

# **Baseline Hydrologic Monitoring for Mining Projects**

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Objectives of baseline hydrologic monitoring are dependent on and derived from the ultimate use of the data. Baseline hydrological data collection for mining projects typically has several functions including: 1) assembly of adequate information to obtain an understanding of hydrologic and hydrogeologic systems; 2) documentation of baseline conditions for permitting and public disclosure purposes; and 3) documentation of baseline conditions for comparison with future conditions to be measured during mine operation. The scope of such investigations and level of detail required for these different objectives may vary significantly. It is in the interest of mining project proponents, the public and the regulatory agencies to ensure that baseline studies are adequate to meet these objectives.

Collection of adequate information to understand the hydrologic system typically requires an inventory of surface and ground water features, characterization of surface and ground water quality, identification and quantification of ground water flow regimes, depth to groundwater, aquifer characteristics, determination of stream flow variation, and establishment of the degree of seasonal variation in these parameters.

The baseline water resources monitoring program conducted by ASARCO, Inc. for the proposed Rock Creek Mine near Noxon, Montana illustrates several issues relating to baseline hydrologic monitoring for mining projects. ASARCO has developed a comprehensive database and has collected more hydrologic baseline data than any mining project in Montana. The proposed Rock Creek Mine is located in the headwaters of Rock Creek, which is a tributary of the Clark Fork River (Figure 1). The Rock Creek ore body underlies the Cabinet Mountain Wilderness Area and will be mined by underground mining techniques from an access point outside of the wilderness area. The proposed mine related surface facilities would be in the Rock Creek drainage except for portions of the tailings impoundment, which is near the Clark Fork River. Rock Creek is an intermittent stream with a drainage area of approximately 33 square miles at its confluence with the Clark Fork River just below the Noxon Rapids Dam, about twenty miles east of the Montana/Idaho state line. Baseline monitoring has focused on surface water and ground water in the Rock Creek drainage near the proposed facilities in the tailings impoundment area.

## **Baseline Monitoring System Design**

Design of a hydrologic monitoring program requires selection of monitoring sites, physical and chemical parameters to be monitored, frequency of monitoring and quality control. Most baseline hydrologic investigations for mining projects require assessment of both surface and ground water characteristics. Baseline monitoring plans are generally reviewed by the regulatory agencies early in the project development process.

The relationship between the stage of development of a mining project and the initiation of baseline hydrological monitoring is important in determining the scope of baseline data collection. Development of a mine is a multi-phased process that typically requires management decisions on whether or not to proceed with the project at each step. The general phases of mine development are:

- Discovery
- Exploration and delineation of ore body
- Conceptual design
- Feasibility study
- Final design
- Construction

The environmental baseline studies, permitting and regulatory environmental analysis commonly begin during the latter part of the exploration phase. At this time the approximate size and location of at least a portion of the ore body is known, however, the location, design and special requirements of the processing and other project related facilities may not be known in detail. Metallurgical testing, preliminary geotechnical investigations, property evaluation, preliminary economic evaluation and more detailed exploration drilling/ore delineation are required to develop a preliminary mine design. This level of information is then used, by the company or an outside reviewer, to prepare a detailed engineering and economic analysis of the project (the feasibility study). The feasibility study, current economic conditions and the site environmental and permitting requirements then determine if the project will proceed to construction. At the time the baseline environmental studies are initiated details of the mineral recovery process and the design and location of all facilities may not be known. The baseline studies must then encompass a large enough area and be broad enough in scope to include sites that may be chosen in the detailed plan of operation. The need for baseline studies to cover a potentially wide range of alternatives inevitably leads to comparing the costs and benefits of the size of the study area, the number of sites monitored and the frequency of monitoring. The extent of the study area and the scope of the investigation are in large part determined by the mining company which must weigh the risks of collecting too little data and the costs of needlessly large and more extensive baseline study boundaries. Additional changes to the mine plan and proposed disturbance areas, which may affect the study area, invariably occur during the development and permitting process.

Baseline surface water data collection requires measurement of both water quality and flow; without both, chemical loads and the potential impacts from lakes, after spills or planned discharges cannot be calculated. Monitoring stations in potential receiving waters both upstream and downstream of planned facilities are typical, required. Chemical parameters to be monitored are determined based on characteristics of the stream, type of mining and processing proposed and characteristics of the ore and waste materials that would be produced. Historic mining problems have most often been associated with metals, acid drainage, erosion, and in some cases, process chemicals such as cyanide. The analytical parameter list for the ASARCQ Rock Creek project is contained in Table 1. This list covers the common ions needed for general characterization of water type, nutrients and selected metals for which the U.S. Environmental Protection Agency has established human health standards or aquatic life criteria. Other parameters associated with specific metallurgical processes or ore types are frequently added on a case-by-case basis. After an initial screening, often two or three samples, a reduced parameter list that contains only those elements of particular concern is often initiated; parameters identified during the screening that are below the detection limit and are not expected because of the geochemical environment are often dropped.

Detection limits for laboratory analyses should be based on approved methods and should be, when reasonably possible, at such a level as to allow measurement of ambient water quality with respect to applicable water quality standards or criteria. For streams with low total dissolved solids and hardness

the calculated aquatic life criteria described in the EP A Goldbook (EP A, 1986) may be lower than present laboratory detection capabilities.

Monitoring of surface water quality and flow in the mountainous regions of Montana and Idaho typically requires collection of representative information from at least three characteristic flow regimes: spring high flow, summer low flow, and fall/winter base flow. These seasonal flow regimes may have different water quality characteristics and have different interrelationships with instream biological communities. Spring high flow periods are characterized by cool water temperatures, high flows and high turbidity resulting from snowmelt runoff and spring rains. The summer low flow season is a period of decreasing flow, increased temperature and high biological activity. The fall/winter period in northern Rocky Mountain streams is often the period of lowest flow, coldest temperatures and greatest effect from ground water on stream flow. Establishment of adequate baseline data typically includes sampling at least once during each of these three seasonal flow regimes. More frequent sampling is often required during critical time periods for specific parameters, such as suspended sediment and total metals during high flow periods or temperature and dissolved oxygen during summer low flow.

Characterization of ground water conditions is frequently more difficult more expensive than surface water baseline monitoring. Surface reconnaissance and existing data from wells and exploration boreholes often do not provide sufficient information to design a detailed ground water monitoring program. Although general criteria for ground water monitoring can usually be defined in a baseline monitoring plan, it may not be possible to determine well depth or even well location until additional drilling data is available. Well locations are often chosen to provide baseline data and also to serve as operational monitoring sites. Wells down gradient of potential contaminant sources are generally completed in the upper 10 to 20 feet of the upper most aquifer. This approach is generally appropriate for alluvium and bedrock systems that behave as a porous medium, but may not be adequate for fractured rock systems and complex geologic systems often associated with hard rock mines. Monitoring wells in fracture-controlled systems should be designed and located with particular consideration to local geology and to protection of areas of existing or potential ground water use.

An important component of any hydrologic monitoring program is quality control and data validation. Development of a reliable database that is capable of meeting the objectives of the monitoring program require that the data are accurate and representative of the conditions being monitored. The level of quality control required for baseline hydrologic data for a mining project may not be the same as required for a Superfund site, but are generally set to meet regulatory and public disclosure requirements. Typical components of a quality assurance/quality control program include collections and analysis of 10 to 20 percent duplicate, blank and known standard samples. These quality control samples are used to evaluate the accuracy of the laboratory results and to identify possible contamination of samples during sampling, transport or storage. Validation of laboratory and field data requires careful documentation of all steps of the data collection process and includes a thorough review of all laboratory data.

Rock Creek Baseline Water Resources Monitoring ASARCO Inc. began baseline hydrologic monitoring in the Rock Creek drainage in the fall of 1984. A monitoring program was coordinated with the Montana Department of Stale Lands, the Montana Department of Health and Environmental Sciences Water Quality Bureau and the U.S. Forest Service Kootenai National Forest. Since monitoring began, data has been collected from 12 principal surface water stations, 28 monitoring wells and a number of springs and private wells (ASARCO, 1989). In addition to ASARCO's monitoring, the Montana Water Bureau has

collected data in the Clark Fork River and selected tributaries Quality of a lower basin monitoring program from 1984 to 1989 (Ingman and Kerr, 1990).

Stream flow in lower Rock Creek (station RC-1; see Figure 1) has varied from 0 to over 300 cfs (cubic feet per second) during the monitoring period. Flow in the West Fork of Rock Creek has varied from 0 to about 10 cfs at station WRC-1 upstream of the proposed mine facilities and from 0 to over 60 cfs at station WRC-2 downstream of the mine site. High flows are associated with late winter and spring when melt runoff; low flows, including complete dewatering of several stream sections, occur during late summer, fall and winter when runoff is limited and surface flows recharge the alluvial ground water system.

Rock Creek and West Fork Creek have high quality, soft, calcium-bicarbonate type waters with very low concentrations of total dissolved solids (TDS) and metals. Occasional baseline samples have calculated exceedences of the aquatic life criteria, however, at these low TDS and hardness levels the meaning of these exceedences is not known. Table 2 shows a summary of water quality analysis from one site on West Fork Rock Creek below the location of the proposed facilities (station WRC-2). Data from this site are representative of the water quality and range of measured baseline values documented in the Rock Creek drainage.

The baseline surface water quality data shows a high degree of variability over the period of record at most sites. Table 3 shows the means, standard deviations and the 90% confidence interval around cumulative sample means for some indicator parameters from stations WRC-2 and WRC-2a. The 90% confidence interval surrounding the means of the first year of data is broad enough too include the means for the latter years for essentially all parameters. These statistics indicate that after the first full year of data collection, or when the number of samples collected exceeds about 4 to 5, that the annual cumulative means of these parameters for subsequent years of data acquisition fall within the 90% confidence interval of the initial baseline year. This suggests that collection of additional baseline data after the first full year has not contributed substantially to improving the annual mean values of the parameters evaluated. Stratification of data to evaluate seasonal water quality variability could potentially be used to better understand the data variability.

The laboratory analyses for the Rock Creek baseline investigation included unusually low target detection limits for nitrate, ammonia, total phosphorous, copper, silver, cadmium, lead and mercury (Table 1). The purpose of these detection limits was to document very low concentrations of these constituents, particularly metals, in the baseline sampling and to determine if aquatic life criteria were being exceeded in these low hardness waters, levels of mercury, cadmium.

Silver and lead measured during the baseline period were still frequently lower than the laboratory detection limits, and the objective of quantifying the baseline values for these parameters was not fully achieved. Laboratory methods for measuring lower concentrations for several of these metals are not currently available.

The ASARCO baseline monitoring program has been designed to provide adequate information for permitting, to meet the public disclosure and environmental assessment objectives of the regulatory authorities and to provide a baseline for comparison with future data. The monitoring program was modified several times during the protracted baseline period; additional surface water and ground water sites were added and the analytical parameter list was revised. Unlike many mining projects,

there have been several years in which to collect baseline data. The Montana Department of State Lands, the Montana Water Quality Bureau, the U.S. Forest Service and the public have all been involved in development and review of the Rock Creek monitoring plan. There are, however, no standards as to what constitutes an acceptable database for a baseline hydrology investigation. One year of baseline data collection is generally required by the Department of State Lands for mine permit applications, but additional data is usually developed prior to permit approval. Establishment of a longer baseline monitoring period during the permitting and environmental analysis process typically provides an additional one to two years of data. Without specific compliance requirements: the need for statistical evaluation of baseline data is difficult for companies to Justify. The complexity and large variations common to natural hydrologic and hydrogeologic systems needs to be kept in mind by all parties involved in the environmental assessment of mining projects.

Figure 1: General location map of proposed tailing impoundment ASARCO Rock Creek project

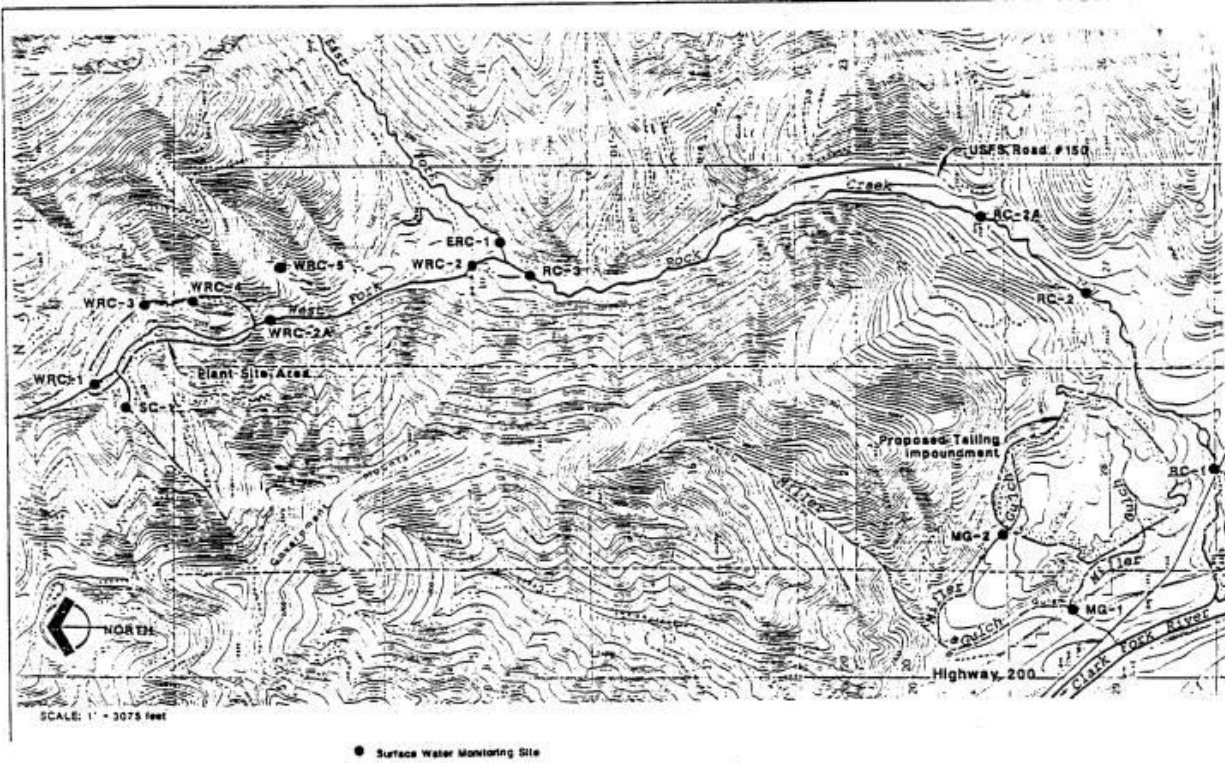


Table 1: Analytical schedule for water resources samples – Rock Creek project.

|  |                                     |
|--|-------------------------------------|
| Specific Conductivity (SC)               | Aluminum (Al) (.005)                |
| Total Suspended Solids (TSS)             | Arsenic (As) (.001) [.19]           |
| Total Dissolved Solids (TDS)             | Copper (Cu) (.001 mg/l) [.0098]     |
| pH                                       | Iron (Fe) (.002) [1]                |
| Field Temperature (°C)                   | Manganese (Mn) (.001)               |
| Flow or Static Water Level               | Silver (Ag) (.0002 mg/l) [.00012]   |
| Total Alkalinity (as CaCO <sub>3</sub> ) | Zinc (Zn) (.001) [.088]             |
| Total Hardness (as CaCO <sub>3</sub> )   | Cadmium (Cd) (.0001 mg/l) [.00095]  |
| Turbidity (TU)                           | Chromium (Cr) (.02) [.011]          |
|  | Lead (Pb) (.001 mg/l) [.0024]       |
| Sodium (Na) (.1)                         | Mercury (Hg) (.0002 mg/l) [.000012] |
| Calcium (Ca) (.1)                        | Molybdenum (Mo) (.02)               |
| Magnesium (Mg) (.1)                      | Nitrate (.01)                       |
| Potassium (K) (.1)                       |                                     |
| Carbonate (CO <sub>3</sub> )             |                                     |
| Bicarbonate (HCO <sub>3</sub> ) (1)      | Phosphate (.02)                     |
| Fluoride (F) (.013)                      | Ammonia (.01) [2.2]                 |
| Chloride (Cl) (.66)                      |                                     |

NOTE: Target Minimum Detectable Concentration shown in parentheses will utilize carbon furnace analysis for Cd, Cu, Pb, Ag. Oil and grease will be analyzed once for each surface water site to establish baseline conditions. Metals will be analyzed for total recoverable constituents as specified by Section 4.1.4 - Methods for Chemical Analysis of Water and Wastes (EPA 600/4-79-020, revised March 1983).

Chronic Aquatic Life criteria for hardness <20 mg/l are shown in brackets [ ].

Table 2: Statistical summary of water quality analysis for site WRC-2 for the period September 20, 1983 to August 8, 1989.

|                                | RANGE        | MEAN  | STANDARD<br>DEVIATION | NUMBER OF<br>SAMPLES |
|--------------------------------|--------------|-------|-----------------------|----------------------|
| <b>**PHYSICAL PARAMETERS**</b> |              |       |                       |                      |
| FLOW (CFS)                     | 0.25-44      | 16.2  | 14.9                  | 16                   |
| WATER TEMPERATURE (FIELD) (C)  | 2-11         | 6.1   | 2.4                   | 18                   |
| SPEC. COND. (UMHOS/CM) LAB     | 15-90        | 68    | 17                    | 23                   |
| PH FIELD                       | 7.74-7.9     | 7.8   | 0.1                   | 2                    |
| PH LAB                         | 7.1-8.1      | 7.7   | 0.3                   | 22                   |
| TURBIDITY (NTU) LAB            | 0.23-1.6     | 0.4   | 0.3                   | 23                   |
| TOTAL SUSP. SOLIDS             | 0.001-4.3    | 1.2   | 1.1                   | 23                   |
| TDS MEAS. # 180 DEG. C         | <1-90        | 51    | 20                    | 20                   |
| OXYGEN (O) DISS                | 11           | 11    | 0                     | 1                    |
| STAGE (FT)                     | 0-1.1        | 0.5   | 0.4                   | 15                   |
| <b>**COMMON IONS**</b>         |              |       |                       |                      |
| TOTAL HARDNESS AS CaCO3        | 21-51        | 33    | 7                     | 23                   |
| CALCIUM (CA)                   | 4.7-9.3      | 7.6   | 1.3                   | 21                   |
| MAGNESIUM (MG)                 | 2.3-3.9      | 3.2   | 0.5                   | 21                   |
| SODIUM (NA)                    | 0.70-1.1     | 0.9   | 0.1                   | 21                   |
| POTASSIUM (K)                  | 0.2-.4       | 0.3   | 0.1                   | 21                   |
| ALKALINITY AS CaCO3 (LAB)      | 25-44        | 35    | 5                     | 17                   |
| BICARBONATE (HCO3) (LAB)       | 31-54        | 42    | 6                     | 18                   |
| CARBONATE AS CO3 (LAB)         | <1           | <1    | 0                     | 17                   |
| SULFATE (SO4)                  | <1-<10       | 2     | 2                     | 20                   |
| CHLORIDE (CL)                  | <0.66-2.6    | 0.7   | 0.5                   | 20                   |
| FLUORIDE (F)                   | <0.013-<0.13 | 0.06  | 0.02                  | 16                   |
| <b>**NUTRIENTS**</b>           |              |       |                       |                      |
| NITRATE + NITRITE AS N         | <0.01-12     | 1.3   | 3.6                   | 21                   |
| KJELDAHL NITROGEN AS N         | <0.01-.5     | 0.12  | 0.14                  | 21                   |
| ORTHO-PHOSPHATE (PO4-P)        | <0.01-<0.05  | <0.01 | 0.01                  | 21                   |
| PHOSPHORUS (P) TOTAL           | <0.01-<0.1   | 0.02  | 0.02                  | 21                   |
| AMMONIA (NH3 AS N)             | <0.01-.4     | 0.08  | 0.10                  | 21                   |

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|                             | RANGE          | MEAN   | STANDARD<br>DEVIATION | NUMBER OF<br>SAMPLES |
|-----------------------------|----------------|--------|-----------------------|----------------------|
| <b>**TRACE ELEMENTS**</b>   |                |        |                       |                      |
| ALUMINUM (AL) TOTAL REC.    | <0.005-.12     | 0.038  | 0.038                 | 17                   |
| ANTIMONY (SB) TOTAL REC.    | <0.01-<0.08    | 0.02   | 0.02                  | 16                   |
| ARSENIC (AS) TOTAL REC.     | <0.001-<0.01   | 0.001  | 0.001                 | 22                   |
| BARIUM (BA) TOTAL REC.      | 0.02-.06       | 0.03   | 0.01                  | 16                   |
| BORON (B) TOTAL REC.        | <0.01-.04      | <0.01  | 0.009                 | 14                   |
| CADMIUM (CD) TOTAL REC.     | <0.0001-<0.003 | 0.0005 | 0.0005                | 23                   |
| CADMIUM (CD) ACID SOL.      | 0.0002-.0039   | 0.002  | 0.002                 | 3                    |
| CHROMIUM (CR) TOTAL REC.    | <0.02-<0.3     | 0.02   | 0.03                  | 16                   |
| COBALT (CO) TOTAL REC.      | <0.02-<0.03    | <0.02  | 0.00                  | 16                   |
| COPPER (CU) TOTAL REC.      | <0.001-.01     | 0.002  | 0.002                 | 23                   |
| COPPER (CU) ACID SOL.       | <0.001-.002    | 0.001  | 0.001                 | 3                    |
| IRON (FE) TOTAL REC.        | <0.002-.12     | 0.037  | 0.035                 | 17                   |
| LEAD (PB) TOTAL REC.        | <0.001-<0.04   | 0.003  | 0.005                 | 23                   |
| LEAD (PB) ACID SOL.         | 0.002-.015     | 0.006  | 0.008                 | 3                    |
| LITHIUM (LI) TOTAL REC.     | <0.002         | <0.002 | 0.000                 | 1                    |
| MANGANESE (MN) TOTAL REC.   | <0.001-.012    | 0.004  | 0.002                 | 23                   |
| MERCURY (HG) TOTAL REC.     | <0.00005-<0.5  | 0.031  | 0.085                 | 16                   |
| MOLYBDENUM (MO) TOTAL REC.  | <0.02          | <0.02  | 0.00                  | 13                   |
| SELENIUM (SE) TOTAL REC.    | <0.004-<0.005  | <0.004 | 0.000                 | 13                   |
| SILVER (AG) TOTAL REC.      | <0.0002-<0.008 | 0.0007 | 0.0013                | 22                   |
| SILVER (AG) ACID SOL.       | 0.0001-.0003   | 0.0002 | 0.0001                | 3                    |
| STRONTIUM (SR) TOTAL REC.   | 0.019          | 0.019  | 0.000                 | 1                    |
| VANADIUM (V) TOTAL REC.     | <0.001         | <0.001 | 0.000                 | 1                    |
| ZINC (ZN) TOTAL REC.        | <0.001-.04     | 0.005  | 0.010                 | 23                   |
| <b>**OTHER PARAMETERS**</b> |                |        |                       |                      |
| OIL AND GREASE              | <1             | <1     | 0                     | 3                    |
| SILICA (SI02)               | 7.7            | 7.7    | 0                     | 1                    |

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Table 3

**Table 3. Surface water quality data statistics stations V and WRC-2A West Fork Rock Creek.**

| CALCIUM - WRC2        |           |      |            |    | CALCIUM - WRC2A       |           |       |             |    |
|-----------------------|-----------|------|------------|----|-----------------------|-----------|-------|-------------|----|
| Baseline Date Through | $\bar{X}$ | S    | 90% CI     | N  | Baseline Date Through | $\bar{X}$ | S     | 90% CI      | N  |
| 1985                  | 7.37      | 1.34 | $\pm 0.61$ | 13 | 1985                  | 11.5      | 0.707 | $\pm 0.820$ | 2  |
| 1986                  | 7.48      | 1.22 | $\pm 0.47$ | 18 | 1986                  | 10.6      | 1.11  | $\pm 0.814$ | 5  |
| 1987                  | 7.62      | 1.21 | $\pm 0.48$ | 21 | 1987                  | 10.3      | 1.79  | $\pm 1.11$  | 7  |
| 1988                  | 7.56      | 1.53 | $\pm 0.58$ | 27 | 1988                  | 8.89      | 2.84  | $\pm 1.34$  | 12 |

| NITRATE + NITRITE AS N - WRC2 |      |      |            |    | NITRATE + NITRITE AS N - WRC2A |       |       |            |    |
|-------------------------------|------|------|------------|----|--------------------------------|-------|-------|------------|----|
| 1985                          | 1.31 | 3.57 | $\pm 1.77$ | 11 | 1985                           | 0.078 | 0.102 | $\pm 0.12$ | 2  |
| 1986                          | 2.62 | 4.89 | $\pm 1.75$ | 21 | 1986                           | 0.051 | 0.051 | $\pm 0.03$ | 6  |
| 1987                          | 2.21 | 4.57 | $\pm 1.50$ | 25 | 1987                           | 0.042 | 0.046 | $\pm 0.03$ | 8  |
| 1988                          | 1.68 | 4.07 | $\pm 1.16$ | 33 | 1988                           | 0.038 | 0.037 | $\pm 0.02$ | 13 |

| TOTAL DISSOLVED SOLIDS - WRC2 |       |       |            |    | TOTAL DISSOLVED SOLIDS - WRC2A |       |       |            |    |
|-------------------------------|-------|-------|------------|----|--------------------------------|-------|-------|------------|----|
| 1985                          | 52.44 | 13.29 | $\pm 7.27$ | 9  | 1985                           | 67.50 | 0.71  | $\pm 0.82$ | 2  |
| 1986                          | 51.42 | 11.10 | $\pm 4.87$ | 14 | 1986                           | 61.40 | 8.70  | $\pm 6.38$ | 5  |
| 1987                          | 50.19 | 11.42 | $\pm 4.68$ | 16 | 1987                           | 60.43 | 7.39  | $\pm 4.58$ | 7  |
| 1988                          | 52.76 | 14.93 | $\pm 5.34$ | 21 | 1988                           | 54.83 | 14.68 | $\pm 7.07$ | 12 |
| 1989                          | 56.30 | 15.54 | $\pm 5.31$ | 23 | 1989                           | 56.30 | 15.54 | $\pm 5.31$ | 23 |

| ZINC - WRC2 |        |        |             |    | ZINC - WRC2A |        |        |             |    |
|-------------|--------|--------|-------------|----|--------------|--------|--------|-------------|----|
| 1985        | 0.095  | 0.0159 | $\pm 0.008$ | 11 | 1985         | 0.0018 | 0.0018 | $\pm 0.002$ | 2  |
| 1986        | 0.0074 | 0.0135 | $\pm 0.006$ | 16 | 1986         | 0.0023 | 0.0023 | $\pm 0.002$ | 5  |
| 1987        | 0.007  | 0.0123 | $\pm 0.005$ | 20 | 1987         | 0.0023 | 0.0021 | $\pm 0.001$ | 7  |
| 1988        | 0.009  | 0.0132 | $\pm 0.004$ | 25 | 1988         | 0.0025 | 0.0017 | $\pm 0.001$ | 11 |
| 1989        | 0.0085 | 0.013  | $\pm 0.004$ | 27 |              |        |        |             |    |

$\bar{X}$  = Sample mean  
 S = Sample standard deviation  
 N = Sample size  
 90% CI = 90% confidence interval

Note: Values of  $\bar{X}$ , S, and confidence intervals are in mg/L.