DISSERTATION

A WATERSHED-BASED METHODOLOGY FOR ASSESSMENT OF

NONPOINT SOURCE POLLUTION FROM INACTIVE MINES

Submitted by

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In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

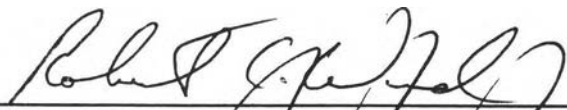Colorado State University

Fort Collins, Colorado

Fall 1995

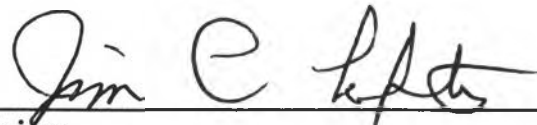COLORADO STATE UNIVERSITY

Fall 1995

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY BRIAN S. CARUSO ENTITLED A WATERSHED-BASED METHODOLOGY FOR ASSESSMENT OF NONPOINT SOURCE POLLUTION FROM INACTIVE MINES BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT

A WATERSHED-BASED METHODOLOGY FOR ASSESSMENT OF

NONPOINT SOURCE POLLUTION FROM INACTIVE MINES

A watershed-based methodology for the screening-level assessment of nonpoint source pollution from inactive and abandoned metal mines (IAMs) was developed, tested, and evaluated in this study. The methodology is intended for use by state and federal agencies responsible for management of these sites, and was designed to generate the common types of baseline site characterization information required for targeting streams and contaminant source areas for remediation. These information goals have been defined as part of this study prior to developing the assessment methodology, and are based on generalized but clearly stated IAM management goals that are most common among agencies.

The research involved the following:

(1) Identifying typical water quality and hydrologic characteristics of and assessment methods for IAMs.

(2) Defining IAM management goals and information goals for targeting.

(3) Identifying and evaluating attributes of data derived from typical synoptic surveys of IAMs.

(4) Identifying common data gaps and data collection and analysis methods to fill these gaps.

(5) Identifying and evaluating applicable assessment and data analysis methods to achieve the stated information goals.

(6) Developing, testing, and evaluating the assessment methodology.

The Cement Creek Basin, part of the Upper Animas River Basin above Silverton in the San Juan Mountains of southwestern Colorado, was used as the primary case

study to develop the recommended methodology. The study showed that the potential error and uncertainty in the data and derived information should be considered explicitly in the assessment process in order to target remediation with a known degree of confidence. Confidence intervals, therefore, should be computed for statistical estimators. Visual aids for data presentation and usage should be used and include graphs, mapping of information, and if possible, GIS. Targeting in Cement Creek and at other sites can be accomplished effectively using the recommended methodology. Some data gaps exist in Cement Creek and at most IAMs with regard to targeting remediation. These can be filled when the required information goals are not met with existing data and when resources are available using some of the methods discussed in this study. The recommended methodology is applicable to and would be very useful for other IAMs.

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My great appreciation to Dr. Jim Loftis who, as my advisor and co-researcher, provided guidance and insight into my research as well as how to maneuver through the formidable academic process. Many thanks also to Dr. Robert Ward for his keen understanding and knowledge of practical environmental management issues and related research needs and methods. Thanks also go to Dr. Jorge Ramirez and Dr. Rick Walters, who served on my graduate committee and provided extensive review of my work and useful comments and advise on the development of this document.

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1.0 INTRODUCTION

One of the primary forces behind the exploration and development of the western United States for over a century was the mining of vast lands for minerals demanded by society. The intensive mining efforts that occurred over the years left a legacy of waste and environmental problems from inactive and abandoned metal, or hardrock, mines scattered throughout the west. Mining prior to 1970 was generally conducted with little environmental cognizance or regulation. Waste rock was left exposed to the elements at the mine site, and tailings were located at the lowest convenient point, typically in or adjacent to stream channels. It is only now being realized that these mine wastes have caused and are continuing to cause significant environmental problems (USEPA, 1987a, 1991a; WGA, 1991). The problems associated with impacts to the water quality of streams and aquatic life are the most common and severe. Many of these mines contribute acidic drainage, sediment, and metals from nonpoint source (NPS) areas, such as waste rock and tailings, to receiving streams, thereby impairing the beneficial uses of the water bodies. Increasing outdoor recreation, urban sprawl, and general population growth into rural areas where many of these sites are located increase the risk of exposure of the general public to hazardous mine waste and increase public awareness of and concern over mine waste problems. The degradation of ecological systems and aquatic life in many of these mountainous locations is also a primary concern for regulatory agencies and the public.

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1.1 Problem Definition

The sites discussed as part of this research project are commonly known as inactive and abandoned mines (IAMs). The definition of an IAM varies somewhat between states, but the most common definition is a mine that operated and ceased operation prior to 1970 and for which there is no party that has a continuing reclamation responsibility (CCEM, 1993). The strict definition of IAMs includes both coal and noncoal mines, but this study only addresses noncoal (also known as metal or hard rock) mines. Most of these sites are located in the mineral belts of the western U.S.

No comprehensive national program currently exists for the management of IAMs, and no federal environmental regulations directly address the vast majority of these sites. Overall management goals for IAMs, therefore, have not been defined. Specific information goals for the assessment of these sites that are based on management goals have also not been defined. Unlike coal, there has been no national inventory of noncoal mine waste problems. Much of the existing data, therefore, are incomplete and inconsistent. Attempts to address the IAM problem are very scattered within the federal and state governments (WGA, 1991). The approaches taken by each of the agencies are not consistent, and the management and information goals of each agency are different. For example, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires federal land management agencies to perform inventories of potential hazardous waste sites on federal property, but the methods and status of the efforts vary considerably among agencies. With regard to state programs, a few states have been addressing this problem for many years while others have not even begun the

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inventorying process. One of the primary reasons for the significant differences in the status of state programs is that the inventorying costs alone can be as high as over one million dollars in states such as Idaho and Montana (WGA, 1991), and funds for most states to address the problem are not currently available.

As a result of the IAM management problems discussed above, several collaborative efforts by state and federal agencies, environmental and research organizations, ad hoc committees, and mining companies are currently underway to address some of the environmental problems associated with mine waste (CCEM, 1993). Congressional legislation in the near future could also result in a greater national effort to remediate these sites. The Western Governors' Association (WGA) Mine Waste Task Force implemented a scoping study (WGA, 1991) funded by the U.S. Environmental Protection Agency (USEPA) using existing data from 18 western states on the size and nature of the IAM problem. The study revealed that there is wide variability in the quality and quantity of information regarding these sites among the states due to inconsistencies in the inventorying and assessment process. Although the data are limited, it is apparent that there are significant environmental, health, and safety problems associated with these sites and that the estimated costs of remediation are substantial. The WGA study (1991) identified thousands of miles of streams and thousands of acres of land impacted by IAM waste throughout the U.S. There are more than 20,000 individual waste sites in Colorado alone, and it has been estimated that over 1,200 miles of streams in Colorado have been adversely impacted to varying degrees by IAM waste drainage. The types and definitions of impacts vary to a certain extent, but many of the problems are similar in nature and are caused by processes that are common in the environments in which

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most of these sites occur. Impacts to streams typically include the following:

- impairment of designated beneficial uses, such as domestic water supply, recreation, aquatic life habitat, wild and scenic river, etc.

- metals concentrations exceeding numeric water quality standards and acidic conditions

- fish kills and aquatic life degradation

- sedimentation

- wetlands, riparian vegetation, and aquatic habitat degradation

- aesthetic problems

- human health risks

Other environmental impacts typically associated with these waste sites include the following:

- upland erosion of waste material and disturbed land
- terrestrial vegetation and habitat degradation
- human safety risks

Most of these sites are located at high altitudes in mountain environments. Many of them are located in relatively isolated headwaters where the environmental conditions and water quality are largely controlled by the dominant hydrologic processes within the basin such as snowmelt. The terrain is often steep and rugged. Natural vegetation in these areas is typically composed of forest or woodland communities and provides good wildlife habitat. The areas are often aesthetically pleasing and provide recreational opportunities for many people.

The sites do vary, however, in terms of size, complexity, and geochemical and physical characteristics as well as in the severity of the impacts to the receiving streams. Some individual sites are very small and isolated and are not located near a stream or appear to have no significant impact on the water environment based on

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limited visual observations and/or data. Other individual sites are part of a historic mining district within a large watershed where there are hundreds of individual sites and problems. These basins can be very complex and could have caused such severe degradation of water quality that no aquatic life exists in receiving waters for some distance downstream from the source areas. Some sites are also located upstream of population centers, water supplies, or recreational areas. This usually adds to the complexity of the impacts.

One of the primary IAM management problems is that specific cleanup and water quality goals have generally not been defined for most of these sites. Are numeric water quality standards applicable in streams where all aquatic life is gone? Numeric goals are one thing, but realistically reaching these goals is another with limited resources and severe problems. Impairment of designated beneficial uses, especially of aquatic life habitat, is a major concern and restoration of the uses and ecological system is a very important cleanup goal. Achievement of this goal could take several decades in some severely impacted areas, or might not even be possible without an exorbitant amount of money and resources. It is also difficult in many cases to quantify the appropriate numeric goals for the water body as well as the degree of impairment of the system.

The WGA study (1991) concluded that well defined management and information goals are required for future inventories, assessment, and remediation of these sites with consistent methods and coordination among the agencies conducting the work.

1.2   Objectives

Given the large scope and complexity of the IAM problem in conjunction with

the lack of a coordinated effort and limited resources to address the problem, overall IAM management goals must first be defined before the effective assessment and remediation of the sites can be accomplished. Prioritizing or "targeting" IAMs for remediation will probably be an integral component of the effective management of these sites given limited financial and human resources to address the problem (WGA, 1991; CCEM, 1993). Information required for targeting is typically derived from limited synoptic monitoring of the sites and analysis of resulting data. In order to make the targeting and remediation of IAMs cost effective, the specific information required for targeting should be clearly defined prior to data collection and analysis and should be somewhat consistent and comparable among sites using similar data collection, analysis, and reporting methods (WGA, 1991; CCEM, 1993). An effective, practical, and consistent quantitative methodology to perform screening-level assessment of these sites to provide the specific information required for targeting is therefore warranted.

The primary objective of this study is to develop a standardized watershed-based methodology for screening-level assessment of NPS pollution from IAMs for targeting remediation. Several specific objectives and tasks have been identified that are required to meet this overall objective:

1.   Identify typical water quality and hydrologic characteristics of and assessment methods for IAMs.

2.   Define IAM management goals and information goals for targeting.

3.   Identify and evaluate attributes of data derived from typical synoptic surveys of IAMs.

4.   Define and evaluate applicable data analysis methods to achieve the stated information goals.

5. Identify data gaps and data collection and analysis methods to fill these gaps (proposed future monitoring system designs).

6. Develop, test, and evaluate the methodology.

The term "methodology" is defined for the purposes of this study as the integration of multiple, specific methods and steps into a logical and useful procedure or protocol that is being developed as part of this study. It does not refer to the methodology used for this study itself.

1.3 Scope

The recommended methodology will be developed based on the following limitations:

1. This study will develop a methodology for screening-level assessment to derive information for targeting. Targeting is generally performed after the inventorying phase but prior to the remediation phase.

2. This study will focus on loadings and concentrations of metals in surface water (runoff and streams) in typical IAM watersheds.

3. Specific assessment methods for groundwater and lakes will not be considered.

4. Methodologies for detailed, process-oriented (physical and chemical) studies will not be presented.

5. Although elements of existing quantitative methods will be used and integrated to develop a methodology, no specific new quantitative methods will be developed.

Chapter 2 of this document presents a discussion of common water quality and hydrologic characteristics of and environmental problems at typical IAMs. Chapter 3 is a discussion of past and present IAM and related monitoring and assessment methods as presented in the literature including federal regulations requiring assessment and federal agency methods, state agency methods, and other assessment methods discussed in the open literature. Chapter 4 presents generalized IAM

management goals and associated information goals, as defined by potential targeting criteria and detailed discussions with key agency personnel. To a certain extent, the information goals are dictated by the available assessment techniques. Chapter 5 presents an evaluation of common attributes of data derived from typical IAMs that might impact data analysis methods and interpretation. Dissolved zinc data from the Cement Creek Basin above Silverton in the San Juan Mountains of southwestern Colorado are used extensively to evaluate attributes. Data collection and management methods that are useful for subsequent data analysis are also discussed in this chapter. Chapter 6 is a discussion of common data analysis methods, as well as information presentation and targeting methods, that might be applicable to and useful for assessment of most IAMs. The methods also are applied, tested, and evaluated in this chapter using the Cement Creek data. The methods will be considered useful if the defined information goals can be reached and if targeting critical areas in the Cement Creek basin can be accomplished in an effective manner. Chapter 7 presents a discussion of important data gaps encountered in the assessment of Cement Creek and for most assessments of IAMs that might require additional assessment activities to fill in the gaps. Typical methods that can be used to fill in these data gaps are also discussed in this chapter. In Chapter 8, the useful methods discussed in Chapter 6 are combined and integrated into a recommended, comprehensive methodology for the screening-level assessment of NPS pollution from IAMs for targeting critical areas. The methodology is also qualitatively tested and evaluated in this chapter using the general site characteristics of and data sets derived from several other IAM watersheds. Chapter 9 is a summary and discussion of conclusions that can be drawn from this study.

2.0 CHARACTERISTICS OF INACTIVE AND ABANDONED MINES

This chapter discusses the history and physical, chemical, ecological, and waste characteristics that are common to many IAMs in the western U.S.

2.1 Location, History, and General Site Characteristics

The exploration and development of the western U.S. was largely influenced by more than a century of mining of vast lands for metallic ores required by an evolving industrialized society. Mineral belts extend across many areas of the western U.S. including most of the 17 western states. The states with the most extensive mineral belts and metal mined areas are Colorado, Idaho, Montana, and California (Martin and Mills, 1976). The Colorado mineral belt, for example, extends from near Durango in the San Juan Mountains in the southwestern part of the state to near Boulder in the Front Range (Moran and Wentz, 1974). Figure 2.1 shows the locations of general problem areas across the U.S. (as defined by USEPA) and the extent of the mineral belt through Colorado.

Major production metals are classified into five groups: base, ferrous, precious, rare, and radioactive (Martin and Mills, 1976). Base metals include copper, lead, and zinc. Ferrous metals include iron, and gold and silver comprise the precious metals. Rare metals include molybdenum, tungsten, and tin. "Complex ore" is typical in Colorado that usually includes base metals and precious metals (Moran and Wentz, 1974). The base metals and silver typically occur as sulfides (and sometimes oxides). Gold and silver tellurides compose a second type of ore found in Colorado.

WA MT ND MN ME
OR VT NH MA
ID WY SD NY RI
NV UT CO NB IA WI MI PA CT NJ
KS IL IN OH MD DE
CA AZ NM MO WV VA
OK KY NC
TX AR TN SC
MS AL GA
LA

HI AK

Water Pollution Problem Areas
as Identified by USEPA (1976)

0   500   1,000 Miles

Uinta Mts.

COLORADO

Park Range

Front Range

Gore Range

White River
Uplift

Explanation

**Maximum Boundary of
Colorado Mineral Belt
(modified after Tweto
and Sims, 1963)**

Elk
Mts.

Sawatch Range

Mosquito Range

Front Range

West Elk
Mts.

Wet Mts.

Sangre De Cristo Range

San Juan Mountains

0   50   100 Miles

Figure 2.1.   General locations of IAM districts in the U.S.
and of the Colorado mineral belt

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A third type of ore is molybdenum ore that usually also contains tin and tungsten. Radioactive elements occur primarily in uranium and vanadium ores (Martin and Mills, 1976).

Production (mining) methods include both surface and underground mining (USEPA, 1975). Surface mining methods include both placer and open cut. Underground mining methods include open or supported stopes, caving, flat seam, and solution mining. Low-grade (non-economic) waste rock from the mining process is called "gangue." Mineral processing (milling or beneficiation) is performed after the production (usually in the same vicinity within 10 or 20 miles of the mine) and includes sizing, sorting, concentrating, and metallurgical processing. Flotation was by far the most common method for concentrating metals. All solid and liquid waste materials from metal processing were typically disposed in tailings ponds (Martin and Mills, 1976).

Little environmental cognizance or regulation existed during most of the exploration and mining of these metals (WGA, 1991). Waste rock was usually left in place adjacent to the mine. Tailings were typically deposited at the lowest convenient location near or in alluvial stream valleys. Adits and shafts were left open and exposed to the public, also exposing the natural and mined metal ores to further oxidation and allowing continued discharge of acid and metals drainage. The topography of the mined area was altered, vegetation removed, and adjacent land disturbed by milling operations, access and haul roads, staging areas, and other ancillary activities that allowed significant erosion and sedimentation. Until the 1970's, no attempts were made to reclaim these mined lands or disturbed areas, and only then reclamation was performed primarily for coal-mined lands and only

because of the requirements of the Surface Mine Control and Reclamation Act (SMCRA) enacted in 1977. The active metal mine operations were exempt from all reclamation requirements, and abandoned or inactive metal mines had no environmental responsibilities (WGA, 1991). With regard to current environmental problems at IAMs, three sources of water pollution are generally recognized: acid mine drainage (AMD), metals drainage, and sediment (Martin and Mills, 1976).

2.2   Solid Waste Characteristics

Solid waste from metal mining operations includes primarily tailings and waste rock (USEPA, 1975). Tailings may be defined generally as solid material disposed of from the milling or processing of metal ores. After the milling process, tailings generally still have high concentrations of minerals. Tailings also have particles with increased surface areas due to crushing and are completely exposed to air. All of these factors result in a significant potential source of metals pollution to nearby water bodies, especially since tailings are typically located near or in stream channels. It also means that the metals may potentially be recovered economically from tailings, even though they were not considered economically recoverable at the time of processing.

Waste rock is typically defined as any solid material removed from a mine in order to access the ore body. Because of its heterogenous nature, most waste rock is non-economic and its use is generally restricted to crude fill material. However, the waste rock is also typically composed of some metal ores that may not have been economically feasible to recover at the time of operation. Therefore, the potential for dissolution and leaching of metals from waste rock is significant. Waste rock generally exists at all IAMs that were explored but never developed, as well as at

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sites that were actually mined (Martin and Mills, 1976).

2.3   Liquid Waste Characteristics

Liquid waste generated by past mining activities that is still a problem today includes AMD and metals drainage (Martin and Mills, 1976). This drainage emanates from both adits/shafts and leaching of solid waste materials. AMD is the result of acid generation from the oxidation of natural pyritic material in mineral belts that is exposed to air and water (Wentz, 1974). This exposure and the generation of AMD is accelerated by mining operations. The acid itself is harmful to aquatic biota and can preclude designated uses of the water. The acidic water also causes and accelerates the dissolution of metals from the ores, tailings, and waste rock. These metals are leached from the material and transported to surface waters where they can be present in concentrations that are toxic to aquatic life and humans and that preclude designated uses.

The overall pyrite (FeS_2) oxidation process is as follows (Wentz, 1974):

$$FeS_{2(s)} + 15/4 O_2 + 7/2 H_2O = Fe(OH)_{3(s)} + 2SO_4^{-2} + 4H^{+1} \qquad (2.1)$$
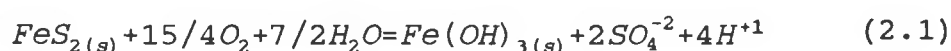
This reaction is not the only oxidation process but it is the dominant process and most important for metal mining sites. Ferrous (Fe^{+2}) ions are released and oxidized to the ferric (Fe^{+3}) ions as the rate-limiting step. The bacterium Thiobacillus ferroxidans catalyzes the reaction and increases the rate of oxidation by five to six orders of magnitude (Stumm and Morgan, 1981). The ferric ions hydrolyze forming relatively insoluble ferric hydroxide [$Fe(OH)_3$] precipitate. Sulfate (SO_4^{-2}) ions and acidity are also produced in the reaction. The acidity causes the leaching and mobilization of metals from the rock material, and results in the predominance of

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metals such as zinc in the dissolved, or bioavailable, form for water transport and uptake by biota. Other metal ions may adsorb onto or coprecipitate with the ferric hydroxide. This forms a metal-rich orange coating (known as yellow boy) on rocks in impacted streams. Other metal sulfides, such as sphalerite (ZnS) and galena (PbS), will also be oxidized in the process. These reactions also result in the dissolution of additional metals to the water, but do not result in the formation of additional net acidity (Wentz, 1974).

2.4   Hydrology

The hydrology of IAM watersheds is the driving force behind transport of contaminants from source areas (solid and liquid) to receiving water bodies. Although the hydrologic characteristics of each IAM are somewhat site-specific, some similarities do exist among many of the sites. Most of these mining sites are located at high altitudes in mountain environments, and many of them are located in relatively isolated headwaters where the environmental conditions and water quality are largely controlled by the hydrologic processes within the basin.

Baseflow generally contributes contaminants from point sources such as draining adits and shafts. A point source can be considered as any source of contaminants that is very limited in areal extent and is not diffuse in nature. Concentrations of metals are usually highest during baseflow conditions when dilution is minimal (although the total loading, which is the product of concentration and flow, may be at a minimum) (Martin and Mills, 1976). Although baseflow conditions may be somewhat constant and predictable, the overall hydrology of these sites can be extremely variable in time and space. Snow accumulation and melt in the late spring generally results in significant seasonality in surface flows and contaminant transport

to receiving waters. Figure 2.2 is a typical average annual hydrograph from a stream in the Clear Creek Basin in Colorado where extensive mineral mining has occurred (CDM, 1990). Because of the nonpoint source nature of many of the solid waste materials and disturbed areas, storm runoff events also contribute large loadings of metals to receiving waters during these events. Both snowmelt and storm runoff cause significant leaching of acids and dissolved metals and erosion (with adsorbed metals) from solid wastes and transport to receiving waters. Loadings of metals are generally highest during snowmelt and storm runoff events. However, metals concentrations are typically lowest during these periods due to dilution (Martin and Mills, 1976). Although the seasonality of snowmelt runoff can be generally described, the temporal variability of storm event runoff is more difficult to evaluate. The spatial variability of snowmelt and storm runoff is also difficult to describe because of variable snow accumulation and melt for different years, and variable storm patterns and contributing areas for different years and different storm events.

2.5   Erosion and Sedimentation

Erosion and sediment transport from solid wastes and disturbed areas (such as access roads or devegetated areas) is a major cause of water pollution at many IAM sites (Martin and Mills, 1976). The sediment may be a problem in itself by causing aquatic habitat degradation, but high adsorbed metals concentrations and loadings are the major problem. These loadings of metals adsorbed to sediment may represent the primary mechanism of metals loadings to receiving waters at some sites. Although these adsorbed metals concentrations are not directly harmful to most aquatic life (except bottom-dwelling macroinvertebrates), they are not as transient in nature as dissolved metals and may persist in the aquatic environment

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CLEAR CREEK NEAR LAWSON
USGS GAGING STATION 06716500

AVERAGE FOR PERIOD OF RECORD 1946-1986
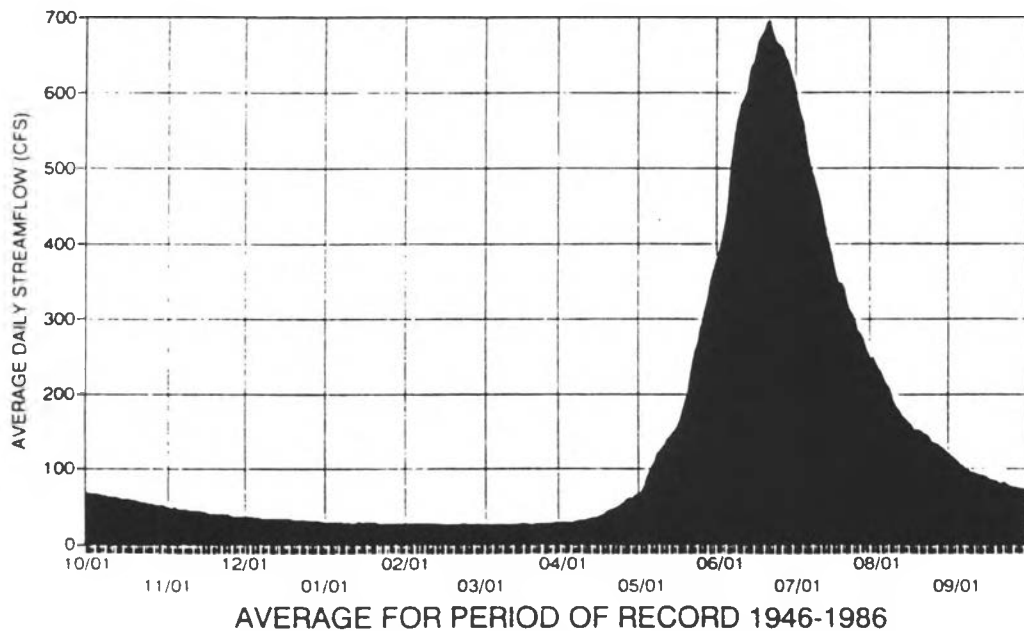
CLEAR CREEK AT GOLDEN
USGS GAGING STATION 06719505

AVERAGE FOR PERIOD OF RECORD 1976-1989
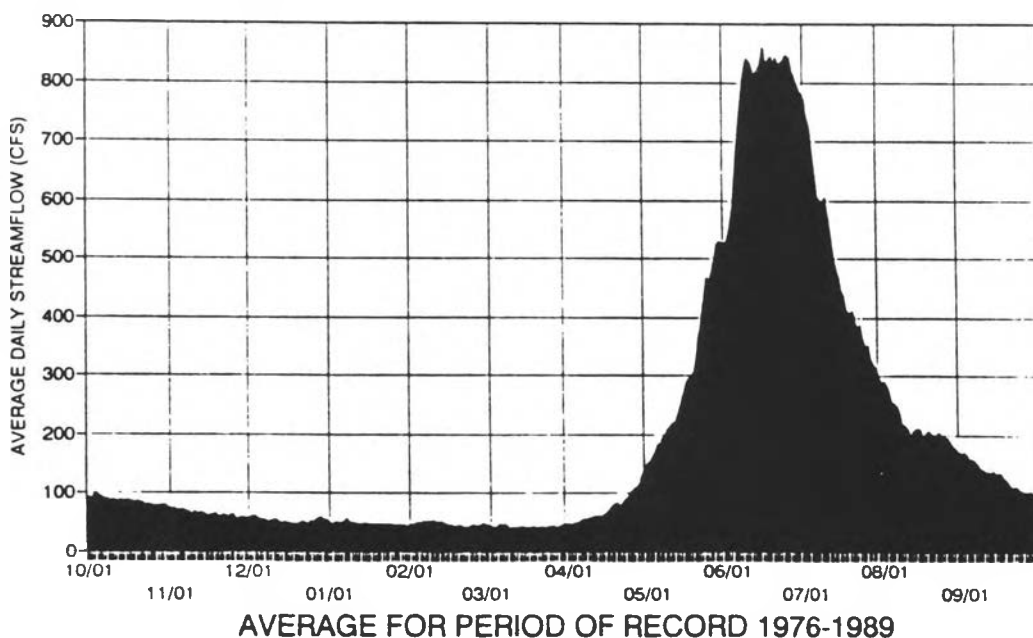
Figure 2.2. Typical annual hydrograph for IAM watershed
(from CDM, 1990)

for a longer time due to sediment deposition. The metals may be released to the water column over time causing chronic impacts to water quality and aquatic life. Sediment with adsorbed metals deposited on the bottom of stream channels or impoundments may also be resuspended and transported downstream during subsequent high flow events (USEPA, 1975).

Erosion and sediment transport at a particular site is dependent on the physical characteristics of the site such as weather, construction method, slope, material characteristics, and particle size distribution (Martin and Mills, 1976). Particle sizes of mine waste materials vary from large boulders to fine clays. Waste rock is particularly variable in size, while tailings particles are generally fine and have a high erosion and transport potential. The location of tailings particles in alluvial streams also increases the potential for erosion and transport of these particles. Six basic types of erosion are generally recognized in watersheds as follows (ASCE, 1985):

1.   sheet and rill erosion
2.   degradation of minor drainageways
3.   gully erosion
4.   floodplain scour
5.   stream bed degradation
6.   stream bank scour

Sediment transport from upland erosion due to overland flow is defined as wash load. Sediment transport in streams may be categorized as suspended sediment or load and bed load. Suspended sediment is composed of finer particles (clays and silts smaller that approximately 0.65 microns in diameter) that are transported with flow and are relatively insensitive to flow parameters. Bed load is composed of coarser particles (sands, cobbles, etc. greater than approximately 0.65 microns in diameter) that are transported dependent on the energy of the flowing water and that

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roll along the bed (ASCE, 1985).

2.6   Receiving Water Quality Impacts

This section discusses typical receiving water quality impacts from IAMs.

2.6.1   Streams and General Water Quality

Impacts to receiving water quality can vary significantly depending on the loadings to the receiving water and the physical and chemical characteristics of the water (Martin and Mills, 1976). The alkalinity and buffering capacity of the water is very important in determining impacts from AMD. Alkalinity is the ability of water to neutralize acid. In natural surface waters, bicarbonate and carbonate are the principal sources of alkalinity. These anions are believed to be released into surface waters through the dissolution of minerals such as limestone and feldspar (Stumm and Morgan, 1981). Carbon dioxide from the atmosphere readily dissolves in water forming carbonic acid. The degree of carbonation along with the reaction with calcareous materials determines the basic buffering system of natural waters. If the acidity added to the system from AMD is greater than the buffering capacity, the pH of the water will decrease to a lower equilibrium value. Downstream in a particular water body, the low pH water will join other inflowing buffered (unimpacted) water resulting in the eventual restoration of neutral conditions. Therefore the length of the stream with a low pH is a function of the following (Martin and Mills, 1976):

1.   AMD reaching the stream
2.   buffering capacity of upstream water
3.   buffering capacity of downstream water entering the stream

Sulfate and/or iron concentrations are sometimes used as indicators of acidity potential of water, although the relationships are typically non-linear (Martin and

Mills, 1976; CDM, 1990).

The chemistry of metals in natural waters and in waters impacted from mine drainage is complex. Reduction of dissolved metals concentrations in surface waters can result from dilution, precipitation, adsorption, uptake by biota, and loss to groundwater. Metals can exist in solution as ionic species or organic and inorganic complexes. Metal cations in water exist in a hydrated state forming aquo complexes (Stumm and Morgan, 1981). The pH of the solution, the concentration of the specific cation and other metal species present, and the redox potential all determine the exact form of the complex. Organic and inorganic metal complexes may or may not be in an ionic form. Metal ions may also complex with ligands to form complex molecules. Wentz (1974) states that metals can be:

1.   adsorbed onto solids including colloids

2.   contained in coatings on sediment grains (precipitates and coprecipitates)

3.   taken up by biota

4.   incorporated in crystalline structures and complexed with organics not in
         solution (chelation)

The effects of these phenomena on metal mobility is unclear. It is believed that the most mobile fraction of the total metal load in streams is the dissolved fraction. The dissolved fraction is dependent on the oxidation-reduction potential (E_h) and pH of the water (Moran and Wentz, 1974).

Jenne (1968) states that the sorption of metals in water is a function of the following factors:

1.   concentration of the metal in question
2.   concentrations of other metals in solution
3.   pH
4.   quantity and strength of organic chelates and complex ion form present

5.   amount and type of organic matter
6.   amount and type of clay
7.   carbonates
8.   precipitation as oxides and hydroxides

2.6.2   Impairment of Beneficial Uses

This section describes typical types of impairment of beneficial uses of receiving waters.

2.6.2.1   Aquatic Life Impacts

The metals associated with mine drainage are naturally occurring in water at low concentrations. In mining districts, many of these metals occur naturally as ores with high concentrations and may therefore occur at higher, even toxic, concentrations in water naturally. Most trace metals are essential to life in small amounts. Others, such as arsenic and cadmium, have no known biological function. All trace metals can be toxic at high enough concentrations, but the "toxicity" of a metal is actually a relative term. The toxic effects of a metal may range from slight discomfort to death. Toxic effects may also be chronic (long-term) or acute (short-term), and most aquatic life standards are categorized as such. Most metals that compose a mixture in an effluent or a stream will exhibit either antagonistic or synergistic toxic effects. Toxic effects also vary considerably between species and during different stages of the life cycle for a given specie (Martin and Mills, 1976).

The toxic effects of metals to aquatic life can vary from decreased species diversity to complete sterility in a particular stream segment. Sediment and precipitates can impact aquatic life in addition to high metals concentrations and low pH. Benthic macroinvertebrates are relatively immobile and, consequently, cannot quickly avoid environmental stresses and adverse impacts to their immediate

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environment. Changes in macroinvertebrate community structure, therefore, tend to reflect long-term changes in the environment. The effects of metals on fish depend on the species, size, age, and physiological condition of the individual fish. Some fish can adapt to changing or somewhat toxic conditions while others cannot. An individual fish may not be affected by metals while the population of fishes may be impacted because of effects on the food base. Hardness is generally believed to be antagonistic to the toxicity of most metals to fish because dissolved metals can form complex compounds with carbonate (Martin and Mills, 1976). Standards for dissolved metals are often developed based on associated hardness values. However, alkalinity is also antagonistic to the toxicity of metals for the same reason and may be more important than hardness in reducing the toxicity of metals (Davies, Colorado Division of Wildlife, personal communication, 1993). The characteristics and toxic effects of specific metals of concern from mining activities may be found in Martin and Mills (1976) and Ridolfi (1991) as well as other references.

2.6.2.2   Municipal, Agricultural, and Industrial Use Impacts

High concentrations of metals in surface waters may impair municipal, agricultural, and industrial uses. Wildlife and domestic grazing animals typically drink from surface water and may ingest toxic levels of metals in both dissolved and suspended form. Irrigation of crops may also use contaminated surface water that may result in toxic levels of metals in sensitive plant species. This could inhibit plant growth and cause local economic problems in certain agricultural areas affected by IAMs. These crops are also intended for animal and/or human consumption. Municipal potable and industrial water supplies derived from contaminated surface waters may not have metals removed to an acceptable degree with standard

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treatment methods. Therefore, metals are either passed through the system to the consumer or the industrial process or more complex and expensive treatment technologies must be incorporated into the system to remove the metals to acceptable levels.

2.6.2.3 Recreational Use Impacts

Many IAMs are located in areas that are heavily used by people for recreational purposes including fishing, swimming, boating, hiking, camping, hunting, off road vehicle use, etc. Some of these recreational uses of water are impaired directly by metals pollution and general water quality degradation. Fishing, swimming, and boating are examples of these uses that may be prohibited in impacted surface waters. Other non-water recreational uses, such as hiking and camping, may not necessarily be prohibited but may be impaired due to dangerous conditions (open shafts and adits) and degraded aesthetics. People may seek more pristine areas for these types of activities. There are related socioeconomic impacts to local communities due to these recreational use impairments. Conversely, some historic mining districts attract many visitors (especially off road vehicle users) primarily due to the attraction of the historic abandoned mining sites. The Upper Animas River Basin and the Silverton area in Colorado is a prime example of this type of attraction.

2.7 Aesthetic Impacts

Related to the recreational use impacts because many IAMs are located in areas that are mountainous and scenic, impacts to the aesthetics of an area may be significant. Although historic structures such as mine shafts, mills, and cabins are not necessarily problematic, large tailings ponds, waste rock, eroded and devegetated

areas, precipitates in streams, and streams devoid of natural aquatic life may pose severe aesthetic problems at some sites. This is especially true in large mining districts were there may be hundreds of such problems within a relatively small area. The problem is even more noticeable in the many scenic natural areas where mining has typically occurred. Again, these aesthetic problems may also have adverse socioeconomic impacts to an area or community where tourism is the major economic component, such as in the Upper Animas River Basin.

2.8   Socioeconomic and Other Impacts

Impairments to designated beneficial uses of water and other impairments have socioeconomic and other impacts to an area or community that has IAMs in the vicinity. If municipal or agricultural uses are impaired, some types of economic development, such as urban growth, may be precluded without expensive water treatment systems. Impairment of aquatic life may inhibit fishing and associated recreational uses that typically may be the primary source of income in a given area. Impairment of recreational uses and aesthetics may also have adverse effects on tourism and the economic well-being of an area with multiple IAMs and severe environmental impacts.

3.0 EXISTING ASSESSMENT METHODS FOR INACTIVE AND ABANDONED MINES

A wide variety of IAM and related monitoring and assessment efforts have been undertaken or proposed by a number of federal and state agencies under the auspices of several management goals and regulatory drivers. These efforts have had some elements in common but generally vary considerably in their purpose and scope. Others have also performed studies or proposed methods related to IAM monitoring and assessment.

3.1 Federal Regulations Requiring Assessment

CERCLA (or Superfund) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, is currently addressing 51 IAMs that are listed on the National Priorities List (NPL), which includes over 1,200 hazardous waste sites. CERCLA also requires all federal land management agencies to inventory potential hazardous waste sites (including IAMs) within their jurisdiction to include in the computerized Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) (Walline, USEPA, personal communication, 1993; USEPA, 1991b). Preliminary Assessments (PAs) are required for all of these sites (USEPA, 1991b). However, no actual field samples are generally collected or analyzed for this first phase of the CERCLA process. This phase is usually based entirely on the use of preexisting field data in conjunction with site reconnaissance. If the PA indicates potentially severe problems at a site, a Site

Inspection (SI) must be performed (USEPA, 1992a). This screening phase usually includes the collection of a minimal number of waste and environmental samples. Historically, about three out of five sites that undergo a PA require an SI. Based on the results of the SI, the site is ranked with respect to its potential human health and environmental hazards according to the CERCLA Hazard Ranking System (HRS). If the site scores high enough using the HRS (28.5 or greater), it is eligible to be placed on the NPL. Historically, only about one out of 20 sites that undergo a PA warrant placement on the NPL. Most of the NPL mining sites are relatively complex or large, are currently causing severe impacts to the environment, and/or are located upstream of or near population centers or water supplies. The Clear Creek/Central City (CDM, 1990), Eagle Mine (Engineering-Science, 1985), and California Gulch (USEPA, 1987b) sites in Colorado, and the Silver Bow Creek/Butte Area and Anaconda Smelter sites (Brown et al., 1991) in Montana are prime examples of Superfund IAMs. As part of the CERCLA process, these sites undergo a complete and comprehensive remedial investigation (RI) and feasibility study (FS) prior to remediation (USEPA, 1988a). A risk assessment is also required and is an integral component of the RI/FS and remediation process. Typically resources (time and money) are not limited when assessing these sites under CERCLA, and the process usually takes at least several years prior to the implementation of remedial actions due to the complex nature of the sites and the CERCLA process. However, most IAMs under CERCLA have a lower priority for remediation relative to other types of hazardous waste sites (such as many industrial sites). In addition, CERCLA has been identified as one of the primary obstacles to remediating non-Superfund IAMs because of potential future liability concerns (WGA, 1991). Monitoring and data

analysis methods for Superfund remedial investigations and risk assessments are not prescribed in detail, but general approaches are recommended (USEPA, 1988a, 1988b). Methods used to assess surface waters at CERCLA mining sites typically involve the following:

- fairly extensive (spatially intensive) synoptic-type flow and water quality (chemical, biological, and sediment) monitoring during important flow regimes (low flow, high flow, and/or storm events) over one, two, or more years

- sampling of waste materials to determine concentrations of contaminants in potential source areas, and estimation of volumes or areas of waste material

- minimal summary statistical analysis of field data including determining frequencies of contaminant concentrations exceeding analytical detection limits or Applicable or Relevant and Appropriate Requirements (ARARs) to determine exposure concentrations for the risk assessment

- mass balances of contaminant loadings and plots of loadings and concentrations from field data versus distance in major streams to evaluate potential source areas and loss areas

Some type of modeling is also usually employed at these sites in conjunction with monitoring data to aid in the estimation of loadings to and/or concentrations in receiving waters. This may include fairly simple empirical or analytical techniques, such as using the Universal Soil Loss Equation (USLE) for sediment and adsorbed metals loadings (CDM, 1990; USEPA, 1988b), but usually includes relatively comprehensive, complex, data intensive, and costly deterministic hydrologic and geochemical modeling (CDM, 1990; Brown et al., 1991).

The Resource Conservation and Recovery Act (RCRA) of 1976 addresses a few active mining sites and facilities that generate, store, or treat hazardous waste (WGA, 1991). As such, RCRA may only address some IAM waste that might be directly associated with active mine sites. There are very few of these types of sites.

SMCRA generally addresses only coal mines. Inactive coal mine reclamation is the focus of an aggressive Abandoned Mine Land (AML) program as part of SMCRA (WGA, 1991). Some noncoal IAM problems can be addressed with AML funds, but only in coal-producing states and most of these reclamation efforts are geared towards public safety problems and hazards as in the case of Wyoming (WGA, 1991).

The Uranium Mill Tailings Reclamation and Control Act (UMTRCA) only addresses remediation of inactive uranium mill tailings sites (WGA, 1991). Therefore, UMTRCA may only address some IAMs that might be directly associated with UMTRCA sites. Very few IAMs contain this type of waste.

The Clean Water Act (CWA) of 1972 and as amended by the Water Quality Act of 1987 provides for a demonstration grant program for controlling NPS pollution (Section 319) that may address some IAMs (WGA, 1991). For example, the Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division is currently implementing an NPS pollution control demonstration project in the Upper Animas River Basin in southwestern Colorado (CDPHE, 1992a, 1993a). The project is in the initial stages of assessment of the sources and quantities of metals loadings to specific stream segments. However, appropriations from Congress for such demonstration programs have been much less than authorizations to date. Therefore, states have not been able to fund many of the proposed projects.

The new stormwater regulations under the CWA are anticipated to eventually address many, if not the majority, of IAMs (Berry, USEPA, personal communication, 1993; WGA, 1991). However, these regulations are still evolving and have not been

implemented at IAMs to date. Although water quality standards are not imposed by the regulations, the intent of the regulations is to regulate or permit discharges from all storm-generated runoff (including snowmelt runoff) from point sources (not NPSs) and to control or remediate any and all potential sources of contamination to receiving waters. Theoretically, this could apply to most IAMs. Depending on the exact definition of point sources versus NPSs and the reference location, however, point sources are sometimes indistinguishable from NPSs. It is not clear, therefore, exactly what will be regulated at IAMs. The regulations will not necessarily apply to groundwater or baseflow pollution problems, or existing environmental damage in the basin or receiving waters. In addition, the large majority of the sites will require only general permits where no monitoring is actually required. Stormwater management plans must be submitted by the IAM responsible party that must be approved by the regulating agency. These plans must identify potential sources of contamination and good-faith measures to remediate these problems. The regulating agency has the authority to inspect the sites to ensure that the management plan is correct and that these measures are being implemented. However, state agencies and USEPA do not currently have the resources to perform this task for the large majority of sites. With no monitoring required or inspections performed at most IAM sites, it is very unlikely that any remediation will actually be implemented. The other major problem with the application of the new stormwater regulations to IAM sites is the complex question of land ownership of and responsibilities for sites. Because most of these sites are abandoned with complex ownership histories and little documentation, the responsibility for compliance is very unclear and the resources required to investigate ownership and take legal action for compliance

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would be significant.

For sites that will require group or individual permits, storm water monitoring will be required as part of the application process and on an annual basis thereafter. The methods are prescribed in USEPA (1992b) and include the following for industrial (mining) sites:

- Monitor at least one representative storm event that occurs during normal operating procedures.
    - depth of storm must be greater than 0.1 inch accumulation
    - storm must be preceded by at least 72 hours of dry weather
    - depth of rain and duration of event should preferably not vary by more than 50% from the average depth and duration

- Grab samples must be collected during the first 30 minutes of discharge.

- Flow-weighted composite samples must be collected during the first three hours of discharge (or the entire discharge, if it is less than three hours).

- Monitoring must be performed at all point sources (outfalls). However, if several outfalls have "substantially identical effluents", only one of the identical outfalls must be monitored.

- Manual or automatic sampling may be employed.

- Flowrate during the sampling must be monitored, and total flow volume during the event must be estimated, but a variety of methods may be used. Rainfall amount and intensity must also be measured.

- Analytes are prescribed by the USEPA guidance document.

- Decontamination and sample handling, preservation, documentation, identification, labeling, packaging, shipping, and chain-of-custody procedures are prescribed.

Water quality standards for receiving waters are typically developed by the states based on federal (USEPA) criteria and guidance (USEPA, 1983; CDH, 1991a). These standards are either narrative or numeric for protection of designated beneficial uses for specific stream segments. Delineation of stream segments is usually based on similar physical and water quality characteristics and uses within

receiving waters in a specific watershed or subbasin (USEPA, 1983). Designated beneficial use classifications are determined based on historical and current uses, and in many cases a use attainability analysis involving a water body survey and assessment. The purpose of a use attainability analysis is to determine if an aquatic life protection use is attainable for a given water body by examining the physical, chemical, and biological factors that may allow or preclude that use (USEPA, 1983). For aquatic life uses, chronic and acute standards are usually derived (this is discussed further below). The CWA also has an antidegradation policy that generally prohibits the degradation of water quality for a particular use or the downgrading of a use classification except under special specific circumstances (USEPA, 1983, 1991c).

Water quality-based effluent limitations (WQBELs) and total maximum daily loads (TMDLs) have been applied to the permitting and regulation of point source discharges to surface waters for several years as part of the waste load allocation (WLA) process, and more recently have been applied to the control of toxic substances (USEPA, 1991c; CDH, 1991b). They are typically applied to water quality-limited segments of water bodies for which technology-based effluent limitations (TBELs) of point discharges are not adequate to attain the designated beneficial uses of the receiving water. The TMDL/WLA process usually involves the application of mathematical models to predict the concentrations of contaminants in receiving waters based on known or future loadings. These concentrations are compared to standards to determine maximum acceptable concentrations to maintain the designated use and then corresponding acceptable loadings are allocated to the point discharges (Ambrose et al., 1988). A mass-balance dilution equation forms the basis for most computations using low-flow minimum dilution chronic and acute

criteria. These design flow criteria are typically known as 30-E-3 flow for chronic standards (empirically based average 30-day low flow with an average 1 in 3 year recurrence interval) and 1-E-3 flow for acute standards (empirically based 1-day low flow with an average 1 in 3 year recurrence interval). This biologically based method uses a 3-year recurrence interval because it is believed that this period provides adequate time for aquatic life to recover between concentration excursion events (CDH, 1992b). Seasonal TMDLs/WLAs may also be computed and used if significant seasonality in flows or effluents can be demonstrated. The modeling may involve either steady-state or dynamic modeling (USEPA, 1991c; Limno-Tech, 1985). Steady state modeling (1) does not consider the frequency and duration of concentrations above water quality standards, (2) does not include instream processes, and (3) only considers a single environmental condition for a single discharge at a single design specification. Alternatively, dynamic modeling explicitly considers the frequency and duration of exposure by considering variable flows and/or variable effluent loadings/concentrations and deriving a probability (frequency) distribution of instream concentrations. Kinetic interactions are also considered and are generally assumed to be first order losses. Three alternative procedures included in dynamic modeling are (1) continuous simulation, (2) Monte Carlo simulation, and (3) lognormal analysis (USEPA, 1991c; Limno-Tech, 1985). The continuous simulation methodology is generally more complex and data intensive than the other two methods.

The TMDL/WLA methodology has also been proposed by environmental groups, USEPA Region X, and others for controlling NPS pollution and has recently been used for several of these situations (USEPA, 1991c; Griffen et al., 1991) (WLAs are

known as load allocations [LAs] for NPS applications). However, its usefulness and appropriateness for NPS loadings is under debate. The first application of TMDLs for NPS pollution control was for the Tualatin River in Oregon (Griffen et al., 1991). More recently, it was used for the South Fork Salmon River in Idaho, and is currently being used for the Coeur d'Alene River Basin in Idaho, a large basin with multiple IAM sites and metals loadings and pollution problems (Mink and Murrey, 1992). Most of these NPS TMDL applications involve a fairly large and heavily used receiving water body. For the Coeur d'Alene River Basin, best management practice (BMP) projects are allocated using the TMDL approach to reduce loadings to Coeur d'Alene Lake, instead of effluent loads from treatment facilities being allocated as is done for point source pollution situations (Harvey, IDEQ, personal communication, 1993). The debate surrounding TMDLs focuses on the appropriateness of using daily load appropriations for NPS pollution that is typically generated as a result of intermittent, highly variable storm runoff or seasonal snowmelt runoff events. Variations of the TMDL approach to account for these significant differences have therefore been proposed for NPS pollution regulation (Griffen et al., 1991). In general, however, non-regulatory and voluntary control of NPS pollution has been preferred over regulatory control programs (CDH, 1991b; Foran et al., 1991).

3.2   Other Federal Agency Assessment Methods

Several guidance documents were prepared by USEPA during the 1970s to assess and/or abate water pollution problems from mining sites. USEPA (1975) presents criteria for developing state pollution abatement programs for inactive and abandoned mine sites of all types. This guidance focuses on all administrative,

socioeconomic, and technical aspects of developing programs, with an emphasis on inventorying and mapping of sites using a watershed-based approach. For data collection, many general options are presented that can be used depending on the complexities and severity of contamination problems in the watershed, the level of detail required, and the resources available to the state agency. However, the following recommendations are presented for hydrologic and water quality analyses:

- Watersheds and subbasins should be delineated on a topographic map and based on field reconnaissance.

- Grab samples with flow measurements should be collected at a large number of sites employing modular, repetitive, and point source sampling schemes. Modular sampling is performed once or twice to define areas of significant contamination as well as marginal and uncontaminated areas. Repetitive sampling is performed at strategic locations to enable periodic assessment of flow and water quality over time. For point source sampling, each potential pollution source and tributary to the main stem is sampled once or twice to isolate pollution sources.

- Prioritization of abatement projects based on watersheds, subbasins, or types of sources using both technical and socioeconomic factors is critical to successful programs. High priority projects will generally be those with either the best cost effectiveness or the greatest predicted downstream water quality improvement.

USEPA (1977) is guidance for water quality management for mine-related pollution sources in relation to the CWA 208 Water Quality Management Program. This guidance emphasizes the CWA areawide approach for identifying, assessing, and controlling mining pollution sources and recommends the following:

- Maximum use should be made of existing water quality data; emphasis on new data acquisition should be placed on improved monitoring in support or ongoing regulatory and abatement programs rather than on monitoring as a part of problem assessment studies.

- A stream-to-source approach using adequate existing water quality data when all sources are not known should be used.

- Assessment must incorporate both chemical and biological information.

- In some cases, quantitative impact description must be performed using pollutant load modeling. This may involve empirical methods such as the USLE or various loading functions, stochastic methods, deterministic methods, or simulation methods. These methods are more reliable for larger watersheds with multiple sources.

- Assessment should include estimates of loadings and receiving water quality impacts at both high and low flows.

- Comparisons should be made between mine and non-mine sources and between subcategories of mine sources.

- Estimates of loadings and impacts from abandoned mines are better suited to the modeling approach than are estimates from active mines because active mines are more dynamic so abandoned mines are easier to model.

Other work sponsored by USEPA was performed for specific mine sites or types of mines. The Montana Department of Natural Resources and Conservation (1977) prepared a feasibility study for mine drainage control from metal mines in a subalpine environment. Cox et al. (1979) developed methods using modeling and high frequency monitoring to assess aquatic impacts from coal strip mine drainage in the eastern U.S. Ridolfi (1991) evaluated the distribution of heavy metal loadings to the South Fork Coeur d'Alene River in northern Idaho using a mass balance approach.

The Office of Technology Assessment (OTA) (1986) also developed some general guidance for permitting and reclamation of western surface mines that emphasized cumulative hydrologic impact assessments (CHIAs). The document states that surface water baseline studies should include the following:

- detailed location of all surface water features

- streamflow quantity data, including seasonal and annual variations, floods, and low flows

- streamflow quality data, including physical and chemical characteristics and the relationship between discharge and quality

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- quantification of physical watershed parameters

- description of climatic characteristics

- description of surface water uses

States may prescribe specific baseline monitoring requirements. In general, a minimum of one year of baseline data is required and continuous recording gages or quantification of maximum, minimum, and average flow conditions are required for perennial and intermittent streams, while crest staff gages may be required for ephemeral streams. For water quality data, either monthly or quarterly monitoring is required for perennial and intermittent streams, while snowmelt and storm monitoring may be required for ephemeral streams (OTA, 1986). For prediction of hydrologic impacts, OTA suggests the Log-Pearson Type III distribution method for gaged sites with many years of data, and statistical models based on multiple regression equations using basin characteristics or deterministic models that may be based on the SCS curve number method for ungaged sites. The USLE is also recommended for predicting erosion and total suspended solids (TSS) concentrations. The limiting factor for most CHIAs is the availability of reliable monitoring data for model input and calibration.

More recently, USEPA has created a small Mining Waste group within the Water Management Division in Region VIII. This group provides expertise in mining waste issues to all USEPA regions (Walline, USEPA, personal communication, 1993). Most of the work performed by the Mining Waste group is in regard to operational mines and permitting and planning for new mines. They are not directly responsible for the assessment and remediation of IAMs, however, except when involved with inactive mining sites being investigated and remediated under CERCLA or active

sites under RCRA. The Water Management Division also gets involved with assessment of IAMs to a limited degree with regard to implementation of and compliance with the new stormwater regulations and National Pollutant Discharge Elimination System (NPDES) permitting and compliance under the CWA for active sites that may also have IAMs associated with them.

Willingham and Medine (1992) recommended a comprehensive Water Quality Assessment Methodology that is being implemented in the Arkansas River Basin, Colorado, by USEPA to address water quality and resource use impairment from the Pueblo Reservoir to the headwaters, emphasizing protection of aquatic life uses. This area is known as the Upper Arkansas River Basin and has been heavily impacted by historic mining activity. They describe six essential steps in a multidisciplinary basin approach to assessment and cleanup:

1. Define environmental system and general statement of goals
2. Data compilation
3. Environmental monitoring program
4. Describe environmental quality
5. Assess potentially attainable or undisturbed conditions (then re-evaluate goals)
6. Link contaminant dynamics to receptor exposure and resource use constraints
7. Resource restoration - assessment and control process implementation
8. Goals attained - maintenance monitoring

The approach used for the Upper Arkansas River Basin is comprehensive and includes simulation modeling and long-term monitoring to assess the basin. This seems to be a good assessment framework when resources are not very limited for large complex mining sites where long-term assessment will definitely be required.

USEPA has also issued guidance and sponsored research regarding a variety of quantitative and statistical methods for monitoring and assessment of different types of water quality problems. Some components of these methods may be appropriate

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for IAM monitoring and assessment. USEPA sponsored a series of guidance documents for design of routine water quality surveillance and data acquisition systems using quantitative methods and a systems approach for pollution prevention and abatement objectives. These studies emphasized the need for clear definition of goals and objectives, the determination of sampling frequencies and locations required for decision-making with a desirable degree of confidence in results, and comparisons between grab sampling, automatic sampling, and remote sensing (NUS Corporation, 1970; Beckers et al., 1972; Ward 1973). Grab sampling was generally believed to be the most cost-effective method for most applications. Loftis and Ward (1979) discussed statistical and economic considerations in regulatory water quality monitoring networks, with an emphasis on determining sampling frequencies required for desired confidence intervals (*CI*s) about the geometric mean of the data considering seasonal variation and seasonal correlation.

With regard to general NPS pollution and stormwater monitoring and assessment, USEPA has performed much work on developing methodologies for the study of storm generated pollution including sampling, monitoring, and empirical analysis methods for urban watersheds (Wullschleger et al., 1976); empirical loading functions (McElroy et al., 1976); a mass balance procedure based on the USLE (Betz Environmental Engineers, 1977); probability distributions of precipitation and related runoff and pollutant loads (Hydroscience, 1979); probability sampling (Humenik et al., 1980); and frequency analysis (Olsen and Wise, 1982). USEPA also performed an investigation of NPS monitoring procedures used in western arid regions using automatic sampling and physical, chemical, and biological monitoring techniques in the White River, Utah, Oil Shale area (Kinney et al., 1982). The research concluded:

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- NPS monitoring should include physical, chemical, and biological components, including flow, in an integrated fashion.

- Sampling frequencies should be maximized during periods of maximum variability in water quality.

- Sources of input, including tributaries, are primary factors to consider in determining the distribution of sampling sites.

- Automatic samplers do not perform well during freezing and thawing conditions.

- Biological monitoring should be performed at least on a seasonal basis.

Mills et al. (1985) present some useful empirical and analytical methods recommended by USEPA for estimating NPS pollution loads from a wide variety of types of sources, including rural lands, as well as methods for estimating concentrations in receiving waters. USEPA has developed a NPS monitoring and evaluation guide that is a compilation of the lessons learned from various nonpoint source programs to date (Dressing, 1987). This includes goals and objectives, water resource considerations, data needs, monitoring recommendations, and data analysis. Donigan and Huber (1991) review many empirical methods, as well as statistical and simulation methods, for estimating NPS pollution in both urban and nonurban areas, and discuss the required input parameters and rationale for their selection and use.

Over the years, USEPA and others have proposed using a watershed or ecosystem approach to assessing and remediating NPS pollution problems (USEPA, 1975, 1977, 1991c; Warren, 1979; Lotspeich, 1980). The watershed approach is also implied in the CWA by reference to an area-wide approach to pollution control. This approach focuses primarily on three components:

1. grouping multiple NPSs together into a watershed or basin based on geographic location and types of sources, receiving water areas, and environmental problems

2.	identifying all potential sources within a watershed and targeting or prioritizing these sites for detailed evaluation and remediation because of limited resources

3.	focusing on ecological receptors and systems being impacted by NPS pollution as an indicator of overall and long-term (chronic) environmental impacts and health

The third item leads to the proposition by USEPA of using more biological monitoring and assessment methods and biocriteria to evaluate ecological impacts to and health of the watershed or ecosystem (USEPA, 1977, 1983, 1990, 1992c). Biological monitoring has the significant advantage over chemical monitoring of being able to provide data for the evaluation of nontransient, long-term impacts to and health of the system. Chemical-specific water quality data are generally representative of the environment at the time they were collected (or shortly preceding it), but may not necessarily provide enough information for the evaluation of chronic problems. Changes in ecological systems revealed with biological monitoring, however, such as the presence of fish or macroinvertebrate species and population and habitat characteristics, tend to reflect the long-term impacts from nonpoint sources of pollution. Therefore, evaluation of the impairment of designated uses such as aquatic life or fishing, and the violations of water quality standards for these uses, is critical in the effective assessment of NPS pollution in general and of IAMs in particular since aquatic life is generally very sensitive to slightly elevated metals concentrations. Biological monitoring or biomonitoring may be divided into two categories: ecological surveys (biosurveys) and toxicity tests (bioassays) (Roop and Hunsaker, 1985). Ecological surveys may use indicator species and ecological community attributes and make comparisons between affected and control areas to indicate the health of a water body relative to pollutant loadings. This is the same

general type of method used in the use attainability analysis incorporating a water body assessment discussed previously. Toxicity testing typically uses single indicator species to determine acute and a variety of chronic effects.

The U.S. Geological Survey (USGS) has developed comprehensive methods for the general study and interpretation of chemical characteristics of natural water that are considered standard practice (Hem, 1985). They present methods to assess accuracy and precision, determine ion ratios and water types, perform statistical treatment, extrapolate water quality data, and use trilinear diagrams and other graphical methods. The USGS also maintains large amounts of historical water quality and hydrologic monitoring information through its network of gaging stations in major rivers and streams across the U.S. in the database WATSTORE. Averett (1976) has developed guidelines for the design of data programs and interpretive projects, primarily for USGS personnel. He emphasizes that data analysis must "tell a story" with the data in order to generate the information required to make effective decisions.

The U.S. Bureau of Mines (USBM) is currently taking a leading role in addressing the IAM problem. Much of the expertise is centered in the Spokane, Washington office where a multidisciplinary staff is currently working on developing methods for the inventorying, assessment, and remediation of IAMs, in particular the East Fork Pine Creek Basin, Idaho (USBM, 1993). This basin is part of the larger South Fork Coeur d'Alene River Basin where historic mining activities have left a wide variety of waste sites. Other land uses that have adversely impacted the waters of the basin and complicated the problem are forestry and agriculture (Mink and Murrey, 1992). Downstream water quality problems in Coeur d'Alene Lake is a

major issue in this area. The East Fork Pine Creek study is a cooperative effort being performed by USBM, the State of Idaho Department of Environmental Quality (IDEQ), the U.S. Bureau of Land Management (USBLM), and USEPA. USBM is studying the East Fork Pine Creek Basin primarily because data gaps exist for this basin relative to the rest of the South Fork Coeur d'Alene River Basin. The data collection activities are documented in USBM (1992) and IDEQ (1992). The general approach is to first collect as much potentially useable data as possible and then to determine the data analysis methods after examining the data. Therefore, the data analysis methods are undocumented at this time. Monitoring is being performed at over 60 stations for dissolved and total metals, indicator parameters, and flow. Six monitoring events have been implemented to date including monitoring during snowmelt runoff, storm runoff, and baseflow. Sediment (bed material) sampling for metals analyses and biological monitoring is being performed at a subset of these stations. Groundwater and vadose zone water is also being monitored at several locations. In addition, NPS waste materials are being sampled for geotechnical and chemical analyses.

The U.S. Forest Service (USFS) is actively assessing IAMs within the National Forest System. Their focus is the assessment and remediation of environmental and water quality impacts caused by these sites (USFS, 1993; Schmidt, USFS, personal communication, 1993). Under the Federal Facilities Compliance Act and CERCLA (CERCLIS), USFS is required to inventory all potential hazardous waste sites on USFS land. Some of the more serious sites will then undergo the PA and SI process to assess sites with regard to inclusion on the NPL (Schmidt, USFS, personal communication, 1993). Ponce has reviewed and summarized water quality data

analysis methods (1980a) and water quality monitoring programs (1980b) for USFS.

The U.S. National Park Service (USNPS) began its inventory of IAMs because of previous lawsuits and concern regarding future liability. Most of its efforts have been directed towards remediating safety problems. Environmental problems are not as much of a concern on lands administered by NPS (WGA, 1991).

3.3   State Agency Assessment Methods

The IAM inventorying and assessment approaches taken by each of the state regulatory agencies are not consistent, and the management and information goals of each different agency within a given state vary. Some states have been addressing the IAM problem for many years while others have basically not addressed the problem at all. For example, Wyoming is a large coal-producing state and as such, has a complete inventory of its coal and noncoal IAMs (WGA, 1991). Although Wyoming estimates that only approximately 15% of its IAMs remain to be remediated, most of the IAM problems in the state are public health and safety problems due to open shafts and adits. Colorado and Montana have also spent considerable funds on IAM inventories and therefore have fairly complete information. Other states, such as New Mexico and Utah, are only now starting to inventory their IAMs and associated water quality problems, and many of these states use historical mining data from USBM, USGS, and other national sources and data bases as a starting point. The methods used for inventorying, as well as the quality and quantity of the data collected, vary considerably from state to state. In some states, several water quality samples are collected and analyzed to provide a screening-level characterization of the water quality problems. Areas or volumes of source waste materials may also be estimated, as well as waste samples collected.

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Other states have not located all of the sites to date. Only seven states throughout the U.S. have performed noncoal field inventories because most states do not have funds to adequately inventory IAMs (WGA, 1991). The inventorying costs can be as high as over one million dollars in states such as Idaho and Montana. However, field data are critical to achieving the desired level of confidence in the inventorying and assessment process and in prioritizing sites for cleanup.

CDPHE Water Quality Control Division is implementing a NPS demonstration program in the Upper Animas River Basin (above Silverton) in the San Juan Mountains of southwestern Colorado as part of a grant received from USEPA under Section 319 of the CWA. This basin was heavily mined for metals over the last century and water quality has been impacted significantly in many locations of the basin. CDPHE has prepared two planning documents for the study and is in the initial stages of assessing the water quality problems in the basin (CDPHE, 1992a, 1993a). The primary objective of the study is to locate and estimate the magnitudes of potential metals loadings to the main stream segments. Several secondary reasons have been identified for implementing this assessment in the Upper Animas River Basin (Harvey, CDPHE, personal communication, 1993):

- Little data have been collected in the Upper Animas River Basin relative to other basins and IAM sites within the state. Part of the reason for this may be the relatively isolated location of the basin with regard to population centers in the state. The study was implemented to fill in this data gap.

- Some observers believe that the water quality of the basin is degraded by naturally-occurring high concentrations of metals in ores, and that the basin and water quality cannot be remediated because of the naturally-occurring metals and the severe impacts from extensive past mining. The study was implemented to determine if these hypotheses were true.

- Initial funds for monitoring and assessment were provided by USEPA. If these funds were not available, the study might not have been implemented.

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This study has taken a synoptic approach to monitoring many sites throughout the basin in a spatially intensive fashion to collect samples at locations in the mainstem and main tributaries, draining known point sources and NPSs, bracketing known or suspected NPS areas, bracketing main tributaries, and in background areas. To date, four monitoring events have been implemented: one during spring snowmelt (June, 1991), one during a summer storm (September, 1991), one during baseflow (October, 1992), and one during the tail end of snowmelt (July, 1993). Analytes include dissolved and total metals, indicator parameters, and flow. Biological monitoring is also being performed at a subset of the monitoring stations at key locations. Sediment has not been monitored to date. A mass balance approach, also termed a NPS reach gain/loss analysis, is being used to assess potential metals loadings to and losses from the system. There is no statistical design or basis for the study. However, the potential or theoretical measurement variability or error of instantaneous flow measurements and of metals analyses of grab samples is being considered in the assessment process (CDPHE, 1993a).

Another good example of a state agency IAM assessment methodology is the IDEQ study of the Coeur d'Alene River Basin being coordinated with USBM, USBLM, and USEPA. As discussed previously, this basin, especially the South Fork Coeur d'Alene River Basin, has been heavily impacted by past metal mining activities as well as by forestry and agricultural activities. In conjunction with USBM, the agency is focusing monitoring and assessment efforts on the East Fork Pine Creek Basin where data gaps have been noted. A general monitoring plan has been prepared by IDEQ (1992) for the study. IDEQ is using a general TMDL/WLA approach to assess point source and NPS contaminant loadings and instream

concentrations and to allocate BMP projects to NPS areas to reduce loadings to Coeur d'Alene Lake to acceptable levels. The specific data analysis methodology used by the state is undocumented at this time.

The states have developed designated beneficial use classifications and associated narrative and numeric water quality standards for specific segments of water bodies based on USEPA requirements and guidance (USEPA, 1983; CDPHE, 1991a). The monitoring and assessment methodologies for determining if these standards and uses are being met vary from state to state and depend on which regulatory program the assessment is being conducted for. Except for use classification, standards development, and a few other specific programs for which USEPA provides required monitoring and analysis procedures (such as stormwater or NPDES permitting and compliance requirements), few detailed state guidelines or documentation exist on specific monitoring or data analysis methods.

For the designated beneficial use classification and standards development process for Colorado, 15 or more samples collected routinely or randomly over a year or more period is considered sufficient, and the data should be representative of the segment as a whole (CDPHE, 1992b). Although sampling multiple sites on the mainstem is recommended, sampling tributaries is acceptable if the intention is to determine if the tributary is similar to or different from the mainstem in terms of water quality characteristics. For segments for which insufficient data are available for classification or development of standards, federal table value standards (TVSs) may be used, or additional data must be collected if TVSs are not deemed applicable. Percentiles are calculated for all data used for a given stream segment to determine ambient conditions and standards. If the computed ambient quality

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that is used for the stream standard exceeds TVSs, the data must represent natural or uncontrollable anthropogenic conditions. For dissolved metals, the 85th percentile of the available data defines the ambient level and standard, and for total or total recoverable metals, the 50th percentile is used. These data are used for chronic standards. For acute standards, the TVS must be used unless site-specific criteria are developed based on toxicity tests. Where adequate flow-hardness data are collected to perform a regression analysis, metals standards based on hardness are computed using the hardness associated with the lower 95 percent confidence limit of the mean hardness value at the low-flow criterion. Alternatively, where there is inadequate flow-hardness data, standards may be computed using either the mean hardness for the segment or representative regional hardness data where segment-specific hardness data are lacking.

3.4   Other Assessment Efforts

This section discusses additional, related monitoring and assessment efforts and studies conducted by others outside of the federal and state agencies and that are part of general areas of study or application that are not necessarily required by any regulations. Some of these general methods, however, do overlap or are incorporated into some of the regulatory requirements. Some of these methods have also been used at IAM or other mining sites. These approaches might be applicable to or useful for the assessment of NPS pollution from IAMs.

3.4.1   Information Systems

The design of a water quality monitoring system and assessment methodology for IAM sites that serves as an effective information system is a concept that may be applied to best make use of limited resources. The information system approach,

which involves clearly defining information goals as an integral element of the design of the monitoring program and efficiently converting "data" into required "information", has been discussed by Ward et al. (1990) for a wide variety of types of water quality monitoring programs. Related to the information system approach, Ward also discussed a "systems" approach to monitoring for effective water quality management (1979). One of the most important features of these approaches is the clear identification of management goals and specific information objectives for reaching those goals. Ward et al. (1990) also emphasized the development of data analysis protocols (DAPs) during the information system design phase to ensure a rational and consistent approach to data analysis for each application and to provide for review from and consensus among all interested parties on the data analysis methods to be used to reach the information goals. Adkins (1993) used this approach to present a framework for the development of DAPs for groundwater monitoring programs.

3.4.2   Statistical Methods

Design of effective water quality monitoring systems for a wide range of management goals has been discussed by Sanders et al. (1983) that emphasized a statistical approach to design and data analysis. Statistical methods have also been discussed by many others, including the general use of statistics in regulatory water quality management (Ward and Loftis, 1983; Schweitzer and Black, 1985; Mar et al., 1986; Ward and Loftis, 1986; Gilbert, 1987; Fisher et al., 1988; Valiela and Whitfield, 1989); appropriate sampling frequencies required to achieve reasonably small and uniform confidence interval widths about means (Loftis and Ward, 1980; Dunnette, 1980); statistical models including probability distribution models, linear regression

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models, log-transformed regression models (typically used for contaminant concentration distributions), and confidence intervals for probability models (Loftis et al., 1983; Koch and Smillie, 1986). The effects of different temporal and spatial scales of interest on water quality monitoring and data analysis were investigated and discussed by Loftis et al. (1991). They concluded that an explicit consideration of scale in the design of water quality monitoring programs and data analysis is very important for generating the desired statistical information.

3.4.3   Empirical Methods

Much research has been performed concerning the development and application of empirical or statistical modeling techniques for predicting NPS and stormwater pollution loadings, especially in urban and agricultural environments. These are typically considered planning or screening-level models and assessment methodologies that are not too data intensive, complex, or costly for most state regulatory agencies to apply. These approaches may be applicable to the screening-level assessment of IAMs because the quantity of data required for complete statistical analyses or simulation modeling that could be performed in later stages of the assessment process are typically not available at this early stage. These methods include the evaluation of pollutant loading/land use relationships in watersheds (Ostry, 1982; Brown, 1988; and Richards, 1989); estimation of loadings based on assumptions regarding population distributions (normal versus lognormal) and correlations between concentration and discharge (Whitfield, 1982); regression (Jewell and Adrian, 1982; Fannin et al., 1985; Hill, 1986); mass balance approaches (Novotny et al., 1985); and the USLE for sediment (Dickenson et al., 1990). Reckhow et al. (1985) provided a good summary of these empirical types of pollutant

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runoff models and their selection and use in the decision-making process. Marsalek (1991) also provided a good review of methods for deriving planning-level estimates for predicting pollutant loads in urban stormwater.

3.4.4   Risk Assessment

A risk-based approach to the environmental assessment process has been emphasized by USEPA (1984, 1989a, 1992c, 1992d) and others and may be effective for assessing and targeting IAMs. Human health and ecological risk assessment is required as part of the CERCLA process (USEPA, 1988a, 1988b, 1989a, 1989b). Risks of adverse impacts to aquatic life are dependent on three primary factors:

1.   concentration of the contaminant(s) that aquatic life are exposed to and associated water quality effects of this concentration (exposure concentration)

2.   frequency of exposure occurrence

3.   duration of exposure occurrence

Therefore, one important phase of the risk assessment process is the exposure assessment, whereby contaminant loadings, concentrations, and exposure are estimated in terms of probability. Exposure assessment typically involves developing a frequency distribution of observed or modeled contaminant loadings or concentrations and evaluating the associated risk of exceeding water quality (especially aquatic) criteria, as well as evaluating the risk of exposure to human or ecological receptors. This allows estimates of uncertainty to be made explicitly as part of the risk assessment process. Risk and exposure assessment is also very useful for targeting the worst source or impacted areas instead of attempting to evaluate and remediate all areas with limited resources. Risks of the greatest contaminant loadings may typically be associated with storm and snowmelt runoff events in the

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high altitude areas where most IAMs are located. Alternatively, risks of the highest concentrations may be associated with baseflows when dilution is at a minimum. This approach explicitly considers the probability of occurrences of these types of events and the uncertainties associated with them. Evaluation of uncertainty allows an estimate of confidence in the data, in the information derived from the monitoring program, and in the decisions made regarding further assessment and remediation. These methods include evaluation of stream standard violations by estimating cumulative density functions (cdfs) using observed data and confidence limits about the cdfs based on normal and nonparametric models (Loftis and Ward, 1981); use of lognormal models (Page and Greenberg, 1982; Di Toro, 1984); Monte Carlo simulation techniques (Haith, 1985, 1987a, 1987b; Marr and Canale, 1988); applications to environmental impact assessment (Suter et al., 1987); and probabilistic evaluation of source-to-stream loading and downstream fluvial transport and attenuation (Phillips, 1989).

3.4.5   High Altitude Environments

A considerable amount of work has been performed on assessment of the hydrology and water quality of mountain and high altitude environments. Jarret (1990) provided a good summary of hydrologic and hydraulic research in mountain rivers, emphasizing that standard hydrologic methods may provide erroneous results when applied to mountain environments due to the heterogeneity of terrain and basin characteristics in these watersheds. Work has been performed on the relationships between stream discharge, chemical loadings, and other watershed characteristics (Lewis and Grant, 1979; Vitek et al., 1981); hydrochemical balances (Stednick, 1981; Baron and Bricker, 1987; and Williams and Melack, 1991); and

regression models (Singh and Kalra, 1984).

3.4.6   Mining

Work that has been performed specifically on the assessment of mining sites includes development of simplified stream models of AMD drainage effects using mass balance approaches (Chadderton, 1979); evaluation of adverse impacts of erosion and sedimentation from mining activities on water quality using sediment and biological monitoring techniques (Duda and Penrose, 1980); watershed planning for AMD abatement using mapping techniques (Ferguson, 1985); control of NPS pollution from mine spoils (Evangelou and Thom, 1985); and gold mining effects on the hydrology and water quality of streams (Bjerklie and LaPerriere, 1985 and LaPerriere et al., 1985). Mining-related NPS pollution was also discussed in general terms by Cohen and Gorman (1991).

3.4.7   Metals

With regard to assessment methods for general metals pollution, work has included general metal monitoring and geochemistry (Latimer et al., 1988) and evaluation of spatial trends and sorption processes of trace metals in sediment from an urban watershed (Combest, 1991). This work found that spatial trends may indicate either differences in metal inputs or differences in sediment sorption processes. This has significant implications for confidence in decisions regarding loadings to a stream segment and targeting remediation.

3.4.8   Sediment

Much work has been performed on the assessment of erosion and sediment transport, including delivery of suspended sediment and particulate pollutants from NPSs during overland flow (Novotny, 1980) and soil loss from precipitation on

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mountain land including using the USLE (Hart, 1981) It was found that (1) low intensity storms of short duration on dry soils produce such small soil loss that these events are insignificant, (2) antecedent soil moisture must be considered because it affects surface runoff (the most important cause of sediment transport), and (3) length-slope factors on slopes greater than 20% may need further evaluation.

3.4.9   Biological Methods

Much work has been performed recently regarding general biological assessment methods, including evaluating relationships among observed metal concentrations, criteria, and benthic community structural responses in streams (LaPoint et al., 1984) and biomonitoring for toxics control in NPDES permitting for complex effluents (Roop and Hunsaker, 1985).   It has been concluded that a combination of biomonitoring and bioassays of benthic fauna during seasonal or critical flow periods provided good information for evaluation of long-term general water quality and metals contamination. The advantages of ecological monitoring and toxicity testing for complex effluents and measuring whole effluent toxicity (WET) relative to standard chemical-specific monitoring have been emphasized.

3.4.10   Synoptic Methods

Research has also been performed on fixed stations versus intensive surveys for monitoring water quality (van Belle and Hughes, 1983). These researchers concluded that:

- Intensive surveys are effective for studying short-term fluctuations in water quality, the relationships of these fluctuations to other hydrologic phenomena, and cause-effect relationships of pollutants.

- Estimates of water quality derived from networks selected by non-probabilistic means may generate biased estimates of absolute water quality, but can give valid estimates of trends with less variability.

Messer et al. (1988) examined the feasibility of a regional probability-based synoptic sampling approach to study stream chemistry, concluding that week-to-week variations in concentrations of key chemical parameters during the spring did not appreciably affect the estimated population distributions and stream classifications, but differences were observed between spring and summer.

3.4.11   Geographic Information Systems

Several authors have used geographic information systems (GISs) or similar technology to aid in identifying and evaluating NPS pollution contributing areas (Gilliland and Baxter-Potter, 1987; Berry and Sailor, 1987). This technology is especially useful for spatial data input and management, linking with watershed or water quality models, and generation of maps that can be used to evaluate NPS pollution sources and impacts and for presentation.

3.4.12   Standards

Research on assessment methods with regard to determining appropriate water quality standards has included alternative approaches to developing standards and assessing biotic impacts of wastewater effluents in relation to these standards (Lee et al., 1982a, 1982b); statistical bases for problems with typical methods used to develop standards and to identify NPDES permit violations (Herricks et al., 1985); and regulating NPS pollution using the TMDL/WLA and permitting process in conjunction with consortia made up of all potential parties responsible for NPS pollution for targeting problems that have the greatest opportunities for risk reduction (Foran et al., 1991).

3.5   Summary

The extensive evaluation in this chapter has shown that there are no federal regulations that explicitly address the vast majority of IAMs. In addition, the assessment methods used by federal agencies, as well as the state agency and other assessment methods, also do not explicitly address the majority of these sites. It is apparent that the biggest problem is that there is no single method that comprehensively addresses IAMs with regard to targeting, especially on a watershed scale. Significant weaknesses in the methods that have been or are currently used include:

- information goals are not explicitly defined prior to the data collection and analysis activities

- too costly or data intensive given very limited resources and data

- not effective or efficient with regard to deriving as much of the required information for targeting or prioritizing sites for remediation as possible from the available data

- too narrowly focused with regard to the types or spatial scale of information required for targeting

- derive too much information that is not initially required for targeting

- do not provide data or information that are consistent or comparable among sites or agencies

- do not incorporate a risk-based approach for targeting

- do not consider or attempt to minimize the uncertainty associated with the data and information derived from the assessment

The importance of these problems is discussed in more detail in the next chapter with regard to defining specific management goals and assessment information goals for IAMs. The methodology developed as part of this study will attempt to overcome all or most of these shortcomings.

4.0 INACTIVE AND ABANDONED MINE MANAGEMENT GOALS AND INFORMATION GOALS FOR TARGETING

This chapter defines generalized, primary IAM management goals common to most agencies. IAM management goals are useful because regulatory information goals generally cannot be identified for these sites. These management goals are then used to formulate common and clearly stated water quality assessment information goals for IAMs. Specific quantitative information goals for the assessment methodology are then defined based on the assessment information goals.

4.1 IAM Management Goals

The overall, primary management goals for IAMs must be clearly defined before resources are allocated to assess and remediate these sites and before assessment information goals can be defined (Parsons, CDPHE, personal communication, 1993). As discussed in the previous chapter, no specific federal regulations for controlling pollution address the vast majority of IAMs, and a national program for management of these sites does not currently exist. Management goals, therefore, vary considerably among agencies and states and clearly defined overall management goals for the majority of these sites do not exist (WGA, 1991). The fact that IAM land ownership is highly variable complicates the management goals and approaches considerably. However, some commonalities in IAM management goals do exist among agencies. These common goals can be defined and generalized to formulate primary IAM management goals that provide the basis for defining associated

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assessment information goals. Management goals that are somewhat more specific for individual sites can also be defined by agencies later on a site-specific basis that take into consideration the various and unique environmental and socioeconomic characteristics of each site. Future generalized national IAM management goals might also help frame these site-specific management goals.

In order to define overall IAM management goals and information goals, a comprehensive literature review was performed and extensive discussions were held with key individuals with organizations involved with IAM assessment and management. The following individuals and organizations provided guidance on identification of management and information goals and review and comment on the goals identified:

- USEPA Region VIII - Rob Walline (National Mining Expert) and Carol Russell (NPS Group)

- CDPHE Water Quality Control Division - Greg Parsons (Head of NPS Unit) and Bob Owen (Standards Unit)

- Colorado Department of Natural Resources (CDNR) Division of Minerals and Geology - Dave Bucknam (Head)

- Colorado Center for Environmental Management (CCEM) - Gary Broetzman (IAM Project Manager)

These individuals and organizations represent a cross-section of those involved with IAM assessment and management; one federal agency, one state agency responsible for water quality protection, one state agency responsible for IAM remediation, and one independent organization creating a forum for IAM management issues.

CCEM has prepared a blueprint for the effective management and cleanup of IAMs (CCEM, 1993). This blueprint builds on information and recommendations presented in the WGA report (1991) and includes many key elements for the

effective management of these sites. Many of these key elements have also been recommended by others involved with IAM management and NPS pollution control (Broetzman, CCEM, personal communication, 1993; Walline, USEPA, personal communication, 1993; Parsons, CDPHE, personal communication, 1993; CDPHE, 1993a; Colorado Department of Natural Resources, 1982). The recommended key elements of an effective IAM management approach are as follows:

- states should have the primary responsibility for management of IAM waste sites (due to significant differences in the scope and characteristics of the problems among states) with support, technical guidance, and significant funding from the federal government

- environmental cleanup goals, especially water quality improvement and restoration of aquatic life, (including risk-based information) that are somewhat site-specific should be used as the basis for defining cleanup actions

- cleanup goals should be integrated with prevailing environmental regulatory requirements where feasible

- collaborative decision-making should be used through broad stakeholder involvement and formulation of Memoranda of Understanding among all interests to enhance public support and probability of success for remediation

- a system should be developed for identifying, ranking, and selecting (targeting) geographic priority areas (generally watersheds)

- a state-wide inventory of IAM problems and needs should be developed and conducted in a consistent manner with state criteria or national criteria where federal funding is involved

- overall criteria or methodologies for area-specific analyses should be formulated utilizing public involvement and a citizens board for problem definition, setting cleanup goals, collecting baseline information, identifying remedial actions, and integrating with cleanup actions for other sources of contamination

- a phased approach to assessment should be used, thereby using limited resources in an efficient manner for areas or sites of concern only when required

- the uncertainty or confidence associated with the information derived from the assessment process and with subsequent management decisions that are based on this information should be considered

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- the potential remining of some sites should be considered

- the maintenance of historic structures associated with IAM sites that are of considerable historic, archaeologic, and/or economic (tourism) interest should be considered

- economic benefits to a geographic area should be considered, such as increasing the public value of a water body and recreational or tourism opportunities, or providing local jobs associated with remediation

- phased remedial actions that enable cleanup to proceed according to availability of funds should be used

- the feasibility and demonstration value of remediation technologies should be considered

- preference should be given to certain types of remedial technologies, such as passive treatment and/or low maintenance technologies to reduce long-term costs, and the costs/benefits of alternatives should be considered

- the aesthetic values of mining areas should be considered

- the compatibility of post remediation land use with surrounding existing or future land uses should be considered

- land ownership of potential remediation areas should be considered

- consideration of any adverse impacts to people or the environment that might occur during or after remediation and of uncorrected conditions, if any, that will continue to exist after remediation

Some of the key elements of an overall management goal or effective management approach listed above impact the definition of specific assessment information goals. These key elements are discussed in subsequent subsections as follows:

- water quality management goals
- risk-based approach
- geographic approach
- consistent methodology
- targeting

In addition, the next section on information goals (Section 4.2) discusses a phased approach to assessment and the uncertainty associated with the information derived

from assessment.

It is generally recognized that overall IAM management goals cannot be easily separated from general water quality management goals in most cases (Walline, USEPA, personal communication, 1994). If IAMs were not adversely impacting water bodies, many of them would not need to be remediated. Overall management goals for IAMs, therefore, are consistent with management goals for many other sources of NPS pollution. For IAMs, however, two primary management goals can be defined. One of these goals is to reduce the public safety hazards, especially the extreme hazards, associated with these sites by closing openings at the mines. This is the primary focus of most state abandoned mine reclamation programs funded under SMCRA. Although it could be cost effective to address these public safety hazards in conjunction with addressing water quality problems at some sites, the management of these sites in relation to water quality management is the focus of this study.

4.1.1   Water Quality Management Goals

The second primary goal for the management of IAMs is to reduce contaminant (metals, acidity, and sediment) loadings from these sites to water bodies for which designated or attainable beneficial uses (primarily aquatic life) are not being achieved in order to accomplish the following:

1.   Attain the designated uses of those stream segments for which the designated uses are not being achieved, or

2.   upgrade the existing uses to the attainable uses of those stream segments for which the attainable uses are not being achieved.

The reduction in contaminant loadings will be accomplished by remediating contaminant sources (i.e., IAMs) targeted as critical areas.

Several organizations involved with the management of IAMs recommend that IAM cleanup, environmental, or water quality goals should be site-specific and not necessarily regulatory driven because some of the existing numeric standards cannot be met given existing resources and reasonable timeframes (or at all) (CCEM, 1993; CDPHE, 1993a; WGA, 1991). The fact that a numeric standard cannot be met should not prevent the implementation of an IAM remediation project if substantial benefits can be recognized. In many cases existing designated beneficial uses and associated numeric standards are not necessarily appropriate for a given water body and/or were not established using optimal methods. Management goals based on these uses and standards, therefore, might not be suitable for achieving the desired benefits. Consequently, water quality goals should be site-specific, realistic, and clearly defined using optimal methods as part of the definition of IAM management goals.

Many water quality goals are based on aquatic life uses. These are considered environmentally-based goals, and are an important part of an ecosystem approach to IAM management. Restoration of fish habitat and populations is one of the primary water quality goals for many receiving water bodies impacted by IAMs. Restoration of other beneficial uses is also an important water quality goal. The designated use or the use attainability of a stream segment should be considered the primary water quality goal. This goal, however, cannot always be achieved without an exorbitant amount of resources and time. If this water quality goal cannot be met, a secondary or interim goal can be defined (this is sometimes allowed by USEPA). This goal can be a different beneficial use that can be achieved in a reasonable timeframe with existing resources, or a partial achievement of the designated or attainable use.

These goals should be defined on a case by case basis. A use attainability analysis can be performed for high priority stream segments to define the appropriate primary water quality goals.

Associated with each attainable use are numeric water quality standards for metals. These numeric standards can be based on ambient conditions, TVSs as defined by USEPA, or site-specific maximum (target) concentrations determined using toxicity tests for the project area. Regardless of the specific water quality goal or attainable use, an associated numeric standard or concentration should be defined for each priority stream segment that is required to attain and maintain the use. These concentrations can be defined on a seasonal basis, thereby reflecting critical conditions impacting the attainable use.

Once the target concentrations of critical metals and other constituents required to support the use have been defined, the maximum loading to the water body and the reduction in loadings during the critical period that are required to achieve the concentration can be determined. This generally must be accomplished using mathematical modeling techniques, such as those used to determine TMDLs for WLAs for point source controls. This task can generally be performed after the screening-level assessment phase for those segments and sites targeted for more detailed assessment and/or remediation.

4.1.2   Risk-based Approach

Some organizations (CCEM, 1993) recommend using an environmental risk-based approach for defining cleanup goals and managing these sites. This approach has been recommended for many areas of toxics control and environmental management (USEPA, 1984, 1992c, 1992d). Human health and ecological risk assessment and

management is used extensively to define cleanup goals and as the basis for making remedial decisions for Superfund sites (USEPA, 1988a, 1988b, 1989a, 1989b). The environmental risk-based approach is based on estimating the probability or frequency of occurrence of some detrimental impact to ecological receptors. Comparison of these risks provides a quantitative basis to compare and prioritize IAMs or water bodies beyond simple comparisons of average or total values. It also provides an explicit measure of the uncertainty associated with estimates of loadings and concentrations to provide estimates of the confidence in the data, in information derived from the data, and in the decisions regarding targeting sites for more detailed evaluation and/or remediation.

The risk-based approach might be somewhat difficult to implement at many IAM waste sites given the general lack of adequate data for an individual site based on typical synoptic or quarterly monitoring over only a relatively short period (often one year). Some type of modeling, therefore, is often employed to enhance the data and perform risk assessment at Superfund sites.

4.1.3   Geographic Approach

Many organizations involved in the management of IAMs recommend an area-wide, geographic, watershed, or ecosystem approach to the management of these sites and associated impacted water bodies (USEPA, 1975, 1977, 1991c; Warren, 1979; Lotspeich, 1980; Maas et al., 1987; WGA, 1991; CCEM, 1993). This approach is recommended for NPS pollution control in general and is implicit in the CWA by reference to an area-wide approach to pollution control. The majority of IAMs are in close proximity to each other and have similar types of sources or receiving water quality problems in historic mining districts. These may be considered multiple sites

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or source areas within a given watershed and are very amenable to management based on a watershed or ecosystem approach. Grouping sites together on a geographic or watershed basis can allow easier and more cost effective analysis and remediation. A geographic approach requires the following (CCEM, 1993):

- identification of the geographic area

- characterization of the environmental quality within the geographic area

- identification of all sources of pollution contributing to the degradation of the geographic area

- characterization of the pollution loading from those sources

- determination of the methods and cost of controlling pollution for the sources

- identification of private and public programs and funds available for the cleanup of the geographic area

- determination of the benefit derived from cleanup of IAMs within the geographic area

- establishment of a decision body responsible for the authorizing funds for the cleanup of IAMs within the geographic area, including defining the conditions to be met to make funds available

Grouping sites together on a geographic or watershed basis can generally be performed after the inventory but before the screening-level assessment. The screening-level assessment, therefore, would then be performed based on the geographic areas of concern. Information from the inventory (field reconnaissance) and USGS topographic maps can be used to delineate areas or watersheds based on the following criteria:

- geographic location

- type of mine, metals contamination problems, and other environmental impacts (such as type of use impairment)

- subbasin physical and ecological characteristics (homogeneity)

- jurisdiction and other socioeconomic factors

- affected water bodies or stream segments, designated beneficial use classifications, and potential exposure points

An alternative approach is to first select priority stream segments, perform screening-level assessment within the segment to identify subbasins that are potentially loading significant quantities of metals to the segment, and then perform inventories in those subbasins to derive data and preliminary information on specific source areas within the geographic area. This approach might save money by inventorying only those sites that appear to be significant sources of metals to the segment of concern, rather than inventorying all sites initially, as is typically done in the initial phases of identifying public safety hazards.

4.1.4   Consistent Methodology

Many organizations recommend a standardized or consistent methodology for data collection and analysis and use of consistent and comparable information among sites in order to effectively evaluate and manage these sites and allocate limited resources with a reasonable level of confidence (WGA, 1991; CCEM, 1993). WGA (1991) states that future inventory and assessment work requires well thought out instructions, consistent standards, and coordination among agencies conducting such work. If effective ranking and prioritization or targeting sites for remediation is desired (as discussed later), information derived from the sites must be comparable. If comparisons are to be made among information and sites, the information must be consistent and obtained using somewhat standardized or consistent methods. This is why a standardized assessment methodology or protocol based on well-defined information goals can be very useful. The term "protocol" as used in this study, as

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well as the advantages of a protocol, have been discussed by Adkins (1993). Several other important reasons exist for using a consistent assessment methodology. Federal funds can be allocated to states or agencies based on the extent of the IAM problem. At the other extreme, liability (such as Superfund) can also be based on the extent of contamination. Some results, therefore, might be skewed in order to receive more federal funding or to minimize liability. A standardized methodology would also reduce duplication of work and save money in the long-term because each state or agency would not have to develop a new procedure each time an assessment is performed or a program is implemented. A consistent methodology would also yield a credible assessment for defining a national problem important for legislature and national public policy purposes. It would also provide a baseline for eventually analyzing cleanup progress.

4.1.5   Targeting

Prioritizing or "targeting" IAMs or areas for remediation has been recommended by many organizations and will probably be one of the primary components of the effective management of these sites (WGA, 1991; CCEM, 1993). The targeting concept is central to the comprehensive State Clean Water Strategies (SCWS) and has been recommended by USEPA as the best management approach for controlling NPS pollution in general (Maas et al., 1987). Targeting has been used very successfully in agricultural NPS control programs under the RCWP to identify and rank priority water bodies and critical areas and select areas for remediation that will provide the maximum visible improvement and beneficial uses for the public, given limited financial and human resources to address all of the NPS problems. Achieving maximum visible benefit is critical for obtaining broad public support for NPS control

projects. Targeting or priority ranking has the following advantages (Maas et al., 1987):

- aids in achieving the greatest public benefit given limited resources
- helps build consensus on priorities
- based on water quality and socioeconomic considerations
- helps organization and interpretation of data

Theoretically, some states or agencies might be required to address all of their IAMs or receiving waters for which beneficial uses are not being achieved. Other states might only address specific areas or receiving waters of special concern or of the highest beneficial use that have the most potential to be remediated. In either case, however, some form of targeting will be required. Even for those states or agencies that must eventually remediate all of their sites, a prioritization scheme must be employed initially because they cannot address all problems at once.

Targeting in watersheds implicitly involves the collection of baseline data and derivation of baseline information on water resources and the associated watersheds. For many of these IAMs, no data have been collected to date (except for possibly limited data collected during the inventory phase). This baseline information, therefore, is critical for making future management decisions regarding more detailed assessment and/or remediation of these areas. The baseline information also provides for the later quantitative evaluation of the effectiveness of IAM remediation and NPS control projects after they have been implemented.

Targeting is based on using specific criteria to designate and rank priority water bodies or critical areas. This requires certain types of information and making comparisons among this information. Many information goals, therefore, can be defined in terms of targeting requirements. These targeting requirements and

information goals should be defined prior to the actual assessment. Methodologies for targeting have generally been developed and used more often for lakes than for streams, and use of biological, as well as chemical, indices is recommended.

Maas et al. (1987), as part of a USEPA guidance document, describe three levels of targeting or setting priorities for NPS control:

1. national and regional water resource priorities
2. priorities at the state level
3. priorities at the watershed level

National and regional water resource priorities are those water resources of national, regional, and/or interstate concern and interest, and should be defined first. State-level targeting generally refers to priority ranking of water resources (water bodies) for treatment, and should generally be performed in conjunction with or after national and regional targeting. Most states use the following criteria for ranking and targeting water bodies for restoration (Adler and Smolen, 1989):

1. severity or threat of impairment (public health and environmental)
2. public value of the water body
3. resolvability of NPS impairment
4. availability and quality of assessment information

Targeting critical areas at the watershed level involves identifying the predominant pollutant sources, prioritizing the sources, and first treating those sources that contribute most to the stream segment impairment identified at the state level. Targeting at the watershed level can be based on four criteria as follows (Maas et al., 1987):

1. type and severity of water resource impairment
2. source magnitude considerations
3. transport considerations
4. project specific criteria and goals (including socioeconomics)

These state- and watershed-level criteria can be considered general types of information that can be used for targeting sites. More specific information for each criterion is discussed in subsequent sections.

Targeting involves making comparisons among these criteria or information derived from different source areas and/or stream segments, and then ranking and selecting those areas that are worst (critical) and/or have the most potential to be remediated. The comparison, ranking, and selection process should be quantitative in order to make management decisions with an acceptable level of confidence. Based on the criteria identified above, targeting for remediation of IAM waste areas can include comparing information on and selecting different types of populations within a geographic area. These populations are dependent on the scale or geographic area of interest and are illustrated schematically in Figure 4.1. These populations can be defined as follows:

Individual point - An individual point is a station monitoring drainage from an individual source, a subbasin, or a watershed, or a monitoring station within a stream segment. Although targeting an individual point is not common, in some cases it might be appropriate if it drains a point source or is a location in a stream segment of special concern.

Stream segment - A stream segment is a stream reach of any length for which inputs of metals occurs from sources, subbasins, and watersheds and that discharges to another stream reach of the same or higher order. A stream segment can be entirely within, partially within, or at the outlet of a subbasin or watershed. A stream segment can have one or more monitoring stations located within it (possibly bracketing a source area). A stream segment is often defined for management purposes by its designated beneficial use classification and associated water quality standards. The stream segment is the receiving water of interest that forms the aquatic ecological system impacted by metals loadings and concentrations.

Individual source - An individual source can be an individual point source or a NPS area consisting of waste rock, tailings, or some type disturbed area for which metals might be leached from and transported and input to a stream segment. An individual source might have stations monitoring its drainage directly or bracketing it.

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X point source	① point draining background subbasin
🗇 nonpoint source	② point draining point source
● monitoring station	④ point draining subbasin and nonpoint source
⋯⋯⋯ stream	③⑤⑥⑧ points bracketing tributaries
– – – subbasin boundary	⑨⑩ points bracketing nonpoint source
⊢——⊣ limits of segment	⑪ point draining watershed
⋯⋯⋯⋯ example first order subbasin boundary	⑤–⑪ points within stream segment
	①–⑪ points within watershed

Figure 4.1.   Schematic representation of an IAM watershed and different spatial scales of interest

Type of source - A type of source is an aggregation of sources that are similar in nature, such as all point sources, all NPSs, or all background sources that might be contributing metals to a stream segment.

Subbasin - A subbasin is an area contributing drainage and metals to a given monitoring station within a stream segment. A first order subbasin is defined as an area contributing to a monitoring station where no other monitoring stations exist upstream or where one or more adjacent upstream monitoring stations form the upstream boundary of the subbasin. A subbasin can entirely or partially contain one or more stream segments, and discharges to a stream segment of the same or higher order.

Watershed - A watershed is an area contributing to a monitoring station that generally includes multiple monitoring stations and subbasins (although theoretically, a watershed with only one station at the mouth may also be considered a subbasin). A watershed may have one or more stream segments entirely or partially within it, and discharges to another stream segment of the same or higher order.

Based on these definitions of geographic and spatial scales of interest, targeting

IAMs can include comparing information on and selecting the following types of

populations:

- stream segments based on:
    - impairment of designated uses
    - ambient water quality (chemical concentrations and/or existing uses)
    - magnitude of loadings to segment
    - use attainability

- individual sources based on:
    - location of loadings relative to stream segment of concern
    - magnitude of loadings

- types of sources (i.e., all background sources, point sources, and/or NPSs) based on:
    - locations of loadings relative to stream segment of concern
    - magnitude of loadings

- subbasins based on:
    - location of loadings relative to downstream segment of concern
    - magnitude of loadings from all first order subbasins to stream segment of concern
    - magnitude of loadings

- watersheds based on:
    - location of loadings relative to downstream segment of concern

- magnitude of loadings from outlet

4.2   Information Goals

Well-defined information goals are required for the development of an effective

assessment methodology and attainment of overall management goals (Ward et al.,

1990).   Information goals, however, can only be defined after overall IAM

management goals are defined, and must be formulated based on these management

goals and targeting criteria. WGA states that future inventory and assessment work

requires well thought out goals (WGA, 1991). As stated above, information should

be somewhat consistent and comparable among sites for the effective targeting and

management of these sites. One of the key questions regarding information required

for the management of these sites is: "At a minimum, what kind of information and

how much information is required to make management decisions with a reasonable

degree of confidence?" Too much or the wrong kind of information results in

inefficient use of limited resources. Not enough or the wrong kind of information

results in an unreasonable amount of uncertainty associated with the information and

subsequent management decisions, as well as making wrong decisions.

Information goals can generally be divided into three categories (Adkins, 1993):

1.   regulatory information goals
2.   monitoring or assessment information goals
3.   statistical or quantitative information goals

Regulatory information goals are usually implied in somewhat vague regulations that

require some interpretation. Because no specific federal environmental regulations

currently address the vast majority of IAMs, these will not be considered directly.

Assessment information goals may be defined as qualitative statements which

describe specific information expectations of the assessment program. These are

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typically more specific than the regulatory information goals, but do not necessarily have to correspond to regulatory goals. Lastly, quantitative information goals are complete and specific statements that explain the quantitative (and statistical) intent. These goals should directly reflect the identified assessment information goals.

Another type of information goal that could be considered in addition to the three types discussed above is public information goals (Parsons, CDH, personal communication, 1994). Public information goals are those types of information that are presented to the public, especially local citizens, to gain their support and participation in the IAM management process. These types of information goals can include those defined above, but may emphasize certain types of information such as local economic impacts from existing environmental degradation, costs of remediation, benefits of remediation, etc.

The identification of information goals is complicated by the fact that (1) no specific regulations are currently in place and no clear regulatory information goals can be defined for IAMs that can be easily translated into specific assessment and quantitative information goals and (2) information goals can vary significantly among agencies depending on the specific management goals of each agency. This is why it is very important to first define overall management goals and targeting criteria for IAMs. Based on common management goals, some common, general assessment information goals for targeting can be defined for these sites. Specific quantitative information goals can then be identified for each assessment information goal.

4.2.1   Assessment Phases

Four primary phases of assessment as part of the effective management of IAMs can be defined as follows:

1. inventory

2. screening- or planning-level assessment for targeting sites for later detailed assessment and remediation

3. detailed assessment for remediation

4. long-term maintenance monitoring and assessment to evaluate effectiveness of remediation

Information goals can be defined for each of these phases. General information goals for the four phases are discussed in the following sections. This research focuses on the second phase, screening-level assessment for targeting. Specific information goals for this phase are discussed in detail in Section 4.2.2.

4.2.1.1   Inventory

The first general information goal for the initial management of IAMs is to determine whether a problem exists and to define the extent of the problem. This is part of the initial phase of the collection of very general baseline data and information. The number, locations, and general types of sites and associated water quality problems must be identified. The effective inventorying of IAMs is critical to achieving this goal. Inventorying has traditionally been performed to identify, locate, and qualitatively describe IAMs that might present public safety problems or hazards, such as open shafts. Inventorying, therefore, is the first step in the assessment process to address public safety hazards. Inventorying might also be the first step in the case of some water quality assessments if it can be used to identify potential source areas related to water quality concerns. In many cases, however, another approach might be more appropriate. As discussed previously in using a geographic approach to management, water quality concerns in priority stream segments can first be defined and the inventorying then performed in the specific

subbasins and watershed contributing metals to the water body.

One of the first steps in the inventorying process is to identify sites using USBM, USGS, USBLM, and state mining agency historical records regarding mining claims, permits, and extraction operations. Historical information may include types of metals mined or characteristic of the area; numbers, types and sizes of extraction/milling operations; and other physical and operational characteristics of each site (USEPA, 1977; USBM, 1993). USGS topographic maps, land ownership and use maps, and historical and current aerial photographs are also very useful for identifying potential sites.

Field reconnaissance should also be performed to confirm historical, map, and aerial photo information and to provide many types of important information that cannot be derived from these sources alone. Information regarding locations and proximity of nearby receiving surface waters is needed. The number and approximate sizes of streams, impoundments, and other surface water bodies in the vicinity of an IAM is required. This information includes visual estimates of physical characteristics including average channel cross-sectional areas, flowrates, and/or volumes of these features. If obvious seeps, point sources, or other pollutant releases are in the vicinity, their locations and estimated flowrates is very useful information. Visual observations of potential contamination or environmental disturbances are also required. These may include signs of fish kills or lack of aquatic life, devegetated areas and other terrestrial and riparian vegetation impacts, discoloration of and precipitates in water, and areas of erosion and sedimentation in upland areas and in stream channels.

Any previous water quality samples or flow data that have been collected certainly provide important information. This may include the number and locations of samples collected or flow estimates, the date of data collection, and the results of the previous water quality analyses and flow estimation. Information on locations, estimated areas and volumes, and composition of obvious waste source areas (such as tailings and waste rock) is also needed. Composition includes any chemical and physical characteristics from previous data or field observations, or preferably, from limited sampling conducted during the inventory. All of this information should be recorded in field logbooks and appropriate forms and delineated on USGS or more detailed topographic maps of the site. A computerized database for all inventory data and information should also be developed.

4.2.1.2   Screening-level Assessment for Targeting

The second phase of the IAM assessment process is the screening-level assessment for targeting critical areas for further more detailed study and/or remediation. The information goals for this phase can be generally defined by the information required for targeting. The screening-level assessment can be considered a continuation of the inventory in that more detailed baseline data and information are collected and evaluated. This screening-level assessment for targeting is the focus of this study. Specific information goals for this phase are discussed in detail in Section 4.2.2.

4.2.1.3   Detailed Assessment for Remediation

The third phase of the IAM assessment process that is sometimes required is a detailed assessment of priority sites for evaluation of potential remedial alternatives and engineering design. This type of assessment builds upon data collected

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previously as part of the inventory and screening-level assessment. Typically, however, more data are collected as part of this process that are specific to meet the information requirements for remediation purposes. More detailed statistical and quantitative analysis of the data from specific points of interest is possible given a larger data set and might be useful for design purposes. Deterministic or continuous simulation modeling for flows and water quality is sometimes used to evaluate potential changes in the flow regime and loadings due to specific remedial activities. Source areas, such as tailings, waste piles, adits, and disturbed land, and loadings and influent to a remedial system might be evaluated in detail in order to design the system and estimate its operational parameters. The theoretical reduction in source loadings, instream concentrations, and risk resulting from implementation of the system might be predicted quantitatively. These reductions are some of the primary factors that determine the effectiveness of the system. The reduction in external source loadings in most cases, however, will not provide immediate signs of success in restoring the water body because large quantities of metals are typically adsorbed or precipitated in the stream bed that will redissolve or otherwise be transported downstream for many years. Other factors that determine the effectiveness of the system might include low maintenance requirements, permanence, low cost, minimal waste generated, demonstration value, etc. The timeframe for risk reduction and system restoration might also be modeled and evaluated to select and design the best system. Methods discussed by Willingham and Medine (1992) might be useful for the detailed assessment phase.

4.2.1.4   Long-term Maintenance Monitoring and Assessment

The fourth and final phase of the assessment process is to evaluate the effectiveness of remediation and aquatic system restoration. Long-term maintenance monitoring and assessment of risk reduction and restoration is performed to meet this goal. Generally, trends and changes are quantitatively evaluated to ensure that loadings and concentrations are decreasing over time in important areas where remedial activities have been implemented. Aquatic life recovery and restoration should be evaluated in critical downstream areas. Statistical tests including hypothesis testing for trend and changes in means of populations is typically performed to quantitatively evaluate the effectiveness of remediation at a specific point or area of interest. Methods discussed by Loftis et al. (1991) can be useful for these purposes.

4.2.2   Screening-level Assessment Information Goals for Targeting

Screening-level assessment information goals can be generally defined by the information required for targeting. The screening-level assessment is the second phase of the collection of more detailed baseline data and information, and is the focus of this study. These goals are discussed in detail in the following sections.

4.2.2.1   State-level Targeting Criteria and Information Requirements

For state-level targeting, criteria and associated information requirements for each criterion are discussed below.

1. Severity or Threat of Impairment

The severity or threat of impairment is one of the most important criteria for targeting water bodies for restoration, and will affect the extent of remediation required. In order to determine the severity or threat of impairment of a water body,

information on the designated uses and associated numeric water quality standards is required. Information is also required on the existing uses, the concentrations of contaminants in the stream segment that are likely impairing the designated uses, the extent of stream impaired, and the frequency or risk of concentrations exceeding the standards. Biological indicators or biocriteria are often used to define the severity of impairment, especially for aquatic life uses. The extent and locations of NPS areas and magnitudes and risks of loadings within the watershed contributing to the water body are also indicators of impairment and can be used to define the threat of impairment. Determining the differences in concentrations between different stream segments is required to compare and prioritize stream segments. Differences in loadings to different stream segments is also important information for comparing and prioritizing stream segments.

2. Public Value of the Water Body

The public value of a water body is important for gaining public support for remediation and producing visible benefits. This criterion is often defined by the designated uses and/or the attainable uses. Some uses are perceived to have a higher value than other uses. Municipal water supply or aquatic life habitat, for example, might be considered to have a higher public value than recreational use. The number of uses of a given water body also affects the public value. The greater the number of uses, the higher the perceived public value. Information on designated and attainable uses, therefore, is required to evaluate this criterion. The amount of recreational activity, size of the water body, amount and quality of wildlife species and habitat, proximity to population centers, public access, and uniqueness of the water body are all additional possible indicators of public value. Some

professional judgement must be used when defining and ranking the public value of the water bodies.

3. Resolvability of NPS Impairment

The resolvability of the use impairment, including the feasibility and costs of possible solutions, is an important criterion for targeting limited resources and includes technical as well as socioeconomic considerations. Technical information includes the concentration that must be attained in the water body to achieve the designated use and the corresponding reduction in loadings that must occur to attain this concentration, physical habitat improvement requirements, engineering technologies available to achieve loading reductions and restore habitat, and time frame for restoration. Socioeconomic information includes funding availability and public support for remediation projects, and costs of specific technologies and alternatives.

4. Availability and Quality of Assessment Information

It is very difficult to remediate a water body or IAMs if little or no information on the area is available or if the quality of the information is not adequate. This criterion requires information on existing data and information derived from any previous monitoring and assessment work. Data obtained from inventories or the standards setting process are examples of this type of information.

4.2.2.2   Watershed-level Targeting Criteria and Information Requirements

For watershed-level targeting, criteria and associated information requirements for each criterion are discussed below.

1. Type and Severity of Water Resource Impairment

This criterion is important for targeting specific stream segments in a priority geographic area and for determining the extent and types of engineering controls that might be appropriate for remediating the problem. The information required for this criterion generally includes that required for the first criterion for state-level targeting, but also includes some more detailed information on the type of impairment. The impairment might be caused by excessive pollutant loading, high average or maximum concentrations, or high frequency of exceeding a given standard/concentration or loading. The impairment might be continuous, seasonal, or periodic during critical conditions. Controls for reducing loadings during storm events could be very different than those for reducing concentrations on a continuous basis. Impairments can include nonattainment of designated beneficial uses; metals concentrations often exceeding numeric water quality standards; acidic conditions; fish kills; aquatic life degradation; sedimentation; wetlands, riparian vegetation, and aquatic habitat degradation; aesthetic problems; and human health risks. A knowledge of the specific type of pollutant(s) causing the impairment is also needed. All of this information, therefore, is required to define the type of impairment and determine potential types of controls.

2. Source Magnitude Considerations

This criterion is the most important for determining the largest sources of loadings to an impaired water body and for identifying those sources for which engineering controls might have the greatest effect in restoring the designated use of the stream segment. Source magnitude considerations include information on aerial extent of NPSs contributing to the stream segment; concentrations or mass of

contaminants within the source areas; average loadings defined on a daily, seasonal, or annual basis; variability of loadings; extreme or critical loadings; and frequency or risk of extreme loadings under critical conditions. This information is required for types of sources, such as the total from all point sources, all NPSs, and all background sources. It is also required for individual sources and for entire subbasins and watersheds that are believed to be major contributors. Erosion rate is often required information because it is used in many cases to aid in the estimation of loadings of metals that can be highly adsorbed to and transported with sediment. Remediation could be targeted to a type of source (i.e., all point sources versus all NPSs), individual significant sources, individual subbasins, or entire watersheds. Determining the differences in loadings between different types of source populations, therefore, is required to compare and target types of sources. This information is required for differences between the total loadings from all point sources and NPSs, between individual significant sources, between individual subbasins, and between watersheds. Differences between loadings from IAMs and background sources is also required information for evaluating if natural background sources might be impairing the designated use. This is especially important because metal mining only occurs in mineralized areas that often produced natural metal inputs to receiving waters before mining operations. Natural sources, therefore, are often apparently the cause of NPS problems in mining areas. Information on the uncertainty of the estimates of magnitudes and variability is also required to estimate the confidence in derived information and in subsequent management decisions.

3. Transport Considerations

Transport considerations are important for targeting sources because many large source areas that release significant loadings can be distant enough from the impaired water body that they might not be impacting the stream significantly and can be eliminated from consideration for remediation. Although loadings from sources and subbasins in headwaters can be significant, a large percentage of the mass of the pollutant might not reach the impaired water body due to such processes as deposition or sedimentation of adsorbed contaminants, or biological uptake, infiltration to groundwater, or some type of conversion of dissolved and reactive contaminants. In addition, loadings to the downstream portion of an impaired stream segment might not have as much impact as loadings to the upstream portion of the segment. Transport considerations, therefore, include information on locations of loadings relative to the stream segment of concern, distance from individual sources to the nearest watercourse, distance from sources to the impaired stream segment, and locations and magnitudes of losses between the source and the stream segment.

4. Project Specific Criteria (Including Socioeconomics)

This criterion includes information that might be somewhat site-specific and not considered for the other criteria, as well as socioeconomic information that might impact targeting resources and remediation decisions. For example, level of available funding and public support for a particular type of remediation for specific sources, or costs of specific technologies relative to possible benefits, might be information required for this criterion. Preference for specific types of technologies, such as passive treatment or minimal maintenance technologies, might also be important information for this criterion.

4.2.2.3   Summary of Screening-level Assessment Information Goals for

Targeting

Based on the above targeting criteria, the general types of information required

by most agencies for screening-level assessment for targeting can be categorized and

summarized as follows:

- locations and extent of problems (use impairment, instream concentrations, and/or loadings)

- average magnitudes

- extreme (critical) magnitudes

- variability and uncertainty

- frequency or risk of extreme magnitudes

- differences between populations

- feasibility of remediation

These general types of information are required at several different temporal and

spatial scales as a result of the attributes of the data derived from the typical data

collection methodologies (discussed in Chapters 3 and 5) and as a result of different

management and targeting approaches.

Temporal Scales

The temporal scales of interest for information goals include the following:

- instantaneous (field measurement scale)
- daily
- seasonal
- annual
- various recurrence intervals of extreme events

Because many constituent concentrations are derived from grab samples and

instantaneous flow estimates are usually made, one important temporal scale for

information is instantaneous. From these measurements, estimates of daily loadings

and average daily concentrations are often made assuming that the measured instantaneous concentrations and flow rates at each monitoring station are constant over the day. These loading estimates are often used as the only means to locate potential loadings to receiving waters and estimate and compare their magnitudes. Daily loadings and mean daily concentrations are also important for the estimation of TMDLs, if this approach is used.

Because seasonality or differences between flow regimes is significant at most sites (primarily due to seasonal flow variation as a result of snowmelt and storm runoff), average or representative conditions during each important season (seasonal total or seasonal mean daily loadings and/or seasonal mean instream concentrations) is very useful information for comparisons among sites and targeting. Annual total or annual mean daily loadings and/or annual mean instream concentrations are also important for broad comparisons among sites and among different subbasins or watersheds. Because of the typical significant variation in flows and loadings between seasons at IAMs, however, annual estimates of these variables are not of much practical use. Stream standards for concentrations are typically not derived on a seasonal basis: the annual time scale is therefore important for concentrations. In addition, recurrence intervals (or frequencies) of extreme values or critical conditions for loadings and/or instream concentrations and probabilities (risks) of exceedances above specific water quality standards or loadings are of interest. These types of data and information are required for frequency analysis and evaluation of risks if a risk-based approach to the assessment process is desirable. Frequency and duration are important for deriving acute and chronic water quality standards for aquatic life, as well as for determining exceedances above these standards. For

example, CDPHE uses a 1-day duration and a 30-day duration with a frequency of three years for acute and chronic standards, respectively.

Spatial Scales

As discussed previously for targeting criteria, the spatial scales of interest for information goals include the following:

- individual point (monitoring station)
- stream segment
- individual source
- type of source
- subbasin
- watershed

Depending on where the receiving water of interest is located, information can be required at a specific point of interest draining a source, within a stream reach (possibly bracketing a source), at the outlet of a subbasin, or at the outlet of an entire watershed. It is even more useful for IAM management purposes to derive many types of information for an area such as a stream segment that has specific water quality standards and beneficial uses, a subbasin, or an entire watershed (Anderson, CDPHE, personal communication, 1993). After all, water quality management decisions are typically made for these types of areas, not points. Comparisons between and decisions regarding areas can then be made using this type of information. An individual stream segment with one classification and set of standards, however, can sometimes be very large. Information such as the average concentration in such a large segment is not of much practical use and does not have much physical meaning given the actual variability within a large segment.

A summary of specific screening-level assessment information goals for the various criteria for targeting includes the following (use of asterisk is explained

below):

- designated, existing, and attainable* beneficial uses of stream segments

- numeric water quality standards and maximum concentrations associated with uses*

- maximum loadings causing maximum concentrations associated with uses*

- type (high concentrations and/or loadings) and extent (locations, size, and/or degree) of water quality impairment and critical conditions (flow conditions, time of year, etc.)

- reductions in concentrations and/or loadings required to achieve desired beneficial uses*

- areal extent and contaminant concentrations of NPSs

- distances between sources and watercourses and impaired stream segments

- locations of loadings to and losses from stream segments

- magnitudes (and associated uncertainty) of:
  - concentrations in a stream segment
  - loadings from a type of source (background, point sources, or NPSs)
  - loadings from all contributing subbasins to stream segments
  - loadings from an individual source
  - loadings from an individual subbasin
  - loadings from a watershed

- differences between magnitudes of:
  - concentrations in different stream segments
  - loadings from different types of sources (background, point sources, and NPSs)
  - loadings to different stream segments
  - loadings from different individual sources
  - loadings from different individual subbasins
  - loadings from different watersheds

- frequency or risk* (and associated uncertainty) of exceeding a:
  - target concentration and/or numeric water quality standard (toxic to aquatic biota) in a stream segment
  - target loading from a type of source (background, point sources, or NPSs)
  - target loading from all contributing subbasins
  - target loading from an individual source
  - target loading from an individual subbasin
  - target loading from a watershed

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- remedial technologies available and costs

- funding availability and public support for remediation*

Information goals with asterisks represent information that is not necessarily considered baseline information on ambient conditions because there is some prediction or estimation of future conditions involved. For example, the determination of maximum concentrations associated with attainable uses generally requires some predictive modeling. These types of information goals are not as important initially for the screening-level assessment as other types of baseline information goals for ambient conditions given limited resources. Some of these goals could be addressed at a later time after the screening-level assessment for targeted stream segments or sources.

4.2.3 Quantitative Information Goals

Quantitative information goals must be well defined for the screening-level assessment information goals listed above in order to develop an effective assessment methodology. Specific quantitative information goals, however, cannot be defined for some of the assessment information goals because they are qualitative in nature and cannot be specified in quantitative terms. In any case, each assessment information goal is discussed in more detail below.

4.2.3.1 Designated, Existing, and Attainable Beneficial Uses of Stream Segments

The designated, existing, and attainable beneficial uses of stream segments must be identified and are generally described in qualitative terms, as discussed in Chapter 2. The total number of uses for a specific segment should also be determined. Designated uses are determined by the state environmental or water resources

regulatory agencies, although as stated previously, these designated uses might not always be appropriate for a given stream segment or assigned using optimal methods. The actual existing uses might be different from the designated uses and can be determined by evaluating the historical and current uses of stream segments. This may include deriving information regarding the aquatic ecology of the system including number, species, diversity, and biomass of fish, and the physical habitat. The attainable uses are the potential uses for the stream segment if contamination was not present and must generally be determined by implementing a use attainability analysis that includes a water body survey and assessment. This is generally a fairly expensive process, and should be performed only for those segments for which significant problems likely exist and restoration is seriously being considered. The actual desired designated beneficial use, known as a "goal" in Colorado, may be different than the current designated use and the attainable use. Although it can be the attainable use, it can also be a more practical use that can realistically be achieved given limited resources or technologies. The desired designated use is a goal that must be selected based on consensus among all stakeholders including regulatory agencies and the public who will be using the resource, and should be based in part on the attainable use, background loadings and concentrations of contaminants, regional concerns, public support, economics, funding availability, and availability of remedial technologies. For segments with multiple desired designated uses, numeric goals are set based on the most restrictive use.

4.2.3.2   Numeric Water Quality Standards and Maximum Concentrations
           Associated with Uses

Numeric water quality standards for specific water quality variables are associated with each designated beneficial use. These are assigned by the state environmental or water resources regulatory agency, using either prescribed state or national criteria for each constituent, or by developing site-specific standards. Development of site-specific standards is typically a fairly expensive process, and should only be performed for those segments of the highest priority. Variables of concern at IAMs for which standards can be defined include total and/or dissolved metals, acidity or pH, sediment (including substances that settle to form bottom deposits that can be either clean or toxic), and whole effluent toxicity (WET). Biological criteria can also be defined and used to set standards. Maximum or "target" concentrations are associated with the existing and attainable uses. For existing uses, these maximum concentrations can be considered ambient water quality criteria. For aquatic life uses, maximum concentrations are typically acute and chronic aquatic life criteria with a 1-day duration and a 4- or 30-day duration with a frequency of three years, respectively. The numeric standards and maximum concentrations associated with the uses might not always be appropriate and/or determined using optimal methods. In some cases, for example, ambient standards significantly higher than the acute or chronic aquatic life criteria may be used for segments not classified for aquatic life even though a viable fish population might exist or have existed in the past. In other cases, the data used to derive the ambient standards may also not be adequate or representative.

CDPHE determines numerical standards for dissolved zinc concentrations using one of three different methods:

1. TVSs that specify the following formulas:

$$Acute = e^{(0.8473[\ln(hardness)] + 0.8604)}$$

$$Chronic = e^{(0.8473[\ln(hardness)] + 0.7614)}$$

2. for the chronic standard, ambient quality-based standards based on the concentration of the 85th percentile of the metal cumulative frequency distribution based on available "representative" data

3. site-specific-criteria-based standards using bioassay or use attainability data

For the first method, the hardness value is based on either the lower 95 percent confidence limit of the mean hardness value at the periodic low flow criteria as determined from a regression analysis of site-specific data, or on other representative or regional data.

If no dissolved zinc data are available, numerical standards for total zinc concentrations can be computed using the concentration of the 50th percentile of the metal frequency distribution. According to the first method for dissolved zinc and the method for total zinc based on the estimated annual frequency distributions, there will be a 15 and 50% risk, respectively, that the estimated standards will be exceeded anywhere in the stream segment at any time during a year. The risks that the concentrations (standards) computed using the hardness data will be exceeded can also be estimated using derived cumulative frequency distributions. These issues related to frequency and risk are also discussed in Section 4.2.3.11

4.2.3.3   Maximum Loadings Associated with Uses

A maximum loading from the watershed to the stream segment is associated with each numerical water quality standard or maximum concentration and, ultimately,

with each beneficial use. This maximum loading can be estimated from existing data for existing uses or ambient conditions, as discussed in Section 4.2.3.9. For attainable or desired designated uses, however, these loadings must be estimated using some type of predictive modeling, as is used for the TMDL/WLA process for water-quality limited stream segments impacted by point sources. Some modifications of this method could be required to account for diffuse loadings under high flow conditions.

4.2.3.4 Type and Extent of Water Quality Impairment and Critical Conditions

This information is related to the beneficial uses, the magnitude of concentrations and loadings, and the frequency and duration of exceeding numeric water quality standards, target concentrations, or target loadings. For stream segments with aquatic life uses or potentially attainable uses, information on the locations, stream length, and degree of impaired aquatic ecology is required. This may include delineating areas with exceedances above acute and chronic standards on an annual or seasonal basis. Identification of seasonal problems can help define the critical conditions causing the impairment. Identification of the type of pollutant causing impairment is also important. Types of pollutants might include dissolved and/or total metals concentrations and loadings, acidity and low pH, and sediment.

4.2.3.5 Reductions in Concentrations and/or Loadings Required to Achieve Desired Beneficial Uses

The reduction in concentrations and/or loadings required to achieve the desired designated uses, target concentrations, and/or numeric standards is very important information for evaluating the feasibility and costs of remediation and must generally be determined using some type of predictive modeling. This reduction may be expressed as a percent reduction. The methods used for the TMDL/WLA process

might be applicable, although some modifications of the method could be required.

4.2.3.6   Areal Extent and Contaminant Concentrations of NPSs

The aerial extent of NPSs may be an indicator of potential loadings to a water body and includes the areas for individual large sources or sources that are believed to be significant metals contributors to the stream segments of concern. It also includes the total NPS areas within individual subbasins and within the entire watershed of interest. The NPS areas can be expressed as total areas (acres, square miles, etc.) as well as the percentage of NPS areas relative to the total area of an individual subbasin or of a watershed. The areal extent of NPSs in a watershed can also be used to estimate costs of remediation. For individual waste areas such as tailings piles, the volume of waste material is also important information that may be an indicator of loadings and can be used to estimate costs. All of this information can be derived from site maps, aerial photographs, and field reconnaissance (inventories). Contaminant concentrations or total mass within the NPS area may also be an indicator of loadings to downstream receiving waters. Concentration can be expressed as mass per unit mass or as a percentage based on limited areally-composited sampling.

4.2.3.7   Distances Between Sources and Watercourses and Impaired Stream
                Segments

The distances between sources and watercourses and between sources and the impaired stream segment should be determined for individual large source areas or areas that are believed to release significant quantities of contaminants, as well as for individual subbasins and/or watersheds that can contribute to a stream segment of concern. Greater losses generally occur with increasing distance, and the distance

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is related to the estimation of first order kinetic losses and travel time. The distance can be expressed in miles or feet. Any obvious isolating factors where losses of loadings can occur, such as impoundments, dams, or surface water features that are dry most of the time, should be described and delineated on a map. This information can be obtained from site maps, aerial photographs, and field observations.

4.2.3.8 Locations of Loadings to and Losses from Stream Segments

The locations of loadings of metals to stream segments should be determined based on monitoring data and field observations. Individual sources near the segment that could be contributing directly to the segment should be identified and delineated on the site map. Tributaries (subbasins and/or watersheds) that are contributing metals to the segment should also be identified and delineated. Some of the locations of loadings can be monitored directly in the drainage from an individual source adjacent to the stream or at the mouth of a tributary. Alternatively, the locations of loadings can be estimated using the NPS reach gain/loss analysis approach by bracketing individual source areas, tributaries, or more widespread NPS areas. Estimates of locations of loadings can also be made using visual observations of areas of erosion and sediment deposition, staining and discoloration, metal precipitation, etc. The locations of losses from the stream segment must be estimated using the NPS reach gain/loss analysis (negative differences in loadings between adjacent stations) and/or visual observations.

4.2.3.9 Magnitudes of Concentrations and Loadings

Finite resources dictate that the magnitudes of pollutant concentrations in and loadings to a stream segment must be estimated with limited data. Uncertainty of

the values will be associated with every measurement and should be estimated explicitly to provide an indicator of the confidence associated with subsequent management decisions.

Required information related to magnitudes of concentrations in a stream segment that is most common among agencies and water quality studies in general is as follows:

- mean concentration and 90% (or 95%) *CI* for each season and for a year

- median concentration and other percentiles and 90% (or 95%) *CI* for each season and for a year

- standard deviation of concentrations and 90% *CI* for each season and for a year

- minimum and maximum concentrations for each season and for a year

Although annual values are not generally recommended due to the potential for significant seasonality, most numeric water quality standards for stream segments are currently established on an annual (not seasonal) basis.

Required information related to magnitudes of loadings to stream segments that is most common among agencies and water quality studies in general is as follows:

- mean daily loading for each season

- mean daily loading for a year and 90% *CI*

- total loading for each season and for a year

- percentage of mean daily and total loadings from a specific source relative to all loadings to a stream segment for each season and for a year

- percentage of total loadings for each season relative to total loading for a year from a specific source

- standard deviation of seasonal mean daily and total loadings and 90% *CI* for a year

- minimum and maximum seasonal mean daily and total loadings for a year

This information might be required from all contributing first order subbasins, from each type of source (background, point sources, and NPSs), from an individual source, from an individual subbasin, and from a watershed to a stream segment. In addition, for each of these sources except for point sources, the required information that is most common is as follows:

- mean (and median) daily unit area loading and 90% (or 95%) *CI* for each season and for a year

- total unit area loading for each season and for a year

- percentage of total unit area loadings for each season relative to total unit area loading for a year from a specific source

- standard deviation of seasonal mean daily and total unit area loadings and 90% *CI* for a year

- minimum and maximum seasonal mean daily and total unit area loadings for a year

Ninety or 95% *CI*s are standard *CI*s used in water quality assessment. A 90% *CI* might be preferred given the general lack of data at these sites, particularly for a point and for estimation of the standard deviation.

4.2.3.10   Differences Between Magnitudes of Concentrations in and Loadings to Stream Segments

Information related to differences in concentrations between two or more different stream segments and in loadings from different source areas is required for the targeting approach. Simple comparison or ranking of magnitudes in different locations is appropriate when beginning the targeting process to identify the worst areas first. However, as the targeting process proceeds and two or more specific sites are being targeted and seriously considered for remediation, for example, the

differences between the sites is required information for actually selecting sites and will need to be evaluated.

Required information on differences between concentrations in different stream segments that is most common among agencies and water quality studies in general includes the magnitude of differences and relative differences between mean (and median) concentrations for a season and between concentrations for a year.

Required information related to differences between loadings across locations that is most common includes the magnitude of differences and relative differences between mean daily (and total) loadings for a season and between mean (and median) daily (and total) loadings for a year. This information is required for differences between loadings from all first order subbasins contributing to different stream segments. It is also often required for differences between loadings from different types of sources (background, point sources, and NPSs), different individual sources, different individual subbasins, and from different watersheds to an individual stream segment. In addition, for each of these sources except for point sources, required information related to differences between loadings that is most common includes the magnitude of differences and relative differences between mean (and median) daily (and total) unit area loadings for a season and between mean (and median) daily (and total) unit area loadings for a year.

In most cases the absolute magnitude of the difference in concentrations or loadings between two areas is not as important as the relative difference. Information on the magnitudes at each location and direct comparison by observing the values and relative differences at multiple locations, ranking the values, and computing relative differences is most common. However, the confidence in the

relative differences is desirable and must be estimated by first estimating the confidence in the absolute differences.

In some cases, the significance of the differences is needed in order to decide which area is worse with an acceptable degree of confidence. This is the case with many common environmental studies, and hypothesis tests have been used extensively for environmental pollution monitoring throughout the years. However, it has been shown that hypothesis testing has severe shortcomings with regard to decision-making and is generally not recommended (McBride et al., 1993). The interval estimation of differences, as discussed above, is preferred.

4.2.3.11   Frequency or Risk of Exceeding a Target Concentration in and Loading to a Stream Segment

The frequency or risk of exceeding a specific concentration in a stream segment is very useful information, especially for establishing ambient stream standards. The 90 or 95% *CI* for the estimated risk is also useful because it provides an explicit estimate of the uncertainty associated with the estimated risk. This information might be required at different time scales including a year, a season, or for a longer time period such as three years. This type of information is also useful for loadings to a stream segment. The frequency or risk and 90 or 95% *CI* of exceeding a target loading (such as a TMDL) is useful information at the different time scales of interest. This information can be required for the frequency of exceeding a target loading from all first order subbasins contributing to a stream segment, or from each type of source (background, point sources, and NPSs), from an individual source, from an individual subbasin, or from an entire watershed to a stream segment.

4.2.3.12   Remedial Technologies Available and Costs

Appropriate remedial technologies must be available to apply to targeted source areas and stream segments. The types and availability of remedial technologies for specific types of sources and impaired stream segments is information required for targeting. Most technologies for control of NPS pollution are BMPs, and are readily available. Technologies that are passive in operation and are designed incorporating the natural features of the site (such as topography and existing wetlands) based on site-specific conditions to minimize long-term operation and maintenance costs are preferred. Descriptions and appropriate applications of these technologies are generally presented in the literature and some information on their performance might be available from the results of various existing NPS control demonstration projects.

The costs of remediation must also be estimated in order to target critical areas. In addition to identifying the remedial technologies available, the areal extent of NPSs and volumes of waste material must be estimated to compute costs. The reduction in concentrations and loadings required to achieve the desired designated beneficial uses by applying these technologies must also be estimated in order to evaluate costs.

4.2.3.13   Funding Availability and Public Support for Remediation

Funding and public support for remediation of particular source areas and stream segments must be available. Public support will generally lead to more funding. Information regarding this availability is required for targeting areas for remediation. This type of information must be obtained from local citizens, mining companies, and local, state, and federal agencies with jurisdiction in the area of interest. Public

support can often be gained by providing appropriate information to the public regarding the problems in the area and the potential remediation schemes, as well as by including citizens in the entire planning, assessment, and remediation process by soliciting their input at public meetings and including them on steering committees. This public involvement is critical for a successful mine remediation and NPS control project given limited resources.

5.0 DATA ATTRIBUTES

In this chapter attributes of data derived from typical synoptic surveys of IAMs are identified. These attributes might impact data analysis methods used to reach the defined quantitative information goals and must be dealt with prior to or within data analysis. In Appendix A, the attributes are discussed and evaluated using data from case study IAMs: the Upper Animas River Basin near Silverton in the San Juan Mountains in southwestern Colorado and the Pecos (Tererro) Mine near Santa Fe in northern New Mexico (discussed in the next section). These attributes affect the applicability, choice, and interpretation of specific data analysis methods.

Attributes of typical IAM data that are important in the identification and selection of analysis methods and are evaluated as part of this study include (Adkins, 1993):

- measurement error and variability
- sample size
- multiple observations for a single sampling time
- censoring
- changing sampling frequencies and missing values
- nonnormality
- seasonality

Serial correlation and outliers are data attributes that are not examined as part of this study. Serial correlation is typically a problem when analyzing data for trend and for some tests for seasonality. This data attribute is not generally a concern for the analysis of data derived from IAMs using synoptic surveys for the following reasons:

1. Data are usually collected infrequently enough (quarterly at most) over such a short time frame (one or two years at most) that (a) serial correlation is not a problem and (b) trend analysis is not practical and the existence of temporal trends is not an information goal for targeting or screening-level assessment.

2. Some types of tests for seasonality that must make use of data derived from high frequency monitoring are usually not feasible based on the synoptic monitoring approach.

In addition, these data collected over a short time span (i.e., one or two years) are usually not representative of long-term conditions. It is also assumed for the purposes of this research that appropriate sample validation and quality control will be performed by the agency conducting the assessment and measurement or recording errors will be minimized as part of their overall quality assurance/quality control (QA/QC) program. Outliers, therefore, will probably represent natural extreme flows or contamination and are not considered a data attribute that must be identified, tested for, and eliminated as part of this study. Apparent outliers are generally data points that must be retained and evaluated with the rest of the data to derive the desired information.

5.1 Case Study IAMs and Data

Case study IAMs and associated data sets will be used to develop the assessment methodology. This section presents a brief discussion of the watersheds and monitoring methods used to derive the data for which attributes will be evaluated and assessment methods will be developed. The actual detailed evaluation of the attributes of interest for the Cement Creek basin and Pecos Mine site data is presented in Appendix A.

Data derived from the Upper Animas River Basin have been collected by CDPHE as part of a NPS demonstration program grant (CWA Section 319) from

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USEPA (CDPHE, 1992, 1993a). CDPHE has provided all of the data collected and is seeking assistance in analyzing the data and recommendations for useful data analysis procedures for targeting critical areas. Four synoptic monitoring events have been implemented during different flow regimes of interest (Section 5.1.1).

The Upper Animas River Basin above Silverton is an historic metal mining district whose streams have been severely impacted by mine drainage. The watershed has an area of approximately 146 mi^2 and ranges in elevation from 9,200 feet to over 13,000 feet. Alpine tundra and Englemann spruce-fir forest are the dominant community types. The watershed is composed of three primary subbasins. The upper mainstem Animas River subbasin is the largest subbasin and is heavily impacted by past metal mining activities. Cement Creek joins the Animas River immediately above Silverton, and the subbasin appears to have been even more severely impacted by past metal mining activities. Mineral Creek joins the Animas River immediately downstream from Silverton. This subbasin is also impacted by past metal mining activities, but not to the extent of the other two subbasins. The Cement Creek subbasin will be the focus of this study because it is believed to be the most heavily impacted subbasin, and the mainstem of Cement Creek and all of its tributaries are categorized by CDPHE (1993b) as one stream segment with a common designated beneficial use classification and associated water quality standards.

Although data from the Cement Creek basin and the Pecos Mine site will be very useful for the initial development of the assessment methodology, data from other IAM watersheds will also be useful during subsequent studies to evaluate, test, and refine the recommended methodology.

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An effective screening-level assessment methodology will probably require the use of an "indicator" or "representative" metal of concern to initially utilize resources efficiently for targeting source areas. A simple screening of data (discussed below) could be used to identify the best water quality variable to use as an indicator metal. Based on the Cement Creek data, dissolved zinc is the best variable to use as an indicator and initially to develop a screening-level assessment methodology for the following reasons:

- CDPHE is using dissolved zinc as a representative metal to define loadings to water bodies in the basin.

- A dissolved zinc standard of 225 micrograms/liter (μg/L) for brown trout is the new water quality goal for the Upper Animas River below Cement Creek. This is the only new, more restrictive proposed standard in the basin because zinc is the primary metal of concern.

- The fact that zinc is the primary metal of concern is evident from an initial screening of all of the metals data to estimate and compare the mean concentrations, maximum concentrations, chronic and acute fish standards, and number and frequency of exceedances of aquatic life standards and toxicity and impacts to fish (this screening procedure is discussed in more detail in Section 6.1).

- Zinc is generally present at higher concentrations than most other metals, thereby increasing the accuracy of the values because they are not as close to the analytical detection limit as the values for most other metals (such as cadmium).

- Dissolved zinc is relatively conservative (nonreactive) compared to other metals, making it somewhat easier to evaluate without considering significant instream processes.

- Zinc has a high solubility at pH less than eight, resulting in potential significant downstream transport.

Other constituents of potential concern in Cement Creek and the Upper Animas River below Cement Creek include aluminum, cadmium, and iron. Although the concentrations and toxicity of these constituents are higher in Cement Creek than in

the other basins, the metals are present at lower concentrations than zinc throughout all of the basins. These metals are present at toxic concentrations in only a few areas. Cadmium is similar to and correlated with zinc in that (1) most of the cadmium is in the dissolved, or bioavailable, form at the pHs exhibited in Cement Creek and (2) cadmium in streams is derived from the same types of source areas as zinc and is mobilized by acidity. Aluminum and iron, on the other hand, are different from and might not be correlated with zinc in that these metals precipitate out of solution at lower pHs, and are indicative of weathering of pyritic materials in the watershed. Adsorption and precipitation of these metals onto solids and stream bed material is a significant problem with regard to impacts to benthic macroinvertebrate communities (fish food supply) and fish spawning areas. This appears to be primarily a problem in the Upper Animas River below Cement Creek. Overall, however, the problem of metals coatings on the stream bed still does not appear to be as significant as the toxicity of zinc to fish.

An alternative or supplement to using a screening-procedure as described above is development and use of a correlation matrix to select an indicator variable. However, this procedure was not performed as part of this study and should be evaluated as part of future research.

Although using zinc alone as an indicator metal is sufficient for the initial development of the methodology given all of the reasons stated above, use and evaluation of other constituents (such as aluminum or iron) would be valuable and can be performed during subsequent studies.

Dissolved and total zinc data derived from the Pecos (Tererro) Mine site in northern New Mexico will also be used to a limited extent. This is a small inactive

lead-zinc mine where more than ten data points are available for some individual monitoring station locations or points of interest as a result of quarterly monitoring for more than two years. Again, zinc (both dissolved and total) is the primary metal of concern in this basin. These data will be useful for evaluation of applicable data analysis methods for individual stations where data are typically lacking. Like the Upper Animas River Basin, this watershed is forested and has steep terrain in a subalpine environment.

5.1.1   Upper Animas River Basin Data Collection

CDPHE has collected data from the Upper Animas River Basin during the following four flow regimes:

1.   storm flow (9/7/91)
2.   snowmelt flow (6/24/92)
3.   baseflow (10/14/92)
4.   receding limb of snowmelt flow (7/21/93)

Figure 5.1 presents a general map of the Upper Animas River Basin. All monitoring stations used by CDPHE are shown in Figure B1 in Appendix B. For synoptic surveys typically used for IAM monitoring and assessment, instantaneous measurements are common that include concentrations from the analysis of grab samples and flowrates (cubic feet per second [cfs]) estimated from the velocity-area method using a current meter. In the case of the Upper Animas River Basin study, "grab" samples were collected using a standard U.S. U-59 suspended sediment sampler across the width and depth of the stream cross-section, resulting in a sample that is actually a depth- and width-integrated composite of the cross section. This method minimizes the possibility that the sample will not be representative of the stream water. Samples were filtered (0.45 micron filter) in the field and analyzed at

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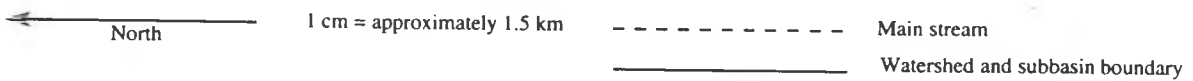
Figure 5.1. Upper Animas River Basin

the CDPHE laboratory for dissolved (soluble) metals, reported in μg/L. For the storm event, total recoverable (total) metals were also analyzed from unfiltered samples. Measurements of field parameters were also taken and included pH (pH units), temperature (degrees C), and specific conductivity (μmhos).

For the Cement Creek subbasin, 49 monitoring stations have been used. Some of these stations monitor background conditions, some monitor NPS areas, and some monitor point sources. Not all of these stations have been sampled during every flow regime. Changing sampling frequencies and missing values, therefore, are the result. To a certain extent, this is a logical and practical way to perform the synoptic surveys because data from one survey can indicate that for the next survey, some locations should be added to the network to provide additional information or that some stations do not need to be sampled again because the area monitored is not a problem or the information derived is repetitive.

5.1.2   Pecos Mine Site Data Collection

Water quality data have been collected at the Pecos Mine site quarterly or more frequently for more than two years using the same methods as discussed above for the Upper Animas River basin. Standard grab samples, however, have been collected at this site. In addition to dissolved zinc, total zinc has been measured. Two monitoring stations are located in Willow Creek, a small tributary flowing past a waste rock pile into the Pecos River. One station is upstream from the pile and is considered a background station. The other station is immediately downstream from the pile. Two stations are also located in the Pecos River: one is upstream from the pile and is considered a background station, and one is downstream from the pile.

5.2   Data Management

Prior to a detailed discussion regarding evaluation of data attributes in Appendix A, some general discussion of procedures for management of data once they have been collected is required. A very large quantity of data can be generated from a monitoring program in a mined watershed of considerable size such as the Upper Animas River Basin. For an effective information system and conversion of data to specific information, data management and manipulation procedures must ultimately be dependent on the selected data analysis and presentation methods. Data management, therefore, is actually an ongoing process throughout the assessment, and is performed as part of data input, analysis, and reporting.

All data for the Upper Animas River Basin were obtained from CDPHE, and data from the Pecos Mine site were obtained from the Cyprus Amax Corporation, in both hardcopy and diskette form. The diskette data were in a spreadsheet format. All unnecessary or ancillary analytical data for the purposes of this study were eliminated from a copy of the spreadsheet. Data attributes of each sample that were retained include watershed, subbasin, stream segment, station identification, sample date, dissolved and total zinc concentrations (μg/L) (and other metals when required), pH, and corresponding flowrate (cfs). All raw data from a subset of the stations are presented in columns A through N in Table C1 in Appendix C.

Information goals discussed in Chapter 4 include loadings at each monitoring station for each measurement. For each Upper Animas River Basin sample, therefore, daily dissolved zinc loading was automatically calculated in the spreadsheet using the following equation:

$$L = QCK \qquad\qquad (5.1)$$

where:

> L = constituent loading (grams/day [g/d])
> Q = flowrate (cfs)
> C = dissolved zinc concentration (μg/L)
> K = conversion factor (converts cfs to liters/day [l/d] and μg/L to grams/liter [g/L])

Loading estimates for a station located immediately downstream from another monitoring station(s) are cumulative and are a summation of the loadings at the upstream stations and (1) any other inputs to the stream from the subbasin in between the upstream and downstream location draining into the downstream station, and (2) loss of mass from the stream. A NPS reach gain/loss analysis, therefore, was used. This method uses measured loadings at each monitoring station to estimate additional loadings and potential losses of contaminant mass that are not measured directly (CDM, 1990; CDPHE, 1993a). Loadings measured in streams at an upstream point (in some cases, up to three upstream points) $(Q_{u1}C_{u1},...,Q_{u3}C_{u3})$ were subtracted from the loadings measured at the adjacent downstream point $(Q_d C_d)$ to estimate NPS loadings to the stream from the subbasin between the two points using the following equation:

$$L = Q_d C_d - Q_{u1}C_{u1} - ,\ldots, - Q_{u3}C_{u3} \qquad\qquad (5.2)$$

If the loading at the downstream point is less than the total loadings at the upstream points, an overall loss of mass in the channel can be assumed. This loss may be attributed to and indicate areas of infiltration to groundwater, metals adsorption to or precipitation on solids, biotic uptake, etc. for dissolved metals, or dissolution or sedimentation, etc. for metals associated with solids.

In cases where the loading estimated using this procedure was negative for the purposes of this study, a loading of zero from the first order subbasin between the upstream and downstream monitoring stations was assumed. This is considered an indirect estimate of the lower limit of the loading to the system from the subbasin, and an indirect estimate of the lower limit of losses from the stream (i.e. losses from the stream must be greater than zero). The estimate of zero loading from the first order subbasin was then lumped with the other loadings from first order subbasins estimated directly from measured data and considered one population for the purposes of evaluation of data attributes and data analysis. All loading estimates are presented in column O in Table C1 in Appendix C.

Information on unit area loadings (Us in grams/acre-day) for each first order subbasin was also identified in the quantitative information goals. These units of measurement are required because loading is a function of flow which is in turn a function of the area of each contributing subbasin area. The daily loading data is normalized by dividing the loading (L) for each subbasin by the corresponding subbasin area (A in acres) as follows:

$$U = \frac{L}{A} \qquad\qquad (5.3)$$

These unit area loadings to each stream segment of interest can then be grouped together and analyzed as one population of interest, as discussed in Chapter 4 of this report. The area of each subbasin was estimated using the following procedure:

1. Obtained USGS 1:24,000 scale topographic maps of the Cement Creek watershed.
2. Identified each monitoring station location on the maps.
2. Delineated the subbasin draining into each station on the maps.
3. Estimated area of each subbasin using a planimeter.

Unit area loading estimates are presented in column AA in Table C1 in Appendix C.

Detailed discussion of specific data management procedures for the evaluation of data attributes is presented in the discussion for each data attribute in Appendix A.

6.0   DATA ANALYSIS METHODS

Seven of the quantitative information goals identified in Chapter 4 have been selected to apply, evaluate, and recommend specific data analysis methods as part of an overall assessment methodology for IAMs:

1.   Type and extent of water quality impairment and critical conditions.

2.   Areal extent and contaminant concentrations of NPSs.

3.   Magnitudes (and associated uncertainty) of concentrations in and loadings to stream segments.

4.   Locations of loadings to and losses from stream segments.

5.   Distances between sources and watercourses and impaired stream segments.

6.   Differences between magnitudes of concentrations in and loadings to stream segments.

7.   Frequency or risk (and associated uncertainty) of exceeding a target concentration in and loading to stream segments.

This chapter discusses specific data analysis methods that can be used to reach each of these information goals. It also presents methods for information presentation, interpretation, and use as part of the targeting process. The methods presented are applied, tested, and evaluated using data from the Cement Creek basin in Appendix D. The methods will be considered useful if the information goals can be achieved and if impaired stream segments and source areas can be targeted for remediation in an efficient manner. After the specific methods are applied and evaluated, the overall assessment methodology, which is a logical integration of many of the

different specific methods discussed in this chapter, is formalized and evaluated in Chapter 8.

6.1   Information Goal #1. Type and Extent of Water Quality Impairment and Critical Conditions

It is difficult to define this information goal in specific quantitative terms. This information is related to the beneficial uses, the magnitudes of concentrations and loadings, and the frequency of exceeding numeric water quality standards, target concentrations, or target loadings. It is also related to the locations of loadings because locations help define the extent of the impairment.

The type of impairment in the stream segment is often known in general terms prior to the assessment phase. Knowledge of some type of impairment is usually the initial catalyst for the assessment and targeting process. The type of impairment is usually defined in terms of the type of beneficial use impairment, as discussed in Chapter 4. It can also be defined by the following:

- specific pollutants or combination of pollutants causing the impairment (these might include metals concentrations and loadings, acidity and low pH, and/or sediment/precipitates)

- whether high concentrations or high loadings (and subsequent precipitation/adsorption, deposition, or high concentrations) are causing the problem

- whether dissolved metals or adsorbed metals are causing the problem

- whether it is an acute or chronic problem

All of these issues can also help define the critical conditions causing the impairment. Critical conditions can also be defined by the existence and magnitude of seasonality of loadings and concentrations and by differences in seasonal values.

Methods for evaluating seasonality are discussed in Appendix A, and differences in seasonal values are discussed for information goal #3. These methods would be useful for helping to determine critical conditions.

The pollutants causing the problem can be identified by sampling and analysis (estimation of magnitudes) of a range of constituents that could be problems (i.e., zinc, iron, and sediment). A simple screening procedure can be used to identify the primary constituents of concern that might be used as indicators of the worst problems and for carrying through the entire assessment. This could first involve estimating the mean value and maximum value (using the methods discussed for information goal #3) for each potential constituent of concern (metal) within the basin and identifying which analyte concentrations appear highest. Potentially applicable standards should also be computed, especially for protection of aquatic life. These can be derived from the state environmental protection or water resources agency. The number or frequency of exceedances of the most stringent standards can be computed and is a good indicator of which metals are problems and should be evaluated in detail.

Whether high concentrations or loadings are causing the problem can be complex, but both are also evaluated as part of information goal #3. Sampling and analysis of both dissolved and total metals concentrations and computing the ratio of dissolved concentrations to total concentrations can be used to aid in determining if dissolved or adsorbed metal concentrations are the primary problem. Whether it is an acute or chronic problem can be determined by first estimating magnitudes and then determining whether acute or chronic standards are exceeded.

The extent of the water quality impairment is usually defined in terms of the degree of beneficial use impairment. For most stream segments, this will include information on the locations, stream length or area, and frequency and duration of contaminant concentrations exceeding water quality standards or target concentrations. For stream segments with aquatic life uses or potentially attainable uses, this type of information on the extent of impaired aquatic ecologic conditions is also required. This might include delineating areas with exceedances above acute and chronic standards on an annual and seasonal basis. Once the magnitudes of concentrations and loadings are estimated using the methods discussed for information goal #3, the locations and stream length of concentrations exceeding standards can be determined (also using methods discussed for information goal #3).

The frequency of concentrations exceeding standards and loadings exceeding target values is addressed under information goal #7.

6.2 Information Goal #2. Areal Extent and Contaminant Concentrations of NPSs

The aereal extent of NPSs includes the areas for individual large sources or sources that are believed to be significant loaders to the stream segments of concern. It also includes the total NPS areas within individual subbasins and within the entire watershed of interest. The NPS areas can be expressed as total areas (acres, square miles, etc.) as well as the percentage of NPS areas relative to the total area of an individual subbasin or a watershed. This information must be estimated from site maps, aerial photographs, and field reconnaissance during the inventorying of sites. The field reconnaissance is particularly important for estimating areal extent because these features are not always easily distinguishable on small-scale maps and aerial photographs. Contaminant concentrations can be expressed as mass per unit mass

or percentage based on limited areally-composited sampling. Volumes of waste material can also be estimated in the field in cubic feet or yards.

6.3   Information Goal #3. Magnitudes of Concentrations and Loadings

The magnitudes of metals concentrations in and loadings to stream segments must be estimated with limited data, and the uncertainty of the values should also be estimated to provide an explicit indication of the uncertainty associated with the assessment and subsequent management decisions.

6.3.1   Concentrations

Section 4.2.3.9 in Chapter 4 presented in detail the quantitative information goals for magnitudes of concentrations in stream segments. This section discusses methods that can be used for deriving this information for IAMs.

6.3.1.1   Mean, Median, and *CI*s of Concentrations

As discussed in Appendix A, the mean and median are statistical estimators of the central tendency of a population, while the *CI* is an estimate of the confidence or uncertainty of the estimator. The mean might not be a good estimator of central tendency or average conditions if the population distribution is not normal (right skewed) or there are large extreme values or outliers. The population mean (μ) can be estimated by the sample mean $(\bar{x})$ using Equation A.2.

The population mean concentration in a stream segment for a season can be estimated by the sample mean concentration for a season $(\bar{C_s})$ using Equation A.2 where:

$$\bar{x} = \bar{C_s}$$
$$x_i = C_i = \text{concentration for sample } i$$
$$n = n_{cs} = \text{sample size for concentrations for season}$$

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If multiple stations within the segment are used to estimate the mean for the season, then n is equal to the total number of samples collected at these stations during the season of interest. It is implicitly assumed that the concentration measured at each station during that season is generally representative for that station for that season, but not necessarily for the whole segment. If only one station is used to estimate the mean in the segment for the season, n is equal to 1 and a true seasonal mean cannot be computed. It is also assumed in this case that the concentration measured at the station is representative for that station for that season. This may be an adequate assumption for baseflow conditions, but not necessarily for snowmelt or storm flows. Variability in runoff temporal and spatial patterns can make instream concentrations highly variable during a given storm or snowmelt event or among events. However, if the storm or snowmelt event sampled is generally representative of average storm or snowmelt conditions, this assumption may be reasonable.

The mean concentration in a stream segment for a year can be estimated by the sample annual mean concentration $(\bar{C}_a)$ using Equation A.2 where:

$$\bar{x} = \bar{C}_a$$
$$n = n_{ca} = \text{sample size for concentrations for year}$$

and x_i is defined as above. If multiple stations within the segment are used to estimate the mean, then n is equal to the total number of samples collected at these stations throughout the year. If, however, only one station is used to estimate the mean in the segment for the year, n is equal to n_{se} (the number of seasons is equal to 4) and includes each seasonal concentration value.

The $100(1-\alpha)\%$ CI width about the sample mean (CI_m) is computed using Equation A.7. For the sample seasonal mean concentration $100(1-\alpha)\%$ CI width

(CI_{mcs}):

$$v = v_{cs} = (n_{cs}\text{-}1)$$
$$s = s_{cs} = \text{sample standard deviation for concentrations for season}$$

For the sample annual mean concentration $100(1\text{-}\alpha)\%$ CI width (CI_{mca}):

$$v = v_{ca} = (n_{ca}\text{-}1)$$
$$s = s_{ca} = \text{sample standard deviation for concentrations for year}$$

The sample standard deviation (s) and the variance (s^2) are estimators of the variability of the population of interest. The sample variance is computed using Equation A.8. For the sample standard deviation of the concentrations for a season (s_{cs}) and the variance for a season (s_{cs}^2), n, $\bar{x}$, and x_i are defined as above for $\bar{C_s}$. For the sample standard deviation for a year (s_{ca}) and the variance for a year (s_{ca}^2), n, $\bar{x}$, and x_i are defined as above for $\bar{C_a}$.

The sample median (x_{50}) is the 50th percentile of any sample distribution, and is generally a better estimator than the mean of central tendency or average conditions for nonnormal (right skewed) distributions because it is based on the ranks of the data and is not as sensitive to large extreme values or outliers. In many cases for screening-level studies, it is assumed that the distribution of interest follows a normal distribution. In some cases a lognormal distribution is assumed because the data appear nonnormal. The importance of the normal assumption is indicated by the amount of nonnormality as measured by the skewness (discussed in Appendix A) or difference between the mean and median. For example, if the mean and median values are fairly close, the distribution might be close to normal, and the normal assumption might be adequate. If, however, the median is significantly smaller than the mean, as is the case for most of the zinc loading data, the distribution is not

normal, and the assumption of normality is not valid. In this case, estimating mean values would probably overestimate average conditions, thereby biasing decisions regarding targeting. However, mean values would still be correct for use in estimating the total mass loads for a given season or year.

The x_{50} is computed using the procedure discussed in Appendix A and equations A.9 and A.10. For the sample median concentration in a stream segment for a season (C_{mds}), x_i and n are defined as above for $\bar{C}_s$. For the sample median concentration in a stream segment for a year (C_{mda}), x_i and n are defined as above for $\bar{C}_a$. The 95% CI about x_{50} (CI_{md}) can be derived from Table A14 in Gilbert (1987). The 90% CI_{md} can be derived from Geigy (1982, pp. 103-107).

In some cases, a quantile (x_p) other than x_{50} is needed, such as when determining an ambient stream standard based on the concentration of the 85th percentile of the data (x_{85}). A simple nonparametric method for estimating quantiles is to use the order statistics discussed above for x_{50} (equations A.9 and A.10). To estimate x_p, compute the following:

$$k = p(n + 1) \qquad\qquad (6.1)$$

If k is an integer, the estimated pth percentile, x_p, is the kth order statistic $x_{[k]}$ (the kth largest datum in the data set). If k is not an integer, x_p is derived using linear interpolation between the two closest order statistics (Gilbert, 1987).

In this case the nonparametric confidence limits for the true pth quantile (x_p) can be computed using the procedure described by Conover (1980, p.12) with his Table A3 if $n \leq 20$. If $n > 20$, compute the following:

$$l = p(n+1) - Z_{1-\alpha/2}[np(1-p)]^{1/2} \qquad (6.2)$$

and

$$u = p(n+1) + Z_{1-\alpha/2}[np(1-p)]^{1/2} \qquad (6.3)$$

where:

l = lower confidence limit
u = upper confidence limit
Z = standard normal deviate

The actual limits (because l and u are usually not integers) are obtained by linear

interpolation between the closest order statistics.

Several alternatives to the sample mean and median concentration in a stream

segment with multiple stations as computed above are available for estimation of

average conditions. These include annual and seasonal stream-length weighted and

flow weighted mean concentrations, and annual time weighted mean concentrations.

It is not quite as straightforward, however, to derive CIs for weighted means.

The weighted mean $(\overline{x}_w)$ for an area can be computed using the following

equation:

$$\overline{x}_w = \sum_{i=1}^{n} x_i f_i \qquad (6.4)$$

where:

f_i = fraction or weight for ith datum

In this case, the CI width for the weighted mean (CI_{mw}) can be computed as:

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$$CI_{mw} = t_{1-\frac{\alpha}{2},v} \sqrt{Var(\overline{x}_w)} - t_{\frac{\alpha}{2},v} \sqrt{Var(\overline{x}_w)} \qquad (6.5)$$

where:

$$Var(\overline{x}_w) = s^2 \sum_{i=1}^{n} f_i^2 \qquad (6.6)$$

This equation assumes that the covariances of the x_is are not significant or are equal to zero. This is the same assumption that is usually made for estimating the variance of the arithmetic mean.

The stream-length weighted mean concentration for a season $(\overline{C}_{lws})$ or for a year $(\overline{C}_{lwa})$ incorporates some of the spatial variability between stations into the estimate, and is computed using Equation 6.4 where for a season:

$$\overline{x}_w = \overline{C}_{lws}$$

or for a year:

$$\overline{x}_w = \overline{C}_{lwa}$$

and for both:

$f_i = f_{li}$ = stream-length fraction for station (stream length for station divided by total stream length)

C_i and n are defined as above for either $\overline{C}_s$ or $\overline{C}_a$. The stream length for each station is determined by marking the midpoint along the stream between each station and all adjacent stations on a topographic map and measuring the distance between midpoints on either side of each station. If a tributary is located between two adjacent stations, the tributary is the midpoint. If only one station is located in a stream or tributary, its length is taken as the entire length of that segment. For stations that are farthest upstream, the stream length is measured from the

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uppermost point of the channel to the midpoint downstream of the station. The stream length for each station is then divided by the total length of the stream segment of interest to obtain a stream-length fraction for each station. The concentrations for each station are then multiplied by the fraction for the station, and all of these results are summed to derive a stream-length weighted mean concentration for the segment.

The flow-weighted mean concentration for a season $(\overline{C}_{fws})$ or for a year $(\overline{C}_{fwa})$ incorporates some of the flow variability among stations into the analysis. Equation 6.4 is used where:

$$\overline{x}_w = \overline{C}_{fws} \text{ or}$$
$$\overline{x}_w = \overline{C}_{fwa}$$

$f_i = f_{2i} =$ flow fraction for sample (flow measured with sample divided by total flow measured with all samples throughout stream segment)

C_i and n are defined as above. The flow measured with each sample is divided by the total flow measured with all samples throughout the stream segment to derive the flow fraction. Alternatively, the flow-weighted mean concentration could be computed by summing the loadings for every sample, and dividing this sum by the total flow measured with all samples throughout the segment.

Estimation of the annual time-weighted mean concentration $(\overline{C}_{twa})$ is a little more complicated because time weighting is a more subjective endeavor based on the annual hydrograph. This time weighting method incorporates some of the annual temporal variability into the analysis, and is therefore not applicable to estimation of seasonal mean concentrations. The time length for each flow regime can usually be determined by evaluation of a hydrograph from a nearby gaging station. Sometimes a USGS or other station is located within the watershed of interest.

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Many other times, however, the closest gaging station must be utilized to estimate the time periods for flow regimes or seasons. The time length for each flow regime (and sample) in days is divided by 365 days to obtain a time fraction for each season. Equation 6.4 is then used where:

$$\bar{x}_w = \bar{C}_{twa}$$
$f_i = f_{3i}$ = time fraction for sample (time length in days for season sampled divided by 365 days)

The stream-length weighted or flow-weighted methods for each season can also be combined with the time-weighted method to derive an annual stream-length and time-weighted mean concentration, or an annual flow- and time-weighted mean concentration.

6.3.1.2   Standard Deviation, *CI*, and Minimum and Maximum of Concentrations

The sample seasonal (s_{cs}^2) and annual (s_{ca}^2) variances of concentrations are estimated using Equation A.8, and the seasonal standard deviation (s_{cs}) and annual standard deviation (s_{ca}) are the square roots of these variances, respectively. The 100(1-α)% *CI* width for the variance (*CI*ᵥ) is computed as:

$$CI_v = \frac{(n-1)\,s^2}{\chi^2_{n-1,1-\frac{\alpha}{2}}} - \frac{(n-1)\,s^2}{\chi^2_{n-1,\frac{\alpha}{2}}} \qquad (6.7)$$

where χ = chi square

For the sample seasonal concentration variance 100(1-α)% *CI* (*CI*ᵥcs), *n* and s^2 are defined as above for *CI*mcs. For the sample annual variance 100(1-α)% *CI* (*CI*ᵥca), *n* and s^2 are defined as above for *CI*mca. The confidence limits for s_{cs} and s_{ca} can be derived by computing the square roots of the confidence limits for *CI*ᵥcs and *CI*ᵥca,

respectively.

Like the standard deviation, the minimum and maximum (or range of) concentrations in a stream segment are indicators of the overall variability of concentrations. These can be determined for a season for a stream segment by simply observing the minimum and maximum concentrations in the segment during that season. For a single monitoring station for one season, only one value is available. The minimum and maximum concentrations for a year (for either a stream segment or an individual station) are easily determined by observing the minimum and maximum values in any season.

6.3.2 Loadings

Section 4.2.3.9 presented in detail the quantitative information goals for magnitudes of loadings to stream segments. This section discusses methods that can be used for deriving this information.

Generally there is greater variability and uncertainty associated with estimates of loadings than with concentrations because:

1. loadings have greater natural variability

2. loading is the product of concentration and flow

3. some loadings for first order subbasins are estimated based on subtraction of measured loadings between two or more adjacent points

6.3.2.1 Mean, Median, and *CI*s of Loadings

For an individual station or first order subbasin, the mean daily loading for a season $(\bar{L}_{ds})$ is simply the instantaneous measured or computed loading converted to a daily value, as discussed in Chapter 5. This loading is not actually a mean value because only one data point is available for each season. It is, however, assumed to

be a representative daily loading for that station for that season. The mean daily loading at a station for a year ($\overline{L}_{da}$) can be computed using Equation A.2 where:

$$\overline{x} = \overline{L}_{da}$$
$$x_i = L_{dsi} = \text{mean daily loading for season } i$$
$$n = n_{se} \ (4)$$

A time-weighted mean daily loading for a year ($\overline{L}_{datw}$) can also be computed using Equation 6.4 where n is equal to n_{se} (4) and f_{3i} is defined as above for the time-weighted mean concentration.

The $100(1-\alpha)\%$ *CI* and standard deviation for $\overline{L}_{ds}$ cannot be computed because n is equal to 1 for an individual station. The $100(1-\alpha)\%$ *CI* for $\overline{L}_{da}$ (CI_{mlda}) can be estimated using Equation A.7, where:

$$\nu = \nu_{lda} = n_{se}\text{-}1$$
$$s = s_{lda}$$
$$n = n_{se} \ (4)$$

The standard deviation for $\overline{L}_{da}$ (s_{lda}) is the square root of s^2 which is computed using Equation A.8 as $s_{lda}{}^2$ where $\overline{x}$, x_i, and n are defined as above for $\overline{L}_{da}$.

6.3.2.2   Total Loadings

The total loading at any station or for any first order subbasin for a season (L_s) can be estimated as:

$$L_s = \overline{L}_{ds}T_s \tag{6.8}$$

where T_s is equal to the time period for the season in days (discussed in Section 6.3.1.1). The total loading for a year (L_a) can be estimated as:

$$L_a = \sum_{i=1}^{n} L_{si} \tag{6.9}$$

where:

L_{si} = total loading for season i
$n = n_{se}$ (4)

or as:

$$L_a = \overline{L}_{da} T_a \qquad (6.10)$$

where T_a is equal to 365 days.

6.3.2.3 Percentages of Loadings

The percentage $(P_x x_i)$ of a value (x_i) with regard to all values for a variable (summation of x_i from $i=1$ to n) is calculated as follows:

$$P_x x_i = \frac{x_i}{\displaystyle\sum_{i=1}^{n} x_i} \qquad (6.11)$$

The percentage of the total loading from a particular source relative to all loadings from all sources to a stream segment for a season $(P_{so} L_{si})$ can be estimated using Equation 6.11 where:

$P_x x_i = P_{so} L_{si}$
$x_i = L_{si}$ = seasonal loading from source i
$n = n_{ss}$ = number of sources for season

The percentage of the total loading for each season relative to the total loadings for a year from a particular source $(P_a L_{si})$ is also computed using Equation 6.11 where:

$P_x x_i = P_a L_{si}$
$x_i = L_{si}$ = loading from source for season i
$n = n_{se}$ (4)

The percentage of the total loading from a particular source relative to all loadings from all sources to a stream segment for a year $(P_{so} L_{ai})$ is also computed using Equation 6.11 where:

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$$P_x x_i = P_{so} L_{ai}$$
$x_i = L_{ai}$ = annual loading from source i
$n = n_{sa}$ = number of sources for year

6.3.2.4   Standard Deviation, *CI*, and Minimum and Maximum of Loadings

The standard deviation of $\bar{L}_{da}$ was discussed above. The CI_{sd} for $\bar{L}_{da}$ can be computed using the procedure described for annual concentrations by first computing CI_v. CI_v can be computed with equation 6.7 as CI_{vida}, with n and s^2 defined as above for $\bar{L}_{da}$.

The minimum and maximum seasonal mean daily and total loadings at a station or from a first order subbasin for a year can be observed directly from the monitoring data.

6.3.3   Unit Area Loadings

Section 4.2.3.9 presented in detail the quantitative information goals for magnitudes of unit area loadings to stream segments. This section discusses methods that can be used for deriving this information.

6.3.3.1   Mean, Median, and *CI*s of Unit Area Loadings

The mean daily unit area loading to a stream segment with multiple loadings (monitoring stations) for a season $(\bar{U}_{ds})$ can be computed using Equation A.2, where:

$\bar{x} = \bar{U}_{ds}$
$x_i = U_{dsi}$ = mean daily unit area loading for source i
$n = n_{uds}$ = sample size of measured or estimated mean daily unit area loadings during season

$\bar{U}_{ds}$ for a single station or a first order subbasin is simply the instantaneous measured or computed unit area loading measured during the season converted to a daily value, as discussed in Chapter 5. This unit area loading is not actually a mean value because only one data point is available for each season. It is, however, assumed to

be a representative daily unit area loading for that station for that season.

The mean daily unit area loading for a year ($\bar{U}_{da}$) can also be computed using Equation A.2, where:

$\bar{x} = \bar{U}_{da}$
$x_i = \bar{U}_{dsi}$ = mean daily unit area loading for source and season i
$n = n_{uda}$ = sample size of measured or estimated mean daily unit area loadings during year

For one station or first order subbasin, n is equal to n_{se} (4). Alternatively for multiple stations, $\bar{U}_{da}$ can be computed using Equation A.2 where:

$x_i = \bar{U}_{dsi}$ = mean daily unit area loading for all sources for season i
$n = n_{se}$ (4)

A time-weighted mean daily unit area loading for a year ($\bar{U}_{datw}$) can be computed using Equation 6.4 where $\bar{x}_w = \bar{U}_{datw}$, x_i and n are defined as above for $\bar{U}_{da}$, and f_{3i} is defined as above for an annual time-weighted mean concentration.

The CI_m for $\bar{U}_{ds}$ (CI_{muds}) can be estimated using Equation A.7, where:

$v = v_{uds} = n\text{-}1$
$n = n_{uds}$
$s = s_{uds}$

The CI_m for $\bar{U}_{da}$ (CI_{muda}) can also be estimated using Equation A.7, where:

$v = v_{uda} = n\text{-}1$
$n = n_{uda}$
$s = s_{uda}$

Use of this equation assumes that the distribtion is approximately normal. Alternatively, the natural logarithms of the data can be used to obtain the CI about the geometric mean.

The sample standard deviation for $\bar{U}_{ds}$ is the square root of s^2 which is computed using Equation A.8 as s_{uds}^2 where $\bar{x}$, x_i, and n are defined as above for $\bar{U}_{ds}$. The

standard deviation for $\bar{U}_{da}$ is the square root of $s_{uda}{}^2$, which can also be computed using Equation A.8 where $\bar{x}$, x_i, and n are defined as above for $\bar{U}_{da}$.

The median daily unit area loading for a season (U_{dmds}) can be calculated using equations A.9 or A.10, where x_i and n are defined as above for $\bar{U}_{ds}$. The median daily unit area loading for a year (U_{dmda}) can also be calculated using equations A.9 or A.10, where x_i and n are defined as above for $\bar{U}_{da}$.

The 95% CI about x_{50} (CI_{md}) can be derived from Table A14 in Gilbert (1987). The 90% CI_{md} can be derived from Geigy (1982, pp. 103-107). For the CI_{md} associated with the median daily unit area loading for a season (CI_{mduds}), n is equal to n_{uds} for multiple stations. CI_{mduds} cannot be computed for an individual station because n is equal to 1. For the CI_{md} associated with the median daily unit area loading for a year (CI_{mduda}), n is equal to n_{se} (4) for one station, or is equal to n_{uda} for multiple stations.

6.3.3.2   Total Unit Area Loadings

The total unit area loading for a season (U_s) can be estimated as:

$$U_s = \bar{U}_{ds} T_s \qquad (6.12)$$

where T_s is equal to the time period for the season (days) (discussed in Section 6.3.1.1). The total unit area loading for a year (U_a) can be computed as:

$$U_a = \bar{U}_{da} T_a \qquad (6.13)$$

where T_a is equal to 365 days, or as:

$$U_a = \sum_{i=1}^{n} U_{si} \qquad\qquad (6.14)$$

where:

    U_{si} = total unit area loading for season i
    $n = n_{se}$ (4)

Equation 6.14 results in a time-weighted estimate of the total unit area loading for a year. Equation 6.13 also results in a time-weighted estimate if $\bar{U}_{da}$ is taken as a time-weighted mean daily unit area loading ($\bar{U}_{datw}$).

6.3.3.3   Percentages of Unit Area Loadings

The percentage of the total unit area loading for a season relative to the total unit area loading for a year from a particular source ($P_a U_{si}$) can be estimated using Equation 6.11 where:

    $P_x x_i = P_a U_{si}$
    $x_i = U_{si}$ = total unit area loading for season i
    $n = n_{se}$ (4)

6.3.3.4   Standard Deviation, *CI*, and Minimum and Maximum of Unit Area Loadings

The standard deviation of seasonal and annual mean daily unit area loadings was discussed above. The CI_v for the seasonal mean daily unit area loading (CI_{vuds}) can be computed using Equation 6.7 where n and s^2 are defined as above for $\bar{U}_{ds}$. The CI_v for the annual mean daily unit area loading (CI_{vuda}) can also be computed using Equation 6.7 where n and s^2 are defined as above for $\bar{U}_{da}$. The CI_ss can then be computed based on the CI_vs using the procedure discussed in Section 6.3.1.2.

The minimum and maximum values of $\bar{U}_{ds}$, U_s, $\bar{U}_{da}$, and U_a on a seasonal and annual basis can all be observed directly from the monitoring data.

6.4   Information Goal #4. Locations of Loadings to and Losses from Stream
       Segments

The locations of loadings of metals to a stream segment of concern should be determined based on field observations and observed monitoring data. During field data collection, individual sources adjacent to or near the segment that could be contributing directly to the segment should be identified and delineated on the site map. Tributaries (subbasins and/or watersheds) that are contributing metals to the segment should also be identified and delineated. Some of the locations of loadings can be monitored directly in the drainage from an individual source adjacent to the stream or at the mouth of a tributary. Alternatively, the locations of loadings can be estimated using the NPS reach gain/loss analysis discussed previously by bracketing individual source areas, tributaries, or more widespread NPS areas. Estimates of locations of loadings can also be made using visual observations of areas of erosion and sediment deposition, staining and discoloration, precipitates, etc.

The locations of losses from the stream segment must be determined using visual observations and/or the NPS reach gain/loss analysis. Field observations can reveal areas of surface water exfiltration to groundwater and isolating features such as impoundments. The NPS reach analysis can be used because the losses are estimated as negative differences in measured loadings between adjacent monitoring stations.

Once the loading data are input to the database, the location of each value can be readily observed from tables developed from the database. These individual values can later be ranked to more easily determine the locations of the highest values. The locations of loadings to stream segments can also be easily determined

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by presenting the magnitudes directly overlain on site maps. The individual values, summary statistics, or bar graphs of the magnitudes can be presented on the maps, or some type of coding system (such as color coding) can be used to represent magnitudes of loadings or losses in the system. An alternative to this is to develop a schematic diagram where the watershed is represented as a system of loadings, concentrations, and sinks (losses) using lines of different thicknesses or types and/or presenting values on the schematic. The significant advantage of these methods is that the magnitudes can be observed directly at their corresponding location in the watershed for easier comparison with other values and locations.

Loadings in the main stem of a stream segment can also be plotted against distance or monitoring stations along the length of the stream to visually observe changes and potential locations of loadings and losses. A variation of this method is to plot loadings to the main stem from the major tributaries that are monitored. Concentrations in the main stem can also be plotted in this manner because the locations of high concentrations in stream segments, and increases in concentrations along the length of the main stem, can also aid in locating loadings to the segment and targeting of source areas.

6.5   Information Goal #5. Distances Between Sources and Watercourses and
        Impaired Stream Segments

The distances between sources and watercourses and between sources and the impaired stream segment of concern should be determined for individual large source areas or areas that are believed to be significant loaders, as well as for individual subbasins and/or watersheds that can contribute to the stream segment. The distances can be expressed in miles or feet, or can incorporate more of a qualitative

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rating system including such terms as "adjacent to channel" or "far from channel". Any obvious isolating factors, such as impoundments, dams, or surface water features that are dry most of the time, should be described and delineated on a map. This information can be obtained from site maps, aerial photographs, and field observations. Field reconnaissance is particularly important for deriving information on isolating factors because small-scale maps and aerial photographs are generally limited to interpretation of large features and many of these types of features can only be observed in the field.

6.6   Information Goal #6. Differences Between Magnitudes of Concentrations in and Loadings to Stream Segments

The evaluation of differences in concentrations in and loadings to different stream segments is required for prioritizing and targeting sites for remediation. Differences have already been discussed in general terms with regard to relative differences of estimated magnitudes between seasons, between individual points, and along the main stem of a segment (as changes along the segment). These relative differences can be observed by directly comparing magnitudes in tables, bar graphs, and on maps, and by plotting concentrations versus distance along the main stem of a segment. Evaluating differences by ranking values at individual points is discussed in Section 6.7.

Although in many cases evaluation of relative differences by simply comparing values by observation is the simplest and most useful method, in most cases targeting stream segments for restoration requires additional analysis. The differences and relative differences should be computed and uncertainties of the different values should be considered when comparisons are made to increase the likelihood that

correct site prioritization decisions are made.

6.6.1 Concentrations

As discussed in Chapter 4, the required information related to differences between concentrations in different stream segments includes the magnitude of differences and relative differences between seasonal mean concentrations and between annual mean concentrations. The difference (D) between two values (x_1 and x_2) of a variable is simply computed as:

$$D = x_1 - x_2 \qquad (6.15)$$

The relative difference (RD) can be calculated as:

$$RD = \frac{D}{x_1} \qquad (6.16)$$

where x_1 is the smaller value. This provides a measure of the relative difference in terms of the percent increase of the larger value over the smaller value. Alternatively, the difference can be computed in terms of the quotient of the larger value divided by the smaller value:

$$Q = \frac{x_2}{x_1} \qquad (6.17)$$

This provides a measure of the relative difference in terms of the factor by which the larger value is greater than the smaller value.

To estimate the magnitude of the difference between mean concentrations in two different stream segments for a given season, Equation 6.15 is used where:

$$x_1 = \overline{C}_{s1}$$

(estimated as the difference between two mean concentrations in the two stream segments). However, the overlap of the *CI*s of the two mean values can also be evaluated. Significant overlap might indicate a small difference, while a small or nonexistent overlap might indicate a large difference. Given the potentially small sample size and large *CI*s computed for IAM sites, however, the *CI*s usually do overlap. This could limit the usefulness of this procedure.

The same equation (6.15) can be used to estimate the magnitude of the difference between mean concentrations in two different stream segments for a given year, where:

$$x_1 = \bar{C}_{a1}$$
$$x_2 = \bar{C}_{a2}$$

The relative difference is also computed with Equation 6.16 or 6.17. Again, the overlap of the *CI*s of the two estimates can also be evaluated.

In some cases, the significance of the difference might be required information. As discussed in Appendix A, hypothesis testing is generally not recommended (McBride et al., 1993) for most environmental studies. If it must be used however, a nonparametric test, such as the Wilcoxon Rank Sum (WRS) test, might be useful because of the nonnormality of the data. This test is the nonparametric equivalent of the t test for two samples, and compares the medians of the two sample populations. The test applies to independent (unpaired) samples. This might be appropriate for comparing concentrations in two stream segments because data can't be paired from two geographically separate stream segments. A 90 or 95% confidence level ($\alpha = 0.1$ or 0.05, respectively) should be used for this test.

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appropriate for comparing concentrations in two stream segments because data can't be paired from two geographically separate stream segments. A 90 or 95% confidence level (α = 0.1 or 0.05, respectively) should be used for this test.

Multiple box-and-whisker plots, as discussed in Appendix A for aiding in the determination of seasonality, can also be used to provide a visual comparison of the statistical characteristics of the concentrations in two different stream segments. This method can be used to help estimate the significance of the difference between mean concentrations in two different stream segments for a given season or year. Differences in the variances of the two data sets can also be observed with these plots. Bar graphs can also be used to directly compare mean concentrations in two or more different stream segments for a given season or for a year.

6.6.2 Loadings

Section 4.2.3.10 presented in detail the quantitative information goals for differences between loadings to stream segments. This section discusses methods that can be used for deriving this information.

The magnitude of the difference between mean daily loadings and between total loadings to two different stream segments, or to one stream segment from two different sources, for a given season can be estimated with Equation 6.15 where:

$$x_1 = \overline{L}_{ds1} \text{ or } L_{s1}$$
$$x_2 = \overline{L}_{ds2} \text{ or } L_{s2}$$

The relative difference can then be computed using Equation 6.16 or Equation 6.17. The same equation (6.15) can be used to estimate the magnitude of the difference between mean daily loadings and between total loadings to two different stream segments, or to one stream segment from two different sources, for a given year,

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where:

$$x_1 = \bar{L}_{da1} \text{ or } L_{a1}$$
$$x_2 = L_{da2} \text{ or } L_{a2}$$

Again, the relative difference can be computed with Equation 6.16 or 6.17.

Bar graphs can also be used to directly compare the loadings.

6.6.3 Unit Area Loadings

Section 4.2.3.10 presented in detail the quantitative information goals for differences between unit area loadings to stream segments. This section discusses methods that can be used for deriving this information.

In this case, Equation 6.15 is used where:

$$x_1 = \bar{U}_{ds1} \text{ or } U_{s1}$$
$$x_2 = U_{ds2} \text{ or } U_{s2}$$

The relative difference can then be computed using Equation 6.16 or 6.17. The same equation (6.15) can be used to estimate the magnitude of the difference between mean daily unit area loadings and between total unit area loadings to two different stream segments, or to one stream segment from two different sources, for a given year, where:

$$x_1 = \bar{U}_{da1} \text{ or } U_{a1}$$
$$x_2 = U_{da2} \text{ or } U_{a2}$$

The relative difference can be computed using Equation 6.16 or 6.17.

Multiple box-and-whisker plots can also be used to provide a visual comparison of the statistical characteristics of the two sets of seasonal or annual mean daily unit area loadings. This method can be used to help estimate the significance of the differences between seasonal or annual mean daily unit area loadings to two different stream segments or to one segment from two different sources. Differences in the

variances of the two data sets can also be observed with these plots. Bar graphs can also be used to directly compare unit area loadings.

6.7 Information Goal #7. Frequency or Risk of Exceeding a Target Concentration in and Loading to a Stream Segment

Section 4.2.3.11 presented in detail the quantitative information goals for the frequency or risk of exceeding a target concentration in or loading to a stream segement. This section discusses methods that can be used for deriving this information.

Exceedances above some critical value or standard can be expressed in terms of probability (or inversely, frequency) or risk of occurrence. Each exceedance may be expressed in terms of frequency, magnitude, and duration. These exceedances may represent water quality standards violations or threats to aquatic life. The magnitude and duration of the exceedance will determine whether acute or chronic standards violations and effects to aquatic life are the problem. These may be exceedances during any given day, season, year, storm event, or longer period.

The magnitudes and associated frequencies of metals concentrations in stream segments and loadings to streams exceeding target values can be estimated at many IAMs. Durations of exceedances, however, are much more difficult to estimate because data are not typically available for this type of analysis.

The population cumulative frequency distribution must be estimated based on monitoring data or estimated (modeled) values in order to assess the risk of exceedances. The probability that a metal concentration (X) observed at random is less than a given value (x_o) is given by the cumulative distribution function (*cdf*) of X, denoted as $F(x_o)$. Therefore, the probability of this event is:

$$P[X \leq x_o] = F(x_o) \qquad\qquad (6.18)$$

If the x_o is written as an upper limit standard (x_s), the probability that the standard will be violated is:

$$P[X > x_s] = 1 - F(x_s) \qquad\qquad (6.19)$$

There are two primary methods for estimating the *cdf* of a population. One method is a nonparametric approach to derive the distribution. This involves ranking the observed or modeled data and developing a cumulative plot of the values. This method is especially useful because, based on ranking the data for the cumulative distribution plot, a listing of concentrations and loadings from highest to lowest values is developed that can be used for identifying and targeting critical areas. A *cdf* for concentrations in a stream segment for the year sampled can be estimated using all of the observed data from the segment over that year. This *cdf* would provide an estimate of the frequency or risk of exceeding a specific concentration anywhere in the stream segment at any time during that year. This is especially useful for determining ambient water quality standards or estimating the risk of exceeding a numeric water quality standard anywhere in the stream segment. A *cdf* for unit area loadings from first order subbasins to a stream segment for the year sampled can also be estimated using all of the observed data collected during that year. This *cdf* would provide an estimate of the frequency or risk of exceeding a specific unit area loading from anywhere in the subbasin draining into the stream segment at any time during that year. In addition, *cdf*s for concentrations and unit area loadings for the different seasons sampled can be estimated based on observed

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data that have been grouped by each season (flow regime).

In order to develop these *cdf*s and make them useful for water quality management, it has to be assumed that each observation represents some finite time period (is not an instantaneous measurement), such as a mean value for the day or season sampled. If this assumption is not made, every value will occur every year. For the assessment of IAMs, a daily or seasonal value should be assumed. In addition, significantly different return periods are obtained depending on the assumed time period. For return periods, each observation usually represents a maximum value for that period.

The *cdf*s estimated using the nonparametric approach are based on ranking the data as follows:

$$F_n(x_o) = \frac{m}{n+1} \qquad (6.20)$$

where:

    m = number of observations less than or equal to x_o
    n = total number of observations

It is not practical, however, to use this approach with observed data for a single monitoring station given the lack of data (1 data point for a season and 3 or 4 for a year). Equation 6.20 represents the proportion (p_{xo}) of a population that does not exceed x_o. The *CI* for a proportion can be obtained using the methods discussed in Gilbert (1987).

Alternatively, a theoretical population cumulative frequency distribution can be assumed or fitted (modeled) to the existing observed or estimated data. Typically in this case a normal or lognormal (skewed) distribution is used because many water

quality variables generally exhibit these types of distributions (Loftis et al., 1983). In the case of the data for Cement Creek, however, it has already been shown in Appendix A that the dissolved zinc concentration data and unit area loading data are neither normal or truly lognormal. This limits the applicability and usefulness of this method, especially given the practicality and usefulness of the nonparametric approach.

If adequate observed data do not exist (the sample size is not large enough) for either method, data can be generated using a Monte Carlo simulation (Haith, 1987; USEPA, 1992c). In this method, distributions for input parameters to a deterministic or empirical model that is used to compute the parameter of interest are estimated more accurately than the distribution of the parameter of interest itself because a more extensive historic data record is available for the input parameters (such as for precipitation). Values from the input parameter distributions are selected randomly, input to the model, and an output distribution of the parameter of interest is derived. Haith (1985, 1987a), for example, used an exponential distribution for precipitation to generate distributions of pesticide loadings to surface waters using a Monte Carlo simulation. This method may be especially useful for deriving a frequency distribution of loadings or concentrations for a point where data are typically lacking. As the spatial scale increases, however, so does the sample size and the ability to estimate a distribution based on observed data. This method is more data intensive and complicated than the other methods that don't require data generation.

7.0   DATA GAPS

This chapter discusses data gaps that are common to the data sets typically developed for the majority of IAMs. These data gaps preclude the use of some types of useful assessment and data analysis methods. Some of these are data gaps that have been defined for the Cement Creek data set, and that prevented the use and evaluation of additional data analysis methods as part of this study that could be useful for the screening-level assessment and targeting process. A discussion of the data gaps specific to Cement Creek and this study is presented in Appendix E. It should be emphasized, however, that overall the data gaps identified for Cement Creek did not preclude the development of a useful assessment methodology and targeting within the basin. Most of the data gaps discussed in this chapter will be important for future recommended work on assessment of IAMs. Although for most sites these data gaps are not critical for screening-level assessment and targeting, if these data gaps are filled the screening-level assessment methodology recommended in the next chapter could be improved. These data gaps will also be important for the next phase of assessment, i.e., the detailed assessment of targeted sites for remedial design purposes.

For some sites when adequate resources are available and the missing data are believed to be critical in the management process, some of these data gaps should be filled to derive specific types of required information. Methods that can be used to fill these data gaps are discussed in Appendix E.

Table 7.1 presents a summary of the data gaps that have been identified for the Cement Creek Basin and that are typical for screening-level assessment of most IAMs. The general types of data gaps discussed in this chapter include:

1. water quality data
2. sediment data
3. aquatic ecologic data

7.1   Water Quality Data

As discussed in previous chapters, water quality data at most IAMs are typically lacking. This is especially true for data from an individual point or monitoring station. Four data points or fewer are typically available at a single monitoring station. In other cases, data from specific locations of interest, either at source areas or in impacted stream reaches, are not available because they have not been monitored. Contaminant concentration and loading data for extreme flow (storm) events, which can have significant adverse impacts on aquatic life, are typically not available. Accurate values of concentrations and loadings during storm runoff events are difficult to estimate because of the large intra-storm and inter-storm variability associated with these events and because one grab sample per station is usually collected for at most one or two events. If the watershed is large, the storm itself may be spatially variable or cover only part of the basin. However, loadings during significant storms may be a very large percentage of the total annual loading at any point in the basin and may have potentially significant acute impacts on aquatic biota during these events. Therefore, storm runoff events are an important component of the total ecological risk in a basin, and it is useful to estimate loadings and concentrations for events of different intensity and frequency. In these cases, some type of simplified empirical and/or statistical modeling can be performed to fill data

Table 7.1.   Data gaps for the Cement Creek Basin and that are typical for IAM
             screening-level assessment

1.   Water quality data
     -        total metals for iron and other constituents

2.   Sediment data
     -        bed material at a subset of stations
              -        metals concentrations
              -        grain size distribution
              -        organic content
              -        possibly toxicity
              -        one or two sampling events

3.   Waste materials metals concentrations
     -        required for modeling for prediction or estimation purposes using
              regression techniques, Universal Soil Loss Equation based methods, or
              more sophisticated models

4.   Areal extent and/or volume of NPSs
     -        USBM and other inventories
     -        also required for modeling

5.   Modeling might be required to estimate necessary reductions in loadings from
     different areas and concentrations in stream segments of interest to achieve
     goal

6.   Aquatic ecological data
     -        use attainability
     -        toxicity of water and sediment at a subset of stations
              -        one or two sampling events
     -        physical habitat for use attainability

gaps and generate data.

At most IAMs, either only dissolved or total concentrations of constituents are measured. In most cases, however, impacts to aquatic life are important. Therefore, information on the dissolved fraction is critical because this is the fraction that affects biota and many numerical standards are developed for the dissolved fraction. In other cases where sediment loading and contaminant adsorption to sediment or precipitation with pH changes are significant, the total fraction and interactions with the dissolved fraction can be important. Some standards for metals are developed in terms of the total fraction. These cases are usually fairly obvious based on site observations of erosion from source areas and sedimentation within water bodies of interest. These cases can also be identified based on pre-existing data that have been collected at the site.

In some cases specific analytes are not measured that could be impacting the uses of the stream or that could provide useful information on cause-effect relationships. These could include specific metal species, or indicator parameters such as sulfate, specific conductivity, or hardness. These cases can be identified by analyzing a complete list of analytes for at least one monitoring event and comparing observed concentrations to potentially applicable standards or by evaluating the correlation between different analytes and observed impacts. Details for identifying the different cases discussed above are presented in Appendix E in the discussion of how to fill data gaps when required.

7.2   Sediment Data

As discussed above, there are many sites where sediment loading to stream segments is significant in terms of both the impacts of the sediment itself as well as

of adsorbed metals. In most cases, data on sediment and/or adsorbed constituent concentrations are not available during the early phases of assessment.

7.3   Aquatic Ecologic Data

At most IAMs, aquatic ecologic data important for evaluating impacts (especially long-term) of metals concentrations and loadings, as well as other adverse impacts such as sediment loading or habitat limitations, are not available. Several reasons exist that cause this situation:

- limited financial resources are available for assessment and biological sampling and monitoring methods are generally more expensive than chemical methods

- biological methods are newer and not as standardized as chemical methods

- some stream segments (such as Cement Creek) are so impacted by mine waste pollution that they are devoid or almost devoid of life (at least fish)

Information on the aquatic ecology and biota of a site is required for a wide variety of reasons, as discussed for the information goals in Chapter 4. It is generally recognized that three types of information are required to evaluate the ecological effects of contaminant loadings to surface waters (USEPA, 1989b). The first type of information is the water and sediment chemistry information needed to evaluate the magnitudes and variabilities of metals concentrations. This information has been discussed in previous sections of this report. The second type includes information on the biology of the stream to determine if adverse ecological effects have occurred. The third type includes information regarding the toxicity of the contaminants to the biota to determine if a correlation exists between toxicity of the contaminants and the adverse effects. Ecological and toxicological information is important for assessing and remediating IAMs because it can be used to evaluate the aggregate

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toxicity of all contaminants, incorporates the bioavailability of the metals into the evaluation process, and provides a realistic measure of the magnitude and variation of biological and ecological effects.

In some cases at IAMs, water quality standards must be derived or revised for streams segments. According to federal regulations, the state water quality agency must evaluate and revise standards on a periodic basis (usually every three years) for all watersheds in the state. When this is performed, information is required regarding which species exist in the water body and must be protected, the biological health of the system, and which species could potentially exist in the water body if the physical and chemical factors impairing the use were corrected (USEPA, 1983). When resources are available, a use attainability analysis and water body assessment is typically performed in these cases. This includes a biological inventory for an existing use analysis, a biological condition/biological health assessment, and a biological potential analysis. Information, including biological information, usually required for use attainability analysis and standards setting is listed in Table 7.2 (USEPA, 1986). For the biological inventory, fish, macroinvertebrates, microinvertebrates, phytoplankton, periphyton, and macrophytes should be considered. At a minimum, information is usually required on species numbers and diversity of fish and benthic macroinvertebrates at a subset of the monitoring locations at which water quality is sampled and analyzed. For the biological condition/biological health assessment, the following information is typically required:

- species richness or number of species
- presence of intolerant species
- proportion of omnivores and carnivores

Table 7.2. Ecological information required for use attainability analyses
(from USEPA, 1986)

Physical Information
Instream Characteristics
    size (mean width/depth)
    flow/velocity
    annual hydrograph
    total volume
    reaeration rates
    gradient/pools/riffles
    temperature
    suspended solids
    turbidity
    sedimentation
    channel modifications
    channel stability
Substrate Composition and
  Characteristics
Channel Debris
Sludge Deposits
Riparian Characteristics
Downstream Characteristics

Chemical Information
Dissolved Oxygen
Toxicants
Suspended Solids
Nutrients
    nitrogen
    phosphorus
Sediment
Salinity
Hardness
Alkalinity
pH
Dissolved solids

Biological Information
Biological Inventory
    fish
    macroinvertebrates
    microinvertebrates
    phytoplankton
    periphyton
    macrophytes
Biological Condition/
  Health Analysis
    diversity indices
    HSI models
    tissue analysis
    recovery index
    intolerant species
    analysis
    omnivore-carnivore
    analysis
Biological Potential
  Analysis
    reference reach
    comparison
Toxicity

- biomass or production
- number of individuals per species

The biological potential analysis evaluates what communities could potentially exist in a particular water body if pollution were remediated or the physical habitat modified.

Biological information is very useful on a seasonal basis under different flow regimes and life cycle stages. These data would optimally be collected during the same or a subset of the sampling events for the water quality data.

8.0   RECOMMENDED METHODOLOGY

In this chapter the methods discussed in previous chapters are integrated to formulate a logical, comprehensive methodology for the screening-level assessment of NPS pollution from IAMs to reach the information goals defined and use the information for targeting remediation. The specific methods were chosen and overall recommended methodology developed based on the following:

- uses a watershed or basin-wide approach for screening-level assessment and targeting of source areas, metals loadings, impacted stream segments, and concentrations

- derives required information efficiently and is relatively easy or practical to implement because resources (time and money) are limited

- is not too data intensive because data are limited

- uses methods that are relatively widely accepted and used

- is applicable to a wide variety of sites and types of metals so that it is somewhat standardized to derive comparable information

- minimizes or considers the uncertainty of the data and information derived

Engineering judgement was also used to a certain extent as necessary.

The assessment information derived and targeting for the Cement Creek Basin using most of the elements of the recommended methodology are presented in detail in Appendix D. If any of the other current assessment methodologies discussed in detail in Chapter 3 were used, at least one of the criteria listed above would not be met, and, more than likely, several would not be met.

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The methodology is presented as steps in an integrated assessment process including definition of information goals; evaluation of existing data/information and identification of data gaps; planning and data collection (if required), management, and analysis; and information presentation and use for targeting. Table 8.1 summarizes the overall recommended methodology including each of the items within the steps. Each step is discussed in more detail in the following sections. In Section 8.6, the recommended methodology is qualitatively tested and evaluated with regard to its applicability and potential effectiveness for targeting in several other IAM watersheds.

8.1 Step 1: Define Information Goals for Watershed

The first step in the assessment methodology is to identify and clearly define site-specific assessment and quantitative information goals for the watershed. These goals will generally be similar to the ones discussed in this study, although they may not include all those discussed or might include some additional goals that are specific to the site or study. It is best to define information goals in cooperation with all stakeholders involved in the watershed to achieve consensus and utilize limited resources for assessment effectively.

8.2 Step 2: Collect, Evaluate, and Summarize Existing Data/Information

Any existing data for the site derived from inventories or previous studies should be collected, reviewed and evaluated, and summarized. This information can be used to help define the potential problems in the watershed and data gaps based on the information goals. Based on the existing information, the information goals for the watershed should then be refined, if necessary.

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Table 8.1	Recommended methodology for screening-level assessment of NPS pollution from IAMs

STEP 1: Define Information Goals for Watershed
- based on cooperative stakeholder involvement

STEP 2: Collect, Evaluate, and Summarize Existing Data/Information
- refine information goals

STEP 3: Identify Data Gaps and Methods to Fill Gaps
- data gaps for required analytes, locations, and frequencies
- identify analytes (and analytical methods), locations, and frequencies for monitoring
- define data collection procedures
- define modeling methods
- determine methods for data management, analysis, reporting, and use
- identify QA/QC procedures
- develop work plan

STEP 4: Data Collection (if required)
- sample collection and field measurements
  - total and dissolved metals, indicator parameters, flows
  - bed sediment metals and physical characteristics
  - aquatic ecology including habitat, fish, and benthos
  - mouths of and other locations in important tributaries to main stem, headwaters including background locations or unimpacted nearby watersheds, mouth of main stem and points bracketing tributaries, points bracketing NPS areas, drainage from point sources, points of obvious or suspected impacts
  - synoptic monitoring during high and low flows for at least 3 or 4 events
  - source/waste material
- documentation in logbook and on site map of monitoring locations, analytes, locations and types of sources, NPS areas/volumes, distances to watercourses, and other features of the station with regard to potential sources and impacts
- measure NPS areas and distances to potentially impacted water bodies from site map
- laboratory analysis
- QA/QC

STEP 5: Data Management
- database input including station and description, type of source, sampling dates, seasons, distances to potentially impaired water bodies, subbasin areas, flowrates, and analytical results

- data manipulation for analysis, presentation, and reporting including:
  - compute mean daily loading at each monitoring station for each season
  - compute differences in loadings between adjacent stations as estimated loadings
  - compute mean daily unit area loadings
  - compute total loading and at each station for each season based on time period for each season
  - compute fish standards based on hardness
- QA/QC

STEP 6: Data Analysis
- use screening procedure to identify indicator metal and primary constituents of concern

Individual Points
- magnitudes of flow, concentration, and loading (and unit area loading) for each station for each season
- only if required for broad comparisons among locations, compute mean concentration and mean daily and total loadings (and unit area loadings) at each station for a year based on time weighting for each season
- estimate differences and relative differences between specific points and/or seasons at a point
- rank concentrations and loadings (and unit area loadings)
- if a specific point is of interest, estimate risks of exceedances at a point in conjunction with modeling
- present required information in summary tables, graphical plots, and on site maps

Areas
- group data appropriately
- plot concentrations and loadings versus distance along main stem
- concentrations
  - compute magnitudes of mean, stream-length weighted mean, and median for each season
  - compute standard deviation and determine minimum and maximum values
  - estimate *CI*s for computed values
- loadings
  - compute magnitudes of mean daily and total (and mean and median daily and total unit area) loadings for each season
  - compute standard deviations and determine minimum and maximum values
  - estimate *CI*s for computed values

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- only if required for broad comparisons among locations, compute values for a year based on time weighting for each season
- estimate differences and relative differences between areas, types of sources, and/or seasons
- if required for revising standards, compute ambient standards for stream segments
- estimate risks of exceedances in an area

STEP 7:   Targeting
- target stream segments using:
  - seasonal concentrations in streams
  - seasonal loadings and unit area loadings to streams
  - ranking of concentrations
  - risks of exceedances
  - differences between segments for specific segments of interest
- target source areas using:
  - seasonal loadings
  - percentages of total loadings
  - seasonal unit area loadings
  - ranking of loadings
  - risks of exceedances
  - differences between sources for specific sources of interest
  - distances to impaired water bodies
- use annual values only if longer-term conditions are being estimated or compared
- also consider the uncertainty of the data/information, type and extent of impairment, feasibility and costs/benefits of remediation, public support and funding availability, availability of remedial technologies, land ownership, etc., in the final targeting process
- present required information in report including
  - tables of magnitudes, differences, ranking, risks of exceedances, distances, uncertainty for easy evaluation
  - graphical plots of these estimated values in bar graphs, pie charts, concentration vs. distance plots for easy presentation
  - site maps with estimated values and coding overlain for easy visual presentation
  - the report should also include an introduction or summary of the problem; specific assessment information goals; and all data collection, management, and analysis methods
  - a target table or map presenting the priority source areas and stream segments recommended for remediation

8.3   Step 3:   Identify Data Gaps and Methods to Fill Gaps

Data gaps should be identified that must be filled to achieve the information goals. If the defined information goals cannot be achieved with the existing data, data gaps will need to be filled. Specific methods to identify data gaps for individual sites are beyond the scope of this study. As discussed in Chapter 7, most of the important data gaps are common and fairly obvious for the majority of these sites. Methods to fill the gaps in a cost efficient manner should then be identified and defined. These methods can include data collection and/or modeling techniques. Cost efficiency should be defined in terms of the labor, materials, and analytical work required to plan for data collection and collect and analyze the data to derive the required information. Cost estimates can be developed for the different types of data collection and/or modeling methods for comparison purposes. Methods should generally be used that derive the required information (with an acceptable degree of uncertainty) for the lowest cost. The degree of uncertainty that is acceptable is generally a political and/or economic decision.

Development of a detailed work plan for data collection activities is very useful at this stage. The purpose of the work plan is to clearly define all aspects of the monitoring process to ensure that resources are used efficiently, to document procedures, and to gain concurrence on the methodology by all involved parties. The work plan should include all of the details for data collection, including analytes (and analytical methods), locations, frequencies or time period of sampling, and field procedures. The recommended analytes, locations, and frequencies are discussed in detail in the next section. The locations and frequencies can be changed based on actual field conditions and observations as long as they are all documented. A work

plan can also be developed for the use of modeling methods. Data management and analysis methods should also be discussed in the work plan. The methods will be dependent on the specific information goals defined, but can generally be similar to those discussed in this study. Information presentation, reporting, and use in the targeting process should also be discussed in general terms. Again, the methods discussed in this study can be used. QA/QC procedures for all data collection activities should also be discussed.

8.4   Step 4: Data Collection (if required)

For most IAMs, the evaluation of existing data will indicate that additional data must be collected to reach the information goals. If the defined information goals cannot be achieved with the existing data or modeling techniques, additional data will need to be collected. The next step of the assessment methodology for most sites, therefore, is the actual field work and data collection. This is discussed in the following sections.

8.4.1   Analytes

Water quality analytes should include both total and dissolved metals for a wide range of species for at least one sampling event. Once the important metals that appear to be impacting the surface waters and aquatic ecology of the site are determined, the list of metals can be reduced to those metals. Iron should be evaluated at most sites because it demonstrates whether the site has a significant amount of sulfide minerals. Additional cations and anions can be analyzed if required for at least one sampling event to perform a cation-anion balance for data QA purposes. If only the dissolved form of a metal seems to be important at the site, because erosion and sedimentation is not significant or the metals of concern

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are primarily in the dissolved form, then only the dissolved fraction may need to be analyzed for subsequent sampling events. Total metals should be analyzed when erosion and sedimentation is significant or when precipitates, especially on the channel bed, may be important. Indicator parameters should generally include field pH, temperature, dissolved oxygen (DO), alkalinity (primarily bicarbonate), TSS, specific conductivity (or laboratory TDS), sulfate, and hardness. Calcium and magnesium can be analyzed and used to estimate hardness. Generally, a minimum of 10% of the samples should be QA samples. Water quality samples can either be collected as grab samples representative of the channel cross-section for small streams, or as depth- and width-integrated (channel cross-section composited) samples using a US DH-48 sediment sampler for larger streams. Flowrate should be measured at each station using the velocity-area method, preferably using a current meter. If flows are too small to be measured using this method, visual estimates should be made and noted.

Bed material should be collected and analyzed at a subset of the surface water stations, especially in areas of apparent sediment deposition and fine material. This is particularly important if erosion and sedimentation appears to be significant or if benthic macroinvertebrate communities and the aquatic ecology of a site is being evaluated. Sediment samples should be collected within 0-6 inches of the top of the bed from several representative locations across the channel cross-section. These grab samples should then be mixed and composited into one sample for each cross-section. Analytes for sediment samples should generally include the metals of concern, total organic carbon (TOC) (or a similar parameter), pH, and grain size distribution. In addition, the toxicity of bed material samples should be analyzed and

cobble imbeddedness should be evaluated if impacts to benthos and/or fish are potential concerns.

With regard to analytes and measurement procedures for derivation of required aquatic ecologic information, many or a subset of the methods discussed in Appendix E can be used, depending on the specific characteristics and requirements of the site. At a minimum for many sites, information derived from a field survey on the physical aquatic habitat, fish populations, and benthic macroinvertebrates is required. For high priority sites or specific locations of concern, toxicity testing of surface waters, in addition to sediment, should be considered.

8.4.2   Locations

Water quality sampling locations should include the following:

- mouths of and other locations in important tributaries to the main stem
- headwaters including possible background locations or unimpacted nearby watersheds if required
- mouth of the main stem and points bracketing tributaries
- points bracketing NPS areas
- drainage from point sources
- points of obvious or suspected impacts

Sediment and aquatic ecology sampling locations should include a subset of the surface water quality stations.

8.4.3   Frequencies

The frequency or time period for data collection should generally include at least one baseflow event during late summer or fall, one snowmelt event during the rising limb of or peak snowmelt (usually during May, June, or July), and one representative

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storm event during summer or fall. If possible, an additional sampling event or quarterly sampling should be performed. In the optimum situation, more than four sampling events or quarterly sampling for more than one year can be performed, where multiple sampling events are performed for each type of flow event or season. This will likely be the case for high priority sites where additional data collection beyond the screening phase is warranted or remediation is being implemented. The frequency for bed material and/or aquatic ecologic data collection can be reduced to two sampling events, if required: at least one during snowmelt runoff (in the spring for life stage considerations) and one during baseflow.

8.4.4   Laboratory Analysis

Water and solid material samples collected in the field should be preserved, containerized, packaged, and shipped to the analytical laboratory according to standard USEPA-approved procedures. Chain-of-custody requirements should also be adhered to. Laboratory analysis is performed within the required holding times using approved analytical methods (and appropriate MDLs), as discussed in the work plan, after samples are received from the field crew. Stringent QA/QC and appropriate reporting procedures should be used.

8.4.5   Additional Data Collection

During the field work, all data collection activities should be documented in field log books and locations of stations and sources and certain other types of information should be delineated on a site topographic map. Data for the log book should include the following:

- designation and detailed description of sampling location
- date and time of sampling
- weather and field conditions

- field crew members
- all field measurement results
- laboratory analytes

Other information to be observed in the field and recorded in the log book to the extent possible includes the following:

- locations of point sources, NPSs, and other disturbed areas

- measured or estimated stream or drainage flowrates

- areal extents/volumes of NPSs

- distances from source areas and sampling locations to nearest watercourse

- other obvious signs of impacts to surface waters including erosion and sedimentation, discoloration or precipitates, and ecological impacts (presence or absence of fish, dead vegetation, etc.)

Some field experience, especially at IAMs, will probably be required to make these types of observations and derive important information from them. In most cases, however, agency personnel performing these reconnaissance surveys do have this type of experience.

In addition, it would be very useful at most sites to collect at least several samples of NPS waste material (tailings, waste rock, etc.) for laboratory analysis. The NPS areas selected should be generally representative of many of the source areas within the basin. This might require some experience and familiarity with these types of sites and the basin. At each NPS location, several grab samples from the surface (0-6 inches) should be collected from representative locations and composited. Analytes should generally include the metals of concern, sulfate, acid generation potential, neutralization potential, grain size distribution, and possibly porosity.

Information to be delineated on the site map during field data collection includes the following:

- sampling station locations
- locations of point sources, NPSs, and other disturbed areas
- areal extent of NPSs
- other obvious signs of impacts to surface waters

From the site maps, NPS areas and distances to potentially impacted water bodies can be estimated.

8.5   Step 5: Data Management

All data collected in the field and received from the laboratory should be input to a computerized database system. Laboratory data are usually received in ASCII format on diskette and can be automatically loaded into the database. Databases developed in spreadsheet format are often useful because all of the data can be observed on the computer screen if necessary and the data can be manipulated and imported into other software packages for data analysis and reporting fairly easily. For larger data sets, however, working with spreadsheets can be somewhat cumbersome and other types of database software programs should be considered.

Data input into the database should include the following:

- sampling station

- condensed description of sampling location and/or drainage

- type of source (NPS, point source, or background)

- date sampled

- season or type of event (baseflow, snowmelt, etc.)

- distances from each sampling station to nearest watercourse (estimated from field) and to each potentially impaired water body of concern (measured from site map)

- subbasin area for each station (estimated from site map)

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- flowrate

- analytical result (concentration) for each metal and indicator parameter

- sediment and/or aquatic ecologic data

Each station can be input as a different row of the spreadsheet. Data for the different sampling seasons can be input as a time series (in successive rows) for each station. The rest of the variables can be input as different columns.

Data management is actually a continuous process that is required from data input to data analysis and reporting. Once the data discussed above are input, the following can be computed successively using the methods described in Section 5.2.

- mean daily and total loadings of important metals at each station for each sampling event (as different columns)

- differences in loadings between all adjacent stations to estimate the loadings from the subbasins between adjacent stations (in the loading columns)

- area of each subbasin between adjacent stations based on site map (separate column)

- loadings from all first order subbasins can be identified and grouped together (separate column)

- mean daily and total unit area loadings from each first order subbasin (separate column)

The remainder of the data management methods will be dependent on the specific data analysis methods used. For example, if the stream-length weighted mean concentrations in different stream segments are required for targeting potentially impacted water bodies, the stream length and fraction for each station can be computed in the spreadsheet from the distance data and stored as a separate column. If required, standards can be computed in the database and used in subsequent analyses. If an analysis of different types of loading sources, such as background versus NPSs or point sources, is required, the data can be grouped in the

database accordingly for analysis. The data presentation methods will also affect the specific data management schemes.

Some of the data input into the database can also be overlaid on the site topographic map in addition to the information discussed above for data collection so that the map could include the following:

- type of source for each subbasin (NPS, point source, or background)
- date sampled and/or season or type of event (baseflow, snowmelt, etc.)
- delineation of subbasin area for each station
- flowrate
- analytical results (concentrations) and/or loadings for important metals and indicator parameters
- sediment and/or aquatic ecologic data

A schematic representation of the watershed with this information can be used as an alternative to an actual map of the site. Data should also undergo QA/QC procedures as part of the data management process.

8.6   Step 6: Data Analysis and Presentation

It is assumed for the purposes of this methodology that data attributes will not necessarily have to be evaluated for most IAMs, and that the attributes described in this study are common to many of the data sets derived from these sites and can be used as guidelines for selection of data analysis methods. If, however, data attributes are examined for a particular site or reason, the methods discussed in Appendix A can be used.

In addition, a simple screening procedure can be used to identify the primary constituents of concern that might be used as indicators of the worst problems and for carrying through the complete assessment. This could first involve estimating the mean value and maximum value for each potential constituent of concern (metal) within the basin and identifying which analytes exhibit the greatest concentrations

relative to potentially applicable standards. Potentially applicable standards for each metal should also be computed, especially for protection of aquatic life. The number or frequency of exceedances of the most stringent standards is a good indicator of which metals are problems and should be evaluated in detail.

Table 8.1 presents a summary of the recommended data analysis methods for the proposed assessment methodology. The information listed can be considered the recommended minimum and most important information required for performing an effective screening-level assessment of IAM watersheds and subsequent targeting.

8.6.1 Analysis of Individual Points

At this point in the assessment process, some of the information goals have already been met, and data analysis and targeting can be performed for individual stations and subbasins or source areas of interest. The magnitudes of concentrations, loadings, and unit area loadings for each station for each sampling event have been determined. Therefore, the locations of these variables are known. Relative differences between specific stations and seasons can be directly observed. The areal extent and metals concentrations of NPSs have also been estimated. Distances from each source area to water bodies of concern have been estimated and can easily be observed from the site maps. For large data sets, however, all of the data in this format can be cumbersome and might still need to be summarized and/or presented using other methods for easier interpretation. The methods discussed below that can be used for these analyses were discussed in more detail in Chapter 6.

Aquatic life chronic and acute standards, if applicable, should be determined or computed using the corresponding hardness values for each station for metals of concern. Other applicable standards should also be determined for stream segments

of interest if appropriate. Each observed concentration should be directly compared to the applicable standard to determine exceedances and potentially impaired areas. These exceedances should be presented on the site map for all locations.

The percentage of the total loading from each station or subbasin relative to the total loadings from all sources to the stream can be estimated. For each station, the percentage of total loading for each season relative to the total loading for a year can also be estimated. Bar graphs should be used to summarize and present information on individual stations and subbasins of interest as well. Pie charts can also be used to present the loading percentages. Magnitudes of differences and relative differences between stations and seasons can easily be observed with these graphs, and they can also be presented on the site maps for easier interpretation.

Ranking of concentrations in stream segments of interest and of loadings and unit area loadings from all first order subbasins to segments of concern is very important for identifying and locating the worst areas, especially for large data sets, rather than trying to sort through all of the raw data in the database and on the site map. With regard to targeting specific source areas for remediation, the worst loaders that are close to the impaired water body will generally be of highest priority. In contrast, the stream reaches exhibiting the highest concentrations might not be targeted because they might be the most difficult to restore initially.

The evaluation of the risk of exceedances of concentrations or loadings at a specific point of interest might be required in a few cases. This can usually only be accomplished using some type of modeling technique in conjunction with very limited observed data.

It is generally not recommended that annual values of concentrations or loadings be estimated for individual stations with only three or four sampling events. If this information is required, however, for individual stations in a particular watershed for broad comparisons among stations, it is useful to estimate the mean, time weighted mean (based on lengths of seasons), and median (because the data are likely right skewed) to estimate average values. The standard deviation and the minimum and maximum values should also be computed to estimate the variability at the station. For the mean values and standard deviation, the 90% *CI*s should be computed to estimate the uncertainty associated with the values. This estimate of the confidence in the values should then be used in the targeting process as necessary when evaluating sites for remediation.

All of the required information on individual points of interest can be presented in summary tables, graphical plots, and on site maps.

8.6.2   Analysis of Areas

If targeting areas at a larger spatial scale than individual stations or subbasins, such as stream segments, is required, summary statistics and/or additional information on the concentrations in the areas and/or loadings to the areas might be needed. Data must first be grouped accordingly in the database. If a stream segment is large, care must be taken that the grouped data can be considered to be from one population.

Concentrations and loadings should be plotted against distance or stations along the main stem of the stream segment of interest to help identify reaches that might be impaired and locations of loadings to and losses from the segment. The loadings themselves should also be plotted in this manner. The sampling stations, major

tributaries, and/or source areas along the main stem should be plotted on the graph as well.

If different stream segments must be evaluated and targeted for restoration, the following information regarding concentrations in each stream segment should be estimated on a seasonal basis:

- mean, stream-length weighted mean, and median concentration (because the data are likely right skewed) to estimate average conditions

- standard deviation and minimum and maximum to estimate variability

- 90 or 95% *CI*s for means, median, and standard deviation to estimate the uncertainty associated with each value

The confidence in the estimates should be used as necessary in the targeting process. It is generally not recommended that annual values be estimated. If, however, they must be estimated for stream segments, it is recommended that the annual mean, time-weighted mean, and median be estimated. The standard deviation, minimum and maximum, and appropriate *CI*s can then be estimated for the annual values. Differences and relative differences in concentrations between stream segments can be computed or observed by directly comparing values. Bar graphs can be used to present the concentration data for easy comparison. If an ambient standard must be estimated, something similar to the concentration of the 85th percentile can be used. *CI*s for the percentiles should also be estimated to evaluate the uncertainty in the values. The risk of exceeding a standard or target concentration in a stream segment, and its associated *CI*, should be estimated using the nonparametric estimate of proportions.

The total loadings to each stream segment should be estimated on a seasonal basis. Annual values can also be estimated, if required, using the time weighted

seasonal values. Differences and relative differences in loadings to different stream segments should be computed or observed by direct comparison of values. Bar graphs can be used to present the total loading values for easy comparison.

The following information regarding unit area loadings to each stream segment should be estimated on a seasonal basis:

- mean and median (because the data are likely right skewed) unit area loadings to estimate average conditions

- standard deviation and minimum and maximum to estimate variability

- 90 or 95% *CI*s for mean, median, and standard deviation to estimate the uncertainty associated with each value

The confidence in the estimates should be used as necessary in the targeting process. It is generally not recommended that annual values be estimated. If, however, they must be estimated at a particular site, it is recommended that the time-weighted mean, as well as the mean and median, be estimated. The standard deviation, minimum and maximum, and appropriate *CI*s should then be estimated for the annual values. Differences and relative differences in unit area loadings to stream segments can be computed or observed by directly comparing values. Bar graphs should be used to present the data for easy comparison. The risk of exceeding a target unit area loading to a stream segment can also be estimated using the nonparametric estimate of proportions. *CI*s for the proportions should also be estimated to evaluate the uncertainty in the values.

For many IAMs, loadings from different types of sources, such as NPSs, point sources, or background sources, to a specific stream segment must be estimated and/or targeted. In this case, the loading data for each type of source should be grouped and the following should be estimated using the loadings for each type of

source (and unit area loadings for NPSs and background sources):

- mean daily and total loadings from each type of source on a seasonal, and if required, an annual (using time weighted seasonal values) basis

- mean and median (because the data are likely right skewed) daily and total unit area loadings from each type of source on a seasonal, and if required, an annual (using time weighted seasonal values) basis

- standard deviation and minimum and maximum to estimate variability

- 90% *CI*s for mean, median, and standard deviation to estimate the uncertainty associated with each value

- percentage of total loading from each type of source relative to the total loadings from all sources to the stream

- for each type of source, the percentage of total loading for each season relative to the total loading for a year

Differences and relative differences between loadings from different types of sources can be computed or observed by direct comparison. Bar graphs should be used to summarize and present the total loading data, and pie charts can be used to present the loading percentages. Magnitudes of and relative differences between types of sources and seasons can be easily observed from these graphs.

8.7   Step 7: Targeting

The next step of the assessment methodology is information use for targeting remediation, as discussed in the following sections. The most important information required for the recommended assessment methodology and targeting approach has been presented in Table 8.1. The targeting approach discussed in the following sections is based primarily on the use of this site information. Although it is not the intent of this study to define the exact targeting methodology (but instead how to derive the information required for targeting), the general targeting approaches must be defined (or assumed) in order to define the information goals and show how the

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information can be used. A targeting (prioritization or ranking) table and site map that is coded with targets or priority source areas and stream segments can be developed that is the primary tool for targeting or is the result of the targeting process. These tables or maps can be standardized and should be presented formally in a targeting report.

Additional information based on other previously defined information goals, such as costs and benefits of remediation, should also be used in the targeting process, especially for the subsequent and ultimate selection of specific areas for remediation. Additional analyses, such as cost/benefit analyses, should be performed after the screening-level assessment and during the targeting process for specific sites of interest.

8.7.1   Stream Segments

It is generally recommended that targeting of stream segments proceed first in order to identify priority areas and to utilize resources for targeting subbasins and individual source areas later more efficiently. Targeting stream segments should be based on comparison, differences, and relative differences of the following estimated values for different segments:

- seasonal mean and median concentrations
- risks of exceeding standards
- seasonal loadings and mean and median unit area loadings
- risks of exceeding target loadings and unit area loadings

Annual values can also be used for comparison, if required. The seasonal values for types of sources should be compared to help determine critical conditions and target remediation for specific source types and seasons. Targeting more localized areas within segments can also be performed by delineating locations of standards

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exceedances and ranking the instream concentrations to easily identify those stations exhibiting the highest concentrations. Comparison of aquatic ecologic information between segments and between more localized areas should also be performed to the extent possible to determine the degree of impairment. Site maps, such as shown in Figure B2 in Appendix B, should also be used as much as possible as a visual aid in targeting stream segments. The confidence in all of the estimated values should be taken into consideration in the final selection of sites for remediation.

Stream segments that have low concentrations, small loadings, and/or do not often exceed standards might not be targeted because they are only slightly impaired. On the other hand, segments that exhibit high concentrations, have significant loadings, and/or a high risk of exceedances might not be targeted because restoration is not likely to succeed. This is generally the case for Cement Creek. In these cases, it is particularly important to consider and use other important criteria in the targeting process, including public support, technical feasibility, land ownership, value of water body, etc.

8.7.2   Source Areas

Once high priority stream segments have been identified, source areas likely contributing metals loadings to those segments should be targeted. Targeting types of sources should be based on comparison, differences, and relative differences of the following estimated values for different sources:

- seasonal loadings to segment

- percentage of loadings from each type of source relative to total loadings from all sources to segment

- mean and median unit area loadings (for NPSs and background sources) to segment

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- risks of exceeding target loadings and unit area loadings

Annual values can also be used for comparison, if required. The seasonal values for types of sources should be compared to help determine critical conditions and target remediation for specific source types and seasons. If annual values are also used, percentages of seasonal loadings relative to the annual total loadings should also be compared. For individual subbasins, targeting should be based on ranking these values as well to easily identify those stations exhibiting the highest loadings. The distances from subbasins (source areas) to the impaired water bodies and isolating factors should also be considered in the targeting process. Site maps, such as presented in Figure B3 in Appendix B, should be used to the extent possible as a visual aid in targeting source areas. In addition, the uncertainty of the estimated values should be used in the decision-making process as needed.

8.7.3   Targeting Report

The key to the effective targeting process is to develop a comprehensive targeting report for presentation to and use by all interested parties in the watershed. The report should present all required information so that all interested parties can observe and understand the assessment and targeting methods and results for the watershed, and, hopefully, to gain concurrence on the targeting. The report should include the following:

- tables of magnitudes, differences, ranking, risks of exceedances, distances, uncertainty for easy evaluation

- graphical plots of these estimated values in bar graphs, pie charts, concentration vs. distance plots for easy presentation

- site maps with estimated values and coding overlain for easy visual presentation

- the report should also include an introduction or summary of the problem; specific assessment information goals; and all data collection, management, and analysis methods

8.8   Testing and Evaluation

The specific methods that are part of the overall methodology have been applied, tested, and evaluated using data from Cement Creek. This was necessary to determine if the methods could be used to reach the information goals defined and target sites for remediation. Most of the methods were successful in that regard, and have now been integrated into a comprehensive methodology. The methodology itself must now be tested in a qualitative manner and evaluated for its applicability to other IAMs. If the overall methodology can be shown to be applicable to typical sites and data sets, then it will be proven to be useful.

In order to test and evaluate the proposed methodology, five other typical IAM watersheds will be used. The general characteristics of each site will be reviewed and the data sets will be evaluated. The types of data, including analytes, and frequencies and locations of data collection, will be identified for each site. Although the actual assessment methodology will not be applied nor targeting tables and/or maps developed for these sites as part of this study, the potential applicability and usefulness of the recommended methodology will be evaluated based on the characteristics of the site and the data. This information is summarized in Table 8.2.

The five sites are as follows:

1.   Upper Animas River and Mineral Creek
2.   Clear Creek/Central City Superfund Site, Colorado
3.   East Fork Pine Creek in the Couer d'Lene Basin, Idaho
4.   Taos Resource Area, New Mexico
5.   Strawberry Creek/Bear Butte Creek Basin, South Dakota

The following sections discuss each site in some detail.

Table 8.2. Potential applicability of recommended methodology to other IAMs

Area	Upper Animas River/ Mineral Creek	Clear Creek Superfund Site	East Fork Pine Creek	Strawberry Creek/Bear Butte Creek	Taos Resource Area
Data Types					
Dissolved metals	√	√	√	√	√
Total metals	√[1]	√	√	√	√
Flow	√	√	√	√	√
Sediment		√	√	√[2]	
Fish	√[1]	√			√
Invertebrates	√[1]	√			√
Habitat		√			√
Source materials		√	√	√[3]	
Source areas/volumes		√	√	√	
Groundwater		√		√	
Frequency					
3-6 or quarterly events	√	√	√	√[4]	
Locations					
Mouth	√	√	√	√	√
Bracketing	√	√	√	√	
Tributaries	√	√	√	√	√
Point sources	√	√	√	√	√
Background	√	√	√	√	
Standards setting	√	√	√		
Recommended Methodology Applicable	√	√	√	√	√

[1] Monitored only once

[2] Planned for monitoring

[3] X-ray diffraction

[4] Quarterly

1.   Upper Animas River and Mineral Creek

These basins have been mentioned previously and are adjacent to the Cement Creek basin in the San Juan Mountains of Colorado near Silverton. Both of these basins have also been heavily impacted by metal mining since the late 1800's. They are both somewhat larger than the Cement Creek basin. The Upper Animas River basin is due east of the Cement Creek basin. Cement Creek is a tributary to the Upper Animas River. Mineral Creek is also a tributary to the Upper Animas River west of and downstream from Cement Creek. Mineral Creek is not as impacted as Cement Creek or the Upper Animas River. Some fish live in Mineral Creek, and aluminum is one of the primary constituents of concern in this stream. The Upper Animas River is very similar to Cement Creek in terms of the types of impacts and constituents of concern, although it is not quite as impacted as Cement Creek. The headwaters of the Upper Animas River are devoid of fish, but the lower reaches near the confluence of Cement Creek and downstream and several tributaries have viable fish populations.

The data collected for these basins are very similar to those collected for Cement Creek because the monitoring was part of the same CDPHE NPS program. The proposed methodology would, therefore, be applicable and potentially very useful for assessment of data from these basins and targeting sites within the basins. In addition, some aquatic ecological data have been collected on fish densities and macroinvertebrates and, as stated previously, the lower reaches of the Upper Animas River are being targeted for restoration. These types of ecologic data, as well as methods for analysis and use in targeting, are discussed in Chapter 7. This information would aid in the targeting process and could help to improve the

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methodology proposed.

2.   Clear Creek/Central City Superfund Site, Colorado

This site is located immediately west of Denver in the Front Range of Colorado, from the continental divide to Golden. The watershed has steep, forested terrain, and has been heavily impacted by historic mining activities. Tailings, waste rock, adits and acid mine drainage, and disturbed areas are present throughout the basin. Other activities have impacted the streams as well, including runoff and erosion from municipalities and residential development, roads, sewage treatment plant discharges, and recreational activities. The basin became a Superfund site in 1983, primarily as a result of its location near metropolitan Denver and other municipalities.

The data collected from this site are fairly comprehensive, largely due to the fact that it is a Superfund site and an RI/FS has been completed. The following types of data are available:

- inventory of source areas and hazards
- dissolved and total metals concentrations and indicator parameters
- flowrates
- sediment (bed material) metals concentrations, grain size distribution, organic carbon content, and toxicity
- fish and macroinvertebrate community data and associated aquatic habitat data
- areas and contaminant concentrations of NPSs
- groundwater data

Data were collected at many locations in the main stem of Clear Creek, including at the mouth and bracketing source areas. Tributaries, point sources, and background areas were also monitored. Data have been collected during high

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(snowmelt and storms) and low flows over more than two years so that four to six data points are generally available for most stations. The biological data have not been collected as frequently.

Remediation goals, or ARARs, have been developed for the site as part of the CERCLA process. Some of the data, therefore, were used for this purpose. The data are also being used for targeting stream segments and source areas for remediation.

Because this site basically has all of the characteristics and types of data required for the recommended methodology, the methodology would be applicable and probably very useful for targeting remediation in this watershed. However, because the watershed is a Superfund site, resources are available to perform additional types of data analysis activities not included in the proposed methodology, such as more complex hydrologic and chemical modeling, to evaluate the watershed (and/or specific sites) in more detail.

3.   East Fork Pine Creek in the Coeur d'Alene Basin, Idaho

The East Fork Pine Creek basin is part of the South Fork Coeur d'Alene Basin in northern Idaho near Pinehurst. The basin has steeply sloped, forested terrain. The watershed has been impacted by historic mining activities and includes tailings, waste rock, acid mine drainage, and outwash deposition along streams. A cooperative assessment by IDEQ, Idaho Water Resources Research Institute, USBLM, USBM, and USEPA is being undertaken to restore the creek and fill in data gaps for the South Fork Coeur d'Alene Basin that exist throughout the East Fork Pine Creek basin. These basins contribute to Coeur d'Alene Lake, a major water supply, recreational attraction, and economic boon to the region.

The mining and other impacts to Coeur d'Alene Lake is a major concern for the whole region. Resources, therefore, have generally been available to perform fairly comprehensive assessments and limited remediation. The following types of data have been collected:

- inventory of source areas and hazards

- dissolved and total metals concentrations and indicator parameters

- flowrates

- sediment (bed material) metals concentrations, grain size distribution, organic carbon content, and toxicity

- areas and contaminant concentrations of NPSs

- groundwater data

Data were collected at many locations in the main stem of East Fork Pine Creek, generally bracketing source areas. Tributaries, point sources, and background areas were also monitored. Six sampling events have been performed during snowmelt, storm, and baseflows over two years.

TMDLs are being developed for the site to reduce loadings to the stream and allocate reductions and loadings to source areas or remedial projects. Much of the data, therefore, are being used for this purpose. The TMDL process can be considered a form of targeting.

Because this site has most of the characteristics and types of data required, the recommended methodology would be applicable and probably very useful for targeting remediation in this watershed. The TMDL process, however, typically includes some type of modeling of contaminant loadings to and concentrations in stream segments. These types of activities are beyond the scope of those

recommended for early screening-level assessment.

4.   Taos Resource Area (TRA), New Mexico

This area in northern New Mexico encompasses BLM land as well as portions of the Santa Fe and Carson National Forests managed by USFS. This area is comprised of a forested and rugged watershed with several historic metal mining districts and surface water impacts. Several active mines are also located within the watershed. Many environmental values and sensitive areas, such as wetlands and endangered species habitat, are present in the area. The TRA has been used by USEPA for a validation study of the proposed NPDES general stormwater permit for inactive mines, landfills, and oil and gas operations on Federal lands (USEPA, 1994). USEPA used the area and pre-existing data/information collected from the area by other agencies (state, USBLM, USFS, etc.) to develop and evaluate a method to use limited existing information to establish priorities for detailed investigation and possible mitigation. Even using very limited water quality and related data, USEPA concluded that Federal land managers should be able to comply with this first phase of the general permit.

Data available for the TRA are from the following existing sources:

- State of New Mexico's 1991 CWA Section 305(b) report
- USEPA STORET database
- limited state and USFS sampling in priority areas

These data are generally limited to inventories of source areas and hazards and dissolved and total metals concentrations and indicator parameters.

The proposed methodology would be applicable and probably very useful for deriving required information and targeting in the TRA given the current general lack of data for the site. Although USEPA concludes that the first phase of

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permitting, prioritization of remediation, can be accomplished using only existing data, the targeting is generally limited to fairly large-scale subbasins that are obvious problem areas. This approach is appropriate during the very early phases of assessment, but it appears that a coordinated synoptic type sampling program has not been implemented for the watershed. Smaller subbasins and specific source areas could be targeted using the assessment methodology presented in this study based on well-defined information goals.

5.   Strawberry Creek/Bear Butte Creek Basin, South Dakota

This 16 mi^2 basin is located in the Black Hills in a historic metal mining district. The basin is forested with steep terrain. Sources include waste rock, tailings, and draining adits and surface water impacts include acidic pH, elevated metals concentrations, and extensive "yellow boy" deposits. Most of the surface water recharges groundwater, which serves as a drinking water supply, in the area downstream.

The assessment being performed for the watershed is a cooperative effort among the State of South Dakota and the South Dakota School of Mines and Technology. The project recently also received a grant from USEPA as part of the Rocky Mountain Headwaters Mining Waste Initiative. Data collected to date include the following:

- inventory of source areas and hazards (on USFS land but not on private land)
- dissolved and total metals concentrations and indicator parameters
- flowrates
- areas and contaminant concentrations of NPSs
- groundwater data

An inventory will soon be performed on private land. Sediment (bed material) samples will also be collected in the near future for analysis of metals concentrations,

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grain size distribution, and organic carbon content. No aquatic ecological monitoring or assessment has been performed to date.

Data were collected at many locations in the main stems of Bear Butte Creek and Strawberry Creek, generally bracketing source areas and tributaries. Tributaries, point sources, and background areas were also monitored. Quarterly sampling over a one and a half year period has been performed. These sampling events did not necessarily correspond to selected flow events, although baseflow and snowmelt have been monitored. Several monitoring stations have been sampled at a higher frequency (monthly) over a longer period of time, and a gaging station is present near the mouth of the basin.

This basin has many of the characteristics and types of data required for the recommended methodology. Therefore, the methodology would be applicable and probably very useful for targeting remediation in this watershed. Impacts to downgradient groundwater (drinking water) would also have to be evaluated using supplemental methods.

8.9   Summary

Based on the methodology developed and recommended in this chapter and the testing and evaluation of the methodology using the sites/watersheds discussed above, some general conclusions can be drawn. On a qualitative basis using the general characteristics of the five sites and associated data sets, it does appear that the recommended methodology is applicable and potentially very useful for targeting within these watersheds. Although each of the sites has somewhat different site characteristics and unique problems, they do have many common characteristics and problems that can be addressed by this methodology. The methodology can also be

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used for each of the sites and provide the required information for targeting even though the data sets are not exactly the same. Most of the datsets are similar enough or have enough elements in common that the methodology, or at least portions of it, can be applied and would be useful for screening-level assessment. For those sites that have large and more comprehensive datasets, the methodology can be used and would be useful for initial targeting, and the additional data analysis methods discussed in Appendix E can be used to derive additional information that could complement the recommended assessment methodology and be used for later more detailed investigation for targeted sites for remedial design purposes.

The recommended methodology can and should also be tested and evaluated more intensively and quantitatively at these or other sites in the future. This would provide a more quantitative basis for extending the use of the methodology to other watersheds so that the derivation of required and comparable information among sites and agencies can be validated further. USEPA has shown considerable interest in funding this work.

9.0 SUMMARY AND CONCLUSIONS

This chapter summarizes the work performed in previous chapters and the recommended methodology for screening-level assessment of NPS pollution from IAMs. Conclusions of the study, as well as some recommendations for further work, are also briefly discussed.

9.1 Summary

The problem was first defined based on work conducted by USEPA, WGA, and CCEM, and typical characteristics and environmental problems at these sites were discussed. Then previous and existing monitoring and assessment methods for mining and related sites were identified and evaluated. These methods include those required by federal regulations for some sites, other federal and state assessment methods, and methods discussed by others in the open literature. Next, generalized, primary IAM management goals that are common to most sites were identified that include water quality management goals and a targeting approach. Typical screening-level assessment information goals and specific quantitative information goals for targeting remediation at these sites were then identified and clearly stated. Most of these goals were related to baseline information regarding metals concentrations in and loadings to stream segments.

Data attributes that are common to these sites (with regard to metals) were then identified and evaluated in detail using data derived from Cement Creek in the Upper Animas River Basin, Colorado, and the Pecos Mine site in New Mexico.

Next, many potentially applicable and/or useful data analysis methods were identified, applied to the Cement Creek data, and evaluated and tested with regard to reaching the defined information goals. Methods for information presentation and use, or targeting, were also discussed. Data gaps were then identified with regard to the Cement Creek data as well as data sets from many other IAM sites, and methods typically used to fill in these data gaps were identified and discussed. The most applicable and useful methods were then integrated into a comprehensive watershed-based methodology for screening-level assessment of NPS pollution from IAMs. The methodology was evaluated and tested qualitatively by assessing its applicability to and usefulness for several other IAM watersheds.

9.2 Conclusions

Many conclusions can be drawn from this study. This section discusses the most important conclusions.

General Conclusions

General conclusions for this study that are applicable to Cement Creek and other IAM watersheds are as follows:

- The primary conclusion of this research is that a watershed-based methodology for screening-level assessment of NPS pollution from IAMs that is effective and somewhat standardized was developed based on generalized, common IAM management goals and specific quantitative assessment information goals for targeting. Therefore, the primary objective of the study was achieved.

- Assessment information goals should include physical, chemical, biological, engineering, and socioeconomic information. These goals can be defined in terms of targeting criteria and usually include the following:
    - designated, existing, and attainable beneficial uses of stream segments
    - numeric water quality standards and maximum concentrations associated with uses
    - maximum loadings associated with uses
    - type and extent of water quality impairment and critical conditions

- reduction in concentrations and/or loadings required to achieve desired beneficial uses
- areal extent and contaminant concentrations of NPSs
- distances between sources and watercourses and impaired stream segments
- locations of loadings to and losses from stream segments
- magnitudes of concentrations and loadings
- differences between magnitudes of concentrations in and loadings to different stream segments
- frequency or risk of exceeding a target concentration in and loading to a stream segment
- remedial technologies available and costs
- funding availability and public support for remediation

- The potential error and uncertainty in the data and derived information should be considered explicitly in the assessment process in order to target remediation with a known degree of confidence. *CI*s, therefore, should be computed for statistical estimators.

- Ambient stream standards can be derived and the risk of exceeding standards or target concentrations/loadings can be evaluated using synoptic data.

- Visual aids for data presentation and use should be used and include graphs, mapping of information, and if possible, GIS.

- Targeting in Cement Creek and at other sites can be accomplished effectively using the recommended methodology.

- Based on the information goals defined and data sets evaluated, data gaps exist in Cement Creek and at most IAMs with regard to targeting remediation. These can be filled when the required information goals are not met with existing data and when resources are available using some of the methods discussed in this study. These methods include additional data collection and simplified modeling techniques.

- The recommended methodology is applicable to and would be very useful for other IAMs.

Cement Creek Case Study Conclusions

Conclusions that are specific to the Cement Creek basin case study are as follows:

- For the Cement Creek dissolved zinc data, the small sample size typically associated with individual monitoring stations generally results in fairly large *CI*s about statistical estimators. The increase in confidence of estimates by increasing the sample size with increased monitoring frequency or time period

might be offset by potential year to year variability. The increase in confidence of estimates by increasing the sample size with increasing spatial scale of interest is generally offset by the increasing spatial variability with scale. This is probably the case for most metals and IAMs in general.

- Cement Creek dissolved zinc concentration data derived from synoptic surveys are not normally or lognormally distributed, but are right-skewed. The dissolved zinc unit area loading data are also not normally or lognormally distributed, and are more right-skewed than the concentration data. Therefore, nonparametric methods are generally recommended. This is probably the case for most metals and IAMs in general.

- Cement Creek flow and dissolved zinc concentration and loading data do generally exhibit seasonality. Flows and loadings exhibit significant seasonality relative to concentrations. In Cement Creek, dissolved zinc concentrations are generally highest during baseflow and lowest during snowmelt. Loadings are highest during snowmelt and lowest during baseflow. This is probably the case for most metals and IAMs in general.

- In Cement Creek, dissolved zinc concentrations and unit area loadings are generally highest in the headwaters in the upper part of the basin. NPSs contribute significantly more loadings than point sources and background sources.

Recommendations

With regard to further work and potential modifications and improvements to the methodology, the following is recommended:

- Additional species of metals (especially metals that are important in the total form) and total metals should be evaluated in the future using the recommended methodology to assess its applicability to other metals.

- The methodology should be quantitatively applied to additional sites throughout the western U.S. by different federal and state agencies for additional testing and evaluation of its applicability and usefulness.

- Biological methods should be evaluated and incorporated into the methodology to a greater extent.

- The optimal methods for establishing appropriate numeric standards and beneficial use classifications for stream segments should be evaluated in more detail. This is especially true with regard to determining the appropriate spatial scale or size of stream segments and number of monitoring stations that should used to classify streams. The TMDL methodology should be used in conjunction with the recommended assessment methodology to aid in the standards setting process as well as in the targeting process.

- The effects of small sample sizes for individual monitoring stations with regard to uncertainty and limitations in the required information should be evaluated in more detail. This appears to be the most significant statistical pitfall requiring further research for IAMs. For the Cement Creek case study, the problem of small sample sizes was dealt with by quantifying the uncertainty of the information and using this uncertainty in the targeting process, as well as by evaluating larger areas of interest instead of single points or monitoring stations.

- Specific methods for identifying data gaps should be developed and could be incorporated into the recommended assessment methodology.

- Significant data gaps should be filled when resources are available to derive the required information, especially for the next phase of assessment, i.e. detailed assessment for remedial design purposes. The methods for filling data gaps should be evaluated and applied for this phase in greater detail.

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APPENDIX A. DATA ATTRIBUTES OF INACTIVE AND ABANDONED MINE CASE STUDIES

This appendix presents a detailed discussion of data attributes that are common to many data sets derived from typical synoptic sampling events in IAM watersheds. These attributes have a significant impact on the applicability, choice, and use and interpretation of different data analysis methods. The attributes are discussed and evaluated using data from case study IAMs: the Upper Animas River Basin near Silverton in the San Juan Mountains in southwestern Colorado and the Pecos (Tererro) Mine near Santa Fe in northern New Mexico (discussed in the next section). Attributes of typical IAM data that might be important in the identification and selection of analysis methods and are evaluated in this section include (Adkins, 1993):

- measurement error and variability
- sample size
- multiple observations
- censoring
- changing sampling frequencies and missing values
- nonnormality
- seasonality

A.1   Measurement Error and Uncertainty

The following model for the measurement x_i on the ith unit of a population is typically used for environmental studies (Gilbert, 1987):

$$x_i = \mu + d_i + e_i = \mu_i + e_i \qquad (A.1)$$

where:

μ = true mean over all N units in the population

$d_i = \mu_i - \mu$ = amount by which the true value for the ith unit, μ_i, differs from μ

$e_i = x_i - \mu_i$ = measurement uncertainty = the amount by which the measured value for the ith unit, x_i, differs from the true value μ_i

The estimated mean $(\bar{x})$ of the actual population mean (μ) is computed as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (A.2)$$

where:

$i = (1,2,...,n)$

x_i = ith datum or measurement

n = sample size of interest

Measurement error or uncertainty (e_i) results from field measurement errors (human and instrument) and analytical limitations and can be positive or negative (Hem, 1985; Suter et al., 1987; CDPHE, 1992a). It can generally be assumed that the average e_i over the population has zero mean. This assumes that there are no systematic measurement biases. Under optimal conditions, the analytical results for major constituents have an accuracy of ± 2 to $\pm 10\%$. This accuracy decreases (error or variability increases) for trace elements such as metals as the concentrations approach the detection limits. The accuracy of most flow meter measurements is generally estimated to be approximately $\pm 10\%$ (Hem, 1985; CDPHE, 1993a). Measurement errors are not necessarily site-specific, although characteristics of different sites may impact them. For example, flow measurements made during high flows may be less accurate because of human limitations and errors made in dangerous field conditions, but flow measurements made at very low flows may also be less accurate because of limitations of and errors in the flow meter at minimal flows. Estimating site-specific analytical variability and error, such as by performing

a cation-anion balance or collecting adequate QA/QC samples, can have significant costs associated with analyzing all major cations and anions and QA/QC samples for all or a subset of the samples collected. In general, measurement and analytical error has been evaluated and discussed in the literature more extensively than other sources of uncertainty. Therefore, it may be possible and practical to estimate typical measurement and analytical errors from previous studies or the literature instead of from each individual site assessment. This is the general approach that CDPHE has used on the Upper Animas River Basin study (CDPHE, 1993a).

The theoretical potential error, or uncertainty, of the instantaneous measured loading estimate can be expressed in terms of the standard deviations or the coefficients of variation (CVs) (standard deviation divided by the mean) of the estimated loading, flowrate measurement, and concentration analysis. Bevington (1969) presents the following equation if L is the product of Q and C:

$$\frac{\sigma_L^2}{L^2} = \frac{\sigma_Q^2}{Q^2} + \frac{\sigma_C^2}{C^2} + 2\frac{\sigma_{QC}^2}{QC} \tag{A.3}$$

where L, Q, and C are measured values that are assumed to represent the average values of multiple measurements, and the last term includes the covariance of Q and C. The covariance term drops out (is equal to zero) because the fluctuations in measurements of Q are not correlated with the fluctuations in measurements of C at a given point in time and space. Using the CVs, the uncertainty of the measured loading estimate can be estimated as (CDPHE, 1993a; Bevington, 1969):

$$U = (S^2 + B^2)^{0.5} \tag{A.4}$$

where:

U = *CV* of loading estimate
s = *CV* of flowrate measurement
B = *CV* of concentration analysis

For the Upper Animas River Basin study, CDPHE has obtained s = 0.15 and B = 0.1. CDPHE based the s value on the literature values as well as on multiple field measurements of flow using several current meters with different field crews at the same location at the mouth of Cement Creek. The average variability of these measurements was within 15%. CDPHE based the B value on the literature values and their average laboratory precision (10%). These *CV* values are considered average estimates of the error or uncertainty associated with the loadings.

Based on the s and B values, CDPHE has assumed U = 0.18. In addition, when the NPS reach gain/loss analysis (Equation 5.2) is used, the potential error or uncertainty of the computed loading between the points is estimated using the uncertainties, as estimated by the average standard deviations, in the equation shown by Bevington (1969) when L is the sum of *L1* and *L2*:

$$\sigma_L^2 = \sigma_{L1}^2 + \sigma_{L2}^2 + 2\sigma_{L1L2}^2 \qquad (A.5)$$

where the last term includes the covariance of *L1* and *L2*. The covariance term drops out (is equal to zero) because the fluctuations in measurements of *L1* are not correlated with the fluctuations in measurements of *L2* at a given point in time. Using the standard deviations, the uncertainty of L (U) is estimated using the uncertainty of the upstream points $(U2,...,U4)$ and the downstream point $(U1)$:

$$U = (U1^2 + U2^2 +, \dots, + U4^2)^{0.5} \qquad (A.6)$$

This results in a higher potential error or uncertainty for estimated instantaneous

loadings relative to measured loadings. These estimated errors are sometimes higher than the estimated loadings themselves, thereby reducing or eliminating the confidence in the values estimated between the measured points. Nevertheless, this NPS reach gain/loss procedure is a common method used to provide information on locations and general magnitudes of loadings and losses of contaminant mass for complex, multiple source IAM watersheds.

The uncertainty or potential error for each loading value was computed automatically in the spreadsheet using the above equations and is presented in column R in Table C2 in Appendix C for the Cement Creek subbasin data.

A.2 Sample Size

Sample size influences the applicable data analysis methods and the associated confidence in the derived information. Statistical analyses using a small sample size generally result in a large *CI* (smaller confidence or less precision) about the results (Loftis and Ward, 1980). This leads to a smaller confidence in management decisions regarding targeting and remediation. The *CI* about the estimated mean (CI_m) is related to the standard deviation and the sample size. The $100(1-\alpha)\%$ CI_m width is computed as:

$$CI_m = t_{1-\frac{\alpha}{2},v} \frac{s}{\sqrt{n}} - t_{\frac{\alpha}{2},v} \frac{s}{\sqrt{n}} \qquad (A.7)$$

where:

t = Student's t statistic
α = significance level (α = 0.1 for 90% *CI*)
v = degrees of freedom (n-1)
s = sample standard deviation
n = sample size

The standard deviation (s) is the square root of the variance (s^2) which is computed as:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \overline{x})^2 \qquad (A.8)$$

The sample median (x_{50}) is the 50th percentile of any sample distribution, and is generally a better estimator than the mean of central tendency or average conditions for nonnormal (right skewed) distributions because it is based on the ranks of the data and is not as sensitive to large extreme values or outliers. To calculate x_{50}, all of the sample data (x_i) are first ranked from smallest to largest. Then x_{50} is calculated from the sample order statistics $x_{(1)} \le x_{(2)} \le ... \le x_{(n)}$ as follows:

$$x_{50} = x_{[(n+1)/2]} \quad \textit{if n is odd} \qquad (A.9)$$

or

$$x_{50} = \frac{1}{2} (x_{[\frac{n}{2}]} + x_{[\frac{(n+2)}{2}]}) \quad \textit{if n is even} \qquad (A.10)$$

The 95% CI about the median (CI_{md}) can be derived from Table A14 in Gilbert (1987). The 90% CI_{md} can be derived from Geigy (1982, pp. 103-107).

This data attribute is very important for IAM assessment because the sample size varies significantly depending on the spatial scale of interest and only three or four data points are typically available for a single monitoring station based on synoptic or quarterly monitoring over only a one year period. As the spatial scale of the analysis increases (such as analysis of a stream segment or a subbasin), however, the sample size increases. This could decrease the CI about a statistical result for a large spatial scale relative to statistical analyses at a single point. However, the standard

deviation could also increase with a larger spatial scale due to a potential increase in spatial variability when more monitoring stations are incorporated into the analysis. This could also cause the *CI* to be larger with a larger spatial scale. The spatial scale of interest and associated sample size, therefore, will impact the identification and selection of applicable data analysis methods and the resulting confidence in statistical results and required information.

If the spatial scale of interest increases too much, where the area to be measured is not only more heterogeneous and variable but is comprised of different populations, then the mean, median, and other statistical parameters of interest lose their physical meaning and cannot be defined. Care must be taken, therefore, not to make the spatial scale of interest too large if estimation of statistical parameters is required. Areas should be subdivided into relatively homogeneous subareas to the extent possible when necessary. The optimum methods to subdivide areas for calculation of statistical estimators is beyond the scope of this study but should be evaluated further in future research. This is especially true for the delineation and evaluation of stream segments for standards setting and restoration.

In order to evaluate the effect of synoptic or quarterly sampling over a year and the spatial scale of interest on the confidence in estimates of average values, the *CI*s for estimates of the annual mean concentration were computed using typical, but different sample sizes and standard deviations estimated from observed data. This was accomplished in three steps. The first step was to estimate the average *CI* for the estimated mean concentrations at all monitoring stations sampled four times in a given year. This involved computing the mean, standard deviation, and 90 and 95% CI_ms for each station within Cement Creek that had a sample size of four. Half

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of each CI_m was also computed as fraction of the estimated mean value. This will be referred to as the coefficient of the CI_m (CCI_m). The average CCI_m was then computed using all of these stations within Cement Creek. The computations are included in columns W through AC in Table C2 of Appendix C. The CI_ms were not computed due to the small sample size.

The average 90% CCI_m is 48% and the average 95% CCI_m is 65% based on a sample size of four. This means that even using only four data points collected during different flow regimes over a year or multiple years, the estimate of the annual mean concentration can still be considered generally about $\pm 50\%$ of the actual mean with a confidence of 90 to 95%.

The second step involved evaluating the effect of increasing sampling frequency to more than four times per year and/or increasing the sampling period to more than one year at a station. This involved using data from two stations in the Upper Animas River Basin as well as data from the Pecos Mine site. For the Pecos Mine site, data were collected from two stations in Willow Creek and two stations in the Pecos River over a two-year period. One of the Pecos River stations and one of the Willow Creek stations is upstream of the waste rock (background stations). This step included estimating the CI_m for the mean concentration computed based on quarterly sampling for a year as well as based on more data points (up to twelve) at each station as a result of quarterly or more frequent monitoring over two years or biquarterly monitoring over a year. The results of these computations are presented in Table A1, and the computations are presented in Table A2.

LOCATION	N	QUARTERLY CI 90% CCIM	95% CCIM	N	BIQUARTERLY CI 90% CCIM	95% CCIM
Table A1. Effect of sample size for individual station on CI of mean zinc concentration						
for the Pecos Mine site						
			DISSOLVED			
WILLOW CREEK						
UPSTREAM	0	N/A	N/A	0	N/A	N/A
DOWNSTREAM	4	2.15	2.91	12	0.84	1.03
PECOS RIVER						
UPSTREAM	4	0.47	0.64	14	0.55	0.67
DOWNSTREAM	4	1.79	2.42	11	1.11	1.37
			TOTAL			
WILLOW CREEK						
UPSTREAM	4	0.45	0.61	12	1.14	1.40
DOWNSTREAM	4	2.14	2.90	12	0.75	0.92
PECOS RIVER						
UPSTREAM	4	0.47	0.64	12	1.53	1.87
DOWNSTREAM	4	1.80	2.44	8	1.02	1.28

Table A1

Abbreviations:

CI = confidence interval
N = sample size
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CCIM = coefficient of 95% CI on mean

Table A2. Calculations for Table A1										
SEGMENT	SUB_SEG	DATE	ZNDCB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Willow	Downstream	1/19/91	40	12	762	1235	640	0.84	785	1.03
		5/21/91	620							
		8/27/91	80							
		3/25/92	2500							
		4/1/92	3600							
		4/9/92	30							
		4/15/92	5							
		5/30/92	100							
		7/7/92	10							
		8/10/92								
		8/11/92								
		8/13/92								
		9/16/92	50							
		1/19/93	80							
		4/1/93	2030							
Willow	Upstream	1/19/91								
		5/21/91								
		8/27/91								
		3/25/92								
		4/1/92								
		4/9/92								
		4/15/92								
		5/30/92								
		7/7/92								
		8/10/92								
		8/11/92								
		9/16/92								
		1/19/93								
		4/1/93								
Pecos	Downstream	1/19/91	40	11	291	592	324	1.11	398	1.37
		4/14/91	94							
		5/21/91	20							
		8/27/91	40							
		11/19/91	140							
		3/25/92	1900							
		4/1/92	890							
		4/10/92	10							
		5/30/92	5							
		7/8/92	30							
		9/16/92	30							

SEGMENT	SUB_SEG	DATE	ZNDCB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Pecos	Upstream	1/19/91	10	14	11	12	6	0.55	7	0.67
		4/14/91	2							
		5/21/91	50							
		8/27/91	20							
		11/19/91	5							
		3/25/92	5							
		4/1/92	5							
		4/8/92	10							
		4/15/92	5							
		5/30/92	5							
		7/7/92	10							
		8/11/92	5							
		9/16/92	5							
		1/19/93	10							

Table A2.	Calculations for Table A1									
SEGMENT	SUB_SEG	DATE	ZNDCQ	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Willow	Downstream	1/19/91								
		5/21/91								
		8/27/91								
		3/25/92								
		4/1/92								
		4/9/92								
		4/15/92								
		5/30/92								
		7/7/92	10	4	543	992	1167	2.15	1579	2.91
		8/10/92								
		8/11/92								
		8/13/92								
		9/16/92	50							
		1/19/93	80							
		4/1/93	2030							
Willow	Upstream	1/19/91								
		5/21/91								
		8/27/91							.	
		3/25/92								
		4/1/92								
		4/9/92								
		4/15/92								
		5/30/92								
		7/7/92								
		8/10/92								
		8/11/92								
		9/16/92								
		1/19/93								
		4/1/93								
Pecos	Downstream	1/19/91								
		4/14/91								
		5/21/91								
		8/27/91								
		11/19/91	140	4	273	415	488	1.79	660	2.42
		3/25/92								
		4/1/92	890							
		4/10/92								
		5/30/92								
		7/8/92	30							
		9/16/92	30							

SEGMENT	SUB_SEG	DATE	ZNDCQ	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Pecos	Upstream	1/19/91								
		4/14/91								
		5/21/91								
		8/27/91								
		11/19/91	5	4	6	3	3	0.47	4	0.64
		3/25/92								
		4/1/92	5							
		4/8/92								
		4/15/92								
		5/30/92								
		7/7/92	10							
		8/11/92								
		9/16/92	5							
		1/19/93								

Table A2. Calculations for Table A1										
SEGMENT	SUB_SEG	DATE	ZNTB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Willow	Downstream	1/19/91	30	12	1249	1815	941	0.75	1153	0.92
		5/21/91	5200							
		8/27/91	80							
		3/25/92	2000							
		4/1/92	4000							
		4/9/92	220							
		4/15/92	170							
		5/30/92	310							
		7/7/92	40							
		8/10/92								
		8/11/92								
		8/13/92								
		9/16/92	80							
		1/19/93	80							
		4/1/93	2780							
Willow	Upstream	1/19/91	10	12	33	73	38	1.14	46	1.40
		5/21/91	260							
		8/27/91	10							
		3/25/92	5							
		4/1/92	5							
		4/9/92	5							
		4/15/92	20							
		5/30/92	50							
		7/7/92	10							
		8/10/92								
		8/11/92								
		9/16/92	10							
		1/19/93	5							
		4/1/93	5							
Pecos	Downstream	1/19/91	15	8	331	506	339	1.02	423	1.28
		4/14/91	114							
		5/21/91	600							
		8/27/91	100							
		11/19/91	140							
		3/25/92	1500							
		4/1/92								
		4/10/92								
		5/30/92	130							
		7/8/92	50							
		9/16/92								

SEGMENT	SUB_SEG	DATE	ZNTB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Pecos	Upstream	1/19/91	10	12	116	342	177	1.53	217	1.87
		4/14/91	5							
		5/21/91	1200							
		8/27/91	80							
		11/19/91	10							
		3/25/92	10							
		4/1/92	5							
		4/8/92								
		4/15/92	5							
		5/30/92	40							
		7/7/92	20							
		8/11/92								
		9/16/92	5							
		1/19/93	5							

Table A2. Calculations for Table A1										
SEGMENT	SUB_SEG	DATE	ZNTB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Willow	Downstream	1/19/91								
		5/21/91								
		8/27/91								
		3/25/92								
		4/1/92								
		4/9/92								
		4/15/92								
		5/30/92								
		7/7/92	40	4	745	1357	1597	2.14	2159	2.90
		8/10/92								
		8/11/92								
		8/13/92								
		9/16/92	80							
		1/19/93	80							
		4/1/93	2780							
Willow	Upstream	1/19/91								
		5/21/91								
		8/27/91								
		3/25/92								
		4/1/92								
		4/9/92								
		4/15/92								
		5/30/92								
		7/7/92	10	4	8	3	3	0.45	5	0.61
		8/10/92								
		8/11/92								
		9/16/92	10							
		1/19/93	5							
		4/1/93	5							
Pecos	Downstream	1/19/91								
		4/14/91								
		5/21/91								
		8/27/91								
		11/19/91	140	4	455	698	821	1.80	1110	2.44
		3/25/92	1500							
		4/1/92								
		4/10/92								
		5/30/92	130							
		7/8/92	50							
		9/16/92								

SEGMENT	SUB_SEG	DATE	ZNTB	N	AVG	STDS	90% CIM	90% CCIM	95% CIMD	95% CCIMD
Pecos	Upstream	1/19/91								
		4/14/91								
		5/21/91								
		8/27/91								
		11/19/91								
		3/25/92								
		4/1/92								
		4/8/92								
		4/15/92	10	4	7.5	2.9	3	0.45	5	0.61
		5/30/92								
		7/7/92								
		8/11/92	10							
		9/16/92	5							
		1/19/93	5							

Table A2

Abbreviations:

ZNDCB = dissolved zinc concentration based on approximately biquarterly monitoring (μg/L)

ZNDCQ = dissolved zinc concentration based on approximately quarterly monitoring (μg/L)

ZNTCB = total zinc concentration based on approximately biquarterly monitoring (μg/L)

ZNTCQ = total zinc concentration based on approximately quarterly monitoring (μg/L)

N = sample size

AVG = mean

STDS = standard deviation

90% CIM = 90% CI width on mean

90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)

95% CIM = 95% CI width on mean

95% CCIM = coefficient of 95% CI on mean

For the Willow Creek downstream station, the 90 and 95% CCI_ms for both dissolved and total zinc based on quarterly monitoring over the latest year of data ($n = 4$) are very large. This is the result of a large standard deviation and the small sample size. When n is increased to 12 for the downstream station based on monitoring over a two-year period, the CCI_ms are more than halved. The CI_ms for dissolved zinc at the Willow Creek upstream station were not computed because of the very small percentage of detected values. The 90 and 95% CCI_ms for total zinc at this station were relatively small for n equal to 4, and increase significantly when n is increased to 12. This may be the result of significant year to year variability. Based on the two years of data available, at least two concentration values were significantly higher during the first year of monitoring than values measured during the second (or latest) year of monitoring. The 90 and 95% CCI_ms for the Pecos River downstream station for both dissolved and total zinc based on four samples are also quite large. When n is increased to 11 (dissolved) and 8 (total) based on almost two years of data, the CCI_ms are again almost halved. For the upstream Pecos River station, the 90 and 95% CCI_ms based on four samples are smaller than those for the downstream station, and even increase when n is increased to 14 (dissolved) and 12 (total) based on two years of data. The increase in the CI could again be the result of year to year variability. One concentration value measured during the first year of monitoring was very high and could be an anomoly. This value indicates this potential year-to-year variability and affects the estimate of the CI. This evaluation shows that interannual variation of zinc concentrations at background stations is less than that at downstream stations, but intraannual variability is probably significant

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at all stations. Although the CI_m for downstream stations decreases as n increases over more than a year, the CIs for the estimated long-term (two-year) mean are still relatively large for all stations due to the year to year variability (even though n increases).

For the Upper Animas River Basin, Colorado River Watch Program data collected over a two-year period at a high frequency (generally more frequently than monthly) were available for the mouth of Mineral Creek (MC34) and the Upper Animas River immediately above Silverton (A68), but not for any stations in Cement Creek. Forty two dissolved and total zinc concentration values were available at MC34, and 44 were available for A68. The 90 and 95% CI_ms and CI_{md}s were calculated for both of these stations. The results of the computations are presented in Table A3, and the data and CIs are presented in Table A4. As can be seen from Table A3, the CCI_ms range from about 15% to 25%. The smaller CI_ms are for Mineral Creek data, where the variability over time (standard deviation) is smaller. In Mineral Creek the CI_ms for total zinc are slightly smaller than those for dissolved zinc, whereas in the Upper Animas River, the CI_ms for total zinc are somewhat greater than those for dissolved zinc. This results from the greater variability of concentrations of dissolved zinc in Mineral Creek, and of total zinc in the Upper Animas River, relative to the other forms of zinc in each of the basins. These CI_ms are at least half the size of the average CI_m computed in Step 1 above for stations in Cement Creek with only four data points available. However, due to the high frequency of data collection at MC34 and A68, some serial correlation in these data at a station might be present that could reduce the confidence in estimates of a long-

Table A3. CI of mean and median zinc concentrations based on large sample size for individual station in the Upper Animas River Basin					
LOCATION	N	90% CCIM	95% CCIM	90% CCIMD	95% CCIMD
ANIMAS RIVER			DISSOLVED		
	44	0.19	0.23	0.69	0.70
			TOTAL		
	44	0.21	0.25	0.63	0.65
MINERAL CREEK			DISSOLVED		
	42	0.15	0.18	1.21	1.25
			TOTAL		
	42	0.14	0.17	1.16	1.17

Table A3

Abbreviations:

N = sample size
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CCIM = coefficient of 95% CI on mean
90% CCIMD = coefficient of 90% CI on median (1/2 CI width divided by median)
95% CCIMD = coefficient of 95% CI on median

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Table A4. Calculations for Table A3		ZNDC	RANK	90% CLMD	95% CLMD		ZNTC	RANK
SEGMENT		ZNDC	RANK	90% CLMD	95% CLMD		ZNTC	RANK
Animas		1790	44				2455	44
Animas		1785	43				2390	43
Animas		1785	42				2030	42
Animas		1474	41				1663	41
Animas		1458	40				1540	40
Animas		912	39				1151	39
Animas		721	38				894	38
Animas		632	37				767	37
Animas		557	36				739	36
Animas		556	35				646	35
Animas		548	34				599	34
Animas		540	33				574	33
Animas		519	32				567	32
Animas		510	31				522	31
Animas		495	30				519	30
Animas		490	29		490		513	29
Animas		489	28	489			513	28
Animas		480	27				511	27
Animas		479	26				510	26
Animas		461	25				504	25
Animas		453	24				489	24
Animas		450	23	447			489	23
Animas		444	22				489	22
Animas		406	21				482	21
Animas		405	20				478	20
Animas		374	19				471	19
Animas		363	18				427	18
Animas		363	17	363			409	17
Animas		356	16		356		391	16
Animas		352	15				381	15
Animas		350	14				370	14
Animas		336	13				365	13
Animas		325	12				364	12
Animas		324	11				361	11
Animas		324	10				354	10
Animas		323	9				351	9
Animas		323	8				347	8
Animas		322	7				338	7
Animas		320	6				338	6
Animas		312	5				335	5
Animas		287	4				314	4
Animas		277	3				290	3
Animas		250	2				277	2
Animas		97	1				274	1
				90% CCIMD	95% CCIMD			
				0.69	0.70			
	MEAN	564		90% CCIM	95% CCIM	MEAN	654	
	SD=	422		0.19	0.23	SD=	535	

Table A4. Calculations for Table A3		
SEGMENT	90% CLMD	95% CLMD
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		513
Animas	513	
Animas		
Animas		
Animas		
Animas		
Animas	489	
Animas		
Animas		
Animas		
Animas		
Animas		
Animas	409	
Animas		391
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
Animas		
	90% CCIM	95% CCIMD
	0.63	0.65
	90% CCIM	95% CCIM
	0.21	0.25

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SEGMENT		ZNDC	RANK	90% CLMD	95% CLMD		ZNTC	RANK
Mineral		732	42				691	42
Mineral		671	41				665	41
Mineral		642	40				651	40
Mineral		607	39				614	39
Mineral		590	38				585	38
Mineral		556	37				559	37
Mineral		544	36				549	36
Mineral		544	35				535	35
Mineral		531	34				526	34
Mineral		527	33				516	33
Mineral		507	32				506	32
Mineral		484	31				501	31
Mineral		474	30				500	30
Mineral		474	29				493	29
Mineral		469	28		469		481	28
Mineral		461	27	461			476	27
Mineral		457	26				471	26
Mineral		397	25				409	25
Mineral		347	24				352	24
Mineral		303	23				333	23
Mineral		302	22	300			322	22
Mineral		297	21				272	21
Mineral		236	20				271	20
Mineral		235	19				267	19
Mineral		234	18				247	18
Mineral		216	17				220	17
Mineral		194	16	194			206	16
Mineral		191	15		191		206	15
Mineral		178	14				199	14
Mineral		175	13				198	13
Mineral		153	12				197	12
Mineral		144	11				151	11
Mineral		142	10				150	10
Mineral		132	9				139	9
Mineral		128	8				133	8
Mineral		127	7				128	7
Mineral		126	6				126	6
Mineral		115	5				124	5
Mineral		115	4				123	4
Mineral		114	3				120	3
Mineral		93	2				118	2
Mineral		86	1				100	1
				90% CCIMD	95% CCIMD			
				1.21	1.25			
	MEAN	335		90% CCIM	95% CCIM	MEAN	344	
	SD=	194		0.15	0.18	SD=	188	

SEGMENT	90% CLMD	95% CLMD
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral	476	481
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral	322	
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral	206	206
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		
Mineral		

	90% CCIM	95% CCIM
	1.16	1.17

	90% CCIM	95% CCIM
	0.14	0.17

Table A4

Abbreviations:

ZNDC = dissolved zinc concentration (μg/L)
ZNTC = total zinc concentration (μg/L)
90% CLMD = 90% confidence limit on median
95% CLMD = 95% confidence limit on median
90% CCIMD = coefficient of 90% CI on median (1/2 CI width divided by median)
95% CCIMD = coefficient of 95% CI on median
SD = standard deviation
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CCIM = coefficient of 95% CI on mean

term mean. The 90 and 95% CCI_{md}s for the Upper Animas River are 63% and 65% for total zinc, respectively, and 69% and 70% for dissolved zinc, respectively. The 90 and 95% CCI_{md}s for Mineral Creek are all greater than 100% for both total and dissolved zinc. The large CI_{md}s for Mineral Creek result from the greater number of small concentration values about the median (resulting in a much smaller lower confidence limit relative to the upper confidence limit) relative to the Upper Animas River data.

The third step involved evaluating the effect of increasing spatial scale on estimates of the size of the CI. This involved dividing the main stem of Cement Creek into two segments: an upstream segment and a downstream segment. The upstream segment is generally believed to be more spatially variable with regard to zinc concentrations than the downstream segment due to a greater number and more variability of source areas. Two adjacent stations that were sampled four times each were selected near the mid-length of each segment, and the mean, median, and 90 and 95% CI_ms and 95% CI_{md} for each segment were computed based on eight data points for each segment. Next, for each segment, data from additional stations upstream and downstream from these two stations were aggregated with the data from these stations. The CIs were again computed for each segment based on the aggregated data. Again for each segment, data from additional stations upstream and downstream were aggregated with the previous data sets incorporating all of the stations within each segment, and the CIs for each segment were computed. The results of these computations are presented in Table A5, and the computations are included in Table A6.

Table A5. Effect of sample size for multiple stations on CI of		zinc		
concentration in Cement Creek				
LOCATION	N	90% CCIM	95% CCIM	95% CCIMD
UPSTREAM CEMENT CREEK	8	0.41	0.51	1.23
	27	0.16	0.19	0.22
	45	0.21	0.26	0.27
DOWNSTREAM CEMENT CREEK	8	0.10	0.13	0.26
	27	0.04	0.05	0.05
	42	0.15	0.18	0.06
	46	0.14	0.16	0.06

Table A5

Abbreviations:

N = sample size
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CCIM = coefficient of 95% CI on mean
95% CCIMD = coefficient of 95% CI on median (1/2 CI width divided by median)

SITE	DATE	ZNDC	N	AVG	STDS	90% CIM	90% CCIM	95% CIM	95% CCIM	MED	95% CIMD	95% CCIMD
CC30	09/07/91	1300										
CC30	06/24/92	1000										
CC30	10/14/92	1000										
CC30	07/21/93	1100										
CC03	09/07/91	2300	8	1575	960	643	0.41	803	0.51	1100	1350	1.23
CC03	06/24/92	1100	27	1699	825	271	0.16	326	0.19	1600	350	0.22
CC03	10/14/92	3700	45	1481	1270	318	0.21	382	0.26	1100	300	0.27
CC03	07/21/93	1100										
CC05	09/07/91	2500										
CC05	06/24/92	1700										
CC05	10/14/92	3700										
CC05	07/21/93	2400										
CC18	09/07/91	3100										
CC18	06/24/92	1600										
CC18	07/21/93	2500										
CC20	09/07/91	1800										
CC20	06/24/92	1600										
CC20	07/21/93	1600										
CC21	09/07/91	1800										
CC21	06/24/92	1000										
CC21	10/14/92	790										
CC21	07/21/93	890										
CC27	09/07/91	1600										
CC27	06/24/92	1000										
CC28	09/07/91	1600										
CC28	06/24/92	1000										
CC28	07/21/93	1100										
CC30	09/07/91	1300										
CC30	06/24/92	1000										
CC30	10/14/92	1000										
CC30	07/21/93	1100										
CC06	09/07/91	4200										
CC06	06/24/92	6900										
CC06	07/21/93											
CC12	09/07/91	230										
CC12	06/24/92	140										
CC13	09/07/91	180										
CC13	06/24/92	230										

Table A6. Calculations for Table A5

CC16	09/07/91	350									
CC16	06/24/92	260									
CC16	10/14/92	510									
CC17	09/07/91	1400									
CC17	06/24/92	340									
CC17	10/14/92	700									
CC17	07/21/93	500									
CC23	07/21/93	350									
CC26	09/07/91	1500									
CC26	06/24/92	950									
CC26	10/14/92	1200									
CC26	07/21/93	840									

SITE	DATE	ZNDC	N	AVG	STDS	90% CIM	90% CCIM	95% CIM	95% CCIM	MED	95% CIMD	95% CCIMD
CC47	09/06/91	960										
CC47	06/24/92	790										
CC47	10/14/92	940										
CC47	07/21/93	870										
CC30	09/07/91	1300	8	995	154	103	0.10	129	0.13	980	255	0.26
CC30	06/24/92	1000	27	972	113	37	0.04	45	0.05	960	45	0.05
CC30	10/14/92	1000	42	780	450	117	0.15	140	0.18	925	60	0.06
CC30	07/21/93	1100	46	788	431	107	0.14	128	0.16			
CC31	09/06/91	1200										
CC31	06/24/92	960										
CC34	09/06/91	1000										
CC34	06/24/92	870										
CC36	09/06/91	960										
CC36	06/24/92	860										
CC36	07/21/93	930										
CC39	09/06/91	1000										
CC39	06/24/92	920										
CC39	10/14/92	1100										
CC39	07/21/93	1100										
CC41	09/06/91	960										
CC41	06/24/92	910										
CC43	09/06/91	990										
CC43	06/24/92	840										
CC43	07/21/93	970										
CC46	09/06/91	990										
CC46	06/24/92	850										
CC46	07/21/93	880										
CC47	09/06/91	960										
CC47	06/24/92	790										
CC47	10/14/92	940										
CC47	07/21/93	870										
CC33	09/06/91	4										
CC33	06/24/92	4										
CC35	09/06/91	280										
CC35	06/24/92	85										
CC38	09/06/91	2100										
CC38	06/24/92	810										
CC38	10/14/92	1300										

CC40	09/06/91	1000									
CC40	06/24/92	280									
CC42	09/06/91	98									
CC42	06/24/92	59									
CC44	09/06/91	180									
CC44	06/24/92	130									
CC45	09/06/91	140									
CC45	06/24/92	39									
CC48	09/07/91	980									
CC48	06/24/92	790									
CC48	10/14/92	910									
CC48	07/21/93	790									

Table A6

Abbreviations:

ZNDC = dissolved zinc concentration (μg/L)
N = sample size
AVG = mean
STDS = standard deviation
90% CIM = 90% CI width on mean
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CIM = 95% CI width on mean
95% CCIM = coefficient of 95% CI on mean
MED = median
95% CIMD = 95% CI width on median
95% CCIMD = coefficient of 95% CI on median (1/2 CI width divided by median)

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As can be seen from Table A5 for the upstream segment, the 90 and 95% CCI_ms for concentrations based on eight samples are similar to the average 90 and 95% CCI_ms based on four samples for stations within Cement Creek (discussed for Step 1). The upstream segment 95% CCI_{md} based on eight samples, however, is much larger than the 95% CCI_m. For the downstream segment, the 90 and 95% CCI_ms and the 95% CCI_{md} based on eight samples are much smaller than the average 90 and 95% CCI_m based on four samples for stations within Cement Creek. This is a result of the smaller spatial variability in the lower segment. Aggregation of data from more stations in the upstream segment ($n=27$) decreases the CCI_ms and CCI_{md} significantly. Additional aggregation of data from more stations ($n=45$), however, tends to increase the sizes of the CIs again somewhat. This pattern can also be observed for the downstream segment, where at $n=27$ the sizes of the CI_ms and CI_{md} become very small, but when n is increased to 42 or 46 the sizes of the CIs increase. This could be attributed to increasing spatial variability (standard deviation) of concentrations with an increase in spatial scale, which offsets the effect of the increase in sample size when computing the CI. This indicates that there might be an upper limit on optimal segment size and number of monitoring stations for estimating a mean concentration that is a function of the spatial variability within the segment. As discussed in previous sections, the area cannot be too large if statistical estimates are required because the estimates (such as the mean or median) lose physical meaning when more than one population is sampled.

A.3   Multiple Observations

Data derived from IAM synoptic surveys typically include multiple observations at some monitoring stations as a result of duplicate sampling and analysis as part of routine QA/QC measures. These observations must be dealt with before proceeding to the analysis of the data. A simple method of handling this attribute is to compute the mean of multiple observations at a station and use this value in the subsequent analysis of the data. This is the method that will be used for this study.

A.4   Censoring

Some data derived from IAMs are censored when metals concentrations are below the method detection limit (MDL) of the laboratory instruments. The MDL for dissolved zinc for the Upper Animas River Basin study is 8 μg/L. CDPHE typically assigns a zero to these values prior to use in their data analysis. This method biases the statistical estimates downward. Other procedures typically used when the proportion of nondetects is less than approximately 50% include assigning the MDL to the censored data prior to the analysis, or completely omitting the censored data from the analysis. These methods bias the statistical results upward. Another simple and useful procedure recommended by USEPA (1989c) is to substitute a value that is 1/2 of the MDL to nondetects. All of these methods, however, are not as straightforward when multiple detection limits are used for a single analyte on different occasions. This is sometimes the case when samples are collected over a number of years by different organizations. MDLs can vary considerably in these cases. In most cases for short-term synoptic studies of IAMs, however, a single detection limit is used by a particular agency.

USGS (Helsel and Gilliom, 1986 and Helsel and Cohn, 1988) also recommends a log regression (or plotting position) method for estimating the statistical parameters of censored data with one or more MDLs. This method assumes that censored observations follow the zero-to-detection limit portion of a lognormal distribution fit to the uncensored observations by least squares regression. An adjusted lognormal maximum likelihood procedure is also recommended for estimating percentiles using censored data. In this method, concentrations are assumed to be lognormally distributed with parameters estimated using logarithms of the uncensored observations using a maximum likelihood method. The mean and standard deviation of the untransformed concentrations are then estimated using the equations given by Aitchison and Brown (1957).

For the purposes of this study and development of an IAM assessment method, the substitution method using 1/2 the MDL will be used. This method is practical and does not bias the results as much as assigning a zero or the MDL to the censored data or as much as omitting censored data from the analysis. Although it might bias the results more than the methods recommended by USGS, it is easier to implement than those procedures. Given the relatively low proportion of nondetects for the Cement Creek data and many IAMs and the consistency of the MDL using synoptic surveys, this method would not be expected to introduce much error in statistical estimates and decision-making for screening-level analysis relative to the USGS method.

A.5   Changing Sampling Frequencies and Missing Values

Changing sampling frequencies and missing values are usually data attributes that are problems when analyzing data for trend and for some tests for seasonality. For

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the case of synoptic surveys performed for IAMs, however, other problems associated with these data attributes must be dealt with. There are two primary problems that arise with regard to data analysis due to changing sampling frequencies and missing values. The first is simply the lack of values at any given station during certain sampling events and the overall reduction in the sample size (for estimation of annual values) at any given station. With regard to an area (such as a stream segment), the sample size is also reduced for estimation of both seasonal and annual values. A reduction in sample size will generally result in a larger *CI* about the estimated parameters of the distribution.

The second primary problem arising from changing sampling frequencies and missing values is the added complexity and additional computations required for estimating first order subbasin drainage areas and stream lengths for individual monitoring stations for each season of interest. If missing values were not a problem, these would be constant among seasons. Because missing values do exist, however, these parameters can be different among seasons and must be recomputed for each season. For example, suppose a station farthest upstream in a tributary, and the adjacent station downstream, are monitored three times. The subbasin draining into the upstream station is a first order subbasin and the area of the subbasin must be computed. The stream length represented by each station must also be estimated for subsequent computations (discussed in Section 6.3.1.1). These computations must be performed only once for multiple seasonal evaluations. If on the fourth sampling event, however, the upstream station is not monitored but the adjacent downstream station is, the area draining into the downstream station is now the first order subbasin and the stream lengths for the stations are different. The area and stream

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lengths must then be recomputed for subsequent evaluations.

A.6   Nonnormality

The nonnormality of the data will affect whether parametric or nonparametric statistical methods might be appropriate and/or whether some type of conversion of the data to approximate normality prior to statistical analysis might be appropriate (Gilbert, 1987). It is believed that most metals concentration and loading data from IAM waste sites exhibit right-skewed distributions (USEPA, 1975). This attribute must be considered when identifying applicable data analysis methods and developing an assessment methodology.

Although the use of nonparametric statistics is generally preferable to the use of parametric statistics if the distribution is not known, this study requires the evaluation of whether NPS metals loadings and/or instream metals concentrations from typical IAM waste sites exhibit normal or skewed distributions because some data analysis methods discussed later (such as regression based on actual values or logtransformed values for prediction purposes) might assume these distributions.

For the evaluation of nonnormality, several simple methods have been used as follows:

- skewness test
- box-and-whisker plots
- normal probability plots

Each of these methods is used for the following populations of interest, as identified in Chapter 4:

- concentrations in a stream segment for each season and for a year
- unit area loadings to a stream segment for each season and for a year

A.6.1   Skewness Test

The skewness is easily computed along with other summary statistics for each data set of interest. These summary statistics should be computed as an initial part of most water quality evaluations to get an overview of many of the statistical characteristics of the data. This is part of an exploratory phase of data analysis. The summary statistics should generally include the mean, median, standard deviation, range, and minimum and maximum values. The skewness (sk) is computed as:

$$sk = \frac{n \sum_{i=1}^{n} (x_i - \overline{x})^3}{(n-1)(n-2) s^3} \qquad (A.11)$$

where the parameters of the equation are defined as previously for the mean and standard deviation.

A normal distribution has a skewness of zero, so significant deviations from this indicate nonnormality. Summary statistics, including the skewness, were computed for each of the populations of interest in Cement Creek listed above. These are summarized in Table A7 for concentrations, and Table A8 for unit area loadings. As can be seen from the tables, most of the computed skewnesses for concentration data are significantly greater than one, indicating right-skewed distributions and nonnormality. The computed skewnesses for unit area loading data are even greater, also indicating nonnormality.

A.6.2   Box-and-Whisker Plots

A simple extension of computing summary statistics and the skewness is the development of box-and-whisker plots. These are simple to develop and present some of the summary statistics and data attributes of interest graphically. These aid

STATISTIC	POPULATION (ug/L)			
Table A7. Summary statistics for Cement Creek dissolved zinc concentrations				
	STORM (9/7/91)	SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
N	43	41	17	128
MEAN	1159	796	1348	1041
90% CIM	479	572	948	278
95% CIM	574	686	1151	332
MEDIAN	1000	810	940	930
90% CIMD	440	526	348	88
95% CIMD	517	590	546	116
MODE	1000	1000	920	1000
GEOMETRIC MEAN	598	368	819	588
ST. DEVIATION	933	1087	1119	950
90% CISD	347	414	714	197
ST. ERROR	142	170	271	84
MINIMUM	4	4	10	4
MAXIMUM	4200	6900	3700	6900
RANGE	4196	6896	3690	6896
LOWER QUARTILE	230	140	790	385
UPPER QUARTILE	1800	960	1300	1200
INTERQUARTILE RANGE	1570	820	510	815
SKEWNESS	0.9	4.6	1.3	2.6
ST. SKEWNESS	2.5	12.0	2.2	12.1
KURTOSIS	1.3	25.8	0.7	11.7
ST. KURTOSIS	1.7	33.7	0.6	27.1
COEF. OF VARIATION	80	136	83	91

Table A7

Abbreviations:

N = sample size
90% CIM = 90% CI width on mean
95% CIM = 95% CI width on mean
90% CIMD = 90% CI width on median
95% CIMD = 95% CI width on median
90% CISD = 90% CI width on standard deviation

STATISTIC	POPULATION (g/ac-day)			
	STORM (9/7/91)	SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
N	43	30	11	93
MEAN	42	77	1.7	46
90% CIM	72	165	3.6	62
95% CIM	86	199	4.5	74
MEDIAN	2.6	5.3	0.2	1.5
90% CIMD	8.9	15.5	1.5	3.5
95% CIMD	9.5	15.8	1.9	5.9
MODE	0	0	0	0
ST. DEVIATION	139	267	3.3	179
90% CISD	52	121	2.8	44
ST. ERROR	21	49	1	19
MINIMUM	0	0	0	0
MAXIMUM	758	1422	11.2	1422
RANGE	758	1422	11.2	1422
LOWER QUARTILE	0	0.27	0.01	0.01
UPPER QUARTILE	16.8	34.1	1.5	13.4
INTERQUARTILE RANGE	16.8	33.8	1.5	13.4
SKEWNESS	4.5	4.8	2.8	6.1
ST. SKEWNESS	12.0	10.8	3.8	24.0
KURTOSIS	20.3	24.3	8.5	41.5
ST. KURTOSIS	27.1	27.2	5.7	81.7
COEF. OF VARIATION	329	346	200	392

Table A8. Summary statistics for Cement Creek dissolved zinc unit area loadings

Table A8

Abbreviations:

N = sample size
90% CIM = 90% CI width on mean
95% CIM = 95% CI width on mean
90% CIMD = 90% CI width on median
95% CIMD = 95% CI width on median
90% CISD = 90% CI width on standard deviation

in the visual examination of the statistical characteristics of the data including the central tendency (median), spread (percentiles), skewness, and extreme values or possible outliers. These plots can also be easily combined into a multiple plot for concentration data and a multiple plot for unit area loading data for the later evaluation of seasonality. Box-and-whisker plots are widely used for the general evaluation of water quality data.

Box-and-whisker plots were developed for each of the populations of interest, and are presented in figures A1 and A2 for concentrations and unit area loadings, respectively. The box represents the interquartile (IQ) range, and the vertical line in the middle is the median. The whiskers extend in each direction to 1.5 times the width of the IQ range from both ends of the box. Values beyond the whiskers are plotted as individual points. The right-skewness of the unit area loading data can be readily observed from these plots.

A.6.3   Normal Probability Plots

Normal probability plots were also developed for each population of interest to visually compare the observed frequency distribution to the best fit normal distribution. These plots are also useful for estimating percentiles and risks of exceedances. These plots are presented in figures A3 and A4 for concentrations and unit area loadings, respectively. As can be seen from the figures, most of the plots tend to exhibit a somewhat concave pattern, indicating a right-skewed distribution (Adkins, 1993). Based on the normal probability plot for snowmelt concentrations, the value of 6,900 μg/L at CC06 could be an outlier. This concentration, however, is still within an order of magnitude of many other values and no supporting information indicates that it is not "real" and should be eliminated. The normal
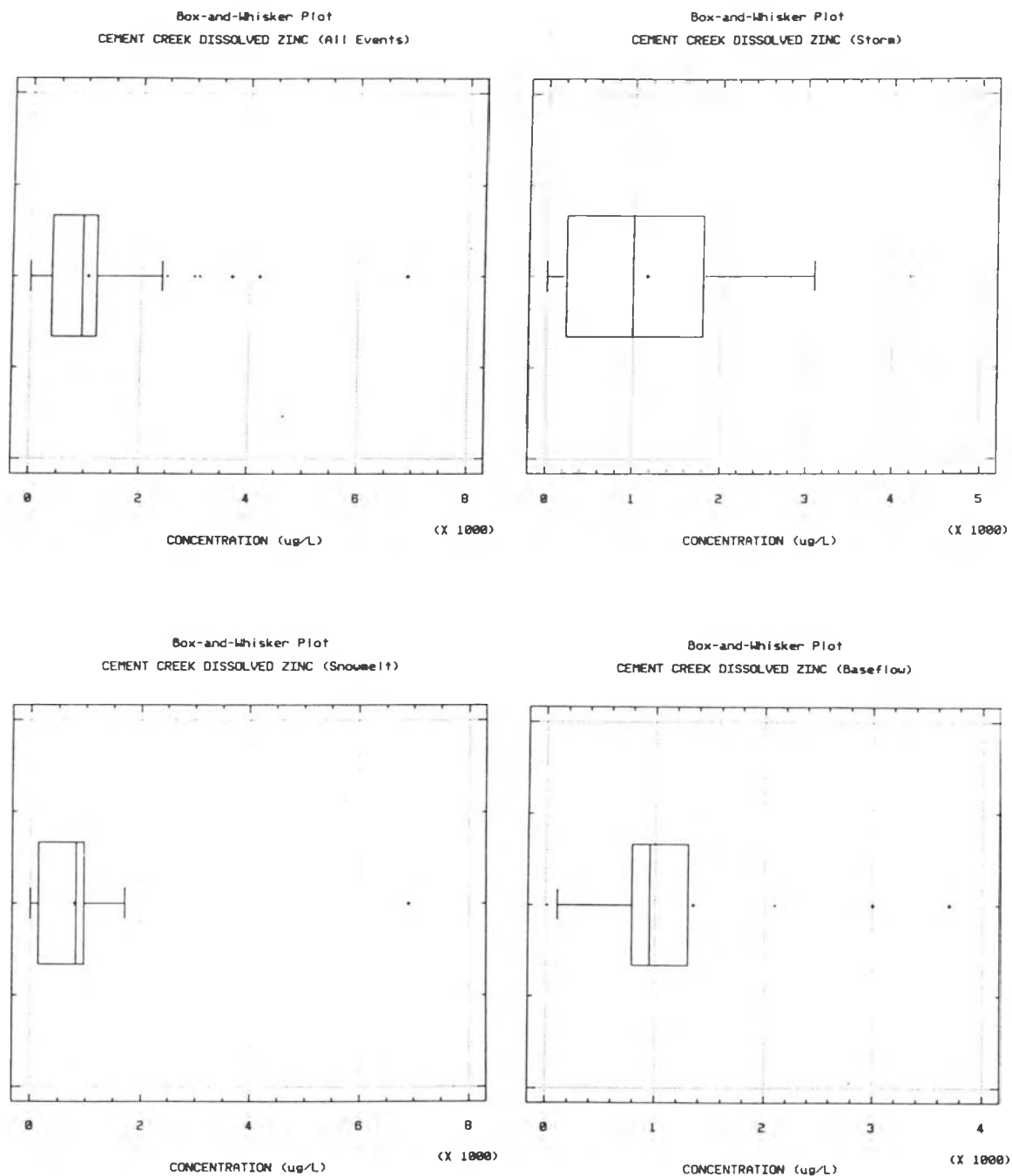
Figure A1.   Box-and-whisker plots for dissolved zinc concentrations in Cement Creek

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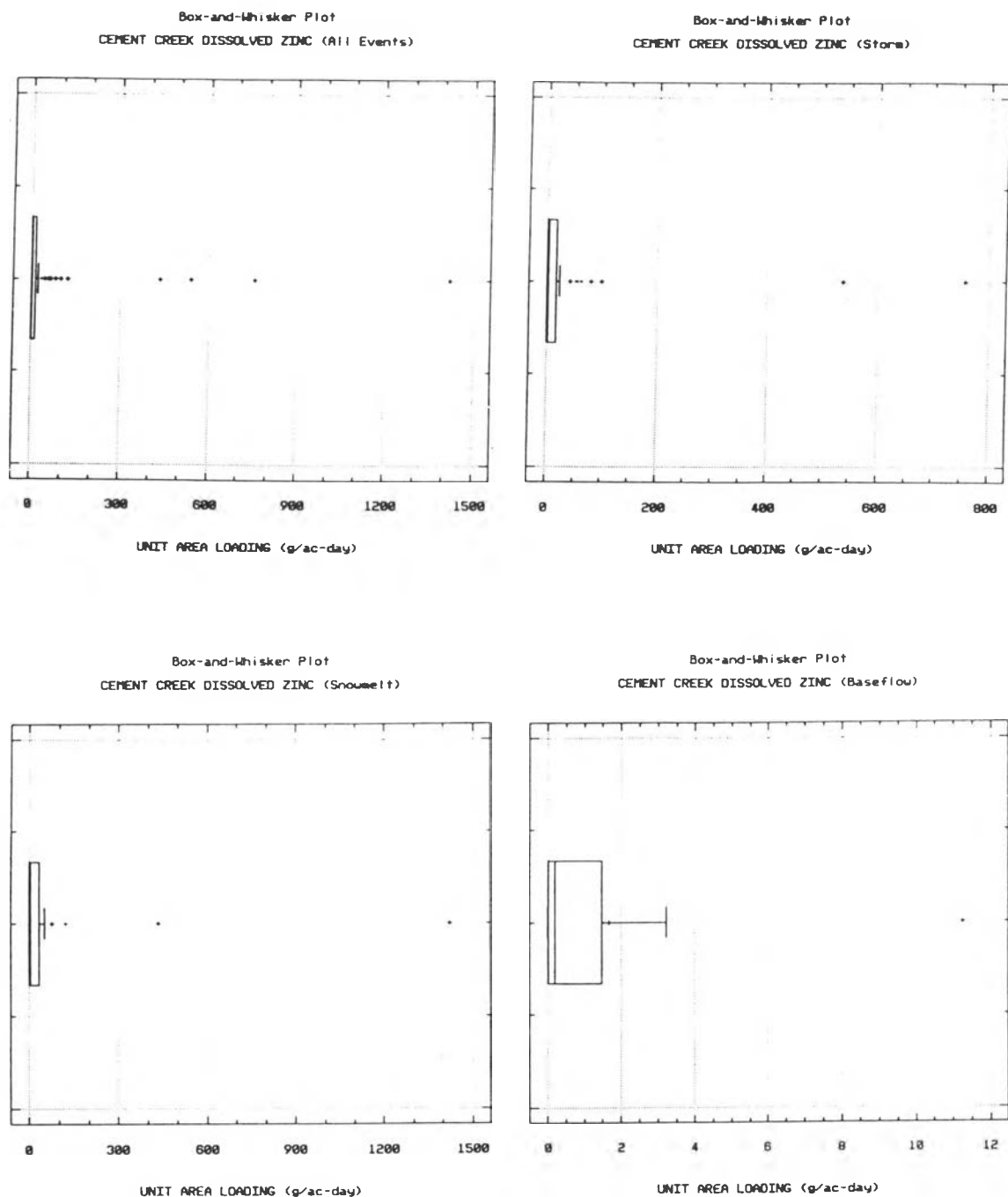
Figure A2.   Box-and-whisker plots for dissolved zinc unit area loadings to Cement Creek

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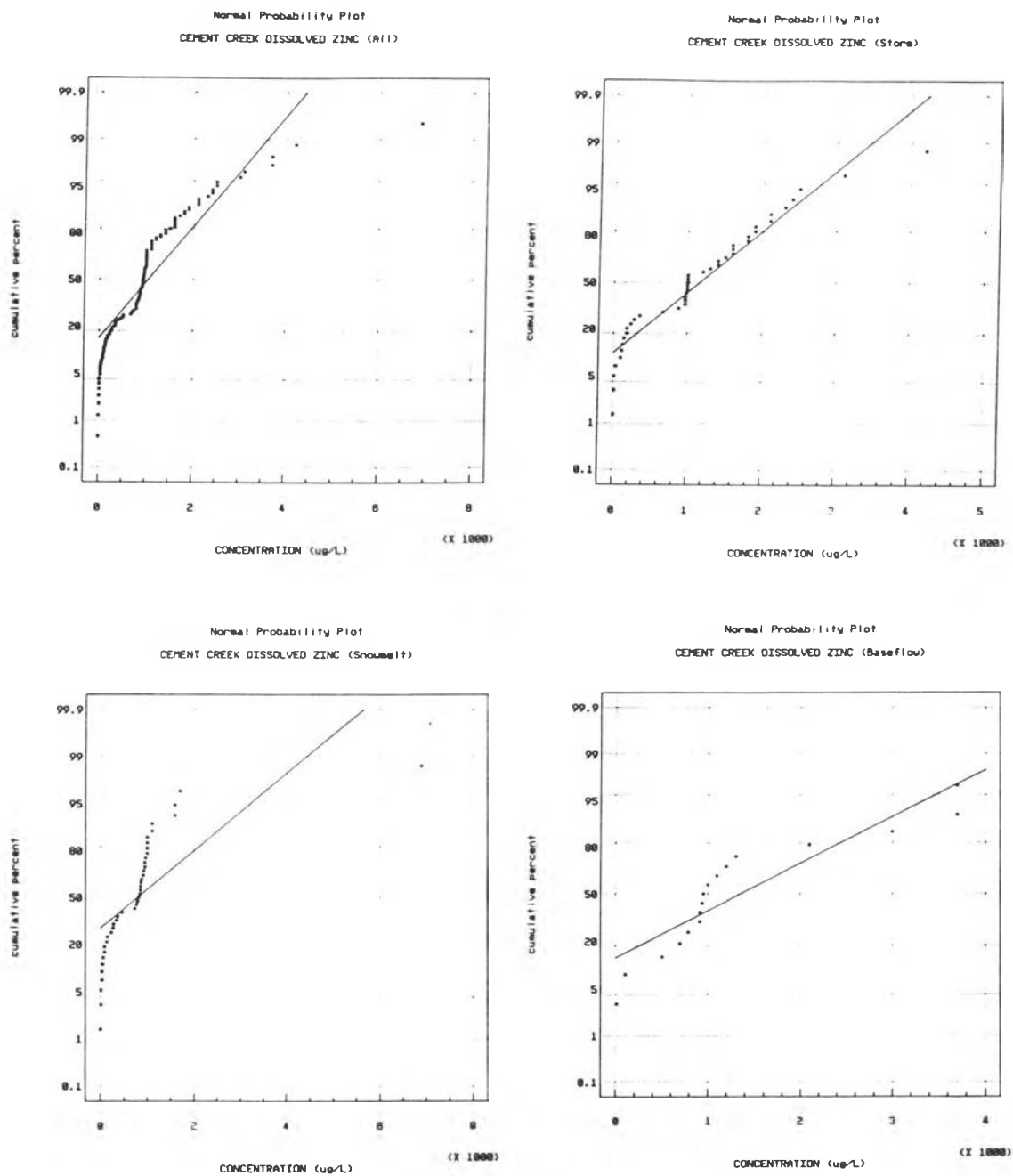
Figure A3. Normal probability plots for dissolved zinc concentrations in Cement Creek
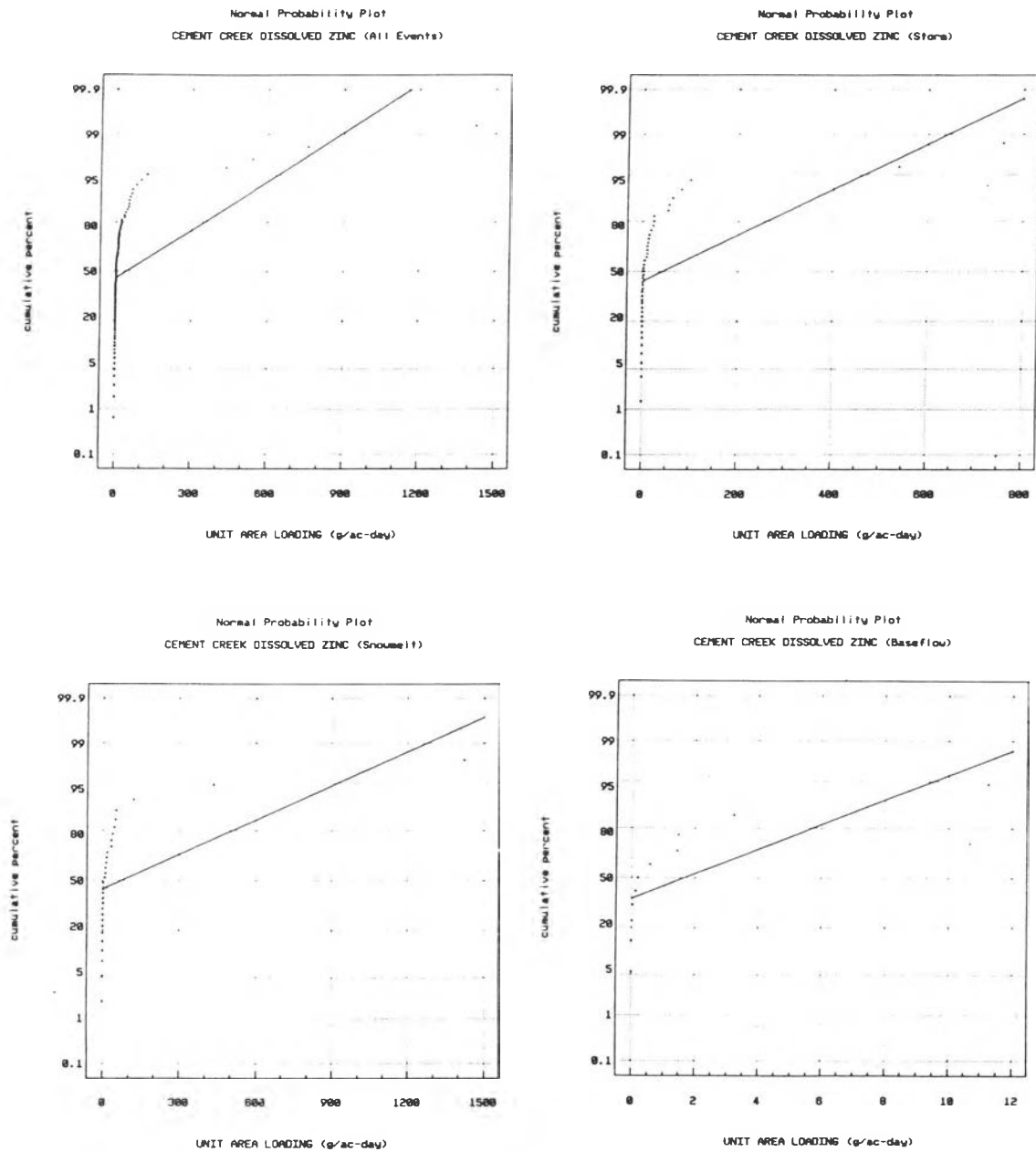
Figure A4.   Normal probability plots for dissolved zinc unit area loadings to Cement Creek

probability plots for unit area loadings are also concave, indicating right-skewed distributions.

A.6.4   Nonnormality Summary

Based on the results of all of these methods, both the annual and seasonal concentration and unit area loading data appear to be nonnormal. Therefore, nonparametric data analysis methods or transformations of the data to approximate normality prior to data analysis might be preferred. Because the evaluation indicates that a right-skewed or lognormal distribution might be a more appropriate model, the data were transformed to their corresponding natural logarithms (ln). Each test for normality was then performed on the logtransformed data. The summary statistics for the logtransformed concentration data are presented in Table A9, box and whisker plots are presented in Figure A5, and normal probability plots are presented in Figure A6. Summary statistics for the logtransformed unit area loading data are shown in Table A10, box and whisker plots are presented in Figure A7, and normal probability plots are presented in Figure A8. The computed skewness, the box-and-whisker plot, and the normal probability plot for the ln of the unit area loading data for all events all tend to indicate approximate lognormality. The tests for normality performed on the concentration data for all events and for each season, however, tend not to indicate lognormality. Logtransformations or a lognormal model for concentrations in Cement Creek, therefore, might not be appropriate. However, logtransformations or a lognormal model for unit area loadings to Cement Creek might be useful for some types of data analyses.

Table A9. Summary statistics for Cement Creek logtransformed				
dissolved zinc concentrations				
		POPULATION (ug/L)		
	STORM	SNOWMELT	BASEFLOW	ANNUAL
STATISTIC	(9/7/91)	(6/24/92)	(10/14/92)	
N	43	41	17	128
MEAN	6.4	5.9	6.7	6.4
MEDIAN	6.9	6.7	6.9	6.8
MODE	6.9	6.9	6.8	6.9
ST. DEVIATION	1.6	1.6	1.4	1.4
ST. ERROR	0.3	0.3	0.3	0.1
MINIMUM	1.4	1.4	2.3	1.4
MAXIMUM	8.3	8.8	8.2	8.8
RANGE	7.0	7.5	5.9	7.5
LOWER QUARTILE	5.4	4.9	6.7	6.0
UPPER QUARTILE	7.5	6.9	7.2	7.1
INTERQUARTILE RANGE	2.1	1.9	0.5	1.1
SKEWNESS	-1.5	-1.1	-2.2	-1.6
ST. SKEWNESS	-4.1	-2.8	-3.6	-7.5
KURTOSIS	2.0	0.8	6.0	2.5
ST. KURTOSIS	2.6	1.1	5.1	5.9
COEF. OF VARIATION	25.1	26.6	20.9	22.4

Table A10. Summary statistics for Cement Creek logtransformed	
dissolved zinc unit area loadings	
	POPULATION (g/ac-day)
STATISTIC	ANNUAL
N	70
MEAN	1.5
MEDIAN	2.2
MODE	2.2
ST. DEVIATION	2.6
ST. ERROR	0.3
MINIMUM	-4.9
MAXIMUM	7.3
RANGE	12.2
LOWER QUARTILE	-0.1
UPPER QUARTILE	3.1
INTERQUARTILE RANGE	3.2
SKEWNESS	-0.4
ST. SKEWNESS	-1.2
KURTOSIS	0.01
ST. KURTOSIS	0.02
COEF. OF VARIATION	175
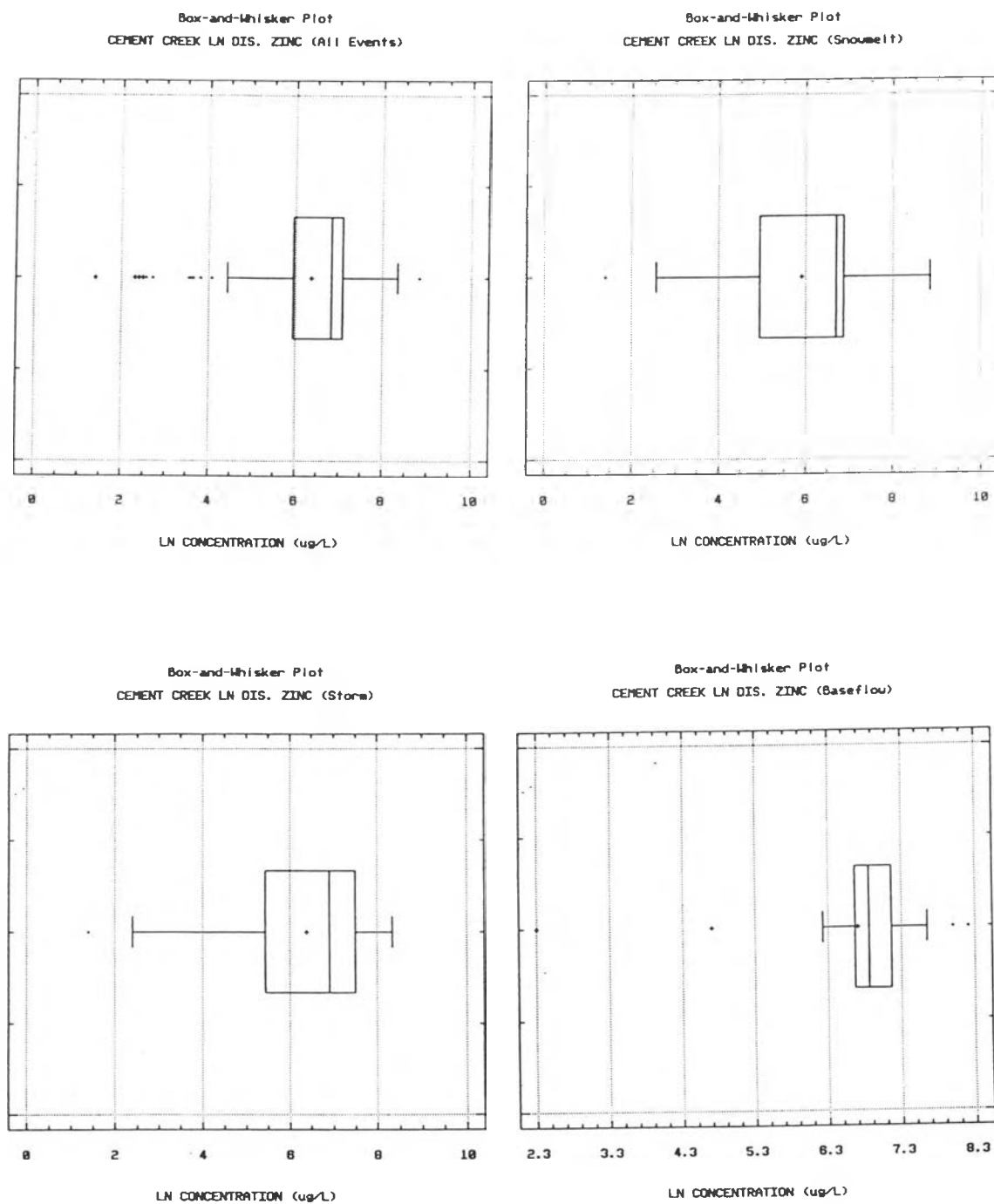
Figure A5. Box-and-whisker plots for logtransformed dissolved zinc concentrations in Cement Creek

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Box-and-Whisker Plot
CEMENT CREEK LN DISSOLVED ZINC (All)

LN UNIT AREA LOADING (g/ac-day)
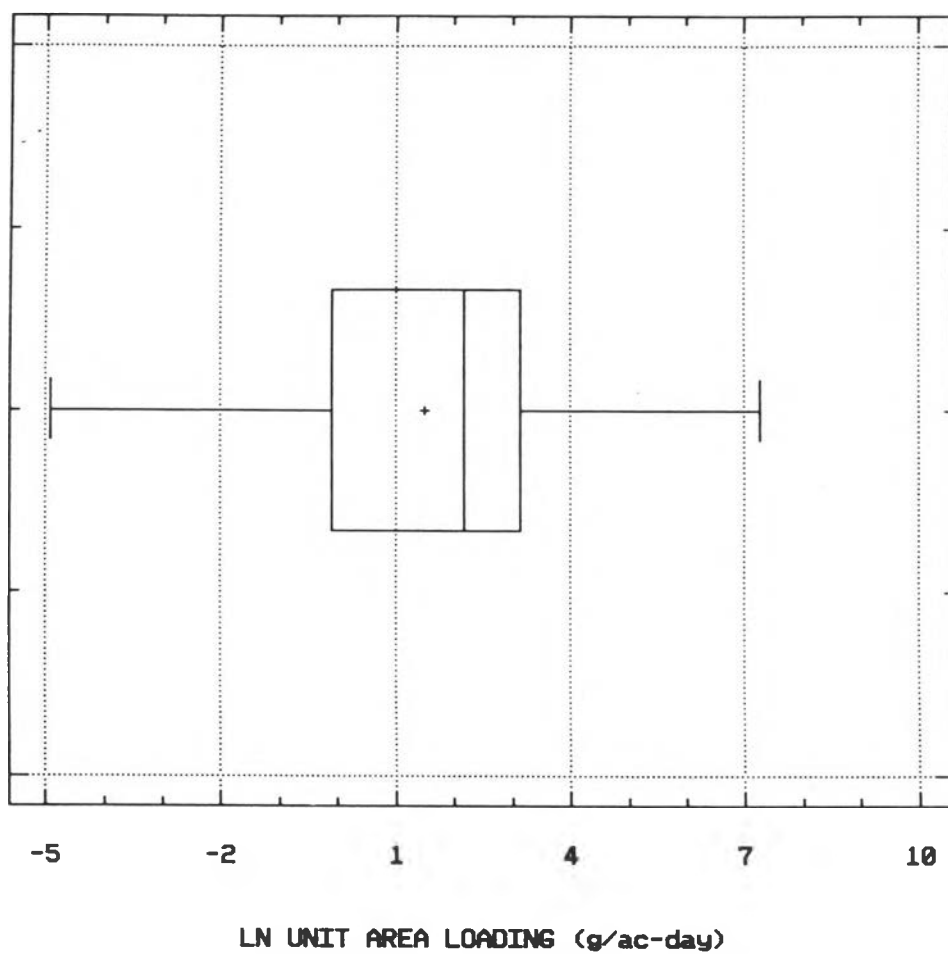
Figure A6.   Box-and-whisker plot for logtransformed dissolved zinc unit
               area loadings to Cement Creek

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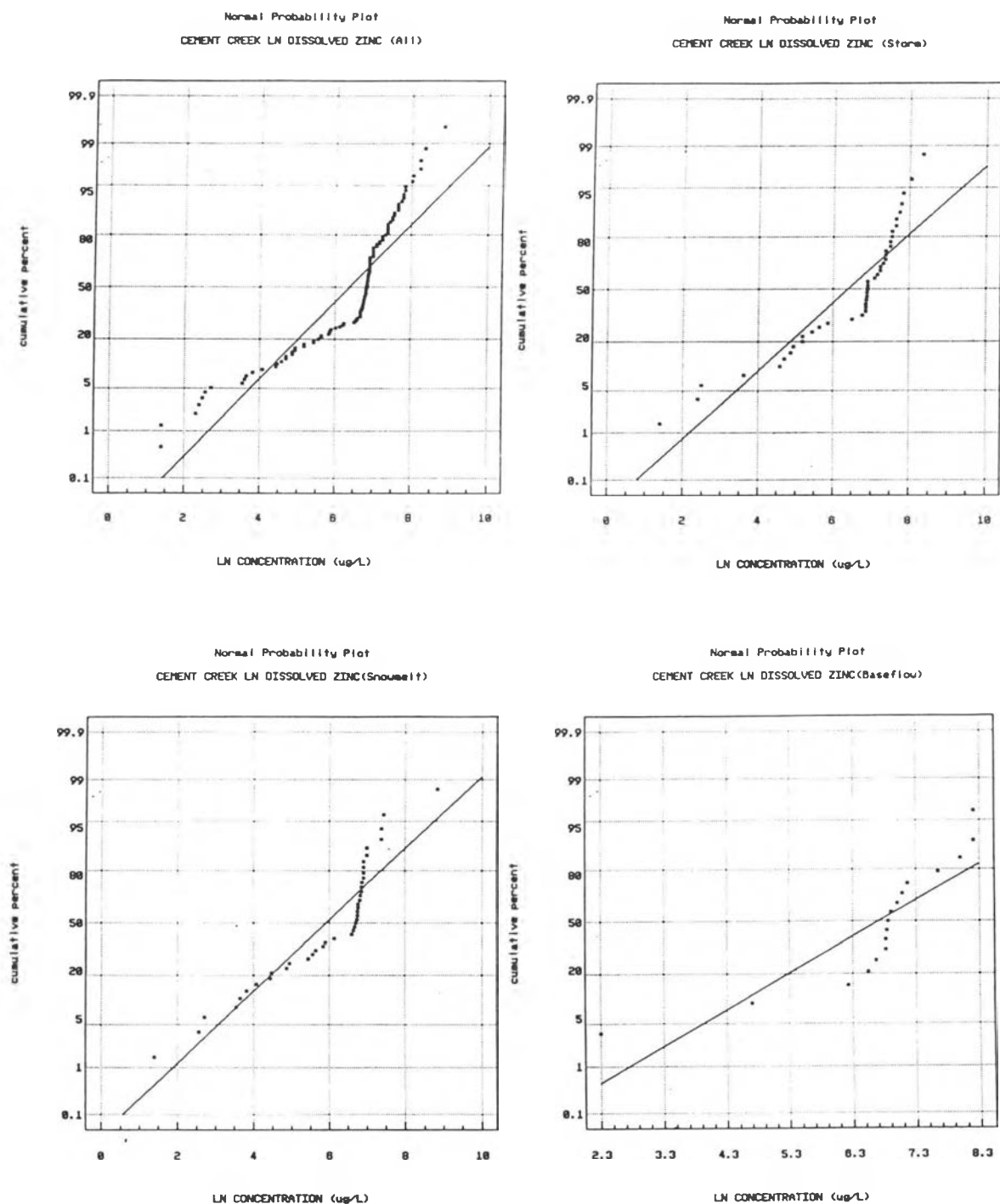
Figure A7.   Normal probability plots for logtransformed dissolved zinc concentrations in Cement Creek
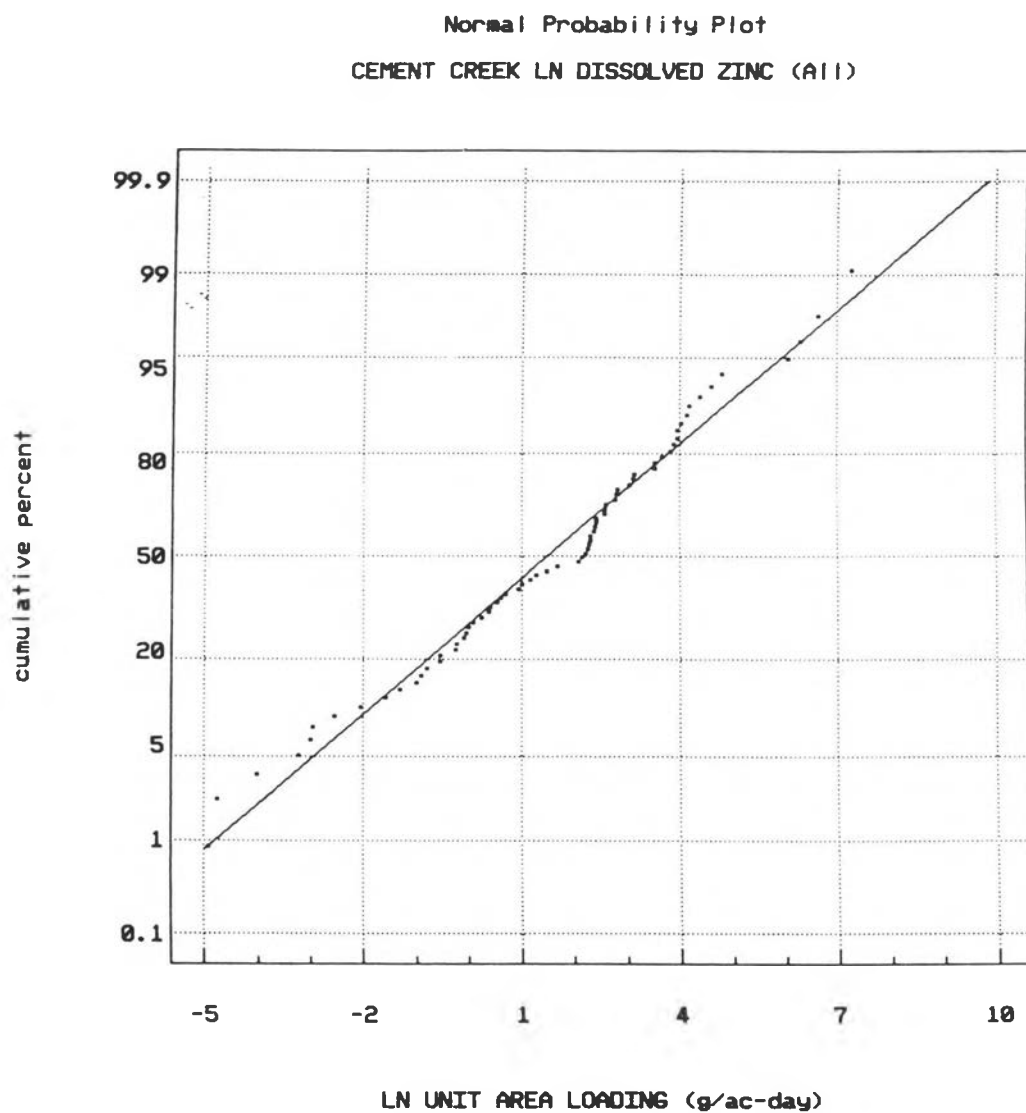
Figure A8. Normal probability plot for logtransformed dissolved zinc unit
area loadings to Cement Creek

A.7   Seasonality

The existence and magnitude of seasonality in flows, metals concentrations, and/or loadings in a basin and in the associated data collected from a basin will impact the identification and selection of applicable data analysis methods (Sanders et al., 1983). The existence of seasonality also affects the definition of the information goals (identification of the temporal scale of interest) and remediation strategies. Potentially significant seasonal variation in impacts of metals to aquatic biota in relation to life stages and cycles also exists at most of these IAMs. Remedial activities might be targeted or designed to reduce loadings and/or concentrations during specific seasons. Most types of information, therefore, will be required on a seasonal basis. Based on the fact that most IAMs are located in high altitude environments where snow accumulation and seasonal snowmelt runoff are significant and tend to dominate the hydrologic variability at a site, it is believed that seasonality in loadings and/or concentrations is significant.

Three seasons or flow regimes are typically sampled at least once and of interest in the assessment of IAMs as follows:

1.   spring snowmelt runoff
2.   fall baseflow
3.   storm runoff

The magnitude of differences between concentrations and between loadings among these three flow regimes are evaluated as part of this study.

Because the frequency of sampling is typically very low at an individual point or a given monitoring station (three or four data points per year in most cases) based on the synoptic or quarterly monitoring that is performed at these IAMs, seasonality cannot be evaluated easily at a point because of the lack of data. It might be more

practical and of more use, however, to evaluate seasonality in an entire stream segment and/or in all subbasins contributing to a specific stream segment instead of at a single point. This approach incorporates more monitoring stations into the analysis, thereby facilitating statistical analysis. This approach also increases the sample size for the analysis and could result in a smaller *CI* about the results. This is the approach, therefore, that has been used as part of this study.

Concentration data derived from an entire stream segment (Cement Creek) and unit area loading data derived from all subbasins contributing to the segment were used for the evaluation of seasonality. The data for each of these populations of interest were grouped by season or flow regime (spring snowmelt, fall baseflow, and storm) by assigning a designator to each datum in the spreadsheet and also by creating a separate column of data for each season. Two general methods were used for determining the magnitude of the differences between concentrations and the differences between unit area loadings among the three different flow regimes:

- multiple box-and-whisker plots
- magnitudes of differences and relative differences

Although hypothesis tests are generally not recommended for estimating the significance of differences because of major shortcomings (McBride et al., 1993), in some cases they might be required to evaluate the significance of differences in concentrations in (and loadings to) a stream segment between seasons. In this case, the following nonparametric tests can be used (Gilbert, 1987):

- WRS test (also known as the Mann-Whitney U test)
- Kruskal-Wallis test
- sign test
- rank test (also known as the Wilcoxon signed rank test)
- Friedman's test

The rank sum test and Kruskal-Wallis test use independent data sets, whereas the

sign, rank, and Friedman's tests use paired data. The WRS test is a nonparametric alternative to the two independent sample t test (Gilbert, 1987) that compares medians instead of mean values. The Kruskal-Wallis test is an extension of the rank sum test from two to multiple independent data sets. The sign test uses the signs of the differences between paired data and the rank test uses the magnitudes of the differences. The sign test has more versatility than the rank test because the sign test can be used for any underlying distribution and can accommodate some nondetects. The rank test requires that the distribution be symmetric (not necessarily normal) and there are no nondetects, but usually has more power than the sign test. Friedman's test is an extension of the sign test from two paired populations to multiple related populations.

Differences between the variances of two or more populations, in addition to differences between the means and between the medians, can also indicate general differences between populations. These types of differences may be apparent from the multiple box-and-whisker plots discussed below.

A.7.1   Multiple Box-and-Whisker Plots

As discussed for the evaluation of normality, a box-and-whisker plot was developed for each population of interest for concentration data and unit area loading data. The previously developed seasonal box-and-whisker plots for concentrations can easily be graphed together to develop a multiple box-and-whisker plot. This can also be performed for the unit area loadings. If the seasonal box-and-whisker plots do not appear to overlap significantly on the multiple plot, seasonal differences between the populations can be inferred (Adkins, 1993). Differences between the variances of two or more populations, in addition to differences between

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the means and between the medians, can also indicate general differences between populations and are apparent from the multiple box-and-whisker plots.

Multiple box-and-whisker plots were developed for concentrations (Figure A9) and unit area loadings (Figure A10). The multiple plot for concentrations shows significant overlap between the storm data and both the snowmelt and baseflow data, indicating insignificant seasonality between these flow regimes. The snowmelt and baseflow plots, however, do not tend to overlap significantly (especially between the interquartile ranges [*IQ* ranges]). This could indicate significant seasonality in concentrations between these two flow regimes. The multiple plots for unit area loadings, however, are not as easily interpreted. The one or two isolated high values for snowmelt flow, and even for storm flow, tend to cause the plot for the baseflow data to be compressed and unreadable. When the vertical scale of the multiple plot is decreased significantly, however, the *IQ* ranges of the plots can be observed much more easily. Although all data sets include many values near zero so that the 25th percentiles seem identical, the 75th percentiles are very different, especially between snowmelt and baseflow. This indicates that seasonality in unit area loadings does exist between these two flow regimes. It is more difficult to distinguish between storm flow and the other flows, so additional differences cannot be concluded.

The box-and-whisker plot evaluation uses all data, or the entire population, from each season. This could provide a higher level of confidence in the conclusions to be drawn from the analysis because of the larger sample size relative to using data from individual points, but it also results in the inclusion of potential spatial variability into the analysis.
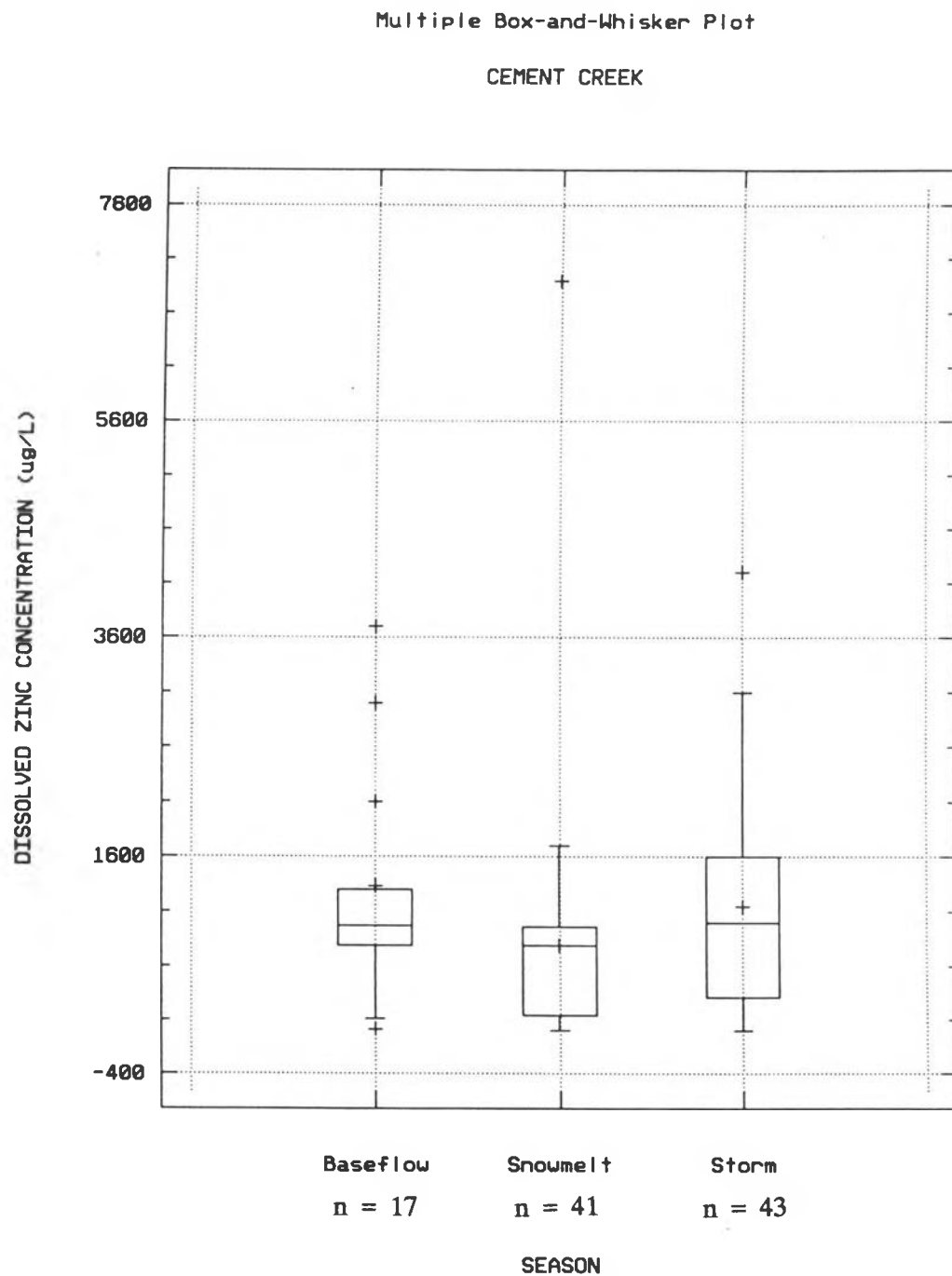
Figure A9.   Multiple box-and-whisker plots for dissolved zinc concentrations
in Cement Creek by season

Multiple Box-and-Whisker Plot
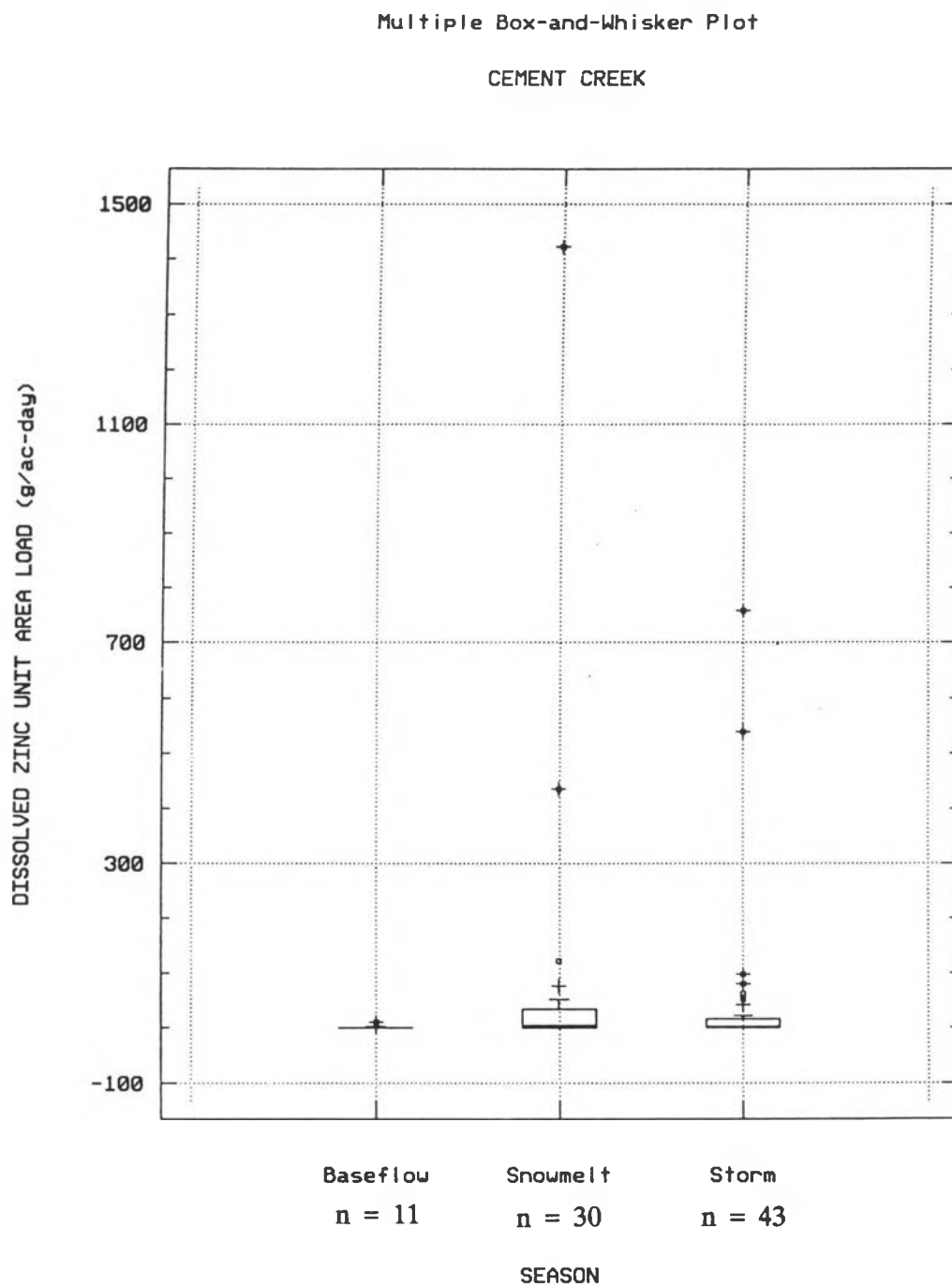
CEMENT CREEK

Figure A10.   Multiple box-and-whisker plots for dissolved zinc unit area
loadings to Cement Creek by season

A.7.2   Magnitudes of Differences

In addition to the box-and-whisker plots, the magnitudes of the differences and the relative differences of concentrations and of loadings between seasons were also computed. The results of these computations are presented in Table A11 for concentrations and Table A12 for unit area loadings.

As can be seen from Table A11 the difference in concentrations in Cement Creek between storm and snowmelt flows is fairly large (363 μg/L) in relation to the lower mean concentration estimated for snowmelt (796 μg/L, as estimated using the methods discussed in Chapter 6). The difference is 45% of the lower value. Although the CI_ms are estimated in Chapter 6, it can be shown that the CI_ms of the two estimates overlap. The difference in concentrations between baseflow and storm flow is small (189 μg/L) relative to the lower mean concentration estimated for storm flow (1,159 μg/L). This value is 16% of the mean for storm flow. The CI_ms also overlap for these estimates. For baseflow and snowmelt flow, the difference is very large (552 μg/L) in relation to the mean concentration estimated for snowmelt. This value is 69% of the mean for snowmelt flow. Again, the CI_ms for the two estimates overlap. It can be concluded from this analysis that differences in concentrations of dissolved zinc in Cement Creek exist between storm flow and snowmelt flow and between baseflow and snowmelt flow, but not necessarily between baseflow and storm flow.

For the unit area loadings, the difference between snowmelt and storm flows is fairly large (35 g/acre-day) in relation to the lower mean unit area loading estimated for storm flow (42 g/acre-day). This value is 83% of the storm flow estimate. The CI_ms for the two estimates overlap because they are so large. The difference in unit

Table A11. Differences in Cement Creek dissolved zinc concentrations			
between seasons			
		SEASON	
	STORM (9/7/91)	SNOWMELT (6/24/92)	BASEFLOW (10/14/92)
MEAN	1159	796	1348
DIFFERENCES	Absolute	Relative	
Storm-Snowmelt	363	0.46	
Baseflow-Storm	189	0.16	
Baseflow-Snowmelt	552	0.69	

Table A12. Differences in Cement Creek dissolved zinc unit area			
loadings between seasons			
		SEASON	
	STORM (9/7/91)	SNOWMELT (6/24/92)	BASEFLOW (10/14/92)
MEAN	42	77	1.7
DIFFERENCES	Absolute	Relative	
Storm-Snowmelt	40.3	24.15	
Snowmelt-Storm	35	0.83	
Snowmelt-Baseflow	75.3	45.11	

area loadings between snowmelt flow and baseflow is very large (75 g/acre-day) in relation to the lower mean estimated for baseflow (1.67 g/acre-day). This value is 4,500% of the baseflow estimate. The CI_ms for the two estimates also overlap because they are so large (at least the CI_m for snowmelt is very large). The difference in unit area loadings between storm flow and baseflow is also large (40 g/acre-day) in relation to the lower mean unit area loading for baseflow. This value is 2,400% of the baseflow estimate. It can be concluded from this analysis that differences in unit area loadings between all of the flow regimes are significant, especially between baseflow and the other two flow regimes.

A.7.3   Seasonality Summary

Based on the analyses discussed above, some general conclusions regarding seasonality in dissolved zinc concentrations in and loadings to Cement Creek can be drawn. The analyses indicate that seasonality in concentrations does exist between snowmelt flow and baseflow (concentrations are significantly lower during snowmelt than during baseflow, likely due to dilution with higher flows) and between snowmelt and storm flows, but not necessarily between storm flow and baseflow. Because storms are highly variable and could have highly variable effects on contaminant concentrations and loadings, it is not possible to conclude that this is always the case. A 100-year storm could dilute concentrations significantly relative to concentrations during baseflow. Most of the analyses also indicate that large differences in unit area loadings between all seasons do exist. Snowmelt flow exhibits the greatest loadings, and baseflow has the smallest loadings.

APPENDIX B

CEMENT CREEK MAPS

This appendix presents three maps for the Cement Creek Basin. Figure B1 is the base map for the basin with monitoring station locations and designations. Figure B2 shows the dissolved zinc concentrations and exceedances of acute and chronic hardness-based standards for fish (Brown Trout) overlain on the base map with corresponding stations. Figure B3 shows the dissolved zinc loadings and unit area loadings from each first order subbasin overlain on the base map with corresponding stations.
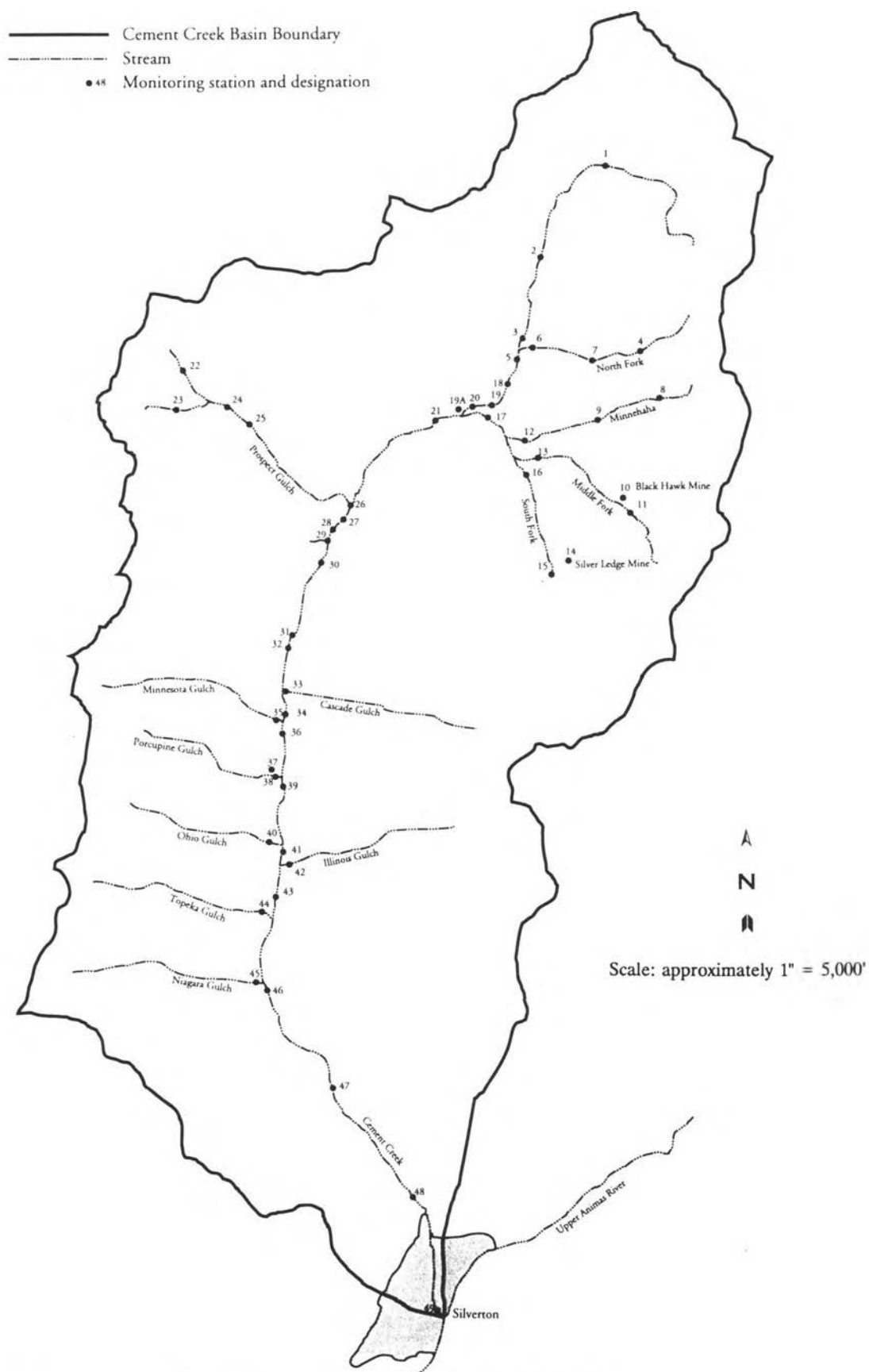
Figure B1. Cement Creek Basin and sampling stations
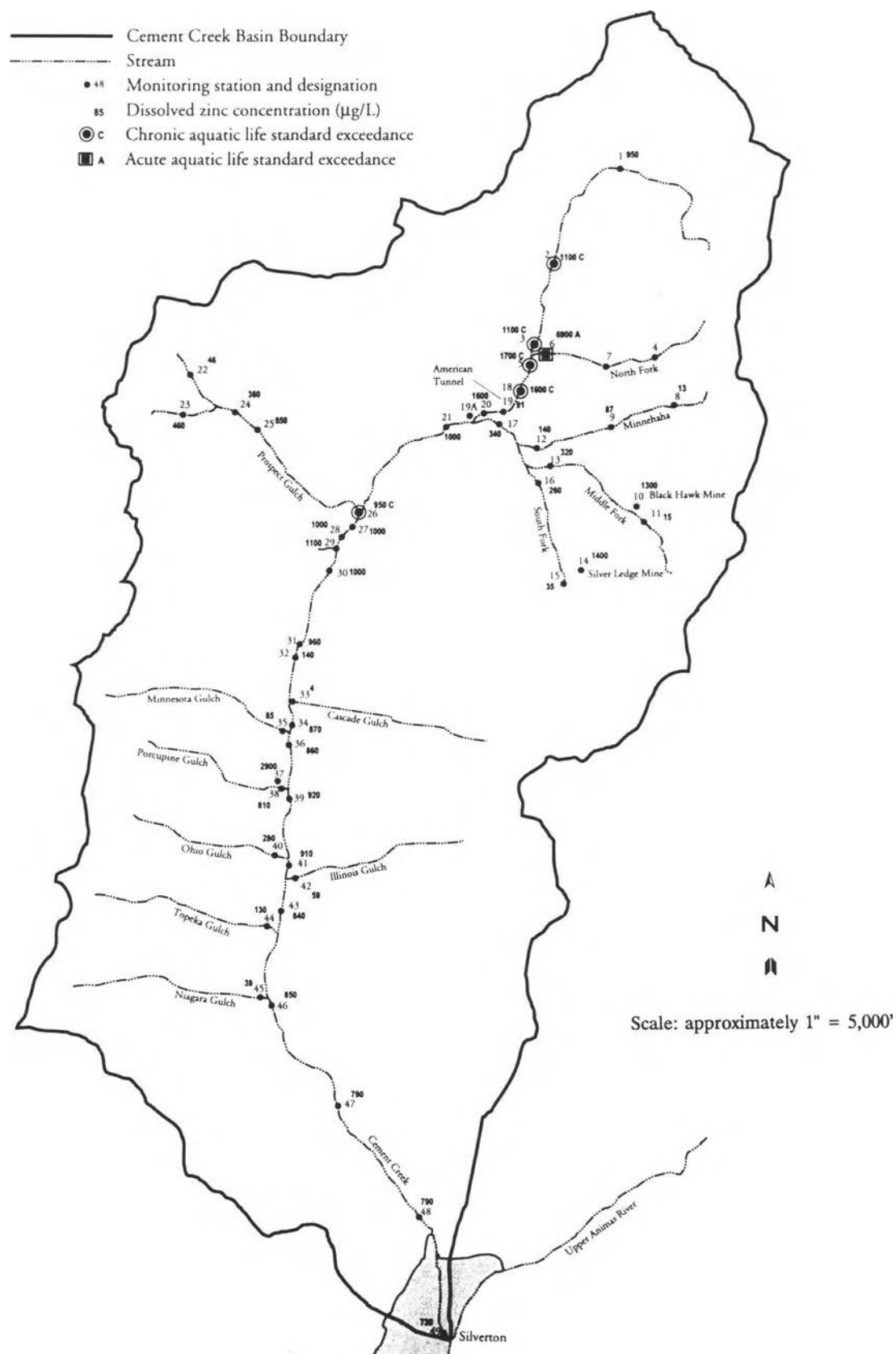
Figure B2. Snowmelt 1992 dissolved zinc concentrations and exceedances of chronic and acute aquatic life standards
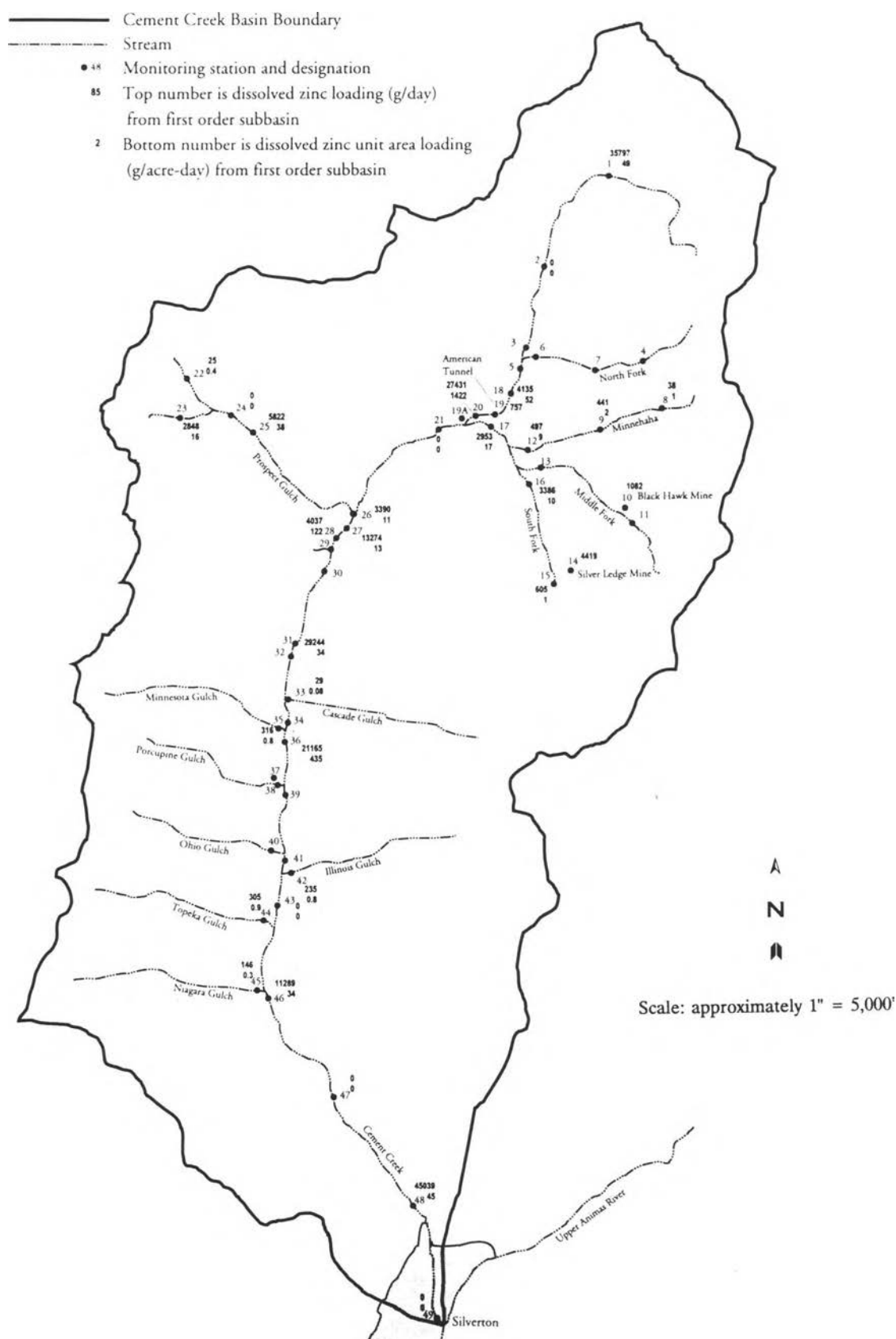
Figure B3.   Snowmelt 1992 dissolved zinc loadings and unit area loadings
                  from first order subbasins

APPENDIX C

CEMENT CREEK EXAMPLE DATA

Table C1   Example of spreadsheet database with raw flow and dissolved zinc concentration data and loading and unit area loading data

Table C2   Example of spreadsheet database with dissolved zinc concentration data, exceedances of aquatic life standards, and related information

This appendix presents an example of the raw data and spreadsheet format database and related computations for a subset of stations in the Cement Creek basin. Table C1 contains most of the raw data, including dissolved zinc loading data, and related information. Table C2 contains dissolved zinc concentration data and related information.

	A	B	C	E	G	H	I	J	K
1	Table C1. Example spreadsheet database with raw flow and dissolved zinc								
2	concentration data and		loading and unit area loading data						
3									
4	SUB_SEG	SOURCE	DISTANCE	AREA	PAREA	SITE	DATE	SEASON	FLOW
5	Cement	NPS	8.39	734.64	0.056	CC01	09/07/91	Storm	1.790
6	Cement	NPS	8.39	734.64		CC01	06/24/92	Snowmelt	15.400
7									
8	Queen Ann Mine adit	PS				CC01a	07/21/93		0.013
9									
10	Mogul tnl mine drng	PS				CC01b	07/21/93		0.031
11									
12	Mine adit abv Mogul	PS				CC01c	07/21/93		0.062
13									
14	adit	PS				CC01d	07/21/93		0.880
15									
16	adit	PS				CC01e	07/21/93		0.635
17									
18	adit	PS				CC01f	07/21/93		1.440
19									
20		NPS		525.27	0.040	CC02-CC01	09/07/91	Storm	0.510
21		NPS		525.27		CC02-CC01	06/24/92	Snowmelt	-3.500
22	Cement	NPS	7.63	1259.91		CC02-CC01a-f	07/21/93		2.409
23									
24	Cement		7.63			CC02	09/07/91	Storm	2.300
25	Cement		7.63			CC02	06/24/92	Snowmelt	11.900
26						CC02	07/21/93		5.470
27									
28		NPS		533.53	0.041	CC03-CC02	09/07/91	Storm	1.050
29		NPS		533.53		CC03-CC02	07/21/93		1.100
30									
31	Cement		7.16			CC03	09/07/91	Storm	3.350
32	Cement		7.16			CC03	06/24/92	Snowmelt	
33	Cement	NPS	7.16	1793.44		CC03	10/14/92	Baseflow	0.637
34	Cement		7.16			CC03	07/21/93		6.570
35									
36	NF Cement	NPS		148.76	0.011	CC04	09/07/91	Storm	0.153
37									
38		NPS		39.49	0.003	CC05-CC03-CC06	09/07/91	Storm	-0.849
39		NPS		39.49		CC05-CC03-CC06	07/21/93		-0.260
40									
41	Cement		7.03			CC05	09/07/91	Storm	2.680
42	Cement		7.03			CC05	06/24/92	Snowmelt	18.300
43	Cement		7.03			CC05	10/14/92	Baseflow	0.468
44	Cement		7.03			CC05	07/21/93		6.880
45									
46		NPS		76.22	0.006	CC06-CC07	09/07/91	Storm	0.116
47									
48	NF Cement					CC06	09/07/91	Storm	0.179
49	NF Cement	NPS		292.94		CC06	06/24/92	Snowmelt	
50	NF Cement	NPS		292.94		CC06	07/21/93		0.570

	L	M	N	O	P	Q	R	S	T	U
1										
2										
3										
4	FLOWL	FLOWR	ZN_DC	ZN_DL	ZN_DLL	ZN_DLR	ZN_DLE	ZN_DLLE	ZN_DLF	ZN_DLF1
5	0.6	1.790	1600	7007.8	8.9	7007.8	1261.4		7007.8	7007.8
6	2.7	15.400	950	35797.4	10.5	35797.4	6443.5		35797.4	
7										
8	-4.3	0.013	1700	54.1	4.0	54.1	9.7		54.1	
9										
10	-3.5	0.031	38000	2882.4	8.0	2882.4	518.8		2882.4	
11										
12	-2.8	0.062	4900	743.4	6.6	743.4	133.8		743.4	
13										
14	-0.1	0.880	130	279.9	5.6	279.9	50.4		279.9	
15										
16	-0.5	0.635	50	77.7	4.4	77.7	14.0		77.7	
17										
18	0.4	1.440	440	1550.3	7.3	1550.3	279.1		1550.3	
19										
20	-0.7	0.510		4810.5	8.5	4810.5	2473.2		4810.5	4810.5
21		-3.500		-3768.1		-3768.1	8646.2	*	0.0	
22	0.9	2.409		6725.8	8.8	6725.8	2297.9		6725.8	
23										
24	0.8	2.300	2100	11818.3	9.4	11818.3	2127.3			
25	2.5	11.900	1100	32029.2	10.4	32029.2	5765.3			
26	1.7	5.470	920	12313.5	9.4	12313.5	2216.4			
27										
28	0.0	1.050		7034.7	8.9	7034.7	4005.2		7034.7	7034.7
29	0.1	1.100		5369.9	8.6	5369.9	3878.7		5369.9	
30										
31	1.2	3.350	2300	18853.0	9.8	18853.0	3393.5			
32			1100							
33	-0.5	0.637	3700	5767.0	8.7	5767.0	1038.1		5767.0	
34	1.9	6.570	1100	17683.4	9.8	17683.4	3183.0			
35										
36	-1.9	0.153	670	250.8	5.5	250.8	45.1		250.8	250.8
37										
38		-0.849		-4298.6		-4298.6	4509.3	*	0.0	0.0
39		-0.260				-270168.8				
40										
41	1.0	2.680	2500	16393.9	9.7	16393.9	2950.9			
42	2.9	18.300	1700	76121.5	11.2	76121.5	13701.9			
43	-0.8	0.468	3700	4237.0	8.4	4237.0	762.7			
44	1.9	6.880	2400	40402.4	10.6	40402.4	7272.4			
45										
46	-2.2	0.116		1623.7	7.4	1623.7	333.4		1623.7	1623.7
47										
48	-1.7	0.179	4200	1839.5	7.5	1839.5	331.1			
49			6900							
50	-0.6	0.570				292887.7				

	V	W	X	Y	Z	AA	AB	AC	AD	AE
1										
2										
3										
4	ZN_DLF1P	ZN_DLF2	ZN_DLF2P	ZN_DLF3	ZN_DLF3P	F2-1	F2-3	F1-3	ZN_DLU	ZN_DLUL
5	0.051	35797.4	0.164			28789.6			9.54	2.3
6									48.73	3.9
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20	0.035	0.0	0.000			-4810.5			9.16	2.2
21									0.00	
22									5.34	1.7
23										
24										
25										
26										
27										
28	0.051								13.19	2.6
29									10.06	2.3
30										
31				5767.0	0.269					
32										
33									3.22	1.2
34										
35										
36	0.002								1.69	0.5
37										
38	0.000								0.00	
39										
40										
41										
42										
43										
44										
45										
46	0.012								21.30	3.1
47										
48										
49										
50										

	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
	ZN_DLU1	ZN_DLU2	ZN_DLU3	U2-1	U2-3	U1-3	ZN_DLN	ZN_DLN1	ZN_DLN2	ZN_DLN3
1										
2										
3										
4	ZN_DLU1	ZN_DLU2	ZN_DLU3	U2-1	U2-3	U1-3	ZN_DLN	ZN_DLN1	ZN_DLN2	ZN_DLN3
5	9.54	48.73		39.19			7007.8	7007.8	35797.4	
6							35797.4			
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20	9.16	0.00		-9.16			4810.5	4810.5	0.0	
21							0.0			
22							6725.8			
23										
24										
25										
26										
27										
28	13.19						7034.7	7034.7		
29							5369.9			
30										
31			3.22							5767.0
32										
33							5767.0			
34										
35										
36	1.69						250.8	250.8		
37										
38	0.00						0.0	0.0		
39										
40										
41										
42										
43										
44										
45										
46	21.30						1623.7	1623.7		
47										
48										
49										
50										

	AP	AQ	AR	AS	AT	AU	AV	AW	AX
1									
2									
3									
4	ZN_DLUN	ZN_DLUN1	ZN_DLUN2	ZN_DLUN3	ZN_DLB	ZN_DLB1	ZN_DLB2	ZN_DLB3	ZN_DLUB
5	9.54	9.54	48.73						
6	48.73								
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20	9.16	9.16	0.00						
21	0.00								
22	5.34								
23									
24									
25									
26									
27									
28	13.19	13.19							
29	10.06								
30									
31				3.22					
32									
33	3.22								
34									
35									
36	1.69	1.69							
37									
38	0.00	0.00							
39									
40									
41									
42									
43									
44									
45									
46	21.30	21.30							
47									
48									
49									
50									

	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH
	ZN_DLUB1	ZN_DŁUB2	ZN_DLUB3	ZN_DLP	ZN_DLP1	ZN_DLP2	ZN_DLP3	ZN_DLC1	ZN_DLC2	ZN_DLC3
1										
2										
3										
4										
5								7007.8	35797.4	
6										
7										
8				54.1						
9										
10				2882.4						
11										
12				743.4						
13										
14				279.9						
15										
16				77.7						
17										
18				1550.3						
19										
20										
21										
22										
23										
24								11818.3	32029.2	
25										
26										
27										
28										
29										
30										
31								18853.0		5767.0
32										
33										
34										
35										
36										
37										
38										
39										
40										
41								16393.9	76121.5	4237.0
42										
43										
44										
45										
46										
47										
48										
49										
50										

Table C1

Columns:

A	Cement Creek sub-segment or location
B	station or subbasin source category
C	distance to mouth (miles)
E	subbasin area (acres)
G	fraction of subbasin area relative to total watershed area
H	site or monitoring station identification
I	sample date
J	sample season
K	flow measured or computed (cubic feet per second)
L	ln of flow
M	flow measured or computed
N	dissolved zinc concentration (μg/L)
O	dissolved zinc mean daily loading (g/day)
P	ln of dissolved zinc mean daily loading
Q	dissolved zinc mean daily loading
R	potential error of loading estimate (g/day)
S	if error is greater than loading estimate, an asterik is used
T	dissolved zinc mean daily loading from first order subbasin
U	storm flow dissolved zinc mean daily loading from first order subbasin
V	fraction of storm flow dissolved zinc loading from first order subbasin relative to total loadings from all subbasins
W	snowmelt flow dissolved zinc mean daily loading from first order subbasin
X	fraction of snowmelt flow dissolved zinc loading from first order subbasin relative to total loadings from all subbasins
Y	baseflow dissolved zinc mean daily loading from first order subbasin
Z	fraction of baseflow dissolved zinc loading from first order subbasin relative to total loadings from all subbasins
AA	difference in dissolved zinc loadings from first order subbasins between snowmelt and storm flows (g/day)
AB	difference in dissolved zinc loadings from first order subbasins between snowmelt flow and baseflow
AC	difference in dissolved zinc loadings from first order subbasins between storm flow and baseflow
AD	dissolved zinc mean daily unit area loading (g/ac-day)
AE	ln of dissolved zinc mean daily unit area loading
AF	storm flow dissolved zinc mean daily unit area loading
AG	snowmelt flow dissolved zinc mean daily unit area loading
AH	baseflow dissolved zinc mean daily unit area loading
AI	difference in dissolved zinc unit area loadings from first order subbasins between snowmelt and storm flows (g/ac-day)
AJ	difference in dissolved zinc unit area loadings from first order subbasins between snowmelt flow and baseflow
AK	difference in dissolved zinc unit area loadings from first order subbasins between storm flow and baseflow
AL	dissolved zinc loading for NPSs
AM	storm flow dissolved zinc loading for NPSs
AN	snowmelt flow dissolved zinc loading for NPSs
AO	baseflow dissolved zinc loading for NPSs
AP	dissolved zinc unit area loading for NPSs
AQ	storm flow dissolved zinc unit area loading for NPSs
AR	snowmelt flow dissolved zinc unit area loading for NPSs
AS	baseflow dissolved zinc unit area loading for NPSs
AT	dissolved zinc loading for background sources
AU	storm flow dissolved zinc loading for background sources
AV	snowmelt flow dissolved zinc loading for background sources
AW	baseflow dissolved zinc loading for background sources
AX	dissolved zinc unit area loading for background sources
AY	storm flow dissolved zinc unit area loading for background sources
AZ	snowmelt flow dissolved zinc unit area loading for background sources
BA	baseflow dissolved zinc unit area loading for background sources
BB	dissolved zinc loading for point sources
BC	storm flow dissolved zinc loading for point sources
BD	snowmelt flow dissolved zinc loading for point sources
BE	baseflow dissolved zinc loading for point sources
BF	storm flow dissolved zinc loading in main stem of Cement Creek
BG	snowmelt flow dissolved zinc loading in main stem of Cement Creek
BH	baseflow dissolved zinc loading in main stem of Cement Creek

	A	B	C	E	G	I	J	K	L
1	Table C2. Example spreadsheet database with dissolved zinc concentration data,								
2	exceedances of aquatic life standards, and related information								
3									
4	SUB_SEG	SOURCE	DISTANCE	LENGTH	PLEN	SITE	DATE	SEASON	FLOW
5	Cement	NPS	8.39	1.36	0.057	CC01	09/07/91	Storm	1.790
6	Cement	NPS	8.39	1.36	0.057	CC01	06/24/92	Snowmelt	15.400
7									
8	Queen Ann Mine adit	PS				CC01a	07/21/93		0.013
9									
10	Mogul tnl mine drng	PS				CC01b	07/21/93		0.031
11									
12	Mine adit abv Mogul	PS				CC01c	07/21/93		0.062
13									
14	adit	PS				CC01d	07/21/93		0.880
15									
16	adit	PS				CC01e	07/21/93		0.635
17									
18	adit	PS				CC01f	07/21/93		1.440
19									
20		NPS				CC02-CC01	09/07/91	Storm	0.510
21		NPS				CC02-CC01	06/24/92	Snowmelt	-3.500
22									
23	Cement		7.63	0.62	0.026	CC02	09/07/91	Storm	2.300
24	Cement		7.63	0.62	0.026	CC02	06/24/92	Snowmelt	11.900
25	Cement		7.63			CC02	07/21/93		5.470
26									
27		NPS				CC03-CC02	09/07/91	Storm	1.050
28		NPS				CC03-CC02	07/21/93		1.100
29									
30	Cement		7.16	0.30	0.013	CC03	09/07/91	Storm	3.350
31	Cement		7.16	0.30	0.013	CC03	06/24/92	Snowmelt	
32	Cement	NPS	7.16	2.28	0.192	CC03	10/14/92	Baseflow	0.637
33	Cement		7.16			CC03	07/21/93		6.570
34									
35	NF Cement	NPS		0.53	0.022	CC04	09/07/91	Storm	0.153
36									
37		NPS				CC05-CC03-CC06	09/07/91	Storm	-0.849
38		NPS				CC05-CC03-CC06	07/21/93		-0.260
39									
40	Cement		7.03	0.16	0.007	CC05	09/07/91	Storm	2.680
41	Cement		7.03	0.16	0.007	CC05	06/24/92	Snowmelt	18.300
42	Cement		7.03	0.45	0.038	CC05	10/14/92	Baseflow	0.468
43	Cement		7.03			CC05	07/21/93		6.880
44									
45		NPS				CC06-CC07	09/07/91	Storm	0.116
46									
47	NF Cement			0.30	0.013	CC06	09/07/91	Storm	0.179
48	NF Cement	NPS		1.13	0.048	CC06	06/24/92	Snowmelt	
49	NF Cement	NPS				CC06	07/21/93		0.570
50									

270

	M	N	O	P	Q	R	S	T	U
1									
2									
3									
4	FLOWL	FLOWCW	FLOWCW1	FLOWCW2	FLOWCW3	PFLOWCW	P2FLOWCW	PFLOWCW1	PFLOWCW2
5	0.6	1.790	1.790			0.001	0.000	0.006	
6	2.7	15.400		15.400		0.012	0.000		0.016
7									
8	-4.3								
9									
10	-3.5								
11									
12	-2.8								
13									
14	-0.1								
15									
16	-0.5								
17									
18	0.4								
19									
20	-0.7								
21									
22									
23	0.8	2.300	2.300			0.002	0.000	0.008	
24	2.5	11.900		11.900		0.009	0.000		0.012
25	1.7								
26									
27	0.0								
28	0.1								
29									
30	1.2	3.350	3.350			0.003	0.000	0.012	
31									
32	-0.5	0.637			0.637	0.000	0.000		
33	1.9								
34									
35	-1.9	0.153	0.153			0.000	0.000	0.001	
36									
37									
38									
39									
40	1.0	2.680	2.680			0.002	0.000	0.009	
41	2.9	18.300		18.300		0.014	0.000		0.019
42	-0.8	0.468			0.468	0.000	0.000		
43	1.9								
44									
45	-2.2								
46									
47	-1.7	0.179	0.179			0.000	0.000	0.001	
48									
49	-0.6								
50									

	V	W	X	Y	Z	AA	AB	AC	AD	AE
1										
2										
3										
4	PFLOWCW3	ZN_DC	AVG	STDS	90% CIM	90% CCIM	95% CIM	95% CCIM	ZN_DCNP	ZN_DCNPL
5		1600							1600	7.38
6		950							950	6.86
7										
8		1700								
9										
10		38000								
11										
12		4900								
13										
14		130								
15										
16		50								
17										
18		440								
19										
20										
21										
22										
23		2100							2100	7.65
24		1100							1100	7.00
25		920							920	6.82
26										
27										
28										
29										
30		2300	2050	1237	1455	0.71	1968	0.96	2300	7.74
31		1100							1100	7.00
32	0.009	3700							3700	8.22
33		1100							1100	7.00
34										
35		670							670	6.51
36										
37										
38										
39										
40		2500	2575	830	977	0.38	1321	0.51	2500	7.82
41		1700							1700	7.44
42	0.007	3700							3700	8.22
43		2400							2400	7.78
44										
45										
46										
47		4200							4200	8.34
48		6900							6900	8.84
49										
50										

	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1									
2									
3									
4	ZN_DCNP1	ZN_DCNP1L	ZN_DCNP2	ZN_DCNP2L	ZN_DCNP3	ZN_DCNP3L	NP1-NP2	NP3-NP1	NP3-NP2
5	1600	7.4	950	6.9			650		
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23	2100	7.6	1100	7.0			1000		
24									
25									
26									
27									
28									
29									
30	2300	7.7	1100	7.0	3700	8.2	1200	1400	2600
31									
32									
33									
34									
35	670	6.5							
36									
37									
38									
39									
40	2500	7.8	1700	7.4	3700	8.2	800	1200	2000
41									
42									
43									
44									
45									
46									
47	4200	8.3	6900	8.8			-2700		
48									
49									
50									

	AO	AP	AQ	AR	AS	AT	AU
1							
2							
3							
4	ZN_DCNPLW	ZN_DCNP1LW	ZN_DCNP2LW	ZN_DCNP3LW	ZN_DCNPFW	ZN_DCNP1FW	ZN_DCNP2FW
5	92	92			2	10	
6	54		54		11		15
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23	54	54			4	17	
24	28		28		10		13
25	0				0		
26							
27							
28							
29							
30	29	29			6	27	
31	14		14				
32	712			712	2		
33	0				0		
34							
35	15	15			0	0	
36							
37							
38							
39							
40	17	17			5	23	
41	11		11		23		32
42	141			141	1		
43	0				0		
44							
45							
46							
47	53	53			1	3	
48	328		328				
49							
50							

	AV	AW	AX	AY	AZ	BA	BB	BC	BD
1									
2									
3									
4	ZN_DCNP3FW	ZN_DCC	ZN_DCC1	ZN_DCC2	ZN_DCC3	HARDNESS	HARDLN	HARDLN1	HARDLN2
5		1600	1600			77	4.3	4.3	
6		950		950		48	3.9		3.9
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23		2100	2100			69	4.2	4.2	
24		1100		1100		45	3.8		3.8
25		920							
26									
27									
28									
29									
30		2300	2300			78	4.4	4.4	
31		1100		1100		41	3.7		3.7
32	34	3700			3700	142	5.0		
33		1100							
34									
35									
36									
37									
38									
39									
40		2500	2500			69	4.2	4.2	
41		1700		1700		41	3.7		3.7
42	25	3700			3700	142	5.0		
43		2400							
44									
45									
46									
47						65	4.2	4.2	
48						52	4.0		4.0
49									
50									

	BE	BF	BG	BH
1				
2				
3				
4	HARDLN3	CHRONIC	ACUTE	CLASS
5		1487	3473	c
6		1016	2371	
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23		1365	3186	c
24		963	2250	c
25				
26				
27				
28				
29				
30		1518	3545	c
31		893	2085	c
32	5.0	2471	5770	c
33				
34				
35				
36				
37				
38				
39				
40		1369	3197	c
41		893	2085	c
42	5.0	2471	5770	c
43				
44				
45				
46				
47		1296	3027	a
48		1084	2532	a
49				
50				

Table C2

Columns:

A	Cement Creek sub-segment or location
B	station or subbasin source category
C	distance to mouth (miles)
E	stream length for station (miles)
G	fraction of station stream length relative to total stream length
I	site or monitoring station identification
J	sample date
K	sample season
L	flow measured or computed (cfs)
M	ln of flow
N	flow for weighting concentrations
O	storm flow for weighting concentrations
P	snowmelt flow for weighting concentrations
Q	baseflow for weighting concentrations
R	fraction of flow for weighting concentrations
S	fraction of flow for weighting concentrations squared
T	fraction of storm flow for weighting concentrations
U	fraction of snowmelt flow for weighting concentrations
V	fraction of baseflow for weighting concentrations
W	dissolved zinc concentration (μg/L)
X	mean
Y	standard deviation
Z	90% confidence interval width
AA	coefficient of 90% CI (1/2 90% CI width divided by mean)
AB	95% confidence interval width
AC	coefficient of 95% CI (1/2 95% CI width divided by mean)
AD	dissolved zinc concentration for NPSs
AE	ln of dissolved zinc concentration for NPSs
AF	storm flow dissolved zinc concentration for NPSs
AG	ln of storm flow dissolved zinc concentration for NPSs
AH	snowmelt flow dissolved zinc concentration for NPSs
AI	ln of snowmelt flow dissolved zinc concentration for NPSs
AJ	baseflow dissolved zinc concentration for NPSs
AK	ln of baseflow dissolved zinc concentration for NPSs
AL	difference in zinc concentrations between storm and snowmelt flows (μg/L)
AM	difference in zinc concentrations between baseflow and storm flow
AN	difference in zinc concentrations between baseflow and snowmelt flow
AO	length weighted dissolved zinc concentration
AP	storm flow length weighted dissolved zinc concentration
AQ	snowmelt flow length weighted dissolved zinc concentration
AR	baseflow length weighted dissolved zinc concentration
AS	flow weighted dissolved zinc concentration
AT	storm flow weighted dissolved zinc concentration
AU	snowmelt flow weighted dissolved zinc concentration
AV	baseflow weighted dissolved zinc concentration
BA	hardness (mg/L as calcium carbonate)
BB	ln of hardness
BC	storm flow ln hardness
BD	snowmelt flow ln hardness
BE	baseflow ln hardness
BF	chronic hardness-based standard for brown trout
BG	acute hardness-based standard for brown trout
BH	class of standard exceedance (c = exceedance of chronic standard, a = exceedance of acute standard)

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APPENDIX D. CEMENT CREEK DATA ANALYSIS

In this appendix, the data analysis methods discussed in Chapter 6 are applied, tested, and evaluated using dissolved zinc data from the Cement Creek basin. The methods will be considered useful if the information goals can be achieved and if impaired stream segments and source areas can be targeted for remediation in an efficient manner. The seven quantitative information goals discussed in Chapter 6 are addressed in this chapter.

D.1 Information Goal #1. Type and Extent of Water Quality Impairment and Critical Conditions

For Cement Creek, the primary type of beneficial use impairment is impairment of Class 1 cold water aquatic life habitat. No fish currently live in the creek, and benthic macroinvertebrate communities, which are the food supply for fish, exist but are impaired. It is not yet known whether the creek could support a viable fish population even if the mining waste problems were remediated due to natural potentially high loadings and concentrations of toxic metals from mineralized sources. Recreational uses, including fishing, are also impaired.

Once the magnitudes of dissolved and total zinc concentrations are known (as discussed for information goal #3) and by using the screening procedure discussed in Section 5.1, it can be shown that dissolved zinc is the primary constituent of concern. Zinc has the highest mean and maximum concentrations in Cement Creek as well as the greatest frequency of exceedances of acute and chronic standards for

fish. Iron is also likely impairing aquatic life in Cement Creek to a certain extent as a result of precipitation and adsorption onto solids on stream bed material. Calculation of the average ratio of dissolved to total concentrations reveals that approximately 90% of the zinc is in the dissolved, or bioavailable form. This is partly the result of the relatively low pH of the creek. Therefore, dissolved zinc can be used as an indicator metal and will also be targeted for control in the basin.

Whether high loadings to or concentrations in Cement Creek are the primary problem is discussed under information goal #3. The frequency of concentrations exceeding standards and loadings exceeding target values is discussed under information goal #7.

One of the primary concerns regarding Cement Creek is its loadings of metals (primarily zinc and aluminum) to the Upper Animas River. The type of beneficial use impairment for this water body is also impairment of Class 1 cold water aquatic life and recreational use. In this case, the river does support a viable fish population that can likely be improved. Therefore, the Upper Animas River is being targeted by CDPHE for restoration and attainment of desired beneficial uses. However, targeting specific NPS areas and point sources in the Cement Creek basin for remediation is required for the restoration of the segment of the Animas River below Cement Creek.

The analysis in Appendix A showed that zinc loadings are significantly different between seasons and are highest during snowmelt, followed by storms and then baseflow. Differences in concentrations are significant between snowmelt and baseflow and between snowmelt and storms, but not necessarily between storms and baseflow. Concentrations are generally highest during baseflow and lowest during

snowmelt. Therefore, critical conditions to aquatic life in Cement Creek tend to occur during baseflow conditions during the late summer, fall, and winter. In addition, zinc loadings to the Upper Animas River during snowmelt and storms might precipitate/adsorb onto solids as the pH of the water increases downstream and be deposited on the channel bottom. Later during baseflows, the solid zinc could redissolve increasing the bioavailable concentrations in the Animas River creating critical conditions. Therefore, both loadings from Cement Creek during high flows and high concentrations in the Animas River during baseflow can be considered critical conditions for this segment and should be targeted for control.

D.2   Information Goal #2. Areal Extent and Contaminant Concentrations of NPSs

As discussed in more detail in Appendix E, this information is currently not available for Cement Creek and cannot, therefore, be used in the targeting process at this time. A cooperative inventorying effort by USBM and USBLM in the Upper Animas River Basin, however, is currently in progress. Although sampling and analysis for contaminant concentrations of NPSs is not being performed, the areal extent and volumes of NPSs are being estimated as part of the study. When these results are available, this information can also be used to aid in the targeting process.

D.3   Information Goal #3. Magnitudes of Concentrations and Loadings

D.3.1   Concentrations

The dissolved zinc concentration at each station for each sampling event was determined directly from the raw analytical results, and is presented in a database (spreadsheet or table) format in column W in Table C2 in Appendix C. Each value is also directly overlain on the site map in Figure B2 in Appendix B. The location of each value can be readily observed from both the table and the map. It is

implicitly assumed that each value represents a mean concentration for each station for each season. These individual concentration values can later be ranked to more easily determine the highest values and their corresponding locations, as discussed in Section D.7.1. The locations of the highest concentrations in stream segments are in the North Fork of Cement Creek (CC06), upper Cement Creek from CC18 upstream, and in Prospect Gulch. During the final targeting process for the basin, the potential uncertainty or measurement error associated with each value should be considered to determine the confidence in the values and in comparisons among values. The estimated uncertainty is assumed to be the same for each measured concentration value is $\pm$ approximately 10% (discussed in Chapter 5).

The information goals defined in Chapter 4 were achieved for the entire Cement Creek stream segment using the data analysis methods discussed in Chapter 6 using all monitoring station locations. This information is presented in Table D1. The stream-length weighted and flow-weighted mean concentrations for Cement Creek were also computed for each season and for a year, and the time-weighted mean concentration was computed for a year. These results are also presented in Table D1.

To derive the time-weighted mean concentration, the average annual hydrograph near the mouth of Cement Creek (CC48) based on only two years of data (water years 1992 and 1993) was used (Figure D1). The time scale is divided into sections based on the time period for each flow regime for which samples were collected. For practical purposes, only two distinct flow regimes or seasons can be observed using the hydrograph: snowmelt flow and baseflow. This time division is also presented in Figure D1. It is estimated from the hydrograph that baseflow occurs

Table D1. Cement Creek dissolved zinc concentrations (ug/L)		SEASON		ANNUAL
STATISTIC	STORM (9/7/91)	SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	
N	43	41	17	128
MEAN	1159	796	1348	1041
90% CIM	479	572	948	278
90% CCIM	0.21	0.36	0.35	0.13
95% CIM	574	686	1151	332
95% CCIM	0.25	0.43	0.43	0.16
LWMEAN	914	815	1639	1364
90% CIMLW				970
90% CCIMLW				0.36
95% CIMLW				1250
95% CCIMLW				0.46
FWMEAN	1194	892	978	987
90% CIMFW				448
90% CCIMFW				0.23
95% CIMFW				576
95% CCIMFW				0.29
TWMEAN	N/A	N/A	N/A	1204
MEDIAN	1000	810	940	930
90% CIMD	440	526	348	88
90% CCIMD	0.22	0.32	0.19	0.05
95% CIMD	517	590	546	116
95% CCIMD	0.26	0.36	0.29	0.06
SD	933	1087	1119	950
90% CISD	347	414	714	197
90% CCISD	0.19	0.19	0.32	0.10
MINIMUM	4	4	10	4
MAXIMUM	4200	6900	3700	6900

Table D1

Abbreviations:

N = sample size
90% CIM = 90% CI width on mean
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CIM = 95% CI width on mean
95% CCIM = coefficient of 95% CI on mean
LWMEAN = length weighted mean
90% CIMLW = 90% CI width on length weighted mean
90% CCIMLW = coefficient of 90% CI on length weighted mean (1/2 CI width divided by mean)
95% CIMLW = 95% CI width on length weighted mean
95% CCIMLW = coefficient of 95% CI on length weighted mean
FWMEAN = flow weighted mean
90% CIMFW = 90% CI width on flow weighted mean
90% CCIMFW = coefficient of 90% CI on flow weighted mean (1/2 CI width divided by mean)
95% CIMFW = 95% CI width on flow weighted mean
95% CCIMFW = coefficient of 95% CI on flow weighted mean
TWMEAN = time weighted mean
90% CIMD = 90% confidence limit on median
90% CCIMD = coefficient of 90% CI on median (1/2 CI width divided by median)
95% CIMD = 95% confidence limit on median
95% CCIMD = coefficient of 95% CI on median
SD = standard deviation
90% CISD = 90% CI width on standard deviation
90% CCISD = coefficient of 90% CI on standard deviation (1/2 CI width divided by standard deviation)

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CEMENT CREEK
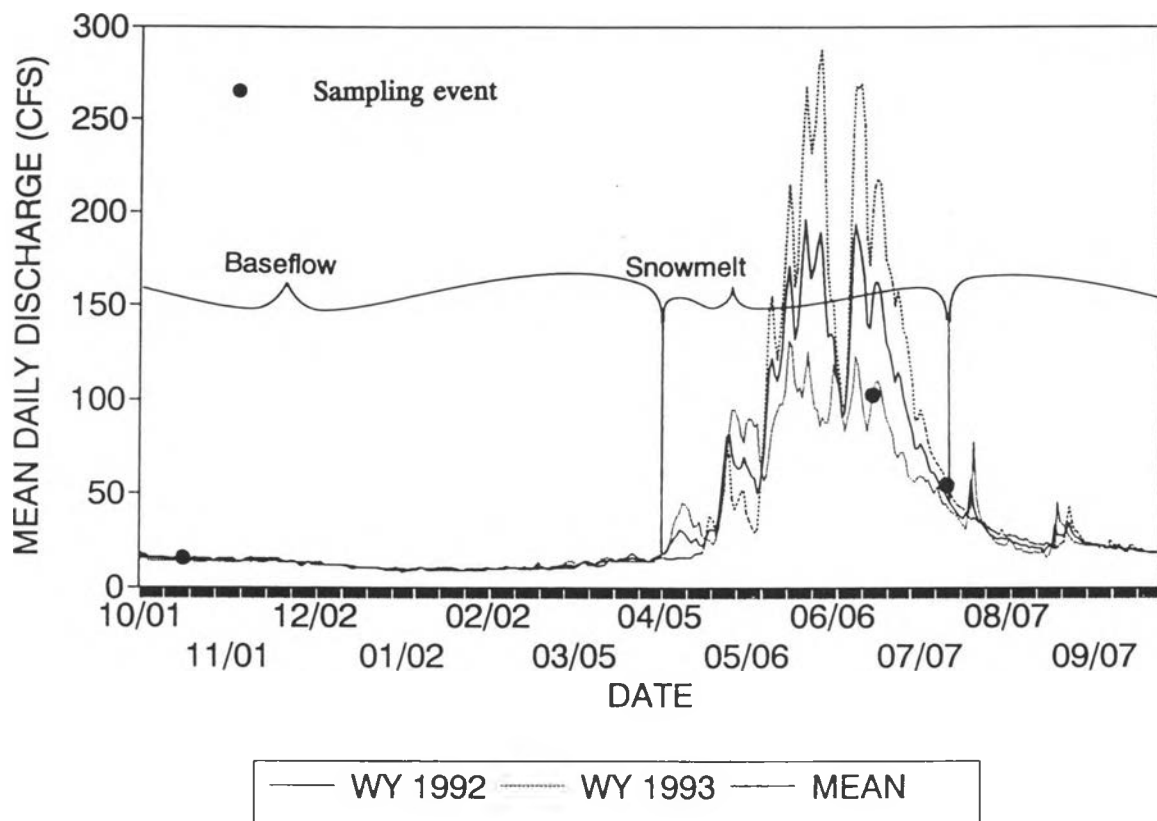## MEAN DAILY DISCHARGE

Figure D1.   Annual mean daily discharge hydrographs for Cement Creek

during approximately 75% of the year, and snowmelt runoff occurs during the other 25% of the year (excluding storm events).

The time period (average number of days in a year) for storm runoff events is derived using a different method. Historical climatological data from the Silverton, Colorado precipitation station were obtained from the Colorado Climate Center in Ft. Collins, Colorado. The storm of 9/7/91 that was sampled had a depth of 0.54 inches. The average number of days in a year for which a precipitation depth of 0.1 inches or greater occurs was determined to be 94 days. However, during six months of the year this precipitation is usually in the form of snow. During the other six months, it is in the form of rain. Approximately 47 days, therefore, have rain events with precipitation greater than 0.1 inches. Forty seven days is the time period used for time weighting the storm results for a year. It was also determined that the storm sampled on 9/7/91 was a very representative, or average, storm in any given year because the precipitation depth for a storm with a return period of 1-year (depending on the storm duration) is approximately 0.5 inches. After the number of days for storm events is subtracted from 365 days, snowmelt occurs during 80 days and baseflow occurs during 238 days.

As can be seen from Table D1, the mean and length-weighted mean concentrations in Cement Creek are both highest during baseflow conditions. All of the computed mean, as well as the median, concentrations are lowest during snowmelt. The length-weighted mean (1,639 μg/L) is significantly higher than the mean (1,348 μg/L), and the mean is higher than the flow-weighted mean (978 μg/L) and median (940 μg/L) during baseflow. The mean (1,159 μg/L) is quite a bit higher than the length-weighted mean (914 μg/L) during the storm event, while the flow-

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weighted mean and median are fairly close to the mean. The flow-weighted mean for the storm event (1,194 μg/L) is higher than the flow-weighted mean for baseflow (978 μg/L). The medians for the storm (1,000 μg/L) and snowmelt (810 μg/L) tend to fall within the range of the means computed using the various methods, whereas the median for baseflow (940 μg/L) is the smallest estimate of average conditions.

The different estimators of average conditions for baseflow tend to be more variable than for the other flow conditions (i.e., the mean, weighted means, and median are not as close to each other for baseflow). This is probably due to the smaller sample size ($n = 17$) relative to storm ($n = 43$) and snowmelt ($n = 41$) used to compute the estimators, and is also reflected in the computed standard deviations. The standard deviation (1,119 μg/L) (and its associated CCI [32%]) and 90% CI_m width (948 μg/L) and 95% CI_m width (1,151 μg/L) for baseflow are greater than for the other two flow regimes. It would generally be expected that the variability would be smaller and the confidence in the estimated mean values would be larger for baseflow than for the other flow regimes because of the small variations in flow during this period. The range of concentrations, however, is greatest for snowmelt.

On an annual basis, the median is also the smallest estimator of average conditions (930 μg/L). The time-weighted mean (1,204 μg/L) and stream-length weighted mean (1,134 μg/L) are both higher than the mean (1,041 μg/L) and the flow-weighted mean (987 μg/L). The 90 and 95% CCI_ms for the arithmetic mean are 13% and 16%, respectively. The 90 and 95% CCI_{md}s are only 5% and 6%, respectively. The 90 and 95% CCI_{mw}s for the stream-length weighted mean are 36% and 46%, respectively, and the 90 and 95% CCI_{mw}s for the flow-weighted mean are

23% and 29%, respectively. The standard deviation is 950 μg/L, and its CCI_s is only 10%.

The estimators of average concentrations in Cement Creek, or at individual stations, can easily be represented as bar graphs. Figure D2 presents a bar graph of mean dissolved zinc concentrations in Cement Creek by season and on an annual basis.

The estimate of and confidence in the mean is dependent on the computation method used (i.e., mean, stream-length weighted mean, flow-weighted mean, or time-weighted mean). However, the mean values estimated using the different methods do not appear to be much different. The arithmetic mean should be computed because it generally has the smallest CCI_ms. It still might be useful to use several computation methods to examine the potential variability of the mean when evaluating priority stream segments. The median is generally the smallest estimator of average conditions, indicating nonnormal and right-skewed distributions, and has the smallest CCIs. The median, therefore, should be computed for concentration data. When using these average concentration values for comparing and targeting stream segments, the CI widths and CCIs should be considered explicitly in the process. For small CCIs, greater confidence can be placed in decisions regarding targeting. For large CCIs, decisions must be made with less certainty about average conditions in the stream and comparisons between segments.

Once the magnitudes of concentrations were estimated, the locations and stream length of concentrations exceeding applicable standards were determined. This was accomplished by computing the acute and chronic standards for each metal

CEMENT CREEK
MEAN ZN CONCENTRATION IN CREEK
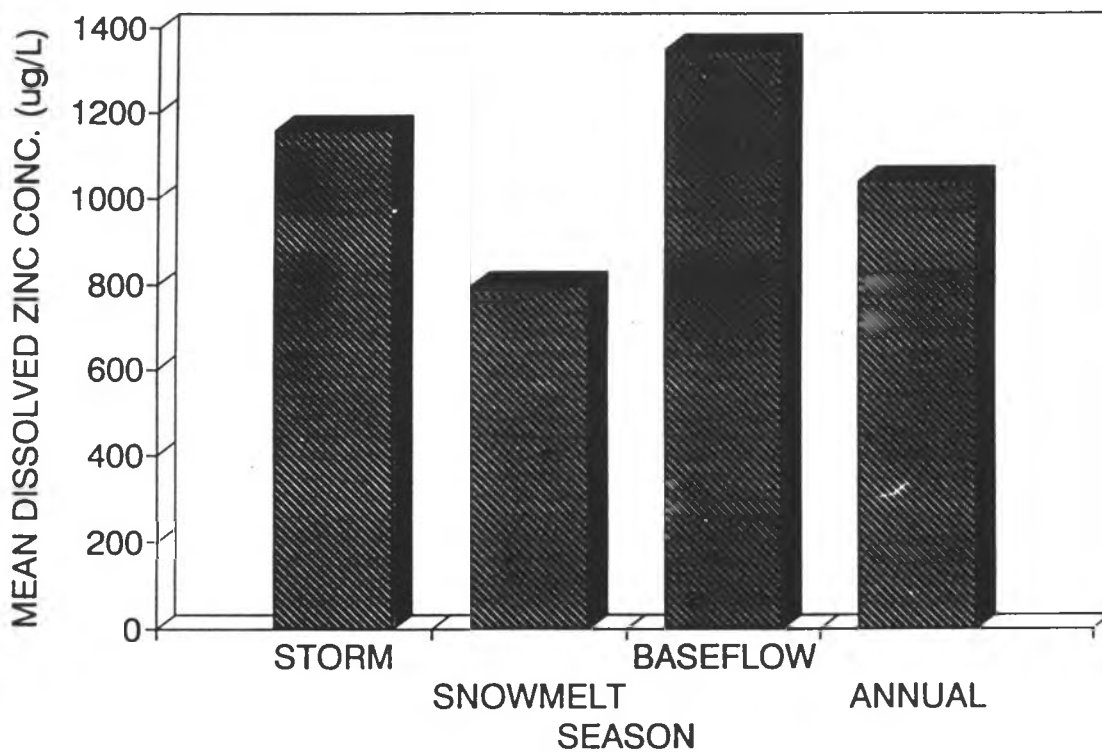
Figure D2.   Bar graph of mean dissolved zinc concentrations in Cement
Creek by season

concentration measured at each station for each season using the corresponding or representative hardness value, and then directly comparing each concentration to the two standards. This analysis was performed for Cement Creek, the results of which are presented in Table C2 in Appendix C in columns BA through BH. Column BH shows the monitoring points where chronic or acute aquatic life standards are exceeded. Figure B2 in Appendix B presents a map of the watershed showing these locations and the extent of the problem during snowmelt. As can be seen from the table and map, most of the exceedances are chronic exceedances and occur in the upper part of the basin. Chronic exceedances occur at CC05 and upstream and at CC18 in upper Cement Creek. The North Fork of Cement Creek exhibits acute exceedances, and Prospect Gulch exhibits chronic as well as acute exceedances. On an annual basis, 16 monitoring stations exhibited chronic exceedances and 4 stations exhibited acute exceedances out of 117 samples. The estimated total stream length exceeding standards is 4.68 miles out of a total of 23.78 miles of stream length in the basin (20%). Most of the exceedances are related to low hardness values as well as elevated zinc concentrations.

Cement Creek will probably not be targeted for restoration in the near future given the current lack of fish in the stream and severity of the problem. The magnitudes of concentrations in Cement Creek, and the extent of the use impairment, would be of more value if this stream segment was being compared to other segments as part of the targeting process and/or being targeted for restoration. If this were the case, the reaches that exhibit lower concentrations and that don't exhibit exceedances might be targeted because they are more likely to be able to support aquatic life even though the locations and stream reaches that exhibit

exceedances are more impaired. Concentrations in the creek during baseflow conditions could be targeted. However, the magnitudes of concentrations in Cement Creek and the exceedances of standards are also indicators of source areas in the basin that are loading metals to the Upper Animas River below Cement Creek as well as to Cement Creek itself.

D.3.2   Loadings

The loading at each station for each sampling event was determined using either Equation 5.1 or 5.2 and the corresponding concentration and flow values. The loadings are presented in a database format in column O in Table C1 in Appendix C, as well as directly overlain on the site map (Figure B3 in Appendix B). The location of each value can be readily observed using both the table and the map. It is assumed that these each value represents a mean loading for each station for each season. These individual loading values can later be ranked to more easily determine the highest values and their corresponding locations, as discussed in Section D.7.1. The greatest loading (45,039 g/day) is from the large subbasin CC48-CC47 during snowmelt. This subbasin also contributed a large loading during the receding limb of snowmelt and even during baseflow. Discharge from Ross Basin to station CC01, and from subbasin CC31-CC30, also exhibited high loadings during snowmelt. The much smaller subbasins CC20-CC19-CC18, CC28-CC27, and CC36-CC34-CC35 also contributed relatively large loadings during snowmelt and storm flows. It should be mentioned that some of the loadings estimated as the differences between loadings measured at two or more adjacent stations using the NPS reach gain/loss analysis have relatively large potential errors associated with them and should be used with caution. During the final targeting process for the basin, the

potential uncertainty or measurement error associated with each value should be considered to determine the confidence in the values and in comparisons among values. This value is $\pm$ at least approximately 18% and can vary depending on whether it was estimated at a monitoring station or estimated using the NPS reach gain/loss analysis and how many upstream stations were used to compute the loading between adjacent stations (discussed in Chapter 5).

The information goals defined in Chapter 4 were achieved using the methods discussed in Chapter 6 for the entire Cement Creek stream segment. All of this information is presented in Table D2. The maximum mean daily loading to Cement Creek from all first order subbasins occurs during snowmelt (218,705 g/day), and the minimum is during baseflow (21,449 g/day). On an annual basis, the mean daily loading (125,634 g/day) is greater than the time-weighted mean daily loading (79,834 g/day). The median daily loading is the highest estimate (136,747 g/day). The 90% CCI_m is 70% and the 95% CCI_m is 109%. The standard deviation is 99,097 g/day, and its CCI_{sd} is almost 200%. All of these CIs are large primarily because of the small sample size ($n=4$). The large CIs indicate that caution must be used when using annual loading values in the final comparison and targeting process for the basin.

The maximum total loading occurs during snowmelt (17,387 kg), and the minimum is during baseflow (5,116 kg). Storms account for 6,427 kg. The time-weighted total loading for a year is 28,930 kg. Therefore, loading during snowmelt accounts for 60%, storm loading accounts for 22%, and baseflow loading accounts for 18% of the annual total. Figure D3a is a bar graph of the total zinc loadings to Cement Creek by season, and Figure D3b is a pie chart showing percentages of the

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STATISTIC	STORM (9/7/91)	SEASON SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
Table D2. Cement Creek dissolved zinc loadings (g/day)				
N	49	33	15	120
MEAN (DAILY)	136747	218705	21449	125634
90% CIM	N/A	N/A	N/A	175888
90% CCIM	N/A	N/A	N/A	0.70
95% CIM	N/A	N/A	N/A	273882
95% CCIM	N/A	N/A	N/A	1.09
TWMEAN	N/A	N/A	N/A	79834
MEDIAN	N/A	N/A	N/A	136747
SD	N/A	N/A	N/A	99097
90% CISD	N/A	N/A	N/A	380532
90% CCISD	N/A	N/A	N/A	1.92
MINIMUM	N/A	N/A	N/A	21449
MAXIMUM	N/A	N/A	N/A	218705
TOTAL (kg)	6427	17387	5116	28930
% OF ANNUAL	0.22	0.6	0.18	1.00
TOTAL MINIMUM	N/A	N/A	N/A	5116
TOTAL MAXIMUM	N/A	N/A	N/A	17387

Table D2

Abbreviations:

N = sample size
90% CIM = 90% CI width on mean
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CIM = 95% CI width on mean
95% CCIM = coefficient of 95% CI on mean
TWMEAN = time weighted mean
SD = standard deviation
90% CISD = 90% CI width on standard deviation
90% CCISD = coefficient of 90% CI on standard deviation (1/2 CI width divided by standard deviation)

STATISTIC	STORM (9/7/91)	SEASON SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
Table D3. Loadings of dissolved zinc into and out of Cement Creek				
MEAN (DAILY) IN (g/day)	136747	218705	21449	125634
MEAN (DAILY) OUT (g/day)	41816	145754	29827	56778
MEAN (DAILY) DIFFERENCE	-94931	-72951	8378	-68856
TOTAL IN (kg)	6427	17387	5116	28930
TOTAL OUT (kg)	1965	11660	7099	20724
TOTAL DIFFERENCE	-4462	-5727	1983	-8206

CEMENT CREEK
ZINC LOADING TO CREEK BY SEASON
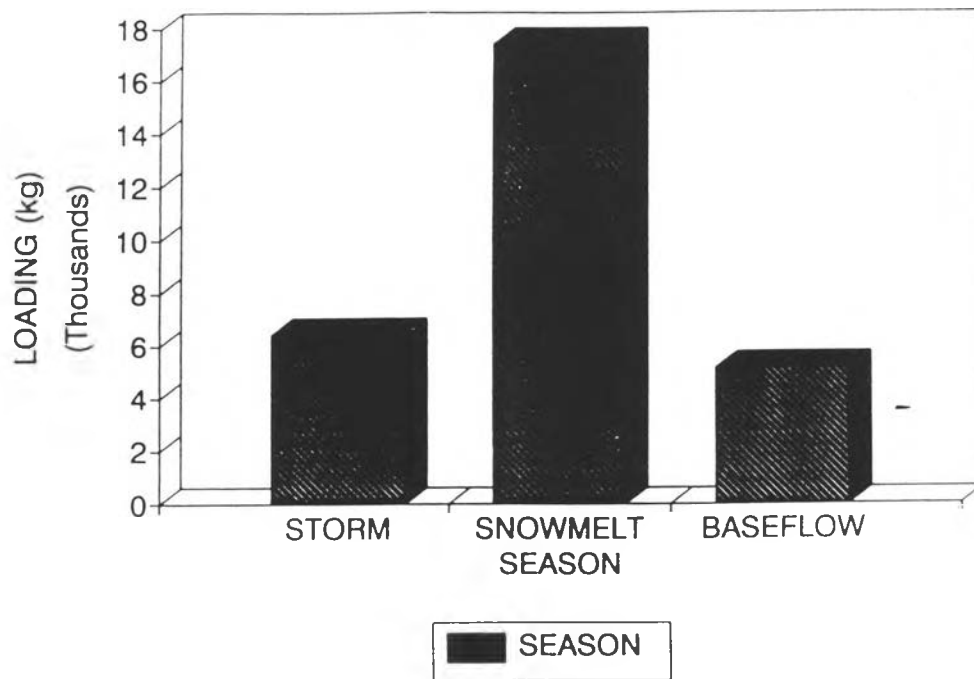
CEMENT CREEK
% OF ANNUAL ZN LOAD TO CREEK BY SEASON
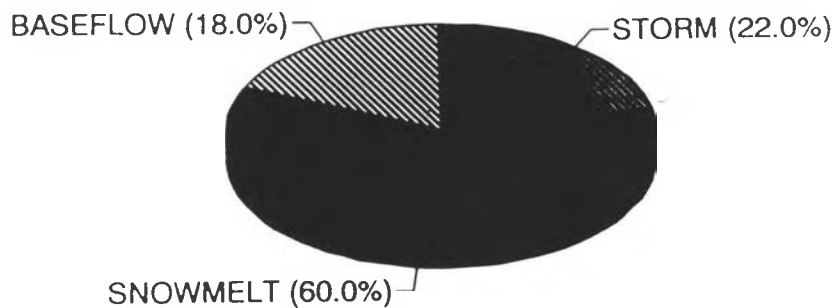
Figure D3.   Total (bar graph) and percentage (pie chart) of annual dissolved zinc loadings to Cement Creek by season

annual zinc loading to Cement Creek by season.

It is useful to evaluate the mass loading of dissolved zinc into Cement Creek in conjunction with the load out of the basin to estimate either the unaccounted for loadings into the creek or losses within the stream. Table D3 presents the estimated total loadings into Cement Creek, loadings at the mouth of the creek, and gains or losses on a seasonal and annual basis. As can be seen from the table during storms and snowmelt, loadings into the creek are greater than loadings out, indicating losses of mass within the creek system. During baseflow, however, loading out is greater than loading into the creek. This shows a net gain in dissolved zinc mass through the system that includes unaccounted for or unmeasured loadings. On an annual basis, the loading into the system is greater than the loading out, indicating a net annual loss of mass from the stream system. All of the estimated differences are less than the corresponding potential errors or uncertainty of the individual loading estimates (as discussed in Chapter 5). This indicates that some confidence can be placed in the positive or negative differences.

Because the Animas River is being targeted for restoration, the loadings to and from Cement Creek can be compared to the loadings from other sources or subbasins to target subbasins for remediation. A preliminary analysis of the loadings from the Upper Animas River and Mineral Creek indicates that Cement Creek is contributing the greatest amount of zinc loadings to downstream areas of the Animas River and should be targeted for remediation. The loadings to Cement Creek, therefore, must be reduced in order to restore the Upper Animas River. Remediation of source area loadings during high flows (snowmelt and storms) should be targeted. Information on the loadings to Cement Creek would also be useful for

comparison among other stream segments (as an indicator of impairment), such as the Upper Animas River or Mineral Creek, if Cement Creek itself were being targeted for remediation. The loadings estimated here can also be used later to estimate the reduction and percentage reduction in loadings required to meet target loadings, water quality standards, or stream restoration goals.

D.3.3   Unit Area Loadings

The unit area loading at each station for each sampling event was determined using Equation 5.3 and the corresponding loading value. The unit area loadings are presented in a database format in column AA in Table C1 in Appendix C, as well as directly overlaid on the site map (Figure B3 in Appendix B). The location of each value can be readily observed using both the table and the map. It is assumed that each value represents a mean unit area loading for each station for each season. These individual unit area loading values can later be ranked to more easily determine the highest values and their corresponding locations, as discussed in Section D.7.1. The small subbasin CC20-CC19-CC18 in the vicinity of the American Tunnel exhibits the greatest mean daily unit area loading (1,422 g/ac-day) during snowmelt. The next greatest mean daily unit area loadings are from the small subbasin CC28-CC27 below Prospect Gulch during the storm event (757 g/ac-day) and from subbasin CC20-CC19-CC18 during the storm (540 g/ac-day). As expected, the smallest unit area loadings are from background areas and during baseflow conditions. It should be noted, however, that each of these loadings was estimated as the difference between loadings at two or more adjacent stations and that the estimated errors in the loadings are not that much smaller than the computed loadings themselves. The greatest unit area loading (48.73 g/ac-day) actually

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measured at a station is at CC01 during snowmelt. During the final targeting process for the basin, the potential uncertainty or measurement error associated with each value should be considered to determine the confidence in the values and in comparisons among values. This value is $\pm$ at least approximately 18% and can vary depending on whether it was estimated at a monitoring station or estimated using the NPS reach gain/loss analysis and how many upstream stations were used to compute the loading between adjacent stations (discussed in Chapter 5).

The information goals that were defined in Chapter 4 were achieved for the entire Cement Creek stream segment using the data analysis methods discussed in Chapter 6 using all monitoring station locations. These results are presented in Table D4. The maximum mean daily unit area loading occurs during snowmelt (77 g/ac-day), and the minimum occurs during baseflow (1.7 g/ac-day). For all flow regimes, the median daily unit area loadings are much smaller than the mean values. This results from the large number of zero or very small unit area loadings and the nonnormal (right-skewed) distributions. The maximum median value is 5.3 g/ac-day for snowmelt, and the minimum is 0.2 g/ac-day for baseflow. The CCI_ms are very large for all flow regimes (ranging from 86 to 134%). The CCI_{md}s are even larger (ranging from 147 to 478%). The computed standard deviations are also large. The range of unit area loadings is greatest for snowmelt and smallest for baseflow.

On an annual basis, the time-weighted mean daily unit area loading (24 g/ac-day) is less than the mean value (46 g/ac-day). The 90 and 95% CCI_ms are smaller for the annual mean than for the seasonal means. The median unit area loading (1.5 g/ac-day) is much smaller than the time-weighted mean, indicating a right-skewed distribution. Although the annual standard deviation is large (179 g/ac-day), its 90%

STATISTIC	STORM (9/7/91)	SEASON SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
Table D4. Cement Creek dissolved zinc unit area loadings (g/ac-day)				
N	43	30	11	93
MEAN (DAILY)	42	77	1.7	46
90% CIM	72	165	3.64	62
90% CCIM	0.86	1.07	1.09	0.67
95% CIM	86	199	4.5	74
95% CCIM	1.02	1.29	1.34	0.80
TWMEAN	N/A	N/A	N/A	24
MEDIAN	2.6	5.3	0.2	1.5
90% CIMD	8.9	15.5	1.5	3.6
90% CCIMD	1.74	1.47	3.63	1.20
95% CIMD	9.5	15.8	1.9	5.9
95% CCIMD	1.85	1.49	4.78	2.00
SD	139	267	3.3	179
90% CISD	52	121	2.8	43
90% CCISD	0.19	0.23	0.43	0.12
MINIMUM	0	0	0	0
MAXIMUM	758	1422	11.2	1422
TOTAL (g/ac)	1989	6133	398	16673
TWTOTAL	N/A	N/A	N/A	8520
% OF ANNUAL	0.12	0.37	0.02	1.00
% OF TWANNUAL	0.23	0.72	0.05	1.00
TOTAL MINIMUM	N/A	N/A	N/A	398
TOTAL MAXIMUM	N/A	N/A	N/A	6133

Table D4

Abbreviations:

N = sample size
90% CIM = 90% CI width on mean
90% CCIM = coefficient of 90% CI on mean (1/2 CI width divided by mean)
95% CIM = 95% CI width on mean
95% CCIM = coefficient of 95% CI on mean
TWMEAN = time weighted mean
90% CIMD = 90% confidence limit on median
90% CCIMD = coefficient of 90% CI on median (1/2 CI width divided by median)
95% CIMD = 95% confidence limit on median
95% CCIMD = coefficient of 95% CI on median
SD = standard deviation
90% CISD = 90% CI width on standard deviation
90% CCISD = coefficient of 90% CI on standard deviation (1/2 CI width divided by standard deviation)
TWTOTAL = time weighted total
TWANNUAL = time weighted annual

CCI_{sd} is not (12%). Figure D4 presents a bar graph of mean daily zinc unit area loadings to Cement Creek by season and on an annual basis.

The estimate of and confidence in the average unit area loading is dependent on the computation method used (i.e., mean, time-weighted mean, or median). It is useful to use several computation methods to examine the potential variability of estimates of average conditions when evaluating priority stream segments. Although it has the largest CCIs, the median is generally the smallest estimator of average conditions, indicating nonnormal and right-skewed distributions. The median, therefore, should be computed for unit area loading data. The arithmetic mean should also be computed because it has smaller CCIs and should be used for estimating total unit area loadings. When using these average unit area loading values for comparing and targeting stream segments and basins, the CI widths and CCIs should be considered explicitly in the process. For small CCIs, greater confidence can be placed in decisions regarding targeting. For large CCIs, decisions must be made with less certainty about average conditions in the watershed and comparisons between basins.

The maximum total unit area loading occurs during snowmelt (6,133 g/ac), and the minimum is during baseflow (398 g/ac). The total unit area loading for a year is 16,673 g/ac, whereas the time-weighted total value is 8,520 g/ac. Unit area loading during snowmelt accounts for 72%, loading during storms accounts for 23%, and loading during baseflow accounts for 5% of the time-weighted total unit area loading for the year. Figure D5a presents a bar graph of the zinc unit area loading to Cement Creek by season, and Figure D5b is a pie chart of percentages of annual

CEMENT CREEK
MEAN DAILY ZN UNIT AREA LD TO CREEK
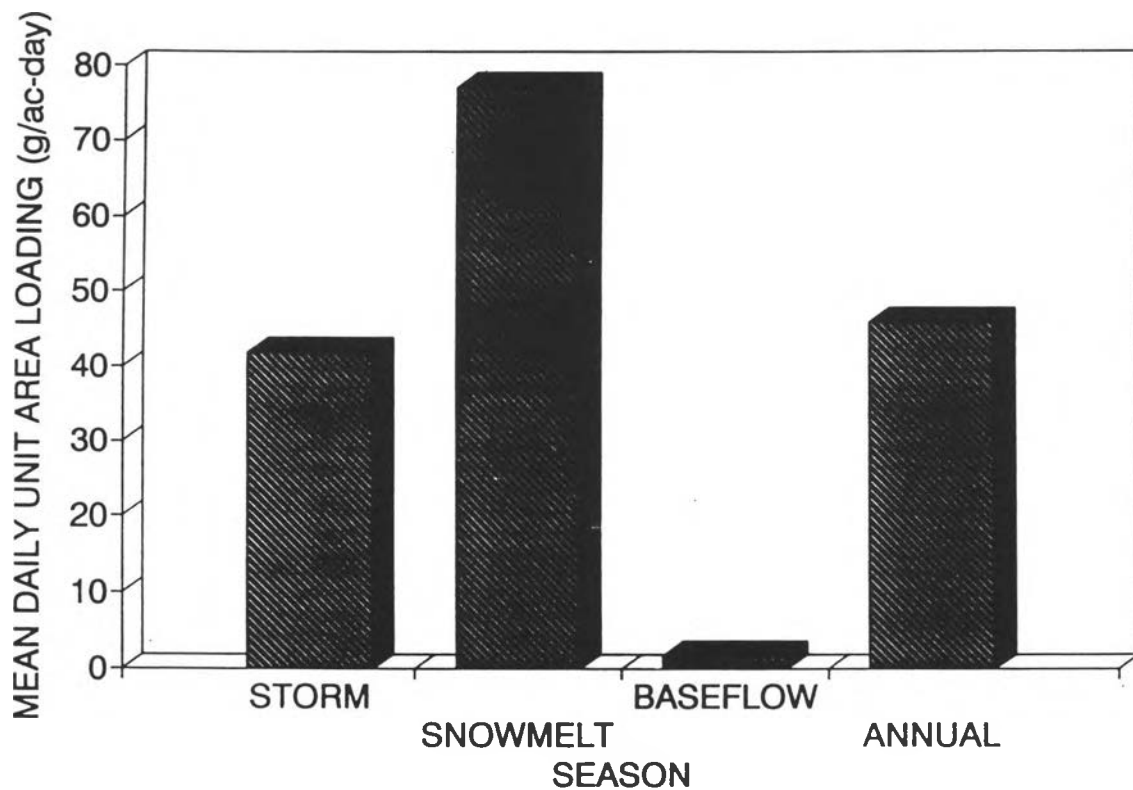
Figure D4.   Bar graph of dissolved zinc mean daily unit area loadings to
                  Cement Creek by season

CEMENT CREEK
ZN UNIT AREA LOADING TO CREEK BY SEASON
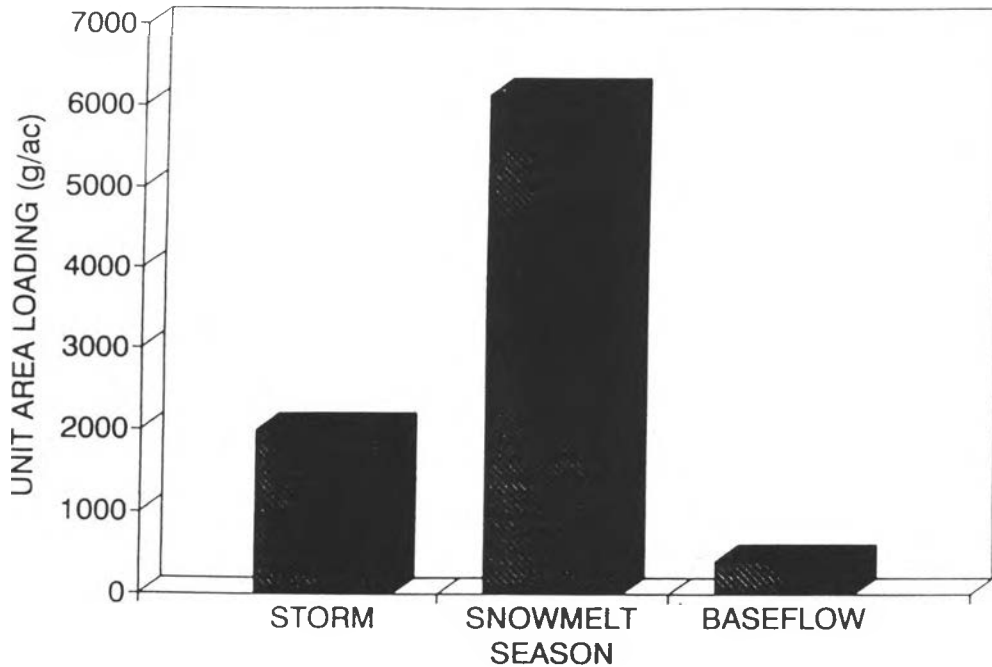
CEMENT CREEK
% ANNUAL ZN UNIT LD TO CREEK BY SEASON
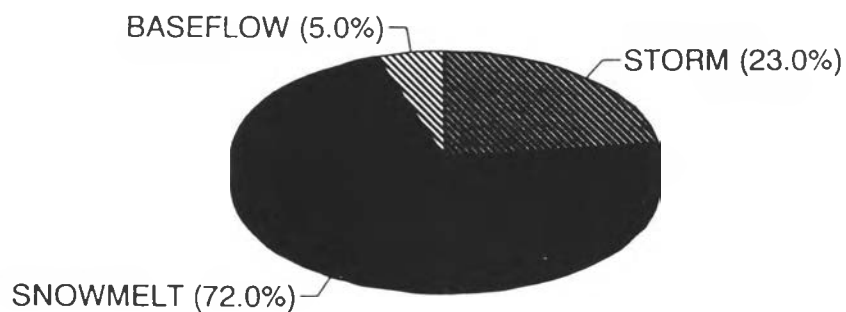
Figure D5.   Dissolved zinc unit area loadings (bar graph) and percent of
                    annual unit area loadings (pie chart) to Cement Creek by
                    season

zinc unit area loading to Cement Creek by season.

This information would be more useful if the loadings to Cement Creek were being compared to the loadings to other stream segments as part of the targeting process or if Cement Creek was being targeted for restoration because the unit area loadings to the creek indicate the intensity of the source areas, and areas that, if remediated, might provide for the most cost effective remediation. The source areas exhibiting the highest unit area loadings can be targeted for remediation, especially during snowmelt and storm flows.

D.4   Information Goal #4. Locations of Loadings to and Losses from Stream
       Segments

For Cement Creek several methods were used to determine locations of loadings to and losses from stream segments within the basin. The location of each loading estimated in Section D.3 is first presented in column H in Table C1 in Appendix C. The magnitudes were also overlain directly on a site map for easy visual reference (Figure B3). In addition, plots of concentrations and loadings versus distance along the main stem of Cement Creek for each season are presented in Figures D6 and D7, respectively.

Figures D6a through D6c show dissolved zinc concentrations versus distance along the main stem of Cement Creek for the storm, snowmelt, and baseflow sampling events, respectively. The first two figures show a significant increase in concentrations between mile 8 and mile 7, with the highest concentration in the main stem near mile 7. The last figure also shows the highest concentration near mile 7. These locations are generally between stations CC05 and CC18. It appears from these figures that the subbasins in the upper part of the Cement Creek basin
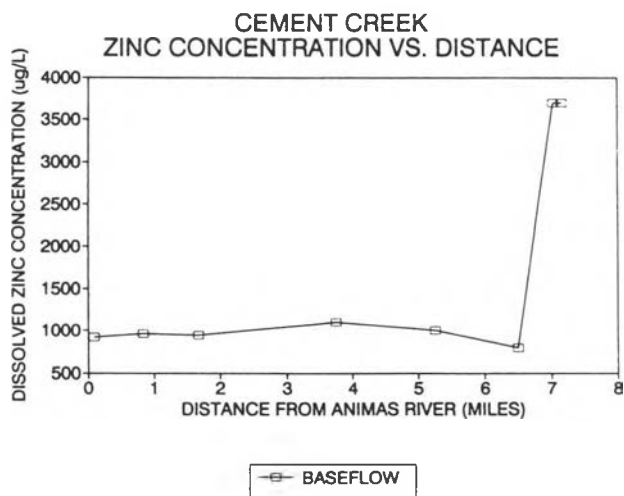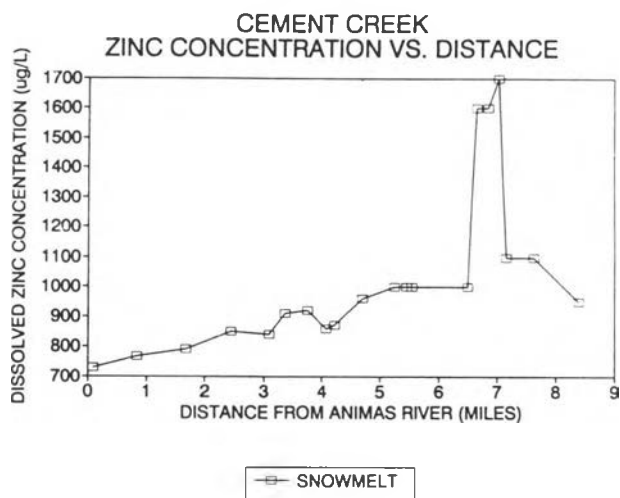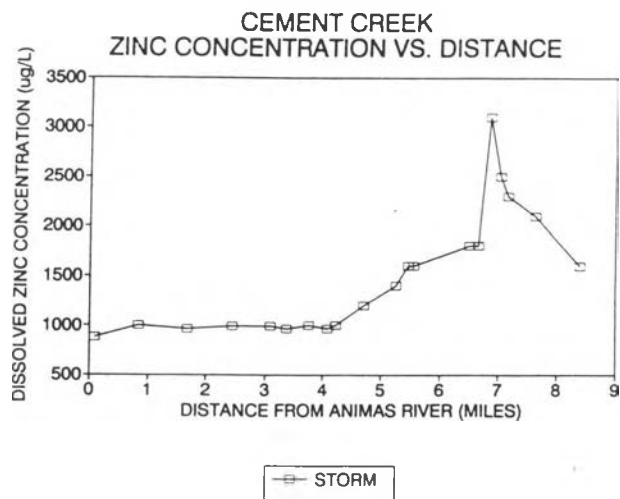
Figure D6.   Dissolved zinc concentrations versus distance in Cement Creek

CEMENT CREEK
ZINC LOADING VS. DISTANCE

STORM

CEMENT CREEK
ZINC LOADING VS. DISTANCE

SNOWMELT

CEMENT CREEK
ZINC LOADING VS. DISTANCE
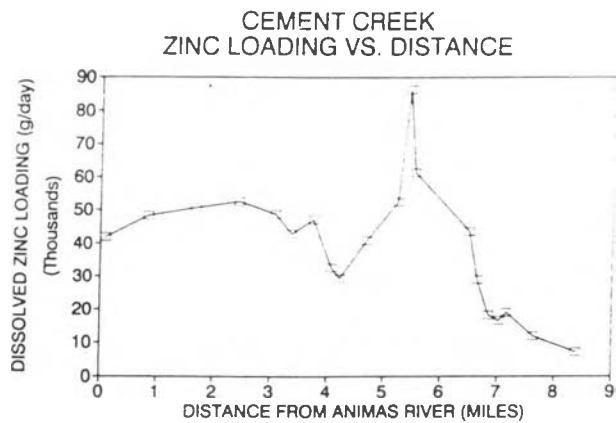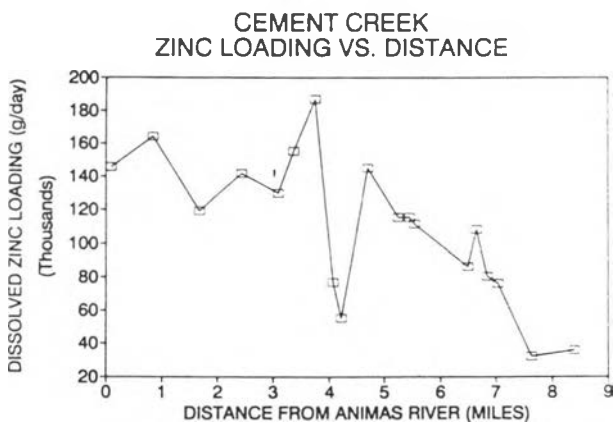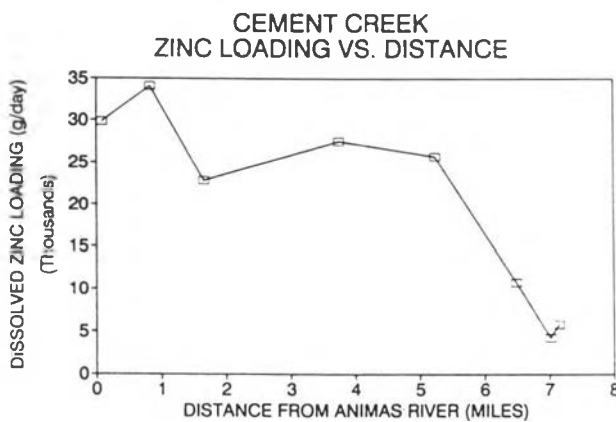
BASEFLOW

Figure D7.   Dissolved zinc loadings versus distance in Cement Creek

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(between CC01 and CC18), including the small subbasin CC18-CC05, and the North Fork of Cement Creek are contributing significant loadings to the main stem. Concentrations decrease again between mile 7 and 6. This indicates either dilution in the main stem from inflowing less contaminated water downstream, loss to groundwater along the main stem, or adsorption/precipitation with increasing pH downstream resulting in decreasing dissolved concentrations. Concentrations continue to decrease gradually or level off all the way to the mouth.

Figures D7a through D7c show dissolved zinc loadings versus distance along the main stem of Cement Creek for the storm, snowmelt, and baseflow sampling events, respectively. Figure D7a shows that during the storm event, loadings generally increase from mile 8.5 to between miles 6 and 5, and that the largest increase occurs between miles 7 and 5 and 1/2. Loadings, however, decrease significantly between miles 5 and 1/2 and 4 and 1/2. This indicates that there is a loss of dissolved zinc mass in this section of the main stem, possibly due to infiltration of water to groundwater or adsorption/precipitation of dissolved zinc onto solids downstream with increasing pH. However, loadings increase again between miles 4 and 3 and 1/2 and then tend to generally level off all the way to the mouth. As Figure D7b shows for snowmelt, loadings tend to increase from mile 7.5 to mile 5, and then decrease sharply to mile 4. Loadings increase again sharply to mile 3 and 1/2, and then decrease to mile 3 and fluctuate to the mouth. Figure D7c shows that for baseflow, loadings increase significantly from mile 7 to mile 5 and then level off somewhat to mile 4. Loadings then decrease slightly from mile 4 to mile 1 and 1/2. Loadings increase again to mile 1, then another loss of the dissolved load to the mouth.

These variations over space indicate that the locations of the greatest loadings to Cement Creek are from upper Cement Creek (CC28 or CC31 and upstream), including the north and south forks of Cement Creek and Prospect Gulch, and the subbasins between CC39 and CC34. The large subbasin CC48-CC47 also contributes a large loading. A significant loss occurs between CC28 and CC34 during the storm, and between CC31 and CC34 during snowmelt. Some of the loadings, however, are estimated as the differences between loadings measured at two or more adjacent stations, have relatively large potential errors associated with them, and should be used with caution.

Figures D8a through D8c are bar graphs showing zinc loadings in tributaries to the main stem of Cement Creek for the different flow regimes. During a storm, loadings from the South Fork of Cement Creek and Upper Cement Creek are the highest (21,581 and 18,853 g/day, respectively), while loadings from Cascade and Topeka are the lowest. During snowmelt, loadings are highest from the South Fork of Cement Creek and Prospect Gulch (15,041 and 11,855 g/day, respectively), and lowest from Cascade and Niagara. Although fewer data points were available for baseflows, loadings are again greatest from Upper Cement Creek and the South Fork of Cement Creek (5,767 and 3,939 g/day, respectively) and lowest from Porcupine Gulch.

Many of these subbasins contributing loadings to the reach of Cement Creek where increases in concentrations, in conjunction with increases in loadings, are observed should probably be targeted for remediation. However, as indicated by the decrease in concentrations downstream due to losses, isolating factors related to distances should also be considered, as discussed in the next section.
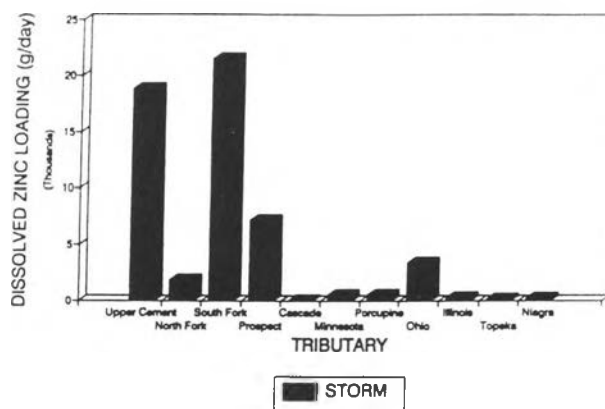
303
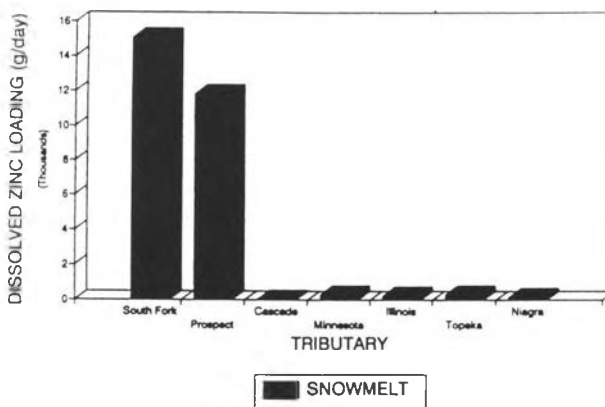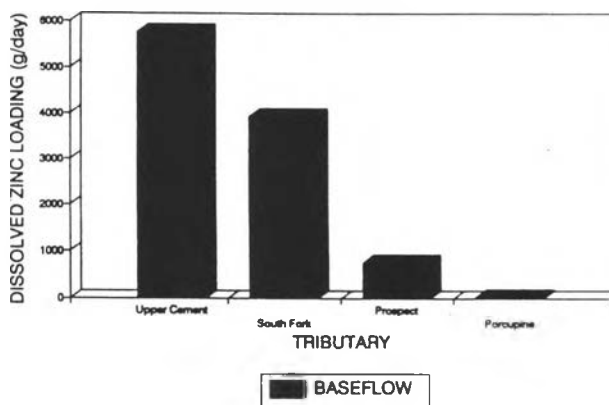
Figure D8.   Dissolved zinc loadings in tributaries to Cement Creek

D.5   Information Goal #5. Distances Between Sources and Watercourses and
       Impaired Stream Segments

For Cement Creek, the distances (miles) from all monitoring stations and first
order subbasins (source areas) to the mouth (confluence of Animas River) were
measured from site topographic maps. These distances are presented in column C
in Table C1 along with the dissolved zinc loadings and unit area loadings from each
subbasin. Each first order subbasin is directly adjacent to a watercourse; Cement
Creek or a tributary to Cement Creek. However, the Upper Animas River is the
primary stream segment of concern in this case. Therefore, the distances from the
source areas to the Upper Animas River were used in this analysis.

As can be seen from the table, the largest loading is from subbasin CC48-CC47,
the outlet of which is less than a mile from the Animas River. The next highest
loading is from subbasin CC01 at the headwaters of Cement Creek (8.39 miles from
the Animas). With the exception of baseflow loading again from CC48-CC47, the
remainder of the top ten loaders are between 3.75 and 6.77 miles from the mouth
of Cement Creek. It is not currently known whether or not there are isolating factors
in that stream reach that prevent a significant fraction of the loading from the farther
source areas from reaching the Animas River. For example, it is not clear whether
much of the loading from subbasin CC01 is actually transported to the mouth. The
loss of loading downstream is greater than the loading from CC01, so that CC01
loadings might not reach the mouth at all. However, some of the loss could be
attributed to precipitation/adsorption. Therefore, the zinc loading from CC01 could
still be transported downstream (only in a different form). Remediation of source
areas in subbasin CC01, therefore, might still be effective. Subbasin CC48-CC47 and

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other subbasins contributing loads between miles 3.75 and 6.77 can also be targeted for remediation. Tradeoffs between distance and loading magnitudes might need to be evaluated using some judgement and additional field reconnaissance to target areas in that stream reach.

With regard to unit area loadings, the largest is from subbasin CC20-CC19-CC18 (location of American Tunnel) located 6.65 miles upstream. The rest of the top ten unit area loadings are from subbasins between 3.09 and 6.84 miles from the Animas River. Again, additional evaluation of source areas, loading magnitudes, and effects of distance within this reach might be required to target specific areas for remediation. However, the American Tunnel and these other subbasins contributing large loadings to this reach should be targeted for remediation.

The loadings and unit area loadings are also presented in Figure B3 in Appendix B, where the distances from the source areas exhibiting the largest loadings to the Animas River can be visually observed. The source areas can be targeted for remediation, considering distances, with the aid of this map.

D.6   Information Goal #6. Differences Between Magnitudes of Concentrations in and Loadings to Stream Segments

D.6.1   Concentrations

In order to obtain the required information and use the methods discussed in Section 6.6, Cement Creek was divided into two stream segments: an upstream segment extending from the headwaters to Station CC30, and a downstream segment extending from CC30 to the mouth. It is believed that the upstream segment is more heavily impacted from mining waste and exhibits higher concentrations than the downstream segment. Information obtained for the two segments of Cement Creek

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included the magnitude of differences and relative differences between seasonal mean concentrations and between annual mean concentrations. In addition, the annual differences were also calculated as the difference between the time-weighted mean concentrations in each segment.

The results of these analyses are presented in Table D5. Figure D9 is a bar graph of the mean concentrations in the two segments on a seasonal and annual basis. The seasonal mean concentrations in the upper segment are consistently higher than those in the downstream segment, with the differences ranging from 365 μg/L during baseflow to 583 μg/L during snowmelt. The relative mean differences range from 42% during baseflow to 72% during the storm. On an annual basis, the difference is 435 μg/L, or 56% of the smaller value for the downstream segment. Because the CI_ms for each of the estimated values are relatively large, they do overlap. This will probably be the case for most IAMs, given the potentially small sample size and large CIs computed. This limits the usefulness of incorporating the overlap of the CIs into the evaluation of the significance of differences in concentrations. However, the CI_m width about each value should be used in the final evaluation of differences and the targeting process because it represents the uncertainty associated with each value. The larger the CI_m, the greater the uncertainty associated with the estimated value and the greater the uncertainty associated with the estimated difference between values.

Figure D10 shows multiple box-and-whisker plots for concentrations in the two reaches of Cement Creek on a seasonal and annual basis. These plots show that the concentrations are different in the two segments on an annual basis and during

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Table D5. Cement Creek differences in dissolved zinc concentrations				
in upstream and downstream segments (ug/L)				
		SEASON		ANNUAL
	STORM	SNOWMELT	BASEFLOW	
STATISTIC	(9/7/91)	(6/24/92)	(10/14/92)	
UPSTREAM MEAN	1390	947	1478	1223
DOWNSTREAM MEAN	807	583	1043	784
DIFFERENCE IN MEAN	583	365	435	439
REL. DIFF. IN MEAN	0.72	0.63	0.42	0.56
UPSTREAM TWMEAN	N/A	N/A	N/A	1350
DOWNSTREAM TWMEAN	N/A	N/A	N/A	911
DIFFERENCE IN TWMEAN	N/A	N/A	N/A	439
REL. DIFF. IN TWMEAN	N/A	N/A	N/A	0.48

Table D5

Abbreviations:

TWMEAN = time weighted mean

Table D6. Cement Creek differences in dissolved zinc loadings				
from NPSs and point sources				
		SEASON		ANNUAL
	STORM	SNOWMELT	BASEFLOW	
STATISTIC	(9/7/91)	(6/24/92)	(10/14/92)	
NPS MEAN (g/day)	134455	211905	17806	121389
POINT SOURCE MEAN (g/day)	1666	6258	3640	3855
DIFFERENCE IN MEAN	132789	205647	14166	117534
REL. DIFF. IN MEAN	80	33	3.9	30
NPS TOTAL (kg)	6319	16846	4247	27413
POINT SOURCE TOTAL (kg)	78	497	868	1444
DIFF IN TOTAL	6241	16349	3379	25969
REL. DIFF. IN TOTAL	80	33	3.9	18

CEMENT CREEK
MEAN ZINC CONCENTRATION BY SEGMENT
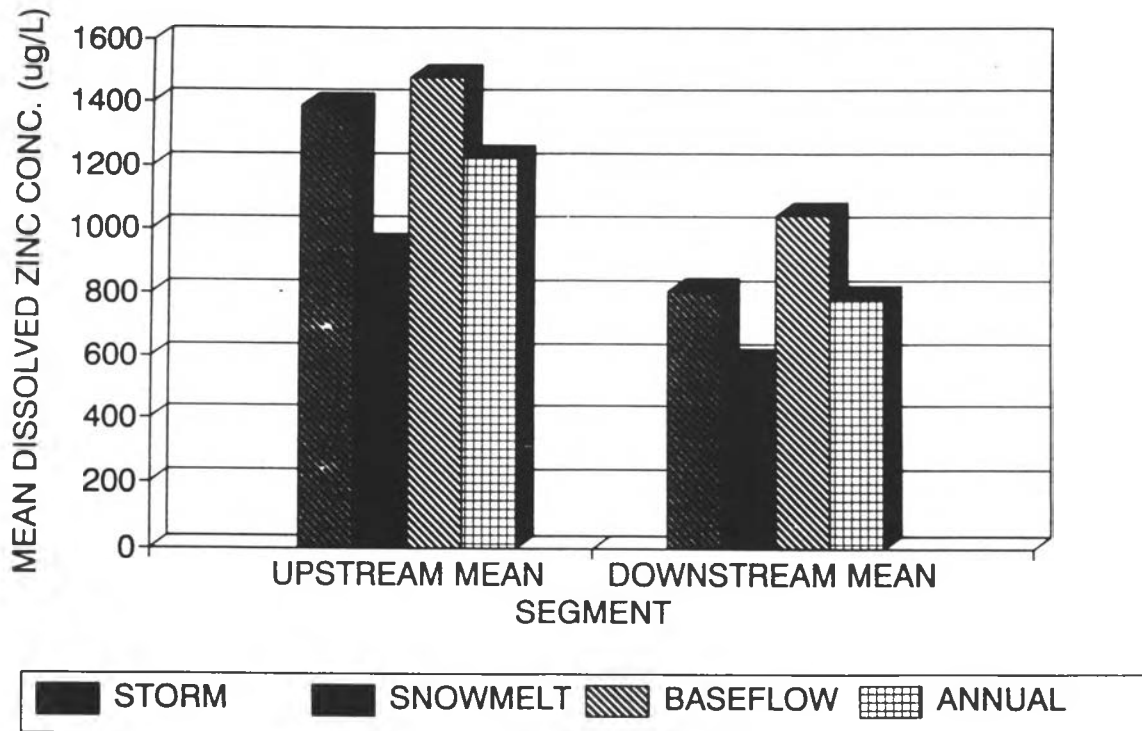
Figure D9.   Bar graph of mean dissolved zinc concentrations in upstream
                  and downstream Cement Creek segments
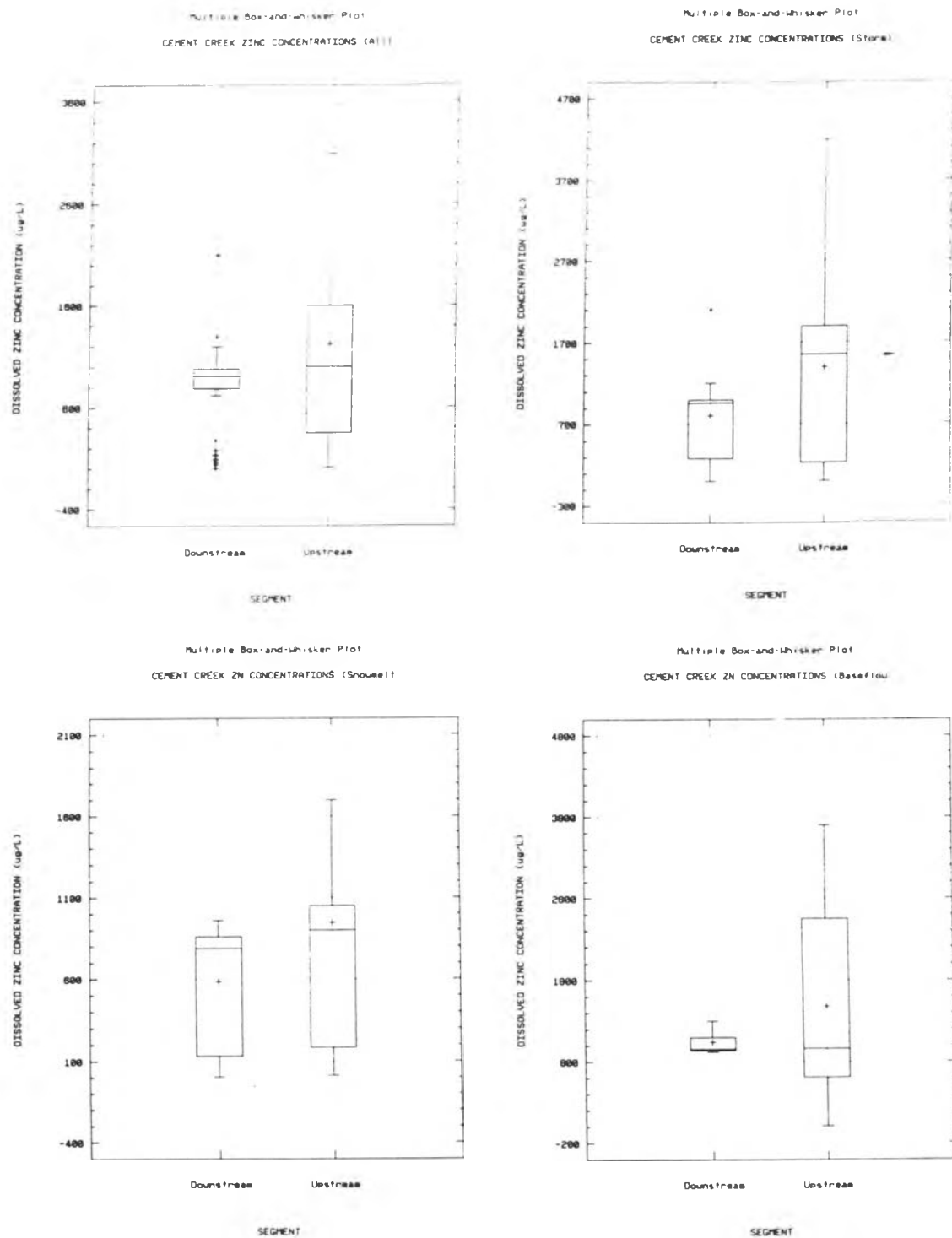
Figure D10.   Multiple box-and-whisker plots of dissolved zinc concentrations
in upstream and downstream Cement Creek segments

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storms, but might not be different during snowmelt and baseflow.

D.6.2   Loadings

In order to obtain the required information (Chapter 4) and use the methods discussed in Section 6.6, differences between loadings to the entire Cement Creek segment from NPSs and point source areas were evaluated. It is believed that NPSs contribute greater loadings to the stream than point sources. To evaluate these differences, NPSs, point sources, and background sources were first delineated. Each monitoring station (and each corresponding subbasin contributing to each monitoring station for NPSs and background sources) was assigned to an NPS, point source, or background source category depending on what type of discharge the station was monitoring. Although not all point sources were sampled, the monitored point sources were the most significant point sources in the basin and were easy to categorize based only on the field sampling activities. Determinations of NPS and background subbasins were somewhat more subjective and were made using USGS topographic maps and aerial color infrared photographs in conjunction with field reconnaissance, discussion with USGS staff conducting a background study in the basin, and limited engineering judgement. Therefore, subbasins were categorized as NPSs if they contained a large number of manmade sources or the fraction of the disturbed areas relative to the total area of the subbasin was large. The determination of "large" values was not made quantitatively: instead engineering judgement was used for the most part. These NPS subbasins also contained some background sources within them, and could have contained a small number of unknown or unmonitored point sources. Alternatively, subbasins were categorized as background if they contained a very small number of manmade sources or the

fraction of the disturbed areas relative to the total area of the subbasin was very small. Again, the determination of "very small" values was not made quantitatively. These background subbasins contained either no manmade sources or a small quantity of NPSs or point sources within them.

The results of these analyses are presented in Table D6. Figures D11 and D12 are bar graphs showing the differences in mean daily and total loadings, respectively, from the two types of sources on a seasonal and annual basis. The measured or estimated loadings from NPSs are consistently much higher than those from point sources on a seasonal and annual basis. The difference between mean daily loadings for the year is 117,534 g/day, and the seasonal differences range from 14,166 g/day during baseflow to 205,647 g/day during snowmelt. The relative differences are all very high, emphasizing the significant differences. The annual difference between total loadings is 25,969 kg, and the seasonal differences range from 3,379 kg for baseflow to 16,349 kg for snowmelt. All of the relative differences are very high.

The CI_m width about each value should be used in the final evaluation of differences and the targeting process because it represents the uncertainty associated with each value. The larger the CI_m, the greater the uncertainty associated with the estimated value and the greater the uncertainty associated with the estimated difference between values.

D.6.3   Unit Area Loadings

Differences in unit area loadings to the entire Cement Creek segment from NPSs and background source areas were evaluated. In order to evaluate these differences, NPSs and background sources were first delineated using the methods discussed in the previous section.

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CEMENT CREEK
MEAN DAILY ZINC LOADING BY SOURCE
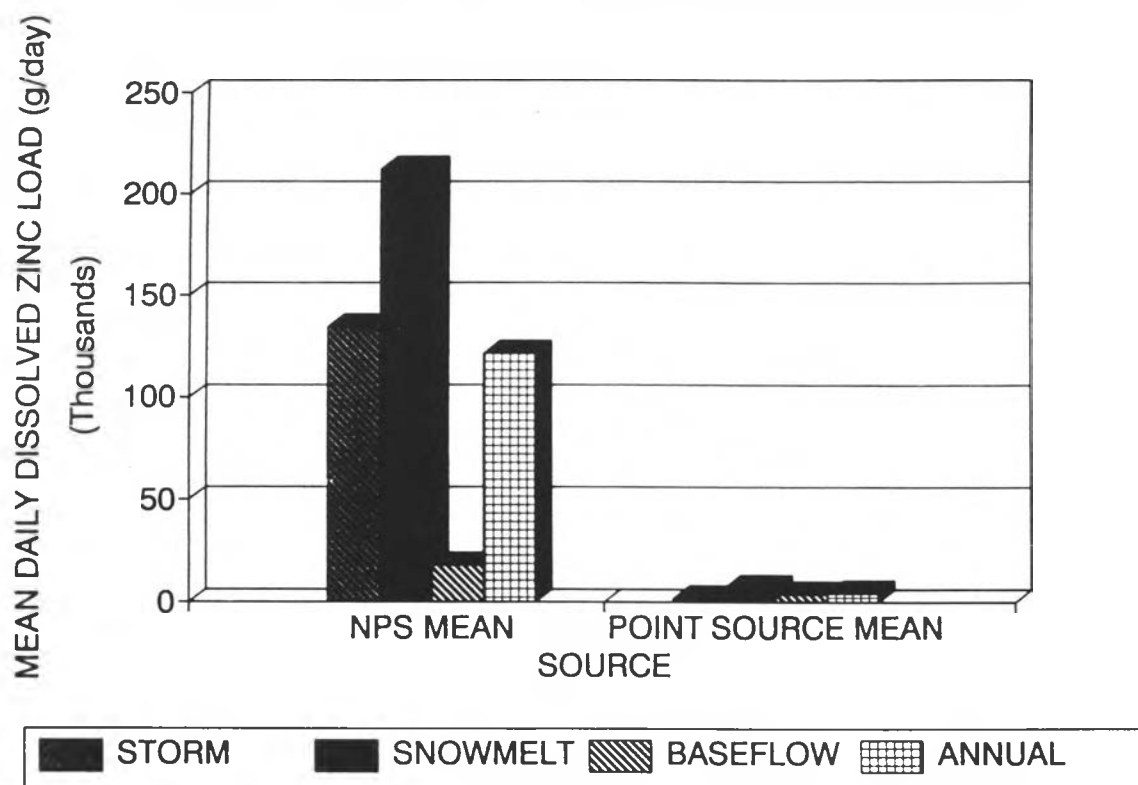
Figure D11.   Bar graphs of mean daily dissolved zinc loadings to Cement Creek from NPSs and point sources

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CEMENT CREEK
TOTAL ZINC LOADING BY SOURCE
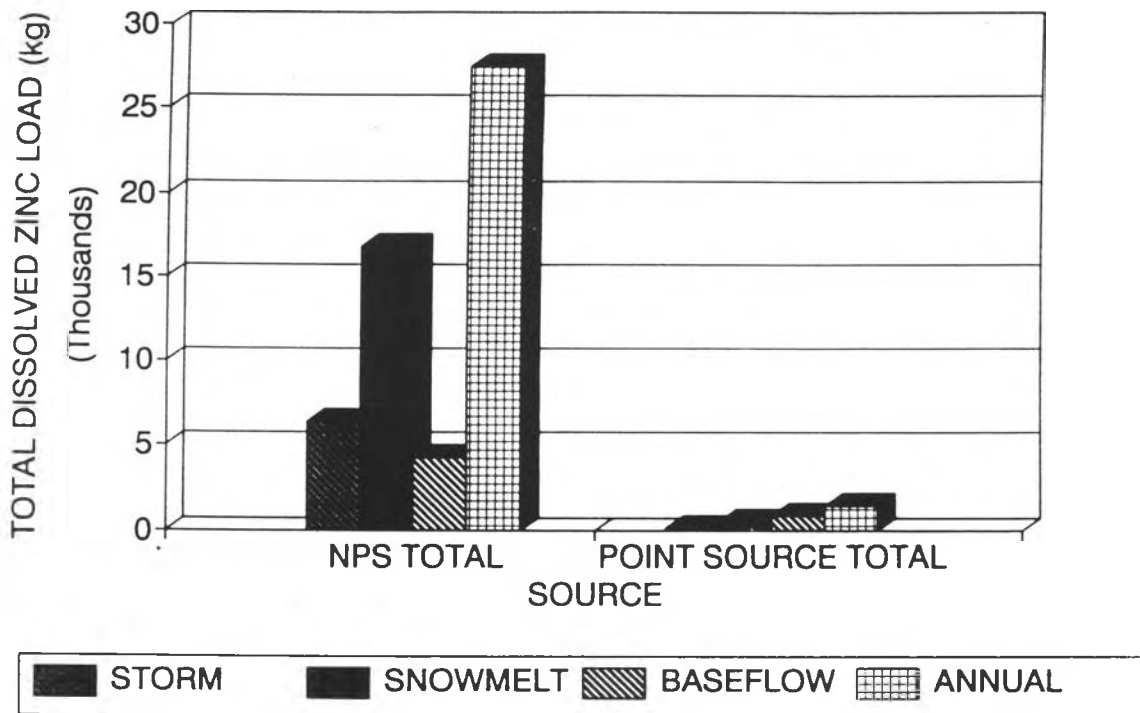
Figure D12.   Bar graphs of dissolved zinc loadings to Cement Creek from NPSs and point sources

The results of these analyses are presented in Table D7. Figures D13 and D14 are bar graphs of the mean daily unit area loadings and total unit area loadings, respectively, to Cement Creek from the two sources on a seasonal and annual basis. As can be seen from the table, the mean daily and total unit area loadings from NPSs are consistently much higher than those from background sources on a seasonal basis. The differences in mean daily unit area loadings range from 2.01 g/ac-day during baseflow to 100 g/ac-day during snowmelt. The difference in annual mean daily unit area loadings is 50 g/ac-day. Using the time-weighted means, the difference is 31 g/ac-day. The relative differences are all extremely high, reflecting the significance of the differences. The differences in total unit area loadings range from 480 g/ac during baseflow to 7,950 g/ac during snowmelt. The annual difference is 21,671 g/ac, and the time-weighted annual difference is 11,084 g/ac. Again, the relative differences are all extremely high. Because the CI_ms for each of the estimated values are very large, they do overlap. This limits the usefulness of this procedure. However, the CI_m width about each value should be used in the final evaluation of differences and the targeting process because it represents the uncertainty associated with each value. The larger the CI_m, the greater the uncertainty associated with the estimated value and the greater the uncertainty associated with the estimated difference between values.

Figure D15 presents a multiple box-and-whisker plot of unit area loadings from the two sources on a seasonal and annual basis. It is obvious from these plots that the unit area loadings from NPSs are consistently greater than those from background sources.

STATISTIC	STORM (9/7/91)	SEASON SNOWMELT (6/24/92)	BASEFLOW (10/14/92)	ANNUAL
Table D7. Cement Creek differences in dissolved zinc unit area loadings				
from NPSs and background sources				
NPS MEAN	57	101	2.03	60
BACKGROUND MEAN	0.48	0.4	0.02	0.37
DIFFERENCE IN MEAN	56	100	2.01	59
REL. DIFF. IN MEAN	117	250	1000	159
NPS TWMEAN (g/ac-day)	N/A	N/A	N/A	31
BACKGROUND TWMEAN (g/ac-day)	N/A	N/A	N/A	0.16
DIFFERENCE IN TWMEAN	N/A	N/A	N/A	31
REL. DIFF. IN TWMEAN	N/A	N/A	N/A	194
NPS TOTAL	2668	7990	485	21806
BACKGROUND TOTAL	23	31	5	135
DIFFERENCE IN TOTAL	2645	7959	480	21671
REL. DIF. IN TOTAL	115	257	96	160
NPS TWTOTAL (g/ac)	N/A	N/A	N/A	11143
BACKGROUND TWTOTAL (g/day)	N/A	N/A	N/A	59
DIFF. IN TWTOTAL	N/A	N/A	N/A	11084
REL. DIF. IN TWTOTAL	N/A	N/A	N/A	189

Table D7

Abbreviations:

TWMEAN = time weighted mean
TWTOTAL = time weighted total

CEMENT CREEK
MEAN DAILY ZN UNIT AREA LOAD BY SOURCE

STORM   SNOWMELT   BASEFLOW   ANNUAL
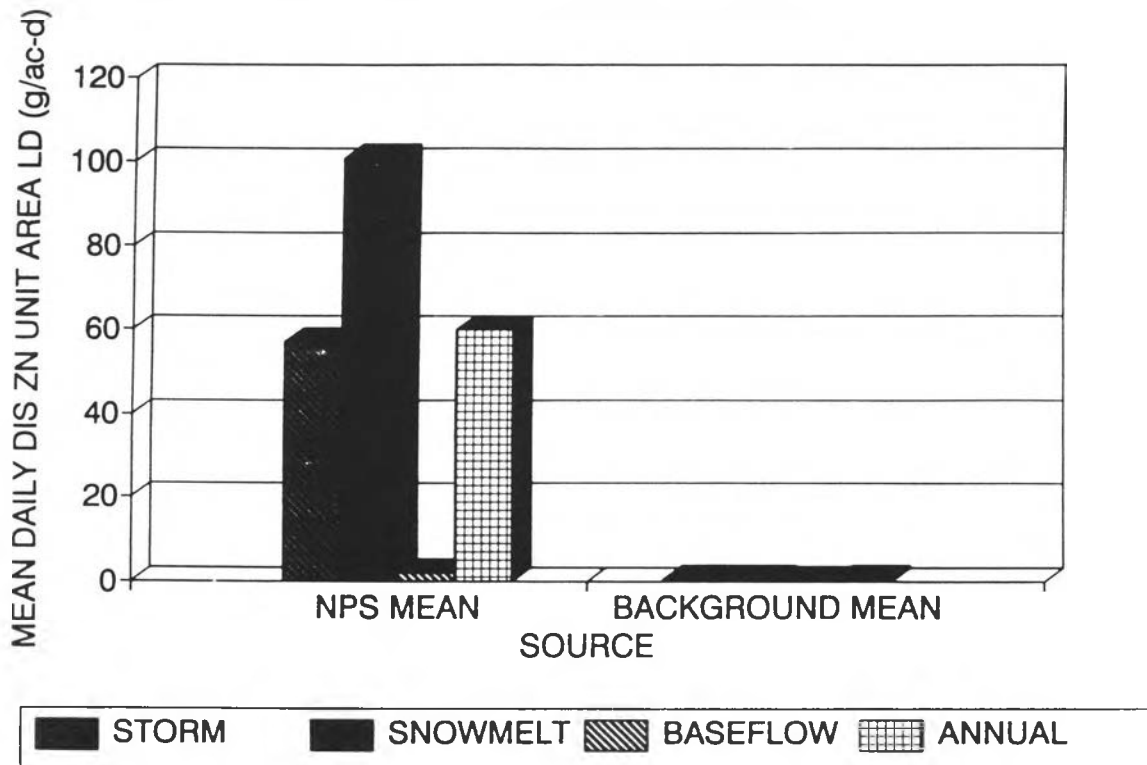
Figure D13.   Bar graphs of dissolved zinc mean daily unit area loadings to Cement Creek from NPSs and background sources

CEMENT CREEK
TOTAL ZN UNIT AREA LOAD BY SOURCE
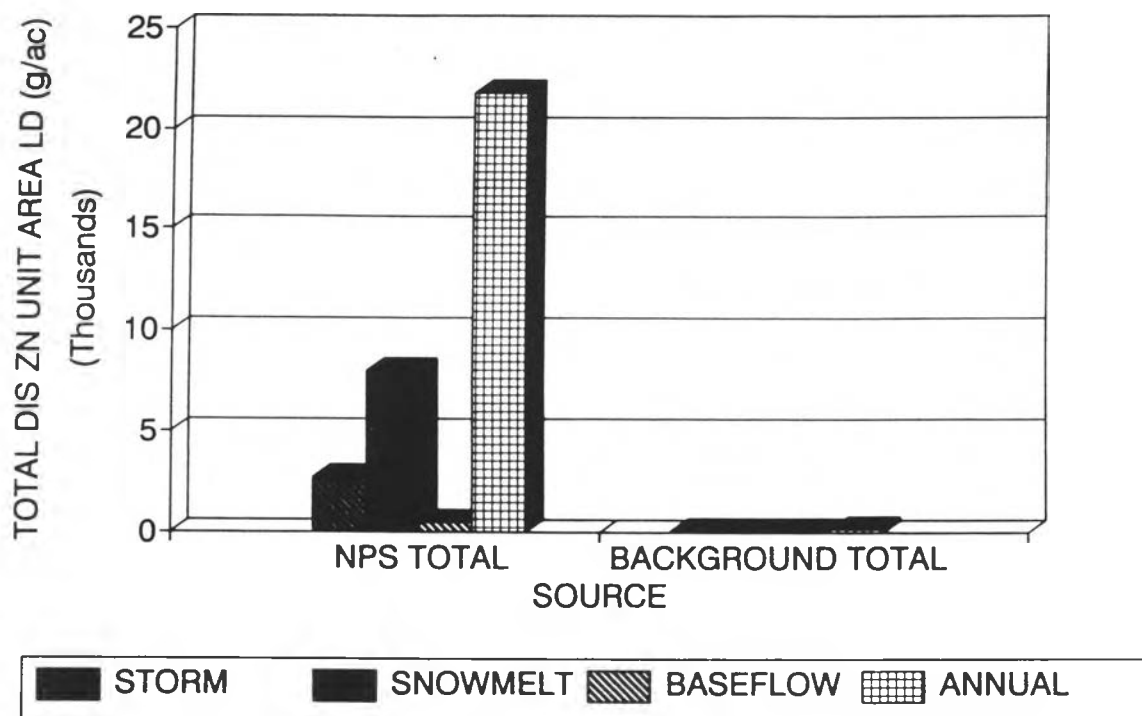
Figure D14.   Bar graphs of dissolved zinc unit area loadings to Cement Creek from NPSs and background sources
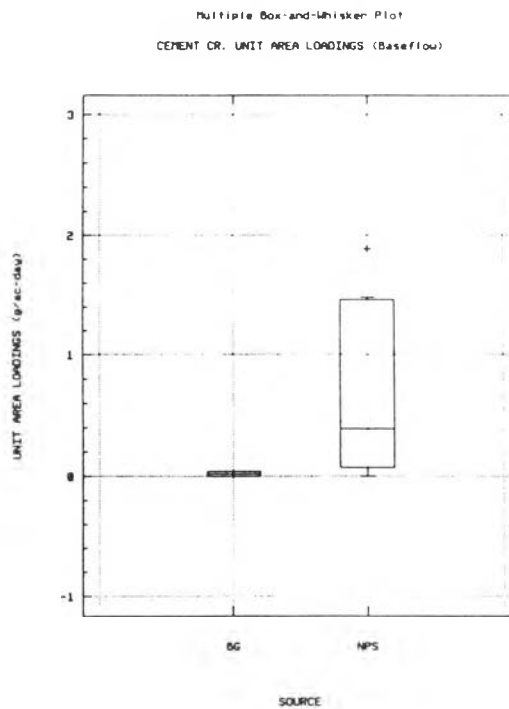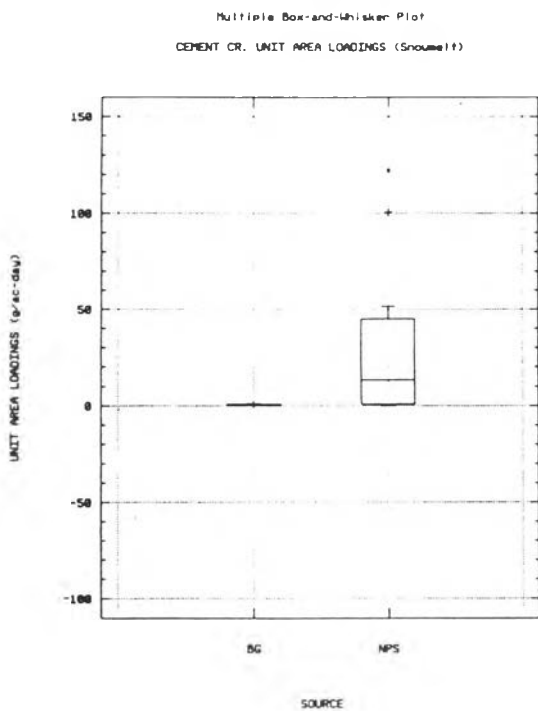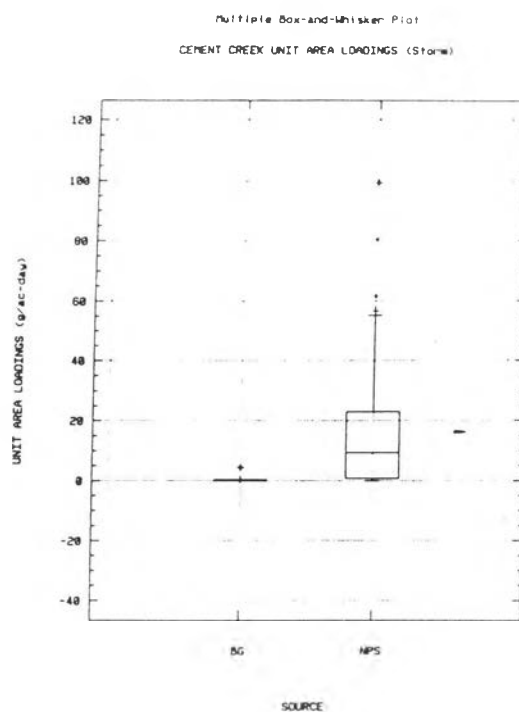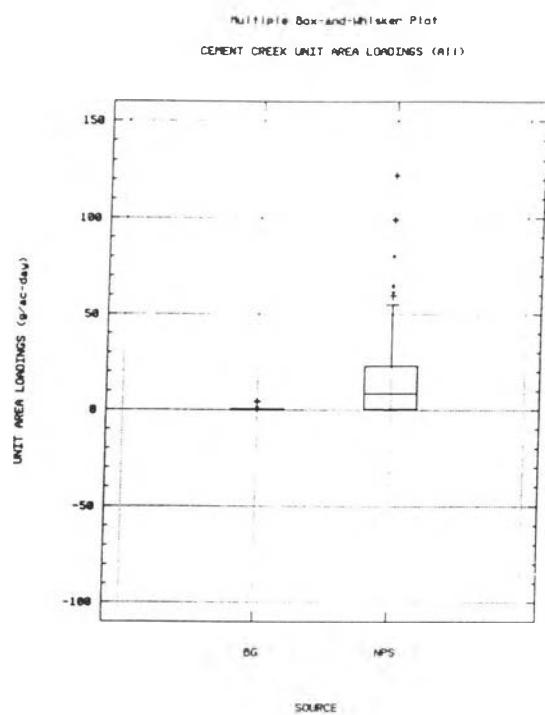
Figure D15.   Multiple box-and-whisker plots of dissolved zinc mean daily unit area loadings to Cement Creek from NPSs and background sources

One of the inherent problems with using the methodology discussed above is in the definition of NPSs and background sources. An area or subbasin that is categorized as an NPS area because it contains a large or multiple NPSs also contains background sources. The NPS loadings are, therefore, overestimated and the background source loadings are underestimated. One way to attempt to account for this situation and estimate loadings from and differences between the two sources more accurately is to extrapolate the estimated unit area loadings from the sampled background sources to the entire watershed. This method implicitly assumes that the mean unit area loading from the measured background areas is representative of the background loading from the rest of the watershed. The time-weighted mean annual unit area loading for background sources was estimated as 58.86 g/ac, or approximately 60 g/ac. If this value is extrapolated over the 13,056 acres of the Cement Creek subbasin, the total loading is equal to 783 kg/yr from all background sources. The 60 g/ac is also subtracted from the time-weighted mean annual unit area loading from NPSs (8,520 g/ac) to derive a "corrected " time-weighted mean annual unit area loading from NPSs equal to 8,460 g/ac. This value is multiplied by the area of the Cement Creek subbasin to derive a value of 110,453 kg/yr from NPSs. This is higher than the total loading from NPSs that was estimated without making the correction for background loadings from NPS subbasins. Therefore, the potential loadings from background sources is estimated at less than 1% of those from NPSs. Even if the estimate of loadings from background sources is actually an order of magnitude higher than 783 kg/yr, the loadings from background sources would still be less than 10% of those from NPSs in the basin.

D.7   Information Goal #7.   Frequency or Risk of Exceeding a Target
        Concentration in and Loading to a Stream Segment

D.7.1   Concentrations

Risk of Exceedance

The nonparametric approach was used to estimate the *cdf*s for dissolved zinc
concentrations in Cement Creek for each season and a year. Figure D16a presents
a cumulative distribution plot of all observed dissolved zinc concentrations in the
Cement Creek segment based on ranking all of the observed data for the year (all
events). Figures D16b through D16d present the concentration cumulative
distribution plots based on ranking the observed data for each season.

All four figures show many values in the range of 1,000 μg/L. The cumulative
distributions for data from all events and from the snowmelt event both show that
the one high value of approximately 6,800 μg/L is considerably higher than the other
values and has a very small probability of being exceeded. The cumulative
distribution for the storm event shows a couple of high values between 3,000 and
4,500 μg/L that have a relatively small risk of being exceeded. The cumulative
distribution for baseflow shows two values in the range of 3,700 μg/L that have less
than a 10% risk of being exceeded.

Numerical standards for dissolved zinc concentrations can be computed for a year
or a season based on the estimated cumulative frequency distributions using two
methods (CDPHE, 1991a):

1.   the ambient concentrations as the values of the 85th percentiles of the metal
      frequency distributions for each season and a year

2.   using the following formulas for fish (Brown Trout):

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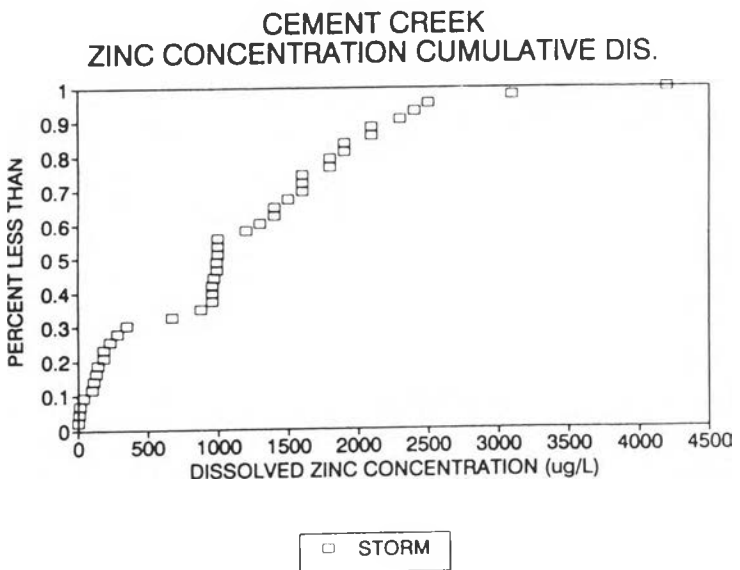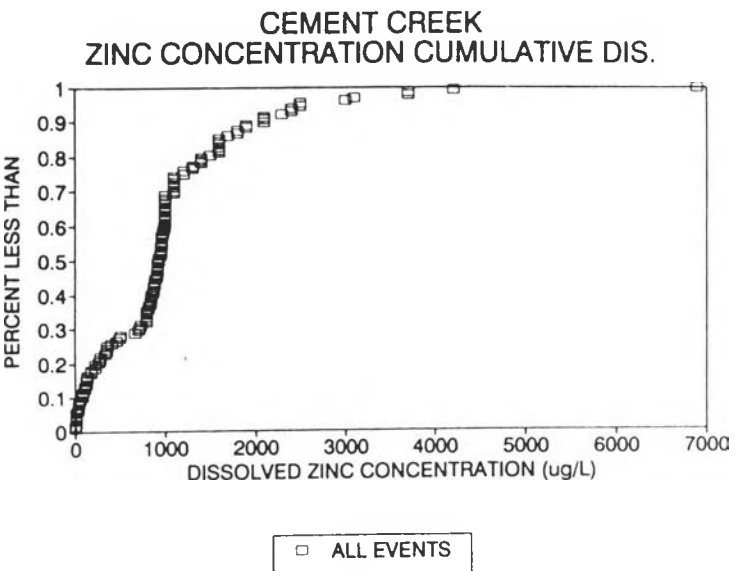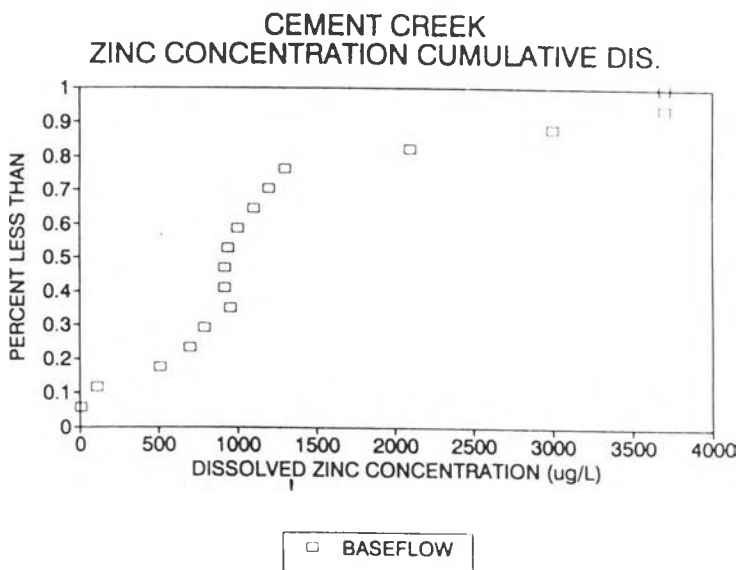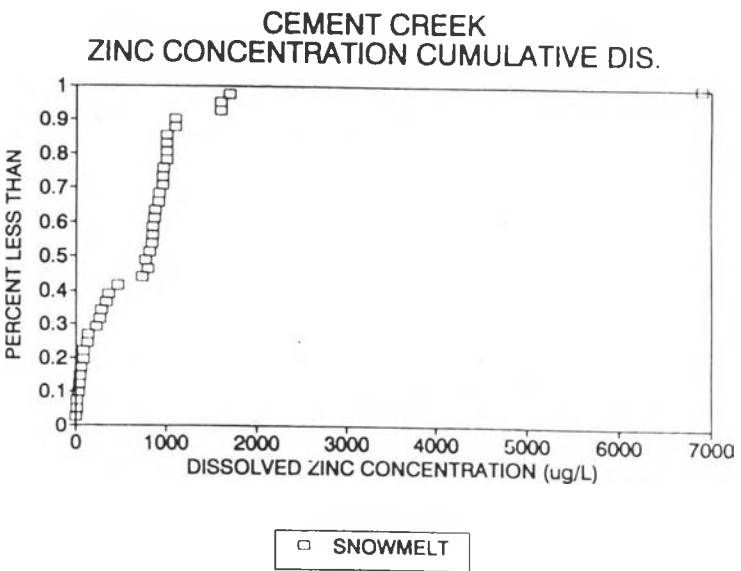
Figure D16.   Cumulative distribution plots of Cement Creek dissolved zinc mean concentrations

$$\text{Acute} = e^{(0.8473[\ln(\text{hardness})] + 0.8604)}$$

$$\text{Chronic} = e^{(0.8473[\ln(\text{hardness})] + 0.7614)}$$

and the hardness measured for each sample or the concentration of the 90th percentile of the observed hardness frequency distributions for each season and a year

Numerical ambient standards for total zinc concentrations can also be computed using the concentration of the 50th percentile of the metal frequency distributions for each season and a year. According to the first method for dissolved zinc and the method for total zinc based on the estimated frequency distributions for each season and a year, there will be a 15% and 50% risk, respectively, that the estimated standards will be exceeded anywhere in the stream segment when a random sample is collected at any given time during those periods. The risks that the concentrations (standards) computed using the hardness data will be exceeded can also be estimated using the derived cumulative frequency distributions.

The ambient standard (concentration) for dissolved zinc in Cement Creek for a year is estimated as 1,600 μg/L using the first method discussed above. By definition, this is the natural concentration in the stream segment that has a risk of approximately 15% of being exceeded anywhere in the creek when a random sample is collected anytime during the year that the data were collected. Using equations 6.2 and 6.3, the 90% CI width for this quantile is 200 μg/L (13% of x_{85}). Using the method discussed in Gilbert (1987) for estimating the CI of a proportion, the CI width for the estimated proportion of 15% is 12% (the lower confidence limit is 9% and the upper confidence limit is 21%). Generally, the most important information regarding uncertainty for the ambient standards is the CI on the percentile (not the CI on the proportion) because we are usually interested in the uncertainty of the

estimated ambient concentration or standard itself. The uncertainty of the values should then be used in the final targeting process.

Using the second method to compute the chronic and acute standards for each sample, the average chronic and acute standards for fish (Brown Trout) anywhere in Cement Creek for a year are 3,542 and 7,272 μg/L, respectively. Based on the observed data, these chronic and acute values have risks (proportions) of approximately 3% and 1%, respectively, of being exceeded anywhere in the creek when a random sample is collected at any time during the year the creek was monitored. Generally, the most important information regarding uncertainty for the fish standards is the *CI* on the proportion (not the *CI* on the percentile) because we are usually interested in the uncertainty of the risk of exceeding the estimated aquatic life standard. The uncertainty of the values should then be used in the final targeting process.

Ranking

Column G in Table D8 shows the ranking of the highest concentration data from a subset of stations in the Cement Creek segment for each season and a year as well as the location of each datum. As can be seen from the table, station CC06 at the mouth of the North Fork of Cement Creek exhibited the highest concentration (6,900 μg/L) during the year which was observed during snowmelt. This is somewhat counterintuitive, since it is generally believed that snowmelt tends to increase loadings but dilute concentrations in the stream segments. The second highest concentration during the year, and the highest during the storm event (4,200 μg/L), was also observed at this station (also counterintuitive). The other highest concentrations were observed in Cement Creek above and below the confluence of

	A	B	C	D	E	G	H	I	J	K
165	Table D8. Ranking of Cement Creek dissolved zinc concentrations									
166										
167						(ug/L)				
168	SUB_SEG	SOURCE	SITE	DATE	SEASON	ZNDCNP	RANK	PERCENT	ZNDCNPI	RANKI
169	NF Cement	NPS	CC06	06/24/92	Snowmelt	6900	128	0.99		
170	NF Cement		CC06	09/07/91	Storm	4200	127	0.98	4200	43
171	Cement		CC05	10/14/92	Baseflow	3700	126	0.98		
172	Cement	NPS	CC03	10/14/92	Baseflow	3700	125	0.97		
173	Cement		CC18	09/07/91	Storm	3100	124	0.96	3100	42
174	Prospect		CC25	10/14/92	Baseflow	3000	123	0.95		
175	Cement		CC18	07/21/93		2500	122	0.95		
176	Cement		CC05	09/07/91	Storm	2500	121	0.94	2500	41
177	Cement		CC05	07/21/93		2400	120	0.93		
178	Prospect	NPS	CC23	09/07/91	Storm	2400	119	0.92	2400	40
179	Cement		CC03	09/07/91	Storm	2300	118	0.91	2300	39
180	Prospect		CC24	10/14/92	Baseflow	2100	117	0.91		
181	Porcupine Gl	NPS	CC38	09/06/91	Storm	2100	116	0.90	2100	38
182	Cement		CC02	09/07/91	Storm	2100	115	0.89	2100	37
183	Prospect		CC24	09/07/91	Storm	1900	114	0.88	1900	36
184	Prospect		CC25	09/07/91	Storm	1900	113	0.88	1900	35
185	Cement		CC20	09/07/91	Storm	1800	112	0.87	1800	34
186	Cement		CC21	09/07/91	Storm	1800	111	0.86	1800	33
187	Cement		CC05	06/24/92	Snowmelt	1700	110	0.85		
188	Cement		CC20	07/21/93		1600	109	0.84		
189	Cement		CC27	09/07/91	Storm	1600	108	0.84	1600	32
190	Cement		CC20	06/24/92	Snowmelt	1600	107	0.83		
191	Cement	NPS	CC01	09/07/91	Storm	1600	106	0.82	1600	31
192	Cement		CC18	06/24/92	Snowmelt	1600	105	0.81		
193	Cement		CC28	09/07/91	Storm	1600	104	0.81	1600	30
194	Prospect		CC26	09/07/91	Storm	1500	103	0.80	1500	29
195	SF Cement		CC17	09/07/91	Storm	1400	102	0.79	1400	28
196	NF Cement		CC07	09/07/91	Storm	1400	101	0.78	1400	27
197	Cement		CC30	09/06/91	Storm	1400	100	0.78		
198	Cement		CC30	09/07/91	Storm	1300	99	0.77	1300	26
199	Porcupine Gl	NPS	CC38	10/14/92	Baseflow	1300	98	0.76		
200	Cement		CC31	09/06/91	Storm	1200	97	0.75	1200	25
201	Prospect		CC26	10/14/92	Baseflow	1200	96	0.74		
202	Cement		CC03	07/21/93		1100	95	0.74		
203	Cement		CC03	06/24/92	Snowmelt	1100	94	0.73		
204	Cement		CC28	07/21/93		1100	93	0.72		
205	Cement		CC39	07/21/93		1100	92	0.71		
206	Cement		CC39	10/14/92	Baseflow	1100	91	0.71		
207	Cement		CC02	06/24/92	Snowmelt	1100	90	0.70		
208	Cement		CC30	07/21/93		1100	89	0.69		
209	Cement		CC28	06/24/92	Snowmelt	1000	88	0.68		
210	Cement		CC30	06/24/92	Snowmelt	1000	87	0.67		
211	Cement Gaging Stn		CC48	09/06/91	Storm	1000	86	0.67		
212	Cement		CC34	09/06/91	Storm	1000	85	0.66	1000	24
213	Cement		CC39	09/06/91	Storm	1000	84	0.65	1000	23
214	Cement		CC21	06/24/92	Snowmelt	1000	83	0.64		
215	Cement Gaging Stn		CC48	10/15/92	Baseflow	1000	82	0.64		

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	L	M	N	O	P	Q	R
165							
166							
167							
168	PERCENT1	ZNDCNP2	RANK2	PERCENT2	ZNDCNP3	RANK3	PERCENT3
169		6900	41	0.98			
170	0.98						
171					3700	17	0.94
172					3700	16	0.89
173	0.95						
174					3000	15	0.83
175							
176	0.93						
177							
178	0.91						
179	0.89						
180					2100	14	0.78
181	0.86						
182	0.84						
183	0.82						
184	0.80						
185	0.77						
186	0.75						
187		1700	40	0.95			
188							
189	0.73						
190		1600	39	0.93			
191	0.70						
192		1600	38	0.90			
193	0.68						
194	0.66						
195	0.64						
196	0.61						
197							
198	0.59						
199					1300	13	0.72
200	0.57						
201					1200	12	0.67
202							
203		1100	37	0.88			
204							
205							
206					1100	11	0.61
207		1100	36	0.86			
208							
209		1000	35	0.83			
210		1000	34	0.81			
211							
212	0.55						
213	0.52						
214		1000	33	0.79			
215							

Table D8

Columns:

A	Cement Creek sub-segment or location
B	station or subbasin source category
C	site or monitoring station identification
D	sample date
E	sample season
G	ranking of dissolved zinc concentrations for NPSs in descending order
H	rank in descending order
I	rank divided by $N + 1 = 129$
J	storm flow ranking of dissolved zinc concentrations for NPSs in descending order
K	storm flow rank in descending order
L	storm flow rank divided by $N + 1 = 44$
M	snowmelt flow ranking of dissolved zinc concentrations for NPSs in descending order
N	snowmelt flow rank in descending order
O	snowmelt flow rank divided by $N + 1 = 42$
P	baseflow ranking of dissolved zinc concentrations for NPSs in descending order
Q	baseflow rank in descending order
R	baseflow rank divided by $N + 1 = 18$

the North Fork with the main stem (stations CC05, CC03, and CC18) and in the upper area of Prospect Gulch (CC25 and CC23) primarily during baseflow and storm flow.

Several point sources also exhibited very high concentrations. In particular, the Mogul tunnel (38,000 μg/L) and the Lark Mine adit (12,000 μg/L) had very high concentrations during the receding limb of snowmelt (7/21/93).

The lowest concentrations in stream segments (4 to 40 μg/L) were observed primarily in areas believed to represent background conditions, including Cascade Gulch, and the headwaters of the south and middle forks of Cement Creek and Minnehaha Creek. Most of the lowest concentrations were observed during the storm and snowmelt runoff events. Discharge from the American Tunnel also exhibited very low concentrations after treatment of the water by Sunnyside Mining Corp.

During the final targeting process for the basin, the potential uncertainty or measurement error associated with each value should be considered to determine the confidence in the values and in comparisons among values. The estimated uncertainty is assumed to be the same for each measured concentration value is $\pm$ approximately 10% (discussed in Chapter 5).

Cement Creek will probably not be targeted for restoration in the near future given the current lack of fish in the stream and severity of the problem. The information on the risk of exceedances in the segment and highest concentrations in various reaches would be more useful if Cement Creek was being compared to other stream segments and/or targeted for restoration. If this were the case, segments with the lowest risk of exceedances and reaches that exhibit lower concentrations might

be targeted because they are more likely to be able to support aquatic life even though the segments that have higher exceedance frequencies and/or reaches that exhibit higher concentrations are more impaired.

D.7.2   Loadings

<u>Ranking</u>

Cumulative frequency distributions cannot be developed for total (not normalized by area) mean daily loadings from all first order subbasins because these loadings may not be considered true random variables from the same population because each loading is a function of a different area. Total mean daily loadings, however, can still be ranked to derive information regarding the largest loadings to a stream segment and where they are generated. The same procedure as for unit area loadings and concentrations can be used.

This ranking procedure was used for mean daily loadings to Cement Creek for a year and for each season, the highest results of which for a subset of stations are presented in column R in Table D9. Loadings during snowmelt, followed by storm flows, are the largest. The greatest loading (45,039 g/day) is from the large subbasin CC48-CC47 during snowmelt. This subbasin also contributed a large loading during the receding limb of snowmelt and even during baseflow. Such a large loading during baseflow conditions, however, is questionable. The primary reason for the large loadings from this subbasin is the significant flow from this large area. This flow seems to be relatively large even during baseflow conditions. Unidentified seeps emanating from groundwater or point sources (adits) within the subbasin could explain these unexpected flows and loadings. Discharge from Ross Basin to station CC01, and from the subbasin CC31-CC30, also exhibited high loadings (35,797 g/day)

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	A	B	D	E	F	G	H	I	J
1	Table D9. Ranking of Cement Creek dissolved zinc loadings								
2									
3			(ac)				(cfs)	(ug/L)	(g/d)
4	SUB_SEG	SOURCE	AREA	SITE	DATE	SEASON	FLOW	ZNDC	ZNDL
5		NPS	1000.95	CC48-CC47	06/24/92	Snowmelt	23.300		45039.1
6	Cement	NPS	734.64	CC01	06/24/92	Snowmelt	15.400	950	35797.4
7		NPS	857.69	CC31-CC30	06/24/92	Snowmelt	14.420		29243.8
8		NPS	19.28	CC20-CC19-CC18	06/24/92	Snowmelt	3.800		27430.6
9		NPS	33.06	CC28-CC27	09/07/91	Storm	6.400		25055.7
10		NPS	48.67	CC36-CC34-CC35	06/24/92	Snowmelt	8.990		21164.5
11		NPS	177.23	CC17-CC16-CC13-CC12	09/07/91	Storm	0.400		17557.1
12		NPS	173.56	CC39-CC36-CC38-CC37	09/06/91	Storm	5.326		13955.8
13		NPS	1000.95	CC48-CC47	07/21/93		10.260		13423.9
14		NPS	1003.70	CC27-CC21-CC26	06/24/92	Snowmelt	5.170		13274.2
15		NPS	333.34	CC46-CC43-CC45-CC44	06/24/92	Snowmelt	2.410		11288.6
16		NPS	1000.95	CC48-CC47	10/14/92	Baseflow	5.380		11251.1
17		NPS	1003.70	CC27-CC21-CC26	09/07/91	Storm	3.860		10780.8
18		NPS	19.28	CC20-CC19-CC18	09/07/91	Storm	0.840		10391.7
19		NPS	151.52	CC25-CC24	09/07/91	Storm	2.010		9344.5
20		NPS	533.53	CC03-CC02	09/07/91	Storm	1.050		7034.7
21	Cement	NPS	734.64	CC01	09/07/91	Storm	1.790	1600	7007.8
22	Cement	NPS	1259.91	CC02-CC01a-f	07/21/93		2.409		6725.8
23		NPS	151.52	CC25-CC24	06/24/92	Snowmelt	1.070		5822.3
24	Cement	NPS	1793.44	CC03	10/14/92	Baseflow	0.637	3700	5767.0
25		NPS	101.93	CC43-CC41-CC42	09/06/91	Storm	0.650		5624.3
26		NPS	533.53	CC03-CC02	07/21/93		1.100		5369.9
27		NPS	79.89	CC18-CC05	07/21/93		0.570		5170.2
28		NPS	525.27	CC02-CC01	09/07/91	Storm	0.510		4810.5
29	SF Cement adit	PS		CC14	06/24/92	Snowmelt	1.290	1400	4419.0
30	SF Cement adit	PS		CC14	07/21/93		1.500	1200	4404.3
31		NPS	79.89	CC18-CC05	06/24/92	Snowmelt	2.200		4135.2
32		NPS	33.06	CC28-CC27	06/24/92	Snowmelt	1.650		4037.3
33	Ohio	NPS	303.96	CC40	09/06/91	Storm	1.400	1000	3425.6
34		NPS	304.88	CC26-CC25	06/24/92	Snowmelt	1.030		3390.1
35		NPS	338.85	CC16-CC15-CC14	06/24/92	Snowmelt	4.860		3385.8
36		NPS	333.34	CC46-CC43-CC45-CC44	09/06/91	Storm	0.590		3289.5
37		NPS	177.23	CC17-CC16-CC13-CC12	06/24/92	Snowmelt	-2.790		2953.3
38	Prospect	NPS	174.48	CC23	09/07/91	Storm	0.500	2400	2936.2
39	Mogul tnl mine drng	PS		CC01b	07/21/93		0.031	38000	2882.4
40	Prospect	NPS	174.48	CC23	06/24/92	Snowmelt	2.530	460	2847.6
41		NPS	120.30	CC24-CC23-CC22	09/07/91	Storm	-0.210		2791.9
42		NPS	48.67	CC36-CC34-CC35	09/06/91	Storm	1.040		2550.6
43	SF Cement adit	PS		CC14	10/14/92	Baseflow	1.000	740	1810.7
44		NPS	79.89	CC18-CC05	09/07/91	Storm	-0.280		1810.7
45		NPS	76.22	CC06-CC07	09/07/91	Storm	0.116		1623.7
46	adit	PS		CC01f	07/21/93		1.440	440	1550.3
47		NPS	338.85	CC16-CC15-CC14	09/07/91	Storm	1.360		1203.8
48	SF Cement adit	PS		CC14	09/07/91	Storm	0.620	750	1137.8
49	Cement Amer Tnl	PS		CC19	10/14/92	Baseflow	3.190	140	1092.8
50	MF Cement adit	PS		CC10	06/24/92	Snowmelt	0.340	1300	1081.5
51		NPS	312.22	CC13-CC11-CC10	09/07/91	Storm	1.596		796.5

	K	L	M	N	O	P	Q	R	S	T
1										
2										
3	(g/ac-day)			*						
4	ZNDLU	ZNDLE	ZNDLLE	ZNDLF	ZNDLF1	ZNDLF2	ZNDLF3	ZNDLN	ZNDLNI	ZNDLN2
5	45.00	36545.3		45039.1		45039.1		45039.1		45039.1
6	48.73	6443.5		35797.4		35797.4		35797.4		35797.4
7	34.10	28115.0		29243.8		29243.8		29243.8		29243.8
8	1422.43	24284.6		27430.6		27430.6		27430.6		27430.6
9	757.91	19054.4		25055.7	25055.7			25055.7	25055.7	
10	434.86	17028.0		21164.5		21164.5		21164.5		21164.5
11	99.06	3919.2		17557.1	17557.1			17557.1	17557.1	
12	80.41	10299.9		13955.8	13955.8			13955.8	13955.8	
13	13.41	19525.1		13423.9				18684.6		
14	13.23	25495.9	*	13274.2		13274.2		13274.2		13274.2
15	33.86	34645.6	*	11288.6		11288.6		11288.6		11288.6
16	11.24	7380.4		11251.1			11251.1	11251.1		
17	10.74	13565.9	*	10780.8	10780.8			10780.8	10780.8	
18	538.87	6106.7		10391.7	10391.7			10391.7	10391.7	
19	61.67	2965.0		9344.5	9344.5			9344.5	9344.5	
20	13.19	4005.2		7034.7	7034.7			7034.7	7034.7	
21	9.54	1261.4		7007.8	7007.8			7007.8	7007.8	
22	5.34	2297.9		6725.8				6725.8		
23	38.43	1596.2		5822.3		5822.3		5822.3		5822.3
24	3.22	1038.1		5767.0			5767.0	5767.0		
25	55.18	11720.6	*	5624.3	5624.3			5624.3	5624.3	
26	10.06	3878.7		5369.9				5369.9		
27	64.71	10962.6	*	5170.2				5170.2		
28	9.16	2473.2		4810.5	4810.5			4810.5	4810.5	
29		795.4		4419.0		4419.0				
30		792.8		4404.3						
31	51.76	19910.6	*	4135.2		4135.2		4135.2		4135.2
32	122.12	28921.1	*	4037.3		4037.3		4037.3		4037.3
33	11.27	616.6		3425.6	3425.6			3425.6	3425.6	
34	11.12	2622.0		3390.1		3390.1		3390.1		3390.1
35	9.99	1713.6		3385.8		3385.8		3385.8		3385.8
36	9.87	12920.7	*	3289.5	3289.5			3289.5	3289.5	
37	16.66	3144.7	*	2953.4		2953.4		2953.4		2953.4
38	16.83	528.5		2936.2	2936.2			2936.2	2936.2	
39		518.8		2882.4						
40	16.32	512.6		2847.6		2847.6		2847.6		2847.6
41	23.21	1202.9		2791.9	2791.9			2791.9	2791.9	
42	52.41	7870.3	*	2550.6	2550.6			2550.6	2550.6	
43		325.9		1810.7			1810.7			
44	22.66	4409.7	*	1810.7	1810.7			1810.7	1810.7	
45	21.30	333.4		1623.7	1623.7			1623.7	1623.7	
46		279.1		1550.3						
47	3.55	535.7		1203.9	1203.9			1203.9	1203.9	
48		204.8		1137.8	1137.8					
49		196.7		1092.8			1092.8			
50		194.7		1081.5		1081.5				
51	2.55	149.1		796.5	796.5			796.5	796.5	

	U	V	W	X	Y	Z	AA	AB
1								
2								
3								
4	ZNDLN3	ZNDLU1	ZNDLU2	ZNDLU3	ZNDLP	ZNDLP1	ZNDLP2	ZNDLP3
5			45.00					
6			48.73					
7			34.10					
8			1422.43					
9		757.91						
10			434.86					
11		99.06						
12		80.41						
13								
14			13.23					
15			33.86					
16	11251.1			11.24				
17		10.74						
18		538.87						
19		61.67						
20		13.19						
21		9.54						
22								
23			38.43					
24	5767.0			3.22				
25		55.18						
26								
27								
28		9.16						
29					4419.0		4419.0	
30					4404.3			
31			51.76					
32			122.12					
33		11.27						
34			11.12					
35			9.99					
36		9.87						
37			16.66					
38		16.83						
39					2882.4			
40			16.32					
41		23.21						
42		52.41						
43					1810.7			1810.7
44		22.66						
45		21.30						
46					1550.3			
47		3.55						
48					1137.8	1137.8		
49					1092.8			1092.8
50					1081.5		1081.5	
51		2.55						

Table D9

Columns:

A	Cement Creek sub-segment or location
B	station or subbasin source category
D	subbasin area (acres)
E	site or monitoring station identification
F	sample date
G	sample season
H	flow measured or computed (cfs)
I	dissolved zinc concentration (μg/L)
J	ranking of dissolved zinc mean daily loadings (g/day) in descending order
K	dissolved zinc mean daily unit area loading (g/ac-day)
L	potential error of loading estimate (g/day)
M	if error is greater than loading estimate, an asterisk is used
N	ranking of dissolved zinc mean daily loadings from first order subbasins in descending order
O	storm flow ranking of dissolved zinc mean daily loadings from first order subbasins in descending order
P	snowmelt flow ranking of dissolved zinc mean daily loadings from first order subbasins in descending order
Q	baseflow ranking of dissolved zinc mean daily loadings from first order subbasins in descending order
R	ranking of dissolved zinc mean daily loadings from NPSs in descending order
S	storm flow ranking of dissolved zinc mean daily loadings from NPSs in descending order
T	snowmelt flow ranking of dissolved zinc mean daily loadings from NPSs in descending order
U	baseflow ranking of dissolved zinc mean daily loadings from NPSs in descending order
V	storm flow dissolved zinc mean daily unit area loading (g/ac-day)
W	snowmelt flow dissolved zinc mean daily unit area loading
X	baseflow dissolved zinc mean daily unit area loading
Y	ranking of dissolved zinc mean daily loadings from point sources in descending order
Z	storm flow ranking of dissolved zinc mean daily loadings from point sources in descending order
AA	snowmelt flow ranking of dissolved zinc mean daily loadings from point sources in descending order
AB	baseflow ranking of dissolved zinc mean daily loadings from point sources in descending order

during snowmelt. These basins also have relatively large areas. The much smaller subbasins CC20-CC19-CC18, CC28-CC27, and CC36-CC34-CC35, also contributed relatively large loadings during snowmelt and storm flows for such small areas. Again, it should be mentioned that some of the loadings estimated as the differences between loadings measured at two or more adjacent stations have relatively large potential errors associated with them and should be used with caution. The point source exhibiting the greatest loadings is an adit discharging to the South Fork of Cement Creek (Silver Ledge Mine) during snowmelt and baseflow.

The subbasins exhibiting the greatest loadings should probably be targeted for remediation considering other factors such as distance to the impaired water body and land ownership issues. Loadings during high flows should be targeted for control. During the final targeting process for the basin, the potential uncertainty or measurement error associated with each value should be considered to determine the confidence in the values and in comparisons among values. This value is $\pm$ at least approximately 18% and can vary depending on whether it was estimated at a monitoring station or estimated using the NPS reach gain/loss analysis and how many upstream stations were used to compute the loading between adjacent stations (discussed in Chapter 5).

D.7.3   Unit Area Loadings

Risk of Exceedance

The nonparametric approach was also used to estimate the *cdf*s for dissolved zinc mean daily unit area loadings to Cement Creek from all first order subbasins for each season and a year. Data were lumped over space to estimate the *cdf*s for each season, and over time and space to estimate the *cdf*s for the year. Figure D17a
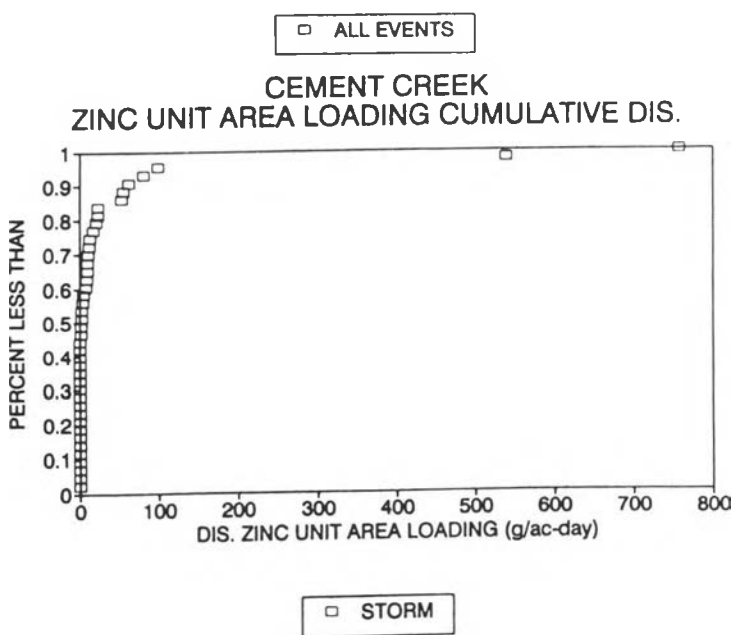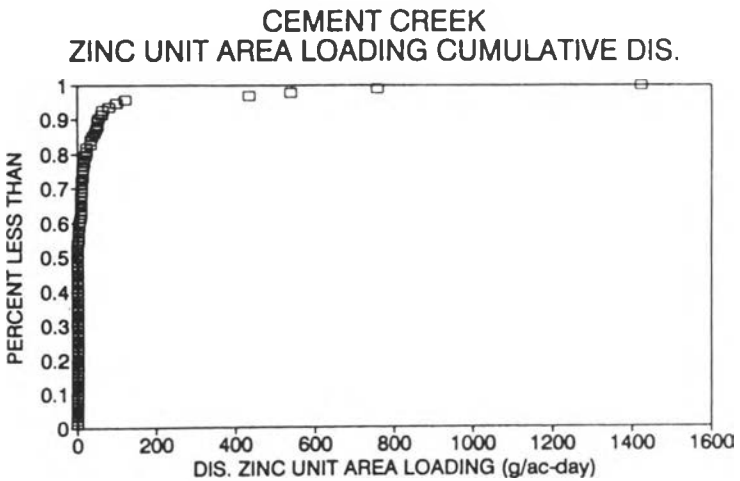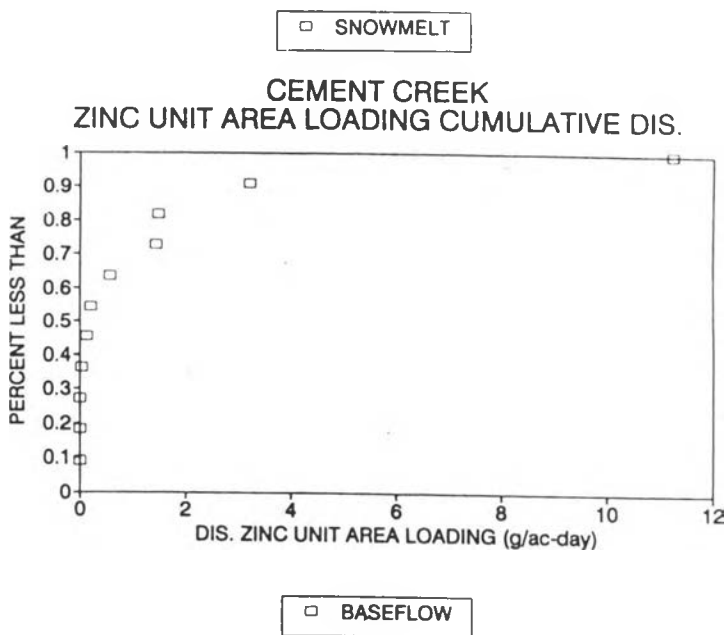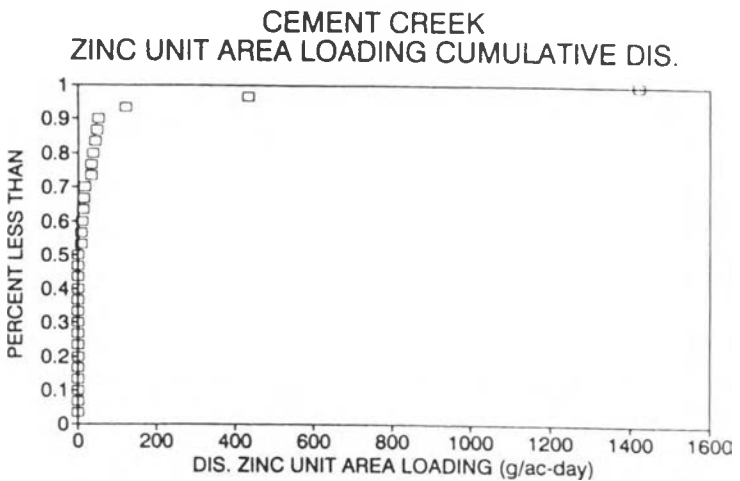
Figure D17. Cumulative distribution plots of Cement Creek dissolved zinc mean daily unit area loadings

presents a cumulative distribution plot of all observed mean daily unit area loadings to Cement Creek from first order subbasins based on ranking all of the observed data from the year. Figures D17b through D17d present the seasonal mean daily unit area loading cumulative distribution plots based on ranking the seasonal data. All of the figures show that most of the values are zero or fairly close to zero g/ac-day. The zero values were derived by estimation of loadings from first order subbasins between adjacent monitoring stations. When negative loading estimates resulted due to channel losses, the loading from the subbasin itself was assumed equal to zero.

As can be seen from the cumulative distribution for all events and for snowmelt, the largest unit area loading occurred during snowmelt (approximately 1,400 g/ac-day) and has a very small probability of occurring. As can be seen from the cumulative distribution for all events and for the storm event, the next two greatest mean daily unit area loadings occurred during a storm (750 and 550 g/ac-day). The fourth highest unit area loading occurred during snowmelt (400 g/ac-day). All of these high loadings have a small risk of being exceeded. All the other mean daily unit area loadings were below 125 g/ac-day. As expected, the baseflow mean daily unit area loadings were very low, ranging from 0 to 12 g/ac-day.

Water quality standards are not directly computed or applicable for loadings. If required for particular sites, however, target loadings or TMDLs can be computed and the risk of exceeding these values can then be estimated from the cumulative frequency distribution.

This risk information would be more useful if Cement Creek was being compared to other subbasins and/or targeted for restoration. The basins with the highest risks

of exceeding target unit area loadings should probably be targeted for remediation. Unit area loadings during high flows (snowmelt and storms) would be targeted for control. Important information regarding the uncertainty for the risk of exceeding a target unit area loading includes both the *CI* on the percentile and the *CI* on the proportion. In some cases we are interested in the uncertainty of the estimated target loading given an acceptable or known risk level. In other cases we could be more interested in the uncertainty of the estimated risk given a known unit area loading. The uncertainty of the values should then be used in the final targeting process.

Ranking

Column K of Table D10 shows the ranking of all of the mean daily unit area loading data from first order subbasins in the Cement Creek basin for the year monitored as well as the location of each datum. As can be seen from the table, the small subbasin CC20-CC19-CC18 in the vicinity of the American Tunnel exhibits the greatest mean daily unit area loading (1,422 g/ac-day) during snowmelt. A closer look at this loading, however, reveals that a point source discharge from treated effluent from the American Tunnel (CC19) is probably the cause of a significant amount of this loading. Although the dissolved loading from this point is very small, the pH of the discharge is very high so that most of the zinc is in insoluble form. When this total zinc loading enters Cement Creek, it redissolves in the low pH water causing a significant increase in the dissolved zinc loading between stations CC18 and CC20. This loading is almost twice the next greatest mean daily unit area loading (757 g/ac-day) from the small subbasin CC28-CC27 below Prospect Gulch during the storm event. A natural iron bog is located immediately adjacent to the stream that

	A	B	D	E	F	G	H	I	J
128	Table D10. Ranking of Cement Creek dissolved zinc unit area loadings								
129									
130			(ac)				(cfs)	(ug/L)	(g/d)
131	SUB_SEG	SOURCE	AREA	SITE	DATE	SEASON	FLOW	ZNDC	ZNDL
132		NPS	19.28	CC20-CC19-CC18	06/24/92	Snowmelt	3.800		27430.6
133		NPS	33.06	CC28-CC27	09/07/91	Storm	6.400		25055.7
134		NPS	19.28	CC20-CC19-CC18	09/07/91	Storm	0.840		10391.7
135		NPS	48.67	CC36-CC34-CC35	06/24/92	Snowmelt	8.990		21164.5
136		NPS	33.06	CC28-CC27	06/24/92	Snowmelt	1.650		4037.3
137		NPS	177.23	CC17-CC16-CC13-CC12	09/07/91	Storm	0.400		17557.1
138		NPS	173.56	CC39-CC36-CC38-CC37	09/06/91	Storm	5.326		13955.8
139		NPS	79.89	CC18-CC05	07/21/93		0.570		5170.2
140		NPS	151.52	CC25-CC24	09/07/91	Storm	2.010		9344.5
141		NPS	101.93	CC43-CC41-CC42	09/06/91	Storm	0.650		5624.3
142		NPS	48.67	CC36-CC34-CC35	09/06/91	Storm	1.040		2550.6
143		NPS	79.89	CC18-CC05	06/24/92	Snowmelt	2.200		4135.2
144	Cement	NPS	734.64	CC01	06/24/92	Snowmelt	15.400	950	35797.4
145		NPS	1000.95	CC48-CC47	06/24/92	Snowmelt	23.300		45039.1
146		NPS	151.52	CC25-CC24	06/24/92	Snowmelt	1.070		5822.3
147		NPS	857.69	CC31-CC30	06/24/92	Snowmelt	14.420		29243.8
148		NPS	333.34	CC46-CC43-CC45-CC44	06/24/92	Snowmelt	2.410		!'288.6
149		NPS	120.30	CC24-CC23-CC22	09/07/91	Storm	-0.210		2791.9
150		NPS	79.89	CC18-CC05	09/07/91	Storm	-0.280		1810.7
151		NPS	76.22	CC06-CC07	09/07/91	Storm	0.116		1623.7
152	Prospect	NPS	174.48	CC23	09/07/91	Storm	0.500	2400	2936.2
153		NPS	177.23	CC17-CC16-CC13-CC12	06/24/92	Snowmelt	-2.790		2953.3
154	Prospect	NPS	174.48	CC23	06/24/92	Snowmelt	2.530	460	2847.6
155		NPS	1000.95	CC48-CC47	07/21/93		10.260		13423.9
156		NPS	1003.70	CC27-CC21-CC26	06/24/92	Snowmelt	5.170		13274.2
157		NPS	533.53	CC03-CC02	09/07/91	Storm	1.050		7034.7
158	Ohio	NPS	303.96	CC40	09/06/91	Storm	1.400	1000	3425.6
159		NPS	1000.95	CC48-CC47	10/14/92	Baseflow	5.380		11251.1
160		NPS	304.88	CC26-CC25	06/24/92	Snowmelt	1.030		3390.1
161		NPS	1003.70	CC27-CC21-CC26	09/07/91	Storm	3.860		10780.8
162		NPS	533.53	CC03-CC02	07/21/93		1.100		5369.9
163		NPS	338.85	CC16-CC15-CC14	06/24/92	Snowmelt	4.860		3385.8
164		NPS	333.34	CC46-CC43-CC45-CC44	09/06/91	Storm	0.590		3289.5
165	Cement	NPS	734.64	CC01	09/07/91	Storm	1.790	1600	7007.8
166		NPS	525.27	CC02-CC01	09/07/91	Storm	0.510		4810.5
167		NPS	57.85	CC12-CC09	06/24/92	Snowmelt	0.600		497.3
168		NPS	57.85	CC12-CC09	09/07/91	Storm	0.396		460.8
169	Cement	NPS	1259.91	CC02-CC01a-f	07/21/93		2.409		6725.8
170	Prospect	BG	61.53	CC22	09/07/91	Storm	1.000	110	269.2
171		NPS	338.85	CC16-CC15-CC14	09/07/91	Storm	1.360		1203.8
172	Cement	NPS	1793.44	CC03	10/14/92	Baseflow	0.637	3700	5767.0
173	Porcupine Gl	NPS	197.43	CC38	09/06/91	Storm	0.104	2100	534.4
174		NPS	312.22	CC13-CC11-CC10	09/07/91	Storm	1.596		796.5
175		NPS	219.47	CC09-CC08	06/24/92	Snowmelt	1.050		440.8
176	Prospect	NPS	174.48	CC23	07/21/93		0.320	410	321.0
177	NF Cement	NPS	148.76	CC04	09/07/91	Storm	0.153	670	250.8
178		NPS	304.88	CC26-CC25	10/14/92	Baseflow	0.217		452.2

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	K	L	M	N	O	P	Q	R	S	T	U
128											
129	*										
130	(g/ac-day)										
131	ZNDLU	RANK	PERCENT	ZNDLE	ZNDLLE	ZNDLF	ZNDLUI	RANKI	PERCENTI	ZNDLU2	RANK2
132	1422.43	93	0.99	24284.6		27430.6				1422.43	30
133	757.91	92	0.98	19054.4		25055.7	757.91	43	0.98		
134	538.87	91	0.97	6106.7		10391.7	538.87	42	0.95		
135	434.86	90	0.96	17028.0		21164.5				434.86	29
136	122.12	89	0.95	28921.1	*	4037.3				122.12	28
137	99.06	88	0.94	3919.2		17557.1	99.06	41	0.93		
138	80.41	87	0.93	10299.9		13955.8	80.41	40	0.91		
139	64.71	86	0.91	10962.6	*	5170.2					
140	61.67	85	0.90	2965.0		9344.5	61.67	39	0.89		
141	55.18	84	0.89	11720.6	*	5624.3	55.18	38	0.86		
142	52.41	83	0.88	7870.3	*	2550.6	52.41	37	0.84		
143	51.76	82	0.87	19910.6	*	4135.2				51.76	27
144	48.73	81	0.86	6443.5		35797.4				48.73	26
145	45.00	80	0.85	36545.3		45039.1				45.00	25
146	38.43	79	0.84	1596.2		5822.3				38.43	24
147	34.10	78	0.83	28115.0		29243.8				34.10	23
148	33.86	77	0.82	34645.6	*	11288.6				33.86	22
149	23.21	76	0.81	1202.9		2791.9	23.21	36	0.82		
150	22.66	75	0.80	4409.7	*	1810.7	22.66	35	0.80		
151	21.30	74	0.79	333.4		1623.7	21.30	34	0.77		
152	16.83	73	0.78	528.5		2936.2	16.83	33	0.75		
153	16.66	72	0.77	3144.7	*	2953.4				16.66	21
154	16.32	71	0.76	512.6		2847.6				16.32	20
155	13.41	70	0.74	19525.1		18684.6					
156	13.23	69	0.73	25495.9	*	13274.2				13.23	19
157	13.19	68	0.72	4005.2		7034.7	13.19	32	0.73		
158	11.27	67	0.71	616.6		3425.6	11.27	31	0.70		
159	11.24	66	0.70	7380.4		11251.1					
160	11.12	65	0.69	2622.0		3390.1				11.12	18
161	10.74	64	0.68	13565.9	*	10780.8	10.74	30	0.68		
162	10.06	63	0.67	3878.7		5369.9					
163	9.99	62	0.66	1713.6		3385.8				9.99	17
164	9.87	61	0.65	12920.7	*	3289.5	9.87	29	0.66		
165	9.54	60	0.64	1261.4		7007.8	9.54	28	0.64		
166	9.16	59	0.63	2473.2		4810.5	9.16	27	0.61		
167	8.60	58	0.62	195.7		497.3				8.60	16
168	7.96	57	0.61	85.1		460.8	7.96	26	0.59		
169	5.34	56	0.60	2297.9		6725.8					
170	4.37	55	0.59	48.4		269.2	4.37	25	0.57		
171	3.55	54	0.57	535.7		1203.9	3.55	24	0.55		
172	3.22	53	0.56	1038.1		5767.0					
173	2.71	52	0.55	96.2		534.4	2.71	23	0.52		
174	2.55	51	0.54	149.1		796.5	2.55	22	0.50		
175	2.01	50	0.53	86.5		440.8				2.01	15
176	1.84	49	0.52	57.8		321.0					
177	1.69	48	0.51	45.1		250.8	1.69	21	0.48		
178	1.48	47	0.50	147.7		452.2					

Row	V	W	X	Y
	PERCENT2	ZNDLU3	RANK3	PERCENT3
178		1.48	9	0.75
177				
176				
175	0.48			
174				
173				
172		3.22	10	0.83
171				
170				
169				
168				
167	0.52			
166				
165				
164				
163	0.55			
162				
161				
160	0.58			
159		11.24	11	0.92
158				
157	0.61			
156				
155				
154	0.65			
153	0.68			
152				
151				
150				
149				
148	0.71			
147	0.74			
146	0.77			
145	0.81			
144	0.84			
143	0.87			
142				
141				
140				
139				
138				
137				
136	0.90			
135	0.94			
134				
133	0.97			
132				
131				
130				
129				
128				

Table D10

Columns:

A	Cement Creek sub-segment or location
B	station or subbasin source category
D	subbasin area (acres)
E	site or monitoring station identification
F	sample date
G	sample season
H	flow measured or computed (cfs)
I	dissolved zinc concentration (µg/L)
J	dissolved zinc mean daily loading (g/day)
K	ranking of dissolved zinc mean daily unit area loadings (g/ac-day) in descending order
L	rank in descending order
M	rank divided by N+1=94
N	potential error of loading estimate (g/day)
O	if error is greater than loading estimate, an asterisk is used
P	dissolved zinc mean daily loading from first order subbasins
Q	storm flow ranking of dissolved zinc mean daily unit area loadings in descending order
R	storm flow rank in descending order
S	storm flow rank divided by N+1=44
T	snowmelt flow ranking of dissolved zinc mean daily unit area loadings in descending order
U	snowmelt flow rank in descending order
V	snowmelt flow rank divided by N+1=31
W	baseflow ranking of dissolved zinc mean daily unit area loadings in descending order
X	baseflow rank in descending order
Y	baseflow rank divided by N=12

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accounts for a significant portion of this loading.

The third highest unit area loading (540 g/ac-day) also is observed from subbasin CC20-CC19-CC18 during the storm. The fourth greatest unit area loading (434 g/ac-day) is from subbasin CC36-CC34-CC35 during snowmelt. It should be noted, however, that each of these loadings was estimated as the difference between loadings at two or more adjacent stations and that the estimated errors in the loadings are not that much smaller than the computed loadings themselves. The greatest unit area loading (48.73 g/ac-day) actually measured at a station is at CC01 during snowmelt. As expected, the smallest unit area loadings tend to be observed from background areas and during baseflow conditions.

All of the subbasins with the greatest unit area loadings should probably be targeted for remediation considering other factors such as distance to the impaired water body and land ownership issues. Again, unit area loadings during high flows should be targeted for control. The *CI* widths and *CCI*s should be considered explicitly in the process. For small *CCI*s, greater confidence can be placed in decisions regarding targeting. For large *CCI*s, decisions must be made with less certainty about average conditions in the watershed and comparisons between basins.

D.8   Summary of Targeting in the Cement Creek Basin

In this chapter, the data analysis methods discussed in Chapter 6 were used to achieve the seven quantitative information goals defined in Chapter 4 for the Cement Creek Basin for dissolved zinc, the primary constituent of concern and indicator parameter for the basin. Specific source areas and locations within the stream segment were targeted on a preliminary basis using the information derived and considering the potential uncertainty of the estimates explicitly in the process. The

target tables (tables D8, D9, and D10) and maps (figures B2 and B3) were used as much as possible to aid in targeting for the basin. It should be emphasized that this work used only the quantitative site information in the preliminary targeting process. Additional socioeconomic information, such as land ownership, costs/benefits, and public support and funding, should also be used for the final targeting of source areas and stream segments to the extent possible.

APPENDIX E. METHODS TO FILL DATA GAPS

This appendix presents methods that might be useful for filling the data gaps discussed in Chapter 7 that are typical of data derived from synoptic surveys of IAM watersheds. For some sites, some of these data gaps should be filled to derive specific types of required information. The general types of data gaps that might require filling and are discussed in this section include:

1. water quality data
2. sediment data
3. aquatic ecologic data

E.1 Methods to Fill Water Quality and Sediment Data Gaps

Data gaps can be filled when required and when resources are available by either collecting additional data or by using some type of simplified modeling techniques. Defining specific methods for determining data gaps and determining in which cases specific data are required is beyond the scope of this study and is somewhat site-specific. These methods should be evaluated, however, during future research. Many of the initial data gaps are common and fairly obvious from the existing limited data sets and can be identified on a preliminary basis by using the simple screening procedure discussed in Chapter 5 to determine the worst or indicator parameters for the site. Methods that can be used for filling the common types of data gaps at IAMs are discussed below.

E.1.1   Additional Data Collection

If resources are available, additional data beyond those typically collected at the majority of IAMs can be collected. These data can include the specific analytes (species of metals) of concern or indicator parameters that influence the effects of the metals or that could provide some additional useful information. The additional data could also include both the dissolved and total fractions of the metals if this information is important at a particular site. The analytical methods should be appropriate for the site so that the MDL is below the applicable standards or concentrations that might cause adverse impacts. The additional data can be collected at specific locations of interest where data have not been previously collected, but are critical to the decision-making process, or where the data set needs to be larger, collected over a longer time period, or during specific types of flow events. For data collection during extreme (high) flow events, automatic flow measurement and sampling equipment should be considered at a key location to minimize potential logistical problems and hazards to field crews due to dangerous field conditions.

With regard specifically to sediment, suspended sediment can be sampled at key locations during high flow events using manual or automatic methods. Suspended sediment concentrations, and adsorbed chemical concentrations of the sediment, can be analyzed for. Alternatively, total suspended solids (TSS), which is closely related to suspended sediment but also includes organic material, can be sampled and concentrations measured. Measurement of turbidity is a field test and is also an indicator of suspended solids and sediment. Turbidity and TSS, however, do not provide a measure of adsorbed metals concentrations. Because the parameters

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discussed above are primarily important during high flows when sampling personnel might not be available or logistical problems may be encountered, sampling and analysis of bed sediment (material) during low flows is very useful and often performed. The concentrations of adsorbed metals, grain size distribution, and organic content are all important analyses for bed material. Analyses of bed material are generally considered good indicators of long-term impacts and are related strongly to ecological conditions in the stream, especially benthic macroinvertebrate community health. Toxicity testing of bed material is very useful for evaluating impacts to benthos and fish. Cobble imbeddedness can also be measured as an indicator of sediment deposition and transport and of impacts to aquatic habitat.

E.1.2   Modeling

An option to additional data collection is some type of simplified modeling to fill in data gaps. Simplified modeling is generally preferred over more sophisticated modeling techniques in the case of most IAMs for the following reasons:

1.   the lack of adequate data precludes the use of more complex models

2.   the lack of adequate resources (i.e., time and money) precludes the use of more complex models

3.   complex models are not necessary to derive the information required for the screening-level assessment phase

Modeling is sometimes the best option for the following cases:

1.   specific points of interest where data are lacking
2.   extreme events that are not practical or possible to sample
3.   large data sets must be generated for risk assessment techniques
4.   prediction of future conditions, especially for potential remediation schemes

In cases such as these, simplified empirical and/or statistical modeling can be used in conjunction with monitoring data to derive estimates of loading or concentration

values. However, modeling results are only as good as the data input to the model, and in the case of most IAMs, good data are lacking. Calibration of model results, therefore, can be very difficult or impossible, and usefulness of the modeling results may be questionable. This is why it is not practical to apply complex and data intensive continuous, deterministic simulation models for the screening-level assessment. The other reason is the high cost of simulation modeling relative to simplified modeling methods. Ultimately, the usefulness, practicality, and costs/benefits of modeling must be balanced against those of additional data collection for each site. The methods to accomplish this are beyond the scope of this study, but could be evaluated as part of future research.

Two simple, generalized methods might be useful for estimating sediment loadings and total and/or dissolved metals loadings and concentrations at a point. The first is an empirical method based on the Universal Soil Loss Equation (USLE). The second method is a statistical technique using correlation and regression of parameters such as flow, erosion, concentration, loading, and/or watershed characteristics. These methods are discussed below.

E.1.2.1   USLE

The USLE has been recommended for use in estimating soil loss and sediment yields from surface mining sites by USDA SCS (1977). The original equation, which is used to estimate soil loss on an annual basis, is as follows (Wischmeier and Smith, 1965):

$$A = R \; K \; L \; S \; C \; P \qquad\qquad (E.1)$$

where:

A = soil loss (tons/acre-year)
R = rainfall factor
K = soil erodibility factor (tons/acre-year)
L = slope length factor
S = slope gradient factor
C = cover or cropping management factor
P = erosion control practice factor

The Revised USLE (RUSLE) (USDA, 1990) is intended for use in subbasins of the western U.S. where slopes may be greater than 20%. The RUSLE uses a different slope length factor (*LS* or *L* and *S* factors combined into one factor) computed as:

$$LS = (length/72.6)^m/S \qquad (E.2)$$

where:

length = distance from point of origin of overland flow to point where deposition occurs (feet)
$m = \beta/(1+\beta)$
$\beta = (\sin a/0.0896)/(3 \times (\sin a)^{0.8} + 0.56)$
a = slope angle
S = slope factor = $((16.8 \times \sin a) - 0.5)$ for slopes over 9%

For storm event loadings, the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) can be used in conjunction with the USDA SCS curve number equation (CNE) (USDA, 1985) as follows:

$$A_s = a(V_r q_p)^{0.56} K L S C P \qquad (E.3)$$

where:

A_s = sediment yield (tons/acre/event)
a = conversion constant (95 English, 11.8 metric)
V_r = volume of runoff (acre-feet, m^3)
q_p = peak flow rate (cfs, m^3/sec)

V_r is computed as follows:

$$V_r = a\ A\ Q_r \qquad\qquad (E.4)$$

where:

a = conversion constant (0.083 English, 100 metric)
A = contaminated area (acres, ha)
Q_r = depth of runoff (in, cm)

Depth of runoff can be determined using a variety of methods, but the most common is the USDA SCS CNE (USDA, 1985):

$$Q_r = (P-0.2S)^2/(P+0.8S) \qquad\qquad (E.5)$$

where:

P = total precipitation (in, cm)
S = water retention factor (in, cm)

S is obtained using the dimensionless runoff curve number (CN) as follows:

$$S = 1000/(CN-10a) \qquad\qquad (E.6)$$

where:

a = conversion constant (1.0 English, 2.54 metric)

Other parameters are defined as previously. An explanation and values for the CN may be found in USDA (1985). For each equation discussed above, the parameter a (conversion constant) is a different value as required.

The peak runoff rate can also be estimated using several methods, but one of the most common is as follows:

$$q_p = (aAr_pQ_r)/(T_r(P-0.2S)) \qquad\qquad (E.7)$$

where:

a = conversion constant (1.01 English, 0.028 metric)

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T_r = storm duration (hr)

Other parameters are defined as previously.

The MUSLE can be used to estimate soil loss (erosion) from a subbasin and NPS waste area. Typically, all of this soil from a subbasin or a diffuse waste source area (especially if the source area is not in direct contact with the water body) does not reach a water body. The total sediment yield or loading to the water body, therefore, is less than the erosion from the source area. This loss is typically accounted for by using a sediment delivery ratio that is expressed as an exponential function of the distance between the source area and the water body (Reckhow et al., 1985). However, because gully erosion is not accounted for in the USLE, and this erosion and contaminant transport mechanism may be significant in tailings and waste rock piles, the USLE may already underestimate loadings to surface waters at many IAMs. This underestimation of loading may counteract the overestimation of loadings that may occur if a sediment delivery ratio is not used. Therefore, it may be prudent and more cost effective in the case of IAMs to not use a sediment delivery ratio to counteract the fact that the USLE does not consider gully erosion.

Almost all of the data required for the equations presented above can be derived fairly easily from the literature and generalized values, site topographic maps, and field measurements.

In order to estimate dissolved and total metals loadings and concentrations associated with the soil losses estimated with the USLE, the methods developed by Haith (1980) can be used. The adsorbed and dissolved zinc quantities (S_s and D_s, respectively in kg, lb) for storm events are estimated as (Haith, 1980):

$$S_s = [1/(1+W_c/(K_dB))]C_iA \qquad \text{(E.8)}$$

and

$$D_s = [1/(1+(K_dB)/W_c)]C_iA \qquad \text{(E.9)}$$

where:

W_c = available water capacity of top cm of soil (difference between wilting point and field capacity) (dimensionless)
K_d = sorption partition coefficient (cm^3/g)
B = soil bulk density (g/cm^3)
C_i = total substance concentration (kg/ha-cm, lb/acre-cm)
A = contaminated area (ha-cm, acre-cm)

This model assumes that only the contaminant in the top 1 cm of soil is available for release via runoff.

The total loading to the receiving water body can then be estimated as (Haith, 1980):

$$PX_i = [A/100B]S_s \qquad \text{(E.10)}$$

plus

$$PQ_i = [Q_r/P]D_s \qquad \text{(E.11)}$$

where:

Q_r = total storm runoff depth (in, cm)
P = total precipitation (in, cm)

Storm events with return periods ranging from 1 to 100 years could be evaluated using this method. This methodology can be applied to specific first order subbasins of interest, the results of which could be qualitatively compared to observed monitoring data.

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The methods discussed above are for modeling storm event contaminant loadings and concentrations. To estimate annual average values, the storm event values must be summed for a given year over a number of years. Therefore, the MUSLE can be used as discussed above to estimate annual values. In order to accomplish this, an average storm duration must be characterized based on historic precipitation records. The amount of rainfall for this duration for a 1-year return period can be determined. This rainfall amount is divided into the mean annual rainfall for the area to obtain the average number of average rainfall events per year. The annual loading of substance can then be estimated as:

$$L_d = PX_iN \qquad\qquad\qquad (E.12)$$

and

$$L_s = PQ_iN \qquad\qquad\qquad (E.13)$$

where:

L_d = average annual dissolved loading in runoff (mass/year)
L_s = average annual adsorbed loading in runoff (mass/year)
PX_i = adsorbed substance loss per event (kg, lb)
PQ_i = dissolved substance loss per event (kg, lb)
N = number of average storm events in one year

The grain size distribution, bulk density, and total organic content (TOC) of the soil and waste material that is eroded must be estimated from sampling data. The grain size distribution is used to estimate K, the erodibility factor. The concentration of zinc in the top one centimeter of soil and/or waste material that is eroded must also be estimated from sampling data. It is best if the physical and chemical analyses are performed on an aerially composited sample.

Some type of zinc adsorption partition coefficient is also required to estimate dissolved versus adsorbed concentrations of the metal in runoff. It might be possible to estimate this parameter from the literature, from limited monitoring data (dissolved versus total fractions), or from laboratory leaching tests of the material. However, metal adsorption is a function of many variables such as species, pH, concentration, and sediment concentration. These adsorption data, therefore, seem to be critical data gaps for modeling purposes at most sites.

E.1.2.2　　Regression

Another potential method that could be used to estimate loadings or concentrations to fill in data gaps is regression based on correlation of variables within the watershed. Regression equations could be developed using concentration and/or loading as the dependent variable and flow, NPS area, and/or contaminant concentration (or erosion rate in the case of sediment) as the independent variable. Like in the empirical sediment equation, distance from the source area to the point of interest might also require consideration. In fact, the input variables for a regression equation could be very similar to those for the USLE. Significant correlation between independent watershed variables and the dependent variables of interest must exist in order to make the regression method useful. The first step in the process, therefore, is an analysis of the correlation between variables of interest.

The dependent variables of interest typically include the total and/or dissolved concentrations and/or loadings of specific metals on and annual, seasonal, or storm event basis. The independent variables might include the following:

- subbasin area

- NPS area or volume
- contaminant concentration or mass in NPS area
- flowrate or volume
- antecedent conditions
- distance to watercourse

The correlations and equations developed could vary by season or flow regime. Linear regression is the simplest type of regression and can be used if the correlation between variables is approximately linear. These equations could be developed first to determine if a linear relation exists. The linear equation is of the form:

$$y = a + bx \qquad (E.14)$$

where:

y = dependent variable
x = independent variable
a = constant (y intercept)
b = constant (slope)

Nonlinear and multiple regression equations can also be used. Nonlinear regression uses a different form of equation, such as logarithmic, exponential, or polynomial. The general logarithmic equation is as follows:

$$y = ax^b \qquad (E.15)$$

where a and b are constants. The exponential equation is of the form:

$$y = ae^{bx} \qquad (E.16)$$

where parameters are defined as for the linear model and e is the exponential function. This equation is often used in population and radioactive decay studies. A polynomial equation is of the form:

$$y = a + b_1x + b_2x^2 + \ldots + b_nx^n \qquad (E.17)$$

This equation can also be treated and analyzed as a multiple regression equation. Multiple regression uses more than one independent variable $(x_1,\ldots,x_n)$, such as flow and NPS contaminant concentration, and a constant $(b_1,\ldots,b_n)$ for each variable. This equation is of form:

$$y = a + b_1x_1 + \ldots + b_nx_n \qquad (E.18)$$

If a logarithmic (as is typical in many water quality studies) or exponential equation is used, the logarithms of the actual data can be used so that the equation is converted to its linear form. The parameters of the linear and nonlinear equations can then be easily determined using standard methods. Depending on the independent variables, time period for the regression, form of the equation, and the form of the data, the best fitting regression equation (as determined by the greatest correlation coefficient) could be selected for use.

E.1.3   Cement Creek Water Quality and Sediment Data Gaps

No sediment data have been collected in the Cement Creek subbasin to date. However, the first sampling event during storm flow (9/7/92) included analysis for total metal concentrations as well as dissolved concentrations. The dissolved fraction of zinc accounted for more than 90% of the total concentration, and had no significant dependence on pH. The percent dissolved fraction was slightly higher in the tributaries than in the main stem. This was likely due to the somewhat lower pH in the tributaries. For zinc in Cement Creek, therefore, analysis of the total fraction and of concentrations adsorbed to sediment is not as important because most of the zinc is in dissolved form.

No data on contaminant concentrations of NPSs are available for the Cement Creek subbasin because no sampling and analysis of waste material has been performed in the past or as part of the CDPHE study. This data gap precludes the use or detailed evaluation of the USLE-based approach at this site, and could impact the applicability of a statistical approach for this basin. The concentration or mass of contaminant in the subbasin that leaches to surface waters might be the most important independent variable and critical for a regression equation. This data gap will likely be the case for the majority of IAMs.

Data are currently being collected on areal extent of NPSs within the Cement Creek subbasin by USBM in a cooperative effort with other federal agencies. Aerial photographs alone do not provide adequate detail, given the small scale of the color photographs, to estimate NPS areas. Fairly extensive field reconnaissance is required in this case. Therefore, these data are not currently available for use in empirical or statistical modeling for this site.

The only currently available data for possible independent variables for the Cement Creek subbasin, therefore, are subbasin areas and flowrates. Flowrate and volume are generally functions of area. Concentrations and loadings in a subbasin are more dependent on variable flows than on a constant area. Therefore, flowrate was used as an independent variable to examine the potential correlation between loadings and/or concentrations with flows within the basin. The procedures discussed above were used including linear regression on the actual and logarithmic data. The logarithmic analysis evaluates nonlinear relationships between variables using an exponential equation. Only annual relationships were examined.

This was accomplished using two methods or data sets. One data set included flows and concentrations/loadings at all monitoring stations throughout the basin and the correlation between flows and concentrations/loadings at any station was evaluated. It was found that no significant correlation exists between concentrations and flows (or their logarithms) among all stations (R^2 less than 0.1). This means that flows alone cannot be used to estimate concentrations at any point the basin with any degree of confidence based on the data collected over a year (given the synoptic study data set). An examination of the correlation between concentration and flow on a seasonal basis was not performed, but might have shown a greater correlation. A significant correlation was found, however, between loadings and flows among all stations ($R^2 = 0.93$). This is not surprising considering that loading is a function of flow. This is known as spurious correlation (Hahn, 1977). The correlation between two variables is spurious when the dependent variable is a mathematical function of the independendt variable (such as when loading is equal to the concentration multiplied by flow). Total and unit area loadings from first order subbasins were also found to have fairly significant correlations with flow ($R^2 = 0.77$ and $R^2 = 0.65$, respectively). Only values measured at monitoring stations were used because the potential error in values obtained using the loading estimation procedure could bias the regression analysis. These relationships tend to be influenced by one large value (15.4 cfs, 35,797 g/day, and 48.73 g/ac-day). However, it still may be possible to estimate the zinc loading at any location within the basin based on the measured or modeled flow at that location using these relationships.

The second data set included the Colorado River Watch Program data. In this case the correlation between flow and concentration at individual stations was

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evaluated. For each station, all data collected over an approximately two-year period were used in the analysis. Station A68 in the Animas River immediately above the confluence with Cement Creek was one of the locations. Station MC34 at the mouth of Mineral Creek was also used. The same regression methods discussed above were used. In this case, no significant correlation existed between concentration and flow at Station A68. However at Station MC34, a significant correlation with an R^2 of 0.64 was found using a nonlinear (logarithms of the data) model. A stronger correlation between concentration and flow might exist in the Mineral Creek Basin relative to that in the Upper Animas River Basin because the dissolved zinc concentrations are lower and less variable in the Mineral Creek Basin as a result of fewer contaminant sources that are influencing concentrations in this basin. The relationships of loadings and flows at these stations was not evaluated although it would be expected that a correlation will exist.

It is difficult to depend on flow only for prediction of loadings or concentrations in a spatially diverse watershed. Some parameter related to contaminant concentrations or mass in subbasins would be a reasonable next step to evaluate correlation of variables in a watershed and might be required for a useful regression equation. This type of information is currently not available for the Cement Creek Basin as well as for most IAM watersheds.

E.2   Methods to Fill Aquatic Ecologic Data Gaps

This section discusses methods that could be used at many IAMs to fill some of the data gaps identified above. Additional data collection is the primary method for filling these data gaps. The feasibility of modeling to derive the required information on aquatic ecology is very limited for these sites.

E.2.1   Additional Data Collection

Depending on the specific ecological information required at particular site, a wide variety of field, laboratory, and data analysis methods are available. The ecological assessment effort can vary in size and scope depending on the information required and the available resources. Much of the required aquatic ecological information can be derived from a use attainability analysis through a comprehensive water body assessment. Many of the methods used for ecological risk assessment (ERA) at CERCLA sites could also be very useful. Although these methodologies are fairly expensive and complex, a subset of the methods could be very useful for some IAMs.

For the biological condition/biological health assessment part of the use attainability analysis, diversity indices, habitat suitability index (HSI) models, tissue analysis, a recovery index, intolerant species analysis, and omnivore-carnivore analysis are methods that can be used. The biological potential analysis makes comparisons between potentially degraded water bodies and reference reaches and/or baseline conditions within a region. The analysis involves:

- defining boundaries of fish faunal regions
- selecting control sampling sites in the reference reaches of each area
- sampling fish and recording observations at each reference sampling site
- establishing the community characteristics for the reference reaches of each area
- comparing the water body in question to the reference reaches

The reference reaches should have the general physical and hydrologic characteristics typical of the region and similar to those of the water body in question. This approach can also be used for other organisms such as macroinvertebrates and/or phytoplankton.

The initial part of the ERA, the ecological assessment, is the screening-level evaluation of a site that includes deriving information on the biology of surface waters to determine if adverse ecological effects have occurred and on the toxicity of contaminants to the biota to determine if a correlation exists between elevated concentrations of the contaminants and the adverse effects (USEPA, 1989b). Assessment endpoints are typically identified that are formal expressions of the actual environmental values that are to be protected. These are environmental characteristics, such as brown trout abundance, that indicate a need for restoration of the water body if they are determined to be adversely affected. Measurement endpoints are also identified that are quantitative expressions of an observed or measured effect of a hazard and are related to the assessment endpoints. In this regard the assessment and measurement endpoints could be considered to correspond to the assessment information and quantitative information goals, respectively, identified in Chapter 4. In some cases the measurement endpoint can be the same as the assessment endpoint, as long as it is measurable.

Assessment endpoints at the population and community scale would be most useful for IAMs. If the organisms provide human food, then human health concerns might also be used as assessment endpoints.

Measurement endpoints at the individual scale are typically used at CERCLA sites. For individual mortality, for example, the median lethal concentration (LC50), the threshold for mortality in a cohort (LC01), and the no observed effect level (NOEL) are typically used. Death, reproduction, and growth of individuals can then be extrapolated to populations or ecosystems by the use of standard models. Overt symptomology (visible effects such as spinal deformities in fish and chlorosis of plant

leaves), biomarkers (biochemical, physiological, and histological indicators of exposure or effects), and tissue analysis of contaminant concentrations are diagnostic of exposure to specific classes of contaminants and are widely used. Only tissue analysis methods have been standardized. Behavioral responses are very difficult to measure in the field or laboratory, difficult to interpret, and are not standardized.

At the population scale, occurrence, abundance, age structure, birth and death rates, and yield are typically measured. Occurrence and abundance are easily measured in the field. Age structure, birth and death rates, and yield are more difficult to measure during relatively short field studies. Although there are accepted methods for population measurements, they are generally not standardized. The frequency of mass mortalities (such as fish kills) and the frequency and nature of overt morbidity are also used, but methods for measurement are not standardized. The mobility of populations at a waste site makes interpretation of data more difficult and should also be considered.

At the community scale, the number of species, species evenness, and species diversity are typically used as measurement endpoints. Although these parameters are easily measured, the methods are not well standardized and changes in the community might not be significant or measurable even though one or two important populations (species) are being impacted. Indices of generic community quality are sometimes used and incorporate information on physical habitat effects as well as pollution effects. These types of indices incorporate all of the information on the community into one number. Indicator species that are sensitive to the contaminants of concern are also sometimes used as measurement endpoints.

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Ecosystem measurement endpoints typically include biomass and productivity of the system or its components and nutrient dynamics. Ecosystem parameters are generally difficult to measure, difficult to interpret, and no standardized methods exist. Often it is useful to develop a conceptual framework or model of the important contamination sources, transport pathways, exposure points, and ecological receptors and effects at a site in order select appropriate endpoints and sampling and analysis methods and to generally perform a cost effective ecological assessment. A tiered or phased approach to the assessment might also be effective for some sites that is dependent on the initial and subsequent information required and available resources. The information derived from the initial phases is fed into the subsequent phases so that limited resources are used in an optimal manner.

E.2.1.1 Toxicity Tests

Toxicity tests are used to measure the effects of contaminated media from the site on the survival, growth, and/or reproduction of aquatic biota. Samples of water and bed sediment are typically collected and submitted to the laboratory for testing with several standard test organisms. Ceriodaphnia and fathead minnow are typical test organisms. Although toxicity tests are sometimes performed in situ or with resident organisms from the site, this is usually not necessary as long as the laboratory test organisms are representative of the resident organisms. Three measurement endpoints are derived from toxicity tests:

1. percent survival of the test organisms in 100% site sample in laboratory tests or in situ exposures

2. a concentration-percent survival relationship for laboratory tests run at several test concentrations of the surface water or sediment

3. estimates of LC50s (mortality), EC50s (growth and reproduction), and other

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parameters

Toxicity tests provide a measure of the integrated effects of bioavailable contaminants and establish the link between elevated concentrations and biological effects. Evaluation of ecological effects, however, still requires a biological survey. Strong evidence exists for metals impacts to the aquatic community if a correlation exists between locations of toxicity and ecological impacts. Methods for toxicity tests are well developed and standardized with stringent QA/QC procedures.

Depending on the length of the exposure of the test organism to the contaminated media, toxicity tests are classified as either acute or chronic. Acute tests are best for initial evaluation of toxic conditions at a site because they are easy, quick, and inexpensive. However, they are also less sensitive to toxicity than chronic tests. Chronic tests, therefore may also be required in many cases to assess less toxic, but still problematic conditions.

E.2.1.2   Biomarkers

Measurements of bioaccumulation or chemical concentrations in organisms are a biomarker of exposure and sublethal stress. Other biomarkers include concentrations of enzymes, genetic abnormalities, physiological responses such as rates of gas exchange in plants, and histopathological (tumors) or skeletal abnormalities. Use of biomarkers has broad applicability among taxonomic levels and has relevance to the assessment of potential hazards to human health. Field and laboratory measurements can be made using the same methods. The information derived from these tests, therefore, is comparable.

Standardized or accepted biomarkers are not available for many contaminants of interest at IAMs. In addition, it is difficult to establish a relationship between a

biomarker and a population-level effect. Therefore, their use is most applicable when in conjunction with toxicity tests and biological surveys.

E.2.1.3   Biological Surveys

Biological surveys measure the structure and function of populations and communities at a site, and are the only method to measure actual ecological effects at the population and community scale. The cause of the effects, however, can only be determined by combining biological surveys with chemical sampling, toxicity testing, and biomarkers. Because of significant natural variability in spatial and temporal conditions, the results of surveys can be difficult to interpret with regard to effects of contamination versus natural variability. Periphyton, plankton, macroinvertebrates, and fish are typically measured. Structural endpoints include relative abundance, species richness, community organization (diversity, evenness, similarity, guild structure, and presence or absence of indicator species), and biomass.

Species richness is the number of species in a community. Relative abundance is the number of individuals in any given species compared to the total number of individuals in the community. These parameters are measured by sampling known substrate area or water volumes. Rapid bioassessment methods measure these parameters only to the family and genus instead of the species level to reduce costs and time requirements, especially for invertebrates.

Biomass is the mass of tissue in an individual, population, or community at a given time. This can be measured gravimetrically on a dry or wet basis, but direct measurement of individuals or biomass is time consuming or impossible. Therefore, pooled samples of individuals or indirect methods are used. The biomass of periphyton is typically measured, while the biomass of invertebrates and fish is not.

Indicator species have been used to assess adverse impacts to ecological communities. The presence or absence of sensitive species that respond negatively to pollutants is used as a measure. Although this method has been used for conventional pollutants, it lacks broad applicability to metal contamination because some sensitive species exposed for long periods become more tolerant of the pollution over time. The indicator species approach is particularly useful, however, when species upstream of the waste site or in unimpacted areas are used as indicators.

Indices simplify data for interpretation or presentation, and can be classified into several different types:

- evenness - measuring how equitable individuals in a community are distributed among the taxa present

- diversity - calculating the abundance of individuals in one taxon relative to the total abundance of individuals in all other taxa

- similarity - comparing likeness of community composition between two sites

- biotic indices - examining the environmental tolerances or requirements of individual species or groups

Indices should be used with caution and in conjunction with other structural endpoints. Statistical assumptions of independence, normality, and homogeneity of variance are frequently violated for these measures. Therefore, statistical transformations or rank-order statistics are recommended (USEPA, 1989b).

Guilds are functional feeding groups in a species and are classified based on how biota obtain their food and energy. For example, fish can be classified as omnivores, insectivores, and piscivores. Changes in community guild structure also represent changes in the trophic-dynamic status of the aquatic system. Changes within guilds

can also occur, but must be fairly significant to be able to be measured.

Many of the data analysis methods that can be used for biological data are similar to those discussed in Section 6 for chemical data. A correlation between biological survey data and the toxicity and chemical data is a strong indication of causality and impacts from a waste site. The strength of the correlation can be evaluated with several statistical methods including regression and nonparametric methods. Plots of toxicity and ecological data versus distance can also be used to locate potential source areas and impacted stream segments. Comparisons of biological information between upstream or unimpacted areas to downstream impacted areas can also be made. Patterns can be observed using these methods providing evidence of causality.

Statistical methods can include correlation, multiple regression, analysis of variance, the nonparametric equivalents of these methods, and comparisons of *cdf*s. Like for chemical data, the uncertainty in the biological data and in the statistical results should be estimated explicitly so that the confidence in the derived information can be used in the decision-making process.

Spatial data analysis methods and GIS are useful for many types of biological information. Maps can be used to plot sampling locations and display spatial patterns using point display methods for spatially discontinuous data and three-dimensional surfaces for continuous data using contours, isopleths, or perspective plots. Simple x-y scatter plots are very useful for visually evaluating the relationships or correlations between variables and identifying nonlinear patterns and outliers. A glyph plot is very similar to a standard x-y scatter plot except that information is conveyed not only by the coordinates but by the use of symbols. Glyph plots are

used to convey information by changing the appearance of a pictograph, and can be used in a coordinate-free manner to visually present multivariate data. Surface methods can be used to represent measured values on a smoothly varying continuous surface using a three-dimensional perspective plot or contours. Interpolation of values between measured points is performed for these methods, usually using specialized computer software. Typical methods of spatial interpolation include Thiessen polygons, spatial splines or polynomial interpolation, distance weighted least squares, and spatial stochastic processes or kriging.

E.2.2   Cement Creek Aquatic Ecologic Data Gaps

Very limited aquatic ecologic data have been collected in Cement Creek by the Colorado Division of Wildlife as part of the CDPHE study. Data collected are limited to fish and benthic macroinvertebrate species and abundance in the main stem of Cement Creek. The data show that no fish currently live in Cement Creek, and that macroinvertebrate populations do exist but are not healthy. Even these limited ecologic data, based somewhat on limited biologic activity, show that the stream is severely impaired, significant loadings of toxic metals probably come from sources within the Cement Creek basin, and that restoration of the aquatic system would be difficult to achieve.

The primary aquatic ecologic data gaps for Cement Creek include the toxicity of both water and bed sediment to fish and macroinvertebrates. Information on the physical habitat in the stream would also be useful with regard to its ultimate use attainability. Given the ecologic degradation of the stream, however, the toxicity of dissolved metals is fairly obvious and the physical characteristics of the channel are not likely impairing aquatic life to any significant degree. This type of information,

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therefore, is not critical to the current assessment of the creek. If Cement Creek is to be targeted for restoration in the future, however, additional and more detailed aquatic ecologic information will be required.

LIST OF ACRONYMS AND ABBREVIATIONS

AMD	acid mine drainage
AML	abandoned mine land
ARARs	applicable and/or relevant and appropriate requirements
ASCII	American Standard Code for Information Exchange
BMP	best management practice
CCEM	Colorado Center for Environmental Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
cdf	cumulative distribution function
CDNR	Colorado Department of Natural Resources
CDPHE	Colorado Department of Public Health and Environment
CHIA	cumulative hydrologic impact assessment
CI	confidence interval
CN	curve number
CNE	curve number equation
CWA	Clean Water Act
DAP	data analysis protocol
DO	dissolved oxygen
DOC	dissolved organic carbon
EC50	median concentration affecting growth and reproduction
ERA	ecological risk assessment
GIS	geographic information system
HRS	hazard ranking system
HSI	habitat suitability index
IAM	inactive and abandoned mine
IDEQ	Idaho Department of Environmental Quality
IQ	interquartile range
LA	load allocation
LC01	threshold for mortality in a cohort
LC50	median lethal concentration
MDL	method detection limit
MUSLE	modified universal soil loss equation
NOEL	no observed effect level
NPDES	National Pollutant Discharge Elimination System
NPL	national priorities list
NPS	nonpoint source pollution
NURP	Nationwide Urban Runoff Program
OTA	Office of Technology Assessment
PA/SI	preliminary assessment/site inspection
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study

RUSLE	revised universal soil loss equation
SARA	Superfund Amendments and Reauthorization Act
SMCRA	Surface Mining Control and Reclamation Act
TBELs	technology-based effluent limitations
TDS	total dissolved solids
TMDL	total maximum daily load
TRA	Taos Resource Area
TSS	total suspended solids
TVS	table value standard
UMTRCA	Uranium Mill Tailings Reclamation and Control Act
USBLM	U.S. Bureau of Land Management
USBM	U.S. Bureau of Mines
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USLE	universal soil loss equation
USNPS	U.S. National Park Service
USSCS	U.S. Soil Conservation Service
WET	whole effluent toxicity
WGA	Western Governors' Association
WLA	waste load allocation
WQBELs	water quality-based effluent limitations