedbed.

- Properly dispose of organic debris generated during road construction (Hynson et al., 1982).

- Stack usable materials such as timber, pulpwood, and firewood in suitable locations and use them to the extent possible. Alternatives for use of other materials include piling and burning, chipping, scattering, windrowing, and removal to designated sites.

- Organic debris should not be used as fill material for road construction since the organic material would eventually decompose and cause fill failure (Hynson et al., 1982; Larse, 1971).
- Debris that is accidently deposited in streams during road construction should be removed before work is terminated.

- All work within the stream channel should be accomplished by hand to avoid the use of machinery in the stream and riparian zone (Hynson et al., 1982).

- Use pioneer roads to reduce the amount of area disturbed and ensure stability of the area involved.

- Pioneer roads are temporary access ways used to facilitate construction equipment access when building permanent roads.

- Confine pioneer roads to the construction limits of the surveyed permanent roadway.
- Fit the pioneer road with temporary drainage structures (Hynson et al., 1982).

When soil moisture conditions are excessive, promptly suspend earthwork operations and take measures to weatherproof the partially completed work (Larse, 1971; Hynson et al., 1982). Regulating traffic on logging roads during unfavorable weather is an important phase of erosion control. Construction and logging under these conditions destroy drainage structures, plug up culverts, and cause excessive rutting, thereby increasing the amount and the cost of required maintenance (Kochenderfer, 1970).

Locate burn bays away from water and drainage courses.

If the use of borrow or gravel pits is needed during forest road construction, locate rock quarries, gravel pits, and borrow pits outside SMAs and above the 50-year flood level of any waters to minimize the adverse impacts caused by the resulting sedimentation. Excavation should not occur below the water table.

Gravel mining directly from streams causes a multitude of impacts including destruction of fish spawning sites, turbidity, and sedimentation (Hynson et al., 1982). During the construction and use of rock quarries, gravel pits, or borrow pits, runoff water should be diverted onto the forest floor or should be passed through one or more settling basins. Rock quarries, gravel pits, spoil disposal areas, and borrow pits should be revegetated and reclaimed upon abandonment.

Road Management

Avoid using roads where possible for timber hauling or heavy traffic during wet or thaw periods on roads not designed and constructed for these conditions.
Evaluate the future need for a road and close roads that will not be needed. Leave closed roads and drainage channels in a stable condition to withstand storms.
Remove drainage crossings and culverts if there is a reasonable risk of plugging or failure from lack of maintenance.
Following completion of harvesting, close and stabilize temporary spur roads and seasonal roads to control and direct water away from the roadway. Remove all temporary stream crossings.
Inspect roads to determine the need for structural maintenance. Conduct maintenance practices, when conditions warrant, including cleaning and replacement of deteriorated structures and erosion controls, grading or seeding of road surfaces, and, in extreme cases, slope stabilization or removal of road fills where necessary to maintain structural integrity.

Conduct maintenance activities, such as dust abatement, so that chemical contaminants or pollutants are not introduced into surface waters to the extent practicable.
Properly maintain permanent stream crossings and associated fills and approaches to reduce the likelihood (a) that stream overflow will divert onto roads, and (b) that fill erosion will occur if the drainage structures become obstructed.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to active and inactive roads constructed or used for silvicultural activities.
Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The objective of this management measure is to manage existing roads to maintain stability and utility and to minimize sedimentation and pollution from runoff-transported materials. Roads that are actively eroding and providing significant sediment to waterbodies, whether in use or not, must be managed. If roads are no longer in use or needed in the foreseeable future, an effective treatment is to remove drainage crossings and culverts if there is a risk of plugging or failure from lack of maintenance. In other cases (e.g., roads in use), it may be more economically viable to periodically maintain crossing and drainage structures.

Sound planning, design, and construction measures often reduce the future levels of necessary road maintenance. Roads constructed with a minimum width in stable terrain, and with frequent grade reversals or dips, require minimum maintenance. However, older roads remain one of the greatest sources of sediment from forest land management. In some locations, problems associated with altered surface drainage and diversion of water from natural channels can result in serious gully erosion or landslides. After harvesting is complete, roads are often forgotten. Erosion problems may go unnoticed until after there is severe resource damage. In western Oregon, 41 out of the 104 landslides reported on private and State forest lands during the winter of 1989-90 were associated with older (built before 1984) forest roads. These landslides were related to both road drainage and original construction problems. Smaller erosion features, such as gullies and deep ruts, are far more common than landslides and very often are related to road drainage.

Drainage of the road prism, road fills in stream channels, and road fills on steep slopes are the elements of greatest concern in road management. Roads used for active timber hauling usually require the most maintenance, and mainline roads typically require more maintenance than spur roads. Use of roads during wet or thaw periods can result in a badly rutted surface, impaired drainage, and excessive sediment leading to waterbodies. Inactive roads, not being used for timber hauling, are often overlooked and receive little maintenance. Many forest roads that have been abandoned may be completely overgrown with vegetation, which makes maintenance very difficult.

Figure 3-24 illustrates some differences between a road with a well-maintained surface, good revegetation, and open drainage structures, and a poorly maintained road.

3. Management Measure Selection

a. Effectiveness Information
Drainage structures must be maintained to function properly. Culverts and ditches must be kept free of debris that can restrict water flow. Routine clearing can minimize clogging and prevent flooding, gullying, and washout (Kochenderfer, 1970). Routine maintenance of road dips and surfaces and quick response to problems can significantly reduce road-caused slumps and slides and prevent the creation of berms that could channelize runoff (Oregon Department of Forestry 1981; Ontario Ministry of Natural Resources, 1988).

Proper road/trail closure is essential in preventing future erosion and sedimentation from abandoned roads and skid trails. Proper closure incorporates removal of temporary structures in watercourses, returning stream crossing approaches to their original grades, revegetating disturbed areas, and preventing future access (Kochenderfer, 1970; Rothwell, 1978) Revegetation of disturbed areas protects the soil from raindrop impact and aids soil aggregation, and therefore reduces erosion and sedimentation (Rothwell, 1978).

b. Cost Information
Benefits of proper road maintenance were effectively shown by Dissmeyer and Frandsen (1988). Maintenance costs for road repair were 44 percent greater without implementation of control measures than for installation of BMPs.

Dissmeyer and Foster (1987) presented an analysis of the economic benefits of various watershed treatments associated with roads. Specifically, they examined the cost of revegetating cut-and-fill slopes and the costs of various planning and management technical services (e.g., preparing soil and water prescriptions, compiling soils data, and reviewing the project in the field). These costs were compared to savings in construction and maintenance costs resulting from the watershed treatments. Specifically, savings were realized from avoiding problem soils, wet areas, and unstable slopes. The economic analysis showed that the inclusion of soil and water resource management (i.e., revegetating and technical services) in the location and construction of forest roads resulted in an estimated savings of $311 per kilometer in construction costs and $186 per kilometer in maintenance costs.

As part of the Fisher Creek Watershed Improvement Project, Rygh (1990) examined the various costs of ripping and scarification using different techniques. The major crux of Rygh's work was to compare the relative advantages of using a track hoe for ripping and scarification versus the use of large tractor-mounted rippers. He found track hoes to be preferable to tractor-mounted rippers for a variety of reasons, including the following:

A reduction in furrows and resulting concentrated runoff caused by tractors;

Improved control over the extent of scarification;
Increased versatility and maneuverability of track hoes; and
Cost savings.
Rygh estimated that the cost of ripping with a track hoe ranged from $220 to $406 per mile compared to a cost of $550 per mile for ripping with a D7 or D8 tractor (Table 3-33).

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

Blade and reshape the road to conserve existing surface material; to retain the original, crowned, self-draining cross section; and to prevent or remove berms (except thosedesigned for slope protection) and other irregularities that retard normal surface runoff (Larse, 1971).

Ruts and potholes can weaken road subgrade materials by channeling runoff and allowing standing water to persist (Rothwell, 1978). Periodic grading of the road surface is necessary to fill in wheel ruts and to reshape the road (Haussman and Pruett, 1978). Maintenance practices must be modified for roads with broad-based dips (Swift, 1985). Maintenance by a motor grader is difficult because scraping tends to fill in the dips, the blade cannot be maneuvered to clean the dip outlet, and cut banks are destabilized when the blade undercuts the toe of the slope. Small bulldozers or front-end loaders appear to be more suitable for periodic maintenance of intermittent-use forest roads (Swift, 1988).

- Clear road inlet and outlet ditches, catch basins, culverts, and road-crossing structures of obstructions (Larse, 1971).
- Avoid undercutting backslopes when cleaning silt and debris from roadside ditches (Rothwell, 1978). Minimize machine cleaning of ditches during wet weather. Do not disturb vegetation when removing debris or slide blockage from ditches (Larse, 1971; Rothwell, 1978). The outlet edges of broad-based dips need to be cleaned of trapped sediment to eliminate mudholes and prevent the bypass of stormwaters. The frequency of cleaning depends on traffic load (Swift, 1988). Clear stream-crossing structures and their inlets of debris, slides, rocks, and other materials prior to and following any heavy runoff period (Hynson et al., 1982).

- Maintain road surfaces by mowing, patching, or resurfacing as necessary.
- Grassed roadbeds carrying fewer than 20-30 vehicle trips per month usually require only annual roadbed mowing and periodic trimming of encroaching vegetation (Swift, 1988).

- Remove temporary stream crossings to maintain adequate streamflow (Hynson et al., 1982).

- Failure or plugging of abandoned temporary crossing structures can result in greatly increased sedimentation and turbidity in the stream, and channel blowout.

- Wherever possible, completely close the road to travel and restrict access by unauthorized persons by using gates or other barriers (Haussman and Pruett, 1978).
- Where such restrictions are not feasible, traffic should be regulated (Rothwell, 1978).
- Install or regrade water bars on roads that will be closed to vehicle traffic and that lack an adequate system of broad-based dips (Kochenderfer, 1970).

Water bars will help to minimize the volume of water flowing over exposed areas and remove water to areas where it will not cause erosion. Water bar spacing depends on soil type and slope. … Water should flow off the water bar onto rocks, slash, vegetation, duff, or other less erodible material and should never be diverted directly to streams or bare areas (Oregon Department of Forestry, 1979a). Outslope closed road surfaces to disperse runoff and prevent closed roads from routing water to streams.

Revegetate to provide erosion control and stabilize the road surface and banks.
Refer to Revegetation of Disturbed Areas management measure for a more detailed discussion.

Replace open-top culverts with cross drains (water bars, dips, or ditches) to control and divert runoff from road surfaces (Rothwell, 1978; Haussman and Pruett, 1978).
Open-top culverts are for temporary drainage of ongoing operations. It is important to replace them with more permanent drainage structures to ensure adequate drainage and reduce erosion potential prior to establishment of vegetation on the roadbed.

Periodically inspect closed roads to ensure that vegetational stabilization measures are operating as planned and that drainage structures are operational (Hynson et al., 1982; Rothwell, 1978). Conduct reseeding and drainage structure maintenance as needed.

Timber Harvesting

The timber harvesting management measure consists of implementing the following:

- Timber harvesting operations with skid trails or cable yarding follow layouts determined under Management Measure A.
- Install landing drainage structures to avoid sedimentation to the extent practicable. Disperse landing drainage over sideslopes.
- Construct landings away from steep slopes and reduce the likelihood of fill slope failures. Protect landing surfaces used during wet periods. Locate landings outside of SMAs.
- Protect stream channels and significant ephemeral drainages from logging debris and slash material.
- Use appropriate areas for petroleum storage, draining, dispensing. Establish procedures to contain and treat spills. Recycle or properly dispose of all waste materials.
- For cable yarding:

- Limit yarding corridor gouge or soil plowing by properly locating cable yarding landings.
- Locate corridors for SMAs following Management Measure B.
- For groundskidding:
- Within SMAs, operate groundskidding equipment only at stream crossings to the extent practicable. In SMAs, fell and endline trees to avoid sedimentation.
- Use improved stream crossings for skid trails which cross flowing drainages. Construct skid trails to disperse runoff and with adequate drainage structures.
- On steep slopes, use cable systems rather than groundskidding where groundskidding may cause excessive sedimentation.

1. Applicability

This management measure pertains to lands where silvicultural or forestry operations are planned or conducted. It is intended to apply to all harvesting, yarding, and hauling conducted as part of normal silvicultural activities on harvest units larger than 5 acres. This measure does not apply to harvesting conducted for precommercial thinnings or noncommercial firewood cutting.
Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint source programs in conformity with this measure and will have some flexibility in doing so. The application of this management measure by States is described more fully in Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to minimize sedimentation resulting from the siting and operation of timber harvesting, and to manage petroleum products properly.
Logging practices that protect water quality and soil productivity can also reduce total mileage of roads and skid trails, lower equipment maintenance costs, and provide better road protection and lower road maintenance. Careful logging can disturb soil surfaces as little as 8 percent, while careless logging practices can disturb soils as much as 40 percent (Golden et al., 1984). In the Appalachians, skid roads perpendicular to the contour, instead of along the contour, yielded 40 tons of sediment per acre of skid road surface (Hornbeck and Reinhart, 1964). Higher bulk densities and lower porosity of skid road soils due to compaction by rubber-tired skidders result in reduced soil infiltration capacity and corresponding increases in runoff and erosion (Dickerson, 1975). Douglass and Swank (1975) found that poor logging techniques increased sediment production during storms by 10 to 20 times more than sediment production from the undisturbed control watershed. A properly logged watershed experienced only slightly increased sedimentation compared to the undisturbed control watershed.

Locating landings for both groundskidding and cable yarding harvesting systems according to preharvest planning minimizes erosion and sediment delivery to surface waters. However, final siting of landings may need to be adjusted in the field based on site characteristics.
Landings and loading decks can become very compacted and puddled and are therefore a source of runoff and erosion (Golden et al., 1984). Practices that prevent or disperse runoff from these

areas before the runoff reaches watercourses will minimize sediment delivery to surface waters. Also, any chemicals or petroleum products spilled in harvest areas can be highly mobile, adversely affecting the water quality of nearby surface waters. Correct spill prevention and containment procedures are therefore necessary to prevent petroleum products from entering surface waters. Designation of appropriate areas for petroleum storage will also minimize water quality impacts due to spills or leakage.

3. Management Measure Selection

This management measure is based on the experience and information gained from studies and from States using similar harvesting practices. Many studies have evaluated and compared the effects of different timber harvest techniques on sediment loss (erosion), soil compaction, and overall ground disturbance associated with various harvesting techniques. …Many local factors such as climatic conditions, soil type, and topography affected the results of each study. The studies also examined harvesting techniques under a variety of conditions, including clearcuts, selective cuts, and fire-salvaged areas. However, the major conclusions from the studies on the relative impacts of different timber harvesting techniques on soil erosion and the causes and consequences of ground disturbance remain fairly constant between the studies and enable cross-geographic comparison.

Some of the most significant water quality impacts from logging operations (especially increased sedimentation) result from the actual yarding operations and activities on landings. The critical factors that affect the degree of soil disturbance associated with a particular yarding technique include the amount of disturbance caused by the yarding machinery itself and the amount of road construction needed to support each system. Stone (1973) presented information suggesting that roads may contribute greater than 90 percent of the sedimentation problems associated with logging operations. Therefore, since road areas represent potential erosion sites, it is important to recognize and consider the amount of land used for roads by various logging systems (Sidle, 1980).

a. Effectiveness Information
The amount of total soil disturbance varies considerably between the different yarding techniques. Megahan (1980) presented the most comprehensive survey of the available information on these impacts, presenting the data in two ways: soil disturbance associated with the actual yarding operation and soil disturbance associated with the construction of roads needed for the practice. The results of his investigation echoed other studies presented in this section and clearly show that aerial and skyline cable techniques are far less damaging than other yarding techniques.

The amount of soil disturbance by yarding depends on the slope of the area, volume yarded, size of logs, and the logging system. … Megahan's ranking of yarding techniques (from greatest impact to lowest impact) based on percent area disturbed is summarized as follows: tractor (21 percent average), ground cable (21 percent, one study), high-lead (16 percent average), skyline (8 percent average), jammer in clearcut (5 percent, one study), and aerial techniques (4 percent average).

The amount of road required for different yarding techniques varies considerably. Sidle (1980) defined the amount of land used for haul roads by various logging methods. Skyline techniques require the least amount of road area, with only 2-3.5 percent of the land area in roads. Tractor and single-drum jammer techniques require the greatest amount of road area (10-15 and 18-24 percent of total area, respectively). High-lead cable techniques fall in the middle, with 6-10 percent of the land used for roads. Megahan (1980) concluded that tractor, jammer, and high-lead cable methods result in significantly higher amounts of disturbed soil than do the skyline and aerial techniques.

Sidle (1980) also presented data showing that tractors cause the greatest amount of soil disturbance (35 percent of land area) and soil compaction (26 percent of land area). Sidle (1980) concluded that skyline and aerial balloon techniques created the least disturbance (12 and 6 percent, respectively) and compaction (3 and 2 percent, respectively).

Miller and Sirois (1986) compared the land area disturbed by cable, skyline, and groundskidding systems. They found groundskidding operations to affect 31 percent of the total land area, whereas cable yarding only affected 16 percent of the total land area. Similarly, Patric (1980) found skidders to serve the smallest area per mile of road (20 acres), with skyline yarding serving the largest area per mile of road (80 acres).

b. Cost Information

The costs and benefits of rehabilitation of skid trails by planting hardwood, hardwood pine, and shortleaf pine in the southeastern United States were studied by Dissmeyer and Foster (1986). The average rehabilitation cost per acre was $360 and included water barring, ripping or disking, seeding, fertilizing, and mulching where needed. The benefit/cost ratio of the rehabilitation cost was $1.33 for hardwood, $2.82 for hardwood pine, and $5.07 for shortleaf pine. The real rate of return over inflation ranged from 2.4 to 4.8 percent.

4. Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully to achieve the management measure described above.

a. Harvesting Practices

Fell trees away from watercourses, whenever possible, keeping logging debris from the channel, except where debris placement is specifically prescribed for fish or wildlife habitat (Megahan, 1983).

Any tree accidently felled in a waterway should be immediately removed (Huff and Deal, 1982).

Remove slash from the waterbody and place it out of the SMA. This will allow unrestricted water flow and protection of the stream's nutrient balance. Remove only logging-generated debris. Leave pieces of large woody debris in place during stream cleaning to preserve channel integrity and maintain stream productivity. Bilby (1984) concluded that indiscriminate removal of large woody debris can adversely affect channel stability. …

b. Practices for Landings

- Landings should be no larger than necessary to safely and efficiently store logs and load trucks.
- Install drainage and erosion control structures as necessary.
- Diversion ditches placed around the uphill side of landings minimize accumulation of water on the landing. Landings should have a slight slope to facilitate drainage. Also, adequate drainage on approach roads will prevent road drainage water from entering the landing area.
- The slope of the landing surface should not exceed 5 percent and should be shaped to promote efficient drainage.
- The slope of landing fills should not exceed 40 percent, and woody or organic debris should not be incorporated into fills.
- If landings are to be used during wet periods, protect the surface with a suitable material such as wooden matting or gravel surfacing.
- Install drainage structures for the landings such as water bars, culverts, and ditches to avoid sedimentation. Disperse landing drainage over sideslopes. Provide filtration or settling if water is concentrated in a ditch.
- Upon completion of harvest, clean up landing, regrade, and revegetate (Rothwell, 1978).
- Upon abandonment, minimize erosion on landings by adequately ditching or mulching with forest litter.
- Establish a herbaceous cover on areas that will be used again in repeated cutting cycles, and restock landings that will not be reused (Megahan, 1983).
- If necessary, install water bars for drainage control.
- Locate landings for cable yarding where slope profiles provide favorable deflection conditions so that the yarding equipment used does not cause yarding corridor gouge or soil plowing, which concentrates drainage or causes slope instability.
- Locate cable yarding corridors for streamside management areas following Management Measure B components. Yarded logs should not cause disturbance of the major channel banks of the watercourse of the SMA.

c. Groundskidding Practices

- Skid uphill to log landings whenever possible. Skid with ends of logs raised to reduce rutting and gouging. This practice will disperse water on skid trails away from the landing. Skidding uphill lets water from trails flow onto progressively less-disturbed areas as it moves downslope, reducing erosion hazard. Skidding downhill concentrates surface runoff on lower slopes along skid trails, resulting in significant erosion and sedimentation hazard (Figure 3-25). If skidding downhill, provide adequate drainage on approach trails so that drainage does not enter landing.

- Skid perpendicular to the slope (along the contour), and avoid skidding on slopes greater than 40 percent.

- Following the contour will reduce soil erosion and encourage revegetation. If skidding must be done parallel to the slope, then skid uphill, taking care to break the grade periodically.

- Avoid skid trail layouts that concentrate runoff into draws, ephemeral drainages, or watercourses. Use endlining to winch logs out of SMAs or directionally fell trees so tops extend out of SMAs and trees can be skidded without operating equipment in SMAs. In SMAs, trees should be carefully endlined to avoid soil plowing or gouge.

- Suspend groundskidding during wet periods, when excessive rutting and churning of the soil begins, or when runoff from skid trails is turbid and no longer infiltrates within a short distance from the skid trail. Further limitation of groundskidding of logs, or use of cable yarding, may be needed on slopes where there are sensitive soils and/or during wet periods.

- Retire skid trails by installing water bars or other erosion control and drainage devices, removing culverts, and revegetating (Rothwell, 1978; Lynch et al, 1985).

- After logging, obliterate and stabilize all skid trails by mulching and reseeding.

- Build cross drains on abandoned skid trails to protect stream channels or side slopes in addition to mulching and seeding.

- Restore stream channels by removing temporary skid trail crossings (Megahan, 1983)

.

- Scatter logging slash to supplement water bars and seeding to reduce erosion on skid trails (Lynch et al., 1985).

d. Cable Yarding Practices

- Use cabling systems or other systems when groundskidding would expose excess mineral soil and induce erosion and sedimentation.
- Use high-lead cable or skyline cable systems on slopes greater than 40 percent.

- To avoid soil disturbance from sidewash, use high-lead cable yarding on average-profile slopes of less than 15 percent.
- Avoid cable yarding in or across watercourses.
- When cable yarding across streams cannot be avoided, use full suspension to minimize damage to channel banks and vegetation in the SMA.
- Yard logs uphill rather than downhill.

In uphill yarding, log decks are placed on ridge or hill tops rather than in low-lying areas (Megahan, 1983). This creates less soil disturbance because the lift imparted to the logs reduces frictional resistance and the outward radiation of yard trails downhill from the landing disperses runoff evenly over the slope and reduces erosion potential. Downhill yarding should be avoided because it concentrates surface erosion.

e. Petroleum Management Practices

- Service equipment where spilled fuel and oil cannot reach watercourses, and drain all petroleum products and radiator water into containers. Dispose of wastes and containers in accordance with proper waste disposal procedures. Waste oil, filters, grease cartridges, and other petroleum-contaminated materials should not be left as refuse in the forest.

- Take precautions to prevent leakage and spills. Fuel trucks and pickup-mounted fuel tanks must not have leaks.

- Use and maintain seepage pits or other confinement measures to prevent diesel oil, fuel oil, or other liquids from running into streams or important aquifers.

- Use drip collectors on oil-transporting vehicles (Hynson et al., 1982).

- Develop a spill contingency plan that provides for immediate spill containment and cleanup, and notification of proper authorities.

- Provide materials for adsorbing spills, and collect wastes for proper disposal.

APPENDIX E – MINING AND ABANDONED MINE BMPS
Excerpts from EPA's Coal Remining BMPs Guidance Manual

The following is excerpted from EPA's Coal Mining Proposed Best Management Practices Guidance Manual 03-24-2009. Though coal mining does not occur in the LCR basin that is the subject of the TMDL study, the BMPs presented are widely applicable to many types of mine operations.

1.3 Sediment Control and Revegetation

Erosion and sediment deposition caused by weathering and precipitation are natural processes that can be accelerated in disturbed watersheds. Disturbances such as surface coal mining involve the removal of vegetation, soil, and rock. Spoil or highwall surfaces create conditions highly vulnerable to erosion and result in adverse sediment deposition that can clog streams, increase the risk of flooding, damage irrigation systems, and destroy aquatic habitats. Sediment deposition in downslope areas can have adverse environmental impacts on watershed soil and vegetation. Abandoned surface mine land, spoil refuse and gob piles often have exposed surfaces that are vulnerable to erosion or conducive to high rates of storm water runoff resulting in increased problems of sedimentation in receiving streams. Re-exposing these abandoned sites during remining operations without concern for sediment control can cause serious solids loading and hydrologic imbalance. Successful implementation of erosion and sediment control BMPs are critical for ultimate landscape stability and receiving stream protection.

Theory

The implementation of the BMPs discussed in this section for management of surface water and ground water at remining operations also can form the basis for sediment control. If implemented properly, site hydrologic controls can serve to prevent erosion, solids loading into receiving waters, and unchecked sediment deposition. Likewise, if hydrologic controls are implemented without consideration for potential sedimentation, conditions leading to discharge of solids and sediment can rapidly increase and result in severe environmental degradation.

Remining and reclamation of abandoned mine lands typically require techniques that involve regrading to approximate original contour, replacing topsoil, applying vegetation amendments, and constructing erosion-control structures. The resulting reclamation often is aesthetically pleasing, but can result in an artificial drainage system that can be problematic and accelerate erosion as natural drainage systems are re-established. If reclamation techniques fail to consider natural drainage patterns and surface water flow characteristics, conditions can become worse than those that existed prior to implementation of these techniques. Sedimentation and erosion problems can be alleviated by proper implementation of some or all of the BMPs discussed in this section.

Site Assessment

Prior to implementation of BMPs to control erosion and suspended solids loading, sites should be assessed to determine existing drainage patterns and topography, to quantify effects of storm runoff and the yield of coarse- and fine-grained sediment, and to determine morphologic evolution of gullies. Natural drainage patterns can be determined using before and after maps and profiles, aerial photography, site mining history information and water quality data. Determinations should also consider precipitation frequency, duration, and intensity. This information can be used to indicate locations where the implementation of sediment control

BMPs will be most effective.In addition to determining sedimentation patterns, it is important to determine the quantity of sedimentation that can be expected. An estimate of sediment erosion and deposition can be derived over time using water samples, sediment traps or sediment accumulation markers. Empirical equations also can be used to estimate the potential for and expected rate of erosion.The Universal Soil Loss Equation (USLE) was developed as a means to predict sediment loss from watersheds and can be used to estimate sediment yield produced by rill or sheet erosion in field areas. A Revised Universal Soil Loss Equation (RUSLE) was developed to estimate quantities of soil that can be lost due to erosion in larger, steeply sloped areas. Predicted soil loss is calculated using the following equation (OSMRE, 1998, PA DEP, 1999, Renard and others,1997):

$A = RKLSCP$

Where:
A = Computed Soil Loss (Annual Soil Loss as tons/acre/year)

R = Climatic Erosivity or Rainfall erosion index - a measure of the erosive force and intensity of a specific rainfall or the normal yearly rainfall for specific climatic regions

K = Soil Erodibility Factor - Ability of soils to resist erosive energy of rain. A measure of the erosion potential for a specific soil type based on inherent physical properties (particle size, organic matter, aggregate stability, permeability). Soils with a K value of 0.17 or less are considered slightly erodible, and those with a K value of 0.45 or higher are highly erodible. Soils in disturbed areas can be more easily eroded regardless of the listed K value for the soil type because the structure has been changed.

LS = Steepness Factor - Combination factor for slope length and gradient

C = Cover and Management Factor - Type of vegetation and cover. The ratio of soil loss from a field with specific cropping relative to that from the fallow condition on which the factor K is evaluated.

P = Support Practice - Erosion control practice factor, the ratio of soil loss under specified management practices.

RUSLE can be used to predict soil loss from areas that have been subjected to a full spectrum of land manipulation and reclamation activities and has been designed to accommodate undisturbed soil, spoil, and soil-substitute material, percent rock cover, random surface roughness, mulches, vegetation types, and mechanical equipment effects on soil roughness, hillslope shape, and surface manipulation including contour furrows, terraces, and strips of close-growing vegetation and buffers. It is important to note that RUSLE estimates soil loss caused by raindrop impact and overland flow in addition to rill erosion, but does not estimate gully or stream-channel erosion.

To establish successful vegetation, the soil loss rate should be minimized. Keeping the soil loss rate below 15 tons/acre for the first year after reclamation should, if surface water controls are included, allow the establishment of successful vegetation (PA DEP, 1999). For successful establishment of vegetative cover on abandoned mine land or redisturbed surfaces, the addition of soil amendments (e.g., soil substitutes, biosolids, etc.) may be necessary. Following regrading, final texture samples should be taken at a rate appropriate for site representation and analyzed for: pH, acid-base account, and fertility ratings for phosphorous, potassium, nitrogen, and magnesium.The necessity of amendments such as limestone, nitrogen, available phosphorous (P2O5), and potash (K2O) can be determined from these analytical results. Additional analyses that can be performed for further determination of site characteristics include: percent sand, silt and clay, textural classification, and water-holding capacity. This information can be used to assist in determination of the extent of final grading, cover preparation, and soil water retention amendments that should be implemented or added.

1.3.1 Implementation Guidelines

The intention of BMPs for control of sedimentation is to minimize erosion caused by wind and water. A remining sediment control plan should demonstrate that all exposed or disturbed areas are stabilized to the greatest extent possible. Operational BMP measures that can be implemented with this intent include:

- Disturbing the smallest practicable area at any one time during the remining operation,
- Implementing progressive backfilling, grading, and prompt revegetation,
- Stabilizing all exposed surface areas,
- Stabilizing backfill material to control the rate and volume of runoff,
- Diverting runoff from undisturbed lands away from or through disturbed areas using
- protected channels or pipes, and
- Using terraces, check dams, dugout ponds, straw dikes, rip rap, mulch, and other measures to control overland flow velocity and volume, trap sediment in runoff or protect the disturbed land surface from erosion (e.g. silt fences and vegetative sediment filters).

Construction of terraces, diversion ditches, and other grading/drainage control measures can be utilized to help prevent erosion and ensure slope stability. It is recommended that drainage ditches, spillways or channels are designed to be non-erodible, to carry sustained flows, or, if sustained flows are not expected, to be earth or grass-lined and designed to carry short-term, periodic flows at non-erosive velocities. Design should demonstrate that erosion will be controlled, deepening or enlargement of stream channels will be prevented, and disturbance of the hydrologic balance will be minimal. All slopes and exposed highwalls should be stable and protected against surface erosion. Slopes and highwall faces should be vegetated, rip rapped, or otherwise stabilized. Hydrologic diversions and flow controls should be free of sod, large roots, frozen soil and acid- or toxic-forming coal processing waste, and should be compacted properly according to applicable regulatory standards. Additional contributions of sediment to streamflow and runoff outside the permit area should be prevented to the greatest extent possible.

Certain sediment control BMPs already are an integral part of mining operations and do not require additional engineering designs or construction. These BMPs are recommended for implementation during pre-, active and post-remining activities, and often are incorporated into remining BMP implementation plans (Appendix A, EPA Remining Database, 1999). These BMPs include:

- Streams, channels, checks dams, diversion ditches, and drains should be inspected regularly and accumulated sediment removed. Channels and ditches should be seeded and mulched immediately after completion, if completion corresponds to regional growing seasons.

- Backfilling and regrading should be concurrent with coal removal and should follow removal as soon as is technically feasible. Final grading should be performed during normal seeding seasons to eliminate spoil piles and depressions at a time expeditious for prompt establishment of vegetation.

Exposed and rounded surfaces should be mulched and vegetated immediately following final grading. It is recommended that mulch be anchored in the topsoil and that vegetation be planted immediately after topsoil grading.

Areas should be reclaimed to an appropriate grade (slopes should not exceed the angle of repose or the slope necessary to achieve minimum long-term stability and prevent slides) to prevent surface-water impounding and promote drainage and stability. All final grading should be completed along the contour. Terrace-type backfilling and grading works to prevent slides and sedimentation while promoting slope stability (this also maximizes coal recovery and eliminates exposed highwalls and spoil piles).

Unstable-abandoned spoil and highwalls should be eliminated to the greatest extent possible. Care should be taken if the remining operation requires disturbance of existing benches and highwalls that have well-established vegetation and drainage patterns. Reaffecting abandoned mine lands that are well-vegetated and stabilized should be avoided to the greatest extent possible.

Overburden and topsoil stockpiles that are not being used for topsoil or the establishment of vegetation should be located to minimize exposure and should be seeded with annual plants when needed to prevent excessive erosion.

Topsoil material should be redistributed on graded areas in a manner which protects the material from wind and water erosion before it is seeded and planted. Compaction of surface topsoil materials should be such as to minimize erosion and surface water infiltration, yet promote establishment of vegetation.

Streams and runoff should be directed away from spoil, refuse and overburden piles, exposed surfaces, and unstable slopes.

Site Stabilization
Minimization of the amount of disturbance during remining operations will decrease the amount of soil and sediment eroding from the site, and can decrease the amount of additional controls or BMPs that will be required. Operations should only disturb portions of the site necessary for coal recovery. Operations also can be staged to ensure that only a small portion of the site is disturbed at any given time. If possible, portions should be remined, regraded and seeded prior to disturbance of the next area.
Preserving existing vegetation or revegetating disturbed soil as soon as possible after disturbance

is the most effective way to control erosion (EPA, 1992). Vegetative and other site stabilization practices can be either temporary or permanent. Temporary controls provide a cover for exposed or disturbed areas for short periods of time or until permanent erosion controls are established. Erosion and sedimentation can be minimized by removing as little overburden or topsoil as possible during remining operations, and by having sediment controls in place before operations begin. Any possible preservation of natural vegetation should be planned before site disturbance begins. The advantages of such preservation include the capacity for natural vegetation to handle higher quantities of surface water runoff.

Revegetation

Revegetation can be one of the most effective BMPs for achieving erosion control. By functioning to shield surfaces from precipitation, attenuate surface water runoff velocity, hold soil particles in place and maintain the soil's capacity to absorb water while preventing deeper infiltration, the establishment of vegetation can stabilize disturbed areas with respect to erosion, and surface water infiltration, and attenuate AMD formation. Implementation of revegetation consists of seedbed preparation, fertilizing, liming, seeding, mulching, and maintenance.

Biosolids are a low-cost alternative to the use of commercially available lime and fertilizers. The biosolids typically used on remining sites are sewage treatment sludge. However, other biosolids can be obtained from paper mill waste and from other industries. Biosolids are available in various forms, but the most common is anaerobically digested materials that require an additional lime amendment.

Abandoned mine lands frequently have large areas with little or no topsoil, devoid of organic matter, and micro-organisms. Biosolids use is beneficial in terms of creating a soil substitute and improving revegetation, but also in developing soil structure through the addition of organic matter which will foster a microbial community needed for the decomposition of biomass and other biochemical activities that take place in soil.

Vegetative cover can be grass, trees or shrubs, but grasses are the most frequently used because they grow quickly, providing erosion protection sometimes within days. Permanent seeding and planting is appropriate for any graded or cleared area where long-lived plant cover is desired, and is especially effective in areas where soils may be unstable because of soil texture and structure, a high water table, high winds, or steep slopes.

[Excerpt resumes below]

Revegetation Plan

- Systematic sample collection and analysis of topsoil, subsoil, and overburden materials to determine the type and amount of soil amendments necessary to maintain vegetative growth.

- Topsoil placement and seeding occur no later than the first period of favorable planting after backfilling and grading. Disturbed areas are seeded/planted as contemporaneously as practicable with completion of backfilling and grading. Backfilled areas prepared for seeding during adverse climatic conditions are seeded with an appropriate temporary cover until permanent cover is established (cover of small grain, grasses, or legumes can be installed until a permanent cover is established).

- Disturbed areas are seeded in such a manner as to stabilize erosion and establish a diverse, effective and permanent vegetative cover, preferably of a native seasonal variety or species that supports the approved post-mining land use.

- Regraded areas are disced prior to application of fertilizer, lime and seed mixture. Fertilizer mixture is applied as determined necessary by soil sample analyses. Treatment to neutralize soil acidity is performed by adding agricultural grade lime at a rate determined by soil tests. Neutralizers are applied immediately after regrading. A minimum pH of 5.5 is maintained.

- Mulch is applied to promote germination, control erosion, increase moisture retention, insulate against solar heat, and supply additional organic matter. Straw, hay, or wood fiber mulch are applied at approximately 1.0 to 2.5 tons/acre. Small cereal grains have been used in lieu of mulch (small grains absorb moisture and act as a soil stabilizer and protective cover until a suitable growing season).

- Conventional equipment is used: broadcast spreader, hay blower, hydroseeder, discs, cyclone spreaders, grain drills, or hand broadcasting. Excess compaction is prevented by using only tracked equipment. Rubber tired vehicles are kept off reconstructed seedbeds.

Maintenance

- Vegetative cover is inspected regularly. Areas are checked and maintained until permanent cover is satisfactory. Bare spots are reseeded, and nutrients are added to improve growth and coverage. Areas that are damaged due to abnormal weather conditions, disease, or pests are repaired.

- Unwanted rills and gullies are repaired with soil material. If necessary, the area is scarified and (in severe cases) back-bladed before reseeding and mulching.

- Revegetation success is determined by systematic sampling, typically at a minimum of 1 percent of the area. Aerial photography can be used to determine success (typically at the 1 percent level - or higher if necessary). Standard of Success (SOS) for revegetation is based on percent of existing ground cover or achievement of vegetation adequate to control erosion.

- Periodic mowing is performed to allow grasses and legumes a greater chance of growth and survival. Plants are not grazed or harvested until well-established.

- Previously seeded areas are reseeded as necessary, on an annual basis until covered with an adequate vegetal cover to prevent accelerated erosion. Areas where herbaceous cover is bare or sparsely covered after 6-12 months are re-limed and/or re-fertilized as necessary to promote vegetative growth, then reseeded and mulched.

The amount of runoff generated from well vegetated areas is considerably reduced and is of better quality than from unvegetated areas. However, it is not possible, based on data currently available, to quantify the water quality benefits of the vegetative coverings as a BMP (EPA, 1996).

Direct Revegetation
Direct revegetation is an alternative to reclamation techniques that are designed to resculpture the existing topography. During direct revegetation, grading is avoided to prevent exposure of deeper, unweathered acid-forming materials and emphasis is placed on preservation of the weathered surficial materials and the network of natural drainage. Direct revegetation is generally low-cost and eliminates the acidity and potential acidity remaining in exposed surface layers by treatment with limestone or other alkaline materials. Once the surficial acidity is removed, natural processes that are aided and accelerated by application of fertilizer, mulch, and other organic amendments, can be relied upon to establish permanent vegetative cover (Nawrot and others,1988). Work may be required for several (typically three) successive growing seasons, in order to ensure the establishment of vegetation across the entire area to be reclaimed (Olyphant, 1995).

Direct revegetation commonly requires the addition of lime and fertilizers to mine spoil or coal refuse piles that are devoid of vegetation. Biosolids can be easily employed in cases of direct revegetation. The material can be spread by use of a hydroseeder or farm equipment. Areas requiring direct revegetation are often poorly accessible due to steep and unstable slopes. Therefore, the ability to spread biosolids from a secure distance makes it ideal for direct revegetation application. Biosolids, in many cases, form the basis of soil material or augment what little soil exists on the site.

Biosolids were used at numerous remining sites in Pennsylvania where little soil existed prior to remining or where, if soil did exist, it was lost due to burial or erosion from pre-SMCRA mining. Increases in plant growth and density can be dramatically improved using biosolids.

Channel, Ditch and Gully Stabilization
Stabilization of channels, ditches, and gullies at remining sites, whether constructed for surface water and erosion control or unwanted, is imperative for controlling sedimentation. In general, formation of unwanted gullies should be avoided. These BMPs are recommended when vegetative stabilization practices are not practical and where stream banks are subject to heavy erosion from increased flows or disturbances. If unwanted or naturally-formed gullies are well-established, stabilization may prove more effective than removal. Gullies that are deeper than nine inches may form in regraded areas and should be filled, graded, and reseeded. Rills or gullies of lesser size may have a disruptive effect on post-mining land use or may add to erosion and sedimentation and should be filled, graded, and seeded (Appendix A, EPA Remining Database, 1999 VA(2)).

It is recommended that permanent channels and gullies be designed and constructed based on 100 year, 24 hour storm event. Channels and gullies can be stabilized and protected from eroding forces by the implementation of linings and/or check dams. Linings can be constructed of grass, rock, rip rap, or concrete. Check dams can be constructed with staked straw bales, wood, or rock. Although channel linings and check dams can trap small amounts of sediment, their primary purpose is to reduce the velocity of storm water flow, thus abating additional erosion.

Channel Linings
Erosion is a serious problem associated with channels and other water control structures.

Sediment loads from eroded channels can cause numerous sediment and hydraulic problems and decrease the effectiveness of other sediment control measures. Depending on flow velocities, channel linings may be required to prevent channel erosion (MD DNR, 1989).

Due to the ease of construction and low cost, a vegetated channel lining is one of the most cost effective ways of reducing channel erosion and is frequently used on diversion ditches. A well-established grass can protect the channel from erosive flow velocities of up to 6 feet per second (fps). Shorter meadow-type grasses with short, flexible blades can withstand a maximum permissible velocity of 5 fps. Bunch grasses or sparse cover provides only marginally better erosion protection than a well constructed earthen channel. For prevention of erosion, the Commonwealth of Kentucky (Kentucky, 1996) recommends that channels having a peak discharge design velocity of less than 5 fps be lined with grass species that are effective against erosion (e.g. Tall Fescue, Reed Canarygrass, Bermudagrass, and Kentucky Bluegrass). Channels having discharge velocities of 5 fps or greater should be lined with rip rap or other non-erodible, non-degradable materials unless the ditch is located in solid rock. Pennsylvania DEP (PA DEP, 1999) recommends a maximum velocity of 3 fps if only sparse cover can be established or maintained (because of shale, soils, or climate); a velocity of 3 to 4 fps if the vegetation is established by seeding (under normal conditions); and a velocity of 4 to 5 fps only in areas where a dense, vigorous sod is obtained quickly or if runoff can be diverted out of the waterway while vegetation is being established.

Vegetative linings typically begin eroding the base of channels, and once started, will continue until an erosion resistant layer is encountered. If it becomes evident that erosion of a channel bottom is occurring, rock or stone rip rap lining should be placed in the eroded areas. Rip rap lining should be durable and should be free of acid-forming materials. Generally, rip rap composed of varying sizes of stones is preferred over rip rap that is uniform, not only because it is less expensive, but because the varying stone size promotes natural settling and grading to form a better seal. In addition, rectangularly shaped stone is preferred for its durability. Smooth or rounded stones should not be used (MD DNR, 1989). A good recommendation is the use of a well-graded mixture down to the one-inch particle size such that 50 percent of the mixture by weight is no larger than the median stone size. Rip rap layers should have a minimum thickness of 1.5 times the maximum stone diameter or no less than six inches, whichever is the lesser value.

Channel banks should be protected to a height equal to the maximum depth of flow (Kentucky, 1996). Rip rap used in diversion ditches and pond spillways should consist of durable sandstone or limestone exhibiting a Slake-Durability Index of 85 or greater. The rip rap should be well-graded with the maximum stone size D(100) equal to the blanket thickness and the median stone size DD(50) equal to one half the blanket thickness (Appendix A, EPA Remining Database, 1999 VA(7)).

Check Dams

The purpose of check dams is to reduce the velocity of concentrated surface-water flow until diversion ditches or gullies are properly vegetated. Check dams can be constructed of straw bales, logs, rocks, or other readily available materials, and should be designed so that water crosses only through a weir or other outlet and never flows along the top or the outside of the dam (Kentucky, 1996). The distance between check dams varies depending on the slope, with a closer spacing when slopes are steeper. Materials used should be relatively impermeable and of appropriate size, angularity, and density. They should be contained in anchored wire mesh or gabions, or staked to prevent flowing water from transporting them.

The material used depends on the size and type of flow that is expected. Straw bale check dams generally are suitable for sediment control where concentrated flows do not develop. The efficiency of straw bale dams is limited by slope length and gradient. Straw or hay bales should be secured with stakes. Log check dams can be used in channels and generally are more effective and stable than straw bale barriers. It is recommended that logs be four to six inches in diameter, driven sufficiently beneath the channel floor, and stand perpendicular to the plane of the channel cross section, with no space between logs (Kentucky, 1996). It also is recommended that rip rap or shorter, wider logs on the downstream side be installed for stability. Rock check dams and straw bales allow water to pass through, controlling sediment movement through filtration and flow control. The size of the stone used in a rock check dam varies, with rock size increasing as flow velocity and discharge volume increase. For most rock check dams, the National Crushed Stone Association no. R-4 stone (3 to 12 inches, 6 inch average) is a suitable stone size (PA DEP, 1999). Filter stone applied to the upstream face of check dams can improve sediment trapping efficiency. Regular removal of sediment that accumulates behind the check dam is imperative for maintenance of efficiency, control of surface water flow, and avoidance of worsening conditions. Check dams also can be built in series, as necessary.

Silt Fences
Silt fences are used as temporary sediment barriers and are commonly constructed of burlap or synthetic materials stretched between and attached to supporting posts. The purpose of silt fencing is to detain sediment-laden, overland (sheet) flow long enough to allow the larger size particles to settle out and to filter out silt-sized particles. Because the screen sizes of synthetic screen fences will vary according to the manufacturer, these fences usually do not have the strength to support impounded water and are limited to control of overland runoff. Common problems associated with silt or filter fabric fences usually result from inappropriate installation such as placement in areas of concentrated flows or steep slopes and placement down rather than along contours. These fences work best when placed on areas with zero slope. Because this often is not possible, flow should be otherwise reduced by the downslope emplacement of hay bales, mulching, or breaking the length of installation into separate sections that will not allow significant flow volumes. Silt fencing is appropriate for sediment control immediately upstream of the point(s) of runoff discharge, before a flow becomes concentrated, or below disturbed areas where runoff may occur in the form of overland flow.

Gradient Terraces
Gradient terraces can be used to control slope lengths, minimize sediment movement, and, on a site-specific basis, to address particular erosion problem spots according to need. Terraces are typically earth embankments or ridge-and-channels constructed along the face of a slope at regular intervals and at a positive grade. These BMPs often help stabilize steeply sloped areas until vegetation can be established and reduce erosion damage by capturing surface runoff and directing it to a stable outlet at a speed necessary to minimize erosion. Terrace locations and spacing can be determined following general grading and location of problem areas. It is recommended that terraces constructed on slopes are not excessive in width and have outer slopes no greater than 50 percent.

Design Criteria

General

- Design should approximate natural drainage as closely as possible.
- Sediment-control structures should be chosen according to review of existing topography, flow direction and volume, outlet location, and feasibility of construction.
- Sediment control structures should be constructed on stable ground.
- Use of costly earth-moving equipment should be minimized.
- Weathered, vegetated and highly established portions of landscape should be preserved to the greatest extent possible.

Revegetation

- Volunteer, natural vegetation should be encouraged, and where possible, undisturbed.

Channel, Ditch and Gully Stabilization

- Liner materials should not contain acid-forming materials.
- Stabilization should be supported properly. Potential for stream bottom and sides to erode should be considered.
- Vegetation-lined ditches should be limited to velocities of 4 to 5 fps, unless documentation is provided that runoff will be diverted elsewhere while vegetation is being established.
- Permanent structures should be designed to handle expected flood conditions.

Check Dams

- Should be used only in small open channels which will not be overtopped by flow once the dams are constructed.
- Check dams should be anchored to prevent failure.
- Dams should be sized according to projected flows.
- The center of the dam should be lower than the edges.
- Straws bale barriers should be placed at zero percent grade, with the ends extended up the side slopes so that all runoff above the barrier is contained in the barrier.
- Stones should be placed by hand or using appropriate machinery, and should not be dumped in place.

Silt Fences

- Support posts should be strong and durable.
- Filter material should be able to retain at least 75 percent of the sediment.
- Fences should be installed in undisturbed ground, and stability should be reinforced with rope or rip rap.
- Adjoining sections of filter fabric should be overlapped and folded.
- Bottom edge should be tied or anchored into the ground to prevent underflow.
- Maintenance should be performed as needed, and material replaced when bulges or tears develop.

Terraces

- Terraces, in general, should not be excessive in width or have outer slopes greater than 50 percent.
- Utilize diversion ditches as necessary, while a vegetative cover is being established.
- Terraces should be designed with adequate outlets, such as a grassed waterway or vegetated area, to direct runoff to a point not causing additional erosion.

[EPA excerpts concluded]