INTERIM STUDY
OF THE ACIDIC DRAINAGE
TO THE MIDDLE RED RIVER,
TAOS COUNTY, NEW MEXICO

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FOR

UNOCAL 76 MOLYCORP, INC.
QUESTA DIVISION

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SANTA FE, NEW MEXICO

JULY 9, 1993

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Introduction and Summary

The Red River, between the town of Red River and the Questa Ranger Station, was investigated in October and November of 1988, on November 22, 1992 and on February 16, 1993 to determine the location and magnitude of sources of acidic drainage to the river. In addition numerous springs, seeps and drainages have been investigated. Reports prepared by HEW-1966, (The Department of Health, Education and Welfare, now the EPA), EPA-1971, Smolka and Tague-NMEID for surveys conducted in 1986 and 1988 and USGS Stream Flow and Water Quality data have been extensively reviewed.

The acidic drainage to the river originates primarily in sulfidized, hydrothermal-scar areas which occur in tributary drainage basins, principally to the north of the river. Pyrite in hydrothermal scar areas breaks down in the presence of air and water to form sulfuric acid. The acid leaches aluminum and other metals from the rocks. Sulfuric acid and the dissolved elements are transported to the river in ephemeral streams, ground water flow, and episodic flood runoff.

Molycorp's mining operation has had an affect on the acidic drainage to Red River. Up to 1956, over 35 miles of underground workings had been developed which intercepted a significant amount of ground water flow and resulted in a lowering of the water table and decrease in the natural acidic drainage from Sulfur Gulch and possibly Goat Hill Gulch and Capulin Canyon. In 1965, Molycorp converted the mine to an open pit operation located in Sulfur Gulch. Overburden above the main ore body was excavated and deposited in dumps along the ridge lines to the west and south. A significant portion of the overburden deposited in the dumps at the heads of Goat Hill and Capulin Canyons consisted of altered rock from the Sulfur Gulch hydrothermal scar area. The dumps to the south above Red River Canyon were mainly composed of fairly inert non-acid forming types of rock. The open pit mine substantially reduced the natural acidic drainage from Sulfur Gulch. Drainage from the dumps at the heads of Goat Hill and Capulin Canyons may be higher in both flow and acidity than the natural drainage from the hydrothermal scar and altered rock areas which underlie much of the dump areas.

In 1983 Molycorp ceased open pit mining and started ore production from the new underground mine located mainly beneath Goat Hill Gulch. Ore removal resulted in a significant caved in area in the bottom of Goat Hill Gulch which, since 1990 has intercepted all of the drainage from the dump area and from the natural scar areas in the upper reaches of the Gulch. In 1992 Molycorp constructed works which intercepted most of the drainage from the dump and natural scar areas at the head of Capulin Canyon. This drainage is being discharged through a bore hole drilled through the ridge between Capulin Canyon and Goat Hill Gulch. The drainage is discharged to the caved area in Goat Hill Gulch. Drainage flowing into the caved area seeps down through the broken rock into the mine. Mining operations were suspended at the end of 1992 and the drainage is presently being allowed to accumulate in the mine. A separate study is in progress to determine what action may be required to prevent drainage of acidic water from the mine to Red River when the water level in the mine approaches the river elevation.

Additional barriers are under construction farther downstream in Capulin Canyon to intercept any drainage from the dump area which may be flowing around the upper catchment system. Preliminary analysis indicates that the downstream flow may be on the order of 15% of that intercepted by the upper catchment system; however, the acidity is much lower indicating that much of the lower flow is from areas outside of the dump area. It is anticipated that the lower catchment system will be in operation by the end of July 1993.

It is anticipated that the dump areas will consolidate and the porosity will decrease as a result of infilling with clays generated by oxidation of the surface material. As this occurs it is expected that drainage from the dumps will approach that of the natural drainage resulting from the hydrothermal scars and altered rock underlying the dumps.

Tributary stream waters near the bases of the hydrothermal scars and below the mine dumps have aluminum concentrations up to approximately 800 mg/l at pH 2.5. Acidic springs along the river contain up to 300 mg/l aluminum at pH values from 3.5 to 5.0. The upper Red River normally has a pH of approximately 8.0 and less than 1 mg/l dissolved aluminum. Spring water entering the middle reach of the river depresses the pH of the river and decreases the alkalinity.

The solubility of aluminum increases exponentially with decreasing pH, from a minimum at pH 6.5. Solubility also rises at high pH (>6.5). The low solubility of aluminum in the river causes precipitation of aluminum hydroxide (gibbsite) which in concentrations of a few mg/l creates a whitish-bluish turbidity in the river. Concentrations of suspended gibbsite generally are fairly low but have been sufficient to create the observed cloudiness in the lower portion of middle Red River during most of the low flow periods of the past several years. Occasionally the turbidity extends upstream to near the Town of Red River and downstream to near the fish hatchery.

Storm runoff creates floods which briefly cause large increases in suspended loads including aluminum and sulfate and a decrease in pH in the Red River.

The milky appearance of the water in Red River has been observed during periods over the past several decades and probably has been more or less prevalent for several thousands of years. A cyclic precipitation pattern probably results in long-term variation in the turbidity in the river. The average discharge of Red River from 1979 through 1992 was more than double of that during the preceding nine year period. This indicates a presently above-normal ground water flow from the hydrothermal scar areas. The above-normal ground water flow may continue for some years after the end of the wet cycle. The higher than normal turbidity in Red River during the past several years may largely be the result of this climatological sequence.

The most acidic spring area located was near the Questa Ranger Station in an area not influenced by Molycorp's operations.

The concentration of aluminum is variable as a result of pH changes both in ground water and river water flow. Suspended gibbsite settles out and then is remobilized as a result of variations in stream flow. Since the dissolved sulfate concentration is much more stable, such has been used for much of the analysis even though the sulfate concentrations in the river are well below water quality standards.

Significant portions of this report were taken from a preliminary report titled "A Geochemical Investigation of the Origin of Aluminum Hydroxide Precipitate in the Red River" which was prepared in 1989 by Scott G. Vail, PHD, while he was employed as the senior geologist with the Vail Engineering firm.

The acidic drainage to Red River is a complex phenomenon which may require observation over many years in order to comprehensively understand what appears to be significant and fairly long term variations in both flow and acidity.

A significant amount of data and information has been accumulated and analyzed for this report. Some of the original goals and objectives, however, have not as yet been fully accomplished and new desirable study areas have developed. For this reason this report is being submitted as an interim report and the study and analysis will continue until all of the goals and objectives are obtained.

Preliminary findings and conclusions resulting from the study and analysis for this report are:

(1) The mass loading of aluminum, sulfates and several other elements increase in a downstream direction with the more significant increases occurring along reaches containing drainage from prominent hydrothermal scar areas.

(2) The acidic drainage results from oxidation of altered rock. The altered rock areas are extensive over much of the region. It appears, however, that most of the acidic drainage is from the hydrothermal scars where erosion maintains a surface of unoxidized soil.

(3) The acidic drainage is not proportional to the area of the scars. It appears that the acidity may increase toward the west where the scars are in an earlier stage of development.

(4) For comparable stream flow rates the mass loading of aluminum, sulfate and some other constituents has been higher in all reaches of middle Red River than the mass loadings several years ago. Such may be due in part to increased spring and seepage flow from an extended above average precipitation period.

(5) Molycorp's mine dumps in Goat Hill Gulch and Capulin Canyon influence the acidic drainage from these areas. Presently most of the drainage from below the dumps is being captured and construction is underway to intercept the balance. This also includes the natural drainage from the hydrothermal scars beneath the dumps. It appears that the acidity and aluminum entering Red River from Goat Hill Gulch has already decreased as a result of interception of drainage from the upper area. The acidic drainage to Red River from these areas, however, may continue to be high for several years because of the slow ground water flow rate from below the catchment areas.

(6) Molycorp's operations have eliminated the potential of major flood and mud flows from Sulfur Gulch and upper Goat Hill Gulch. Substantial storm drainage improvements have also been completed in Capulin Canyon and along the area between the mill and Columbine Creek.

Respectfully Submitted:
VAIL ENGINEERING, INC.

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Chief Engineer

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STATE OF NEW MEXICO
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Purpose

This report has been prepared at the request of Molycorp, Inc. The purpose is to provide a quantitative assessment of the origin and sources of acidic drainage accretions to the Red River between the town of Red River and the Questa Ranger Station.

Background

A cloudy, white precipitate, tentatively identified as gibbsite $[Al(OH)_3]$ occurs in the Red River from the town of Red River to below the Questa Ranger Station, mainly at times of low water flow. The affected reach includes the area of Molycorp's Questa Operations, particularly the Sulfur Gulch, Goathill Gulch and Capulin Canyon drainages.

The precipitate has historically been considered to be the product of leaching of aluminum from "hydrothermal scar" areas by acidic ground and surface water, followed by re-precipitation in the river. The scar areas are at least several thousands of years old, and the precipitate is known to have existed for at least several decades (A. Greslin, pers. comm., 1988). The cloudiness in the river, however, has perhaps been more noticeable and/or has received increased attention in recent years. For this reason, in part, this investigation has been commissioned to evaluate the effect, if any, that the mine dumps at the Molycorp Questa Operations have on the acidic drainage to Red River. The possible effect of the dumps on the acidic drainage is confused by the fact that the dumps in part overlie natural hydrothermal scars.

Several studies of the Red River have been made in recent years (Federal Water Pollution Control Administration, 1966; U.S. Environmental Protection Agency, 1971; Smolka and Tague, 1987, 1989). Thorne Ecological Institute (1972) Investigated the Red River for Molycorp. They noted that natural springs and hydrothermal scars were affecting the water quality of the river. A substantially large number of sampling points were used for Molycorp's surveys which defines and limits the sources of aluminum and other factors to a much greater degree than previous studies. Nevertheless, in relationship to the complexity of the acidic water accretions, this report is based on limited data, especially long term historical data. Seasonal variability in the chemistry of the river is substantial. Additional data are needed to evaluate several influences on the chemistry of the Red River including seasonal variability and stream-water inhomogeneity over short distances and short times, and to identify long-term changes caused by climatic change and evolution of the mine dumps.

Method of Investigation

Three principal objectives were identified as being fundamental to evaluating the origin and controls of acidic drainage to Red River: 1. define the chemical controls of aluminum dissolution, transport and precipitation in the ground and surface water environment; 2. determine the magnitude and distribution of acidic drainage to the Red River; and 3. evaluate the relative importance of the mine dumps and natural scars as sources of acidic drainage. The following tasks were outlined to achieve these objectives:

- A literature study was made of the chemical systematics of aluminum in the weathering environment.
- Detailed surveys of the affected river area were performed to quantify the location and magnitude of acidic drainage.
- An accretion profile of the Red River was calculated to provide a baseline for the chemical mass flow analysis.
- Limited geological field investigations were carried out in the scar areas and dumps.

The field studies of the dump and natural scar areas were briefer than originally planned, owing to time limitations.

Geological Setting

The Questa mine area is very complex geologically, as is typical of sulfide ore deposits. However, for the purposes of this report, a few basic observations are significant.

Rocks in the district can be divided into three groups. The oldest is a complex of Precambrian quartzite, amphibolite and granite. Tertiary volcanic rocks, dominantly andesite, were erupted over the Precambrian rocks. Eruption of the lavas and silicic tuffs led to caldera collapse. The youngest group, Tertiary granitic rocks, were intruded into the Precambrian and volcanic rocks late in the history of the caldera. Hydrothermal solutions, related to the younger granites, altered and sulfidized the county rocks, especially the volcanics. The principal ore deposits of the district are within altered volcanic rocks.

Exposures in the mine area are dominantly andesite north of the Red River and Precambrian granite south of the river. Tertiary granite intrudes both of these. Rocks in the mine area are extensively fractured and faulted.

Hydrothermally Altered Areas. Volcanic rocks in the mine area and over much of the area around the town of Red River are extensively altered. Significant zones of alteration extend as far west as the ranger station near Questa. The alteration is characterized by replacement of feldspars and ferromagnesian minerals by clays, sericite, secondary feldspars, chlorite, epidote and pyrite. The areal extent of alteration has not been mapped in detail.

Weathering of the altered areas has produced prominent "hydrothermal scars" in Hanson Creek Canyon, Goathill Gulch and many of the other canyons along the Red River. The scars originate from deep erosion in sulfidized areas. The location and areal extent of the prominent hydrothermal scars as determined from aerial photos and USGS mapping is shown on Drawing A and on Figure A. Pyrite in these rocks dissolves and oxidizes to form sulfuric acid. Most of the acid is formed at or near the surface because of a depletion of oxygen at depth. The acid causes further degradation of the rocks to clay end-products. Metallic elements including aluminum are leached and removed. The result is a "scar" area which is deeply eroded and lacking in plant cover. Little infiltration of precipitation appears to occur below the steep slopes of the scars, as the clay-rich surface is highly impermeable. Consequently, most precipitation is removed through surface run off. Mud flow

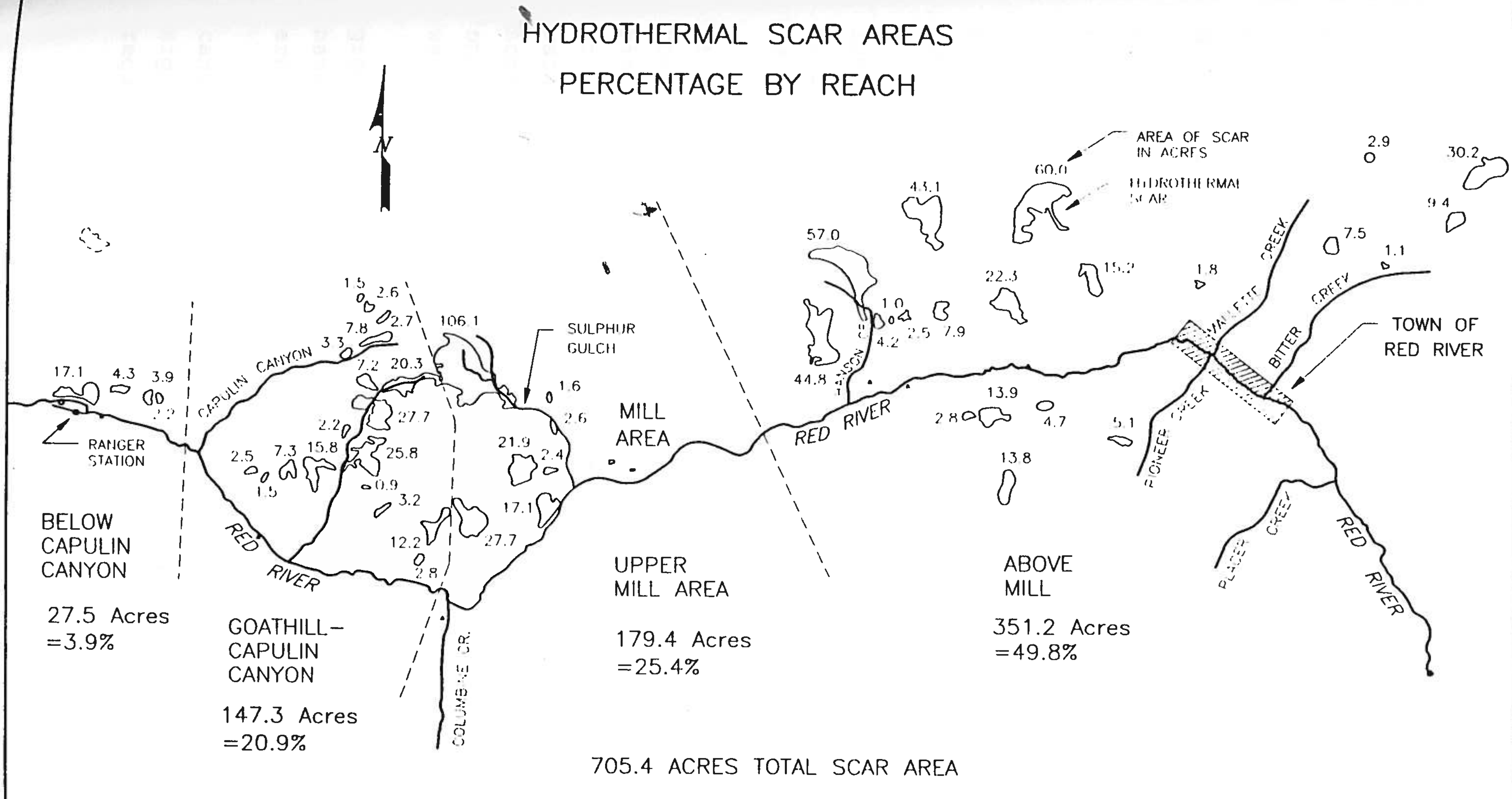

FIGURE A
HYDROTHERMAL SCAR AREAS

deposits, caused by summer flash floods are extensive below the base of the scars and extend to the Red River. The flow deposits are also very clay-rich and fairly impermeable, further limiting infiltration of precipitation.

Mine Dumps

The principal dumps are located in the heads of Capulin Canyon and Goathill Gulch (185 acres combined) and to the north of the Red River between the Molycorp mill and Columbine Creek (413 acres). The dumps consist of overburden which was excavated from the open-pit mine area. The rock types are mainly andesite and granite, as is the area in general. A considerable part of the dump material in the Goathill Gulch and Capulin Canyon areas is altered, sulfidized, hydrothermal-scar material; however, the proportion of sulfidized material and the sulfide content have not been determined.

Highly aluminous, acidic streams emanate from the base of the Goathill and Capulin dumps. The combined flow of these streams is generally about 60 gpm with somewhat higher and less acidic flow occurring following the spring snow melt. The degree to which the acidity of the stream water is caused by the dumps is difficult to determine. According to Schilling's mapping (1956) the dumps are built on altered, sulfidized material, which, generates acidic water.

By analogy to Hanson Creek, it can be expected that the greater part of natural flow from scar areas comes from the base of cliffs at the head of the scars. The lower areas are too impermeable to permit significant gain.

The dumps are located at the heads of their respective canyons, overlying the natural upper spring areas. A significant amount of additional study and analysis will be required before a realistic determination can be made of the difference between the drainage from the dump areas and the original natural scar areas.

The dump area to the south of the open pit mine generates water that is only mildly acidic, although it also is partly underlaid by altered bedrock and hydrothermal scars. The degree of alteration and sulfidization of the underlying rock is not known, but the relatively small areal extent of presently exposed scar areas and altered rock and type of dump material may be a partial explanation of the low aluminum gain along the reach.

Prior to extensive mine development, the scar area in Sulfur Gulch was a significant source of acidic drainage to the Red River. This drainage to the river was substantially reduced by the underground and the open pit mine. The volume of water originally flowing in Sulfur Gulch was probably more than that in Hansen Creek or Goathill Gulch, or in excess of 30 gpm.

Ground Water Flow

There is little data available for determination of the ground water flow characteristics of the canyon areas north of the Red River. Several test holes were drilled in Goathill Gulch upstream from the underground mine. Indications were that a ground water table was present at a fairly shallow depth; however, inflow was at such a slow rate that a pump test was not conducted. The low inflow rate did indicate a very low hydraulic conductivity. Based on this observation and an evaluation of the fine-grained, clayey nature of the material, we estimate that the conductivity of the material is probably less than 10^{-4} Cm/sec. The permeability of the underlying bedrock is even less.

The hydraulic gradient of the water table is estimated to be on the order of 15 percent. These values indicate that ground water movement is on the order of a few hundred feet per year.

A significant portion of the drainage flow from some of the active natural scar areas is by surface flow over much of the distance to the Red River. Prior to development of the caved area in Goat Hill Gulch and the catchment system in Capulin Canyon, much of the drainage from these areas was by surface flow to within a short distance of the river. After seepage into the ground, this flow may be conducted fairly rapidly through more permeable material near the surface. In contrast the portion of the drainage that is transported by ground water flow over much of the distance down gradient of the scars, may have travel times extending for many years.

In consideration of the foregoing, further study and analysis will be necessary to project the rate of decrease of the acidic drainage to Red River in the Goat Hill Gulch and Capulin Canyon areas which is anticipated as a result of the catchment provisions effected and in progress by Molycorp. The latest stream surveys indicate that highly acidic drainage from Goat Hill Gulch is already declining. This may reflect the elimination of the surface flow. Continued high sulfate accretions indicate that the deeper ground water seepage, which probably is less acidic, has not significantly decreased as of February 1993.

Historical Data

Stream flow records have been kept for the Red River since 1913. Figure B gives a summary of the mean daily flow rates since 1960.

Chemical data are available for the Red River for studies in 1965, 1970, 1986 and 1988 (Federal Water Pollution Control Administration, 1966; U.S. Environmental Protection Agency, 1971; Smolka and Tague, 1987, 1989). Monthly data for the gauging station near Questa are available for 1979 to 1982. There has been a significant increase between the time of the earlier surveys (1965-1970) to the time of the more recent surveys in acidic drainage along all of the middle Red River. This probably has been caused by significantly higher precipitation during the past several years. There also is a significant difference between the surveys, in the amount of stream flow. The amount of stream flow substantially affects both concentrations and mass flow. This makes comparisons on such basis very difficult. Comparison of the percent of the total gain in sulfate for each individual segment of the middle Red River, was found to be the most informative indicator of possible change in the relative amounts of acidic drainage from the individual stream segments. Table 1 summarizes the results of such an analysis. The data base and method of calculation of the values in Table 1 are set forth in Appendix 4.

TABLE 1
HISTORICAL REVIEW OF TOTAL
SULFATE GAIN TO MIDDLE RED RIVER

Percent for Each Segment of the Total
Sulfate Gain from Above Town of Red River
to Ranger Station

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Station	1965	1970	1988	1988	1988	1992	1993
Above Town Red River							
	32.9	17.2	19.6	8.3	8.3	17.7	18.2
Below Town							
	33.9	28.7	14.2	20.5	20.5	16.8	22.3
Above Molycorp Mill							
	5.1*	24.5	22.7	10.9**	39.7	38.6	25.3
Below Col.Crk.							
	28.2	29.6	43.5	60.2	31.5	26.9	34.1
@ Ranger Station							

(1) HEW 11-04-1965 (*Probable low value resulting from sample biased with excess of Columbine Creek water).
(2) EPA 11-04-1970 (Gains in lower two reaches include estimated 6.5 CFS diversion at Mill by Molycorp @ 65 mg/l SO_4).
(3) Smolka-Tague 10-25-1988 (Sampling point below Columbine Creek was father downstream at Goat Hill Camp Ground).
(4) Scott Vail 11-29-1988 (*Probable low value resulting from sample biased with excess of Columbine Creek water).
(5) Scott Vail 11-29-1988 (Concentration at Goat Hill Camp Ground used instead of below Columbine Creek).
(6) Ralph Vail 10-22-1992.
(7) David Shoemaker 2-16-1993.

* Low value may be due to interception of drainage by original under ground mine.

** The "Below Columbine Creek" sampling point is at a fairly short distance downstream from the mouth of Columbine Creek which generally has a flow of about 25% of that in Red River above the creek. It appears that the sample for Scott Vail 1988 (and possibly HEW 1965) may have been collected from near the south shoreline where there was an above average percentage of creek water. As evidence of this for Scott Vail's survey the calculated mass sulfate flow was higher above Columbine Creek than that calculated using the below Columbine Creek concentration. Subsequent surveys indicate that there is only a nominal sulfate gain from below Columbine Creek to Goat Hill Camp Ground. The percentage of gain for Scott's survey using the Goat Hill sampling point is, therefore, believed to be more representative.

The analysis indicates that the percentage of sulfate gain may have increased from Molycorp's mill to the ranger station. This section includes drainage from Goat Hill Gulch and Capulin Canyon and from scar areas near the ranger station. Part of the increase may reflect exceptionally low drainage from the downstream scar areas at the time of the early surveys. Below normal stream flow for several years preceded these surveys. Unfortunately the early surveys had too few sampling points for a determination of specific areas where possible increases in the percentage of the total gain may have occurred.

A cloudy appearance of the water in Red River has been observed during periods of low water over the past several decades and probably has existed for several thousands of years. The variation in the amount of cloudiness (aluminum- hydroxide precipitate) is undoubtedly influenced by fairly long-term precipitation cycles. Years of high precipitation increase the amount of ground water flow. Ground water moves very slowly, and the aquifer acts as a storage reservoir. Higher than normal ground water flow, therefore, may continue for several years beyond the end of the high precipitation period. It is probable that the milky appearance of Red River is most pronounced when the ground water flow is relatively high at a time of below average river flow.

The yearly mean flow in Red River varies with the amount of precipitation and in particular with the winter snowfall precipitation as shown in Figure B and Table 2.

Table 2

Mean daily flow in cfs of the Red River at the gauging station near Questa for water years 1961 to 1992.

Year	flow	Year	flow	Year	flow	Year	flow
1961	44.80	1969	40.50	1977	13.40	1985	72.30
1962	47.80	1970	34.90	1978	25.70	1986	61.40
1963	19.70	1971	11.80	1979	87.60	1988	35.10
1964	24.40	1972	15.50	1980	47.00	1989	41.1
1965	60.60	1973	51.70	1981	14.00	1990	35.3
1966	39.60	1974	19.10	1982	39.40	1991	57.7
1967	40.50	1975	41.70	1983	71.00	1992	53.8
1968	34.90	1976	32.60	1984	48.60		
8 year average	39.03		30.98		43.34		
						32 year average	41.37

Near drought conditions prevailed from 1970 through 1978 during which the discharge of Red River was only 66% of the 32 year average. Since 1983 the discharge has been 130% of the 32 year average or nearly double that of the preceding eight years. Near record snowfall during the winter of 92-93 indicates continued above average flow for water year 1993 (water years extend from October 1 of the preceding year through September of the water year).

U.S.G.S. STREAM GUAGE
RED RIVER NEAR QUESTA
AVERAGE DAILY STREAM FLOW 1961 – 1992

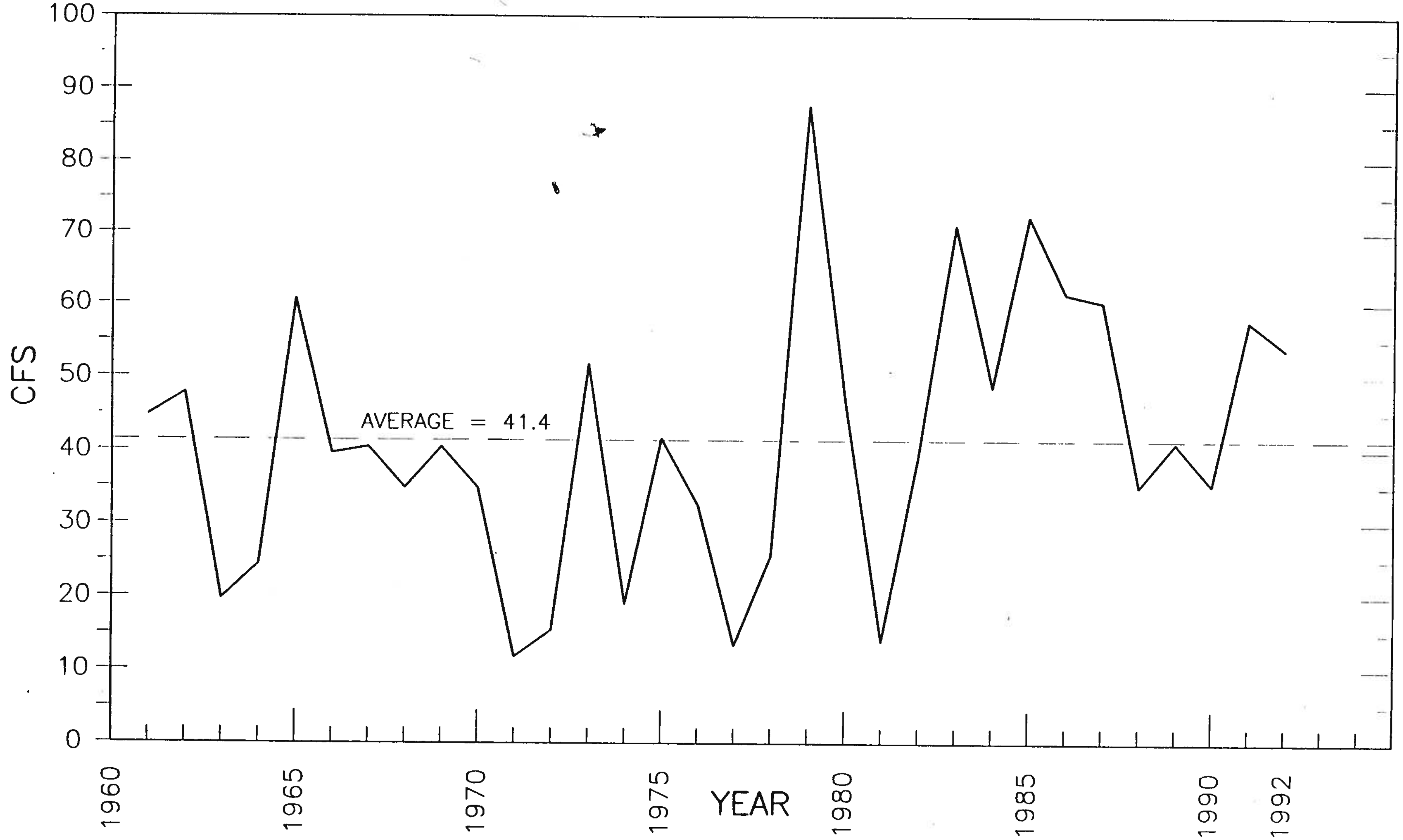

FIGURE B

One can hypothesize that after several years of below normal precipitation, the ground water flow from the hydrothermal scar areas decreases and generally the river has low turbidity (1973-1978). During years of above normal precipitation, there is generally sufficient river flow to dilute the gibbsite precipitate and the resulting turbidity (1979-1987). Following several years of above normal precipitation there is a high ground water flow from the scar areas, and during periods of low river flow, increased gibbsite precipitation results in high turbidity (1988-1992).

Geochemical Overview

Relatively little research has been done regarding the chemical behavior of aluminum in natural waters; however, sufficient data are available to permit a general overview (Roberson and Hem, 1969, Hem 1970). Aluminum is generally present in natural waters in concentrations of 0.1 to 1 ppm. Higher values are reported; but those are thought to reflect the presence of minute colloidal particles which can pass through most filter media (Hem, 1970). The exception is low pH waters, including mine waters, in which aluminum concentrations can exceed 1000 ppm.

The principal control of aluminum stability in solution is acidity. In natural systems the solubility curve for gibbsite [$Al(OH)_3$] as a function of pH approximately represents the solubility controls of dissolved aluminum species. Figure C (Drever, 1982) shows that aluminum is highly soluble in both strongly acid and strongly alkaline solutions. In approximately neutral solutions, including most river waters, the solubility of aluminum is quite low, on the order of 10^{-7} to 10^{-6} moles/liter (0.27 to 2.7 ppm).

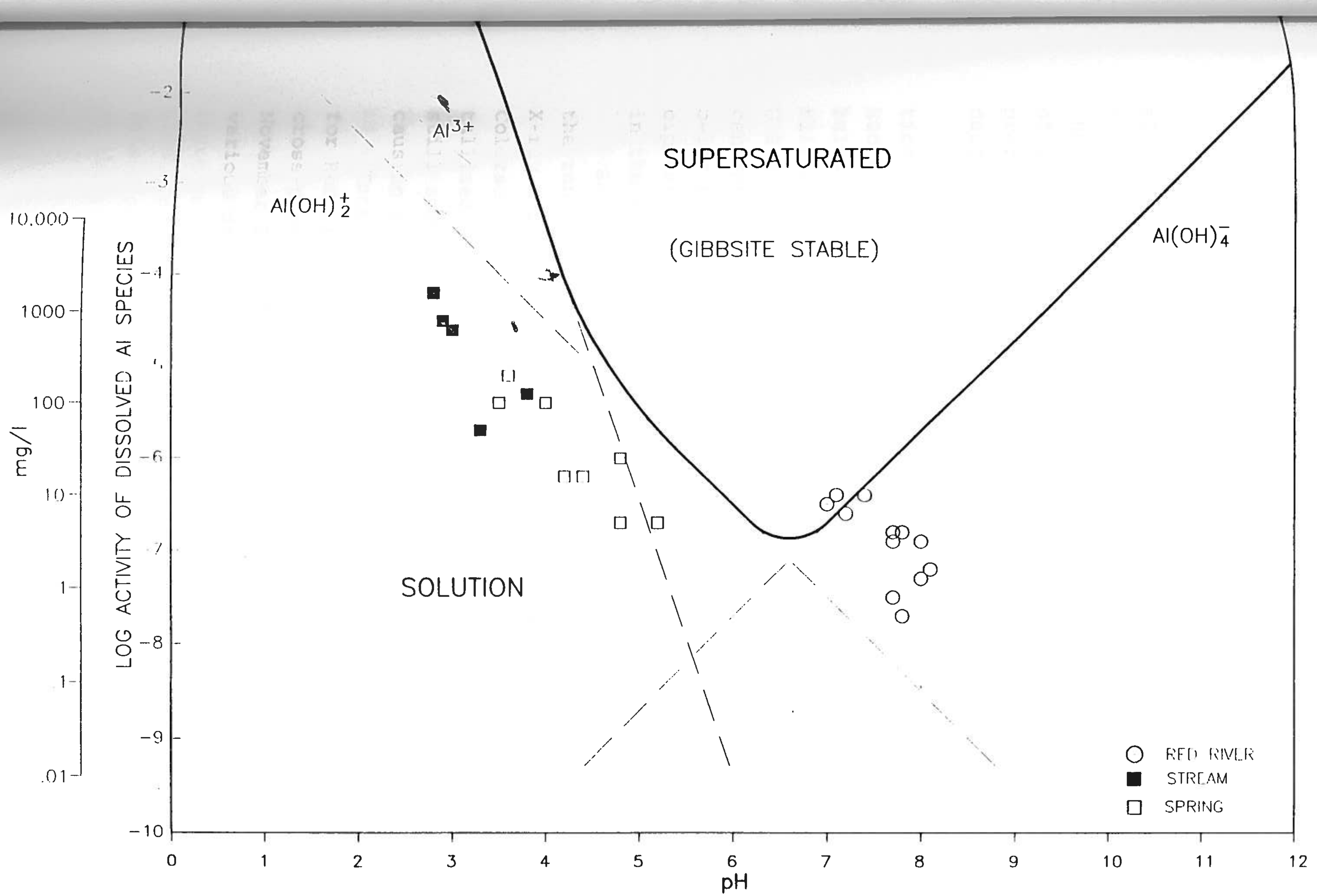

FIGURE C – ACTIVITIES OF DISSOLVED ALUMINUM SPECIES IN EQUILIBRIUM WITH GIBBSITE [$AL(OH)_3$] AT 25°C.

RED RIVER DATA ARE FROM 11/29/88. STREAM & SPRING DATA ARE FROM VARIOUS DATES.

The presence of other ions which can combine with aluminum can affect solubility. High concentrations of fluoride and sulfate can respectively increase or decrease the solubility of aluminum. At fairly high concentrations of dissolved silica (greater than 10^{-4} molar) clay minerals precipitate before gibbsite and solubility of aluminum is decreased.

Application to the Red River. The maximum concentrations of fluoride (1.6 mg/l) and sulfate (202 mg/l) in the Red River for the period of the investigation are well below the levels at which they would affect aluminum solubilities. Few data for silica are available, but older U.S.G.S. data (Water Supply Report NM-80-1) indicate concentrations on the order of 10 mg/l ($10^{-6.7}$ molal), well below the concentration at which clay minerals would precipitate; therefore, gibbsite is the expected precipitate in the Red River.

Samples of precipitate collected above the river near the ranger station and along Hanson Creek were scanned by X-ray diffraction at the Molycorp laboratory at Louviers, Colorado. The material was found to be too poorly crystallized to yield a mineral identification. Thus, it is still somewhat conjectural that gibbsite is the mineral causing cloudiness in the river.

Total aluminum concentration (suspended + dissolved) for Red River samples and tributary springs and streams are cross-plotted with pH in Figure C. The river data are from November 29, 1988. The spring and stream data are from various dates.

The river data show a steep trend of increasing aluminum concentration with falling pH. In general, the higher concentrations come from downstream locations, especially below Capulin Canyon. The lower concentrations cluster around an aluminum concentration of roughly 1 mg/l and tend toward a pH of 8.0.

Compositions of spring and stream waters fall on the left side of the diagram at low pH values and high aluminum concentrations. Dilution of any of these waters would cause the concentration to move on a straight line path toward the diluting water. It can be seen that most of the spring and stream waters would cross the stability boundary and precipitate gibbsite if diluted by pH 8.0/1 ppm Al water.

Solubility of aluminum decreases with increasing total ionic strength. Because the spring waters have very high concentrations of total dissolved solids, the solubility boundary may lie closer to the spring and creek samples than indicated by the curve in Figure C.

Most of the river waters fall outside the gibbsite stability boundary, even though moderate amounts of gibbsite are visible along much of the river course. This suggests that gibbsite is unstable along most of the river. The dissolution rate is probably too low, however, to have an appreciable effect on the turbidity of the river.

If the diluting water were consistently the composition of Columbine Creek and Pioneer Creek (about pH 8.0 and less than 0.5 mg/l Al) no precipitation would occur. Precipitation occurs only at times when the aluminum concentration increases to above 1 ppm. Above this concentration, dilution lines of spring waters cross the gibbsite boundary. This affords an explanation of why gibbsite is not visible at the town of Red River although milky water has been observed on occasion in Bitter Creek upstream from Red River. The aluminum concentration probably seldom exceeds 1 mg/l in the town area.

Spring and stream waters also exhibit a trend of increasing aluminum with falling pH. Stream samples are mostly more acidic and more aluminous than spring samples (which were collected at the river). No acidic streams were reaching the river by surface flow at the time of Molycorp's surveys. Rather, these streams infiltrated gravels above the river area. Many of the springs are probably fed by infiltration of the streams. The spring water is diluted by ground water and subsurface river water flowing in gravels adjacent to the river. Dilution raises the pH of the water and lowers the solubility of aluminum. Comparison of aluminum concentrations in the upper reaches of Capulin Canyon (655 mg/l) and Goathill Gulch (560 mg/l) with that in corresponding springs (113-225 mg/l) indicates that the streams may be diluted by a factor of three to six. It is also probable that the acidity of the drainage water is buffered during ground water flow by carbonates and other elements in the soil which would result in precipitation and deposition of the aluminum along the flow route.

The majority of the aluminum entering the Red River appears to originate at springs emerging downstream from Capulin Canyon. It is likely that aluminum concentrations at these springs are high as a result of the spring water in this area being more acidic than elsewhere (pH 3.5-4.5). This could be caused by low precipitation/infiltration rates and/or because of fairly small drainage areas, a low dilution in the narrow canyons and relatively short distance between the scar areas and the river.

Red River Survey - pH

A detailed survey of the pH of the Red River in the study area was carried out from October 15 to October 21, 1988. The objective of the survey was to determine the locations of the sources of acid water accreting to the river by recording variations in the pH of the river water.

Measurements were made with a pH meter at 300-foot or smaller intervals. Where found, the location and pH of springs were noted. Portions of the survey were carried out on three separate days. The weather and river level were similar on each of the survey days, and data from overlapping river survey segments indicate that no significant changes in the chemistry of the river as a whole affect the data.

The results are plotted on Drawing 1 and Drawing A. The pH of the river ranged from 6.8 to 8.1. The local average pH varied considerably from place to place, varying from about 7.3 to 8.0. It was found that a sharp dip in acidity of 0.3 or more pH units occurred at all observed acid springs. Similar dips, as shown on the drawings, infer the location of additional springs and seeps. Measured pH values generally returned to the local background level within abut 500 feet downstream of a source.

The rebound of pH cannot be explained by dilution, as not enough water is available. Roughly 1000 times the volume of the acid water would be required, as pH 5 water contains 1000 times the H^+ ion content of pH 8 water. It is apparent that the acidity of the river is buffered by bicarbonate ion (HCO_3^-) and related species. Bicarbonate buffering is normal for river waters (Drever, 1982). Without buffering, the pH of the river would be 6.0 or less at the Questa Ranger Station. Correspondingly, total alkalinity decreases downstream (Drawing 3).

Spring waters were generally acidic on the north bank of the river and slightly alkaline on the south bank. More springs were observed on the north bank, probably because they were easier to identify because of their associated low pH and white precipitate. Also, much of the water in the southern drainage flows to the river in tributary streams rather than springs. The acid springs ranged from pH 3.5 to near neutral. Both spring and creek waters from the south side of the river were about pH 8.0.

The pH data indicate that acid springs occur at irregular intervals along the entire river segment from Red River to the ranger station. The frequency of springs is highest between the ranger station and Goathill Gulch (ten or more indicated).

Only one spring was identified in the Red River town area; however, the relatively low pH (7.5) of the river indicates that acid seepage occurs in this area. Bitter Creek was only intermittently flowing when sampled. It was somewhat acidic (pH 6.3).

Large hydrothermal scars are present from Hanson Creek to the town of Red River; however, significant acidic springs do not appear to be associated with these scars, except below Hanson Creek. Very little accretion and only one observable spring were noted in this area. The scar areas are deeply weathered to a heavy clay soil. Consequently, surface runoff predominates and apparently very little ground-water flow is present. Sulfides have largely been removed from the surface by weathering. Freshly broken boulders in the cliff area do contain disseminated pyrite on fractures. Nominal gains in sulfate and aluminum in the Red River indicate some continued dissolution of pyrite in these areas.

Red River Survey - Geochemical

Water samples were collected along the middle Red River on November 29, 1988, October 22, 1992 and on February 16, 1993. There is evidence that the survey in November 1988 was carried out during a time when aluminum concentrations were unusually high (see Table 4). From eleven to nineteen samples were collected during each run over a 12-mile segment of the river. Sample locations were selected to separate and measure the effect of each of the major tributary drainages to the river. Care was taken to choose locations in which the river water and emerging spring waters should be well mixed. The runs were made over about four-hour time periods. PH and conductivity were measured in the field.

The samples were analyzed by the assay laboratory at the Questa mine. Determinations were made for Al, $SO_4^=$, TDS, TSS, total alkalinity, turbidity, F^- and several metallic cations. Analytical results are presented in Appendix 2.

Stream Flow. In order to make quantitative comparison, it was necessary to weight the data at individual sample locations for accretions to stream flow. Data for two U.S.G.S. stream surveys of the Red River were used as a baseline. Flow rate at the time of these surveys was comparable with the flow rates during Molycorp's sampling surveys. Stream flow at locations along the river for the dates of the surveys was estimated to be proportional to that of the two surveys (Table 3). Adjustments were made for the size of the drainage basins of the tributary canyons. The measured flows at the stream gauge near the Questa Ranger Station on the dates of the surveys were used as datum.

Table 3

Stream flow surveys for Red River and proportionally calculated stream flows in cfs for 11-29-88.

Water Sample Location	Survey Location	11-4-65	10-25-88	11-29-88 (Calculated)
	Below Zwergle damsite	11	11	7 .
	Below Placer Creek	9.94		
1	Red River (town)			8.5
	Below Red River	16.3		
5	Elephant Rock C.G.		16	10.0
7	Above Moly Mill	16.2	20	10.6
10	Above Columbine Creek	18.2	19	11.3
11	Below Columbine Creek	23.6		16.3
13	Above Bear Canyon		29	16.6
16	Ranger Station	25.5	30	17(gauged)
2	Pioneer Creek	.81	.78	.4
9	Columbine Creek	5.29	6.0	4.5

Table 4

Aluminum and Sulfate Discharge past the Questa
Gauging Station for Dates from 1987 to 1989

Date	Stream Flow (cfs)	S^{O4} (mg/l)	Al (mg/l)	SO^4 (g/sec)	Al (g/sec)	Comments
2-27-86*	17	123	3.4	59	1.6	Low stable stream flow
8-18-86*	42	105	3.34	125	4.0	Moderate stable stream flow
8-19-86*	40	115	3.26	130	3.7	Moderate stable stream flow
8-19-86*	40	160		182		Questionable analysis
8-20-86*	38	118	3.41	127	3.7	Moderate stable stream flow
11-12-87	21	178	5.7	106	3.4)	Low slowly declining flow-decrease
11-20-87	19	152	3.7	82	2.0>	in SO^4indicates declining gr.water
11-25-87	18	139	3.9	71	2.0)	Al probably precipitating
1-05-88	8-19	186	13.4	100	7.2	Sudden flow increase-Al.remobilizing
2-27-88	23	246	6.0	160	3.9	Low stable flow
3-14-88	21		6.4		3.8	Low stable flow
3-19-88	21	185	8.0	110	4.8	Low stable flow
5-16-88	51	80	10.6	116	15.3	Increasing flow-Al.remobilizing
6-06-88	74	54	3.4	113	9.2	Steady high flow
7-26-88	37	278	1456.0	292	1528	Probable short thunderstorm
9-13-88*	138	120	17.0	470	67	Thunderstorm
9-20-88*	57	85	2.0	137	3.2	Moderate stable flow
9-26-88*	47	96	2.1	128	2.8	Slowly declining flow
10-14-88	39	110	5.4	127	6.0	Slowly declining flow
10-18-88	32	130	4.3	118	3.9	Low stable flow
10-21-88	32	126	3.8	114	3.5	Low stable flow
10-25-88*	30	118	1.3	131	1.1	Slowly declining low flow
11-29-88	14-17	137	11.5	66	5.5	Small sudden flow increase
4-14-89	88	77	3.3	192	8.2	Increasing flow
4-18-89	99	68	1.4	191	4.6	Increasing flow

* From Smolka and Tague, 1989

The calculated incremental gains in stream flow are illustrated in Figure 1.

Results. Analytical results are summarized in Appendix 2. Aluminum, sulfate, TDS, TSS and turbidity generally increased downstream from Red River to the Ranger Station. Alkalinity was variable, but overall showed a decreasing trend. In order to make quantitative comparisons of gains and losses to the river, analytical values were multiplied by the estimated stream flow at each sample location. The result is the mass flow rate of each parameter passing by the sample location, expressed as grams per second. These values are plotted on Drawings 1 to 6. The magnitude of each line at any point expresses the total flow of a parameter in the river at that point. The slope of the line reflects the rate of input or removal of the parameter from the river.

The rate of constituent increase to the river can more readily be seen by plotting the incremental changes from location to location as histograms. Histograms for stream flow and five stream factors are shown in Figures 1 to 6.

Incremental values for sulfate and TDS (g/sec) should nearly always be positive, as no known mechanism for substantive removal from the river was present at the time of the survey. At times during the year significant stream flow is lost to ground water in the Molycorp mill and Columbine Park areas; however, it is doubtful that significant losses were occurring on the dates of the surveys. Apparent decreases of sulfate and TDS occurred in a few samples. These probably represent either analytical error or non-representative samples. Obtaining representative samples of well-mixed river water is difficult in areas of spring activity. Interpretation of these anomalies was made by comparison to samples up and downstream from the

STREAM FLOW

INCREMENTAL GAINS

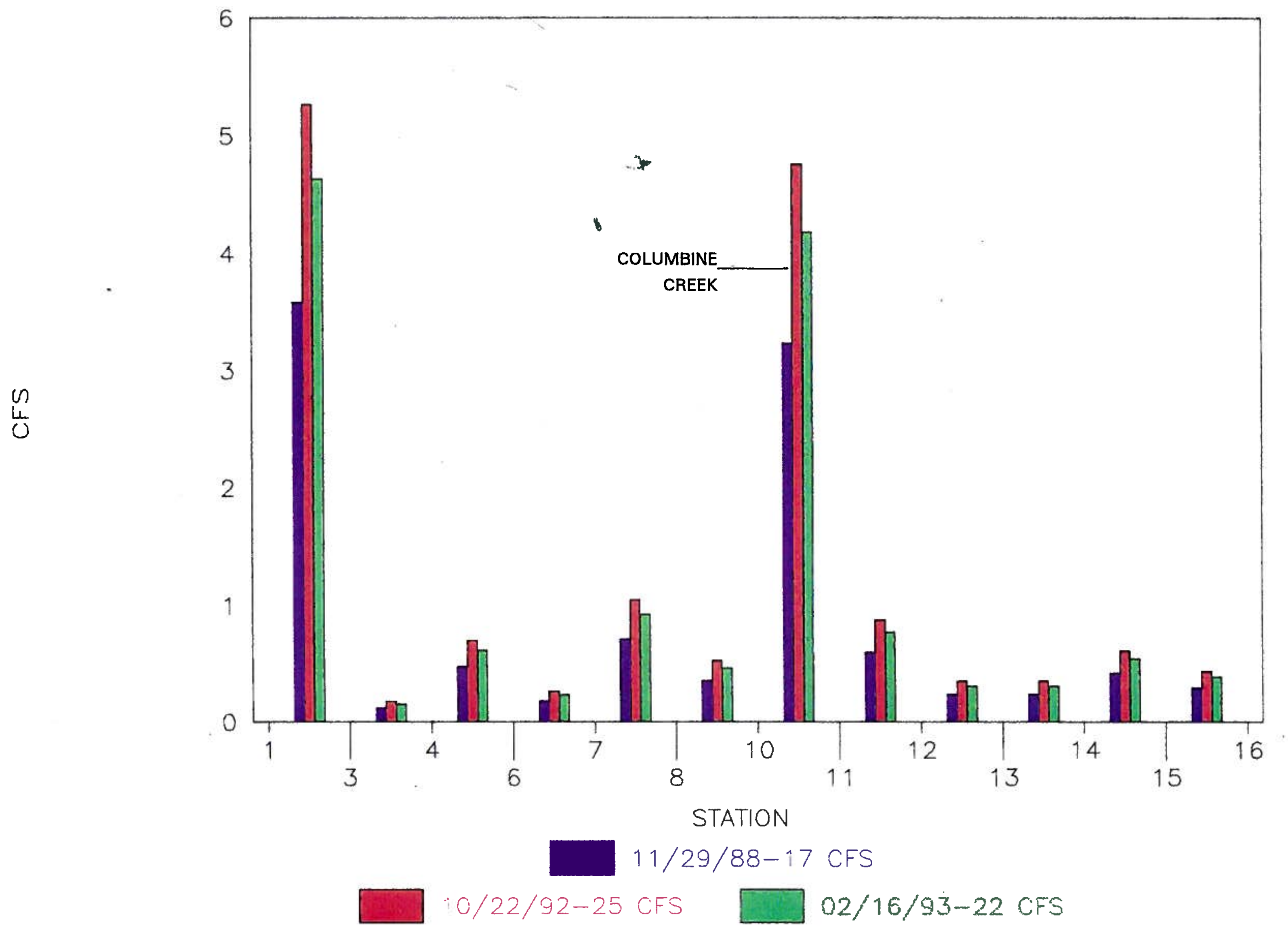

FIGURE 1

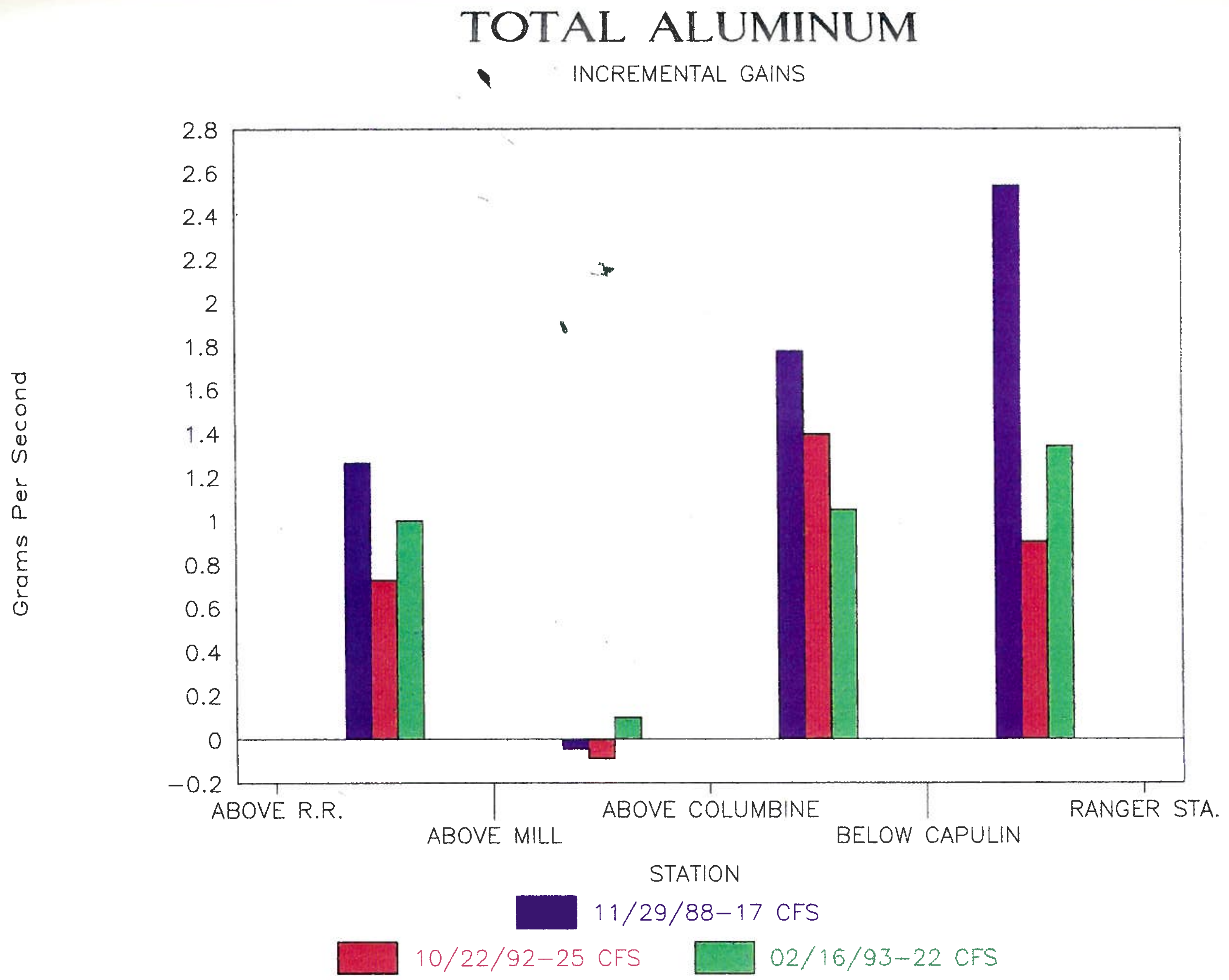
TOTAL ALUMINUM
INCREMENTAL GAINS
Grams Per Second
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
ABOVE R.R.
ABOVE MILL
ABOVE COLUMBINE
BELOW CAPULIN
RANGER STA.
STATION
11/29/88−17 CFS
10/22/92−25 CFS
02/16/93−22 CFS

FIGURE 2

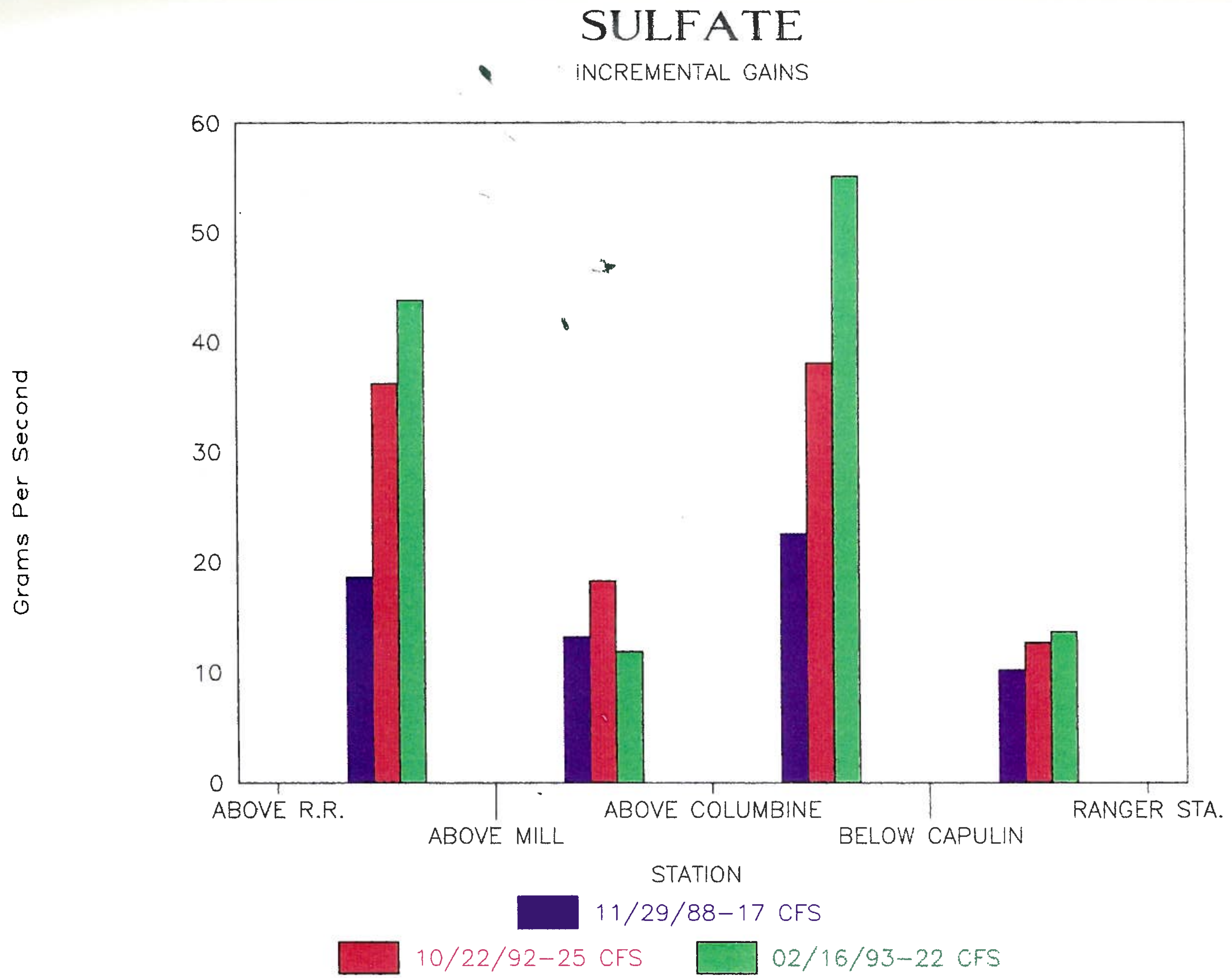
SULFATE
INCREMENTAL GAINS
Grams Per Second
0
10
20
30
40
50
60
ABOVE R.R.
ABOVE MILL
ABOVE COLUMBINE
BELOW CAPULIN
RANGER STA.
STATION
11/29/88–17 CFS
10/22/92–25 CFS
02/16/93–22 CFS

FIGURE 3

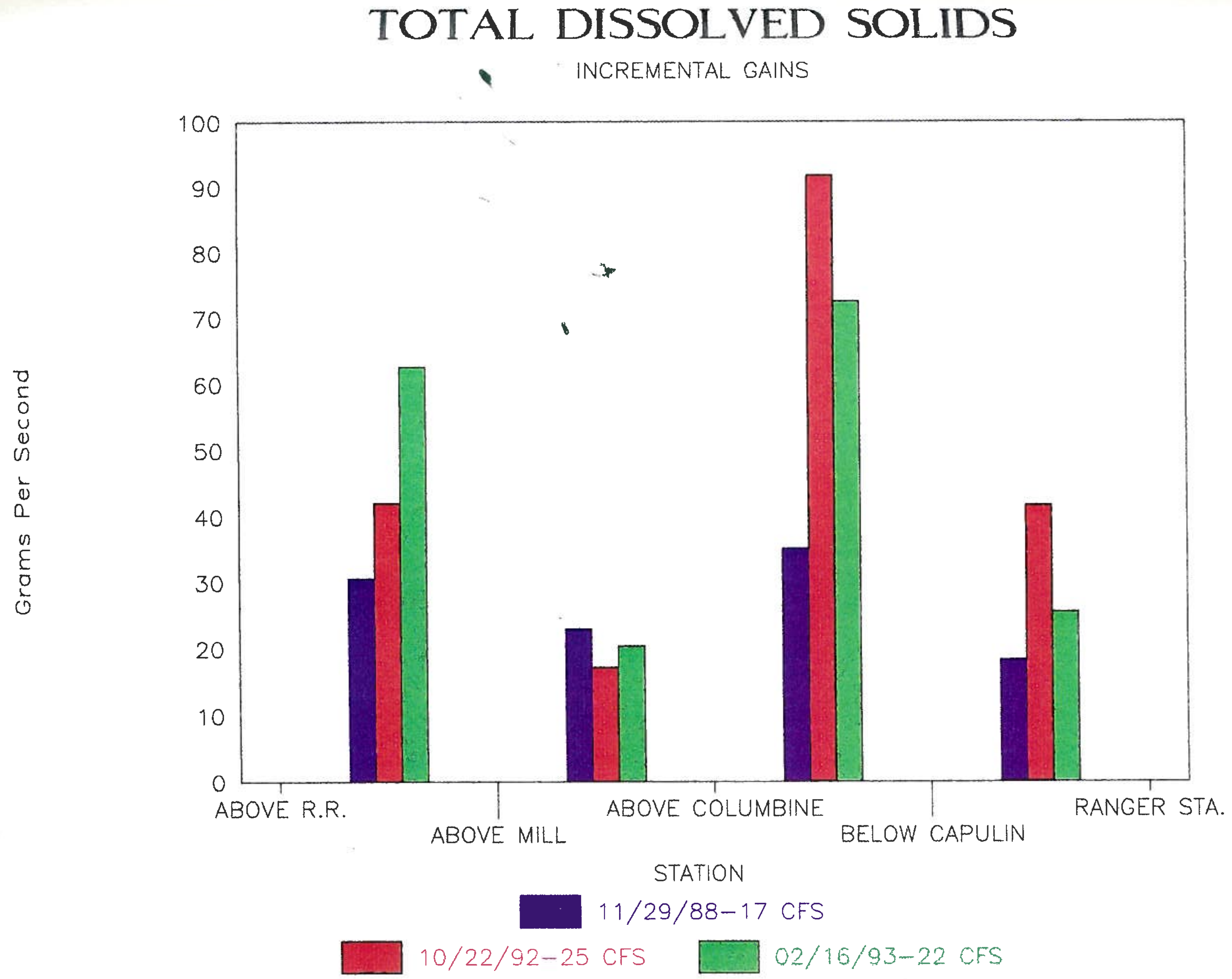
TOTAL DISSOLVED SOLIDS
INCREMENTAL GAINS
Grams Per Second
100
90
80
70
60
50
40
30
20
10
0
ABOVE R.R.
ABOVE MILL
ABOVE COLUMBINE
BELOW CAPULIN
RANGER STA.
STATION
11/29/88–17 CFS
10/22/92–25 CFS
02/16/93–22 CFS

FIGURE 4

TOTAL SUSPENDED SOLIDS

INCREMENTAL GAINS

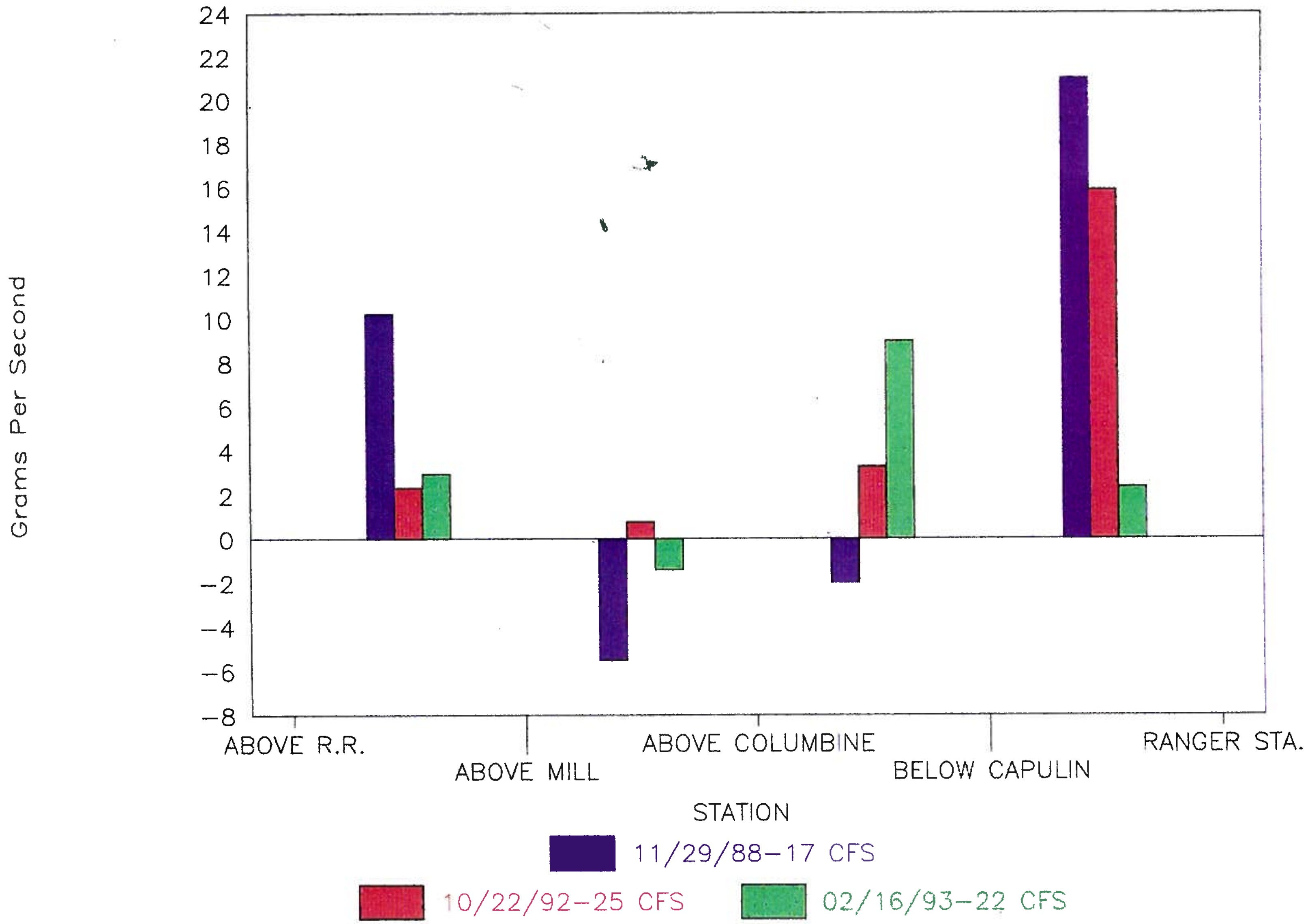

FIGURE 5

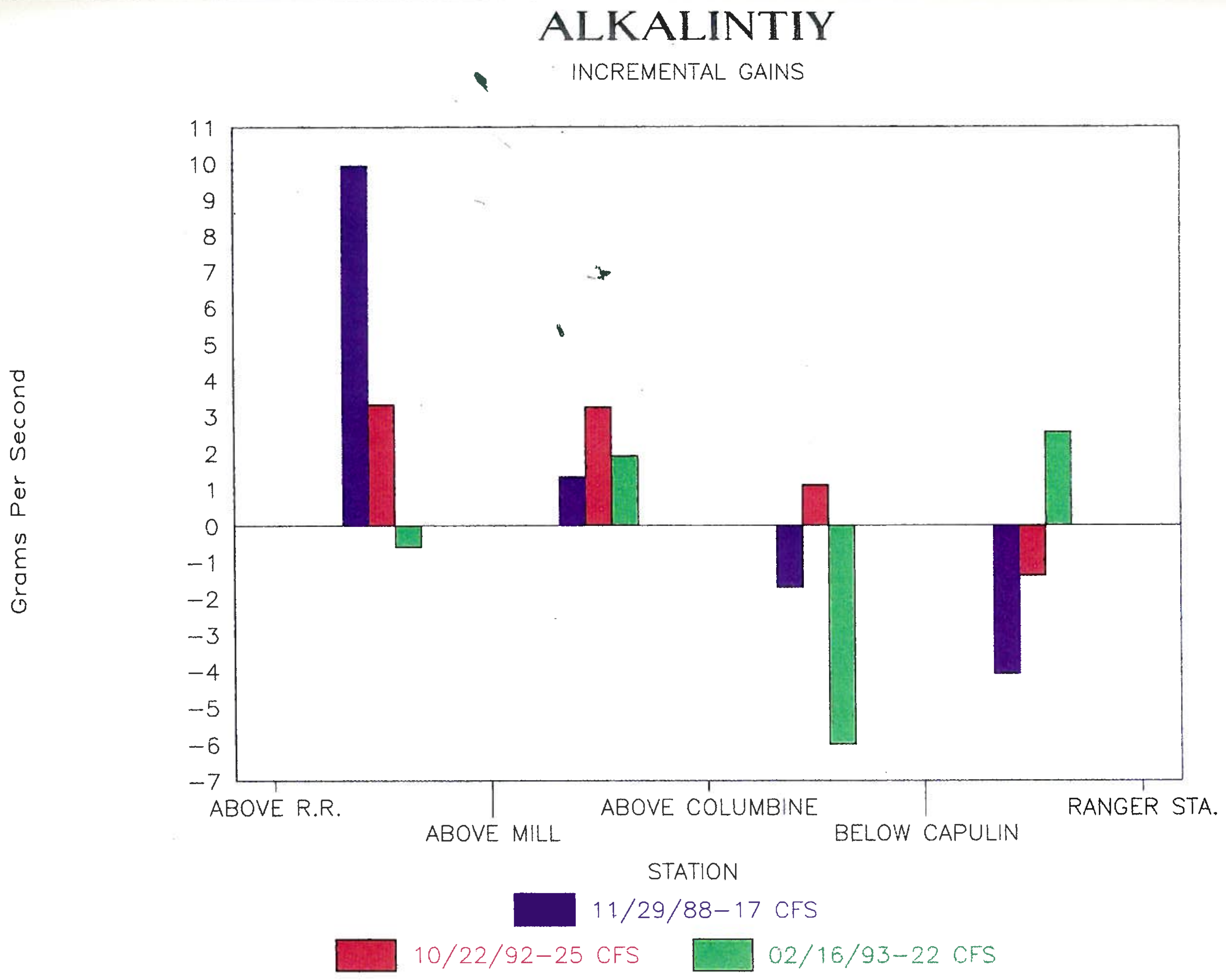
ALKALINTIY
INCREMENTAL GAINS
Grams Per Second
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
ABOVE R.R.
ABOVE MILL
ABOVE COLUMBINE
BELOW CAPULIN
RANGER STA.
STATION
11/29/88−17 CFS
10/22/92−25 CFS
02/16/93−22 CFS

FIGURE 6

affected value, and by comparison to similar sample runs on other dates.

Aluminum. Aluminum increased fairly steadily downstream. There were fairly sharp rises at Hanson Creek, Goathill Gulch and Capulin Canyon; however, by far the greatest part of the gain was from below Capulin Canyon to the ranger station.

The indicated gains in aluminum correlate well with the location of acid springs in which aluminum precipitate was observed. Moreover, there is a particularly strong association of aluminum in river water with the pH of the springs. Only springs with pH 5.0 or lower input significant quantities of aluminum to the river. The largest gains are from downstream springs with pH as low as 3.5. The solubility relationships shown in Figure C indicate that dissolved aluminum is mainly transportable at pH values less than 5.0.

There was a significant indicated loss of aluminum between some stations for some surveys. This generally was attributed to settling out of precipitated gibbsite along the stream bed. Similarly substantial gains in aluminum may have resulted in part from remobilization of the precipitate.

Sulfate. The distribution of sulfate gains to the river does not correlate proportionally with aluminum gains. Sulfate gain is informative, as it is a measure of the distribution of acid ground water sources. The distribution of sulfate gains indicates that sources of acidic water are fairly extensive along the river. Observed pH and transportation of aluminum, however, are not always proportional to the sulfate content of the water.

In particular, the Goathill Gulch area was responsible for a significantly large percentage of the sulfate gain and a fairly low percentage of the aluminum gain.

Total Dissolved Solids. Gains in total dissolved solids (TDS) agree somewhat with the pattern of gains in sulfate. This is to be expected, as roughly 60 percent of the gain in TDS is sulfate. Thus, TDS is also apparently controlled principally by stream accretion.

Total Suspended Solids. Changes in total suspended solids (TSS) vary widely over the study area. The largest gains agree with the gains in aluminum at Hanson Creek and at the ranger station. The amount of suspended solids can decrease along some reaches settling out along the stream bed and plating of rocks by the gibbsite. At other times, particularly with rising stream flow, the suspended solids may increase above natural accretions as a result of re-mobilization of the precipitated material. Gibbsite also precipitates out as suspended material and re-dissolves with increases and decreases in river pH.

Alkalinity. Total alkalinity (as $CO_3^{=}$) also varies considerably, although there is a general, decreasing trend of incremental changes. This is to be expected, as acid waters react with and neutralize alkaline components downstream.

Bicarbonate is the principal alkaline ion. It is principally atmospherically derived, and thus tends to replenish downstream, buffering the pH at around 8.0. The decline in alkalinity reflects the input of sulfuric acid overwhelming the natural buffer. The declines occur at roughly downstream locations from Hanson Creek, Goathill

Gulch and Capulin Canyon with a one-half to one-mile lag indicating that neutralization is not instantaneous. The cause of the sharp gain at Red River has not been determined. Perhaps a man-made source of alkalinity is present in the town area.

Turbidity (Jackson Turbidity Units). Turbidity was not converted to flow-compensated values, as it is measured in light absorption units rather than concentration; however, it is useful in that the turbidity plot in Drawing 3 closely follows suspended aluminum and TSS, confirming that the most important sites of clouding occur below Capulin Canyon, at Goathill Gulch, and at Hanson Creek.

Other Metals and Fluoride. Samples collected during the river surveys were also analyzed for several other trace metals and fluoride.

Cadmium, barium and molybdenum concentrations were below the detection limit in all samples for the analytical methods used.

The lead concentration was below the detection limit in most samples.

Copper concentrations remained nearly constant at .01 mg/l, suspended and .02 mg/l, dissolved from the Town of Red River to above Capulin Creek. Below Capulin Creek the copper concentration increased slightly.

Concentrations of zinc, manganese and iron are shown on Drawings 2, 4 and 6. There was a general increase in a downstream direction in the concentration of all of these elements. The pattern of increase was similar to that of aluminum, with the larger incremental increases occurring downstream of Capulin Canyon. Such adds evidence of the high leaching activity in the mountain slopes above the lower stream reach even though there is evidently only a small ground water flow.

Most of the iron concentration is suspended matter. The significant fluctuation in iron concentration along the stream is attributed to oxidation and precipitation. Red staining by iron oxide is present along several reaches of Red River.

The zinc concentration at the Ranger Station ranged from .27 mg/l to .37 mg/l. The zinc concentration increased slightly in a downstream direction to Capulin Canyon with larger increases indicated along the lower reach.

Manganese concentrations were largely dissolved matter.

Discussion

For the purposes of discussion, we have divided the length of the Red River studied into four segments. Figure A shows the location of the prominent hydrothermal scars and the percentage of the total scar area along each segment.

1. Red River town to Molycorp mill area (stations 1 - 7). This reach is characterized by low accretion to the river and widespread scar and mud flow areas on the north and the smaller June Bug Creek scar on the south. Pioneer Creek, Mallette Creek, Bitter Creek, and Hansen Creek are intermittent flowing tributary streams in this reach. Below Hanson Creek, springs are the only significant source of acidic water and aluminum. Mildly acidic water enters the river in the town area, but no precipitate was observed there.

This reach contains approximately 45% of the middle Red River stream length and about 50% of the hydrothermal scar area.

Approximately 40% of the flow in Red River at the Ranger Station, during periods when the flow is less than 40 cfs, originates above the Town of Red River. The stream water above the Town has a high pH, and concentrations of aluminum, sulfate and other constituents are very low. About 34% of the flow accretion to the middle Red River occurs in the vicinity of the Town of Red River and another 7%± originates from springs and seepage flow from below the Town to above Molycorp's mill area.

For Molycorp's surveys the gain in aluminum along this reach ranged from 24 to 28% of the total gain above the ranger station and the gain in sulfate ranged from 27 to 34% of the total. There was, however, a significant variation in the location of the accretions between the segment in the vicinity of the Town and the segment from below the Town to above the mill. Approximately one-half of the gain in both aluminum and sulfate along this reach appears to originate from drainage below the hydrothermal scar areas in the vicinity of Hansen Creek. Hansen Creek has surface flows on the order of 20 to 30 gpm at pH 3.5 during much of the time. The surface flows often extend all the way to the Red River.

2. Mill area to Columbine Creek (sample stations 8 - 11). This area contains the upstream mine dumps. There are a few acidic springs, notably at Sulfur Gulch, but little aluminum precipitate. Columbine Creek (sample 9), flowing from the south, is near the west end of this reach. Water quality in Columbine Creek is non-acidic with very low aluminum and sulfate concentrations. Chambers Spring, flowing from the south, discharges a small flow of moderately alkaline water to the river near the west end of the mill area. The river was generally relatively clear over this reach.

This reach extends over approximately 23% of the length of the middle Red River survey area. About 25% of the original hydrothermal scar area is drained along this reach including Sulfur Gulch which probably was one of the most active of the scar areas. An estimated 25% of the total stream flow accretion along the middle Red River accrues along this reach which includes about 19% flowing from Columbine Creek.

Aluminum gains along this reach ranged from 7% of the total at the Ranger Station in 1988 to 13% in 1992 and 11% in 1993. Sulfate gains ranged from 18% in 1988 to 36% in 1992 and 26.6% in 1993. Most of both the aluminum and sulfate gain originated near the westerly end of this reach. Springs located along this reach on the north side of Red River had slightly acidic water (ph > 5.0).

3. Above Goathill Gulch to below Capulin Canyon (sample stations 12 - 14).

This reach extends along approximately 23% of the middle Red River survey area. Approximately 21% of the hydrothermal scar area including Goat Hill Gulch and Capulin Canyon, drain to Red River along this reach. The mine dumps at the heads of these drainages contain the majority of the altered rock material placed in the mine dumps. An estimated 6.3% of the total accretion to middle Red River occurs along this reach. This includes flow from Bear Canyon, a small non-acidic intermittent creek flowing from the south and the Goat Hill and Capulin drainages which had surface flow extending nearly to Red River a significant amount of the time until the flow was intercepted by Molycorp's activities.

Aluminum gain along this reach increased from 30.6% of the total in 1988 to 39.5% in 1992 and then decreased to 25.5% in 1993. Sulfate gain decreased from 41% in 1988 to 22% in 1992 and then increased to 32.5% in 1993. There was a significant variability between the three Molycorp surveys along this reach; however, all surveys indicated that there was a significantly higher aluminum gain from the Capulin drainage than the Goat Hill drainage and less sulfate gain from the Capulin than the Goat Hill drainage. In 1988 and 1992 the aluminum gain from Goat Hill was about 12% of the total at the ranger station. In 1993 the survey indicated a slight decrease in aluminum in this reach. In the reach below Capulin Canyon the aluminum gain was 19% in 1988, 28% in 1992 and about 25% in 1993. Sulfate gain in the Goat Hill reach was 28% of the total at the ranger station in 1988; 11% in 1992 and 25% in 1993. Sulfate gain in the Capulin reach was about 12% in 1988 and 1992 and 7% in 1993.

There apparently is a significant difference in the drainage between Capulin Canyon and Goat Hill Gulch. The seeps and springs below Capulin are considerably more acidic resulting in higher aluminum transportation relative to the sulfate loading which is similar to that indicated from the drainage below Capulin to the ranger station. Drainage from Goat Hill Gulch is less acidic and more like the drainage from the scar areas upstream from the mill.

4. Below Capulin Canyon to Questa Ranger Station.

The downstream segment of the river is relatively short (.85 miles or 8% of the length of the river studied) and contains only 4% of the hydrothermal scar area. The acidity of the springs and seeps along this reach was generally lower and the aluminum gains generally higher than any of the other stream reaches. In this reach the pH of the river dropped to as low as 6.8 owing to the presence of many small acidic springs (pH 3.5 to 4.5). The greatest increase in cloudiness of the river was along this reach and the alkalinity was the lowest. Accretion to stream flow was low here as well (Figure 1). Taken together, these observations indicate that a small flow of very low pH water carries concentrated amounts of metals to the river. Many small springs were observed in this area, mostly at pH 3.5 to 4.5. The solubility of aluminum increases 50-fold between pH 5.0 and 4.0, (Figure C) more than compensating for the low ground water flow.

The source of aluminum accretion from this segment is in all likelihood the small altered area which lies above the river on the north. Conditions here seem to favor generation of low pH waters. The altered area is rocky, fractured and not deeply weathered, which promotes infiltration of precipitation. The area is close to the river and no live streams are present. Consequently, the opportunity for dilution is diminished.

The aluminum gain along this reach was 38.6% of the total gain to the ranger station in 1988, 21% in 1992 and 36% in 1993. The sulfate gain was 14% in 1988, 9% in 1992 and 7% in 1993. The largest gains in zinc, copper and other trace metals occur along this reach. Accretions of aluminum and acid in the reaches upstream have raised the river to near saturation level, so that the large additions in the lower reach must precipitate rather than staying dissolved. This results in the greatest amount of turbidity occurring along this reach.

Temporal Variability of Mass Loading

There are significant variations over time in both concentration and total discharge of aluminum and sulfate in the Red River. Analysis of the available data, part of which is shown in Table 4, has led to development of reasonable correlations between aluminum and sulfate variations and variations in surface and ground water flow.

The primary controls on water chemistry are the quantity and source areas of surface and ground water discharge. Stream flow resulting from snow melt at higher elevations and south of the river is relatively dilute. Stream and ground water flow from lower, altered areas has comparatively high concentrations of dissolved constituents. Increases in stream flow principally result from surface runoff. As most of the surface runoff is comparatively dilute, increased stream flow generally causes a decrease in aluminum and sulfate (and other) concentrations simultaneously with an increase in total mass loading. The change in concentration and mass flow is not proportional to the change in stream flow. In general, and except for ephemeral events, it appears that as the stream flow increases, the percentage of the flow that originates from acidic drainages becomes less and less. Above a flow of about 40 cfs at the ranger station, the concentration does not decrease substantially and the mass loading of constituents becomes more proportional to stream flow. This indicates that nearly all of the flow above 40 cfs originates from snow melt or precipitation runoff which reaches the stream by surface flow. The data also indicates that for any specific flow rate the percentage of the flow that is attributable to acidic drainage may vary substantially over a period of years. This again reflects the probable effects of the long term precipitation cycles.

Relative loadings of aluminum and sulfate, measured at the Questa Ranger Station vary substantially. The data indicates that aluminum decreases relative to sulfate during declining and stable stream flow conditions. Aluminum increases relative to sulfate when stream flow rapidly increases. Apparently, gibbsite precipitated during low stream flow settles to the stream bed and is remobilized by the increased velocity and turbulence of rising stream flow. It appears that even small increases in stream flow are sufficient to remobilize significant amounts of the precipitate. It is probable that stream flow of 200 cfs or greater would be sufficient to substantially scour the stream bed; however, the data was insufficient to confirm this.

Sulfate is fully dissolved in the river. Variability in sulfate is caused only by variation in the rate of input to the stream system. Changes in sulfate loading, therefore, are not as pronounced as aluminum changes, except during thunderstorm flood flows.

Changes in the composition and flow of ground water accreting to the river are generally gradual over fairly short periods of time but may be significant over long periods of time. Short- term changes in aluminum to sulfate ratios in the river as a result of change in ground water flow are probably insignificant compared to the effects of surface tributary variation.

The data indicates that except for thundershower-type events, the highest aluminum and sulfate loadings may occur following the spring snow melt period at the lower elevations. The data also indicates that there may generally be a significant decrease in total drainage from the altered areas in the late fall and early winter months. This may be due to decreased surface flow from the scar areas to near the river. The data was insufficient for analysis of loadings during the winter months.

It is difficult to obtain analytical results from stream samples with a high degree of consistency. For example during one survey the stream was sampled three times in one day at several locations. The reported sulfate concentrations for the three runs were 76, 66 and

49 mg/l at one station; 47.5, 40 and 42.8 mg/l at another station; and 56, 64 and 80 mg/l at another station. During this survey the flow in Red River was reportedly fairly stable.

Comparison of the sampling surveys of Red River; however, indicates a generally good consistency of overall results in that most of the surveys indicated comparable percentages of constituent gain for the major stream reaches (Table 1).

Erratic data points occur in most of the stream surveys. Such points varied from survey to survey. It is believed that at least part of the apparent discrepancy was caused by sampling bias. In particular it appears that some samples may have been collected from near the stream shore where water from hidden springs or flow from upstream tributaries had not been completely mixed in the stream flow. Most of the aluminum is in the suspended fraction. It is possible, therefore, that the collected samples captured varying amounts of the precipitate depending on whether the sample was collected from relatively quiescent or highly turbulent areas or from near the surface or near the stream bottom. There were a much higher number of sampling points for Molycorp's surveys which made the identification of the location and magnitude of erratic data points more apparent.

In order to minimize sampling bias it is proposed that future samples be consistently taken from the portions of stream reaches with high velocity and turbulent flow, and from about the midpoint of stream width. For consistency the samples for each run should be collected from the identical locations to the extent practical.

In areas where complete mixing of spring or tributary water may not be present, a conductivity survey should be made across the stream section to insure selection of a sampling point which reflects the average stream concentrations.

As stated, there appears to be a high variability in both short term and long term discharge of aluminum and sulfate by the Red River. Therefore, estimates of contributions to the river from various sources are somewhat tenuous. Continuation of sampling and analysis will make it possible to better define the average discharge and variation of aluminum and sulfate in the river. This will lead to more precise determination of the relative and absolute contributions from Goathill Gulch, Capulin Canyon and other drainages.

Interception of Acidic Drainage

For years the original underground and open pit mine have intercepted a large portion of the acidic drainage from the hydrothermal scars in the Sulfur Gulch area. The dumps to the south of the open pit mine are partially underlain by natural hydrothermal scars. These dumps are mainly composed of un-altered non acid forming rocks which probably have reduced the precipitation infiltration into and oxidation of the scar material. There are still a few mildly acidic springs and seeps along this reach of Red River. It is believed that these are attributable mainly to drainage down the southern outer slopes of the mountain.

Removal of ore from beneath Goat Hill Gulch by the new underground mine has resulted in the subsidence of a large area in the bottom of the gulch which is generally referred to as the caved area. This area has the shape of an inverted cone with a diameter of about 600 feet and a depth of approximately 175 feet. Since 1990 all of the drainage from the mine dumps and scar areas in the upper part of Goat Hill Gulch has been drained into this caved area. Prior to this, there was a highly acidic surface flow in Goat Hill Gulch that extended to near Red River much of the time. As indicated by Hansen Creek, it is probable that the surface flow was present much of the time even before the dumps were developed. In addition to drainage from the Goat Hill dumps and underlying hydrothermal scars, the caved area is probably intercepting the natural drainage from over 60% of the other scar areas along the gulch.

Drainage into the caved area seeps through the fractured rock and into the underground mine where the water level is substantially below the river level. At the present time the mine is not in operation and the water is being allowed to accumulate and fill the mine. A separate study is being conducted to determine how the drainage water will be modified by dilution with the natural and presumably greater amount of non-acidic ground water flow and by the buffering effect of flow through the non-altered formations prevalent in most of the mine workings. The study will also access measures that may be required to prevent drainage of acidic water from reaching Red River when the water level within the mine reaches a critical elevation.

In 1992 Molycorp constructed six collection sumps downstream of the mine dumps in Capulin Canyon. The sumps were constructed at spring areas and across the natural drainage channels. Concrete cutoff walls or plastic liners were installed to restrict downstream flow from the sumps and perforated pipes were installed to collect the intercepted drainage. This was piped away to the upper end of the bore hole. The sumps were backfilled with clean gravel.

An 1130 foot long, nearly horizontal bore hole was drilled across the ridge between Capulin Canyon and Goat Hill Gulch. The bore hole was cased with 6 5/8" steel pipe with a 5" PVC inner conduit. Drainage water from the collection sumps is diverted through the bore hole from Capulin Canyon to Goat Hill Gulch upstream of the caved area. The discharge end of the bore hole is 64 feet below the inlet end in Capulin Canyon. The 5" inner casing has a capacity of over 500 gpm.

The following table lists the measured flows collected from Capulin Canyon and discharged through the bore hole.

TABLE 5

CAPULIN CANYON BORE HOLE DISCHARGE

Date	GPM	Date	GPM	Date	GPM
		9-08-92	31.5	12-08-92	24
7-09-92	40	9-18-92	31.5	12-17-92	23
8-10-92	33	9-24-92	34	1-06-93	22
8-12-92	33	10-13-92	28	4-01-93	38*
8-13-92	36	10-20-92	27	4-27-93	75*
8-20-92	31	10-27-92	26	5-10-93	50*
8-21-92	32	11-05-92	26	5-19-93	43*
8-24-92	34	11-10-92	26	6-15-93	31.5*
8-26-92	36	11-25-92	24	6-22-93	26

* Larger flows attributed to snow melt.

Measurements and samples indicate that the drainage flow from the Goat Hill Gulch dump area is generally slightly greater in flow and a little less acidic than the drainage from the Capulin dump area.

In 1993 a continuing drainage flow was observed downstream of the collection sumps below the dump area in Capulin Canyon. This flow appears to be on the order of 15% of the flow captured by the sumps. Since the downstream flow is less acidic, it is probable that at least part of the flow is from natural drainage outside of dump and scar areas. A portion of this flow may also be residual drainage from the aquifer after the completion of the upper collection system. In consideration that part of the lower drainage flow may be seepage that is flowing past the upper collection system; Molycorp is presently constructing a catchment basin some 1200 feet downstream from the existing collection system. The downstream catchment basin is also being constructed to collect and retain storm drainage which may flow past the upper system. The downstream catchment basin is over 200 feet lower in elevation than the bore hole inlet. Molycorp, therefore, has constructed an electric power line into the area and is constructing a station to pump the drainage from the lower catchment basin up to the bore hole inlet works. The lower seepage collection system is scheduled to be completed and in operation by the end of July 1993.

Molycorp Drawings 152-27, 152-28 and 152-29 which are included with this report, show the location and details of the Capulin Canyon seepage collection system.

A detailed analysis of the flow time from the heads of Capulin Canyon and Goat Hill Gulch has not been made. For the portion of the drainage that was transported over most of the distance by surface flow, the travel time was probably fairly short. For this portion of the flow, the drainage collection system should decrease the discharge to Red River within a fairly short period of time if such is not already occurring. Ground water flow is considerably much slower and drainage from the dump areas which occurred prior to the construction of the collection system may continue to reach Red River at a decreasing rate over the next several years.

There are extensive areas of altered rock and hydrothermal scars downstream of the drainage collection systems in both Goat Hill Gulch and Capulin Canyon. These will result in some continuing acidic drainage from these basins. It is anticipated, however, that within a reasonable period of time, the total acidic drainage from these basins will be significantly less than the natural drainage before the mine was developed.

Storm Drainage

Intense thunderstorms frequently occur in the area during the summer months. Moderately intense storms on the order of one to two inches result in surface drainage from some of the hydrothermal scars directly to Red River. These flows have low pH and very high concentrations of aluminum, sulfate, other dissolved metals and suspended solids. Drainages from the moderately intense storms have a significant short term impact on the water quality of Red River. Very intense thunderstorms, on the order of three inches or more, result in large mud flows from the hydrothermal scar areas which sometimes blocks the highway near the mouth of the canyons and may temporarily dam the river. Such intense storms may occur about once a decade. At such times, suspended solids in Red River may exceed 10% with high turbidity extending in the Rio Grande to Cochiti Lake. Investigations by the Thorne Ecological Institute (1972) indicate that storm runoff has only transient effects on water quality and faunal assemblages of the Red River.

Molycorp's open pit mine intercepts nearly all of the storm drainage from the Sulfur Gulch area and the caved area in Goat Hill Gulch intercepts the drainage from the dump area and hydrothermal scars in the upper portion of Goat Hill Gulch. The caved area has sufficient volumetric capacity to contain the drainage from several flows resulting from three inch and greater amounts of precipitation.

Molycorp has also constructed a number of catchment basins in Capulin Canyon and the lower reach of Goat Hill Gulch and has constructed large berms above the highway along reaches below the mine dumps from the mill area to Columbine Creek. These catchment basins and berms significantly reduce the amount of flood drainage which directly flows to Red River.

The effects of a moderately intense storm were observed by Smolka and Tague on September 13, 1988 and data from other events are contained in USGS publications. Observed concentrations in the Red River following a storm are shown in Table 6. A large increase in suspended aluminum was observed which is probably attributable in large part to metallic aluminum in suspended clays, rather than aluminum hydroxide.

Table 6

Analytical data for a flood water sample from the Red River at the Questa Gauging Station, July 26, 1988.

Al(susp) mg/l	1453
Al (dis) mg/l	3
SO_4	278
TDS mg/l	1112
TSS mg/l	47844

Another storm occurred on June 25, 1992 with a measured precipitation of 1.05 inches at Molycorp's mill area. This storm extended over the mine area and up the river basin past Hansen Creek. Water samples were collected at several locations immediately following the passage of the storm. The results of the analysis are shown on the following Exhibit No. 1. The analysis indicates that drainage from the hydrothermal scars and mine dumps in the mine area

TABLE 7

STORM WATER ANALYSIS
COMPOSITE SAMPLES OF RAIN STORM OF JULY 25, 1992
TOTAL RAINFALL 1.05 INCHES
ALL UNITS IN PPM

SAMPLE SOURCE	PH	TSS	F	TDS	CD	PB	FEME	MO	ZN	CU	AL	SO4	
RED RIVER ABOVE TOWN OF RED RIVER	8.4	21.0	0.1	94	<.01	<.1	1.3	.05	<.01	.010	<.02	1.0	13.4
BITTER CREEK		NO FLOW ENTERING RED RIVER											
HAUT N TAUT WASH CREEK		NO FLOW ENTERING RED RIVER											
HANSEN WASH CREEK	3.1	43000	1.0	4094	<.01	5.2	2500	25.4	8.0	7.4	3.0	755	686
MILL DRAINAGE BASIN	7.9	2500	1.7	268	<.01	1.2	144	9.2	5.9	1.4	0.76	113	61
RED RIVER ACROSS AND UP FROM MILL YARD	7.3	829	0.3	194	<.01	<.1	52	.85	0.45	.184	<.02	16	62
GOAT HILL GULCH WASH CREEK	6.5	530	0.8	200	<.01	<.1	43	.72	0.82	.230	<.02	16	37
CAPULIN CANYON		NO FLOW ENTERING RED RIVER											
RED RIVER AT RANGER STATION	7.5	450	0.8	236	<.01	0.12	27.9	1.2	0.50	.281	.114	12.8	59

LESS THAN SYMBOLS ARE DETECTION LIMITS
ALL METAL ANALYSIS ARE FOR TOTAL METAL
TOTAL METALS: THE CONCENTRATION OF METALS DETERMINED ON AN UNFILTERED SAMPLE:

was mainly contained in the mine area. In comparison, there was a significant amount of low pH drainage and high suspended solids from Hansen Creek where there was no drainage control.

A detailed investigation of the chemistry of the storm runoff waters is beyond the scope of this report.

Summary

In the preceding pages it has been shown that significant gains in aluminum, sulfate and other constituents occur in the Red River from the town of Red River to the Questa Ranger Station. The details of the mechanism of aluminum hydroxide accretion in the river are still uncertain; however, a tentative model can be made:

. Aluminum is leached from sulfidized country rocks and transported to the river by sulfuric acid which is created by the breakdown of pyrite.

. Aluminum is transported in the subsurface and in small streams at concentrations up to about 1000 mg/l and pH 2.5.

. Dilution of the aluminum laden water occurs by intermingling with ground water above the river. This reduces the composition of the aluminous water to about 200 mg/l Al or less at pH 3.5 to 5.0.

. Aluminum emerges at springs along the river. Increase of pH to near neutral causes precipitation of gibbsite [$Al(OH)_3$].

. The greatest concentration of gibbsite occurs where the pH of the acid spring water is lowest. This occurs between Capulin Canyon and the Questa Ranger Station. Apparently, the spring water is relatively undiluted in this reach.

. Natural sources account for most of the aluminum and sulfate gains to the river. Contributions may vary seasonally.

. Long term variations in seepage and springs, controlled by precipitation cycles, are possibly responsible for observed increases in sulfate and aluminum hydroxide in the Red River in recent years. Long term, systematic sampling of the Red River is needed to establish this relationship conclusively.

The results of this investigation are tentative. In large part this is because of several limitations to the present data base. One drawback is that ground water accretion along the individual stream reaches is too small to be accurately quantified by the obtainable precision of standard stream gauging field methods. In addition, the spacing of measurement stations in the available U.S.G.S. data is too great to clearly define local accretion rates. A second problem is that large changes in stream chemistry occur from sample to sample at the present data spacing. In many instances, it is not possible to determine if an apparent abrupt change is caused by real change in the river, by sampling technique, analytical error or by inhomogeneity of the river water. There is a substantial variation in the concentrations of sulfates, aluminum etc. over short periods of time. For example, at the ranger station, sulfate increased from 186 mg/l on 1-5-88 to 356 mg/l on 2-27-88 while aluminum declined from 13.4 mg/l to 6.0 mg/l on the same dates. Recorded flow on these dates increased from 19 cfs to 23.

The earlier stream surveys conducted by HEW in 1965 and EPA in 1970 are not comparable with the more recent surveys conducted by Smolka and Tague - EID 1986-1988 and Molycorp 1988-93. The 1965 survey was conducted following two years of very low precipitation and it is probable that spring and ground water flow from the hydrothermal scar areas was a much lower percentage of the total river flow. In 1970 Molycorp was diverting several cubic feet per second of water from the river. The survey data indicates a decrease in flow from below Hansen Creek to Goat Hill of over 3 cfs even though Columbine Creek and Chambers Springs enter along this reach. This survey also indicated a large decrease in the sulfate concentration which would have been due to the dilution of the remaining stream flow below the mill with Columbine Creek water.

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APPENDIX 1

Analytical data for water samples from the Red River, November 29, 1988

Major Consituents

Station	pH	Al mg/l (Suspended)	Al mg/l (Dissolved)	$SO_4^{=}$ mg/l	TDS mg/l	TSS mg/l	Tot. Alk.	JTU
1	7.8	<.5	<.5	8	106	<1	38	1
2	8.1	<.5	<.5	33	115	5.2	67	1
3	7.7	<.5	.8	34	138	1.9	71	3
4	8.0	.5	.7	43	133	1.6	68	4
5	8.1	.5	1.0	40	140	6.0	65	4
6	7.7	1.2	1.8	46	149	17.8	62	8
7	7.7	2.3	1.8	65	163	33.7	55	10
8	7.7	1.6	1.9	85	173	8.7	56	7
9	8.4	<.5	<.5	5	73	<1	60	2
10	8.0	1.6	2.0	98	216	14.4	54	9
11	7.7	1.6	1.8	68	171	16.1	54	6
12	7.8	1.7	2.6	106	229	14.6	54	5
13	7.7	1.6	3.0	131	246	9.2	45	5
14	6.2	2.9	3.6	121	235	6.2	36	7
15	7.0	5.2	4.0	136	276	14.9	26	14
16	7.1	7.1	4.4	137	263	49.6	26	22
17	7.4	6.6	4.0	140	296	35.3	30	20

Appendix 1 continued

Spring and Creek Data
Major Constituents

	Date	pH	Al suspended mg/l	Al dissolved mg/l	$SO_4^{=}$ mg/l	TDS mg/l	TSS mg/l	Tot Alk mg/l	JTU
Streams:									
Haut N Taut Cr.	3-16-88	3.3	32	19	450	925			
Hanson Creek	3-15-88	3.8	50	65	1130	1785			
Goathill Gulch	3-16-88	3.0	41	560	9560	5820			
Goathill Gulch	4-14-88	2.6	7	611	9730	11832	127	<2.0	50
Capulin Creek	3-15-88	3.0	5	650	8980	11440			
Springs:									
Junebug Seep	9-06-88	4.8		6.0	796	1466	14.1		
Hanson Spring	10-15-88	4.4	<.5	18.2	573	813	3.6		2
Assay Lab	10-21-88	5.2	1.8	3.1	359	600	115.1		34
Above Goathill	10-21-88	4.2	1.4	16.1	836	1492	15.9		4
Goathill Seep	3-16-88	3.6	9.2	216	3100	5155			
Above Capulin	10-14-88	4.8	10.9	321	520	366			100
Capulin Seep	10-14-88	4.0	1.1	110.4	1244	2296	43.8		20
Old Channel (near Capulin)	10-14-88	3.5	<.5	116.5	1404	2463			

Appendix 1 continued

Spring and Creek Data (continued)
Trace Constituents (mg/l)

	F^-	Cd	Pb	FE	Mn	Mo	Zn	Cu
Streams:								
Hot & Tot Creek	3.0	.020	.24	82	4.84	<.02	2.03	.47
Hanson Creek	3.8	.018	.11	5.3	8.42	<.02	3.83	.16
Goathill Gulch	32	.300	.23	274	222	<.02	52	7.4
Capulin Creek	38	.320	.20	238	296	<.02	60	7.2
Springs:								
Junebug Seep	4.8	.018	<.05	.32	3.59	<.02	1.10	.26
Hanson Spring	1.6	<.018	<.05	.13	3.16	<.02	.70	.13
Assay Lab	3.5	<.01	<.05	.85	.68	<.02	.52	.05
Above Goathill	4.6	.017	<.05	.68	4.82	<.02	1.46	.26
Goathill Seep	8.0	.070	.18	106.20	38.72	.05	9.63	1.22
Above Capulin	2.4	.010	<.05	16.76	3.23	<.02	.83	.47
Capulin Seep	4.2	.018	.10	25.42	16.33	.03	4.35	1.26
Old Channel (near Capulin)	4.1	.032	.06	2.65	18.42	<.02	4.90	1.46

MOLYCORP INC.
RED RIVER ALUMINUM SURVEYS

SUMMARY OF RED RIVER DATA 11-29-88 (SGV)
Laboratory Analytical Results

STATION LOCATION	STA.	SO4 mg/l	Sus. Al mg/l	Dis. Al mg/l	Total Al mg/l	ALK mg/l	TDS mg/l	TSS mg/l	Turb. JTU	F mg/l	Fe mg/l	Mn mg/l	Zn mg/l	Cond uMHO	pH
1 ABOVE RED RIVER	60600	8	0.01	0.00	0.01	38	106	1.0	1	0.2	0.15	0.03	0.01		7.8
3 BELOW RED RIVER	55300	24	0.02	0.80	0.82	71	138	1.9	3	0.4	0.15	0.11	0.04	N O	7.7
4 JUNEBUG CAMPGROUND	50400	43	0.53	0.70	1.23	68	133	1.6	4	0.3	0.41	0.13	0.04	T	8.0
5 ELEPHANT ROCK CG	43800	40	0.53	1.00	1.53	65	140	6.0	4	0.4	0.51	0.11	0.02	R U	8.1
6 BELOW HANSON CR.	39100	46	1.20	1.80	3.00	62	149	17.8	8	0.5	0.64	0.18	0.04	N	7.7
7 ABOVE MILL	31800	65	2.30	1.80	4.10	55	163	33.7	10	0.5	1.48	0.23	0.08		7.7
8 BELOW SULFUR GULCH	29800	88	1.60	1.90	3.50	56	173	8.7	7	0.7	0.39	0.16	0.07		7.7
10 ABOVE COLUMBINE CR.	22400	98	1.60	2.00	3.60	54	216	14.4	9	0.4	0.58	0.2	0.03		8.0
9 COLUMBINE CR. (Not Red River)		5	<0.5	<0.5	<0.5	60	73	<0.1	2	0.2	0.13	0.02	0.01		8.4
11 ABOVE THUNDER BR.	18300	63	1.60	1.80	3.40	54	171	16.1	6	0.5	0.62	0.32	0.08		7.7
12 GOAT HILL TURNOUT	14400	106	1.70	2.60	4.30	54	229	14.6	5	0.7	0.44	0.33	0.08		7.8
13 ABOVE CAPULIN	10300	131	1.60	3.00	4.60	45	246	9.2	5	0.8	0.23	0.39	0.1		7.7
14 BELOW CAPULIN	7800	121	2.90	3.60	6.50	36	235	6.2	7	0.9	0.4	0.53	0.14		6.2
15 EAGLE ROCK CG	5500	136	5.20	4.00	9.20	26	276	14.9	14	1.3	1.27	1.27	0.31		7.0
16 RANGER STATION	3300	137	7.10	4.40	11.50	26	263	49.6	22	1.2	2.17	1.39	0.37		7.1
17 EAGLE ROCK LAKE	1400	140	6.60	4.00	10.60	30	296	35.3	20	1	1.27	1.3	0.35		7.4

MOLYCORP INC.
RED RIVER ALUMINUM SURVEYS

SUMMARY OF RED RIVER DATA 10-22-92 (REV)
Laboratory Analytical Results

STATION LOCATION	STA.	SO4 mg/l	Sus. Al mg/l	Dis. Al mg/l	Total Al mg/l	ALK mg/l	TDS mg/l	TSS mg/l	Turb. JTU	F mg/l	Fe mg/l	Mn mg/l	Zn mg/l	Cond uMHO	pH
1 ABOVE RED RIVER	60600	9	<0.5	<0.5	0.00	91	152	1.5	1	0.1	0.214	0.01	0.013		7.80
3 BELOW RED RIVER	55300	50	0.78	0.70	1.48	78	186	8.0	5	0.26	0.673	0.224	0.085	240	7.53
4 JUNEBUG CAMPGROUND	50400	53	0.39	0.50	0.89	88	154	2.0	3	0.263	0.396	0.154	0.054	265	8.15
6 BELOW HANSON CR.	39100	66	0.39	0.50	0.89	72	176	4.7	4	0.268	0.359	0.126	0.053	286	8.23
7 ABOVE MILL	31800	85	0.90	0.70	1.60	62	184	6.0	4	0.358	0.31	0.21	0.071	317	8.19
8 BELOW SULFUR GULCH	29800	98	0.84	0.50	1.34	56	214	7.0	5	0.452	0.305	0.21	0.092	334	7.69
8A ABOVE PORTAL	25000	97	0.86	0.50	1.36	62	214	5.0	5	0.452	0.203	0.234	0.072	336	8.06
10 ABOVE COLUMBINE CR.	22400	114	0.78	0.50	1.28	63	202	7.0	5	0.222	0.252	0.21	0.084	343	8.19
9 COLUMBINE CR. (Not Red River)		9	<0.5	<0.5	<0.5	72	98	1.0	2	0.211	0.04	0.03	0.01	161	8.28
10A COMPANY CABINS	21000	113	1.1	0.50	1.60	61	210	16.7	4	0.776	0.147	0.462	0.108	356	7.61
11 ABOVE THUNDER BR.	18300	125	1.10	0.77	1.87	56	216	8.0	4	0.762	0.249	0.476	0.133	352	7.86
11A THUNDER BRIDGE	16400	131	1.4	0.62	2.02	68	200	5	4	0.744	0.159	0.434	0.127	391	7.62
12 GOAT HILL TURNOUT	14400	132	1.50	0.55	2.05	54	266	3.3	3	0.762	0.191	0.378	0.12	401	7.88
13 ABOVE CAPULIN	10300	125	1.50	0.50	2.00	62	244	6.7	5	0.772	0.209	0.448	0.135	400	7.76
14 BELOW CAPULIN	7800	140	2.50	0.50	3.00	48	284	10.0	6	0.841	0.272	0.658	0.206	416	7.45
14A BEAR CANYON	6650	143	2.74	0.65	3.39	51	328	20	8	0.877	0.231	0.742	0.197	419	7.46
15 EAGLE ROCK CG	5500	156	3.56	1.20	4.76	38	336	24.0	9	0.921	0.361	1.13	0.263	431	7.24
16 RANGER STATION	3300	152	3.36	0.79	4.15	44	331	32.0	9	0.948	0.2	1.13	0.273	427	7.39
17 EAGLE ROCK LAKE	1400	153	3.00	0.79	3.79	34	326	27.0	9	1.09	0.181	1.18	0.323	436	7.51

MOLYCORP INC.
RED RIVER ALUMINUM SURVEYS

SUMMARY OF RED RIVER DATA 02-16-93 (DRS)
Laboratory Analytical Results

STATION LOCATION	STA.	SO4 mg/l	Sus. Al mg/l	Dis. Al mg/l	Total Al mg/l	ALK mg/l	TDS mg/l	TSS mg/l	Turb. JTU	F mg/l	Fe mg/l	Mn mg/l	Zn mg/l	Cond uMHO	pH
1 ABOVE RED RIVER	60600	6	<0.5	<0.5	0.00	84	122	1.0	N O	0.1	0.101	0.03	0.02	194	7.6
6 BELOW HANSON CR.	39100	86	0.83	0.50	1.33	46	200	6.0	T	0.32	0.467	0.179	0.041	305	7.6
7 ABOVE MILL	31800	113	2.00	0.50	2.50	49	230	8.0	R U	0.37	0.442	0.274	0.083	336	7.7
8A ABOVE PORTAL	25000	105	1.80	0.50	2.30	43	238	7.0	N	0.498	0.281	0.234	0.072	371	7.8
10 ABOVE COLUMBINE CR.	22400	130	2.00	0.50	2.50	49	256	4.0		0.606	0.636	0.309	0.504	393	7.8
10A COMPANY CABINS	21000	131	1.80	0.50	2.30	49	266	7.0		0.812	0.278	0.221	0.063	369	7.6
11A THUNDER BRIDGE	16400	166	1.6	0.50	2.10	47	292	6		0.812	0.214	0.504	0.111	416	7.3
12 GOAT HILL TURNOUT	14400	182	1.40	0.50	1.90	47	302	11.0		0.831	0.236	0.474	0.112	414	7.6
13 ABOVE CAPULIN	10300	177	1.40	0.50	1.90	43	302	12.0		0.862	0.245	0.518	0.127	436	7.5
14 BELOW CAPULIN	7800	188	3.10	0.50	3.60	26	310	18.0		0.968	0.421	0.755	0.179	444	7.3
16 RANGER STATION	3300	202	5.10	0.50	5.60	29	338	21.0		1.1	0.524	1.5	0.348	458	7.2

MOLYCORP INC.
RED RIVER ALUMINUM SURVEYS

SUMMARY OF RED RIVER DATA 10-22-92 (REV)
Calculated Mass Flow Data (Grams/Sec)

STATION LOCATION	STA.	FLOW CFS	SO4	Sus. Al	Dis. Al	Total Al	ALK	TDS	TSS	Turb. JTU	F	Fe	Mn	Zn	Cond uMHO	pH
1 ABOVE RED RIVER	60600	9.7	2.46	0.00	0.00	0.00	24.85	41.51	0.41	1	0.03	0.06	0.00	0.00	--	7.80
3 BELOW RED RIVER	55300	14.9	21.10	0.33	0.30	0.62	32.92	78.50	3.38	5	0.11	0.28	0.09	0.04	240	7.53
4 JUNEBUG CAMPGROUND	50400	15.1	22.63	0.17	0.21	0.38	37.57	65.75	0.85	3	0.11	0.17	0.07	0.02	265	8.15
6 BELOW HANSON CR.	39100	15.8	29.49	0.17	0.22	0.40	32.17	78.63	2.10	4	0.12	0.16	0.06	0.02	286	8.23
7 ABOVE MILL	31800	16.1	38.61	0.41	0.32	0.73	28.17	83.59	2.73	4	0.16	0.14	0.10	0.03	317	8.19
8 BELOW SULFUR GULCH	29800	17.1	47.43	0.41	0.24	0.65	27.10	103.56	3.39	5	0.22	0.15	0.10	0.04	334	7.69
8A ABOVE PORTAL	25000	17.4	47.70	0.42	0.25	0.67	30.49	105.23	2.46	5	0.22	0.10	0.12	0.04	336	8.06
10 ABOVE COLUMBINE CR	22400	17.6	56.86	0.39	0.25	0.64	31.42	100.76	3.49	5	0.11	0.13	0.10	0.04	343	8.19
9 COLUMBINE CR. (Not Red River)		4.7	1.20	<0.05	<0.05	<0.05	9.63	13.10	0.13	2	0.03	0.01	<0.01	<0.01	161	8.28
10A COMPANY CABINS	21000	22.4	71.47	0.70	0.32	1.01	38.58	132.83	10.56	4	0.49	0.09	0.29	0.07	356	7.61
11 ABOVE THUNDER BR.	18300	22.4	79.15	0.70	0.49	1.18	35.46	136.77	5.07	4	0.48	0.16	0.30	0.08	352	7.86
11A THUNDER BRIDGE	16400	23.0	85.36	0.91	0.40	1.32	44.31	130.32	3.26	4	0.48	0.10	0.28	0.08	391	7.62
12 GOAT HILL TURNOUT	14400	23.3	86.85	0.99	0.36	1.35	35.53	175.02	2.17	3	0.50	0.13	0.25	0.08	401	7.88
13 ABOVE CAPULIN	10300	23.6	83.48	1.00	0.33	1.34	41.41	162.96	4.47	5	0.52	0.14	0.30	0.09	400	7.76
14 BELOW CAPULIN	7800	24.0	94.89	1.69	0.34	2.03	32.53	192.49	6.78	6	0.57	0.18	0.45	0.14	416	7.45
14A BEAR CANYON	6650	24.3	98.14	1.88	0.45	2.33	35.00	225.10	13.73	8	0.60	0.16	0.51	0.14	419	7.46
15 EAGLE ROCK CG	5500	24.6	108.44	2.47	0.83	3.31	26.41	233.56	16.68	9	0.64	0.25	0.79	0.18	431	7.24
16 RANGER STATION	3300	25.0	107.54	2.38	0.56	2.94	31.13	234.18	22.64	9	0.67	0.14	0.80	0.19	427	7.39
17 EAGLE ROCK LAKE	1400	25.0	108.25	2.12	0.56	2.68	24.06	230.64	19.10	9	0.77	0.13	0.83	0.23	436	7.51

MOLYCORP INC.

RED RIVER ALUMINUM SURVEYS

SUMMARY OF RED RIVER DATA 02-16-93 (DRS)
Calculated Mass Flow Data (Grams/Sec)

STATION LOCATION	STA.	FLOW CFS	SO4	Sus. Al	Dis. Al	Total Al	ALK	TDS	TSS	Turb. JTU	F	Fe	Mn	Zn	Cond uMHO	pH
1 ABOVE RED RIVER	60600	8.5	1.44	0.00	0.00	0.00	20.19	29.32	0.24	N O	0.02	0.02	0.01	0.00	194	7.6
6 BELOW HANSON CR.	39100	13.9	33.81	0.33	0.20	0.52	18.09	78.63	2.36	T	0.13	0.18	0.07	0.02	305	7.6
7 ABOVE MILL	31800	14.1	45.17	0.80	0.20	1.00	19.59	91.95	3.20	R U	0.15	0.18	0.11	0.03	336	7.7
8A ABOVE PORTAL	25000	15.3	45.43	0.78	0.22	1.00	18.61	102.98	3.03	N	0.22	0.12	0.10	0.03	371	7.8
10 ABOVE COLUMBINE CR	22400	15.5	57.06	0.88	0.22	1.10	21.51	112.37	1.76		0.27	0.28	0.14	0.22	393	7.8
10A COMPANY CABINS	21000	19.7	72.92	1.00	0.28	1.28	27.27	148.06	3.90		0.45	0.15	0.12	0.04	369	7.6
11A THUNDER BRIDGE	16400	20.1	94.26	0.91	0.28	1.19	26.69	165.80	3.41		0.46	0.12	0.29	0.06	416	7.3
12 GOAT HILL TURNOUT	14400	20.5	105.38	0.81	0.29	1.10	27.21	174.86	6.37		0.48	0.14	0.27	0.06	414	7.6
13 ABOVE CAPULIN	10300	20.8	104.03	0.82	0.29	1.12	25.27	177.50	7.05		0.51	0.14	0.30	0.07	436	7.5
14 BELOW CAPULIN	7800	21.1	112.13	1.85	0.30	2.15	15.51	184.90	10.74		0.58	0.25	0.45	0.11	444	7.3
16 RANGER STATION	3300	22.0	125.77	3.18	0.31	3.49	18.06	210.44	13.07		0.68	0.33	0.93	0.22	458	7.2

APPENDIX 4

COMPUTATIN OF THE PERCENT OF THE TOTAL GAIN WHICH WAS INDICATED FOR MAJOR STREAM SEGMENTS

HEW-11/04/1965

	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	9.9	5.3	52.5		
				278.4	17.2
BELOW RR TOWN	16.3	20.3	330.9		
				464.7	28.7
BELOW HANSEN	17.0	46.8	795.6		
				396.2	24.5
BLW COL. CREEK	23.6	50.5	1191.8		
				478.2	29.6
RANGER STATION	26.3	63.5	1670.1		
TOTALS				1617.6	100.0

EPA-11/04/1970

	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	4.2	10.1	42.5		
				369.9	32.9
BELOW RR TOWN	10.0	41.2	412.4		
				380.7	33.9
BELOW HANSEN	12.7	62.5	793.1		
				56.9	5.1
BLW COL. CREEK	9.6	44.4	427.6		
+ EST MC DIVER.	6.5	65.0	422.5		
				316.6	28.2
RANGER STATION	11.2	66.5	744.1		
+ EST MC DIVER.	6.5	65.0	422.5		
TOTALS				1124.1	100.0

SMOLKA-TAGUE 10/25/1988

	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	11.6	12.0	139.2		
				666.3	19.6
BELOW RR TOWN	17.9	45.0	805.5		
				484.3	14.2
BELOW HANSEN	19.3	67.0	1289.8		
				770.5	22.7
@ GOAT HILL	28.3	72.8	2060.2		
				1479.8	43.5
RANGER STATION	30.0	118.0	3540.0		
TOTALS				3400.8	100.0

APPENDIX 4 - (continued)

COMPUTATIN OF THE PERCENT OF THE TOTAL GAIN WHICH WAS INDICATED FOR MAJOR STREAM SEGMENTS

	SCOTT VAIL 11/29/1988			W/BLW COL CREEK	
	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	6.6	8.0	52.8		
				189.6	8.3
BELOW RR TOWN	10.1	24.0	242.4		
				466.1	20.5
BELOW HANSEN	10.9	65.0	708.5		
				249.1	10.9
BLW COL. CREEK	15.2	63.0	957.6		
				1371.4	60.2
RANGER STATION	17.0	137.0	2329.0		
TOTALS				2276.2	100.0

	SCOTT VAIL 11/29/1988			W/GOAT HILL	
	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	6.6	8.0	52.8		
				189.6	8.3
BELOW RR TOWN	10.1	24.0	242.4		
				466.1	20.5
BELOW HANSEN	10.9	65.0	708.5		
				902.7	39.7
@GOAT HILL	15.2	106.0	1611.2		
				717.8	31.5
RANGER STATION	17.0	137.0	2329.0		
TOTALS				2276.2	100.0

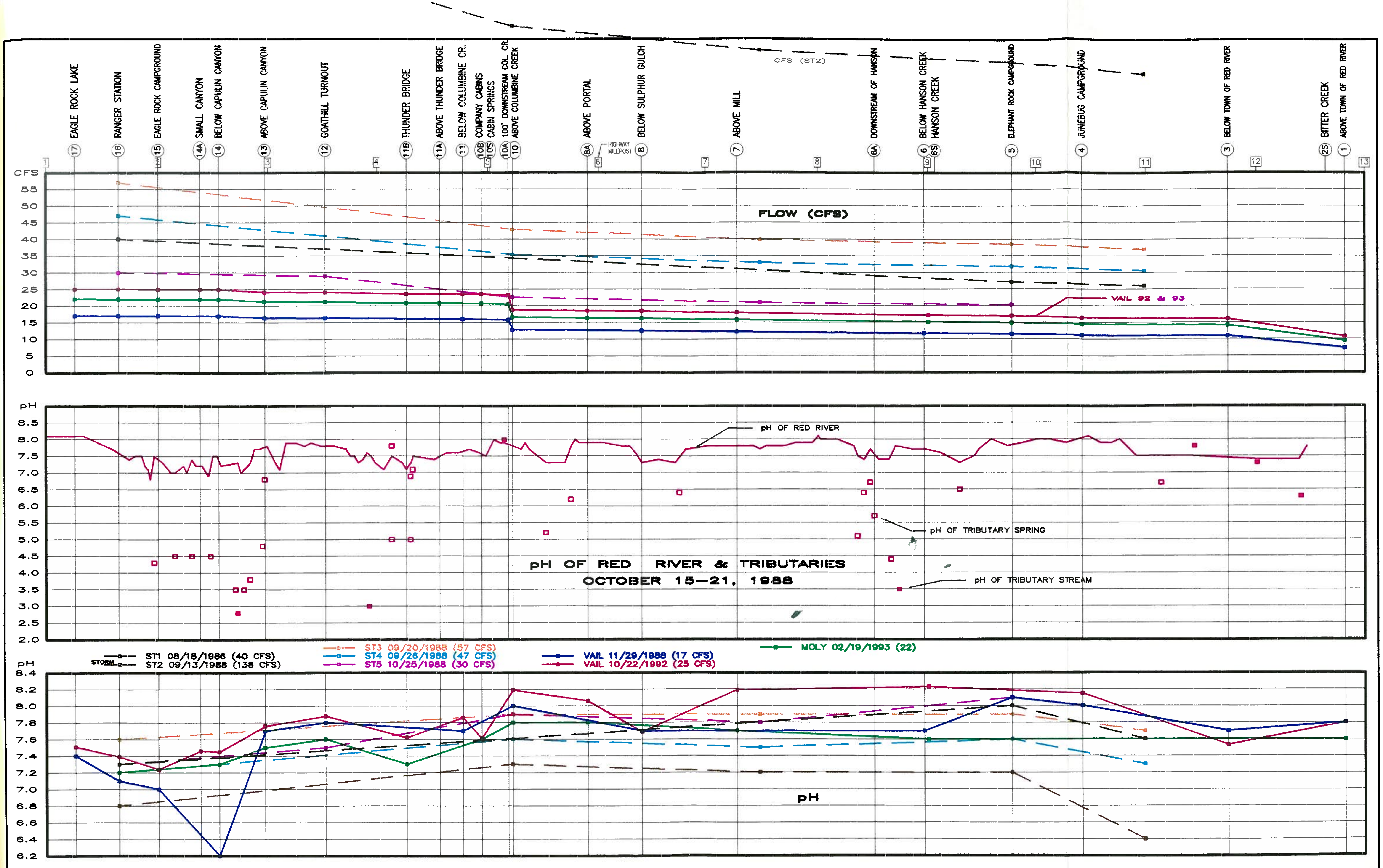
	RALPH VAIL 10/22/1992				
	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	9.7	9.0	87.3		
				657.7	17.7
BELOW RR TOWN	14.9	50.0	745.0		
				623.5	16.8
BELOW HANSEN	16.1	85.0	1368.5		
				1431.5	38.6
BLW COL. CREEK	22.4	125.0	2800.0		
				1000.0	26.9
RANGER STATION	25.0	152.0	3800.0		
TOTALS				3712.7	100.0

APPENDIX 4 - (continued)

COMPUTATIN OF THE PERCENT OF THE TOTAL GAIN WHICH WAS INDICATED FOR MAJOR STREAM SEGMENTS

DAVID SHOEMAKER 02/16/1993

	FLOW CFS	CONC. mg/l	FLOW X CONC.	MASS GAIN	% OF TOTAL
ABOVE RR TOWN	8.5	6.0	51.0		
				800.5	18.2
BELOW RR TOWN	13.1	65.0	851.5		
				981.5	22.3
BELOW HANSEN	14.1	130.0	1833.0		
				1112.2	25.3
BLW COL. CREEK	19.9	148.0	2945.2		
				1498.8	34.1
RANGER STATION	22.0	202.0	4444.0		
TOTALS				4393.0	100.0



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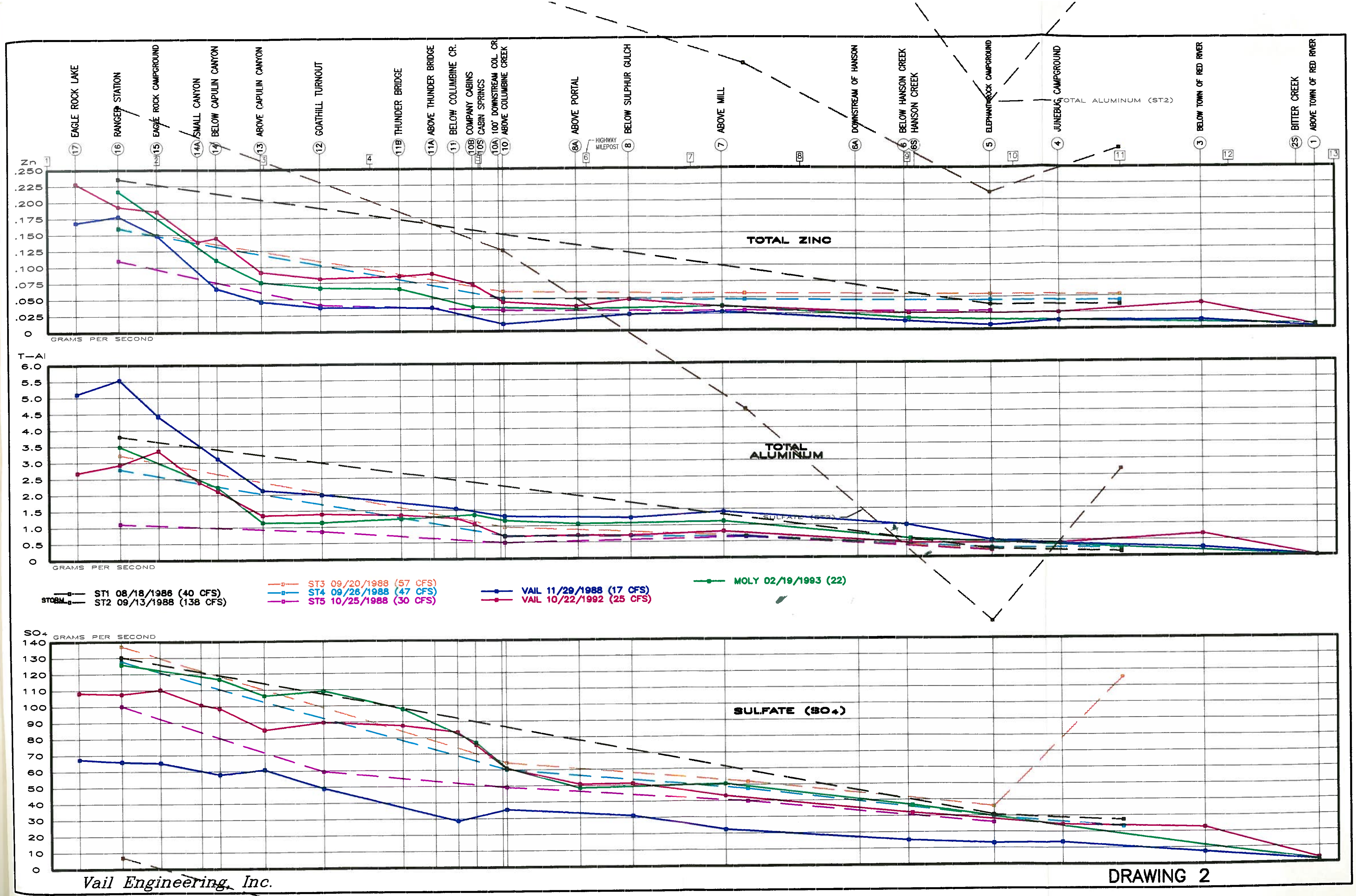

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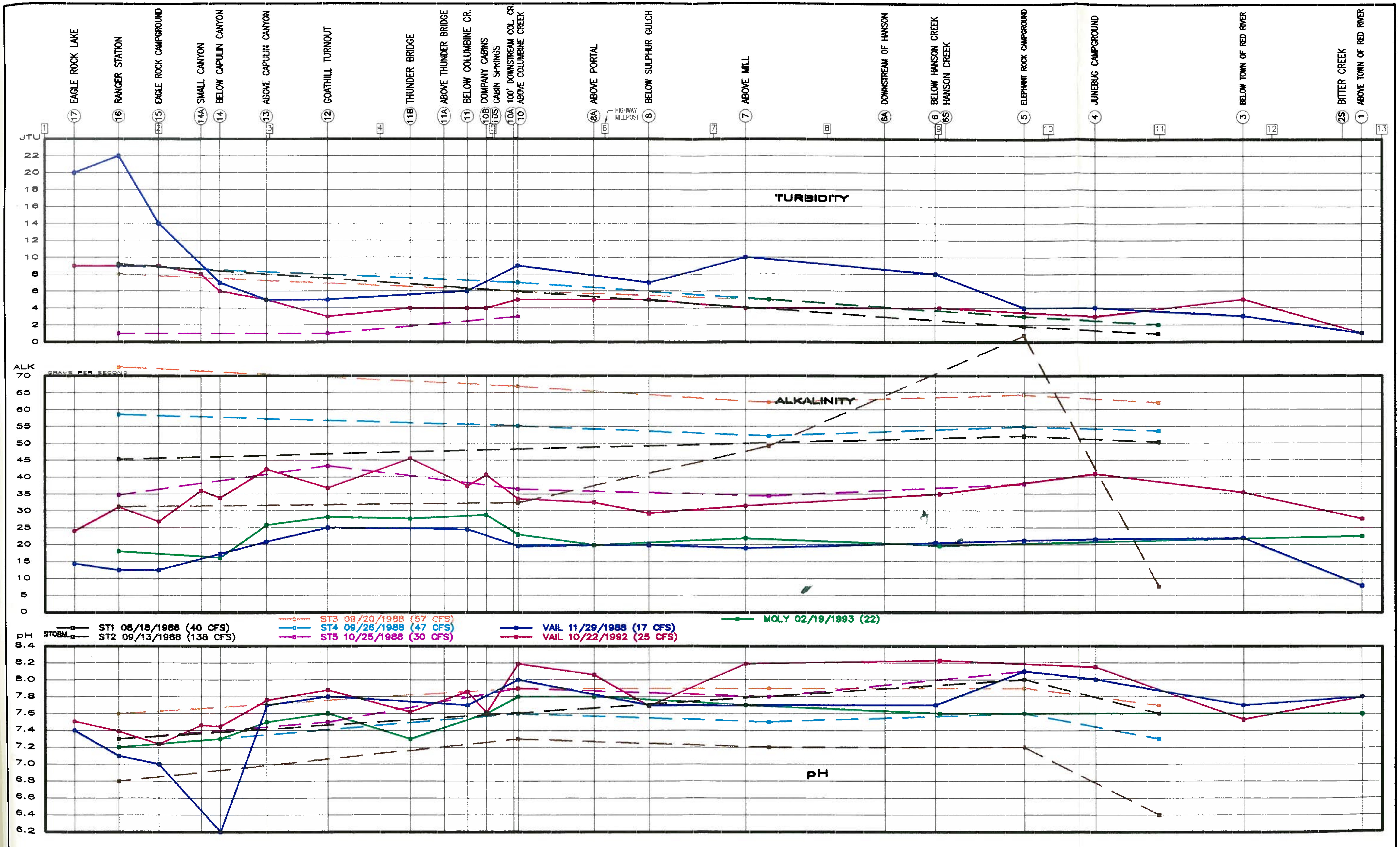

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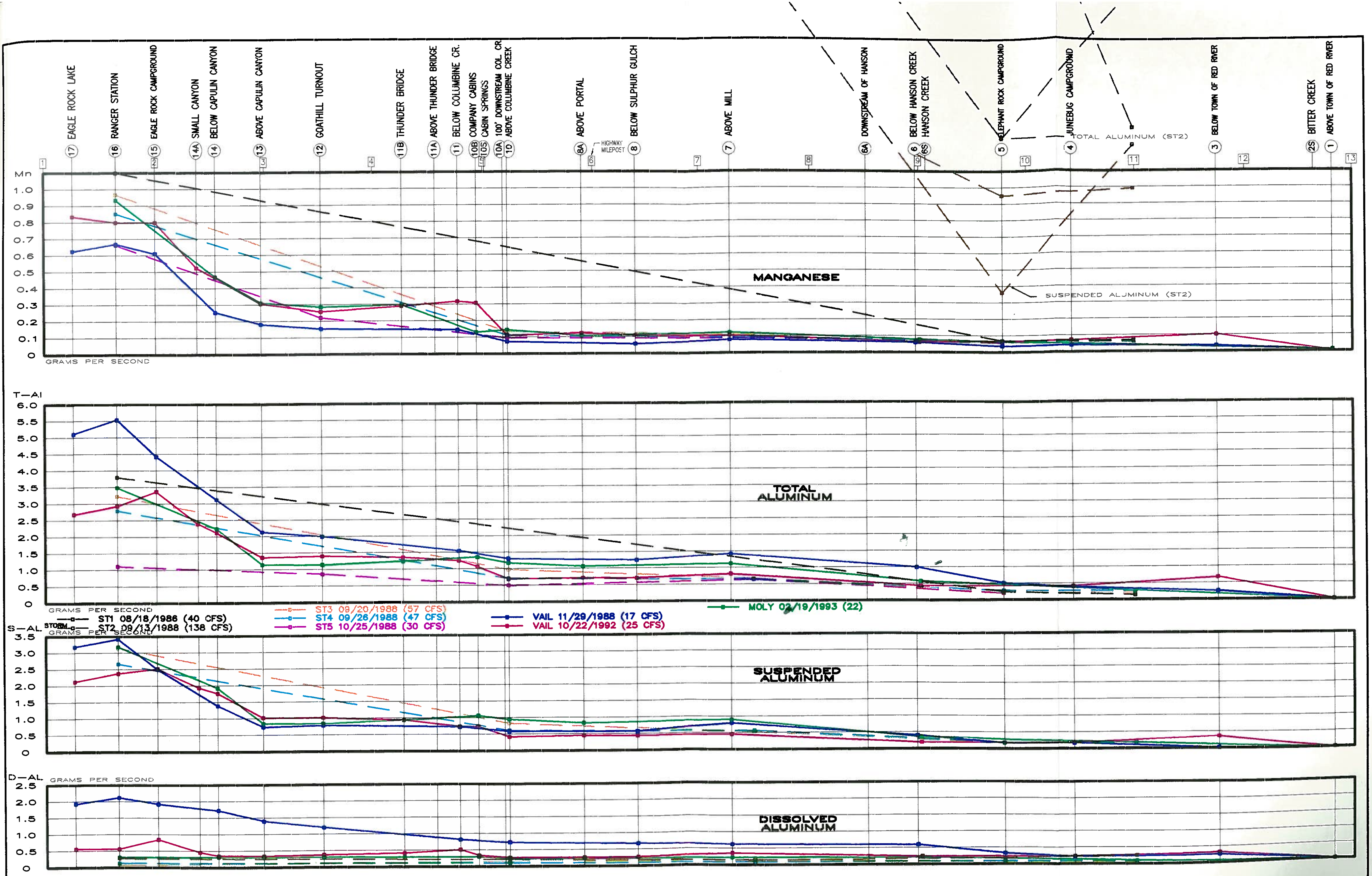

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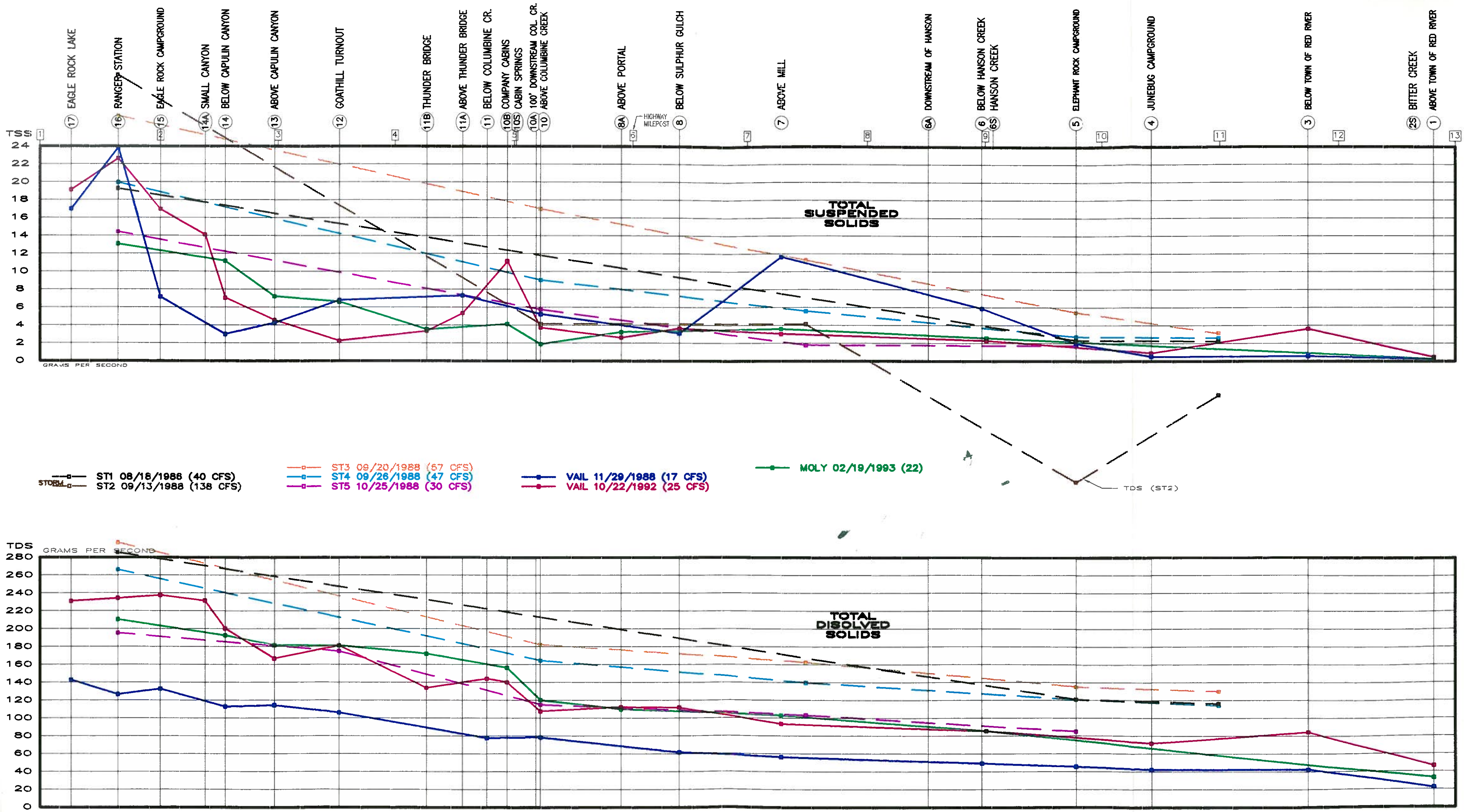

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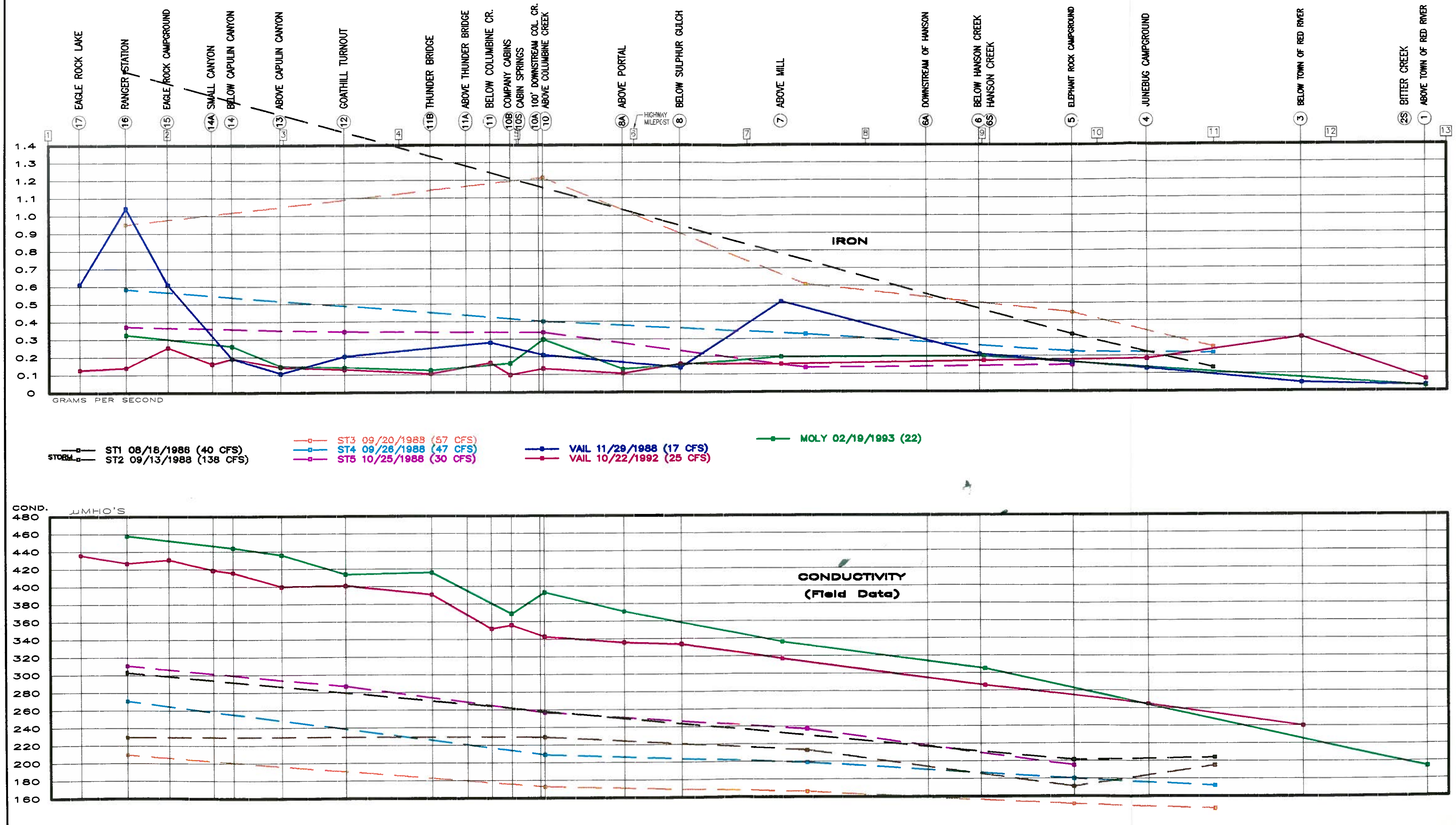

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