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The Management of Nonpoint Sources of Contamination from the Embudo Watershed in the Vicinity of Albuquerque, New Mexico

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by

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Committee Approval

The Master of Water Resources Professional Project Report of **Rosemarie Chora** is approved by the committee:

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Introduction

For the people living in the Rio Grande Valley, the importance of water, both quantity and quality, is an ongoing issue. Water resources issues of a local or regional nature are in the news almost every day. As competition for limited water resources intensifies, major economic decisions, both locally and regionally, will be controlled by the availability of usable quantities of ground and surface water. The urbanization of the Albuquerque area has changed the natural workings of its surrounding watersheds. Water quality, vegetation and erosion patterns have been altered by the vast amount of impervious surfaces present within the city. With this altered state of the physical surface, there are also changes in the runoff characteristics within Albuquerque watersheds.

The 1995 report by Kyle Harwood titled "The Urban Stormwater Contribution of Dissolved Trace Metals from the North Diversion Floodway Channel, Albuquerque, NM to the Rio Grande", examines the metal contribution of the North Diversion Channel into the Rio Grande. The metals that Harwood examined are dissolved copper, dissolved aluminum and dissolved zinc. This project will analyze contaminant loading to the Rio Grande from the North Diversion Channel watershed and focus on the Embudo sub-watershed, as it relates to this loading. Embudo was selected because it originates in the relatively undeveloped Cibola National Forest and is prone to flooding and erosion.

It is thought that the Embudo data can be used to provide background data for metals. Also, soil loss from the National Forest land can be computed using data from the U.S. Forest Service's Terrestrial Ecosystem Survey and utilizing U.S. Department of Agriculture's Modified Universal Soil Loss Equation (MUSLE) (Brooks, et al., 1997).

There are many constituents in urban stormwater runoff. Metals, organics, sediment, and floatables, are just a few. This investigation will examine the loading of metals and sediments to the Rio Grande. The rationale for this study is several fold. Metals are of particular interest in urban runoff, in that they are representative of particular urban processes. Copper and zinc are often found in highway environments (Turer, et. al., 2001), probably due to a heavy concentration of automobiles, which are ever present in large cities (Sutherland, et. al.,2001).

Because metals do not degrade naturally, high concentrations of them in runoff can result in accumulation in the roadside soil at levels that are toxic to organisms in surrounding environments (Turer, et al., 2001). Wash-off of road deposited sediment into storm drain systems is one of the major contributors to nonpoint source pollution in urban river networks (Sutherland, et. al., 2001). Because the city of Albuquerque is almost completely developed, there is a large amount of sediment that runs off from the city and neighboring areas, including the Sandia Mountains (personal communication with Loren Meinz, February 2002). Sediment in streamflow affects biota and causes habitat destruction. Also, sediment is a vehicle for transporting other pollutants, including metals.

Water quality in the Rio Grande is regulated by the EPA and is of particular concern to Tribal governments downstream who depend on the waters of the Rio Grande for many purposes, including ceremonial.

The need for an effective water quality monitoring system is of great importance to the metropolitan Albuquerque area. There is currently only minimal monitoring between the Embudo watershed and the North Diversion Channel outflow. While the gauge at the outlet of the North Diversion Channel has been invaluable in gathering data on the pollutant load from the entire northeast quadrant of Albuquerque, more is needed. It is important to critically evaluate the water quality monitoring system to ensure that it is not only describing total loads, but also helping to identify the sources of these pollutants. An example of improved monitoring is continuous monitoring of flow. This project will look at the current data collection system and identify problems and recommend improvements in the monitoring program.

Background

The Embudo Canyon Watershed begins in the Cibola National Forest on the west face of the Sandia Mountains, east of Albuquerque (see Fig. 1). Water from Embudo flows west to the foothills and continues through urbanized areas in the city of Albuquerque (see Fig. 2).

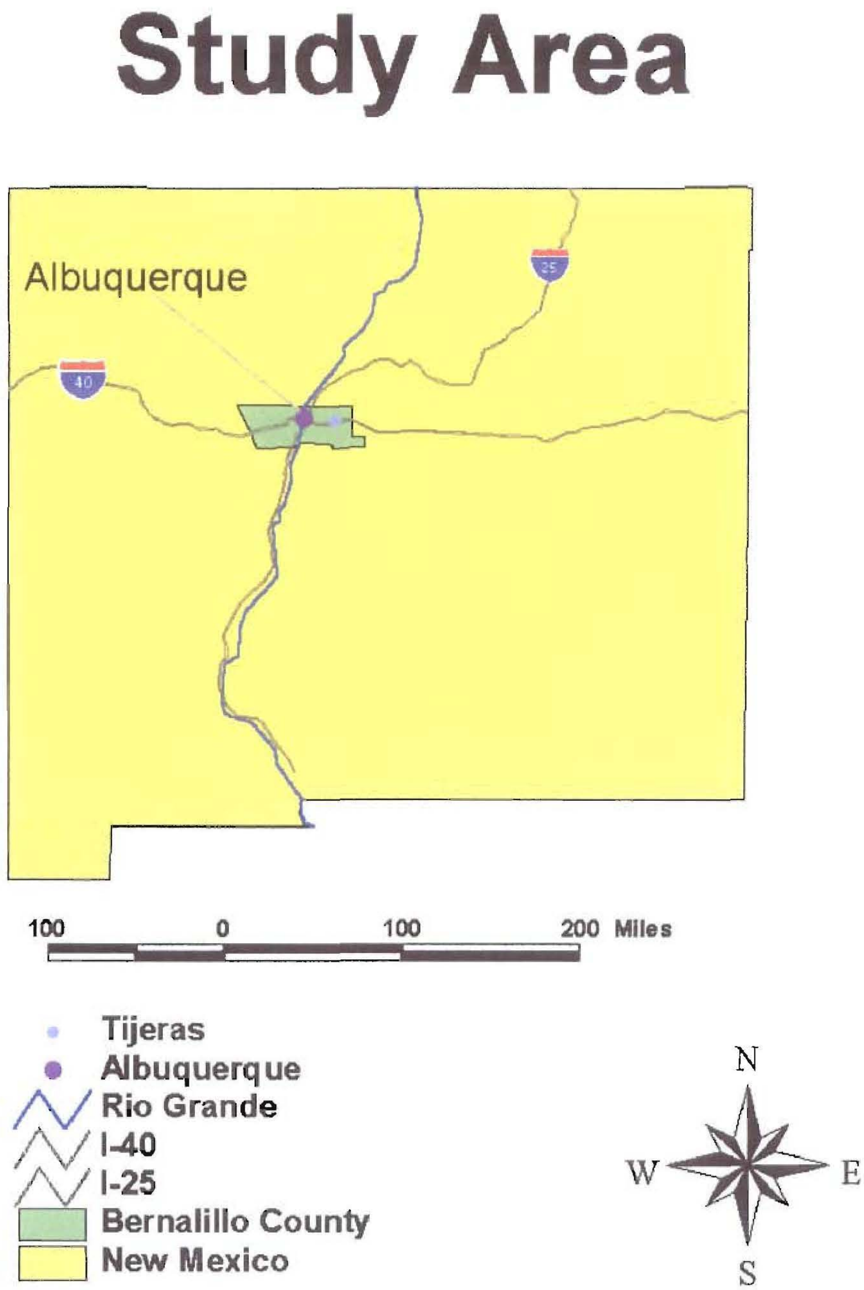

Figure 1. Location map of the study area.

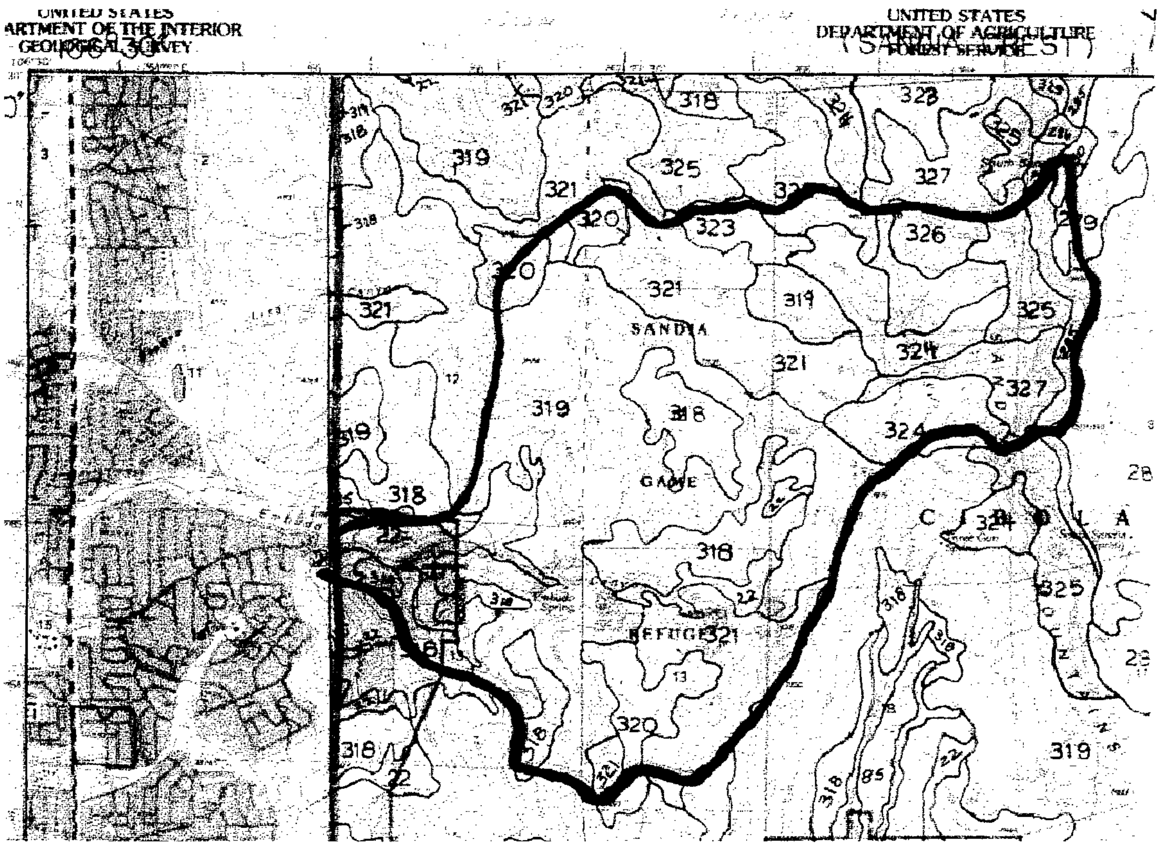

Fig.2. Embudo watershed as it enters the city limits of Albuquerque. U.S. Forest Service Terrestrial Ecosystem Survey, 2000.

Once the Embudo water leaves the National Forest lands, it is channeled, diverted and emplaced in concrete-lined channels (see Fig. 3). As the flow enters the city's open space it encounters the Embudo Dam and enters a lined channel at the USGS Embudo Gauge.

low from Embudo Canyon remains in the lined Embudo Arroyo until it joins with the Interstate 40 channel. Finally, it enters the North Diversion Channel near the intersection of Menaul and Carlisle where it remains until it reaches the Rio Grande (see Fig. 3.).

Fig. 3. Path of the Embudo Arroyo as it enters the I-40 Channel.

Water leaving the undeveloped portion of Embudo Canyon invariably carries with it sediments and other sources of pollution from the upper watershed, including elevated loads of fecal coliform (Water in the West, 2002). Once this water enters the city of Albuquerque, and the lined channels, it encounters a different type of pollution. This pollution is generally categorized as nonpoint pollution derived from roadways, driveways, lawns, exhaust, and residential and industrial areas. Some of the pollutants can include gasoline, oil, antifreeze, fertilizers, salt metals and various other chemicals. The Embudo Canyon watershed contains elevated amounts of nonpoint source pollutants.

Objectives

The objectives of this investigation are to: 1) identify characteristics of the Embudo watershed that influence the transport of nonpoint source pollution; 2) assess amounts of nonpoint source pollution affecting the Embudo watershed, with a focus on sediments and dissolved aluminum, dissolved copper and dissolved zinc; and 3) make recommendations designed to mitigate nonpoint source pollution and improve monitoring of the Embudo watershed.

Significance

Thirty-year rainfall averages are shown in Figure 4. Gauges located in the Sandia Mountains collect a significant amount more rain than in the valley areas of Albuquerque (NRCS, 2002). Orographic precipitation occurs when circulation forces an air mass up over the mountain range. As the air mass becomes lifted, a greater volume of the air mass reaches saturation vapor pressure, resulting in more precipitation with increasing elevation (Brooks, et al., 1997)

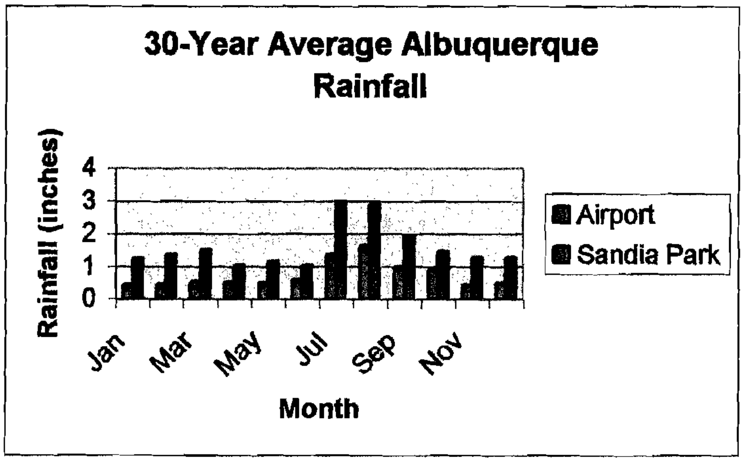

Figure 4: NRCS 30-year average rainfall at the Albuquerque airport and Sandia Park.

Embudo Canyon, though producing a small subset of Albuquerque runoff, is thought to be representative of runoff in the city, since the watershed originates in the Sandias and enters the urbanized areas of Albuquerque in lined channels. It is important to consider the major role this runoff plays in the pollutant loading in the channels of Albuquerque, particularly the North Diversion Channel, which drains directly into the Rio Grande. Federal, state and local regulations limit the type and quantity of pollutants transported to the Rio Grande. There are also issues of water quality on Native American lands, as the North Diversion Channel empties into a portion of the Rio Grande that is located on Sandia Pueblo land.

Agencies Involved

For many years the City of Albuquerque (COA), the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) and the United States Geological Survey (USGS)

have worked conjunctively to gather and assess data. Information for this study relies heavily on these agencies, along with assistance from the U.S. Forest Service and water professionals in the Albuquerque area.

Watershed Description

Geographical Setting

The Embudo Canyon watershed is one of several arroyos that drain the west face of the Sandia Mountains. The Embudo watershed extends from the crest of the Sandia Mountains down to Albuquerque's foothills and the I-40 channel. The Embudo system has an area of 32.18 square miles. The watershed boundary has been altered by flood control structures. The headwaters of Embudito now flow into Bear Canyon, instead of Embudo.

Climate

The climate in the vicinity of Albuquerque is classified as semi-arid continental, characterized by fairly hot summers, mild winters, and short temperate spring and fall seasons (NRCS, 2002). Figure 5 shows annual precipitation in New Mexico. The average precipitation for the area ranges from 8 inches in the valley to 19 inches on the mountain peaks bounding the eastern side of the city (NRCS, 2002).

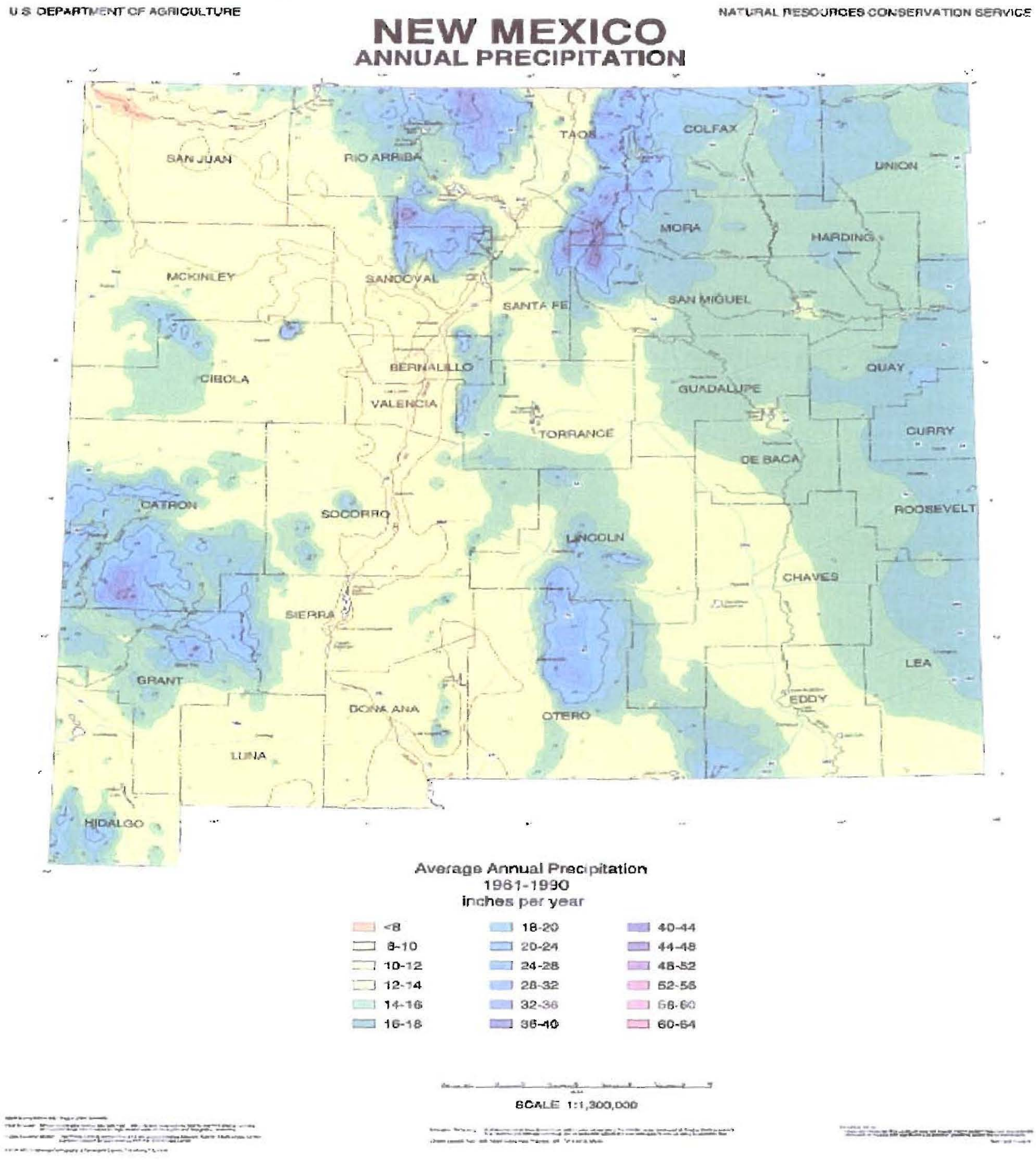

Figure 5. NRCS map showing New Mexico average annual precipitation.

About two-thirds of the average precipitation in the valley occurs from May to October with almost one-third of the annual amount falling during July and August (see Fig.6). Most of the rainfall during this period is the result of brief but intense thundershowers (NOAA, 1974). During the winter months, most precipitation occurs as snowfall. The average monthly snowfall in the valley area is 2 inches with average annual snowfall recorded at 7.26 inches (USACE, 1991).

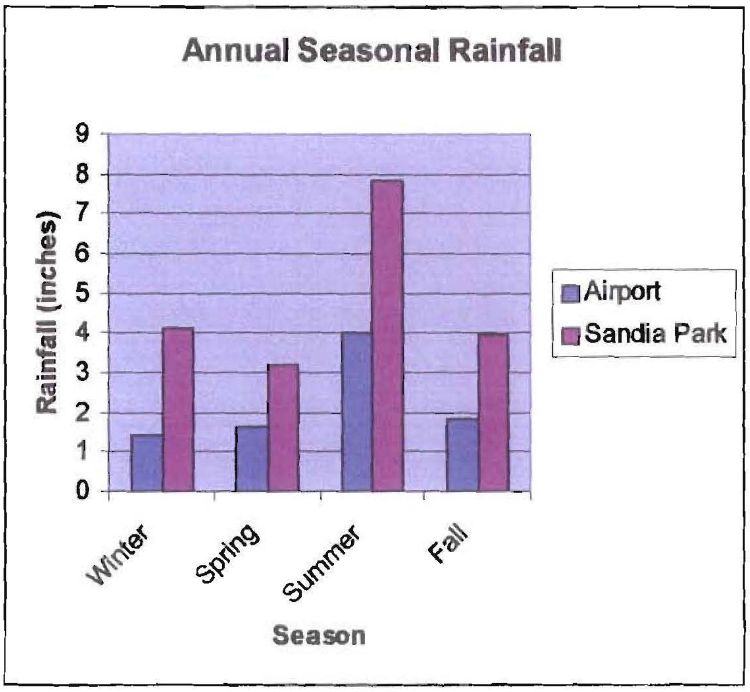

Figure 6: Albuquerque Annual Seasonal Rainfall. Data obtained from NRCS TAPS stations, 2002.

The Rio Grande Basin is in a transitional zone between the Gulf and Pacific rainfall regions, with meteorological conditions further complicated by the presence of extensive mountainous areas. The major portion of the precipitation in the watershed is derived from the tropical Gulf source region (NOAA, 1974). During the summer months, tropical Pacific air seldom enters the watershed. Precipitation usually occurs as the result of thunderstorm activity caused by convective or orographic lifting (NOAA, 1974).

Vegetation

Vegetation recorded in the study area includes upland species, Apache Plume (*Fallugia paradoxa*), gray rabittbrush (*Chrysothamnus nauseosus*), oneseed juniper (*Juniperus monosperma*), blue grama (*Bouteloua gracilis*), Sonoran scrub oak (*Quercus turbinella*), alderleaf mountain mahogany (*Cercocarpus montanus*), gray oak (*Quercus grisea*), twoneedle pinyon (*Pinus edulis Engelm*), gambelii x turbinella (*Quercus x pauciloba Rydb.*), Gambel oak (*Quercus gambelii Nutt.*), white fir (*Abies concolor*), Rocky Mountain Douglas-Fir (*Pseudotsuga menziesii (Mirbel) Franco var. glauca*), ponderosa pine (Pinus ponderosa) and New Mexico locust (*Robinia neomexicana Gray var.*)

Topography

The Embudo Canyon watershed has a significant amount of relief, 3623 feet, with the highest point located along the south Sandia Peak at 9782 feet above sea level (see Fig. 2). The lowest point is at the confluence of Embudo Canyon and the Embudo channel at 6159 feet.

The topographic profile of Embudo Canyon from east to west reveals a steeply inclined segment followed by a flat segment. The steeply inclined segment is the west face of the Sandia Mountains, and the relatively short flat segment is an alluvial fan at the base of the mountain.

Alluvial fans are formed when water flows from a mountain channel onto an open plain. As the water spreads out, the increase in friction greatly reduces the velocity, causing rapid deposition of the largest grains and cobbles. Over time, this sediment builds up in one area, greatly decreasing the gradient and water takes a different path across the plain. This frequent shifting of direction creates the characteristic fan shape. The processes of the alluvial fan mirror those of the alluvial plain, which extends beyond. Numerous channels are present as water flow moves from one to another, over geologic time.

Geology

The study area lies within the Santo Domingo-Albuquerque-Belen Basin, the largest in a series of complex structural basins which collectively form the Rio Grande Trough, a graben fault depression that extends from the northern end of the San Luis Valley in Colorado to near El Paso, Texas (Kelly, 1952). The Basin, extending west of the study area, is about 90 miles long and is approximately 30 miles wide (Kelly, et. al., 1976). The basin was probably formed during Late Tertiary (Miocene and Pliocene) time, the occurrence being coincidental with the uplifting of the Sandia-Manzano-Los Pinos

easterly tilted fault block range. The sedimentary rocks under much of the basin are likely of Cretaceous age and older, although some early Tertiary deposits may be present (Bogart, 1961). In the Albuquerque area, the Sandia mountain range forms the eastern boundary of the Basin. Pennsylvanian and Mississippian aged limestone layers form the caprock of the mountains and are underlain by Precambrian and metamorphic rocks (Ferguson et al., 1996). Precambrian granite occupies the western face of the mountains and is partially buried by alluvial fans to the west (Bogart, 1961). Throughout most of the basin, the western boundary is formed by a series of north-south trending, high angle and parallel normal faults that step down eastward into the Basin. Volcanoes sporadically mark the western boundary of the area and fissure flows that erupted in Tertiary time.

As uplifting occurred during Late Tertiary time, a sequence of gravel, sand, silt, caliche and volcanic deposits known as the Santa Fe formation was created. Unconsolidated Quaternary alluvium and locally thick piedmont rock fragments overlies much of the Santa Fe Formation. The thickness of the Tertiary deposits in the deeper parts of the Basin has been estimated at 18,000 feet (Black and Hiss, 1974).

Soils

The characteristics of soils are the result of the interaction of parent materials, relief, climate, plants, animals and time. Soils were derived from several kinds of parent material - sandstone, granite, schist, gneiss, basalt, shale, limestone, alluvium, and eolian

sand (Middle Rio Grande Council of Governments, 1976). Numerous processes were responsible for the physical and chemical decomposition of the parent material, creating the soil present today.

Within the Embudo system, Embudo gravelly sandy loam is found only within the arroyos, which are defined as being the 100-year flood plain by AMAFCA. Soils #400 (stony land), 401 (rock land frigid), 404 (rock land mesic), and 442 (chinchonte-rock land complex) are located in the areas of steeper slopes, generally in excess of 15% (City of Albuquerque, 1976). These soils are found in the areas included in the Cibola National forest. Soils #52 (Embudo-Tijeras gravelly sandy loam), 115 (Tesajo-Tram very stony sandy loam), and 116 (Tijeras gravelly sandy loam) are primarily located on slopes of 0% to 10%, though some areas of 10% to 15% slopes and steeper are also present (City of Albuquerque, 1976).

Arroyo System

The Albuquerque metropolitan arroyos generally constitute a single purpose utility system, which operates seasonally and is rarely at its full capacity (Facility Plan for Arroyos, City of Albuquerque, 1986). Arroyos are primary elements in the natural drainage system, and since the establishment of AMAFCA in 1963, they have been seen as vital for Albuquerque's flood control system.

Under natural conditions, arroyo channels meander within their floodplains, shifting the locations of the floodplains themselves in response to storm runoff. The width of the natural floodplain varies along its course, determined by the soil type, slope and history of flow. An arroyo may have multiple intertwining channels. This helps to compensate for the unpredictable nature of stormwater runoff.

Arroyos are dry for most of the year. Intense, but short thundershowers in the summer produce streams in these channels, causing flash floods to occur. These streams generally only flow long enough to carry away runoff from the basins they drain. Severe thunderstorms produce high flows that erode natural channels. As rainfall flows down steep and sandy slopes, it picks up sediment and debris, dramatically changing the slope and paths of the arroyos (AMAFCA Bulletin, 2002). When the existing channels cannot accommodate the flow by cutting a wider and deeper bed, the stream overflows its banks, flooding the surrounding area.

The changes that urbanization produces in the natural drainage system can increase the likelihood of flooding. In urbanized areas, rain falls on impervious rooftops, driveways, parking lots, sidewalks and streets. Before urbanization it fell on permeable soil and vegetation. Impervious surfaces allow almost no infiltration of water into the ground and allow water to runoff faster than in undeveloped places. Generally, arroyos in urban areas are required to accommodate more water in a shorter time than would be the case under natural conditions (City of Albuquerque, 1986). This rapid flow of discharge

water increases the available energy in the stream, making it capable of doing more damage to its channel and to the surrounding land.

In addition, runoff from an urbanized watershed may pick up only small amounts of sediment as it passes over hard surfaces. When this water reaches an unlined channel, it picks up sediment, thus eroding the channel. Protection from flooding in urban areas has involved stabilizing channels in a variety of ways. Typical channel treatments include graded earth; stabilization with rip-rap at points vulnerable to erosion; stabilization of side slopes with native vegetation implanted in stabilizing material such as paving blocks; a soft bottom with rip-rap side slopes and drop structures regrading the channel so that it steps downhill, with concrete or gabions (City of Albuquerque, 1986). The Embudo system is lined when it enters the urbanized City limits of Albuquerque, in the Embudo Channel.

In Albuquerque, open channel drainage facilities are generally located within publicly controlled lands. Granted as easements or dedicated as rights-of way, these narrow continuous strips of land occur throughout the city.

Embudo System

The Embudo System is located in the near Northeast Heights in an area designated Established Urban by the Albuquerque Comprehensive Plan. The Embudo system

naturally includes the Embudito, Glenwood Hills, and Piedra Lisa channels. Concrete lining is the commonly used treatment for these channels. The exception is the extreme upper reaches of the tributaries which are in the Major Open Space and National Forest Wilderness areas within the Sandia Foothills. These upper reaches remain in a natural state. The Embudo System connects with the I-40 Diversion Channel just south of the Winrock Shopping Center (see Fig.3). A City bike trail parallels the Embudo between Pennsylvania and Tramway, NE, connecting a number of parks and schools with residential development.

Hydrology

The North Diversion Channel was designed to divert flow from the major arroyos that drain the northeast portion of Albuquerque and provide standard flood protection from these arroyos to the urban and suburban areas of Albuquerque's Rio Grande Valley.

The Rio Grande valley is relatively flat compared to nearby upward-sloping mesas. Cut terraces characterize the transition from valley floor to mesa. These terraces are cut many times by draining arroyos, which empty into the Rio Grande. The eastern mesa is an alluvial plain formed by outwash material from the Sandia and Manzano mountains.

Short- and mid-grasses once covered the plain, and it is here that most of the Albuquerque metropolitan area is now located. The watershed that drains into the North Diversion Channel encompasses the tributary arroyos, which flow generally east to west from the Sandia Mountains. The combined drainage area of the tributaries is approximately 100 square miles (City of Albuquerque, 1993), and the eleven major arroyos with inlets to the North Diversion Channel are shown in Table 1.

ARROYO	DRAINAGE AREA (SQ.MI.)
Campus Wash	7.2
Embudo System Arroyo	32.18
Hahn Arroyo	6.7
Grantline Channel Arroyo	0.95
Vineyard Arroyo	0.98
Bear Arroyo	13.6
South Pino Arroyo	8.23
North Pino Arroyo	2.82
Domingo Baca Arroyo	11.55
La Cueva Arroyo	8
Camino Arroyo	5.8

Table 1: Drainage areas of Arroyos contributing to the North Diversion Channel
U.S. Army Corps of Engineers, 1991: Albuquerque Arroyos

The hundred-year storm, as defined by the National Oceanic an Atmospheric Administration (NOAA), is the flood magnitude that has one chance in100 of being exceeded in any future 1-year period (AMAFCA Bulletin, 2002). The occurrence of floods is assumed to be random in time. The risk of experiencing a large flood within time periods longer than 1 year increases in a non-additive fashion. For example, the risk of exceeding a 1-percent chance flood one or more times during a 30-year period is 25 percent and during a 70-year period is 50 percent. Near the Sandias, the hundred-year storm consists of 2.9 inches falling within six hours (AMAFCA Bulletin, 2002)

Storm Water Regulations

One of the most important items of legislation has been the Federal Clean Water Act (CWA) of 1972. The goal of the Clean Water Act is to eliminate the discharge of pollutants to waters of the United States and that the waters of the U.S. should be fishable and swimable. The Clean Water Act has set the direction of water pollution control in the United States since 1972. It is based on the following principles (Kovalic, 1987):

1. Waters of the United States: No one has a right to pollute the navigable waters of the United States. Anyone wishing to discharge pollutants must obtain a permit to do so.
2. Discharge permits: Permits shall limit the composition of a discharge and the concentrations of the pollutants in it. Anyone violating the conditions of a permit is subject to fines and imprisonment.
3. Technology-based controls: Some permit conditions require specified levels of control based on a consideration of technology and cost, regardless of the receiving water's ability to purify itself naturally. In other words, some levels of control are always presumed to be worth their cost.
4. Water-quality-based controls: Any limits or control higher than the minimum federal requirements must be based on the receiving water quality. The only way to impose higher standards than those required under the CWA is to

demonstrate that continued protection of the receiving water demands such limits.

The Clean Water Act also established the National Pollutant Discharge Elimination System (NPDES). Section 301 requires all point source discharges of pollutants to water of the U.S. have an NPDES permit (excluding agricultural discharges) (Dodson, 1999). The Clean Water Act has been amended several times. In 1977, the term "Best Management Practices (BMPs)" was introduced to describe activities performed for compliance with NPDES permits (Sharpe, 2001). The National Urban Runoff Program Report (NURP) was presented to Congress in 1983. The NURP report concluded that there was no way to achieve the goals of the CWA without addressing urbanized discharges (stormwater). One important set of amendments was the Water Quality Act of 1987 that established a phased approach for stormwater discharge regulation in the United States.

Water Quality Act of 1987

In 1987, Congress passed a set of amendments to the Clean Water Act now referred to as the Water Quality Protection Act of 1987 (WQA). This act establishes the National Storm Water Program. The WQA provides administrative provisions for civil enforcement by the EPA; section 402(p) requires EPA to permit stormwater discharges;

and creates regulations in a two-phase stormwater program. This incorporates a system which prioritizes the approach to stormwater.

Phase I of the National Stormwater Program

Phase I of the NSWP regulates, among other things, discharges from large and medium municipal separate storm sewer systems. A municipal separate storm sewer system (MS4) is a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches artificial channels, or storm drains) that is owned or operated by a state, city, town, borough, county, parish, district, association, or other public body which is designed or used for collecting or conveying storm water (Dodson, 1999). An MS4 that serves an urban population of 250,000 or more is considered large. The city of Albuquerque currently has a half million residents (City of Albuquerque website, 2002) and is considered a large MS4.

Phase II of the National Stormwater Program

The Storm Water Phase II Final Rule expands the Phase I program by requiring additional operators of MS4s in urbanized areas and operators of small construction sites to implement programs and practices to control polluted storm water runoff. Phase II is

intended to further reduce adverse impacts to water quality and aquatic habitat by instituting the use of controls on the unregulated sources of storm water discharges that have the greatest likelihood of causing continued environmental degradation (EPA, 2002).

Stormwater Regulation

Title IV of the CWA gives the EPA the authority and responsibility to issue discharge permits to every point source discharger in the country. As of 1991, the EPA and authorized NPDES states had issued almost 50,000 NPDES permits for industrial process discharges and 16,000 NPDES permits for publicly owned treatment works. These numbers are small compared to the number of facilities that discharge storm water. For example, the EPA estimates that approximately 150,000 individual industrial facilities are required to obtain storm water discharge permits under the initial requirements (U.S. Environmental Protection Agency, 1995).

Any public drainage system owned by a nonfederal government agency could be considered to be a municipal system. A separate storm system is one that is designed to carry only wet-weather flows (as opposed to a combined sewer, which carries sewage as well as wet-weather flows) (Dodson, 1999). Two technology–based standards have been established for discharges from municipal separate storm sewer systems (MS4s). The first standard states that permits must contain a requirement to prohibit non-storm water

discharges into the system. The other standard requires that permits for discharges reduce the discharge of pollutants to the maximum extent practical (MEP). This includes management practices, control techniques, systems, design, and engineering methods. Permits for discharges have generally required the development and implementation of comprehensive municipal storm water management programs to implement these two standards. The EPA has not issued a national guideline defining these standards. Instead, specific best management practices (BMPs) or measures for implementing these standards are established on a case-by-case basis.

In 1973, EPA issued its first stormwater regulations. Because of the intermittent, variable, and unpredictable nature of stormwater discharges, EPA decided that stormwater issues would be better managed on the local level (Dodson, 1999). The EPA also decided that it would not be an effective use of resources to issue permits for all stormwater sources. Therefore, the first stormwater regulations required permits only for particular storm water discharges identified as significant contributors of pollution. The Natural Resources Defense Council (NRDC) then sued the EPA over its authority to decide which categories to exempt from permit requirements [NRDC v. Train, 396 F. Supp. 139 (D.C. 1975), aff'd, NRDC v. Costle, 568 F. 2d 1369 (D.C. Cir. 1977)]. The U.S. district court ruled in favor of the NRDC and required that every municipal stormwater outfall must have a permit.

State Water Quality Standards

States are required to develop water quality standards for waters of the United States within their boundaries. States are required to review their water quality standards at least once every 3 years and, if necessary, make revisions. The minimum elements that must be included in a state's water quality standards include the designated uses for all water bodies in the state, water quality criteria sufficient to protect those use designations, and an antidegradation policy consistent with EPA's water quality standards [40 CFR 131.13].

New Mexico Water Quality Standards

The state of New Mexico does not have NPDES permitting authority. The EPA region VI office in Dallas is responsible for permitting stormwater dischargers under the EPA industrial, construction and multi-sector general permits. However, the state has certain additional conditions that apply to stormwater dischargers. New Mexico requires that all notifications be sent to the New Mexico Environmental Department as well as to the EPA. The New Mexico Water Quality Act of 1978 establishes the Water Quality Control Commission, which implements water quality regulations (New Mexico Water Quality Control Commission, 2000). According to the state of New Mexico, the segment of the Rio Grande that the North Diversion Channel drains to is designated as having the

following uses: irrigation, limited warmwater fishery, livestock watering, wildlife habitat and secondary contact. The standards applicable to irrigation, limited warmwater fisheries and livestock watering are shown in Table 2:

Standards Applicable to Designated Uses				
The following numeric standards shall not be exceeded:				
Metal Constituent	Irrigation (mg/L)	Limited Warmwater Fishery		Livestock Watering (mg/L)
		Acute (ug/L)	Chronic (ug/L)	
Dissolved Al	5	750	87	5.0
Dissolved Cu	0.2	e^(0.9422[ln(hardness)]-1.7408)	e^(0.8545[ln(hardness)]-1.7428)	0.5
Dissolved Zn	2	e^(0.8473[ln(hardness)]+0.8618)	e^(0.8473[ln(hardness)]+0.8699	25.0

Table 2: New Mexico Water Quality Control Commission Standards for Interstate and Intrastate Surface Waters.

According to the New Mexico Water Quality Commission (2000) , there are no set numerical limits for aluminum, copper and zinc in wildlife habitats. Wildlife habitats "should be free from any substances at concentrations that are toxic or will adversely affect plants and animals that use these environments for feeding, drinking, habitat or propagation, or can bioaccumulate and impair the community of animals in a watershed or the ecological integrity of surface waters of the state" (New Mexico Water Quality Control Commission, 2000). In the case of secondary contact, "no numeric standards apply uniquely to these uses" (New Mexico Water Quality Control Commission, 2000).

Under phase I in New Mexico, the City of Albuquerque, the Albuquerque Metropolitan Flood Control Authority, the New Mexico Department of Transportation and the University of New Mexico must obtain stormwater discharge permits for their municipal

separate storm sewer system [60 FR 50804 (Sept. 29, 1995)]. Part 1 of the MS4 application was submitted to the EPA in 1991 and part 2 was submitted in 1993. As of the writing of this paper, there has not been an MS4 permit issued (personal communication with Brian Wolfe, Senior Engineer, COA, Public Works Department, January 2002).

Management of Stormwater Runoff by the Albuquerque Metropolitan Arroyo Flood Control Authority

Localized thunderstorms are typically of high density and short duration (AMAFCA, 2002). The thunderstorm season in Albuquerque occurs mostly from June through September when moist air from the Gulf of Mexico moves north. Albuquerque is built on alluvial fans formed from the runoff from the Sandia Mountains. Rain that falls in the Sandias flows down the steep, sandy slopes, picking up sediment and debris and depositing them as the flows slow. Urbanization and development changes the rainfall to runoff relationship in very dramatic ways.

Stormwater runoff in Albuquerque is directed toward concrete-lined channels that are owned and maintained by several agencies. The city of Albuquerque maintains the channels that run throughout the city, the New Mexico State Highway Department maintains the channel that runs along interstate 40, and AMAFCA is responsible for the city's main drainage thoroughfare, the North Diversion Channel.

The Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) was created in 1963 by the New Mexico Legislature to reduce the impacts of flooding in the Albuquerque area. AMAFCA's mission is to prevent injury or loss of life and to minimize property damage (AMAFCA, 2002). Within the Embudo watershed, AMAFCA operates the Embudo dam and the North Diversion channel. AMFAFCA also establishes drainage policy and regulates development within its defined boundaries. AMAFCA is a political subdivision of the State of New Mexico, and is governed by a publicly elected board of directors. AMAFCA's funding comes from the ad valorem (property) tax. The annual operating budget for AMAFCA is about $1.2 million, half of which goes directly toward maintenance of flood control facilities (AMAFCA, 2002).

Almost all major flood control structures are designed for the hundred-year storm. That means that channels are built to carry the hundred-year flow, and dams are built to contain the hundred-year stormwater volume. Floodplain maps are also based on the hundred-year flow.

Urban Stormwater Quality Monitoring in Albuquerque, New Mexico

To adequately address the stormwater quality regulations promulgated by the U.S. Environmental Protection Agency, a cooperative between, AMAFCA, the City of Albuquerque and the U.S. Geological Survey was begun in 1976. The water-quality

sampling program began in 1992. The U.S. Geological Survey conducted sampling and sample analysis for five streamflow stations and two background sites that first year. Since 1994, the sampling program has been included in the urban data collection program agreement. Water-quality monitoring under the NPDES program has now entered a phase aimed at better defining storm-water quality on an individual watershed basis (personal communication with Orlando Romero, April 11, 2001).

Water Quality and Soil Loss Information

Soil Loss in the Embudo Watershed: Modified Soil Loss Equation

The Universal Soil Loss Equation (USLE) was developed by the U.S. Department of Agriculture in 1965 to predict erosion rates. The USLE is based on the analysis of data collected from agricultural plots under natural rainfall (Brooks, et al., 1997). The USLE has been modified to address soil loss in forested areas (Brooks, et al., 1997). The Modified Soil Loss Equation (MSLE) is best suited to determine soil loss in forested wilderness since it incorporates important criteria for a stable watershed. This includes rainfall intensity, soil stability, slope length and steepness, and vegetative cover. According to Brooks, the Modified Soil Loss Equation is as follows:

$$A = RK(LS)(VM)$$

Where A is the amount of soil loss in tons per acre; R is the rainfall erosivity factor for a particular area; and K is the soil erodibility factor for a particular soil horizon. LS is the dimensionless topographic factor which accounts for slope length and slope gradient. In this analysis, LS was determined using tables derived by March (1998). S is the ratio of soil loss from a given slope steepness to soil loss from a 9% slope under the same conditions. VM is the vegetative management factor. The vegetative management factor is the ratio of soil loss from land managed under certain conditions of vegetative cover, to that of fallow condition on which the K factor is evaluated. VM in this analysis was determined using data from the U.S. Soil Conservation Service (1977) (Brooks, et al., 1997).

Vegetative cover and soil surface conditions of natural ecosystems are described by the VM factor. Three different kinds of effects are considered as sub-factors: (1) canopy cover effects; (2) effects of low-growing vegetative cover, mulch and litter; and (3) bare ground with fine roots (Brooks, 1997).

It is important to note that the MUSLE is a theoretical calculation. The calculations used for the MUSLE are based on field measurements of slope, the erodibility of soil, and vegetation cover. Considered to be an effective measurement of erosion, the MUSLE has been utilized in conjunction with erosion plots, erosion pins and other field measurements by Debby Mandeville (2001) and Elaine Brouillard (1999).

In 2001, the U.S. Forest Service completed the Cibola National Forest Terrestrial Ecosystem Survey (TES). The TES contains quantitative information on the soils, slope steepness, slope length, vegetation present, and the percentage of vegetative cover within the Cibola National Forest. These data, along with rainfall intensities gathered from the U.S. Department of Agriculture Soil Conservation Service, have been used to determine soil loss in the Embudo watershed. Utilizing the MUSLE and the TES, soil loss was calculated in various subsections of the Embudo watershed. Table 3 shows the results of the soil loss calculations. The calculations for Table 3 can be found in Appendix B.

Map No.	Soil Loss (A) (tons/acre/yr)	Acres (per map unit)	Soil Loss (tons/year)	Percentage of unit	Total Loss per Unit
22-0.1	0.27	145.22	39	0.7	27
279-0.1	3.5	22.42	78	0.7	55
280-0.1	[illegible]	27.29	960	0.4	380
280-0.2	9.9	27.29	270	0.3	81
285-0.1	93	55.55	5200	0.5	2600
318-0.1	1.6	315.79	500	0.3	150
318-0.2	1.2	315.79	380	0.3	110
319-0.1	9.9	870.37	8600	0.5	4300
319-0.2	1.2	870.37	1000	0.25	250
320-0.1	[illegible]	124.76	1600	0.45	720
320-0.2	7.3	124.76	910	0.3	270
321-0.1	6.5	455.16	3000	0.45	1400
321-0.2	40	455.16	18000	0.2	3600
323-.01	[illegible]	86.74	1100	0.5	550
323-0.2	[illegible]	86.74	1600	0.4	640
324-0.1	40	200.78	8000	0.6	4800
325-0.1	45	70.18	3200	0.6	1900
327-0.1	60	155.95	9400	0.1	940
					23000

0-5 Tolerable
[illegible]10 Moderate
[illegible] High
Severe

Table 3. Soil loss by Map Number according to USFS TES Survey.

According to Table 3, there are several map units with severe erosion rates. These map numbers include 280-0.1, 285-0.1, 321-0.2, 324-0.1, 325-0.1 and 327-0.1. The three map numbers with the most total soil loss are map numbers 319-0.1, 321-0.1 and 324.01; of these, only the latter two map numbers have severe erosion rates.

The areas within Embudo Canyon with severe erosion rates generally tend to be in the far eastern side of the canyon. This is due to extremely steep slopes on the western face of the Sandias. Areas of concern are where the hiking trail enters areas with severe erosion rates. This occurs in portions of 321-0.2, 324-0.1 and 327-0.1. These are areas where additional erosion prevention measures should be considered.

The map numbers with the largest total amount of erosion occurring are shaded in green in Table 3 (319-0.1, 321-0.2 and 324-0.1). Map numbers 321-0.2 and 324-0.1 fall into this category due to their extremely high erosion rate of 40 tons/acre/year. Map unit 319-0.1, while only having a moderate erosion rate of 9.9 tons/acre/year, has the second largest overall amount of soil loss. This is due to the large acreage represented by map number 319-0.1.

Water Quality of Urban Runoff

Harwood (1995) evaluated the metal contribution of the North Diversion Channel into the Rio Grande. The metals that Harwood examined are dissolved copper, dissolved aluminum and dissolved zinc. Harwood's report compared the loads from the North Diversion Channel to two wastewater treatment plants discharging into the Rio Grande and also to an upstream site on the Rio Grande.

This report looks to build upon the work done by Harwood in two ways. First it is important to update the amount of metals being discharged from the North Diversion Channel. By comparing the North Diversion Channels loading to two wastewater treatment facilities, Harwood's work shows the need for the regulation of stormwater runoff, which was not in place in 1995. This work clearly illustrates how Albuquerque runoff is more polluted than the discharges from the wastewater treatment plan and the upstream flow of the Rio Grande. The updated comparison to wastewater treatment facilities is not included here since treatment facilities are under the same regulations as in 1995 and Albuquerque is still in the process of obtaining a Municipal Separate Storm Sewer System (MS4) permit. Table 4 displays the annual mean concentration of aluminum, copper and zinc reported by Harwood (1995), for 1993-994.

System Name	Dissolved Al (ug/L)	Dissolved Cu (ug/L)	Dissolved Zn (ug/L)
North Diversion Channel	200	6.3	13.6
Rio Grande	10	1	2

Table 4. 1993-1994 Annual Mean Concentration as reported by Harwood

To further describe the runoff from the NDC, Embudo Canyon was selected to represent a subsection of the Albuquerque northeast quadrant. Embudo was chosen because it originates in the pristine Cibola National Forest. Embudo is prone to flooding and erosion. It is thought that the Embudo data is representative as background data for metals. In addition to the above modifications, a look at dissolved solids was included in this study. This was done to begin to assess the volume of sediment entering the Rio Grande. Suspended solids are also important to examine due to their ability to attach and transport metals.

The CY2000 USGS Embudo gauge data shows dissolved aluminum at 18ug/L and suspended solids at 3075 mg/L; concentrations higher than the NDC (see Table 5). The Embudo gauge recorded lower levels of dissolved copper and zinc (5ug/L and 6.49yg/L, respectively) than the NDC during this period. The increase of copper and zinc occurs somewhere between the Embudo gauge and the outflow of the North Diversion Channel. This is probably due to land usage in the areas leading to the NDC outlet and the flow peaks associated with those land uses. Urbanization increases the amount of flow and nonpoint pollutants washing into channels that flow into the NDC.

Gauge Site	Dissolved Aluminum (ug/L) (1106)	Dissolved Copper (ug/L) (1040)	Dissolved Zinc (ug/L) (1090)	Dissolved Solids (mg/L) (70301)
Embudo Gauge (UR650)	18	5	6.49	3075
North Diversion Channel (UR9900)	14.4	5.51	13.14	388
Rio Grande (San Felipe Station)	< 1.8	< 1.18	< 1	85.2

Table 5. USGS Water-Quality Data, Annual Mean Concentration Calendar Year 2000

According to Harwood (1995), there has been a significant decrease in the amount of aluminum being discharged into the Rio Grande (See Fig. 7). This could be due to several factors, including the number and intensity of storms present in the year of the Harwood study and also the amount of erosion occurring at that time. The erosion rate could possibly be related to development in the far northeast heights at the time of the Harwood study.

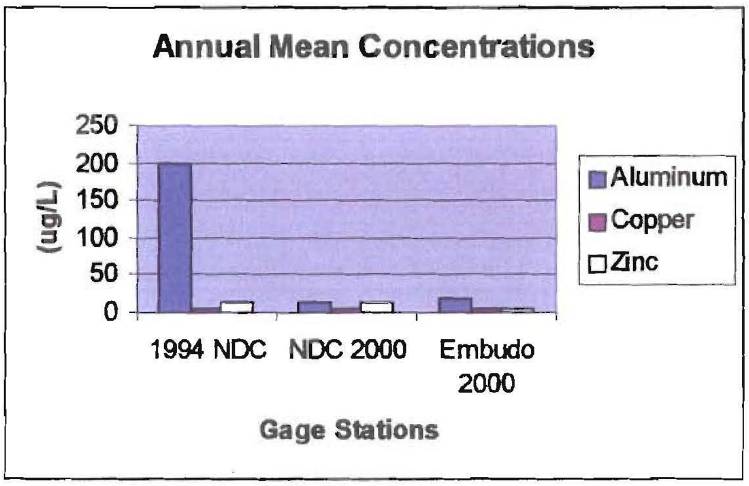

Figure 7. USGS Annual Mean Concentrations by Gauge Station

The amount of copper and zinc being deposited by the NDC into the Rio Grande has stayed relatively constant between 1994 and 2000 (see Fig.8). Metal loads upstream of Albuquerque in the Rio Grande have also remained near constant for copper and zinc since 1994.

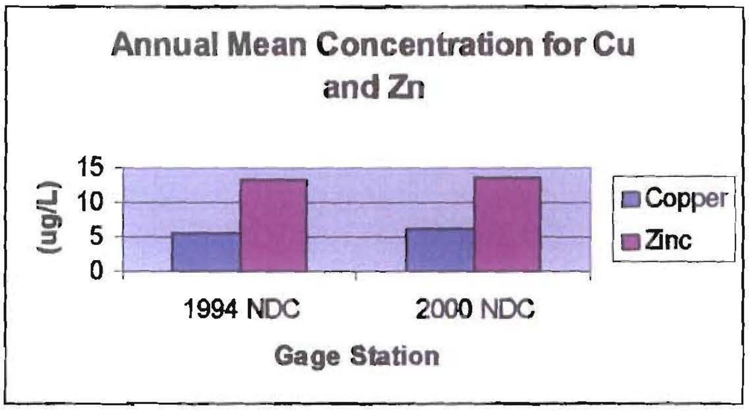

Figure 8: USGS Annual Mean Concentration for Copper and Zinc.

Resource Management Issues

Land Use Change over time

Sometime during the last ice age, humans found their way into the Albuquerque area. Currently there is no proof that places man on the Rio Grande much before 12,000 years ago (MacNeish, 1973). The Rio Grande Valley is said to be the oldest continuously settled region in the United States. As early as 1100 A.D., numerous Indian Pueblos were supported by irrigated agriculture along the Rio Grande and its tributaries. The environmental impact of the Native Americans in Embudo Canyon was limited to small game hunting, firewood gathering and logging. The first known settlement in the vicinity of Albuquerque was in 1598, located on the west bank of the Rio Grande.

About 1610, the Spanish established settlements at Santa Fe, Santa Cruz, Los Cerrillos and Bernalillo.

The Acting Governor of Bernalillo sent 30 families to the site of the present city of Albuquerque and in 1706 the city was founded. The plaza and some of the structures of this period still remain in an area known locally as Old Town on the east side of the river.

The area grew slowly until the coming of the railroad in 1880 (Simmons, 1982). As with other communities, the railroad brought immigrants and health seekers who started new enterprises and established ranches in the area. Albuquerque became a shipping point for cattle, sheep, hides, wool and ore (Simmons, 1982), and by 1881, the town qualified as the first city in New Mexico.

The Spanish, Mexican and American colonizers of the region had a significant impact on Embudo Canyon with domestic grazing. Portions of the west Sandia foothills were used for grazing for over 400 years. According to Grubbs (1960), "during the early nineteenth century, sheep herds a half million strong were common in New Mexico". The watershed displays the effect of overgrazing by its stripped vegetation cover. "The stubby growth which now covers the landscape little resembles the luxurious grasses which once grew there" (Sargeant and Davis, 1986). When the Sandia Mountain Wilderness within the Cibola National Forest was established in 1980, all domestic grazing was stopped. There was limited logging and fire woodcutting until the 1960s with most of the commercial logging done on the east side of the mountain. Currently

there is no logging or clearing occurring on the west face of the Sandias (personal communication with Cliff Dils, Tijeras District Office, U.S. Forest Service, April, 2002).

The development of the Albuquerque area has increased steadily throughout its history. In 1994, land use within the entire drainage basin of the North Diversion Channel was mostly Non-Urban (see Table 6).

Land Use	Percentage
Residential	18.7
Commercial	3.8
Industrial	1.7
Total Urban	24.2
Open Space	5.5
Vacant	13.1
Forest	57.2
Total Non-Urban	75.8

Table 6. Percentage of Land Use types for the NDC basin (University of New Mexico, 1994)

According to the Albuquerque MS4 NPDES permit application, land use within the city limits of Albuquerque were far different than that of the entire NDC basin (see Table 7). In 1992, only 4% of the land within the city was considered open space, compared to 75.8% in the entire basin.

Land Use	Percentage
Residential	41
Agricultural	36
Commercial	15
Industrial	4
Open Space	4

Table 7. Land Use within the City of Albuquerque (City of Albuquerque, 1992)

Erosion and Sediment Yield

The most prevalent form of stormwater pollution in the Rio Grande is the presence of suspended matter that is eroded by stormwater or washed off paved surfaces (Water of the West, 2002). Although erosion is a natural process, scientists estimate that human caused erosion is twice the natural rate (Water of the West, 2002). Suspended solids increase the turbidity of the receiving waters, resulting in decreased activity and growth of photosynthetic organisms. Increased turbidity detracts from the aesthetics of natural waters. Fish gill clogging has also been attributed to suspended solids.

The effects of sediment on biota, recreation and the economy are both subtle and profound. Of particular concern is the effect of deposited sediments on biotic habitats. Siltation and the subsequent shifting and smothering of the stream or river bottom are major factors in the decline of species. Recent research has also revealed that rare and threatened fish species are vulnerable to even relatively small increases in stream turbidity. Kundell and Rasmussen (1995) recently reported on the sensitivity of six, state or federally listed endangered fish species in Georgia rivers that were adversely impacted when turbidity exceeded 10 to 25 nephelometric turbidity units (NTUs). Three-quarters of these species were eliminated when turbidity occasionally exceeded 25 NTU on a monthly basis and all were lost when turbidity more frequently exceeded 25 NTU. In

New Mexico, the Rio Grande Silvery Minnow (*Hybognathus Amarus*) is an important consideration for sediment yields, due to its listing as an endangered species.

Situations that are particularly susceptible to soil loss include (1) sloping ground, particularly hills with shallow soils; (2) soils with inherently low permeabilities; and (3) sites where denudation of vegetation is likely (Brooks, et.al, 1997). The movement of soil particles at the soil surface by energy imparted to the surface by falling raindrops is a primary agent of erosion, particularly on soils with sparse vegetative cover (Brooks, et. al. 1997). Construction site erosion is the first sediment load associated with urban development (Dodson, 1999). A second and possibly greater sediment pulse occurs as stream banks beginning to erode in response to the greater volume and frequency of stormwater flows generated by impervious cover.

Heavy metals

Studies in the United States and Canada indicated that heavy metals were the most prevalent toxic contaminant found in urban runoff (US EPA, 1983;Marsalek et al., 1997). In urban runoff, commonly found metals include lead, copper, iron, zinc and aluminum. Rainfall runoff from urban roadways often contains elevated amounts of heavy metals in both particulate and dissolved forms (Turner, et. al.2001). Because metals do not degrade naturally, high concentrations of them in runoff can result in accumulation in the roadside soil at levels that are toxic to organisms in surrounding environments.

The heavy metal concentrations in water have been observed to depend largely on the amount of flowing water and are negatively correlated with flow. Sediment analysis indicates that the large amount of heavy metals is associated with organic matter (Jain and Sharma, 2001). Heavy metal concentrations generally increase with the decreasing particle size of the sediments. Washoff of road deposited sediment into storm drain systems is one of the major contributors to nonpoint source pollution in urban river networks. Road sediment data indicates that aluminum is primarily lithogenic in origin, while copper and zinc showed very significant anthropogenic signals, most-probably from vehicle-related sources (Sutherland, 2001). Since highway environments are a relatively constant source of anthropogenic organic matter as well as heavy metal, heavy metals will continue to remain bound to organic matter.

Forest Management

Eighty percent of upland water systems in the United States originate on National Forest lands (personal communication with Cliff Dills, Tijeras district Ranger, April 2002). The National Forest System is composed of many tracts of land throughout the United States. Within the National Forest system is the Cibola National Forest, which includes the Sandia Mountains. On the southwest face of the Sandias lies the Embudo watershed. The watershed originates in a portion of the Cibola National Forest that is designated

wilderness by the Forest service. The watershed continues into Albuquerque open space and then into the urbanized area of Albuquerque.

A wilderness designation by the Forest Service imparts several restrictions on use. In wilderness-designated areas, motorized vehicles, including motorbikes and quads are prohibited. All wheeled entry (e.g. bicycles) is also prohibited. The only exception is for emergency purposes, such as a gurney that contains wheels.

The Sandia Mountains are home to over 200 miles of trails. Trails within the National Forest are tediously designed to reduce impacts to the surrounding wilderness. Location and the stability of the area is a large consideration when developing a trail. Within the Cibola National Forest there are several types of erosion control mechanisms, including water-bars and earthen structures. Trails are designed to slow the flow of water with "bumps in the road" and also by being angled to divert water. Although many trails are built with much forethought, many trails begin as "user" trails. This is when a trail is developed by people entering the forest to hike, climb or explore. The trail at Embudo is one such trail. The Embudo trail follows the Embudo Arroyo up the Sandias from the foothills to the crest. Unfortunately, having the trail close to the stream disturbs the sediments and propagates the downstream movement of solids.

The vegetation in the Cibola National Forest is not in a natural balance (personal communication with Cliff Dills, Tijeras district Ranger, April 2002). The Sandias have not been supporting grazing animals since the 1960's, yet it is believed that the native

grasses have not fully recovered from when the Spaniards allowed their animals to roam freely. It is thought that the species of the grasses today are different than they historically have been. This, though, is not the major change in the vegetative cover. Since the development of Albuquerque as a metropolitan city, there has been a strong policy to eliminate fires in the Sandias as soon as possible. Although this was thought to be good forest policy, it has been found to offset the balance of species present. Void of fire, the larger species, such as fir, spruce and ponderosa dominate the vegetative landscape, while native grasses struggle for survival. A denser forest has resulted because the grass cover was depleted and outcompeted by brush and trees. A healthy grass cover is more likely to capture water, reducing surface water flows.

Recommendations

Land Use in Albuquerque

The city area contributing to the North Diversion Channel is nearly completely developed. There is little additional land available to dedicate as open space. Impervious surfaces including rooftops, driveways, sidewalks and concrete lined arroyos are now the dominating feature of the area. It is critical to manage runoff and pollution coming from these impervious surfaces.

One method to limit urban runoff and pollution is to limit impervious services. This can be done with porous pavement, nonsolid decking, sand walkways, organic mulch and crushed gravel within curbing. Runoff from impervious sources can be directed to well-vegetated areas for infiltration. Sloping, crowning or redirecting water flow to infiltration trenches and improving infiltration can help to offset the effects of impervious surfaces. Residential areas should be landscaped with native vegetation. This helps reduce the amount of watering (runoff) and fertilizers (pollution).

Stormwater runoff in Albuquerque is a growing concern for the City of Albuquerque. Since the Harwood study was conducted in 1995, the city has worked diligently to address stormwater issues, both with the EPA and the Pueblo of Sandia. Most of these efforts have been in preparing and processing the cooperative MS4 permit and analyzing

the nature of the city's stormwater. Currently, stormwater concentrations for the NDC remain relatively constant compared to the levels observed in 1995.

Pollution prevention is not an easy issue to address in stormwater runoff. By its very nature, stormwater is a nonpoint source of pollution. It is difficult to identify specific sources and enforce regulations. There are several methods to address stormwater runoff.

The city should implement monitoring for illicit connections and illegal dumping. Discharges from storm drains can be monitored during wet and dry weather to attempt to detect illegal dumping. An industrial facility database and inspection program can be implemented to assist the industrial community to meet compliance requirements. This can also be done with the construction industry. Strict regulations can be applied to land use changes within the Albuquerque area. Some examples would include mandatory monitoring of construction activities to reduce erosion and runoff, requiring detention of runoff caused by new development; and requiring that runoff be addressed in the permitting process. Ultimately, education is important in assisting the business, industrial and construction communities to comply with NPDES stormwater regulations.

Forest Management

The most economical way to mitigate erosion is to avoid watersheds under circumstances and land uses that cause soil loss in the first place. The most important guideline to

reduce erosion is to always take into consideration fundamentals of erosion processes. This is true when considering trail development or maintenance, water resources management or forest management. Most erosion problems in Embudo Canyon are attributed to improper trail design, steep slopes and low vegetative cover. Maintaining a vegetative cover is the best means of reducing erosion. The occurrence of an adequate amount of cover cannot always be relied upon in drylands (Brooks, et. al., 1997), as is the case in some parts of the Sandias. Soil loss, due to improper trail design and forest management, inhibit vegetative cover and increases erosion. Methods to increase grass coverage include reducing soil loss including the thinning of the forest and implementing prescribed burns.

Water erosion can be mitigated in several ways. First is by keeping the soil in a condition that readily allows water to infiltrate. This includes a vegetative cover that reduces rainfall impact. Water should not be allowed to flow along channels or trails for long amounts of time or length. Water bars can be implemented with greater frequency along the trails and channels within Embudo, particularly in areas with severe erosion rates such s 321-0.2, 324-0.1, and 327-0.1.

The trail alongside the Embudo Arroyo should be moved away from the stream. This action would decrease downward movement of sediment and increase the quality of the arroyo. Planning is important to develop a trail system and not a random network of trails. Steep slopes should be avoided, as they are less stable and expose more soil due to

excessive cut-and-fill requirements. Steeper slopes concentrate water more quickly and impart a higher velocity to flow than less steep slopes (Brooks, et. al., 1997)

Gauging of the Watershed

The gauging system in the Metropolitan Albuquerque area is a means to gather representative data throughout the city. Although this has been adequate in describing the general types of runoff in particular areas and the total load at the outfall of the North Diversion Channel, it is hardly adequate for future regulations on Albuquerque stormwater runoff.

Table 5 shows an increase in copper and zinc at the outflow of the North Diversion channel, compared to the Embudo gauge. This is reasonable considering that the water downstream from the Embudo gauge travels alongside Interstate 40 and down the entire length of the NDC before being sampled again. It has been valuable to know the total load placed on the Rio Grande by the City of Albuquerque, particularly in preparing the city's MS4 permit. Now, it has become increasingly important to learn more about the specific locations of the sources of pollution flowing into the Rio Grande. It would be extremely useful to know whether the additional metals come from I-40 runoff or a more dispersed area in the northeast quadrant. Without knowing where the contaminants come from, it is difficult to focus resources to significantly reduce stormwater runoff.

In the case of the Embudo Canyon watershed, there are several options to improve data collected. The Embudo gauge is considered a background site for data on the northeast quadrant. Water that flows through the Embudo gauge is not monitored again until the outfall of the NDC, several miles away. It would be useful if gauges were installed just before the Embudo channel enters the I-40 channel and again as it enters the NDC. This type of comprehensive data would more clearly identify sources and help in the remediation process. Armed with data, the city can also better focus on enforcement in areas where urban pollution is highest.

Although the Embudo gauge is representative of background metal data, it does little to reveal the erosion occurring in the National Forest. Information on erosion is important to better stabilize soils and prevent sediments from entering the Rio Grande.

Conclusion

The data presented here shows that stormwater runoff is of a highly variable nature. It is important to monitor runoff thoroughly to be more effective with remediation. Future work needs to be done in implementing erosion controls in various parts of the National Forest, particularly in those areas with severe erosion rates. Plans to reduce urban pollution and runoff need to be prepared and implemented. Finally, the data in this report can be digitized to make it more easily manipulated and entered into a GIS system. This would increase access for the Forest Service and assist when planning erosion control and trail development.

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Appendix A
Definitions

Arroyo - a small steep-sided watercourse or gulch with a nearly flat floor: usually dry except after heavy rains (chiefly found in the southwest United States), also referred to as a "wash" or "gulch".

Clean Water Act (CWA) – the Clean Water Act (formally referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which established the total maximum daily load program.

Floodplain – the area within the 100-year flood boundary as described by Flood Insurance Rate Maps prepared by the Federal Emergency Management Agency.

Municipal separate storm sewer system (MS4) - a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches artificial channels, or storm drains) that is owned or operated by a state, city, town, borough, county, parish, district, association, or other public body which id designed or used for collecting or conveying storm water (Dodson, 1999). Any public drainage system owned by a nonfederal government agency could be considered to be a municipal system. A separate storm system is one that is designed to carry only wet-weather flows (as opposed to a combined sewer, which carries sewage as well as wet-weather flows).

National Pollutant Discharge Elimination System (NPDES) – the national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under section 307, 402, 318, and 405 of the Clean Water Act. The CWA prohibits discharge of pollutants into waters of the United States unless the EPA, a state, issues a special permit or, where delegated, a tribal government on an Indian reservation.

Non-point source – diffuse pollution sources (i.e., without a single point or origin or not introduced into a receiving stream form a specific outlet). The pollutants generally are carried off the land by stormwater. Nonpoint sources can be divided into activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

NTU - nephelometric turbidity units based on a standard method using formazin polymer or its equivalent as the standard reference suspension. Nephelometric turbidity

measurements expressed in units of NTU are numerically identical to the same measurements expressed in units FTU (formazin turbidity units).

One hundred-year storm - defined by the National Oceanic and Atmospheric Administration (NOAA), is the flood magnitude that has one chance in100 of being exceeded in any future 1-year period. The occurrence of floods is assumed to be random in time, or regularity of occurrence is implied. The risk of experiencing a large flood within time periods longer than 1 year increases in a non-additive fashion. For example, the risk of exceeding a 1-percent chance flood one or more times during a 30-year period is 25 percent and during a 70-year period is 50 percent.

Point source – any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may e discharged. This term does not include return flows from irrigate agricultural stormwater runoff.

Pollutant - for purposes of the Clean water Act means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954 as amended (42 USC 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water.

Secondary contact - any recreational or other water use in which contact with the water may occur and in which the probability of ingesting appreciable quantities of water is minimal, such as fishing, wading, commercial and recreational boating and any limited seasonal contact.

Sediment – material, both mineral and organic, that is in suspension, is being transporter, or has been moved from its site or origin by water, wind, ice, or mass wasting and has come to rest on the earth's surface either above or below sea level. Sediment piles up in reservoirs, rivers, and harbors, destroying fish and wildlife habitat and clouding the water so that sunlight cannot reach aquatic plants. Careless farming, mining, and building activities will expose sediment materials, allowing them to wash off the land after rainfall.

Sediment yield – the total sediment outflow from a watershed or drainage basin measured for a specific period and at a defined point in a stream channel.

Technology based controls - the application of technology-based effluent limitations as required under Section 301(b) of the federal Clean Water Act. Some permit conditions require specified levels of control based on a consideration of technology and cost, regardless of the receiving water's ability to purify itself naturally. In other words, some levels of control are always presumed to be worth their cost.

Urban Recreational Arroyos – are considered either in their entirety, to be planned as corridors, or as discrete segments connecting parks and activity areas with residential development. Dedication, construction, and maintenance of park facilities will be managed by the city. No specific channel treatment is required, and some design criteria are established for adjacent development.

Warmwater fishery - a surface water of the state where the water temperature and other characteristics are suitable for the support of propagation or both of warmwater fishes.

Water quality-based controls - means effluent limitations, as provided under Section 301(b)(1)(C) of the federal Clean Water Act, which are developed and imposed on point-source dischargers in order to protect and maintain applicable water quality standards. These controls are more stringent than the technology-based effluent limitations required under the paragraphs of Section 301(b).

Appendix B
Soil Loss Calculations

Map No.	Soil Name/Misc Area		Phase	Veg. Symbols	Slope/Comp	Table 2	Table 3
22-0.1	Typic sandy-skeletal mesic	Haplustolls mixed	deep extremely gravelly coarse sandy loam calcareous	Fapa Chna2	0-15% 70%	X	X
22-0.2	Riverwash			Barren	0-15% 10%		
22-0.5	Typic sandy-skeletal	Ustifluvents mixed	very deep extremely gravelly fine sandy loams	Fapa Chna2	1-15% 10%		
279							
280							
285							
318-0.1	Typic loamy-skeletal superactive mesic	Argiustolls mixed	moderately deep Very gravelly coarse sandy loam	Jumo Bogr2	15-40% 30%	X	X
318-0.2	Typic loamy-skeletal superactive mesic	Argiustolls mixed	moderately deep Very gravelly sandy loams	Qutu2 Cemo2	15-40% 30%	X	X
318-0.3	Rock Outcrop			Barren	15-120% 30%		
318-0.5	Lithic Loamy-skeletal active mesic	Haplustalfs mixed	Very gravelly sandy clay loams	Qutu2 Cemo2	15-40% 10%		
319-0.1	Typic loamy-skeletal active mesic	Haplustalfs mixed	moderately deep Very bouldery sandy loams	Qugr3 Qutu2 Cemo2	40-80% 50%	X	X
319-0.2	Typic Loamy-skeletal superactive mesic	Argiustolls mixed	moderately deep Very gravelly sandy loams	Jumo Bogr2	40-80% 25%	X	X
319-0.3	Rock Outcrop			Barren	40-120% 15%		
319-0.5	Lithic loamy-skeletal active mesic	Haplustalfs mixed	Very gravelly sandy loams	Qugr3 Qutu2 Cemo2	40-80% 5%		
319-0.6	Lithic	Argiustolls		Jumo	40-80%		

	loamy-skeletal superactive mesic	mixed	Very gravelly sandy loams	Bogr2	5%		
320-0.1	Typic loamy-skeletal active mesic	Haplustalfs mixed	Very gravelly sandy loams	Pied Jumo Qugr3	15-40% 45%	X	X
320-0.2	Lithic loamy-skeletal semiactive mesic	Haplustepts mixed	moderately deep Very gravelly coarse sandy loam	Pied Jumo Qugr3	15-40% 30%	X	X
320-0.4	Rock Outcrop			Barren	40-120% 10%		
320-0.5	Lithic loamy-skeletal superactive mesic	Argiustolls mixed	Very gravelly sandy loams	Pied Jumo Qugr3	40-80% 10%		
320-0.6	Pachic loamy-skeletal superactive mesic	Argiustolls mixed	moderately deep Very gravelly sandy loams	Pied Jumo Qugr3	40-80% 5%		
321-0.1	Typic loamy-skeletal superactive mesic	Argiustolls mixed	deep extremely gravelly coarse sandy loam	Pied Qupa4	40-80% 45%	X	X
321-0.2	Typic loamy-skeletal superactive mesic	Argiustolls mixed	moderately deep Very gravelly sandy loams	Pied Quga	40-80% 20%	X	X
321-0.3	Rock Outcrop			Barren	40-120% 15%		
321-0.5	Lithic loamy-skeletal superactive mesic	Haplustolls mixed	Very gravelly sandy loams	Pied Qupa4	40-80% 10%		
321-0.6	Typic loamy-skeletal semiactive mesic	Haplustepts mixed	moderately deep Very gravelly sandy loams	Pied Qupa4	40-80% 10%		
323-.01	Typic sandy-skeletal frigid	Udorthents mixed	moderately deep gravelly sandy loams	Abco Psmeg Pipos Quga	15-40% 50%	X	X
323-0.2	Entic sandy-skeletal frigid	Hapludolls mixed	moderately deep gravelly sandy loams	Abco Psmeg Pipos Quga	15-40% 40%	X	X

323-0.5	Lithic Udorthents sandy-skeletal mixed frigid	Very gravelly sandy loams	Abco Psmeg Pipos Quga	40-80% 5%		
323-0.6	Rock Outcrop		Barren	40-120% 5%		
324-0.1	Typic Hapludolls loamy-skeletal mixed superactive frigid	moderately deep very gravelly coarse sandy loam	Psmeg Pipos Abco Pied	40-80% 60%	X	X
324-0.2	Rock Outcrop		Barren	40-120% 20%		
324-0.5	Pachic Hapludolls loamy-skeletal mixed superactive frigid	moderately deep cobbly sandy loams	Psmeg Pipos Abco Pied	40-80% 10%		
324-0.6	Dystric Eutrudepts loamy-skeletal mixed semiactive frigid	moderately deep gravelly coarse sandy loam	Psmeg Pipos Abco Pied	40-80% 10%		
325-0.1	Pachic Hapludolls loamy-skeletal mixed superactive frigid	deep very bouldery sandy loams	Quga Ronen	40-80% 60%	X	X
325-0.2	Rock Outcrop		Barren	40-120% 20%		
325-0.5	Typic Hapludolls loamy-skeletal mixed superactive frigid	moderately deep very cobbly sandy loams	Quga Ronen	40-80% 10%		
325-0.6	Dystric Eutrudepts loamy-skeletal mixed semiactive frigid	moderately deep very cobbly sandy loams	Quga Ronen	40-80% 10%		
326						
327-0.1	Pachic Loamy-skeletal Hapludolls superactive mixed frigid	deep extremely stony sandy loams	Abco Psmeg Potr5	40-80% 70%	X	X
327-0.2	Rock Outcrop		Barren	40-120% 20%		
327-0.5	Typic Hapludolls loamy skeletal mixed superactive frigid	deep extremely stony sandy loams	Abco Psmeg Potr5	40-80% 10%		

Table 1			Table 2		Table 3					
Map No.	Veg. Symbols (NRCS)	Slope/Comp	Gradient (%)	Length (ft)	% Surface Cover				Canopy	K factor
					RkFr	Veg.BA	Litter	Soil	OvStry (%)	(dim)
22-0.1	Fapa Chna2	0-15% 70%	5	147.63	60	5	20	15	50	0.02
279										
280										
285										
318-0.1	Jumo Bogr2	15-40% 30%	30	49.21	70	15	5	10	10	0.02
318-0.2	Qutu2 Cemo2	15-40% 30%	32	49.21	70	20	5	5	15	0.02
319-0.1	Qugr3 Qutu2 Cemo2	40-80% 50%	66	49.21	75	2	5	20	35	0.02
319-0.2	Jumo Bogr2	40-80% 25%	45	32.81	70	20	5	5	15	0.02
320-0.1	Pied Jumo Qugr3	15-40% 45%	25	65.62	60	5	25	10	35	0.15
320-0.2	Pied Jumo Qugr3	15-40% 30%	25	65.62	50	10	25	15	35	0.1
321-0.1	Pied Qupa4	40-80% 45%	50	49.21	75	2	15	10	40	0.02
321-0.2	Pied Quga	40-80% 20%	60	49.21	50	5	20	25	40	0.1
323-.01	Abco Psmeg Pipos Quga	15-40% 50%	32	49.21	40	2	50	10	60	0.1
323-0.2	Abco	15-40%	30	32.81	5	5	90	0	65	0.24

	Psmeg Pipos Quga	40%								
324-0.1	Psmeg Pipos Abco Pied	40-80% 60%	60	49.21	60	5	20	16	60	0.1
325-0.1	Quga Ronen	40-80% 60%	55	82.02	55	5	30	15	60	0.1
326										
327-0.1	Abco Psmeg Potr5	40-80% 70%	75	32.81	60	5	35	5	65	0.1

Table 1				Table 2		Table 3					
Map No.	Veg. Symbls (NRCS)	Veg Type	Slope/ Comp	Gradient (%)	Length (ft)	% Surface Cover RkFr	Veg.BA	Litter	Soil	Canopy OvStry (%)	K factor (dim)
22-0.1	Fapa Chna2	shrub shrub	0-15% 70%	5	147.63	60	5	20	15	50	0.02
279-0.1	Quga Rone	Tree	0-15% 70%	4	131.23	0	5	95	0	2	0.37
280-0.1	Quga Ronen	Tree Tree	15-40% 40%	20	131.23	10	5	80	5	80	0.37
280-0.2	Quga Ronen		15-40% 30%	20	147.64	35	5	40	20	50	0.1
285-0.1	Potr5 Quga Ronen	Tree Tree Tree	40-80% 50%	78	32.81	25	5	65	10	30	0.2
318-0.1	Jumo Bogr2	Tree graminoid	15-40% 30%	30	49.21	70	15	5	10	10	0.02
318-0.2	Qutu2 Cemo2	Tree Tree	15-40% 30%	32	49.21	70	20	5	5	15	0.02
319-0.1	Qugr3 Qutu2 Cemo2	Tree Tree	40-80% 50%	66	49.21	75	2	5	20	35	0.02
319-0.2	Jumo Bogr2	Tree graminoid	40-80% 25%	45	32.81	70	20	5	5	15	0.02
320-0.1	Pied Jumo Qugr3	Tree Tree Tree	15-40% 45%	25	65.62	60	5	25	10	35	0.15
320-0.2	Pied Jumo Qugr3	Tree tree tree	15-40% 30%	25	65.62	50	10	25	15	35	0.1
321-0.1	Pied Qupa4	tree tree	40-80% 45%	50	49.21	75	2	15	10	40	0.02
321-0.2	Pied Quga	tree tree	40-80% 20%	60	49.21	50	5	20	25	40	0.1
323-.01	Abco Psmeg Pipos Quga	tree tree tree tree	15-40% 50%	32	49.21	40	2	50	10	60	0.1
323-0.2	Abco Psmeg Pipos Quga	tree tree tree tree	15-40% 40%	30	32.81	5	5	90	0	65	0.24
324-0.1	Psmeg Pipos Abco Pied	tree tree tree tree	40-80% 60%	60	49.21	60	5	20	16	60	0.1
325-0.1	Quga Ronen	tree tree	40-80% 60%	55	82.02	55	5	30	15	60	0.1

327-0.1	Abco Psmeg Potr5	tree tree tree	40-80% 70%	75	32.81	60	5	35	5	65	0.1

LS calculated from Marsh, 1998 Landscape Planning Environmental Applications 3rd Edition
Rainfall intensity obtained from U.S. Dept. of Agriculture Soil Conservation Service, Portland, OR,1981
VM calculated from data obtained from the U.S. Soil Conservation Service, 1977

Calculated		
R Factor (dim)	VM (dim)	LS (dim)
50	0.3875	0.7
50	0.3875	0.49
50	0.3875	4.9
50	0.3875	5.1
50	0.3875	72
50	0.2625	6
50	0.2	6.2
50	0.425	23.3
50	0.2	6
50	0.3875	4.5
50	0.325	4.5
50	0.425	15.4
50	0.3875	20.4
50	0.425	6.2

327-0.1	Abco Psmeg Potr5	tree tree tree	40-80% 70%	75	32.81	60	5	35	5	65	0.1

LS calculated from Marsh, 1998 Landscape Planning Environmental Applications 3rd Edition
Rainfall intensity obtained from U.S. Dept. of Agriculture Soil Conservation Service, Portland, OR,1981
VM calculated from data obtained from the U.S. Soil Conservation Service, 1977

Calculated		
R Factor (dim)	VM (dim)	LS (dim)
50	0.3875	0.7
50	0.3875	0.49
50	0.3875	4.9
50	0.3875	5.1
50	0.3875	72
50	0.2625	6
50	0.2	6.2
50	0.425	23.3
50	0.2	6
50	0.3875	4.5
50	0.325	4.5
50	0.425	15.4
50	0.3875	20.4
50	0.425	6.2

50	0.3875	4
50	0.3875	20.4
50	0.3875	23
50	0.3875	30.9

LS calculated from Marsh, 1998 Landscape Planning Environmental Applications 3rd Edition
Rainfall intensity obtained from U.S. Dept. of Agriculture Soil Conservation Service, Portland, OR,1981
VM calculated from data obtained from the U.S. Soil Conservation Service, 1977

Map No.	K factor (dim)	R Factor (dim)	VM (dim)	LS (dim)	Soil Loss (A) (tons/acre/yr)	Acres (per map unit)	Soil Loss (tons/year)	Percentage of unit	Total Loss per Unit
22-0.1	0.02	50	0.3875	0.7	0.27125	145.2234	39.39185	0.7	27.57429
279-0.1	0.37	50	0.3875	0.49	3.5126875	22.41703	78.74402	0.7	55.12081
280-0.1	0.37	50	0.3875	4.9	35.126875	27.29029	958.6226	0.4	383.449
280-0.2	0.1	50	0.3875	5.1	9.88125	27.29029	269.6622	0.3	80.89865
285-0.1	0.2	50	0.3875	24	93	55.5524	5166.373	0.5	2583.187
318-0.1	0.02	50	0.2625	6	1.575	315.7877	497.3656	0.3	149.2097
318-0.2	0.02	50	0.2	6.2	1.24	315.7877	391.5767	0.3	117.473
319-0.1	0.02	50	0.425	23.3	9.9025	870.3655	8618.794	0.5	4309.397
319-0.2	0.02	50	0.2	6	1.2	870.3655	1044.439	0.25	261.1097
320-0.1	0.15	50	0.3875	4.5	13.078125	124.7556	1631.569	0.45	734.2062
320-0.2	0.1	50	0.325	4.5	7.3125	124.7556	912.2753	0.3	273.6826
321-0.1	0.02	50	0.425	15.4	6.545	455.1631	2979.042	0.45	1340.569
321-0.2	0.1	50	0.3875	20.4	39.525	455.1631	17990.32	0.2	3598.064
323-.01	0.1	50	0.425	6.2	13.175	86.74415	1142.854	0.5	571.4271
323-0.2	0.24	50	0.3875	4	18.6	86.74415	1613.441	0.4	645.3765
324-0.1	0.1	50	0.3875	20.4	39.525	200.7786	7935.774	0.6	4761.464
325-0.1	0.1	50	0.3875	23	44.5625	70.17504	3127.175	0.6	1876.305
327-0.1	0.1	50	0.3875	30.9	59.86875	155.9445	9336.202	0.1	933.6202
									22702.13

0-5	Tolerable according to USFS
5-10	Moderate
10-20	High
20+	Severe

Map No.	Squares	Sq.Inches	Sq. Miles	Acre
22	149	1.49	0.226913	145.2234
279	23	0.23	0.035027	22.41703
280	28	0.28	0.042641	27.29029
285	57	0.57	0.086805	55.55524
318	324	3.24	0.493421	315.7877
319	893	8.93	1.359952	870.3655
320	128	1.28	0.194932	124.7556
321	467	4.67	0.711196	455.1631
323	89	0.89	0.135538	86.74415
324	206	2.06	0.313718	200.7786
325	72	0.72	0.109649	70.17504
327	160	1.6	0.243664	155.9445
			3.953456	2530.2

Map No.	Soil Loss (A) (tons/acre/yr)	Acres (per map unit)	Soil Loss (tons/year)	Percentage of unit	Total Loss per Unit
22-0.1	0.27125	145.223	39.392	0.7	27.574
279-0.1	3.5126875	22.417	78.744	0.7	55.121
280-0.1	35.126875	27.290	958.623	0.4	383.449
280-0.2	9.88125	27.290	269.662	0.3	80.899
285-0.1	93	55.552	5166.373	0.5	2583.187
318-0.1	1.575	315.788	497.366	0.3	149.210
318-0.2	1.24	315.788	391.577	0.3	117.473
319-0.1	9.9025	870.366	8618.794	0.5	4309.397
319-0.2	1.2	870.366	1044.439	0.25	261.110
320-0.1	13.078125	124.756	1631.569	0.45	734.206
320-0.2	7.3125	124.756	912.275	0.3	273.683
321-0.1	6.545	455.163	2979.042	0.45	1340.569
321-0.2	39.525	455.163	17990.322	0.2	3598.064
323-.01	13.175	86.744	1142.854	0.5	571.427
323-0.2	18.6	86.744	1613.441	0.4	645.376
324-0.1	39.525	200.779	7935.774	0.6	4761.464
325-0.1	44.5625	70.175	3127.175	0.6	1876.305
327-0.1	59.86875	155.945	9336.202	0.1	933.620
					22702.135

0-5	Tolerable according to USFS
5-10	Moderate
10-20	High
20+	Severe
	Trail

Soil loss by Map Number according to USFS TES Survey.