RESEARCH

Assessment of Nonpoint Source Pollution from Inactive Mines Using a Watershed-Based Approach

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ABSTRACT / A watershed-based approach for screening-level assessment of nonpoint source pollution from inactive and abandoned metal mines was developed and illustrated. The methodology was designed to use limited stream discharge and chemical data from synoptic surveys to derive key information required for targeting impaired waterbodies and critical source areas for detailed investigation and remediation. The approach was formulated based on the required attributes of an assessment methodology, information goals for targeting, attributes of data that are typical of basins with inactive mines, and data analysis methods that were useful for the case study. The methodology is presented as steps in a framework including evaluation of existing data/information and identification of data gaps; definition of assessment information goals for targeting and monitoring design; data collection, management, and analysis; and information reporting and use for targeting. Information generated includes the type and extent of and critical conditions for water-quality impairment, concentrations in and loadings to streams, differences between concentrations in and loadings to streams, and risks of exceeding target concentrations and loadings. Data from the Cement Creek Basin, located in the San Juan Mountains of southwestern Colorado, USA, were used to help develop and illustrate application of the methodology. The required information was derived for Cement Creek and used for preliminary targeting of locations for detailed investigation and remediation. Application of the approach to Cement Creek was successful in terms of cost-effective generation of information and use for targeting.

Integrated watershed management for water resource protection and improvement is generally considered a relatively new and effective approach for environmental management. The US Environmental Protection Agency (USEPA) and other organizations have been recommending and using a watershed, geographic, or ecosystem approach to achieve broad water-quality management goals across the United States (USEPA 1975, 1977, 1991a, Warren 1979, Lotspeich 1980, Maas and others 1987, WGA 1991, CCEM 1993). However, it is often difficult to define site-specific watershed and water-quality objectives based on broad goals and to achieve objectives using a watershed approach within the framework of existing regulations and increasingly limited resources. A specific *regulatory* approach for management of watersheds and comprehensive control of point source and nonpoint source (NPS) pollution within them has not been implemented. NPS pollution can be defined as pollution originating from diffuse sources associated with land and human use of it, that is usually intermittent, and that does not fall under the regulatory definition of a point source (WPCF 1990).

KEY WORDS: Water quality assessment; Nonpoint source pollution; Inactive mines; Watershed

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Many mountainous basins in the western United States have large historic mining districts with inactive and abandoned mines (IAMs) causing widespread water-quality problems (USEPA 1987, 1991b, WGA 1991, CCEM 1993). These metal (or hardrock) mines contribute acidic drainage, sediment, and metals from NPS areas, such as waste rock and tailings, to receiving streams, thereby impairing beneficial uses of the waterbodies. Impacts of toxic metals on the water quality, aquatic life, and ecological integrity of mountain streams are the most common and severe. Increasing outdoor recreation and population growth into mountain areas also increases the risk of exposure of the public to hazardous mine waste and public concern over IAM problems.

No comprehensive national program currently exists for management of IAMs, and no federal environmental regulations directly address the vast majority of these sites (WGA 1991, CCEM 1993). Attempts to address IAMs are limited and not well coordinated among federal and state agencies, and assessment and management approaches vary considerably. IAM management goals, and assessment information goals and methods using a watershed-based approach, have not been well defined. Resources (time and money) needed for effective management are currently insufficient, and much of the existing data are incomplete and inconsistent among agencies and basins (WGA 1991, CCEM 1993). In cases were funding is available, limited synoptic surveys are often initially performed for the collection of streamwater chemistry and discharge data at key locations during important times of the year, such as during high and low flows (see CDM 1990, Ridolfi 1991).

Prioritization or targeting of impaired waterbodies and critical NPS areas in IAM watersheds is required for effective management (USEPA 1987, 1991b, WGA 1991, CCEM 1993). Targeting has been used successfully in many agricultural basins, and involves identifying the predominant pollutant sources, prioritizing the sources, and first treating those sources that contribute most to the stream impairment (Maas and others 1987, Adler and Smolen 1989). Targeting can aid in achieving the greatest public benefit given limited resources, help build consensus on priorities, be based on water-quality and socioeconomic considerations, and help organization and interpretation of data. Targeting should be based on four criteria: (1) type and severity of water resource impairment, (2) source magnitude considerations, (3) transport considerations, and (4) project specific criteria and goals (including socioeconomics) (Maas and others 1987).

A cost-effective methodology for screening-level assessment of critical NPS areas and impaired waterbodies in IAM basins is required to enable targeting of locations for detailed investigation and remediation. The goal of this study was to develop and illustrate a watershed-based methodology for deriving the key information needed to rapidly assess NPS pollution and target areas in watersheds impacted by IAMs. The methodology is designed to derive as much information as possible from the limited stream chemistry and discharge data that are typically collected during synoptic surveys, early in the assessment process. Data from a case study watershed (Cement Creek Basin) was used to help develop the methodology and illustrate application of the approach. Development of the methodology included reviewing literature on IAM and NPS problems; discussing the issues with key personnel from organizations involved in IAM management to help define required attributes of the methodology, assessment information goals, and monitoring design; data collection; evaluation of data attributes; data analysis; evaluation of results and preliminary targeting; and formulation of the methodology.

The methodology presented here could be used in conjunction with biological and ecological assessment methods to evaluate important cause–effect relationships and applied to other types of basins with NPS problems for screening-level assessment and targeting. The biological health of waterbodies is increasingly being monitored and assessed by USEPA (1989, 1990) and other organizations, particularly at the screening level. These approaches, such as rapid bioassessment protocols (USEPA 1989) and the index of biological integrity (IBI) for fish (Karr 1981, Karr and others 1986), can be very valuable and cost-effective because they directly evaluate the long-term condition of waterbodies and integrated effects of NPS loadings on biota (Karr and Dudley 1981, 1987). However, biological data are often not collected during initial assessment of IAMs and were not collected by agencies during initial synoptic surveys of the case study basin.

Methods

We reviewed literature on IAM and NPS problems and discussed the issues with key individuals from several federal and state agencies and other organizations involved with IAM and NPS management. Organizations included US EPA Region VIII, US Forest Service, Bureau of Land Management, Bureau of Mines, US Geological Survey (USGS), Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Division, Colorado Department of Natural Resources Division of Minerals and Geology, Colorado Center for Environmental Management, and the Western Governors' Association. Results were used to define required attributes of an effective assessment methodology and screening-level assessment information goals that are common among agencies. Required attributes have been recommended by many organizations (Colorado Department of Natural Resources 1982, WGA 1991, CCEM 1993, CDPHE 1993a) and include using the following: a geographic or watershed approach, targeting, a consistent methodology to provide consistent and comparable data, a phased approach, and water-quality management goals and an environmental risk-based approach as a basis for assessment and targeting. In addition, the uncertainty associated with the information derived from assessment should be evaluated quantitatively and used explicitly in the decision-making process.

The environmental risk-based approach includes estimating the probability or frequency of occurrence of some detrimental impact to ecological receptors, such as the probability of an acute toxicological effect (such as death) to a specific proportion of a fish

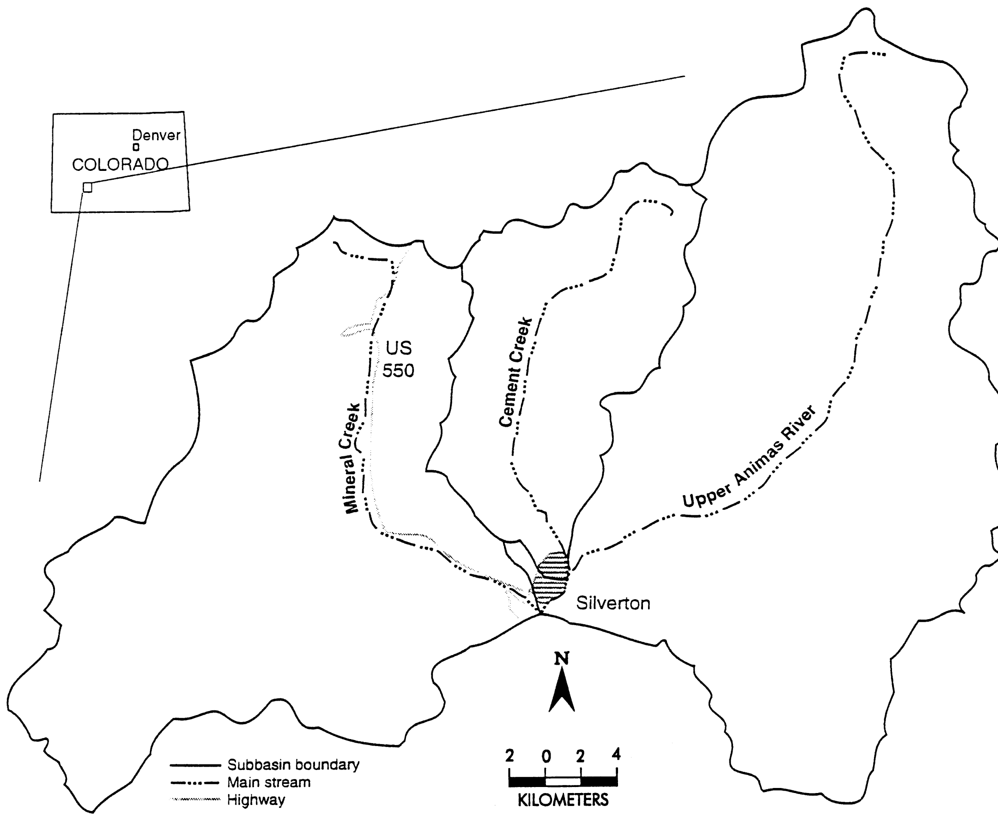

Figure 1. Upper Animas River Basin and Cement Creek Basin location.

population, due to a given metal concentration. It also provides an explicit measure of the uncertainty associated with estimates of concentrations and loadings, thereby providing estimates of the confidence in the data, information, and management decisions (USEPA 1984, 1992a,b).

Study Area

The Upper Animas River Basin is an historic metal mining district whose streams have been severely impacted by mine drainage. It is located immediately north of Silverton in the San Juan Mountains of southwestern Colorado, and is one of the most heavily impacted basins in the state. The watershed has an area of approximately 378 km^2 and ranges in elevation from 2800 m to over 4000 m. Alpine tundra and Engelmann spruce–fir forest are the dominant plant community types. The watershed is composed of three primary subbasins (Figure 1): the Upper Animas River Basin, Mineral Creek Basin, and Cement Creek Basin (53 km^2). Cement Creek joins the Animas River at Silverton and is believed to be the most heavily impacted subbasin. CDPHE designated the mainstem of Cement Creek and all of its tributaries as one stream segment with a common beneficial use classification (cold water fish habitat) and associated water-quality standards. The current water-quality standards for dissolved metals are the ambient concentrations defined as the values of the 85th percentiles of the frequency distributions for observed concentration data (CDPHE 1992a, 1993b). These standards, however, are not adequate to protect aquatic life in Cement Creek or downstream waterbodies.

Cement Creek was used as a case study to help develop a screening-level assessment methodology that could be applied to other IAM basins and to support management of the Cement Creek and Upper Animas River basins. One of the primary concerns regarding the creek is its metals loadings to the Upper Animas River, resulting in impairment of cold water fish habitat and recreational uses, such as fishing and swimming. The Upper Animas River supports a viable fish population that can likely be improved and has been targeted by CDPHE for restoration and attainment of desired beneficial uses (Parsons, CDPHE, personal communication, 1993). Brown trout (*Salmo trutta*) are being targeted for protection and enhancement. Remediation of NPS and point sources in the Cement Creek Basin is necessary for restoration of the Upper Animas River downstream from the creek. Because insufficient data

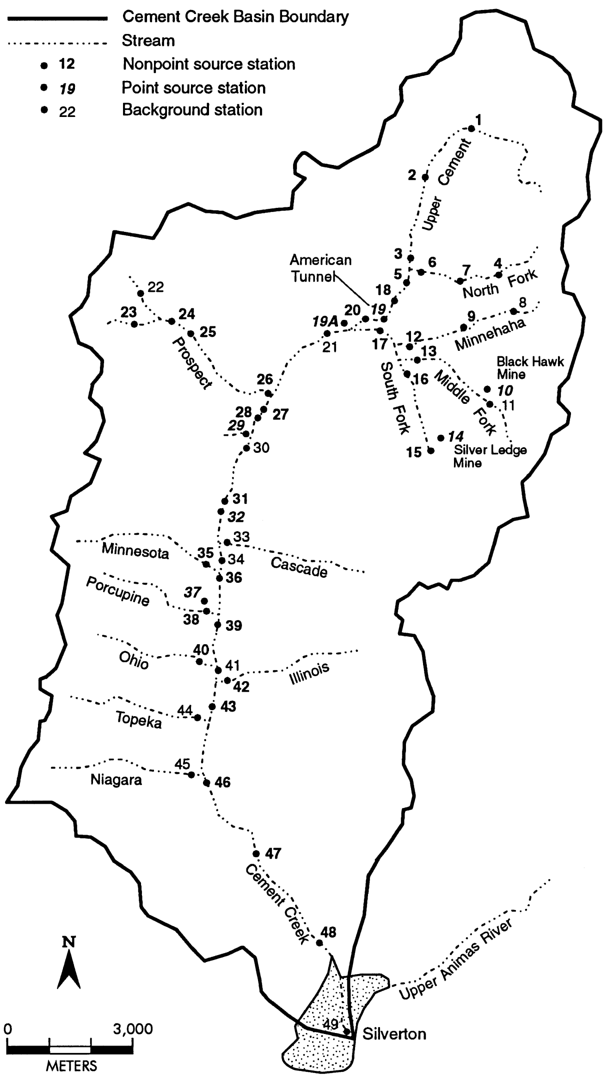

Figure 2. Cement Creek Basin monitoring stations.

were available for assessment and management of the basins, data were initially collected in all the basins by CDPHE as part of a NPS demonstration program grant (Clean Water Act Section 319) for approximately $250,000 from USEPA (CDPHE 1992b, 1993a).

Information Goals and Monitoring Design

Monitoring or assessment information goals are qualitative statements that describe specific information expectations, and statistical or quantitative information goals are complete and specific statements that explain the quantitative (and statistical) intent that should directly reflect the assessment information goals (Ward and others 1990, Adkins 1993). Four screening-level assessment information goals were defined based on the targeting criteria and are common to most agencies and IAM watersheds (Caruso 1995): (1) type and extent of and critical conditions for water-quality impairment, (2) magnitudes of concentrations in and loadings to streams, (3) differences in magnitudes between concentrations in and loadings to streams, and (4) risks of exceeding target concentrations and loadings. Levels of confidence in the data and information were also required. This information was needed at several temporal and spatial scales, which influence monitoring design and choice of data analysis methods (Loftis and others 1991). Temporal scales included instantaneous, daily, seasonal, annual, and various recurrence intervals of extreme events. In general, information was required for three flow events: baseflow, snowmelt, and stormflow. Spatial scales included individual monitoring stations, stream segments, individual sources, individual subbasins, types of sources (NPS, point sources, and background sources), and entire watersheds (Caruso 1995).

Forty-nine stations were used in the Cement Creek basin to monitor NPS areas, point sources, and background areas (Figure 2). Stations were selected and categorized by type of source monitored using field reconnaissance, detailed topographic maps, and aerial photographs. Point sources included draining adits and the ore processing wastewater discharge at the American Tunnel (station CC19). Some stations were located at point sources to measure the discharges directly. NPS areas included areas with substantial extent of waste rock, tailings, and other disturbed and eroded areas that exhibit diffuse discharges. Background areas were defined as areas that had minimal impacts from mining activities, including no observed point sources and a very small extent of NPS areas. Some stations were located in headwaters to monitor small NPS or background subbasins, and other stations were located at the mouths of main tributaries to monitor large subbasins and loadings to the mainstem. Many stations were located immediately upstream and downstream from (bracketing) NPS areas near or adjacent to channels of tributaries and the mainstem. Station CC49 was located at the mouth of Cement Creek to monitor outputs from the entire basin. Station CC48 was instrumented with a USGS gaging station during the fall of 1991.

Loading estimates (grams per day) for a given station were a summation of the loadings at any stations immediately upstream, loadings from the subarea in between the upstream and given downstream stations, and losses of mass along the stream reach (Figure 3). A subarea was defined as an drainage area contributing to a station where no other stations existed upstream (subbasin), or where one or more adjacent upstream stations formed the upstream boundary of the contributing area. Net gains or losses along the stream reach

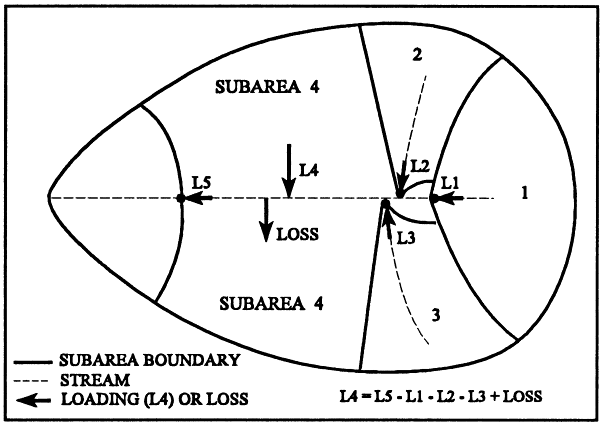

Figure 3. Schematic diagram of loadings from subareas and loss from stream reach.

between the stations were estimated by subtraction; if the loading at the downstream station was less than the total loadings at the upstream stations, an overall loss of mass along the channel was inferred (CDM 1990, CDPHE 1993a). For dissolved metals, this loss could be attributed to infiltration to groundwater, adsorption to or precipitation on solids, or biotic uptake. In these cases, a loading of zero was assigned to the subarea between the stations. This was considered to be an estimate of the lower limit of the loading to the stream from the subarea (i.e., the loading is unknown but must be greater than zero). Therefore, this method could not be used to distinguish between loadings from subareas and losses along the reach between stations. However, it was used to identify locations where losses of metals occurred in streams and downstream transport was reduced. This information was needed to identify sinks for metals, and upstream NPS source areas that might not be significantly impacting downstream waterbodies.

Information on unit area loadings (grams per hectare per day) from subareas was also required because loading is a function of discharge, and discharge is a function of area. Loadings from subareas were normalized by dividing by the areas. Unit area loadings represented the intensity of the source areas and provided information on where the most cost-effective remediation could potentially be performed.

Quantitative information on magnitudes of concentrations in and loadings to streams that is needed by most agencies is presented in Table 1. For concentrations, information is required for individual stations and entire stream segments. Information is also needed on daily and total (kilograms) loadings from all sources at all spatial scales. In addition, information is required on daily and total (grams per hectare) unit area loadings from all sources except point sources. Values

Table 1. Quantitative information goals for magnitudes of concentrations in and loadings to streams

Concentrations for each flow event and for all events
Mean and associated 90% and 95% confidence intervals (CIs)
Median, 85th percentile, and CIs
Standard deviation and CI
Minimum and maximum values
Loadings
Daily loading for each flow event
Mean daily loading for all events and 90% CI
Total loading for each flow event and for all events
Proportion of daily and total loadings from a specific source relative to loadings from all sources for each flow event and for all events
Proportion of total loadings for each flow event relative to total loading for all events from a specific source
Standard deviations of daily and total loadings and 90% CIs for all events
Minimum and maximum values
Unit area loadings
Mean and median daily unit area loading and CIs for each flow event and for all events
Total unit area loading for each flow event and for all events
Proportion of total unit area loadings for each flow event relative to total unit area loading for all events from a specific source
Standard deviations of mean daily and total unit area loadings and 90% CIs for all events
Minimum and maximum values

for all events (or for a year) are problematic because of the potential significant seasonality in discharges and concentrations. However, most ambient numeric water-quality standards are established on an annual (not seasonal) basis. Most water-quality criteria based on toxicological effects are independent of season.

Quantitative information on magnitudes of differences is required for mean concentrations in different streams. Information on differences is also needed for daily and total loadings from different sources for all spatial scales. With the exception of point sources, information on differences is also required for mean daily and total unit area loadings from different sources. Information is needed for each flow event and for all events. In most cases, information on relative differences is more important than absolute magnitudes of differences.

Quantitative information on risks of exceeding target concentrations or water-quality criteria in streams is required, especially for establishing ambient stream standards (for Cement Creek, the 85th percentile of observed concentrations). Information on risks of exceeding target loadings to streams, such as a total maximum daily load (TMDL), is also needed. A TMDL can be defined as the maximum daily loading of a pollutant from all point, nonpoint, and background sources that does not result in a concentration in the receiving waterbody that exceeds the water-quality standard (USEPA 1991a). Risk information is required at the different spatial scales of interest for each flow event and for all events. The 90% or 95% confidence intervals (*CI*s) for risk values are also needed to evaluate uncertainties.

Measurements

CDPHE collected data as part of synoptic surveys during four flow events: (1) stormflow (7 September 1991); (2) snowmelt flow (24 June 1992); (3) baseflow (14 October 1992); and (4) receding limb of snowmelt flow (21 July 93). The fieldwork was a cooperative effort by several state and federal agencies. One measurement was made at a station for each flow event. Forty-one stations were sampled (41 samples collected) for the storm event, and 40 stations were sampled for snowmelt. However, only 17 stations were sampled for baseflow because many streams are ephemeral and had no water flowing at that time. Stream width- and depth-integrated samples were collected using a US DH-48 suspended sediment sampler and were filtered in the field with a 0.45-μm filter for subsequent analysis of dissolved metals. These samples were acidified with nitric acid to $pH < 2$ and cooled to 4°C using blue ice in a cooler for transport. Samples were analyzed at the CDPHE laboratory in Denver, Colorado, using atomic absorption spectroscopy within six months after collection. Analytes included aluminum, arsenic, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc. The dissolved zinc practical quantitation limit was 4 μg/liter. Total recoverable metals were also analyzed for a subset of stations using unfiltered samples. Calcium and magnesium were analyzed for estimation of hardness (milligrams per liter as calcium carbonate). Indicator parameters, including alkalinity and total suspended solids, were also measured, and pH, temperature, and specific conductivity were measured in the field. Stream discharge was estimated by the velocity–area method using a pygmy current meter (CDPHE 1992b).

Data Analysis

Summary statistics for each metal were computed, including the mean, median, and maximum concentrations and frequencies of exceedances of water-quality criteria. The criteria used were USEPA national acute and chronic criteria for aquatic life (CDPHE 1991). It was hypothesized that it would be cost-effective to use an indicator or representative metal to develop the screening-level assessment methodology and facilitate targeting. Dissolved zinc was selected and used as an indicator because it had the highest values relative to the criteria and the greatest frequency of criteria exceedances. The dissolved form of zinc, which is the primary bioavailable form, also accounted for more than 94% of the total zinc concentrations in the basin for all events. Many NPS areas exhibited high zinc levels (CDPHE unpublished data), and elevated concentrations of other metals in streams were correlated with high zinc concentrations (Caruso 1995). However, use of an indicator and analyses of a limited number of analytes (including only the dissolved form) must not result in missing important pollutants or impacts. In some catchments, for example, loadings of particulate metal forms (measured partially in total recoverable and total analytical methods) can be important. Particulate metals can contribute to total loadings, deposition and accumulation on streambed material, toxicological and physical effects on aquatic life, and other downstream impacts. Deposited particulate forms can be toxic to benthic macroinvertebrates and can redissolve over time, thereby increasing dissolved concentrations in the overlying water column (Martin and Mills 1976).

For each water sample (each station and flow event), the cumulative dissolved zinc daily loading was computed as the product of concentration and discharge (cubic meters per second). Daily loading for each subarea and flow event was also estimated by subtraction of loadings between adjacent upstream and downstream stations. Daily unit area loading for each subarea and flow event was then computed by dividing the loading by the subarea. Total loadings and total unit area loadings for each flow event (flow regime) were estimated by multiplying daily loading by the estimated number of days for each flow regime. Using the annual discharge hydrograph from the USGS gaging station at CC48, it was estimated that baseflow occurred for approximately 238 days, snowmelt occurred for 80 days, and stormflows occur, on average, 47 days during a year (Caruso 1995). Concentrations, loadings, and unit area loadings for individual stations and subareas were overlaid on site base maps.

Because data attributes affect selection of data analysis methods and interpretation of results (Ward and others 1990, Adkins 1993), an evaluation was performed of the important attributes of dissolved zinc concentration and unit area loading data from the Cement Creek basin and how to handle the attributes for subsequent data analysis. Attributes of typical IAM data that were evaluated included measurement error and uncertainty, sample size, nonnormality, and seasonality (Adkins 1993). Estimates of potential measurement error and uncertainty for concentrations and discharges were based on published values (USGS 1977, Hem 1986) and field and laboratory quality assurance/quality control (QA/QC) measurements performed by CDPHE (1992b). The uncertainty estimates for concentrations and discharges, in conjunction with the methods presented by Bevington (1969), were used to estimate the uncertainty for loadings at a station. Skewness tests and normal probability plots were used to evaluate nonnormality. Multiple boxplots were used to evaluate seasonality by assessing the degree of overlap between plots (Ward and others 1990, Adkins 1993). Hypothesis or significance tests, such as *t* tests and analysis of variance, were not used to evaluate differences between seasons or flow events because they have shortcomings with regard to decision making and are generally not recommended (McBride and others 1993). The primary problem with hypothesis tests is that a "significant" difference will always be detected if the sample size is large enough, and such a detected significant difference has no relationship to a difference that is important from a management perspective (McBride and others 1993).

Because sample size (n) influences applicable data analysis methods and the associated confidence in information (Loftis and Ward 1980), the effect of n on the confidence in estimates of the annual mean dissolved zinc concentration was evaluated. The confidence (in terms of the half *CI* width divided by the mean) in estimates of the annual mean at each station with $n = 4$ was estimated, and the mean of all these values was then computed. The effect of increasing n associated with increasing monitoring frequency was evaluated by increasing n to more than 40 over an approximately one-year period at two stations where data were available: at the mouth of Mineral Creek, and on the Upper Animas River immediately downstream from the confluence with Mineral Creek. The effect of increasing n associated with increasing spatial scale was evaluated by increasing n to more than 40 with aggregation of data from stations in the mainstem of Cement Creek for all events.

Magnitudes of concentrations in, and loadings and unit area loadings to, Cement Creek were estimated based on the quantitative information goals presented in Table 1. Locations where dissolved zinc concentrations exceeded USEPA national acute and chronic criteria for brown trout were identified by comparing individual values with the criteria. These are hardness-based criteria computed using the following formulas (CDPHE 1991):

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

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

and the corresponding hardness measured for each sample. The minimum, median, and maximum hardness values for all stations and all events were 11, 140, and 1141 μg/liter, respectively.

Magnitudes of differences and relative differences were estimated for mean dissolved zinc concentrations in upstream and downstream reaches of Cement Creek because it was hypothesized that upstream reaches were more heavily impacted by mine waste. For this analysis, therefore, the creek was divided into two segments: an upstream segment extending from the headwaters to Station CC30, and a downstream segment from CC30 to the mouth. Differences were also estimated for magnitudes of loadings to Cement Creek from NPS subareas and point sources, and for magnitudes of unit area loadings from NPS subareas and background subareas, because it was not known which type of source contributed the greatest loadings to the creek. Magnitudes of differences and relative differences were estimated for each flow event and for all events.

A nonparametric approach was used to estimate the cumulative distribution functions (*CDF*s), based on the observed cumulative frequency distributions, for dissolved zinc concentrations in Cement Creek for each flow event and for all events (Loftis and Ward 1981, Caruso 1995). Data were aggregated over space to estimate *CDF*s for each flow event, and over time and space to estimate the *CDF* for all events. The following equation was used:

$$F_n(x_0) = m/(n + 1)$$

where $F_n(x_0)$ is the *CDF* of dissolved zinc concentration; x_0 is the target dissolved zinc concentration; m is the number of observations less than or equal to x_0; and n is the total number of observations.

The cumulative frequency distribution plots were used to establish ambient water-quality standards for dissolved zinc and to estimate the risk of not exceeding, or inversely, exceeding target concentrations and/or national water-quality criteria. By definition, there was a 15% risk that the ambient water-quality standards (the 85th percentiles of the frequency distributions) would be exceeded if a sample was collected at a randomly selected location in the stream at any time during the period monitored (CDPHE 1991, 1992a). As part of the nonparametric method for developing *CDF*s, the concentration data were ranked in descending order for each flow event and for all events. The nonparametric approach was also used to estimate *CDF*s for mean daily unit area loadings to Cement Creek from all subareas for each flow event and for all events. Subarea loadings and unit area loadings were also ranked in descending order.

Results and Discussion

Data Attributes

For the Cement Creek study, CDPHE estimated an average or potential relative uncertainty (error) for each discharge measurement equal to 0.15 (discharge was measured to within 15%) and an average relative uncertainty for each concentration measurement equal to 0.1. Using these values and the methods presented by Bevington (1969), the relative uncertainty for each measured loading was 0.18. Loadings estimated for subareas between stations had higher relative errors compared to the measured loadings. These errors were sometimes higher than the estimated loadings themselves, thereby reducing confidence in the loadings. However, the analysis provided important information on locations and general magnitudes of loadings to and losses from Cement Creek.

The average confidence in estimates of the annual mean concentration at individual stations with $n = 4$ was approximately $\pm$50% of the mean. The confidence increased to between $\pm$15% to 25%, depending on the station, as n increased to more than 40 with frequent monitoring at each of the stations at the mouth of Mineral Creek and on the Upper Animas River immediately downstream from the confluence of Mineral Creek. As n increased with increasing spatial scale using data aggregated from additional stations in Cement Creek, the confidence in the mean also increased. However, at the largest spatial scale aggregating data from all stations in the mainstem, the confidence decreased. This resulted from a greater increase in the spatial variability (variance) associated with the increasing spatial scale relative to the increase in n.

Skewness tests and normal probability plots using data aggregated from all stations showed that concentration and unit area loading data for each event and for all events were nonnormal. The logarithm of unit area loading data for all events approximated normality, but the logarithm of concentration data for each event and for all events did not.

Multiple boxplots indicated that seasonality in dissolved zinc concentrations existed between snowmelt and baseflow and between snowmelt and the storm event flow, but not between stormflow and baseflow (Figure 4A). These results could vary among storms because these events are highly variable and could have different effects on contaminant concentrations and loadings. Seasonality in unit area loadings was also present between all flow events (Figure 4B). Snowmelt exhibited the greatest loadings and generally the lowest concentrations. The lower concentrations probably resulted from dilution with higher flows. Baseflow had the lowest loadings and generally the highest concentrations. Stormflow was intermediate between snowmelt and baseflow. Concentration and loading values for all of the flow events are presented below as part of the discussion on magnitudes of concentrations and loadings.

Type and Extent of and Critical Conditions for Water Quality Impairment

The primary type of beneficial use impairment for Cement Creek is degradation of 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 adversely affected by metals contamination (CDPHE unpublished data). It is not yet known whether the creek could support a viable fish population even if the mining waste problems were remedied due to natural potentially high loadings and concentrations of toxic metals from mineralized sources. Recreational uses, including fishing and swimming, are also precluded.

Dissolved zinc is the primary constituent of concern in Cement Creek: it had the highest concentrations relative to national acute and chronic criteria for aquatic life, and the greatest frequency of exceedances of the criteria. More than 94% of the zinc was in the dissolved, or bioavailable, form for all events. This was partly the result of the relatively low pH of the creek (median pH was approximately 4.9, and 85% of the values were below 7.0). Iron is another potential detriment to aquatic life in Cement Creek as a result of precipitation and adsorption onto the streambed (Owens, CDPHE, personal communication, 1994).

Conditions critical to aquatic life occur in Cement Creek during baseflow in late summer, fall, and winter because dissolved zinc concentrations are generally highest relative to the water-quality criteria. In addition, high dissolved 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 and increase the bioavailable concentrations in the Animas River creating critical conditions (Owens, CDPHE, personal communication, 1994). Therefore, loadings from Cement Creek during high flows contribute to elevated concentrations in the Animas River during baseflow, and both can be considered critical conditions.

Magnitudes of Concentrations in and Loadings to Streams

Magnitudes of dissolved zinc concentrations, loadings, stream reach losses, and unit area loadings at individual locations are discussed in detail later as part

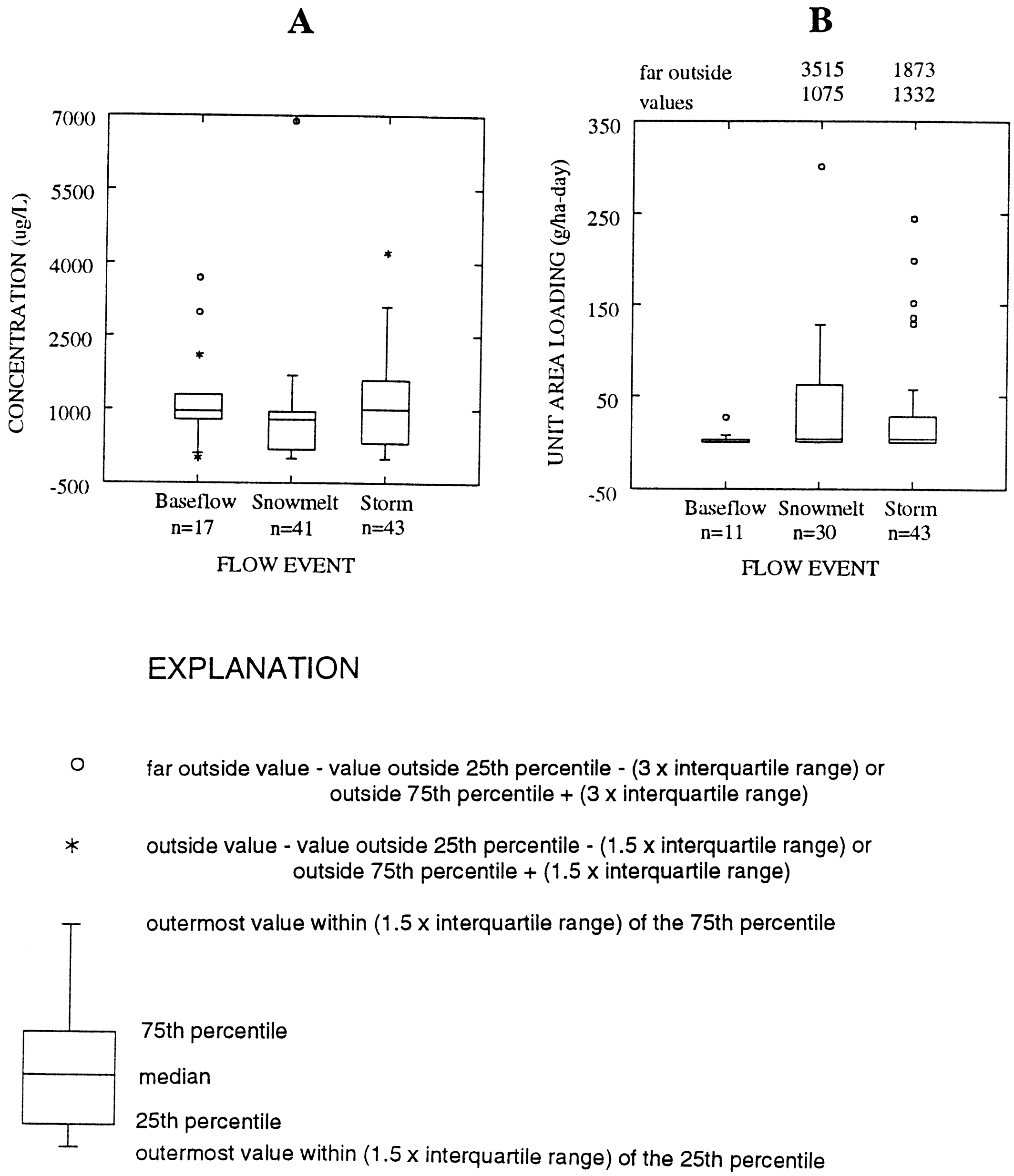

Figure 4. Multiple box plots for Cement Creek dissolved zinc data by flow event: (**A**) concentrations, and (**B**) unit area loadings.

of ranking concentrations and loadings and preliminary targeting. The concentration for each station and flow event is implicitly assumed to be representative of concentrations for each station and flow regime. The highest concentrations occurred in the headwaters and upper part of the basin immediately downstream from source areas. Although the maximum value and range for the entire Cement Creek segment were greatest for snowmelt and smallest for baseflow, the mean concentration was highest during baseflow and lowest during snowmelt (Table 2). However, the median for the storm event was slightly higher than for baseflow because the baseflow data were more highly skewed than data for the other two events. The median values were more consistent among flow events than the mean values. The 90% and 95% *CI*s on the mean for all events were considerably smaller than for the individual events due to the larger n. The standard deviation and *CI*s on the mean for baseflow were greater than for the other two flow events. It would generally be expected that the variability would be smaller and the confidence in the mean would be larger for baseflow because of the smaller variations in flow during this period. However, the small n for baseflow (n = 17) relative to the other

Table 2. Magnitudes of dissolved zinc concentrations in and loadings to Cement Creek

Statistic	Flow event: Storm (7 Sept 1991)	Flow event: Snowmelt (24 June 1992)	Flow event: Baseflow (14 Oct 1992)	All events
Concentrations (µg/liter)				
N	43	41	17	128
Mean	1,160	796	1,350	1,040
90% CI	479	572	948	278
95% CI	574	686	1,150	332
Median	1,000	810	940	930
90% CI	440	526	348	88
95% CI	517	590	546	116
Standard deviation	933	1,090	1,120	950
90% CI	347	414	714	197
Minimum	4	4	10	4
Maximum	4,200	6,900	3,700	6,900
Loadings (g/day)				
N	49	33	15	120
Daily	137,000	219,000	21,400	126,000
90% CI	N/A	N/A	N/A	176,000
95% CI	N/A	N/A	N/A	274,000
Standard Deviation	N/A	N/A	N/A	99,100
90% CI	N/A	N/A	N/A	381,000
Minimum	N/A	N/A	N/A	21,400
Maximum	N/A	N/A	N/A	219,000
Total (kg)	6,430	17,400	5,120	28,900
Proportion of all events	0.22	0.6	0.18	1.00
Total minimum	N/A	N/A	N/A	5,120
Total maximum	N/A	N/A	N/A	17,400
Unit area loadings (g/ha/day)				
N	43	30	11	93
Daily mean	104	190	4.2	114
90% CI	178	408	9	153
95% CI	213	492	11	183
Median	6.4	13	0.5	3.7
90% CI	22	38	3.7	8.9
95% CI	23	39	4.7	15.0
Standard deviation	343	660	8.2	442
90% CI	128	300	6.9	106
Minimum	0	0	0	0
Maximum	1,870	3,510	28	3,510
Total (g/ha)	4,920	15,150	983	41,300
Time-weighted total	N/A	N/A	N/A	21,050
Proportion of all events	0.12	0.37	0.02	1.00
Proportion of time-weighted	0.23	0.72	0.05	1.00
Total minimum	N/A	N/A	N/A	983
Total maximum	N/A	N/A	N/A	15,150

flow events ($n = 41$–43) resulted in larger *CI*s. The *CI*s on the medians were consistently smaller than those on the means. Most exceedances of water-quality criteria for brown trout were chronic exceedances, occurred in the upper part of the basin, and were a function of the low hardness (median was approximately 140 µg/liter) of the water as well as elevated zinc concentrations.

Subareas in the upper part of the watershed exhibited high loadings during snowmelt and the storm event. However, the greatest individual loading was from the large subarea CC48–CC47 in the lower part of the watershed near the mouth of Cement Creek during snowmelt. This subarea also had a large loading during the receding limb of snowmelt and even during baseflow. These loadings were probably from unmeasured point sources or groundwater discharges, but the specific sources are not known. Losses of dissolved zinc from stream reaches were greatest at CC21–CC20–CC17 during snowmelt and also at several other locations along the mainstem of Cement Creek. Daily and total loadings from all subareas to Cement Creek were highest during snowmelt and lowest during baseflow

Table 3. Differences between magnitudes of dissolved zinc concentrations in and loadings to Cement Creek

Statistic	Flow event: Storm (7 Sept 1991)	Snowmelt (24 June 1992)	Baseflow (14 Oct 1992)	All events
Concentrations (μg/liter)				
Upstream mean	1,390	947	1,480	1,220
Downstream mean	807	583	1,040	784
Difference in means	583	365	435	439
Relative diff. in means	0.72	0.63	0.42	0.56
Loadings				
NPS mean (g/day)	134,000	212,000	17,800	121,000
Point source mean (g/day)	1,670	6,260	3,640	3,860
Difference in means	133,000	206,000	14,200	118,000
Relative diff. in means	80	33	3.9	30
NPS total (kg)	6,320	16,800	4,250	27,400
Point source total (kg)	78	497	868	1,440
Difference in totals	6,240	16,300	3,380	26,000
Relative diff. in totals	80	33	3.9	18
Unit area loadings				
NPS mean (g/ha/day)	141	250	5	148
Background mean (g/ha/day)	1.2	1	0.05	0.91
Difference in means	140	249	4.95	147
Relative diff. in means	117	249	99	162
NPS total (g/ha)	6,597	19,743	1,198	53,867
Background total (g/ha)	57	77	12	334
Difference in totals	6,540	19,666	1,186	53,533
Relative diff. in totals	115	255	99	160

(Table 2). The maximum daily value and range were greatest for snowmelt and smallest for baseflow. The *CI*s for the mean daily loading and standard deviation for all events (based on $n = 4$) were very large.

Subareas in the upper part of the basin also had the highest unit area loadings during snowmelt and storm flow. Mean daily and total unit area loadings from all subareas were greatest during snowmelt and smallest during baseflow (Table 2). The maximum mean daily value and range were highest for snowmelt and lowest for baseflow. For all flow events, the median daily values were much smaller than the means. This resulted from the large number of zero or very small unit area loadings and the nonnormal (right-skewed) distributions. The *CI*s for the means and medians, and the standard deviations, were all very large.

Differences Between Magnitudes of Concentrations in and Loadings to Streams

Mean concentrations in the upper Cement Creek segment were consistently higher than those in the downstream segment for each flow event and for all events (Table 3). Relative differences in means ranged from approximately 42% during baseflow to 72% during the storm event, and the relative difference for all events was 56%. Loadings from NPS subareas were always greater than those from point sources for each event and for all events (Table 3). Relative differences in daily loadings ranged from approximately 390% during baseflow to 8000% during the storm event. The relative difference for all events was about 3000%. Unit area loadings from NPS subareas were consistently much higher than those from background subareas (Table 3). Relative differences in mean daily unit area loadings ranged from approximately 9900% during baseflow to 25,000% during snowmelt, and the relative difference for all events was 16,000%.

Risks of Exceeding Target Concentrations and Loadings

The dissolved zinc concentration cumulative frequency distribution plots, based on data aggregated from all stations in Cement Creek, used to estimate the *CDF*s are shown in Figure 5. The ambient standard (85th percentile) in the creek for all events was estimated as 1600 μg/liter. By definition, this is the concentration that had a risk of approximately 15% of being exceeded anywhere in the creek if a sample was collected at a randomly selected location anytime during the year that the data were collected. The 90% *CI* width for this quantile was 200 μg/liter. Using the method discussed in Gilbert (1987) for estimating the *CI* of a proportion, the *CI* width for the estimated proportion of 15% was 12% (the lower confidence limit was 9% and the upper confidence limit was 21%). Generally, the most important information regarding uncertainty for

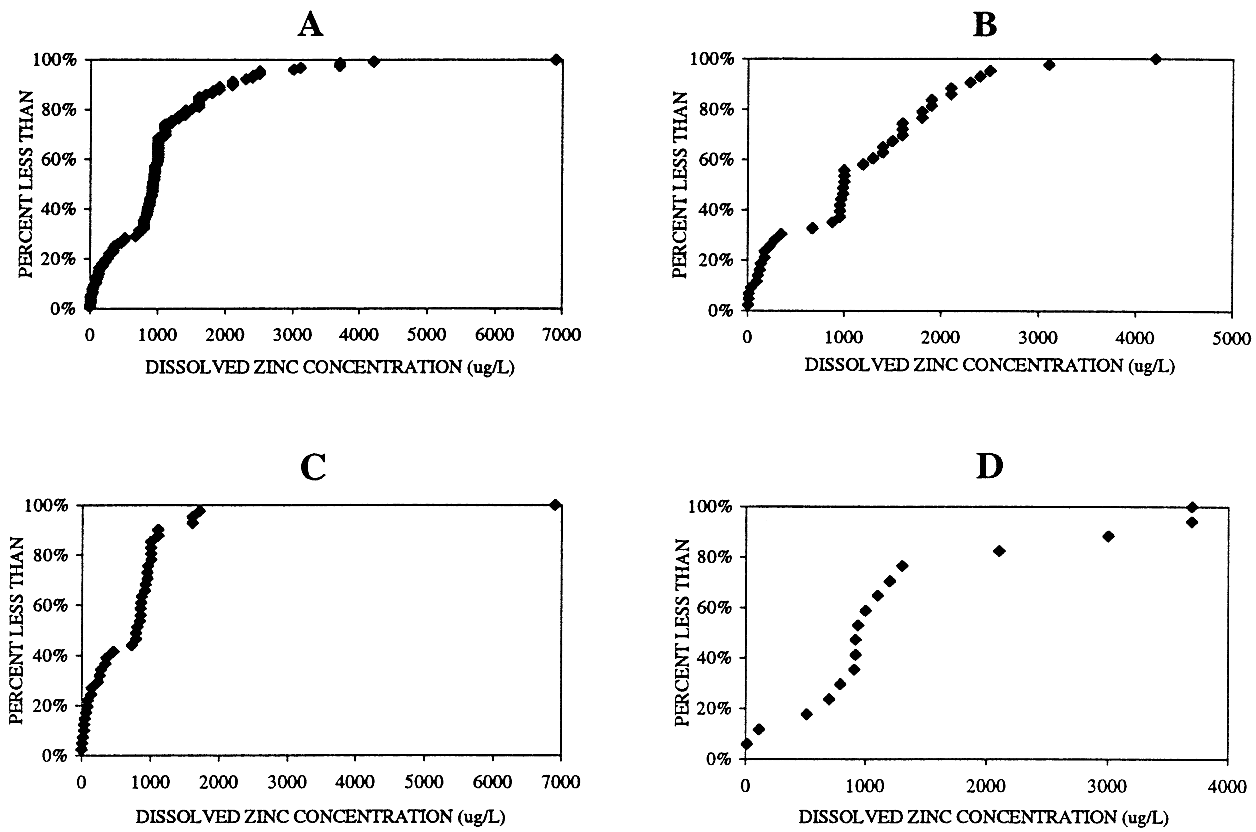

Figure 5. Cumulative distribution plots of Cement Creek dissolved zinc concentrations: (**A**) all events, (**B**) stormflow, (**C**) snowmelt, and (**D**) baseflow.

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 standard.

Based on computation of the chronic and acute criteria for each sample, the average chronic and acute criteria for brown trout anywhere in Cement Creek for all events were approximately 3500 and 7300 µg/liter, respectively. Based on the observed data, these chronic and acute values had risks of approximately 3% and 1%, respectively, of being exceeded anywhere in the creek if a sample was collected at a randomly selected location anytime during the year the creek was monitored. Generally, the most important information regarding uncertainty for the brown trout 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 standard.

Ranking concentrations for all events showed that station CC06 at the mouth of the North Fork of Cement Creek exhibited the highest value (6900 µg/liter) during the year, which was observed during snowmelt (Table 4). This was somewhat unexpected, because it is

Table 4. Ranking of 20 dissolved zinc concentrations in Cement Creek[a]

Station	Location	Flow event	Concentration (ug/liter)	Rank	% less than
CC06	NF Cement	Snowmelt	6900	1	99.2
CC06	NF Cement	Storm	4200	2	98.4
CC05	Cement	Baseflow	3700	3	97.7
CC03	Cement	Baseflow	3700	4	96.9
CC18	Cement	Storm	3100	5	96.1
CC25	Prospect	Baseflow	3000	6	95.3
CC05	Cement	Storm	2500	7	94.6
CC18	Cement	RL	2500	8	93.8
CC23	Prospect	Storm	2400	9	93.0
CC05	Cement	RL	2400	10	92.2
CC03	Cement	Storm	2300	11	91.5
CC24	Prospect	Baseflow	2100	12	90.7
CC38	Porcupine	Storm	2100	13	89.9
CC02	Cement	Storm	2100	14	89.1
CC24	Prospect	Storm	1900	15	88.4
CC25	Prospect	Storm	1900	16	87.6
CC20	Cement	Storm	1800	17	86.8
CC21	Cement	Storm	1800	18	86.0
CC05	Cement	Snowmelt	1700	19	85.3
CC27	Cement	Storm	1600	20	84.5

[a]NF = North Fork, RL = receding limb of snowmelt.

Table 5. Ranking of reach losses from Cement Creek[a]

Subarea/reach	Location	Source	Flow event	Loss (g/day)	Unit area loss (g/ha/day)	Rank	% less than	Error > loss
CC21–CC20–CC17	Cement	BG	Snowmelt	−37,038	−1488	1	1.1	
CC30–CC29–CC28	Cement	BG	Storm	−28,230	−344	2	2.2	
CC43–CC41–CC42	Cement	NPS	Snowmelt	−25,550	−619	3	3.2	Yes
CC47–CC46	Cement	NPS	Snowmelt	−22,577	−51	4	4.3	Yes
CC49–CC48	Cement	BG	Snowmelt	−18,552	−149	5	5.4	Yes
CC21–CC20–CC17	Cement	BG	RL	−12,085	−485	6	6.5	
CC34–CC31–CC33–CC32	Cement	BG	Storm	−11,620	−210	7	7.5	
CC31–CC30	Cement	NPS	Storm	−11,598	−33	8	8.6	Yes
CC26–CC25	Prospect	NPS	Storm	−8,148	−66	9	9.7	
CC41–CC39–CC40	Cement	BG	Storm	−7,590	−74	10	10.8	Yes
CC21–CC20–CC17	Cement	BG	Storm	−6,915	−278	11	11.8	Yes
CC49–CC48	Cement	BG	Storm	−6,607	−53	12	12.9	Yes
CC30–CC29–CC28	Cement	BG	RL	−5,598	−68	13	14.0	Yes
CC05–CC03–CC06	Cement	NPS	Storm	−4,299	−269	14	15.1	Yes
CC49–CC48	Cement	BG	Baseflow	−4,240	−34	15	16.1	Yes
CC02–CC01	Upper Cement	NPS	Snowmelt	−3,768	−18	16	17.2	Yes
CC20–CC19–CC18	Cement	NPS	RL	−2,384	−305	17	18.3	Yes
CC48–CC47	Cement	NPS	Storm	−2,268	−6	18	19.4	Yes
CC47–CC46	Cement	NPS	Storm	−1,851	−4	19	20.4	Yes
CC47–CC46	Cement	NPS	RL	−521	−1	20	21.5	Yes
CC24–CC23–CC22	Prospect	NPS	Snowmelt	−230	−5	21	22.6	Yes
CC16–CC15–CC14	SF Cement	NPS	Baseflow	−206	−2	22	23.7	Yes
CC07–CC04	NF Cement	NPS	Storm	−35	−1	23	24.7	Yes

[a]SF = South Fork, NF = North Fork, NPS = nonpoint source, BG = background, RL = receding limb of snowmelt.

generally hypothesized that snowmelt increases loadings but dilutes concentrations in streams. Ranking loadings from subareas and losses from stream reaches showed that the greatest loading (approximately 45,000 g/day) was from CC48–CC47 in the lower part of the watershed during snowmelt. Although this loading might be derived from NPS areas and/or unmonitored groundwater discharges, it is unclear why this subarea exhibited the greatest loading. The greatest reach loss (approximately 37,000 g/day) was from reach CC21–CC20–CC17 during snowmelt (Table 5). This is a location where the steeper upper basin joins the flatter lower basin valley. Therefore, water and dissolved zinc loadings from the upper basin can slow down and accumulate here as the slopes are greatly reduced, thereby providing a mechanism for some ponding and infiltration to the shallow alluvial groundwater system. Several other locations along the mainstem of Cement Creek exhibited losses during snowmelt and the storm event.

The unit area loading cumulative frequency distribution plots, based on data aggregated from all subareas in the basin, used to estimate the *CDF*s are shown in Figure 6. Ranking unit area loadings from subareas for all events showed that the largest value (approximately 3,500 g/ha/day) occurred during snowmelt from the small subarea CC20–CC19–CC18 in the upper part of the watershed along the mainstem (Table 6). This loading probably resulted from the point source discharge from the American Tunnel (CC19) within the subarea, which is treated to a high pH prior to discharge, but which has high particulate zinc concentrations. When this discharge enters the low pH water of Cement Creek, the zinc redissolves, resulting in a high dissolved loading. This loading was not observed from the sampling results at the point source because the zinc was not in the dissolved form. Analysis of total zinc would have explicitly revealed this high zinc loading. The unit area loading from this subarea had a very small probability of occurring or being exceeded anywhere else in the basin. Many of the unit area loadings were zero or near zero.

Information Summary and Preliminary Targeting Illustration

The goal of this study was to develop and illustrate an assessment methodology for deriving information for targeting, and not necessarily to perform detailed targeting. However, information derived from analysis of Cement Creek data was used for preliminary targeting of locations for more detailed investigation and/or remediation to illustrate application of the information for targeting and the effectiveness of the assessment methods used. In general, locations that had high concentrations, loadings, or risks, and large associated uncertainties, should be targeted for more detailed

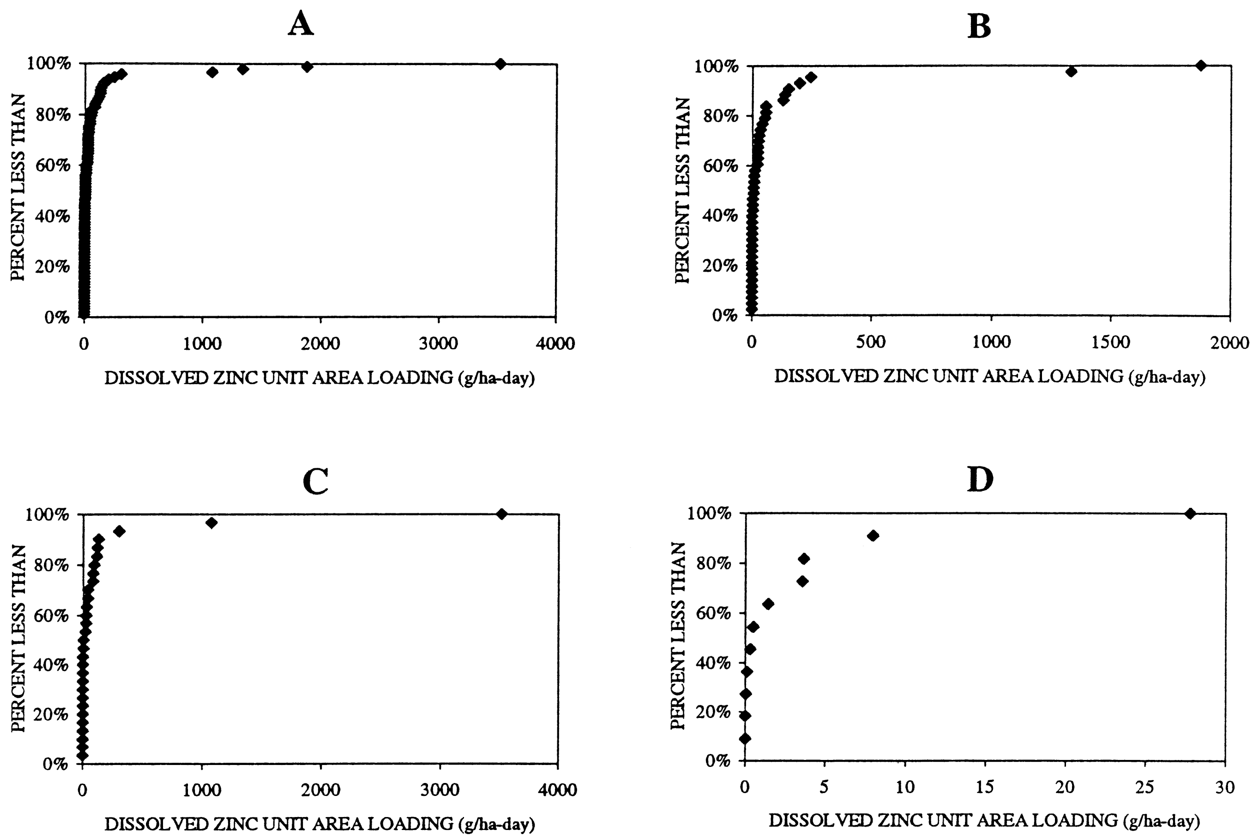

Figure 6. Cumulative distribution plots of Cement Creek dissolved zinc unit area loadings: (**A**) all events, (**B**) stormflow, (**C**) snowmelt, and (**D**) baseflow.

Table 6. Ranking of 20 subarea unit area loadings to Cement Creek

Subarea/reach	Location	Source	Flow event	Loading (g/day)	Unit area loading (g/ha/day)	Rank	% less than	Error > loading
CC20–CC19–CC18	Cement	NPS	Snowmelt	27,431	3515	1	98.9	
CC28–CC27	Cement	NPS	Storm	25,056	1873	2	97.8	
CC20–CC19–CC18	Cement	NPS	Storm	10,392	1332	3	96.8	
CC36–CC34–CC35	Cement	NPS	Snowmelt	21,165	1075	4	95.7	
CC28–CC27	Cement	NPS	Snowmelt	4,037	302	5	94.6	Yes
CC17–CC16–CC13–CC12	SF Cement	NPS	Storm	17,557	245	6	93.5	
CC39–CC36–CC38–CC37	Cement	NPS	Storm	13,956	199	7	92.5	
CC18–CC05	Cement	NPS	RL	5,170	160	8	91.4	Yes
CC25–CC24	Prospect	NPS	Storm	9,345	152	9	90.3	
CC43–CC41–CC42	Cement	NPS	Storm	5,624	136	10	89.2	Yes
CC36–CC34–CC35	Cement	NPS	Storm	2,551	129	11	88.2	Yes
CC18–CC05	Cement	NPS	Snowmelt	4,135	128	12	87.1	Yes
CC01	Cement	NPS	Snowmelt	35,797	120	13	86.0	
CC48–CC47	Cement	NPS	Snowmelt	45,039	111	14	84.9	
CC25–CC24	Prospect	NPS	Snowmelt	5,822	95	15	83.9	
CC31–CC30	Cement	NPS	Snowmelt	29,244	84	16	82.8	
CC46–CC43–CC45–CC44	Cement	NPS	Snowmelt	11,289	84	17	81.7	Yes
CC24–CC23–CC22	Prospect	NPS	Storm	2,792	57	18	80.6	
CC18–CC05	Cement	NPS	Storm	1,811	56	19	79.6	Yes
CC06–CC07	NF Cement	NPS	Storm	1,624	53	20	78.5	

investigation. Alternatively, locations that had high values and small uncertainties should be targeted for remediation. Estimation and ranking of individual dissolved zinc concentrations showed that locations in, and immediately downstream from, the North Fork of Cement Creek (including CC06) and other headwaters had the highest values and most exceedances of water-quality criteria. Estimation of differences in mean concentrations between the upstream and downstream reaches also showed that the upstream reach was more heavily impacted. Therefore, these locations should be targeted for more detailed investigation. However, restoration of locations and reaches that are most heavily impacted is probably not cost effective or possible due to technical and financial constraints. The estimated mean, median, and maximum concentrations and risks of exceeding water-quality criteria for the entire Cement Creek segment were higher than those for Mineral Creek and the Upper Animas River. Therefore, although Cement Creek is the most impacted stream, it would probably be more cost effective to target the other two streams for restoration. The Upper Animas River downstream from Cement Creek is the impaired waterbody that CDPHE is targeting for restoration.

Estimation and ranking of individual loadings showed that subarea CC48–CC47 should be targeted for further investigation because it had the greatest loading and is very close to the Upper Animas River, but the specific loading sources have not been identified. CC01 on Upper Cement Creek should also be targeted for investigation because it exhibited high loadings, but is very distant from the Upper Animas River. It is not known if metals originating from such distant sources are transported all the way to the mouth of Cement Creek because of known locations of losses along the creek. These locations of losses, including reach CC21–CC20–CC17, should also be targeted for further investigation (Table 5). Estimation and ranking of individual unit area loadings indicated that subarea CC20–CC19–CC18 should be targeted for control. Other subareas with the highest loadings and unit area loadings should also be targeted for investigation or remediation, depending on distances to the Upper Animas River.

Estimation of differences between types of sources showed that NPS areas contributed the greatest loadings and unit area loadings to Cement Creek relative to point sources and background sources and should be targeted for remediation. Differences between daily and total loadings to the entire Cement Creek segment, and loadings to Mineral Creek and the Upper Animas River, should be estimated to target the basins for remediation. Differences in mean, median, and maximum daily and total unit area loadings, and risks of exceeding target loadings, to the different streams should also be estimated for targeting basins. To date, however, these values have not been estimated for basins other than Cement Creek.

Although the above discussion illustrates the usefulness of the Cement Creek assessment methods and information for preliminary targeting, more detailed targeting should incorporate additional socioeconomic factors. These factors include availability of remedial technologies, feasibility and costs/benefits of remediation, land ownership and landowner cooperation, and public support and funding availability. However, the assessment methods and information for Cement Creek were very useful for preliminary targeting. The cost for the screening-level assessment and preliminary targeting was approximately \$2500/station, or \$1500/km^2, based on the initial budget for Cement Creek of approximately \$83,000 and an additional \$40,000 added later for data analysis and reporting. This also includes costs for plan preparation and most of the field measurement and analytical costs. These costs compare very favorably with other costs presented for chemical/physical and biological assessment. More detailed chemical/physical evaluation can cost about \$8600 for four samples per site, and screening-level biological assessment can range from \$3600 for toxicity testing to \$7800 for fish and macroinvertebrate evaluations (Karr 1991). Therefore, the assessment methods used for Cement Creek appeared to be cost-effective and provided the basis for developing a generalized, recommended methodology for screening-level assessment of NPS pollution from IAMs in other watersheds.

Recommended Methodology

The recommended screening-level assessment methodology (Table 7) is presented as steps in a framework including evaluation of existing data/information and identification of data gaps; definition of assessment information goals for targeting and monitoring design; data collection, management, and analysis; and information reporting and use for targeting. The choice of specific methods and formulation of the overall methodology were based on the required attributes of an assessment methodology, generalized information goals for targeting, attributes of data that are typical of IAM basins, and data analysis methods that were useful for the Cement Creek case study. The approach was designed to generate the common types of baseline information required for targeting using limited, but typical stream discharge and chemical data collected during synoptic studies. It incorporates and builds upon some existing methods for watershed and water-quality

Table 7. Recommended methodology for screening-level assessment of NPS pollution from IAMs

Step 1	Collect, evaluate, and summarize existing data/information and identify data gaps
Step 2	Define assessment information goals for targeting (see text)
Step 3	Design monitoring program
	Identify analytes (and analytical methods), locations, and frequencies for monitoring
	Define data collection procedures
	Identify methods for data management, analysis, reporting, and use for targeting
	Identify QA/QC procedures
Step 4	Data collection
	Perform sample collection and field measurements
	Grab samples and/or stream depth- and width-integrated samples
	Discharges using current meter and, if possible, gaging station at mouth of mainstem
	Total and dissolved metals and indicator parameters
	Locations at mouths of and other points in important tributaries and mainstem, headwaters including background locations or unimpacted nearby watersheds, points bracketing NPS areas, drainage from point sources, and other points of obvious or suspected impacts
	Synoptic surveys during high and low flows for at least 3 or 4 events (at least baseflow, snowmelt, and storm flow)
	Collect additional data to fill gaps for a subset of stations and/or flow events (possibly during later phases or if funding available)
	Source/waste material metals and physical characteristics and NPS areas/volumes
	Streambed material metals and physical characteristics
	Aquatic ecology including habitat, fish, and benthos
	Estimate distances from source areas to potentially impacted waterbodies from site base map and in the field
	Document in logbook and on map: station locations and types of sources monitored, analytes, NPS areas/volumes, distances to watercourses, and other features of stations with regard to potential sources and impacts
	Conduct laboratory analyses
	Perform QA/QC for field and laboratory work
Step 5	Data management
	Input to data base: station, location and description, type of source monitored, sampling dates, flow events, distances to potentially impaired waterbodies, subareas, discharges, and analytical results
	Manipulate data for analysis and reporting
	Compute cumulative daily loading for each station and flow event
	Estimate daily loading for each subarea
	Compute mean daily unit area loading for each subarea
	Compute total loading and unit area loading for each subarea based on time period for each flow regime
	Compute aquatic life acute and chronic water-quality criteria (usually based on hardness)
	Perform QA/QC
Step 6	Data analysis
	Compute summary statistics and standards or criteria exceedances to select indicator metal and primary constituents of concern
	Individual Points
	Plot magnitudes of concentrations, loadings, losses, and unit area loadings for each station and flow event on site base map
	If required for broad comparisons among individual points, compute mean values for each station and subarea
	Estimate differences and relative differences between individual stations or subareas
	Rank individual concentrations, loadings, losses, and unit area loadings
	Present information in summary tables
	Areas
	Aggregate data by areas of interest
	Concentrations
	Compute median in stream segment for each flow event
	Compute standard deviation and determine minimum and maximum values
	Estimate CIs for computed values
	Loadings
	Compute daily and total loadings, and median daily and total unit area loadings, to stream segments for each flow event
	Compute standard deviations and determine minimum and maximum values
	Estimate CIs for computed values
	If required for broad comparisons among areas, compute mean values for areas for all events
	Compute total loadings and unit area loadings for areas of interest based on time period for each flow regime
	Estimate differences and relative differences between areas and between types of sources
	Compute ambient water-quality standards for streams (85th or other appropriate percentiles based on observed data)
	Estimate risks of exceeding target concentrations and loadings in areas of interest

Table 7. (Continued)

Step 7	Information reporting and use for preliminary targeting
	Target impaired streams using
	Concentrations for each flow event
	Daily and total loadings and unit area loadings to streams for each flow event
	Ranking of individual concentrations
	Risks of exceeding target concentrations
	Differences between specific streams of interest
	Target critical source areas using
	Daily and total loadings and unit area loadings for each flow event
	Proportions of total loadings
	Ranking of individual loadings
	Risks of exceeding target loadings
	Differences between specific sources of interest
	Distances to impaired waterbodies
	If required for broad comparisons among locations, use values for all events
	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 information in assessment / targeting report including
	Tables of magnitudes, differences, rankings, risks of exceedances, distances, and uncertainties
	Graphical plots of estimated values in bar graphs, pie charts, for easy presentation
	Site base maps with estimated values overlaid for easy visual presentation
	Also include an introduction or summary of the problem; specific assessment information goals and monitoring design; and all data collection, management, and analysis methods
	A targeting table and map presenting the priority critical source areas and impaired stream segments recommended for further investigation or remediation

assessment. However, the methodology improves on existing methods for IAM screening-level assessment because they do not achieve all of stated information goals, and no single methodology has been developed that can be used for the majority of sites.

The methodology includes collection and analysis of data on dissolved and total metals and indicator parameters and recommendations for additional data to fill gaps if funding is available or as part of more detailed investigation. Although these types of additional data were not used in this study because they were not collected by CDPHE, they could be useful for screening-level or more detailed assessment. Data on source / waste material metals and physical characteristics and NPS areas / volumes can be collected to evaluate potential loadings and the correlation of source area characteristics with downstream concentrations and loadings. Collection and analysis of streambed material physical / chemical data at a subset of stations and / or for a subset of flow events is recommended. This information is important for evaluating the fate of some metals that might be highly adsorbed or precipitated / deposited, such as iron, and long-term effects on aquatic biota, remobilization downstream during high flow events, and / or redissolution of metals to the water column. The methodology also includes collection and analysis of biological / ecological data at a subset of locations or for a subset of events. It is important that biological information is ultimately used in conjunction with physical and chemical information to gain an understanding of the cause–effect relationships and integrated long-term effects of metals on aquatic biota. All information collected in the field should be documented in a logbook and on a site base map. Standard QA / QC should also be performed for all field and laboratory work.

Data management includes data input, storage, manipulation for data analysis and information reporting, and extensive QA / QC. Many standardized methods and software are available and can be used. Detailed analysis of total metals should be performed if summary statistics indicate that particulate forms constitute more than approximately 75% of the total concentrations. In addition, more than one metal should be evaluated in detail (instead of one indicator) if a good indicator is not obvious or if evaluation of summary statistics indicates that several metals are of primary concern. Because most of the concentration, and especially the unit area loading, data are right-skewed, nonparametric data analysis methods or transformations of the data to approximate normality prior to data analysis are recommended. In most cases, for example, estimation and use of medians is recommended over mean values. Annual values, such as for loadings and unit area loadings from all subareas to streams, are useful for broad comparisons among watersheds, but should be used with caution because of the large uncertainties associated with the estimates.

The last step of the methodology includes information reporting and use for preliminary targeting. Although the intent of this study was not to present a detailed targeting method, methods for preliminary targeting were illustrated and can be used. An important aspect of the methodology is to develop a comprehensive report presenting relevant background information; assessment information goals and monitoring design; methods used for the assessment; summaries of the resulting information required for targeting in text, tables, and graphs; and results of the preliminary targeting and recommendations for future work.

Summary and Conclusions

A methodology for screening-level assessment of NPS using a watershed-based approach was developed and illustrated to derive key information for targeting in IAM basins. The methodology should be applied early in the assessment process to collect baseline data and rapidly assess NPS problems, generate the information required for targeting impaired waterbodies and critical source areas, and target those areas for more detailed investigation and/or remediation. The approach is designed to use limited, but typical stream discharge and chemical data collected during synoptic studies. Information needed for targeting includes the type and extent of and critical conditions for water-quality impairment, concentrations in and loadings to streams, differences between concentrations in and loadings to streams, and risks of exceeding target concentrations and loadings. The approach can be integrated with screening approaches using biological data, and could also be easily used in conjunction with geographic information systems for easier manipulation and analysis of spatial data, derivation of information, and presentation and mapping of results.

The results of the Cement Creek assessment and targeting illustration indicated that locations that had high dissolved zinc concentrations, loadings, or risks and large associated uncertainties should be targeted for more detailed investigation. Locations that had high values and small uncertainties should be targeted for remediation. Locations in, and immediately downstream from, the North Fork of Cement Creek and other headwaters had the highest concentrations and most exceedances of water-quality criteria and should be targeted for more detailed investigation. Although Cement Creek is the most impacted stream, it would be more cost effective to target Mineral Creek and the Upper Animas River for restoration. Subarea CC48–CC47 in the lower part of the basin, and subarea CC01 on Upper Cement Creek, should be targeted for further investigation. Locations of losses, such as CC21–CC20–CC17, should also be targeted for more detailed investigation. Subarea CC20–CC19–CC18, and other subareas with the highest loadings and unit area loadings that are not too distant from the Upper Animas River should be targeted for remediation. NPS areas contributed the greatest loadings and unit area loadings to Cement Creek relative to point sources and background sources and should be targeted for remediation.

Although more detailed targeting should incorporate additional socioeconomic factors, the assessment methods and information for Cement Creek were very useful for cost-effective, preliminary targeting. Therefore, the assessment methods used for the case study provided the basis for developing a generalized, recommended methodology for screening-level assessment of NPS pollution from IAMs in other watersheds. The methodology includes evaluation of existing data/information and identification of data gaps; definition of assessment information goals for targeting and monitoring design; data collection, management, and analysis; and information reporting and use for targeting. It incorporates and builds upon some existing methods for watershed and water-quality assessment, but significantly improves on existing methods for IAM screening-level assessment.

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