Appendix K

An Investigation of the Quantity and Source of Mine-Water Discharge Through Time

AN INVESTIGATION
OF THE QUANTITY AND SOURCE
OF MINE-WATER DISCHARGE THROUGH TIME

PINE CREEK FACILITY,
U.S. TUNGSTEN CORPORATION

PINE CREEK VALLEY, CALIFORNIA

prepared for

U.S. TUNGSTEN CORPORATION

PINE CREEK ROAD, ROUTE 2

BISHOP, CALIFORNIA

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EXECUTIVE SUMMARY

An investigation of the surface- and ground-water systems of the Pine Creek and Rock Creek drainages was conducted, with the general goals of estimating the quantity of water discharged from Pine Creek mine into the Pine Creek hydrologic system, evaluating the sources of water currently discharged from the mine, and assessing the effects of this volume of water on the hydrology of the Pine Creek and Rock Creek sub-basins. The principal objectives of the investigation were to:

- Describe the general character of the sub-basins;
- Compile a quantitative description of the hydrologic system of the drainage sub-basins;
- Estimate the proportion of mine discharge that consists of developed ground water, versus the proportion of mine discharge that is intercepted ground water;
- Evaluate the effects of discharge of developed ground water on the past, present, and future hydrology of the Pine Creek hydrologic system; and
- Calculate the potential for increased ground-water development within the Pine Creek mine.

The investigation was divided into two general tasks. The first task consisted of research into the general physiographic, geologic, and hydrologic conditions of the Pine Creek and Rock Creek areas; this included the field collection and analysis of fracture data, and environmental isotope analyses of water samples. The results of the background investigation were incorporated into a conceptual model that describes the hydrologic system of the Pine Creek and Rock Creek watersheds. The conceptual model contains the following elements:

- The hydrologic system of Pine Creek and Rock Creek canyons possesses a surface-water component and a ground-water component that are interdependent.
- The hydrologic system is developed in glaciated valleys, with alpine watersheds. Precipitation is orographically controlled, and varies from a mean annual value of about 8 inches at Rovana to more than 40 inches near the maximum elevation of the watersheds. Mean annual precipitation over both sub-basins is about 30 inches; the corrected mean annual surface discharge of Pine Creek at Rovana is

about 47 cubic feet per second (cfs). A single August discharge measurement of Rock Creek at the inlet to Rock Creek Lake is about 17 cfs.

- Pine Creek canyon and Rock Creek canyon are cut into crystalline bedrock; Pine Creek valley has been filled with unconsolidated glacial and fluvial deposits having a maximum thickness in excess of 300 feet. The hydraulic conductivity of the unconsolidated deposits is on the order of 50 feet per day (ft/day). Conversely, the crystalline bedrock possesses a low bulk porosity and a hydraulic conductivity in the range of 0.1 to 0.01 ft/day. Flow in the crystalline bedrock is conducted primarily by fractures that impart a high degree of anisotropy to ground-water flow.

- Most water that flows through the Pine Creek/Rock Creek hydrologic system originates as snowmelt at higher elevations. Water is conducted both as surface runoff and as fracture-controlled ground-water flow into the canyons. Ground water recharges the crystalline bedrock through fractures. Ground-water underflow from the mouth of Pine Creek canyon is about 30 cfs, while there is almost no ground-water underflow near the inlet to Rock Creek Lake.

- Evapotranspiration losses from both valleys are small.

- A comparison of streamflows in Pine Creek with streamflows in other nearby watersheds shows that flows in Pine Creek have increased, on average, since mining advanced beneath the water table. This excess discharge is estimated to have been 2.4 cfs on average between 1945 and 1964, and 5.3 cfs from 1965 to the present. This excess streamflow represents developed ground water, removed from storage in the fractured-rock reservoir, and discharged from the Pine Creek mine.

The conceptual model was used as the framework on which a three-dimensional numerical model, describing the hydrologic system in the vicinity of the Pine Creek mine, was constructed. During this second task, the numerical model was assembled and used to quantitatively assess the response of the hydrologic system to stresses imposed by discharge from the mine.

The input parameters to the numerical model were selected based on values that were compatible with the conceptual model. The following parameters were incorporated into the numerical model:

- three-dimensional anisotropic hydraulic conductivity tensors;
- ground-water storage (specific yield and specific storage);
- ground-water recharge;
- discharges of water from the model;
- boundary conditions, including initial ("steady-state") conditions, and regional, transient post-mining conditions; and
- a parameter to account for non-Darcian (or turbulent) flow in the near vicinity of the mine workings.

Calibrations were conducted to adjust the values of certain hydraulic parameters as necessary to reproduce the actual conditions in the system. The calibrated model predicts values of hydraulic potential, mine and stream discharge, and changes in ground-water storage that are in good agreement with the known values of these quantities. The numerical model was therefore judged to be appropriate for use in predicting future effects to the system resulting from mine discharge.

The calibrated model was used in several predictive simulations. The time period 1945 to the present was simulated to estimate the current potentiometric surface and the changes that have occurred in ground-water storage since the commencement of mining below the water table. Next, the simulation was continued through a 50-year period of time into the future, to assess the effects of continued mine drainage into the year 2040. Finally, a simulation was conducted to assess the effects of increased ground-water development.

The results of the simulation 1945 to the present indicated that about 5.8 cfs of the total mine discharge in 1989 was developed ground water, resulting from mine withdrawals from ground-water storage. This agrees well with the average value of discharge at Rovana in excess of precipitation, calculated during the statistical analysis of Pine Creek discharges. As a result of 18 years of discharge from the EZ-Go adit, a decline in the potentiometric surface has been propagated northwards towards Wheeler Crest from the mine area. The historical simulation also indicates that both Rock Creek and Morgan Creek have been affected by past mine discharges. Base flows in Rock Creek appear to have been only slightly affected, declining at most a few tenths of a cfs over the period of historic mining. Over the same period of time (1945 - 1990), base flows in Morgan Creek have declined substantially.

The results of the 50-year predictive simulation indicate that in the year 2040, about 1.8 cfs of the total mine discharge will be developed ground water, due to mine withdrawals from ground-water storage. The calculated potentiometric surface that would result from continued mine discharge over this period, assuming all other conditions remain the same, has declined in the region around Wheeler Crest. The predictive simulation indicates that both Rock Creek and Morgan Creek will continue to be affected by mine discharges in the future. Total flows in Pine Creek, consisting of Pine Creek base flow plus mine discharges, will remain somewhat in excess of the natural Pine Creek base flows (in the absence of mining). This phenomenon is a result of the interception by the mine of ground water that would otherwise discharge into the Pine Creek hydrologic system, and of the discharge of developed ground water by the mine from ground-water storage.

A final transient simulation was undertaken to assess the effects that might result from increased ground-water development, designed to augment withdrawals from storage in the fractured-rock reservoir. For the purposes of this simulation, it was assumed that development of ground water would be maximized by the installation of horizontal drains. This predictive mathematical simulation was also conducted for a 50-year period (years 1990 - 2040).

The results of this simulation indicate that if this strategy were pursued, developed ground-water discharges could be immediately increased to about 17 cfs; after a period of 50 years (year 2040), developed ground-water discharge will have declined to about 3.4 cfs of the total mine discharge. At the end of the 50-year simulation, the calculated potentiometric surface that would result from continued discharge of developed ground water over this period, assuming all other conditions remain the same, has declined by over 200 feet in the region around Wheeler Crest; this is approximately 150 feet lower than the potentiometric surface that would result if ground-water development were not increased. Predicted total flows in Pine Creek, consisting of Pine Creek base flow plus mine discharges, will still be somewhat in excess of the natural Pine Creek base flows, and greater than Pine Creek flows with no additional development. The results of this predictive simulation also indicate that neither Rock Creek nor Morgan Creek will be affected to any greater degree by increased ground-water development than if no additional development had occurred. This shows that directed ground-water development could probably be effective in removing increased quantities of ground water from storage, while affecting the surface hydrologic regime to a minimal extent.

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Mine Water Discharge Investigation, Pine Creek Facility)

HCI HYDROLOGIC CONSULTANTS, INC.

PROFESSIONAL CERTIFICATION

AN INVESTIGATION OF THE QUANTITY AND SOURCE OF MINE-WATER DISCHARGE THROUGH TIME

Pine Creek Facility
U.S. Tungsten Corporation
Pine Creek Valley, California

HCI-531

July 1990

This report has been prepared by the staff of Hydrologic Consultants, Inc., under the professional supervision of the Officer whose seal and signature appear hereon.

The services performed by Hydrologic Consultants, Inc. have been performed in a manner consistent with the level of care and skill ordinarily exercised by members of our profession currently practicing under similar conditions in the State of California. The findings, recommendations, specifications or professional opinions are presented, within the limits prescribed by the client, after being prepared in accordance with generally accepted professional geologic practice. There is no other warranty, either expressed or implied.

Timothy J. Durbin, P.E.
President

1.0 INTRODUCTION

1.1 SCOPE OF PRESENT INVESTIGATION

An investigation of the surface-water and ground-water systems of the Pine Creek and Rock Creek drainages in the vicinity of the Pine Creek facility of the U.S. Tungsten Corporation (U.S. Tungsten) was conducted by Hydrologic Consultants, Inc. (HCI). The general goals of the investigation were to estimate the quantity of water discharged from the Pine Creek mine into the Pine Creek hydrologic system, and to assess the sources of water and the effects of this volume of discharge on the past, present, and future hydrology of the Pine Creek and Rock Creek sub-basins.

The principal objectives of the investigation were to:

- Describe the general character of the sub-basins, including surface features and physiography, local geology, and local hydrogeology;
- Compile a quantitative description of the hydrologic system of the drainage sub-basins;
- Estimate the proportion of water discharged from the mine that originates from ground-water storage in the fractured-rock aquifer and is discharged through the mine, versus the proportion of mine discharge that is due strictly to surface-water infiltration or annual precipitation recharge of the ground-water system;
- Evaluate the effects of discharge from ground-water storage on the past, present, and future hydrology of the Pine Creek hydrologic system; and
- Calculate the potential for increased ground-water development within the Pine Creek mine.

Under natural circumstances (i.e., prior to the commencement of mining activities), the Pine Creek/Rock Creek hydrologic system existed in hydrologic equilibrium. That is, as a long-term average, the amount of water that was discharged from the system was equal to the amount of precipitation that was delivered to the Pine Creek and Rock Creek drainage basins. The ground-water flow systems in the drainage basins had achieved a condition of steady state, and the long-term potentiometric surface elevations in the basins and along the drainage divide (Wheeler Crest) were essentially constant. The ground water below the water table in this area essentially occupied a large storage reservoir, and contained water that was not contributed to the Pine Creek/Rock Creek surface-water systems, but was available for ground-water development.

The discharge of ground water from this storage reservoir began with the initiation of mining beneath the water table in the 1940s, and has continued to the present time; the discharge of water from ground-water storage has been accompanied by a concomitant lowering of the water table beneath the drainage divide. However, not all of the water that is discharged from the mine consists of water that originated in ground-water storage. For the purposes of this report, the water that originates in ground-water storage and is discharged from the mine, and that would not otherwise be discharged into the Pine Creek hydrologic system, will be termed "**developed ground water**", or "**developed ground-water discharge**". Similarly, that part of mine discharge that either originates as surface water in the Pine Creek hydrologic system, or that consists of infiltrated precipitation which would, under natural conditions (i.e., in the absence of mine workings), recharge the ground-water system and eventually be discharged to the Pine Creek hydrologic system, will be termed "**intercepted ground water**", or "**intercepted ground-water discharge**". Finally, the sum of developed ground-water discharge and intercepted ground-water discharge will be termed **"total discharge"**, or **"total discharge from ground water"**.

The investigation was divided into two general tasks. The first task consisted of research into the general physiographic, geologic, and hydrologic conditions of the Pine Creek and Rock Creek areas. This task was conducted using available literature and maps, including the reports of previous investigations dealing with the surface-water and ground-water hydrology of the Pine Creek basin, and was augmented by the results of a National Pollutant Discharge Elimination System (NPDES) discharge permit investigation that had been conducted by HCI on behalf of U.S. Tungsten (HCI, 1989a; ibid., 1989b). Work performed in support of the NPDES discharge permit investigation had included three rounds of stream-gaging measurements along Pine and Rock Creeks, hydrochemical sampling, and geophysical surveys conducted in May, June, and August of 1989.

Additional field data were collected for the present water resources investigation. These consisted of fracture data collected at surface exposures of rock types present in the Pine Creek and Rock Creek drainages, as well as at subsurface locations in the Pine Creek mine. In addition, water samples were collected and submitted for environmental isotope analyses.

The next major task was undertaken after the field data had been analyzed. A statistical analysis of existing stream discharge data (U.S. Geological Survey, 1960; ibid., 1963; ibid., 1970; ibid., 1974; ibid., 1971 - 87; LADWP, 1989a; ibid., 1989b) was conducted to estimate the quantities of flow in Pine and Rock Creeks, and to assess the changes in streamflow over time. The data collection and interpretation, and the statistical analysis of the sum of developed ground-water discharge and intercepted ground-water discharge will be termed **"total discharge"**, or **"total discharge from ground water"**.

The investigation was divided into two general tasks. The first task consisted of research into the general physiographic, geologic, and hydrologic conditions of the Pine Creek and Rock Creek areas. This task was conducted using available literature and maps, including the reports of previous investigations dealing with the surface-water and ground-water hydrology of the Pine Creek basin, and was augmented by the results of a National Pollutant Discharge Elimination System (NPDES) discharge permit investigation that had been conducted by HCI on behalf of U.S. Tungsten (HCI, 1989a; ibid., 1989b). Work performed in support of the NPDES discharge permit investigation had included three rounds of stream-gaging measurements along Pine and Rock Creeks, hydrochemical sampling, and geophysical surveys conducted in May, June, and August of 1989.

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This report presents the results of HCI's investigation. Background information is presented in Section 2.0. In Section 3.0, the conceptual hydrogeological model is developed, and its incorporation into a numerical model of the Pine Creek/Rock Creek hydrologic system is discussed. The results of numerical simulations of the hydrologic system are presented in Section 4.0. Section 5.0 presents estimates of effects on the system over time due to discharges from the mine, and summarizes the results of the investigation.

1.2 PREVIOUS WORK

The region around Pine Creek canyon has been an area of intensive exploration for mineral resources over a period of at least 70 years. Consequently, the bedrock and economic geology of the area are rather well known. The regional and local geology, and the geologic history of the rocks in the immediate vicinity of the Pine Creek facility have been described in detail (Bateman, 1956; Bateman et al., 1965). Several investigations have been conducted on behalf of the operators of the U.S. Tungsten facility over a period of nearly 20 years. Previous research has addressed the stability of existing tailings ponds under static and seismic loadings (Dames & Moore, 1973; Chen & Associates, 1983), possible remedial measures to be undertaken to improve the resistance to flooding of the tailings piles under an estimated 100-year flood condition in Pine Creek, and the surface-water hydrology of the Pine Creek canyon system from its headwaters to the Owens River (Buchberger, 1987).

Attempts have been made to describe the ground-water system of Pine Creek, and to estimate the interactions of the ground-water and surface-water systems. These investigations have included estimates of ground-water movement and storage (Williams, 1988) and solute-transport modeling (Anderson, 1987). Comprehensive investigations of the Pine Creek hydrologic system have been undertaken by HCI in support of U.S. Tungsten's application for a discharge-permit revision (HCI, 1989a; HCI, 1989b). Many of the streamflow and other data obtained during the discharge-permit investigation were used during the present water-rights investigation; additionally, the conceptual hydrogeologic model that was developed for the mill-discharge investigation was expanded and incorporated into the present work.

2.0 BACKGROUND INFORMATION

2.1 LOCATION AND DESCRIPTION

The Pine Creek facility of U.S. Tungsten is located on the eastern slope of the Sierra Nevada mountains about 17 miles west of Bishop, California (Folio Sheet 1). U.S. Tungsten, a subsidiary of Strategic Minerals Corporation, extracts and processes tungsten ores at the facility to produce ammonium paratungstate. The milling facility is situated at about the 8,000-foot (NGVD; National Geodetic Vertical Datum of 1929, equivalent to mean sea level) elevation just above the confluence of Morgan and Pine Creeks in Pine Creek canyon (Sheet 2).

2.1.1 History of Mining Activities

The ore zone at the Pine Creek facility is adjacent to the western contact of the Pine Creek metasomatic pendant with intrusive granitic rocks of the Sierra Nevada batholith (Bateman et al., 1965). Tungsten mining commenced at the Pine Creek mine in 1916, but mining operations were suspended at the end of the First World War because of a slump in the tungsten market. The mine was reopened in 1936, with mining concentrated in the known reserves above the "A" level, at an elevation of about 11,000 feet. As reserves were depleted during the 1940s, an exploratory drilling program was initiated that subsequently identified additional ore zones at deeper levels in the pendant. A tunnel was driven at an elevation of about 9,500 feet to gain access to the ore zones on the 1500 level. This tunnel (the "1500-haul", or "Zero adit"), was begun in 1944 and was completed into the ore zones on the 1500 level in 1949; it is about 8,000 feet in length (Sheet 3). In 1962, work commenced on a new adit at an elevation of about 8,000 feet at the present mine portal near the milling facilities. This adit was driven with the dual purposes of gaining access to deeper ore zones, and improving the ore-handling characteristics of the mine. The "EZ-Go adit" was driven to the northwest beneath the north fork of Morgan Creek, for a distance of about 12,000 feet from the portal to its terminus in the roots of Mount Morgan (Sheet 3). Drifting was essentially completed in May 1966, and the underground facilities were finished by 1969.

2.1.2 Production of Water during Tunneling Activities

The current elevation of the potentiometric surface over the Pine Creek mine is at about 9,400 - 9,450 feet NGVD (Table 1). This is the approximate elevation of the 1500 level, or Zero adit. The occurrence of inflows to the Pine Creek mine was not documented prior to the driving of the Zero adit; however, estimates of potentiometric elevations indicate that the "A" level and higher levels in the mine were probably dry.

Mine records show that substantial inflows have occurred into the Zero adit. The earliest quantitative inflow information was recorded during the driving of the EZ-Go adit, beginning in 1962. The discharge rates of water from the Zero adit and the deeper EZ-Go drift were recorded at irregular intervals during drifting; the length that the EZ-Go drift had advanced from the portal was also recorded. These data demonstrate that in general the flow rate of ground water into the EZ-Go increased as the drift was advanced (Figure 1); simultaneously, the flow rate into the Zero adit declined. This indicates that the advance of the EZ-Go drift into the mountain caused a depression in the local potentiometric surface and reduced the potential for flow into the Zero adit. Note that the recorded discharge rates from both tunnels may be somewhat in excess of the actual discharge values. Subsequent reported discharge measurements for the years 1973 to 1987 (HCI, 1989a, Appendix A) occasionally exceeded the actual capacity of the mine effluent system. The outflow discharge-measurement system was recalibrated in 1987; if reported discharges for the periods 1962 to 1966 and 1973 to 1987 are corrected to recalibrated values, the resulting corrected discharges are somewhat lower (Table 1). Current mine records indicate that the total discharge of ground water from the EZ-Go adit is occurring at an average rate of 12.5 to 13.0 cubic feet per second (cfs).

Water pressures encountered in the rock mass have been recorded for several of the coreholes drilled during the mine's exploratory drilling program (Table 1). The range of pressures observed during drilling indicate that water pressures decline rapidly in the near vicinity of the adit, so that flow into the adit probably occurs in the turbulent regime (Sharp and Maini, 1972).

The bulk of the water produced by the mine flows from individual fractures or discrete fracture zones. Wide ranges of flow rates are observed - from trickles or weeps issuing from hairline fractures to flows of hundreds of gallons per minute (gpm) produced by large fractures. Certain shear zones or faults that transmit water may extend for large distances through the rock mass. This interconnectedness is suggested by historic flow rates observed during the driving of the EZ-Go adit (Figure 1): rapid increases in flows produced by the EZ-Go adit were accompanied by rapid decreases in flows produced by the Zero adit. At the completion of the EZ-Go adit in 1966, the net discharge from the two levels was several times the original discharge from the Zero adit (recorded in 1962); however, the total discharge rate from the mine has declined over subsequent years (Figure 2).

2.2 PHYSIOGRAPHY AND GEOLOGIC SETTING

Pine Creek canyon is a steep, northeast-trending glaciated valley in the eastern front of the Sierra Nevada range in the Sierra Nevada physiographic province (Sheet 2). The Owens Valley, just to the east, is situated in a deep trough that forms the western boundary of the Basin and Range province. Considerable relief is present in the area; altitudes range from less than 4,000 feet (NGVD) on the floor of the Owens Valley to more than 14,000 feet along the Sierra Nevada crest just west of the Pine Creek area. Vertical relief of up to 6,400 feet exists between the floor of Pine Creek canyon and adjacent mountain peaks, which range in elevation from 12,700 to about 13,600 feet. The canyon walls are steep; the average slopes are about 80 percent. The canyon walls are formed of quartz monzonite and granodiorite and are mantled with talus cones and debris-flow deposits derived from the bedrock (Sheet 4). The talus material consists primarily of cobble- to boulder-sized clasts, while debris-flow deposits contain unsorted material ranging in size from granules to boulders in a matrix of silty sand (Chen & Associates, 1987).

The floor of Pine Creek canyon slopes gently downward to the northeast from an elevation at the U.S. Tungsten mill facilities of about 8,000 feet to an elevation at the canyon mouth of about 5,800 feet. The average gradient through the canyon is about 6 percent. The valley floor is an alluvial floodplain of Holocene age, developed on glacial and fluvial deposits of Pleistocene age (Bateman et al., 1965).

The headwaters of Rock Creek are located to the north and west of Pine Creek canyon, just across Morgan Pass and Wheeler Crest (Sheet 2). Rock Creek flows nearly due north from Little Lakes valley, across a roche moutonee ('rock step') at Rock Creek Lake, and continues north nearly to Tom's Place, at which point the creek and Rock Creek canyon turn abruptly east. The topography and relief of Rock Creek canyon are similar to Pine Creek canyon, except that the floor of Rock Creek canyon is narrower, and topographic relief is not as pronounced as in Pine Creek canyon. Due to intensive glaciation in the upper part of Rock Creek canyon, the canyon floor above Rock Creek Lake is developed directly on bedrock; there is essentially no alluvial fill in the canyon above the roche moutonee. Alluvial fill material begins to appear in the canyon below Rock Creek Lake; morphological evidence suggests that the thickness of alluvium increases rapidly towards the mouth of Rock Creek canyon.

Pine Creek and Rock Creek canyons were cut through intrusive plutonic rocks of the Sierra Nevada batholith (Bateman et al., 1965). The batholith is composed of a mosaic of discrete Cretaceous plutons which are either in sharp contact with one another or are separated by thin septa of metamorphic or mafic igneous rocks. Compositions of the intrusive plutons range from hornblende gabbro through granodiorite to quartz monzonite. The plutons were intruded into a sequence of sedimentary rocks of Paleozoic and lower Mesozoic age. During cooling and crystallization the intrusive rocks expelled heated solutions that reacted with, and metamorphosed, sedimentary wall and roof rocks. The Pine Creek pendant, visible at the head of Pine Creek canyon, is a relict of the metamorphosed roof rocks. The pendant is almost seven miles long and about one mile wide (Sheet 5) and extends from the northeast face of Basin Mountain, across Horton Creek, Mt. Tom, and Pine Creek into the south part of Wheeler Crest. The metasomatic units in the pendant were syntectonically folded during emplacement of the Mesozoic plutons (Bateman et al., 1965) into a tight syncline that is strikingly visible from the U.S. Tungsten facilities.

Erosion that occurred during Mesozoic time exposed the batholith and produced a surface of low relief. During late Cretaceous to Eocene time, the Sierra Nevada surface was tilted westward, probably as part of a broad upwarp that affected a wide area east and west of the present range. Tectonic movement recurred throughout Tertiary time, culminating in an orogeny during middle Pleistocene time (Bateman et al., 1965). The subsidence of the Owens Valley to the east began somewhat later, probably in late Pleistocene time. This structural movement was accommodated by repeated small displacements along numerous faults. The Wheeler Crest fault (Sheet 5) is the primary tectonic structure that controlled movement along the eastern range front. At least 8,700 feet of total vertical displacement has occurred along this fault during Quaternary time (Bateman et al., 1965). Fresh fault scarps throughout the Pine Creek area, as well as historic evidence in the immediate vicinity, indicate that tectonic movements have continued to the present time (Chen & Associates, 1987). In fact, many of the nearby faults must still be considered active features (Dames & Moore, 1973).

The bedrock of the region is pervasively fractured; jointing is apparent both in outcrop and from examination of aerial photographs (U.S. Geological Survey, 1947). Predominant joint trends are northwest and northeast and may be related to regional structures. Numerous lineaments are visible in the area (Sheet 5; Bateman et al., 1965) and are possibly related to regional fracture trends. Many of the stream valleys along the eastern Sierra front define lineaments.

2.3 HYDROLOGY

The headwaters of Pine Creek and Rock Creek are in the perennial snowfields of the eastern slope of the Sierra Nevada range (Sheet 2). Pine Creek flows northeastward from its alpine watershed in the John Muir Wilderness Area to its juncture with the Owens River just north of Bishop. The two principal tributaries of Pine Creek are Morgan and Gable Creeks. The confluence of Pine and Morgan Creeks is at the head of Pine Creek canyon near the U.S. Tungsten mill; the confluence with Gable Creek is about one-half mile downstream. Morgan Creek flows perennially in the reach immediately above its junction with Pine Creek because ground-water inflow that is collected within the Pine Creek mine is conveyed out of the main portal (EZ-Go adit) and is discharged directly to the stream (HCI, 1989a). Gable Creek is perennial in its upper reaches; however, during dry months, flow in Gable Creek becomes subsurface near the junction of Gable Creek canyon with Pine Creek canyon, and the stream vanishes (Wilder, 1989). Features of the Pine Creek watershed are summarized in Table 2; historical discharge data are presented in Appendix A.

Continuous streamflow measurements on Pine Creek have been made by Los Angeles Division of Water and Power (LADWP) at the Rovana Division Box (Rovana gage) since 1922 (LADWP, 1989a). Summary runoff statistics for the period of record from 1922 to 1988 are presented in Table 2. In addition to recorded surface discharge, seepage surveys and mass-loading calculations demonstrate that ground-water underflow discharges into the Owens Valley alluvium in the subsurface below the mouth of Pine Creek canyon at an average rate of about 20 cfs (HCI, 1989a; ibid., 1989b). The total discharge from Pine Creek canyon (ground water and surface water) is equivalent to about 30 inches of precipitation distributed uniformly over the Pine Creek watershed area.

Rock Creek flows nearly due north through Little Lakes Valley from its headwaters on the northwest slope of Mount Morgan. Near Tom's Place, Rock Creek turns abruptly eastward, and flows east about five miles to its juncture with the Owens River. Although Rock Creek is fed by numerous intermittent streams, it has no major tributaries above Tom's Place. Several diversions remove water from Rock Creek just above Tom's Place; the largest diversion (owned by the LADWP) removes water from Rock Creek during peak stages, and transports it to Crowley Lake for hydropower production. Features of the Rock Creek watershed are summarized in Table 3. Historical discharge data for the creek are presented in Appendix A.

Continuous streamflow measurements on Rock Creek have been made at the gage at Little Round Valley since 1918 (U.S. Geological Survey, 1960; ibid., 1963; ibid., 1970; LADWP, 1989b). Summary runoff statistics for the period of record from 1918 to 1988 are presented in Table 3.

Annual precipitation in the eastern Sierra Nevada is not uniformly delivered over the year. The mean monthly streamflow and mean monthly precipitation for the Pine Creek and Rock Creek watersheds exhibit an inverse relationship typical of alpine basins. Historical data (National Climatic Data Center, 1987; ibid., 1988; U.S. Weather Bureau, 1955; ibid., 1964) show that 75 percent of the moisture in the watershed is received over a six-month period from October to March, as winter snowfall. However, this same period coincides with the lowest discharges in the streams. During the summer months when the least precipitation occurs, the remaining snowmelt, together with water naturally discharged from the ground-water system, is released to the surface-water system and streamflows tend to be high.

Base flows observed during the winter months serve as an indicator of the average rate of ground-water discharge to the Pine Creek and Rock Creek hydrologic systems. In the spring, the melting snowpack releases accumulated moisture to the local ground-water and surface-water systems. Snowmelt water in the upper and middle reaches of the watersheds is conveyed through the crystalline rock mass via fractures. Although the bulk porosity of the rock mass is probably quite low, the conductivity of individual fractures can be high (Freeze and Cherry, 1979). Considerable evidence, including fracture-controlled surface drainage, seeps in rock faces, and springs and seeps associated with lineaments, indicates that much recharge to the Pine Creek and Rock Creek ground-water systems, and nearly all the flow to the Pine Creek mine, occurs through fractures.

3.0 HYDROGEOLOGIC MODELS

The ground water in the Pine Creek/Rock Creek hydrologic system is present within the rock mass of the mountains because precipitation that falls on the mountains infiltrates into fractures and is recharged to the ground-water system. Most of this recharged ground water eventually flows into the Pine Creek or Rock Creek surface-water systems. The installation of mine workings below the water table has affected the long term ground-water storage in the Pine Creek sub-basin; the removal of ground water from storage in the rock mass has resulted in a lowering of the water table, and ground water that would not otherwise flow into the surface-water system is being discharged by the mine. Some proportion of the total ground-water discharge from the Pine Creek mine then must consist of developed ground water, made available by mine development work; the remainder is intercepted ground water.

In order to calculate the proportion of developed ground water, it is necessary to quantify the changes in ground-water storage of the sub-basin hydrologic system that have been induced by the mine, and to estimate the extent and propagation of these effects into the future. Therefore, the hydrologic data of the area were quantified, a predictive numerical hydrogeologic model of the system was assembled.

The results of the background investigation were incorporated into a conceptual model that describes the hydrologic system of the Pine Creek and Rock Creek watersheds. The conceptual model was then used as the framework upon which the numerical model, that mathematically describes the surface- and ground-water system of the area, was constructed. It must be emphasized that the effects of stresses applied to the hydrologic system of the canyon cannot be correctly assessed using either numerical or analytical methods if the system itself is not well understood.

3.1 THE CONCEPTUAL MODEL

An essential step in assembling a conceptual model is to obtain values for the hydrologic parameters that govern the system (Atkinson et al., 1989). Consequently, a part of the second task of this investigation was devoted to the acquisition of reliable estimates of values for the following:

- hydrologic inputs to, and surface-water outflows from, Pine Creek canyon and Rock Creek canyon;
- evapotranspiration within the canyons; and
- ground-water outflows from Pine Creek canyon.

Subsequent sections of the report will address the methods followed during the hydrologic investigation and will describe the results that were obtained.

3.1.1 Precipitation

Precipitation, as rainfall and snowfall, is the sole source of hydrologic inputs to the Pine Creek and Rock Creek systems. The distribution of precipitation in the Pine Creek and Rock Creek watersheds is orographically controlled and varies widely in time and space (Buchberger, 1987). An orographic relation was developed for the eastern Sierra Nevada (Figure 3) using data collected at several precipitation reporting stations in the Owens Valley and eastern Sierra regions (Table 4). Note that data from the Florence Lake reporting station differs significantly from the other reporting stations. Because Florence Lake is located on the western slope of the Sierra Nevada divide, while all the other reporting stations that were tabulated are located on the eastern slope, data from the Florence Lake station were not considered in developing the orographic relation.

An isohyetal map of precipitation for the eastern Sierra Nevada in the vicinity of Pine and Rock Creeks (Sheet 6) was constructed using the orographic relation. The isohyetal map for the region demonstrates that the amount of annual precipitation varies considerably between the valleys and the crests of Mount Morgan and Wheeler Ridge. If the indicated values of annual precipitation are distributed over the isohyetal areas indicated (Sheet 6), the annual basin average for both the Pine Creek drainage sub-basin and the Rock Creek drainage sub-basin is about 30 inches.

3.1.2 Surface-Water Inflows

The Pine Creek mine is situated in the Pine Creek/Rock Creek hydrologic system. The geographic extent of the complete system covers the combined areas of the Pine Creek and Rock Creek drainage basins (Sheet 6). However, only part of the complete hydrologic system has been, or is likely to be, affected by the mine. Accordingly, the areal extent of the study area that was established is somewhat smaller than that of the combined drainage basins. The study area is bounded on the southeast by Pine Creek and on the northwest by Rock Creek. The boundaries of the study area are such that while all the flow in Rock Creek originates in the tract, the headwaters of Pine Creek are actually outside the study boundaries; Pine Creek flows into the area near the head of Pine Creek canyon (Sampling Station 29, HCI, 1989a; ibid., 1989b).

The flow of Pine Creek into the study area represents a hydrologic input that must be taken into account. Gaging measurements taken along Pine Creek in May, June and August 1989 (HCI, 1989a; ibid., 1989b) allowed estimates of the flow of Pine Creek into the area to be made. The base flow of Pine Creek into the area (at Sampling Station 29) was estimated to be 3.3 cfs.

3.1.3 Surface-Water Outflows

Discharges from the Pine Creek mine are a result of the flow of ground water into drifts, stopes, and adits. Water flowing from the mine is discharged directly into the Pine Creek hydrologic system and is included in the total flow measured at the Rovana gage at the canyon mouth. Some of the mine-discharge water is certainly withdrawn from ground-water storage, and consists of developed ground water that would not have been discharged without mine development. The remainder of the mine discharge represents precipitation that has been removed from the normal surface-water cycle, has infiltrated into the rock mass and flowed into the mine, and has been returned to the surface system via mine discharge; this is intercepted ground water. In order to assess the actual surface-water outflows from the Pine Creek hydrologic system, it is necessary to estimate the amount of surface flow that would occur normally through the Pine Creek watershed in the absence of influences from mining, and to estimate the amount of excess flow that may be due to discharges of developed ground water from ground-water storage.

Several creeks in the Bishop area were selected for comparative analysis. A divide (the Sierra Nevada) is present between the Owens Valley and the Central Valley to the west; many streams in the region around the Pine Creek facility have been monitored for a long period, and the stream gaging record on both sides of the divide is excellent. A check of U.S. Geological Survey (USGS) and LADWP gaging records revealed that Pine Creek, Bear Creek and Mono Creek have a continuous gaging record dating to 1922, while stream recording on Rock Creek began in 1918, and gaging of Bishop Creek was initiated in 1936 (USGS, 1960; ibid., 1963; ibid., 1970; ibid., 1974; ibid., 1971 - 87; LADWP, 1989a; ibid., 1989b). The locations of the stream gaging stations are shown in Figure 4; the mean annual discharge data for each of the creeks are presented in Appendix A.

During the analysis, the period from 1922 to the present was divided into three time periods that span different stages of mine development. The years 1922 to 1945 represent the period during which mining was conducted above the water table; 1946 to 1964 is the period during which mining below the water table took place only from the Zero adit; and from 1965 to 1988, flows to Pine Creek occurred via the EZ-Go adit. A comparison of the mean annual streamflow data for the creeks in the Bishop area (Figure 5) suggests that Pine Creek received water in excess of precipitation inputs after the mine was advanced through the water table. As shown in Figure 5, the mean annual flows of Rock, Bishop, Mono and Bear Creeks declined between the pre-mining period and the Zero adit time period, while flows in Pine Creek increased. In addition, a larger proportional increase in mean annual stream flows occurred between the Zero adit and the EZ-Go adit time periods in Pine Creek than in the other creeks over the same time periods.

A statistical analysis of stream flows was conducted to quantify the changes that were observed to occur over time in Pine Creek. Z-statistics (Davis, 1973) were calculated for the mean annual discharge of each creek for the period 1922 to 1945 as:

$$Z = \frac{X - \bar{X}}{s} \qquad (3.1)$$

where

X = the sample: the mean annual discharge for a given year;

$\bar{X}$ = the average of the mean annual discharges between 1922 and 1945; and

s = the standard deviation of the mean annual discharges, 1922 - 1945.

Calculation of the Z-statistic has the effect of normalizing the stream discharge data, thus removing observed differences in flow that are due to differing basinal areas in each watershed. Because all the creeks originate in alpine watersheds in similar climatic and geologic terranes in the Sierra Nevada, normalization of the discharge data should enable valid comparisons between streams to be made. A plot of the Z-statistics (Figure 6) illustrates the similarities among the normalized discharge characteristics of Pine, Bear, Mono, Rock and Bishop Creeks during the period 1922 to 1945; it is apparent that the streams are responding to generally similar climatic influences.

The quantity of water discharged from Pine Creek in excess of precipitation inputs was estimated by performing a multiple regression (Riggs, 1968) of Pine Creek mean annual discharge versus Mono and Bear Creek mean annual discharge (data presented in Appendix A) for the period 1922 to 1945, during which time period no mining activities could have affected stream flows in Pine Creek. No extensive mining activities have occurred in the other two watersheds. The multiple regression relation among the sets of data is:

$$\text{Pine} = 0.056\ \text{Mono} + 0.323\ \text{Bear} + 378.7 \qquad (3.2)$$

where mean annual discharges from each stream are given in acre-feet (ac-ft).

The correlation coefficient calculated for the multiple regression is statistically highly significant ($r^2 = 0.937$). The high value of the correlation coefficient indicates an excellent correspondence among Pine Creek, Mono Creek and Bear Creek mean annual discharge data (Fiering, 1963; Riggs, 1968; Searcy, 1960); this good agreement is apparent in Figure 6.

The mean annual discharges from Pine Creek that would have occurred in years subsequent to 1946, had stream flows not been affected by mining, can then be estimated using Equation 3.2. The actual mean annual flow rates and regression-corrected mean annual flow rates in Pine Creek calculated for each of the three time periods are compared in the first two columns of Table 5 (flow rates have been converted to annual average cfs). The difference between the amount of flow predicted by the Mono/Bear Creek regression and the actual amount of flow that was recorded is shown as excess water (Column 3 of Table 5), that is, developed ground water discharged from ground-water storage. The results indicate that, on average, flows in Pine Creek were augmented by 2.4 cfs between 1946 and 1964 as a result of mine discharge from the Zero adit, and were augmented, on average, by 5.3 cfs between 1965 and 1989 following completion of the EZ-Go adit. Over the dewatering life of the Pine Creek mine (1945 to the present), flows in Pine Creek have been augmented by an average of 4.0 cfs, or 2,900 ac-ft/yr. These calculated excess flows represent developed ground water, withdrawn from ground-water storage, that would not otherwise have been available for flow down Pine Creek. The year-to-year contribution of developed ground water from the mine is shown as the difference between the recorded Pine Creek discharges and the regression-corrected discharges (Figure 7).

Bishop Creek data were not included in the multiple regression calculation because no records for the years 1922 to 1936 could be located in USGS Water-Supply Papers. A regression analysis of Pine Creek data versus Bishop Creek data for the years 1936 to 1945, and subsequent correction of post-1945 Pine Creek discharges using Bishop Creek flows, yielded results similar to the results of the Mono/Bear Creek multiple regression.

Gaging data from Rock Creek over time display a trend in discharge rates that have deviated significantly since the mid-1950s, possibly as a result of a change in recording method at the Rock Creek gage (the stage recorder was replaced with a Parshall flume in 1953). This trend was confirmed using a double-mass curve analysis (Searcy and Hardison, 1960). Rock Creek data were therefore not utilized in the Pine Creek discharge analysis.

A similar analysis was also conducted to estimate the average base flow in the Pine Creek watershed for the years 1922 to the present. Statistical techniques were again employed, as it was necessary to estimate the naturally-occurring base flow, without the effects of mine discharges of developed ground water from ground-water storage. A regression was performed using the average winter flows (November through March) of Pine Creek and the average winter flows of Mono Creek for the years 1922 to 1945 (before the Zero adit was advanced beneath the water table). Then an average value of base flow in Pine Creek for the entire period of record was calculated using the regression relation that was developed. Pine Creek base flow, in the absence of mining activity, was estimated to be 20 cfs.

3.1.4 Evapotranspiration Losses

Estimates of losses due to evapotranspiration (ET) were calculated for phreatophytes located in Pine Creek canyon for the stream reach between the U.S. Tungsten facilities (unsurveyed T7N, R30E, Sec. 5) and the bridge on Pine Creek Road (T6N, R30E, Sec. 24) near the canyon entrance. Estimates of ET were calculated for phreatophytes in Rock Creek canyon only for the reach from the headwaters of Rock Creek in Little Lakes valley to the northern boundary of the region of investigation at the inlet to Rock Creek Lake. Phreatophytes in the Pine Creek and Rock Creek drainages consist principally of alder, birch, willow and cottonwood that generally are located within 50 to 200 feet of the stream (Sheets 7 and 8). The average depth to ground water in these areas was estimated to be five feet. The growing season for the vegetation in the canyons was considered to be five months long.

A modification of the Blaney-Criddle relation (Blaney and Criddle, 1962) was used to calculate ET along the stream channels. This model assumes that the amount of ET is a function of temperature, amount of daylight, and type of plant. The modified Blaney-Criddle formula is:

$$U = k \times T \times P/1200 \qquad (3.3)$$

where

U = evapotranspiration during the growing period (feet);

k = consumptive-use coefficient (dependent on plant type);

P = monthly percentage of daylight hours; and

T = monthly mean temperature (°F).

Consumptive-use, or Blaney-Criddle coefficients (k) were calculated using the method outlined by Rantz (1968) for the principal phreatophytic plant types. Published data are not available for water use by alder; however, it was assumed to have a coefficient similar to cottonwood and willow (Trondle, 1989). Information needed to obtain these coefficients included the depth to water (about 5 feet) and the density of the vegetation, both of which were estimated in the field. Vegetation densities were used to scale the k factor by multiplying by the following constants:

Dense = 1.0,
Medium = 0.85, and
Light = 0.70.

Tables 6 and 7 summarize the calculated ET for the study area. These basin-wide ET losses, together with sublimation from snowfall, represent the only known water losses other than ground-water outflows. While total sublimation losses are not known, these were estimated using published values (Croft and Monninger, 1953); it is estimated that annual sublimation equivalent to 2.5 inches of precipitation is lost from each sub-basin. ET and sublimation losses as a proportion of average flow are small (Tables 6 and 7), but were nevertheless incorporated into the conceptual and numerical models of the hydrologic system.

3.1.5 Ground-Water Outflows

In addition to the mechanisms of surface flow and ET, water can also exit the Pine Creek and Rock Creek watersheds via ground-water underflow. Ground-water underflow here refers to the rate of continuous ground-water flow through the unconsolidated deposits ("alluvium") beneath Pine Creek, at the mouth of Pine Creek canyon (Sampling Station 3, HCI, 1989a; ibid., 1989b). The rate of ground-water underflow at this point can be calculated using the concept of mass balance of water above and below Sampling Station 3.

Gaging measurements taken along Pine Creek demonstrate that Pine Creek is a gaining stream in the reach just below Sampling Station 3; that is, some ground water is discharging to Pine Creek in this reach (HCI, 1989a; ibid., 1989b). Therefore, the ground-water mass balance equation at Sampling Station 3 can be expressed as:

$$Q_{gw3} = Q_{discharge} + Q_{underflow} \qquad (3.4)$$

where

Q_{gw3} = total ground-water flow at Sampling Station 3;

$Q_{discharge}$ = ground-water discharge to Pine Creek downstream from Sampling Station 3; and

$Q_{underflow}$ = ground-water underflow through the unconsolidated sediments at a point downstream from Sampling Station 3.

Both the total ground-water flow at Sampling Station 3 (Q_{gw3}) and the ground-water underflow ($Q_{underflow}$) in the reach below Sampling Station 3 can be expressed in terms of Darcy's law:

$$Q_{gw3} = K \times b_3 \times w_3 \times i_3 \tag{3.5}$$

and

$$Q_{underflow} = K \times b_u \times w_u \times i_u \tag{3.6}$$

where

K = hydraulic conductivity of the unconsolidated deposits;

b_3 = thickness of the unconsolidated deposits at Sampling Station 3;

b_u = thickness of the unconsolidated deposits at a point downstream from Sampling Station 3;

w_3 = width of the unconsolidated-sediment section at Sampling Station 3;

w_u = width of the unconsolidated-sediment section at a point downstream from Sampling Station 3;

i_3 = ground-water hydraulic gradient at Sampling Station 3; and

i_u = ground-water hydraulic gradient at a point downstream from Sampling Station 3.

The thicknesses of the unconsolidated deposits at Sampling Station 3 and at a point downstream from Sampling Station 3 were estimated using the results of surface electrical-resistivity surveys and seismic-reflection soundings (HCI, 1989b, Appendix A) to be about 300 feet. The widths of the unconsolidated-sediment sections at these points can be measured from geologic maps (HCI, 1989a), and are about 1,700 feet at Sampling Station 3, and about 1,300 feet downstream from Sampling Station 3. The ground-water hydraulic gradients can be estimated using a map of the potentiometric surface (HCI, 1989a, Folio Sheet 16); these gradients are approximately 0.095 at Sampling Station 3, and 0.083 downstream from Sampling Station 3. Finally, the ground-water discharge to Pine Creek in the reach below Sampling Station 3 ($Q_{discharge}$) is estimated from stream-gaging data (HCI, 1989a) to be about 10 cfs.

If these known values, together with the expressions for total ground-water flow at Sampling Station 3 (Q_{gw3}) and ground-water underflow ($Q_{underflow}$) from Equations 3.5 and 3.6 are substituted into Equation 3.4, the resulting equation may be solved for K; the computed value of K (50 ft/day) is then substituted into Equation 3.4, which can be solved for $Q_{underflow}$. The calculated value for underflow of 20 cfs downstream from Sampling Station 3 is consistent with the known physical characteristics of the ground-water system (HCI, 1989b). Because Sampling Station 3 was selected as the downstream control point of the study area, the value of ground-water underflow incorporated into the conceptual and numerical models of the system was actually Q_{gw3}, the total ground-water flow at Sampling Station 3 (30 cfs).

The northernmost boundary of the study area along Rock Creek was located at the inlet to Rock Creek Lake. At this point, the stream passes over a roche moutonee, and virtually no unconsolidated sediments are present; the ground-water underflow from Rock Creek Valley at the lake inlet is assumed to be negligible. Similarly, near gaging Station 29, Pine Creek also passes over a roche moutonee just prior to entering Pine Creek canyon, so that ground-water inflow along the creek into the study area at this point is also assumed to be negligible.

3.1.6 Model Boundaries

The mine is situated between Rock Creek and Pine Creek, which occupy hydrologic regimes that are reasonably well known, and that probably function as local hydrogeologic divides (HCI, 1989a; ibid., 1989b). These two creeks were therefore selected as the northwest and southeast boundaries of the modeled area (Sheet 9). The Rock Creek boundary extends from its headwaters in Little Lakes valley to the inlet of Rock Creek Lake, where stream gaging measurements were available (HCI, 1989b). The Pine Creek boundary was established from Pine Creek Lake to gaging Station 3 (HCI, 1989a; ibid., 1989b).

Because the modeled area does not encompass the complete Pine Creek and Rock Creek drainage basins, it was necessary to scale the hydrologic discharges of the two drainage sub-basins from historic discharge information for the complete watersheds. Flow measurements had been taken in Pine Creek at Rovana and at Stations 3 and 29, and in Rock Creek at the inlet to Rock Creek Lake, during the August 1989 sampling (HCI, 1989b). A gaging measurement of 44.7 cfs was taken at Station 3, and a gaging measurement of 5.6 cfs was taken at Station 29 on Pine Creek in August 1989, approximately contemporaneous with a gaging measurement of 38.6 cfs at Rovana. (The Rovana gaging measurement was lower than the Station 3 measurement because the complete reach of Pine Creek between Station 3 and Rovana is known to be losing; HCI, 1989b). The ratio of August flows at Stations 3 and 29, and at Rovana was assumed to remain constant; surface flows in Pine Creek were then scaled, using the August ratio, to historic discharges recorded at Rovana. Pertinent features of the Pine Creek drainage sub-basin (Pine Creek watershed above Station 3) are presented in Table 8. Note that because runoff for the sub-basin has been scaled to historic Pine

Creek discharges at Rovana, the tabulated flows include drainage from the mine.

The quantity of base flow in Rock Creek was estimated at the inlet to Rock Creek Lake. A gaging measurement of 16.6 cfs was taken at Station J (inlet to Rock Creek Lake) on Rock Creek in August 1989, approximately contemporaneous with the August Pine Creek gaging measurements at Station 3 and at Rovana (HCI, 1989b). The August flow measured at Pine Creek Station 3 was observed to be approximately twice the value of the average base flow at Rovana. If similar hydrologic conditions apply in the Rock Creek sub-basin, the measured August flow value of 16.6 cfs at the inlet to Rock Creek Lake corresponds to a base flow in Rock Creek at that point of about 8 cfs. If flow in Rock Creek at the inlet to Rock Creek Lake is scaled to historic values recorded at the Little Round Valley gage, a similar result is obtained. Pertinent features of the Rock Creek drainage sub-basin are presented in Table 9.

The hydrologic inputs and discharges of the two sub-basins are summarized in Table 10; recorded mean annual values for discharge and equivalent annual precipitation are compared with values of discharge and equivalent precipitation calculated using the isohyetal map (Sheet 6). These calculated values are in good agreement with the basin-wide average precipitation values necessary to sustain the observed flows (Table 10).

3.1.7 Elements of the Conceptual Model

The conceptual model of the Pine Creek/Rock Creek hydrologic system contains the following elements:

1. The hydrologic system of Pine Creek and Rock Creek canyons possesses a surface-water component and a ground-

water component. The two components of the system are interdependent, as demonstrated by (a) the sustained discharge of the creek during seasons of low precipitation; (b) gaining and losing stream reaches that correspond to areas of hydraulic communication between the surface- and ground-water components; and (c) the transfer of mass loads between the surface-water and ground-water components of the system (HCI, 1989a; ibid., 1989b). The results of environmental isotope analyses (Appendix B) also provide an indication of the interconnectedness of the systems.

2. The hydrologic system is developed in glaciated valleys, and originates in alpine watersheds. Precipitation is orographically controlled, and varies from a mean annual value of about 8 inches at the Rovana gage to more than 40 inches near the maximum elevations of the watersheds (Sheet 6). The Pine Creek and Rock Creek watersheds each cover an area of about 36 square miles; the restricted sub-basins included in the conceptual model are somewhat smaller (Tables 8 and 9). Mean annual precipitation over both sub-basins is about 30 inches (Table 10). The corrected mean annual surface discharge of Pine Creek at Rovana is about 46 cfs (Table 5, Column 2). The measured August discharge of Rock Creek at the inlet to Rock Creek Lake is about 16.6 cfs (HCI, 1989b). These correspond to base flow values of approximately 26 cfs in Pine Creek and 8 cfs in Rock Creek. The estimated value of base flow in Pine Creek, in the absence of mining (corrected base flow) is 20 cfs.

3. Pine Creek canyon and Rock Creek canyon are cut into crystalline bedrock; Pine Creek valley has been filled with unconsolidated glacial and fluvial deposits having a maximum thickness in excess of 300 feet (Chen & Associates, 1987; HCI, 1989b). The hydraulic conductivity of the unconsolidated deposits is on the order of 50 feet per day (ft/day; HCI, 1989b); the bulk porosity of these materials is approximately 0.25 (Freeze and Cherry, 1979). Conversely, the crystalline bedrock possesses a low bulk porosity, probably on the order of .02 (Freeze and Cherry, 1979), and a hydraulic conductivity in the range of 0.1 to 0.01 ft/day. Flow in the crystalline bedrock is conducted primarily by fractures; this imparts a high degree of anisotropy to ground-water flow.

4. Most water that flows through the Pine Creek/Rock Creek hydrologic system originates as snowmelt at higher elevations within the watersheds. The topographic divide

of the Sierra Nevada to the west that serves as a surface-water divide also functions as a ground-water divide. Water is conducted both as surface runoff and as fracture-controlled ground-water flow into the canyons. Some of the water that enters the canyon via the surface-water system serves to recharge the alluvial ground-water system. Ground water recharges the crystalline bedrock through fractures. Ground-water underflow from the mouth of Pine Creek canyon is about 30 cfs; there is negligible ground-water underflow at the inlet to Rock Creek Lake.

5. Evapotranspiration losses from both valleys are small, amounting to 0.7 cfs on average for Pine Creek valley, and 0.07 cfs for Rock Creek valley above the inlet to Rock Creek Lake.

6. A comparison of streamflows in Pine Creek with nearby watersheds shows that flows in Pine Creek have increased, on average, since mining advanced beneath the water table in the 1940s. Flows in Pine Creek are estimated to have been augmented by an average of 2.4 cfs between 1945 and 1964, and 5.3 cfs from 1965 to the present. This excess streamflow represents developed ground water removed from storage in the fractured-rock reservoir, and discharged from the Pine Creek mine.

3.2 THE NUMERICAL MODEL

The conceptual model was used as the framework on which a three-dimensional numerical model, describing the hydrologic system in the vicinity of the Pine Creek mine, was constructed. The model was designed to portray, as accurately as possible, the hydrogeologic system of the Pine and Rock Creek sub-basins. The resulting numerical model was then used to estimate the amount of ground water produced by mining activities, and to assess the effects on the hydrologic system, over time, that might result from continued development of ground water by mining.

The mathematical model is based on the three-dimensional form of the equation that describes ground-water flow:

$$\frac{\partial}{\partial y}\left(K_{xx}\frac{\partial h}{\partial x}\right)\ \frac{\partial}{\partial x}\left(K_{xy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial x}\left(K_{xz}\frac{\partial h}{\partial z}\right)$$

$$+ \frac{\partial}{\partial y}\left(K_{yx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial y}\left(K_{yz}\frac{\partial h}{\partial z}\right)$$

$$+ \frac{\partial}{\partial z}\left(K_{zx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_{zy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)$$

$$+ Q = S_s\frac{\partial h}{\partial t}$$

where

- h = hydraulic potential ("head");
- K = hydraulic conductivity;
- Q = recharge or discharge;
- S_s = specific storage;
- t = time;
- x,y,z = Cartesian coordinates.

This equation is solved by the finite-element method using a computer code developed by Durbin (1985) and documented by Durbin and O'Brien (1987). The solution method includes an explicit representation of the storage changes that occur with changes in the position of the water table.

The input parameters to the numerical model were selected based on values that were compatible with the conceptual model. In some cases it was necessary to adjust the digital code to incorporate elements of the conceptual model. The following parameters were incorporated into the numerical model:

- three-dimensional anisotropic hydraulic conductivity tensors;
- ground-water storage (specific yield and specific storage);
- ground-water recharge;
- discharges of water from the model;
- boundary conditions, including initial ("steady-state") conditions, and regional, transient post-mining conditions; and
- a parameter to account for non-Darcian (or turbulent) flow in the near vicinity of the mine workings.

3.2.1 Assessment of Hydraulic Conductivity in Fractured Rock

Fractured rocks function as porous materials in which permeability depends on a large number of planar conduits, having dispersed orientations. Since in most cases it is impossible to measure the orientation of every fracture, the problem must be solved statistically, by random sampling of the orientations. The procedures used to assess fractured-rock anisotropy in the Pine Creek system have been outlined by Snow (1968; 1969) and developed in some detail by Bianchi (1968).

This procedure requires the sampling of fracture orientations along an oriented baseline of known length. To conduct a sampling program of this type (a "scanline survey" or "detail-line survey"), the spacing and orientations of all joints or fractures located along a baseline are measured (ISRM, 1978). Several criteria must be observed if detail-line data so collected are to be a statistically-valid representation of the population of discontinuities in the rock mass:

1. The sampling points should be randomly-located (ISRM, 1978);
2. 60 to 80 joints should be sampled per location (Pincus, 1951);
3. To obtain a three-dimensional representation of rock-mass discontinuities, data should be collected from baselines that have varying orientations (Terzaghi, 1965).

Snow's method of calculating the contribution of each fracture to the permeability of the fractured medium consists in determining the permeability of a cubic element of a continuous medium having sides equal to the average spacing between fractures belonging to a given joint set. The discharge through the face of such a cube would be equal to the discharge of the fracture under identical gradient conditions (Bianchi, 1968; Snow, 1969).

A total of 1,566 joints from 22 different sampling stations within the study area and the mine (Sheets 10 and 11) were measured. At each sampling station a baseline, delineated by a surveyor's tape, was laid out along the outcrop to be studied. The orientation (bearing and plunge) of the tape, the location of the station, and the type of rock (marble, granodiorite, etc.) that was being sampled were recorded. Different line orientations were used at different sampling locations, thus assuring representation of all joint sets (Terzaghi, 1965). The orientation of each fracture intersecting the baseline was measured with a Brunton pocket transit and recorded, together with the tape distance at the point of intersection, and an estimate of the joint aperture width.

After all field data had been collected, the joint orientations for each detail line were plotted on a Schmidt equal-area stereonet, as poles to joint planes; data were then filtered by plotting the poles as numbers of poles per 1% of stereonet area (Call et al., 1976). The plotted joint data were then contoured to show the distribution of joint orientations about a mean (or modal) value (Call et al., 1976; Goodman, 1980). This procedure allowed each fracture that was recorded to be assigned to a joint set. The stereoplots of joint data that were collected at each sampling location are presented on Sheets 10 and 11.

Once joints had been assigned to sets, it was possible to estimate the mean, maximum, and minimum spacings of joints within sets. The joints recorded along a given detail line were sorted into joint sets, and the spacings between joints of a given set were calculated based on the recorded location of each joint along the baseline. Thus spacings between joints within joint sets for each detail line could be calculated; the spacing data for all joint sets were then assembled from the joint spacing information calculated for each detail line.

A rock mass is by nature both heterogeneous and anisotropic; however, for analytical and numerical purposes it was necessary to divide the rock mass in the study area into parts within which jointing characteristics (and hence, presumably, hydraulic characteristics) are statistically similar. The smaller parts of the rock mass within which joint characteristics are similar are called <u>structural regions</u>; the systematic sets of joints occurring within these structural regions are called <u>design joints</u>. Designation of a structural region is made exclusively on the basis of similarities of design joint orientations (Piteau, 1972).

The orientation data for all detail lines in the fracture study were plotted and compared. At least four distinct intrusive rock units and three metasomatic rock units have been mapped in the vicinity of the Pine Creek facility (Bateman et al., 1965). However, only three separate structural (or lithostructural) units were identified, based on the observed similarities of design joint orientations. These units were:

- metasomatic rocks (including all units in the Pine Creek pendant);
- granodiorite (including the granodiorite, diorite, and quartz diorite of Bateman et al., 1965); and
- quartz monzonite.

All rocks that are grouped into a single lithostructural unit can be expected to function in hydrologically similar ways because of statistical similarities in joint orientations. Different lithostructural units are expected to function in hydrologically different ways, because of differences in jointing characteristics. The alluvial fill material in Pine Creek and Rock Creek valleys was expected to function as an isotropic, homogeneous porous medium at the scale of this investigation. Therefore, alluvium was the fourth geologic unit in the study area (Sheets 10 and 11).

Once the data from each detail line had been assigned to a lithostructural unit, the relative permeability tensors were computed for each unit, using all pertinent fracture data, following the method of Snow (Bianchi, 1968). The orientations of the principal permeability vectors for each lithostructural unit are presented in Table 11; the hydraulic conductivity tensors, corresponding to these vectors, that were used in the numerical model are presented in Table 12.

3.2.2 Ground-Water Storage

The values assigned to ground-water storage parameters were based on previous results, or on values from the literature. The specific yield of the alluvium was estimated during previous work conducted in Pine Creek valley (HCI, 1989b). A value of 0.02 was used for the specific yield of the igneous rocks (Freeze and Cherry, 1979), and the value of specific yield for the metasomatic rocks was assumed to be similar.

Values for specific storage were calculated using representative values of the bulk modulus ("inverse coefficient of compressibility") for rock (Houston and Kasim, 1982) and for pervasively-fractured rock (Rodrigues, 1974). Values for the ground-water storage parameters used in the numerical model are presented in Table 12.

3.2.3 Recharge and Model Discharges

Under steady-state conditions, the annual average basin inflows (precipitation) must equal the total outflows from the basin (sum of annual average surface-water flow, ground-water underflow, and ET) as outlined in the conceptual-model (Section 3.1). Since the proportion of precipitation that recharges to the ground-water system was not known with certainty, the amount of recharge necessary to maintain equilibrium was calculated from stream base flows, ground-water underflow, and ET and sublimation losses for each sub-basin. The values assigned to each of these components of flow have been outlined in Section 3.1.

In the construction of the model, the quantities of precipitation, surface discharge and base flow, ground-water underflow, and ET within the modeled region were apportioned based on the fractional area of each sub-basin that lies within the model boundaries (Sheets 9 and 12). It was estimated that 57% of the Pine Creek sub-basin and 56% of the Rock Creek sub-basin are within the modeled area. Precipitation was estimated using the isohyetal relation that had been developed for the eastern Sierra Nevada (Sheets 6 and 14); the quantity of recharge necessary to achieve equilibrium with a mean discharge of 46 cfs in Pine Creek and 8 cfs in Rock Creek was then calculated. It was estimated that recharge equivalent to 60% of precipitation was necessary to sustain these flows; this value is reasonable for recharge in fractured-rock terranes in the high mountains of California (Troxel, 1953). Recharge and discharge values used in the numerical model are summarized in Table 13.

3.2.4 Boundary and Initial Conditions

Both boundary conditions and initial conditions must be considered during the construction of a numerical model. Because Rock Creek and Pine Creek occupy hydrologic regimes that are reasonably well known, and because the stream valleys probably function as local hydrogeologic divides, these two creeks were selected as the northwest and southeast boundaries of the modeled area (Sheets 9 and 12), and were assigned as constant-head boundaries. The southwest and northeast borders of the model were assumed to be no-flow boundaries (Sheet 12).

The initial water-level conditions in the present model correspond to the steady-state potentiometric surface that existed prior to mine dewatering. (The term steady-state indicates that water levels in the modeled domain do not change appreciably over time). Steady-state conditions depend on long-term equilibrium between the computed natural recharge and computed ground-water and surface-water discharges.

A steady-state calibration process was initiated to adjust various hydraulic parameters to fit the conceptual model of the hydrologic system. In particular, steady-state calibration depended to a large extent on the values of hydraulic conductivity assigned to the various lithostructural groups. Initial estimates of hydraulic conductivity for the four lithostructural groups were obtained from the anisotropy calculations (Section 3.2.1). During steady-state calibration the magnitudes of the original hydraulic conductivity values were adjusted to maintain the water table above the northwest end of the present EZ-Go adit at an elevation of approximately 10,000 feet NGVD, while keeping the water table below topography in the remainder of the modeled domain. However, the relative orientations of the principal permeabilities were judged to be representative of known data, and were not changed. The final values of the hydraulic conductivity tensors that were used are presented in Table 12; the resulting steady-state potentiometric surface is shown in Sheet 15.

3.2.5 Transient Calibrations and Predictive Simulations

The initial conditions that resulted from the steady-state calibrations were then used in model simulations to evaluate the effects of mining activities on the Pine Creek sub-basin. These transient calibrations were performed to bring the modeled values of hydraulic potential and discharge into better agreement with the historical values. The initial values of specific storage that were calculated from bulk moduli (Section 3.2.2) were adjusted until modeled discharges from ground-water storage were approximately equal to the excess Pine Creek discharge values that were calculated during the statistical analysis of historic discharges (Section 3.1.2). The values of specific storage that were used in the transient simulations are presented in Table 12.

The presence of the mine workings within the saturated rock mass represents an additional transient boundary condition that must be satisfied. Lines of constant-head nodes, corresponding to mine workings at atmospheric pressure, were introduced into the model at elevations corresponding to the Zero and EZ-Go adits. This was performed in different time steps during transient simulations to approximate the actual advance of the drifts.

Some information is available regarding the quantities and locations of inflow to the mine workings (Figure 1). These data were used in transient simulations to adjust the values of the "skin effect" terms, which account for turbulent flow into the adit (Section 3.2.6). The final "skin effect" terms were established by comparing the quantities and rates of inflow predicted by the model with the historical inflows observed at the mine.

3.2.6 Simulation of Turbulent Flow

It was necessary to incorporate a term to account for non-Darcian flow to better portray inflow to the mine. "Non-Darcian" flow refers to the effects associated with turbulence that occurs as water under a high potential gradient flows through fractures near the mine workings. This turbulent flow produces an energy loss that raises the observed water levels in the immediate vicinity of the mine (Louis, 1969; Atkinson et al., 1989). If non-Darcian flow is not taken into account, the simulation would predict drawdowns in the vicinity of the mine more extensive than probably occurred, and would predict inflows to the workings far in excess of the inflows that were observed. However, in the absence of turbulence, such large initial inflows could not be sustained. It should be noted that despite 40 years of mining activity, minor inflows still occur in the 1500 level of the mine, indicating that the potentiometric surface in the immediate vicinity of the mine has not yet fallen below this elevation. This observation tends to confirm the occurrence of turbulent flow conditions.

A "skin effect" term, that effectively reduced the hydraulic conductivity near the mine workings, was included in the computer program to simulate the effects of non-Darcian flow in the region immediately adjacent to the mine. This "skin effect" term is geometrically related to the turbulent-flow coefficient (C) in the classic Jacob equation (Jacob, 1947).

3.3 DISCUSSION

The numerical model of the Pine Creek/Rock Creek hydrologic system was constructed based on the available geologic, hydrologic, and historical information. Calibrations were conducted to adjust the values of certain hydraulic parameters as necessary to reproduce the actual conditions in the system. The calibrated model predicts values of hydraulic potential, mine and stream discharge, and changes in ground-water storage that are in good agreement with the known values of these quantities. The numerical model that was constructed to describe the Pine Creek/Rock Creek hydrologic system was therefore judged to be appropriate for use in predicting future effects to the system resulting from mine discharge.

4.0 RESULTS OF PREDICTIVE NUMERICAL MODELING

The calibrated numerical model describing the Pine Creek/Rock Creek hydrologic system was used in several predictive simulations to assess the effects on the system through time resulting from drainage through the Pine Creek mine. The time period 1945 to the present was simulated to estimate the current potentiometric surface and the changes that have occurred in ground-water storage since the commencement of mining below the potentiometric surface. Next, the simulation was continued through a 50-year period of time into the future, to assess the effects of continued mine drainage into the year 2040. Finally, a simulation was conducted to assess the effects of purposeful additional development of ground water.

4.1 SIMULATION OF HISTORIC DISCHARGES

The historic discharges for the period of record 1945 to 1989 were simulated in two stages: the period 1945 - 1961, when only the Zero adit was in place, and the period 1962 - 1989 when nearly all drainage occurred from the EZ-Go adit. The initial conditions resulting from the steady-state simulation were selected to represent 1945; at that point, "drains" were installed in nodes of the numerical model corresponding to the Zero adit. The adit was allowed to drain for a simulated period of time corresponding to 18 years (until 1962); at this point, the effects of mine dewatering were only slightly apparent in the simulated potentiometric surface (Sheet 16). A second series of "drains" was then installed in model nodes corresponding to the EZ-Go adit. After 18 years of discharge from the EZ-Go adit, some noticeable effects appeared in the simulated potentiometric surface (Sheet 17); a decline in the potentiometric surface has been propagated northwards towards Wheeler Crest from the mine area.

The discharges resulting from this simulation correspond closely with observed historical discharges (Figure 8); as expected, soon after the EZ-Go nodes are installed, the Zero adit ceases to discharge water (Figure 9; compare with Figure 1). The simulation results do not correspond exactly with historical discharges in the early part of the period; this is partly a result of the many simplifications inherent in modeling, and particularly due to the fact that the simulated "adits" began to discharge instantaneously, rather than advancing over a period of time. The agreement of the simulations with historical discharges in later time (e.g. 1970s - 1980s) is judged to be excellent.

The results of the historical simulation (Table 14) indicate that about 5.8 cfs of the total mine discharge in 1989 was developed ground water, due to mine withdrawals from ground-water storage. This agrees well with the 35-year average value of discharges at Rovana in excess of precipitation, calculated during the statistical analysis of Pine Creek discharges (Section 3.1.2; Table 5). Note that the total mine discharges reported for the historic simulation (Table 14) consist of discharges from the Zero adit alone during the years 1946 through 1962; the sum of discharges from the Zero and EZ-Go adits during the years 1963 through about 1965; and discharges from the EZ-Go adit alone in subsequent years, because the Zero adit ceases to produce water.

The historical simulation also indicates that both Rock Creek and Morgan Creek have been affected by past mine discharges (Table 14). Base flows in Rock Creek appear to have been only slightly affected, declining at most a few tenths of a cfs over the period of historic mining (Figure 10). This slightly-reduced base flow is probably a result of the decline in the potentiometric surface beneath Wheeler Crest. Over the same period of time (1945 - 1990), base flows in Morgan Creek have declined substantially (Figure 11).

While some of the decline in Morgan Creek flows may be due to the lowered potentiometric surface, most of the decline is probably a result of the capture of ground water and surface water in the Morgan Creek sub-drainage by the mine. This hypothesis is supported by the results of the environmental isotope analysis (Appendix B).

4.2 SIMULATION OF FUTURE EFFECTS OF MINE DISCHARGE

The potentiometric-surface (Sheet 17) and discharge conditions resulting from the 1945 - 1989 transient simulation were next used as the initial conditions for a predictive model. The predictive numerical simulation was conducted for the years 1990 to 2040 (a 50-year predictive simulation). The results of this simulation (Table 15) indicate that in the year 2040, about 1.8 cfs of the total mine discharge will be developed ground water, due to mine withdrawals from ground-water storage. The calculated potentiometric surface that would result from continued mine discharge over this period, assuming all other conditions remain the same, has declined noticeably in the region around Wheeler Crest (Sheet 18).

The predictive simulation indicates that both Rock Creek and Morgan Creek will continue to be affected by mine discharges in the future (Table 15). Base flows in Rock Creek at the inlet to Rock Creek Lake may decline to only half their present rate (Figure 10), while it is probable that Morgan Creek base flow will disappear entirely, and Morgan Creek will become an ephemeral stream (Figure 11). The decline of base flow in Rock Creek is attributed to the redirection of ground water from the Rock Creek sub-basin into the Pine Creek sub-basin, due to changes in the drainage divide beneath Wheeler Crest. As the rock mass above the mine is dewatered, the ground-water divide is predicted to move northward, towards Rock Creek. This reduces the area within which precipitation inputs are directed towards Rock Creek, and increases the area within which precipitation inputs will flow into Pine Creek. The flow volumes lost from Rock Creek base flow are eventually incorporated into the ground-water system of the Pine Creek sub-basin, and serve to increase base flows in Pine Creek. The decline in Rock Creek base flows are not accounted against mine discharges from ground-water storage (developed ground water), which are calculated separately in the numerical simulations. Rather, base flows in the Pine Creek drainage sub-basin are increased by the same flow volumes by which Rock Creek base flow has decreased. The decline of base flow in Morgan Creek is attributed to the capture of both surface flow and ground water in the Morgan Creek sub-drainage by the mine. However, the decline of flow in Morgan Creek is of no consequence to the overall hydrology of the Pine Creek system, because flow captured from Morgan Creek by the mine is returned to the Pine Creek system as mine discharge.

Pine Creek base flows are predicted to decline over the period; however, total flows in Pine Creek, consisting of Pine Creek base flow plus mine discharges, will still be somewhat in excess of naturally-occurring Pine Creek base flows (Figure 12, middle curve). This phenomenon is a result of the interception by the mine of ground water that would otherwise discharge into the Pine Creek hydrologic system, and of the discharge of developed ground water by the mine from ground-water storage. The naturally-occurring base flows in Pine Creek, that result from the discharge of ground water into the creek, will decline as ground water is intercepted by the mine. This intercepted ground water is still returned to Pine Creek as mine discharge; however, for accounting purposes, it is no longer considered to be a component of base flow. Additionally, Pine Creek base flows are increased slightly by ground-water discharge that has been captured from the Rock Creek sub-basin. At the same time, the component of total mine discharge that consists of developed ground water, discharged from ground-water storage, serves to augment the discharge from the system, so that total flows in Pine Creek are increased over natural conditions (in the absence of mining).

4.3 SIMULATION OF THE EFFECTS OF INCREASED GROUND-WATER DEVELOPMENT

A final transient simulation was undertaken to assess the effects that might result from increased ground-water development, designed to augment withdrawals from storage in the fractured-rock reservoir. For the purposes of this simulation, it was assumed that horizontal drains (Atkinson et. al, 1989) would be installed on 500-foot centers in the EZ-Go adit; these drains would consist of 4-inch coreholes, drilled 500 feet into the rock. Most of the drains would be installed to the northeast of the EZ-Go adit (away from Morgan Creek) to maximize the amount of water that could be removed from storage.

The predictive mathematical simulation was conducted for the years 1990 to 2040 (a 50-year simulation). The results of this simulation (Table 16) indicate that if the above strategy were pursued, developed ground water discharges could be immediately increased to about 17 cfs; after a period of 50 years (year 2040), developed ground-water discharge will have declined to about 3.4 cfs of the total mine discharge. At the end of the 50-year simulation, the calculated potentiometric surface that would result from continued discharge of developed ground water over this period, assuming all other conditions remain the same, has declined by over 200 feet in the region around Wheeler Crest (Sheet 19); this is approximately 150 feet lower than the potentiometric surface that would result if ground-water development were not increased (Sheet 18). A noticeable depression has also developed in the potentiometric surface in the vicinity of the mine workings.

Predicted total flows in Pine Creek, consisting of Pine Creek base flow plus mine discharges, will still be somewhat in excess of the natural Pine Creek base flows, and greater than Pine Creek flows with no additional development (Figure 12, upper curve). However, the total flows through the Pine Creek system will only be increased by the additional amount removed from storage, together with the small amount of flow captured from the Rock Creek system. The simulation also predicts that discharges from the mine would be substantially greater than the present total mine discharges (Table 16), and would also be greater than the predicted mine inflows with no increased ground-water development (Figure 13).

The results of this predictive simulation also indicate that neither Rock Creek nor Morgan Creek will be affected to any greater degree by increased ground-water development than if no additional development had occurred (Table 16). Base flows in Rock Creek and Morgan Creek are predicted to decline, but the reduction in base flows is no greater than for the predictive simulation with no additional mine development (Table 15). This indicates that directed ground-water development could probably be effective in removing increased quantities of ground water from storage, while affecting the surface hydrologic regime to a minimal extent.

5.0 CONCLUSIONS AND RECOMMENDATIONS

An investigation of the Pine Creek/Rock Creek hydrologic system was conducted to estimate the quantity of water discharged from the Pine Creek mine into the Pine Creek hydrologic system, and to assess the sources of water and the effects of this volume of discharge on the past, present, and future hydrology of the Pine Creek and Rock Creek sub-basins.

A calibrated numerical model, based on a conceptual model of the hydrologic system, was assembled and used to quantitatively assess the historic and current effects of the mine on the hydrologic system, and to predict the effects of continued mine drainage on the system over a 50-year period.

The results of the numerical simulations indicate that:

- The Pine Creek mine is currently producing on average about 5.8 cfs of developed ground water from the fractured-rock aquifer. This agrees with recorded flows in Pine Creek that are observed to exceed precipitation inputs.

- If the mine continues to discharge under the conditions that obtain at the present, and no additional mine development or other hydrologic changes occur, discharges from the mine will decline over time, until new equilibrium conditions are established (Figure 14). Under the conditions of the simulation, the mine is predicted to produce on average about 1.8 cfs of developed ground water in the year 2040 (50 years from the present).

- Flows in both Morgan Creek and the upper part of Rock Creek are expected to decline as a result of continued discharges from the mine. The decline of base flow in Rock Creek is attributed to the capture of ground water from the Rock Creek sub-basin by the Pine Creek sub-basin, due

> to changes in the drainage divide beneath Wheeler Crest. The flow volumes lost from Rock Creek base flow are eventually incorporated into the ground-water system of the Pine Creek sub-basin, and serve to increase base flows in Pine Creek. Therefore, replacement of water lost to Rock Creek discharge should be simply a matter of water accounting (Rock Creek declines are matched against Pine Creek increases). The decline in Rock Creek base flows are <u>not</u> accounted against mine discharges from ground-water storage (developed ground water), which are calculated separately in the numerical simulations. Decline of flow in Morgan Creek is of no consequence to the Pine Creek hydrologic system, because flow captured from Morgan Creek by the mine is returned to the Pine Creek system. No other adverse effects to the Pine Creek or Rock Creek hydrologic system are anticipated as a result of these continued discharges.

Finally, a simulation was conducted to assess the effects on the system that might result from increased ground-water development, designed to augment withdrawals from storage in the fractured-rock reservoir. For the purposes of this simulation, it was assumed that withdrawals from ground-water storage would be maximized by the installation of horizontal drains. This predictive mathematical simulation was also conducted for a 50-year period. The results of this simulation indicate that if this strategy were pursued, developed ground water discharges could be immediately increased to about 17 cfs; after a period of 50 years, developed ground-water discharge will have declined to about 3.4 cfs of the total mine discharge (Figure 15). Base flows in Rock Creek and Morgan Creek are predicted to decline, but the reduction in base flows is no greater than for the predictive simulation with no additional mine development.

This development scenario assumes that all the proposed horizontal drains would be installed at once, and that this installation would be accompanied by high initial flow rates, that would decline over time (Table 16; Figure 15). A more realistic development program would involve the progressive installation of drainholes over time, corresponding with some "scheduling" of ground-water development. The initial flows that would result would not be as great as predicted by the present simulation; however, developed ground-water flows could probably be sustained at relatively constant rate of production for a longer period of time. Directed ground-water development could thus be effective in removing increased quantities of ground water from storage, while affecting the surface hydrologic regime to a minimal extent.

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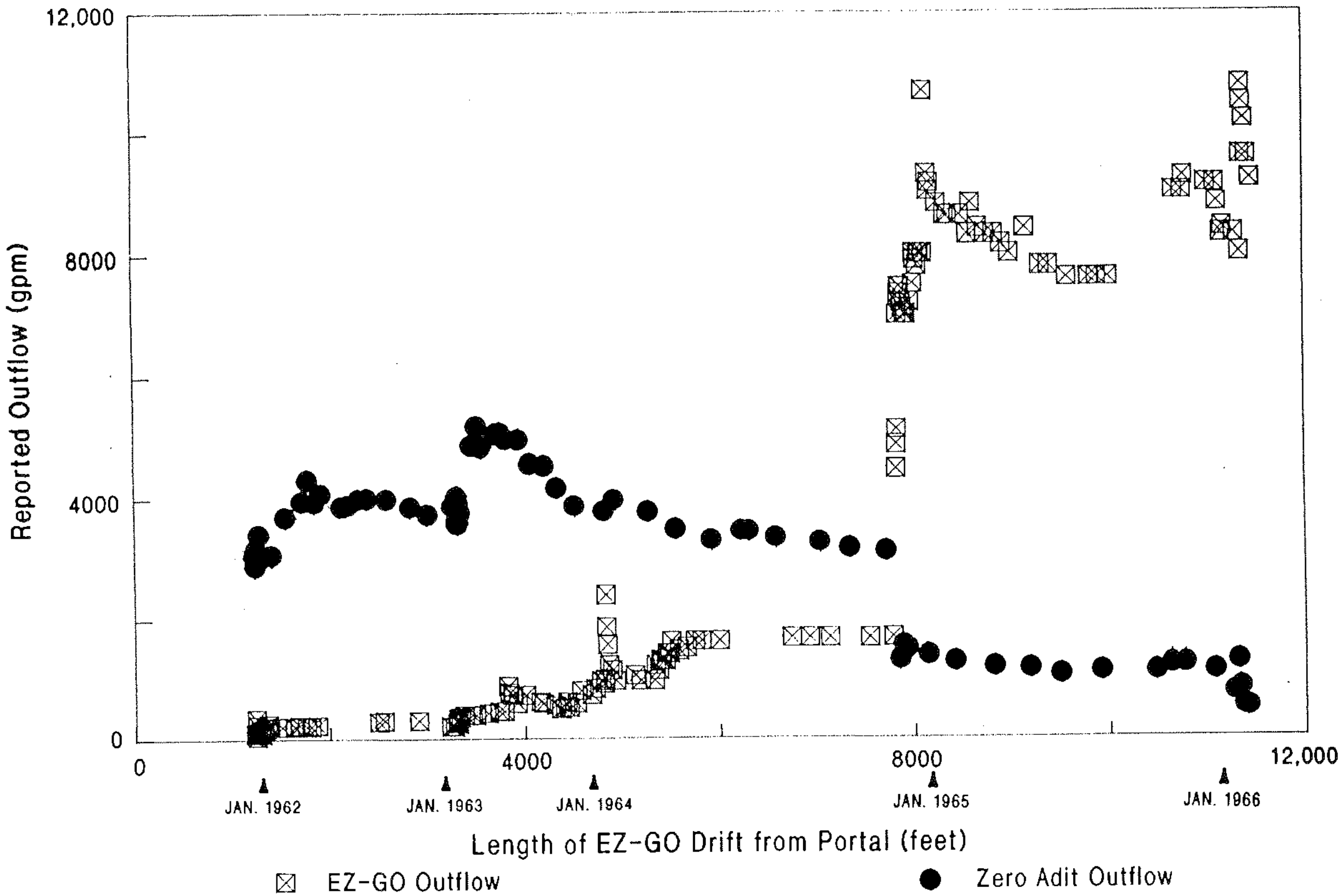
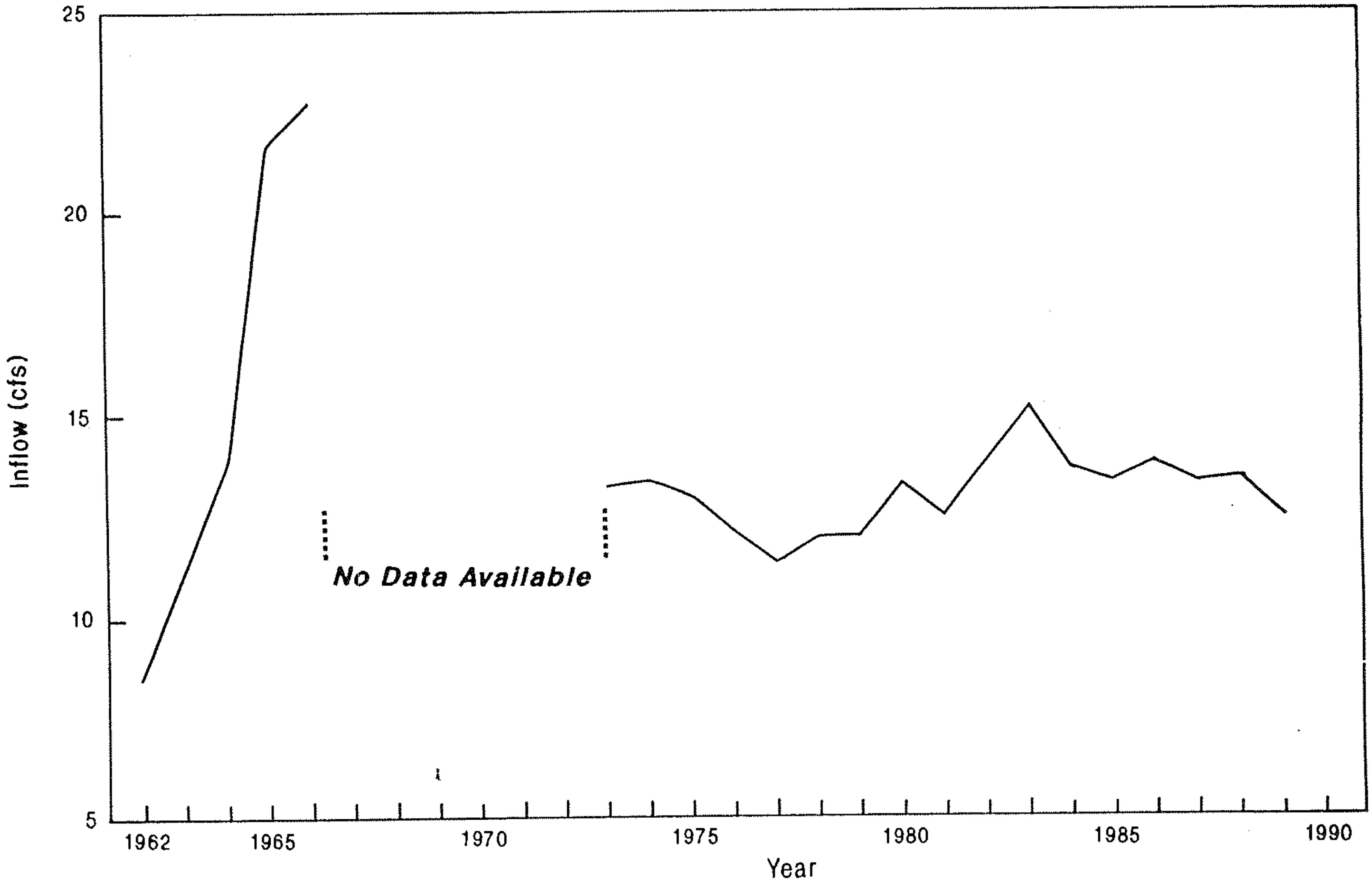
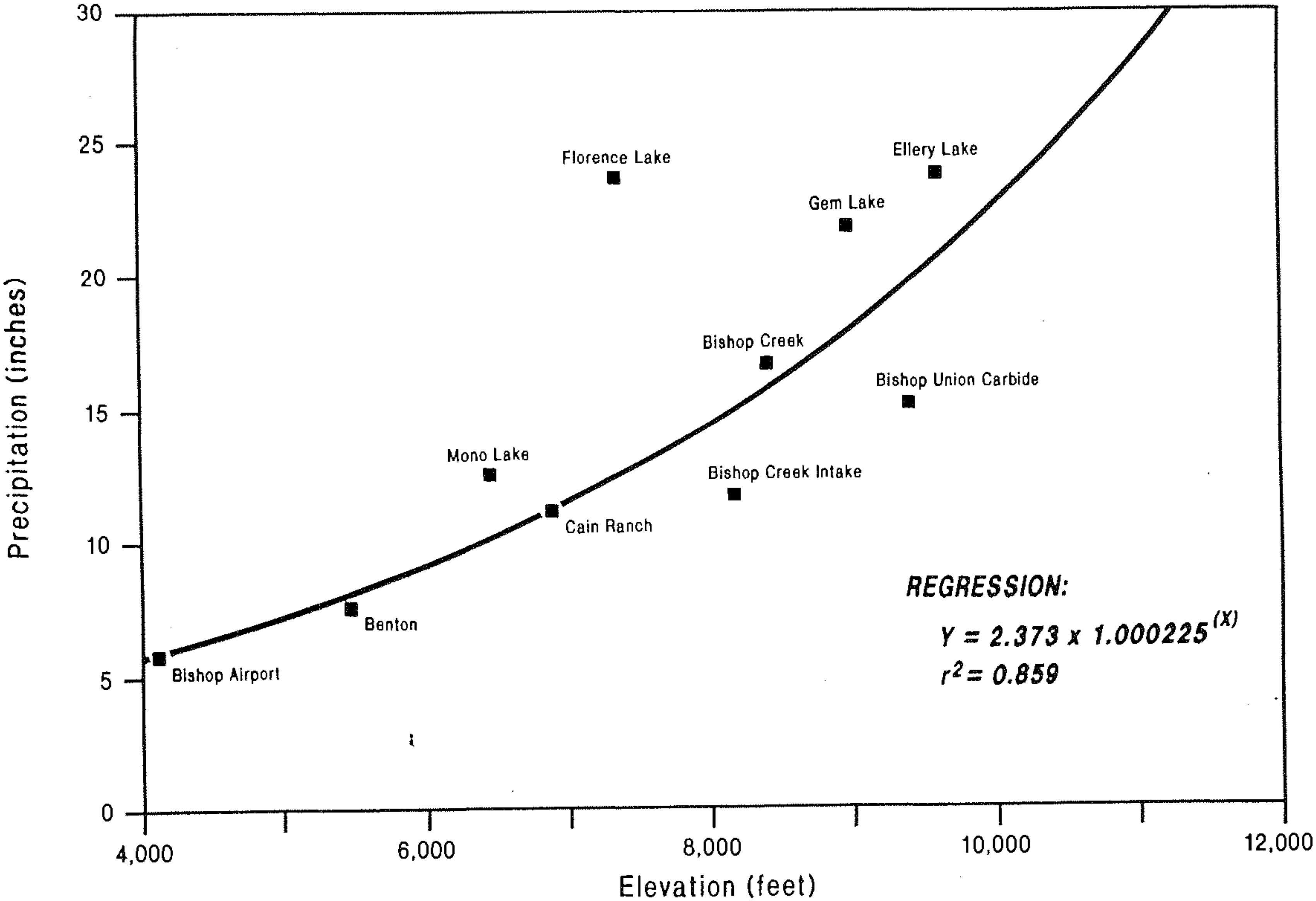


HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1) BY: JWA CHKD:	DATE: 1-23-90 REV: 1-29-90 DRAWN: JF	**REPORTED TOTAL OUTFLOW in EZ-GO and ZERO ADITS during ADVANCE of EZ-GO**	FIGURE 1

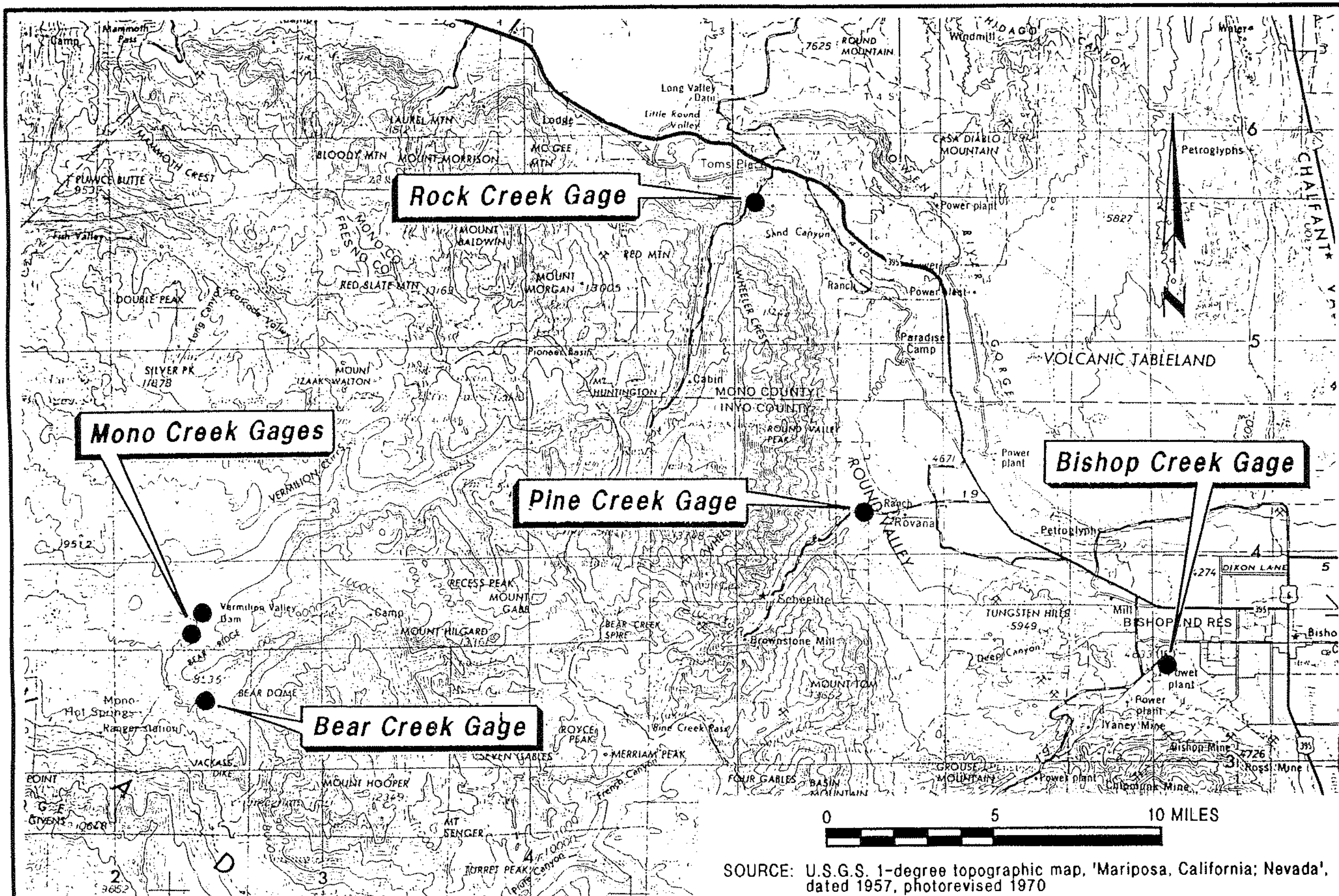


——— Historical Mine Discharges
(Note: No Data Available 1966 through 1973)

HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 3-16-90	HISTORICAL TOTAL MINE DISCHARGES	FIGURE: 2
	BY: GDN	DRAWN: RM		
	CHKD: JWA	REV: 3-21-90		

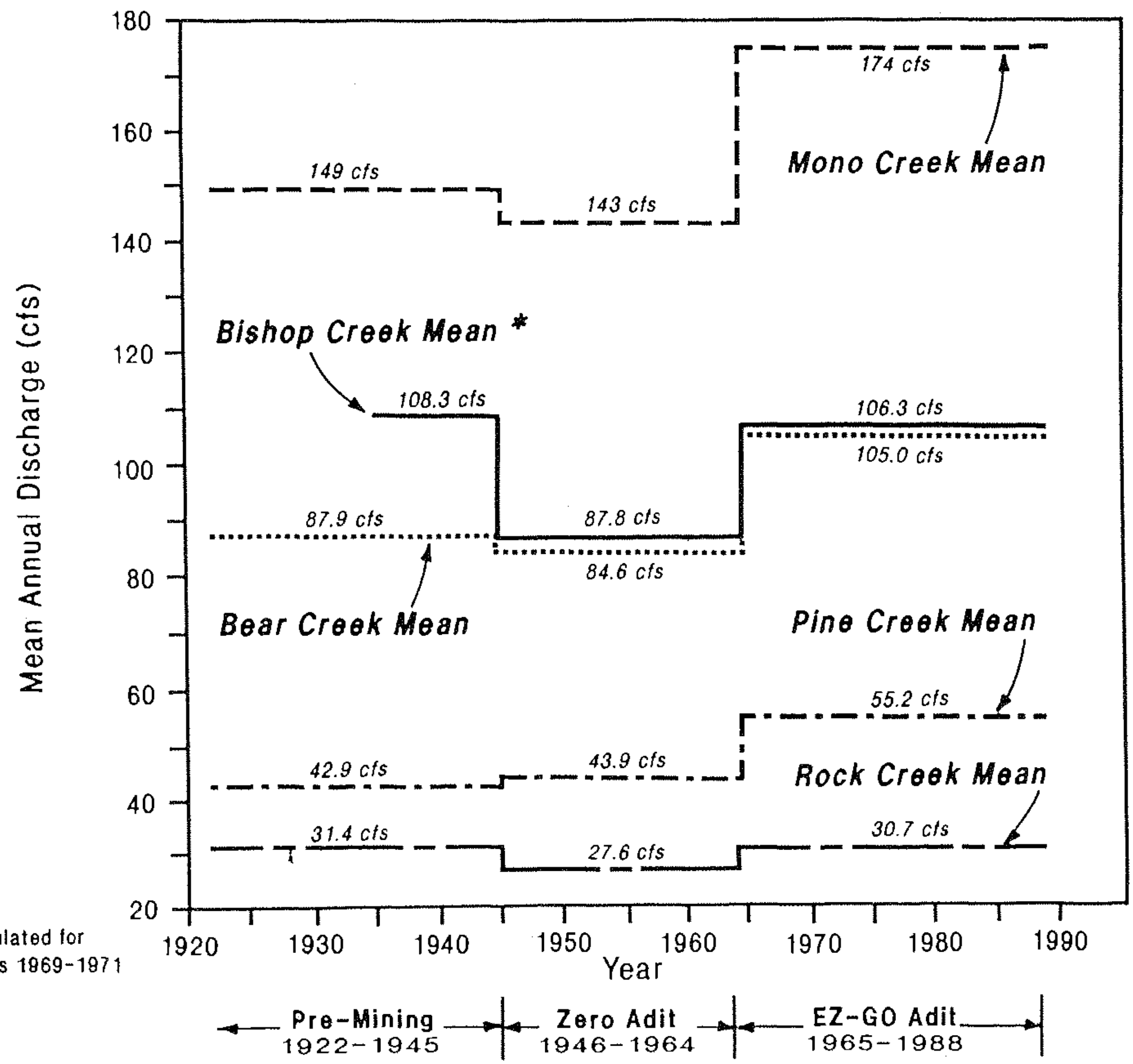


HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 1-29-90	OROGRAPHIC CONTROL of PRECIPITATION	FIGURE 3
	BY: JWA	REV:		
	CHKD:	DRAWN: JF		



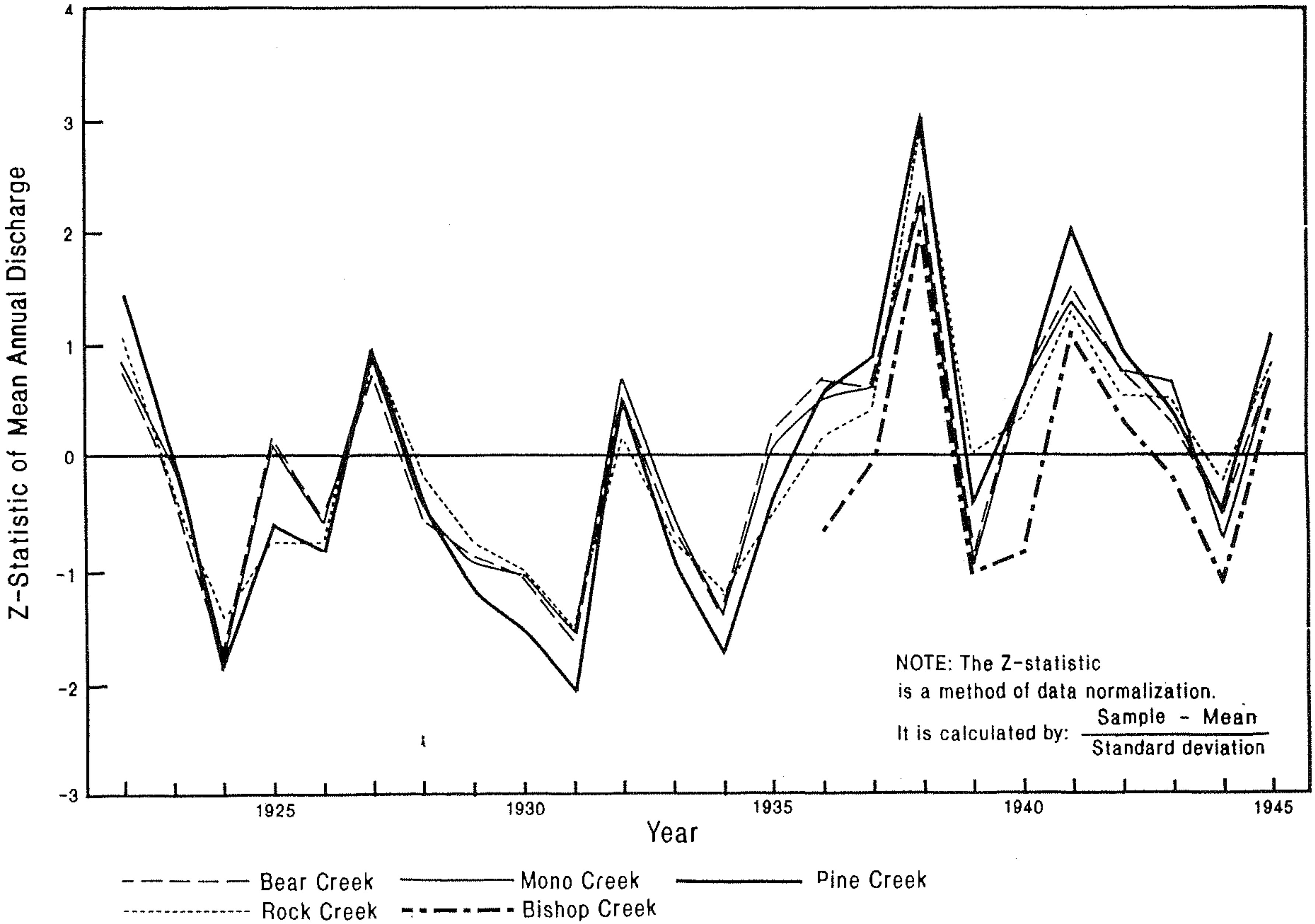
SOURCE: U.S.G.S. 1-degree topographic map, 'Mariposa, California; Nevada', dated 1957, photorevised 1970

HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-5-90	LOCATION of STREAM GAGES in BISHOP AREA	FIGURE 4
	BY: JTF/MSM	DRAWN: JF		
	CHKD:	REV:		



* Pre-mining Mean calculated for 1936-1945; the years 1969-1971 have been corrected

HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-6-90	COMPARISON of AVERAGED MEAN ANNUAL FLOWS for DIFFERENT PERIODS of MINE DEVELOPMENT	FIGURE 5
	BY: JTF	DRAWN JF		
	CHKD:	REV: 5-10-90		

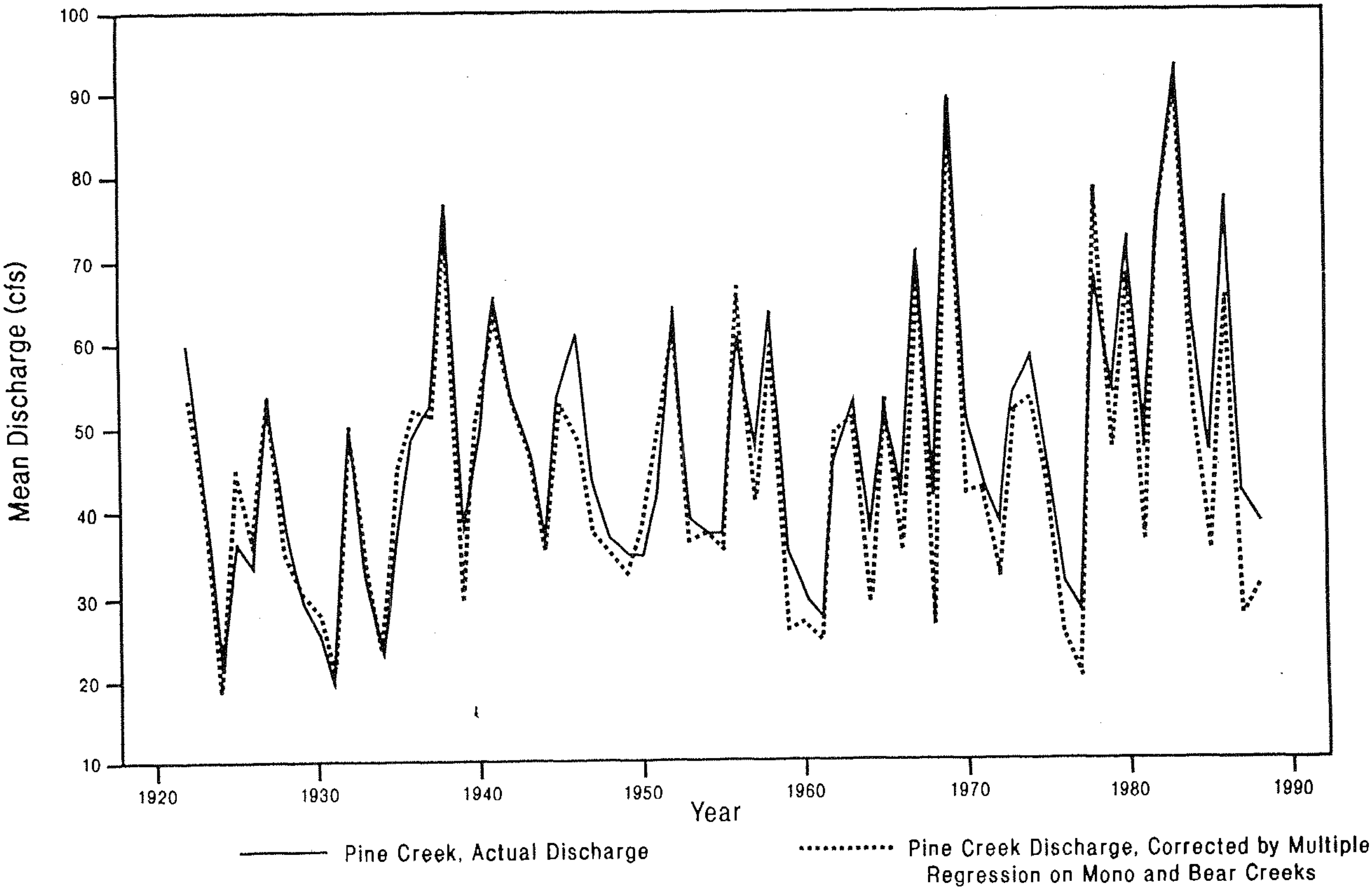


HCI HYDROLOGIC CONSULTANTS, INC.

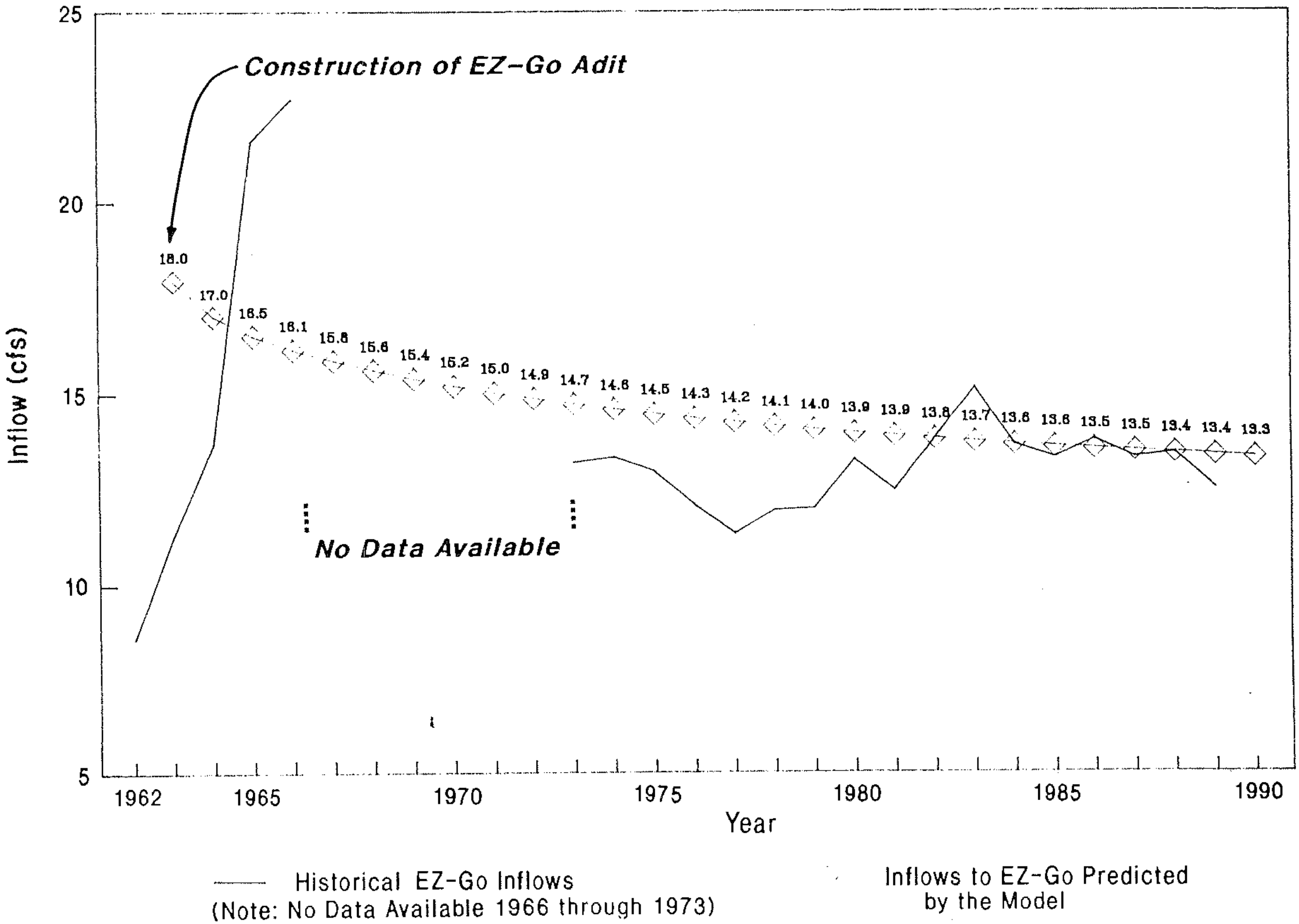
HCI-531(1)	DATE: 2-2-90	
BY:	DRAWN:	
CHKD:	REV:	

COMPARISON of MEAN ANNUAL DISCHARGES in WATERSHEDS near PINE CREEK, PRE-MINING PERIOD 1922-1945

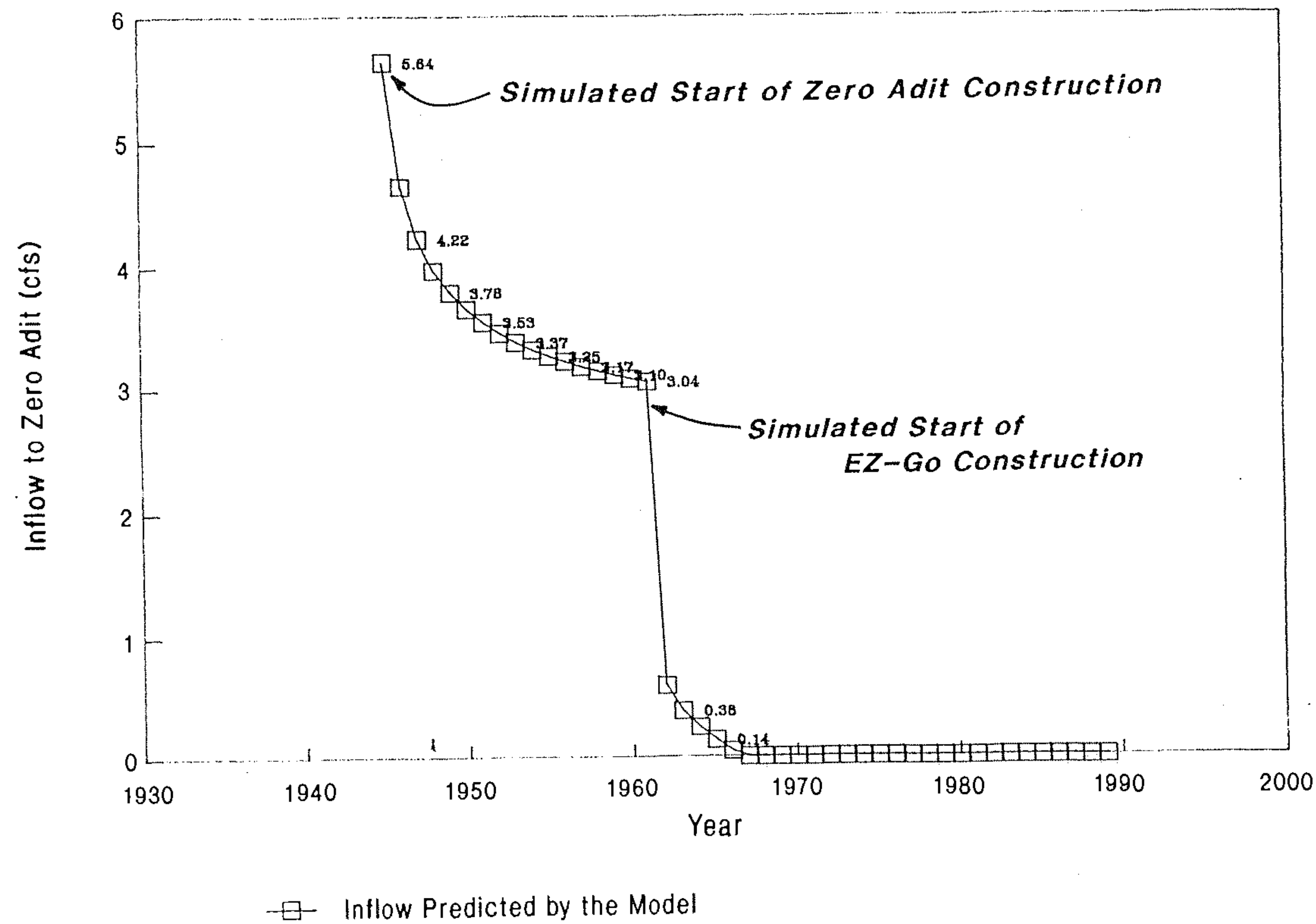
FIGURE 6



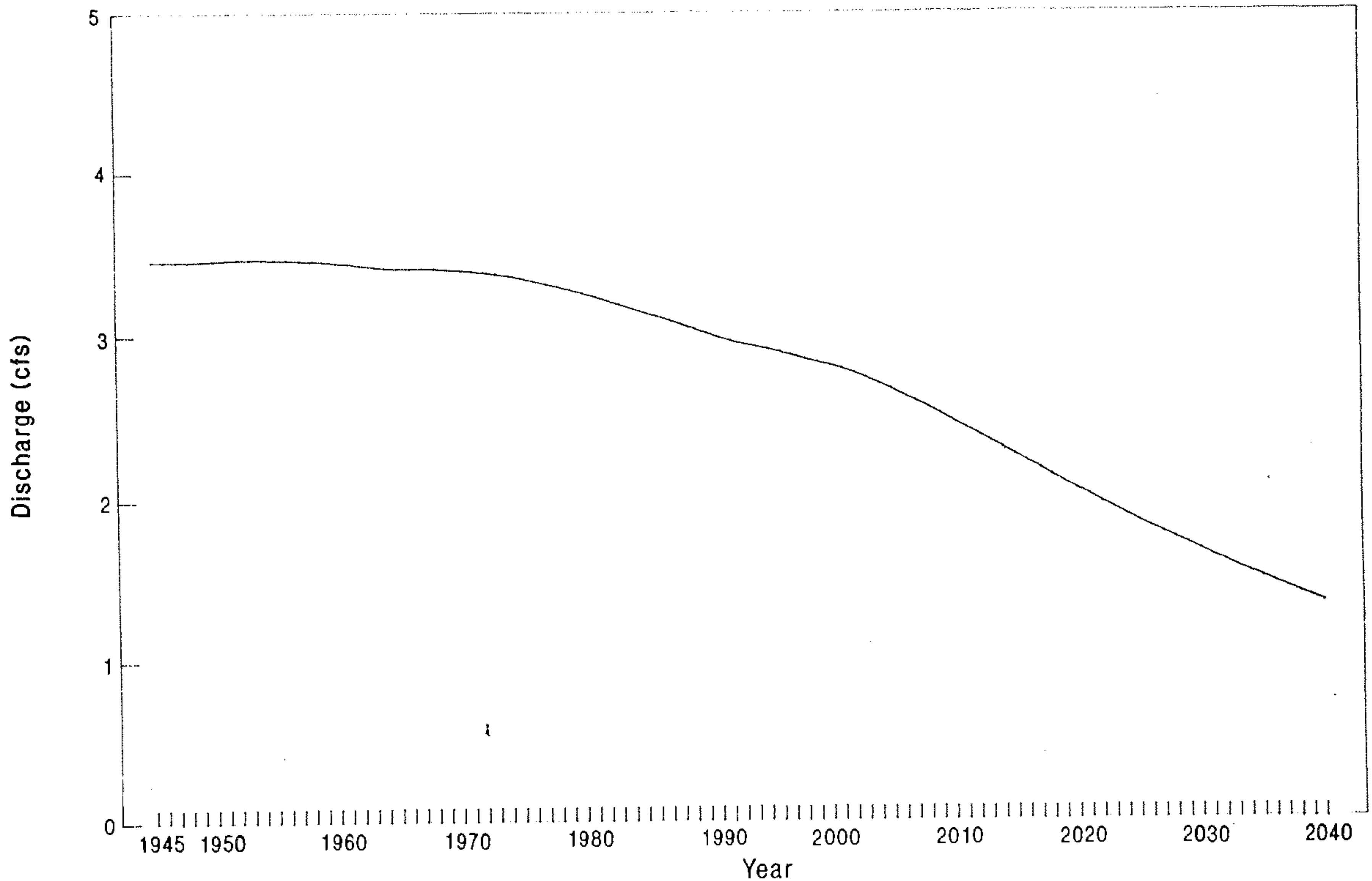
HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-2-90	RESULTS of PINE CREEK DISCHARGE ANALYSIS	FIGURE 7
	BY: JTF	DRAWN: JF		
	CHKD:	REV: 5-10-90		



HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-6-90	HISTORICAL INFLOWS vs. PREDICTED INFLOWS to the EZ-GO ADIT	FIGURE 8
	BY: GDN	DRAWN: JF/RM		
	CHKD:	REV: 3-1-90		

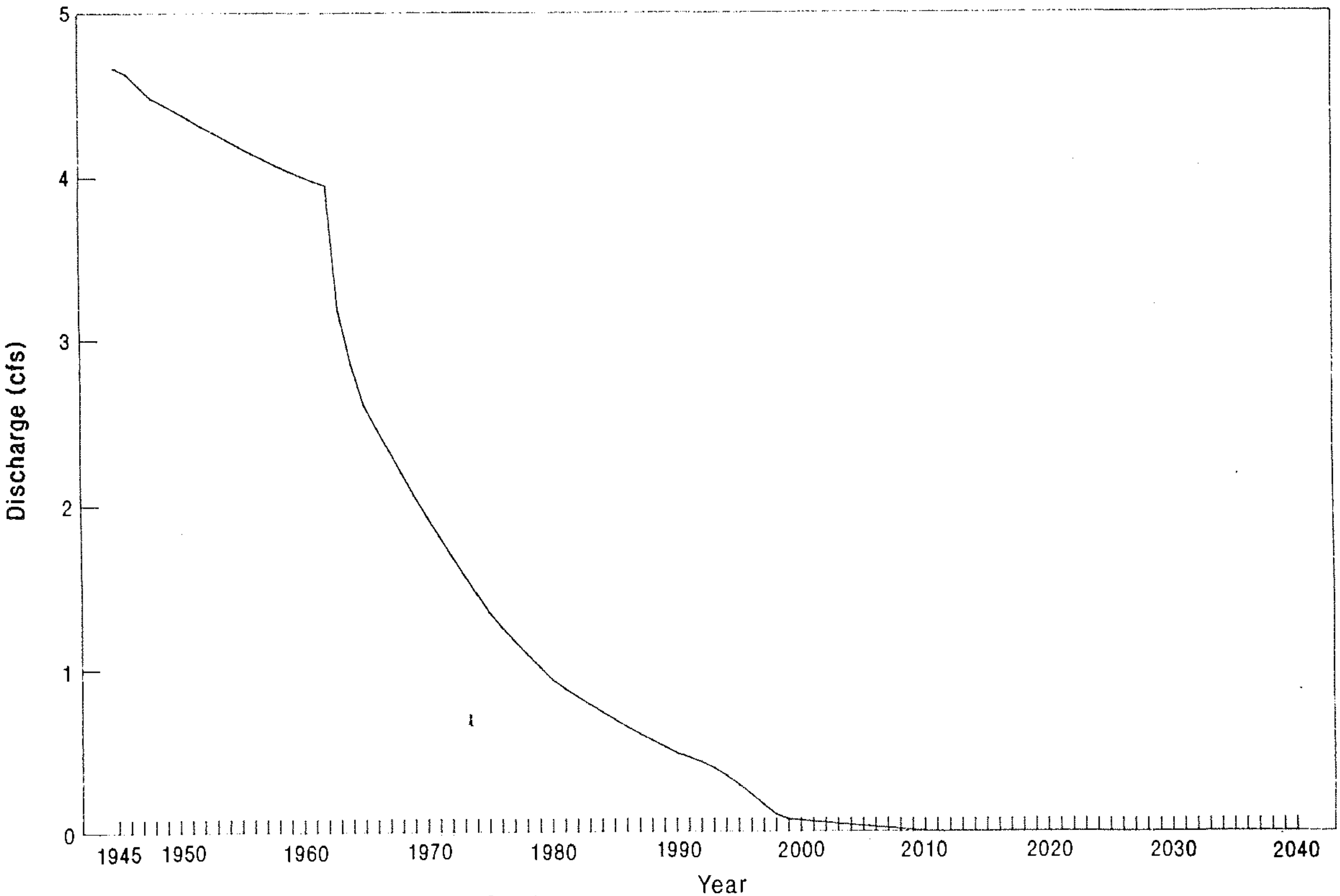


HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-6-90	INFLOWS to ZERO ADIT PREDICTED by the MODEL	FIGURE 9
	BY: GDN	DRAWN: JF/RM		
	CHKD:	REV: 3-1-90		



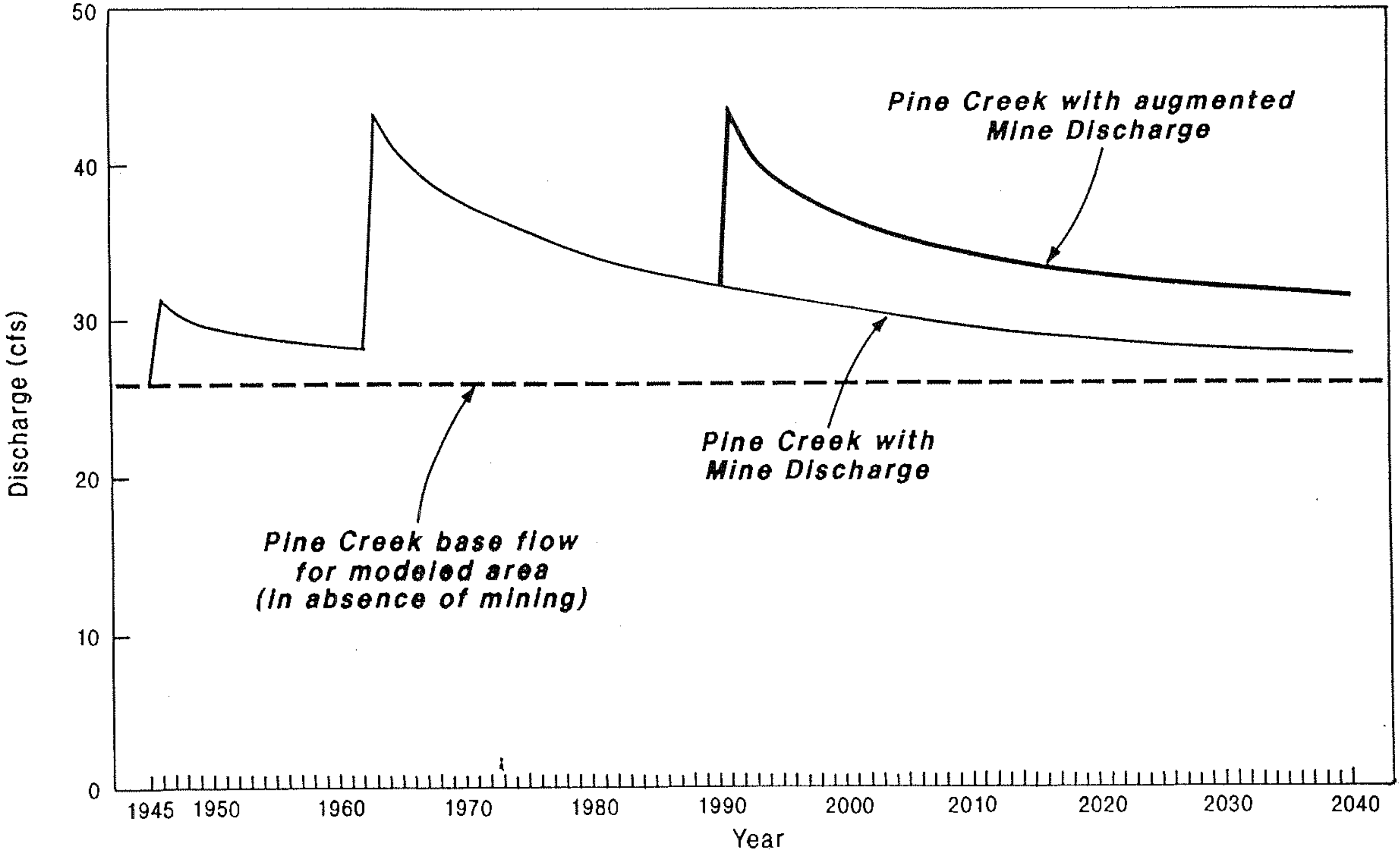
Note: Base Flow at Inlet to Rock Creek Lake

HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 3-1-90	PREDICTED DISCHARGE through TIME from ROCK CREEK	FIGURE 10
	BY: GDN	DRAWN: RM		
	CHKD:	REV:		

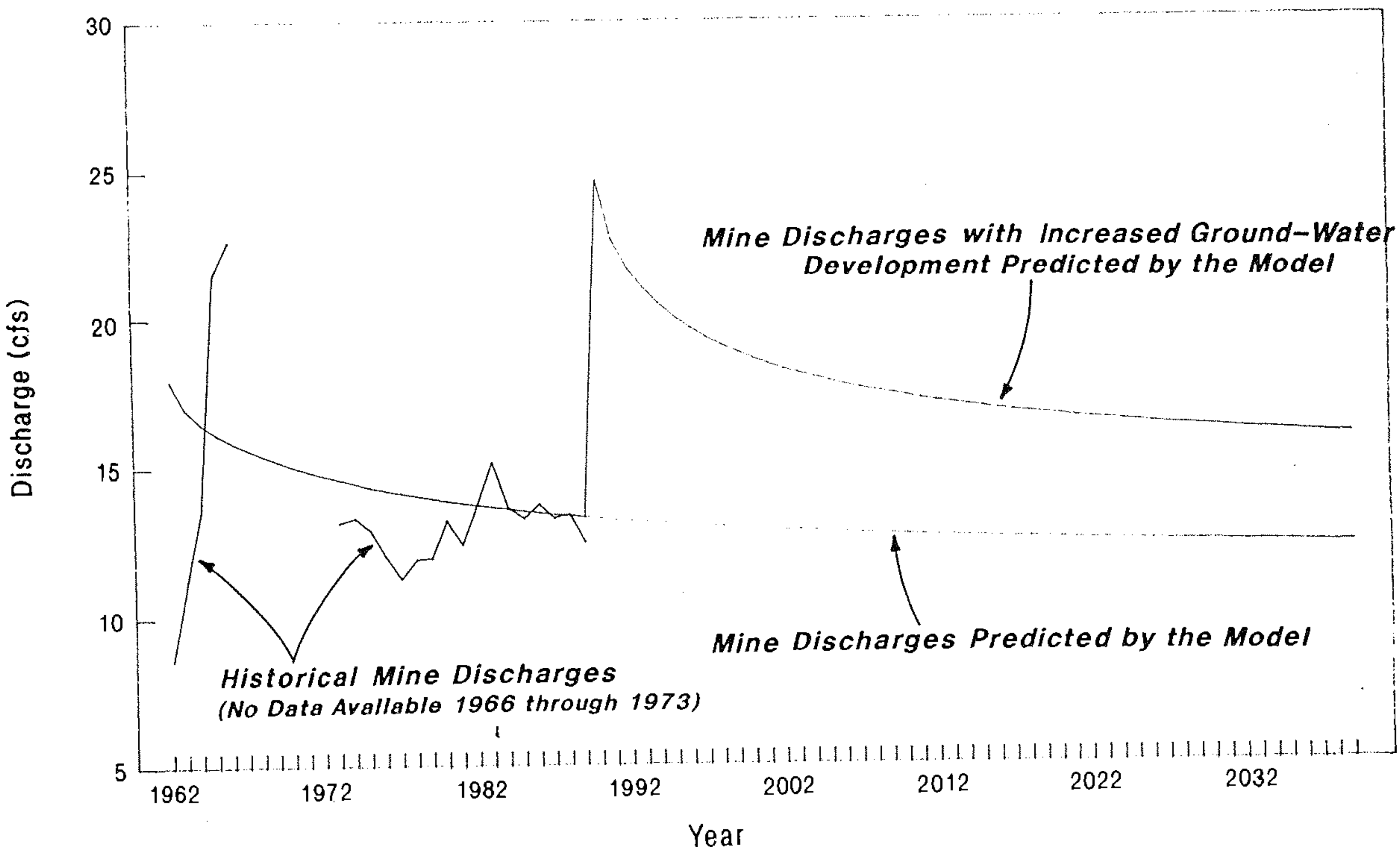


Note: Base Flow at Junction with Pine Creek

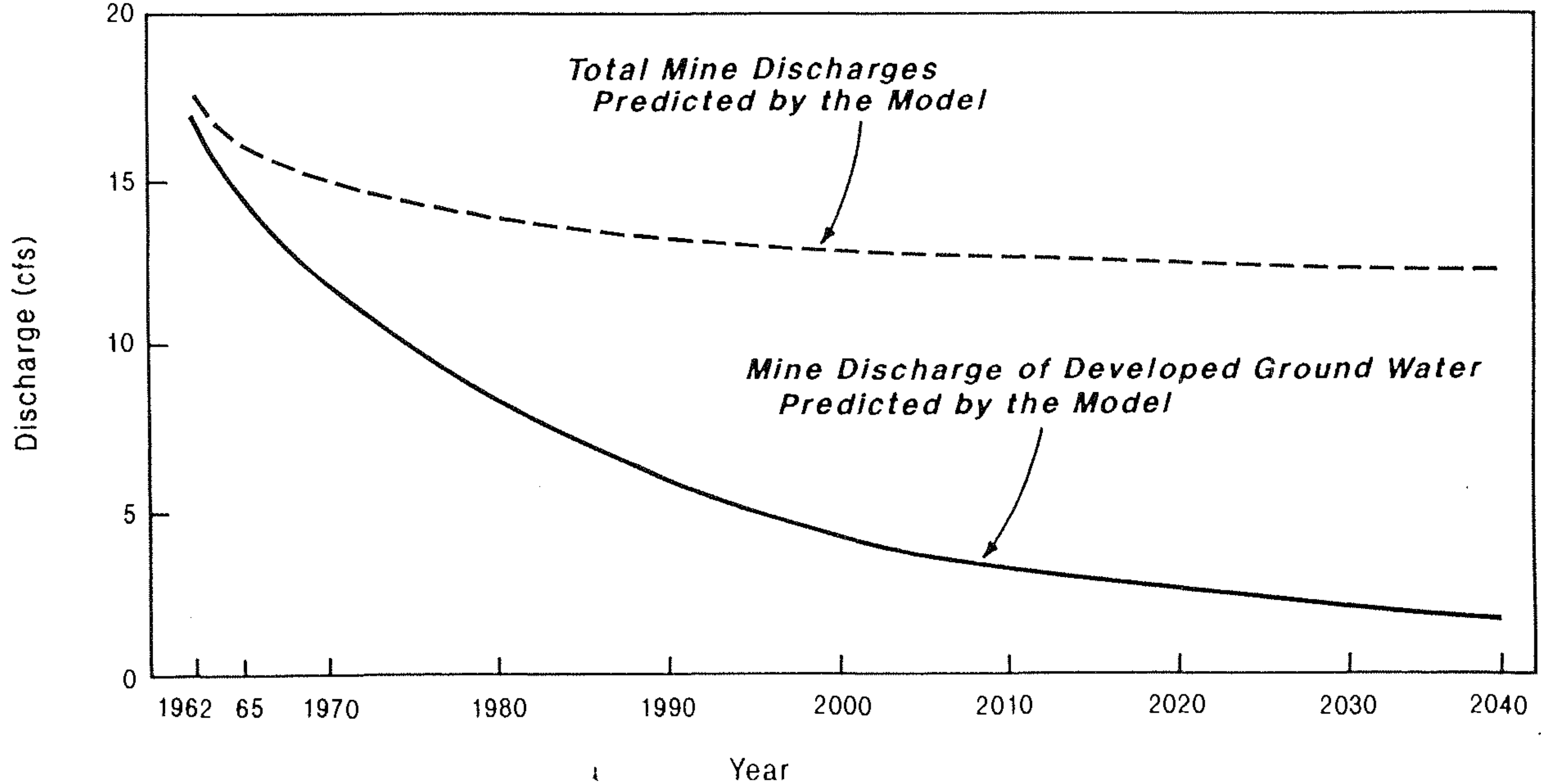
HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 3-1-90	PREDICTED DISCHARGE through TIME from MORGAN CREEK	FIGURE 11
	BY: GDN	DRAWN: RM		
	CHKD:	REV:		



HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 3-1-90	PREDICTED DISCHARGE through TIME from PINE CREEK	FIGURE 12
	BY: GDN	DRAWN: RM		
	CHKD:	REV: 5-10-90		

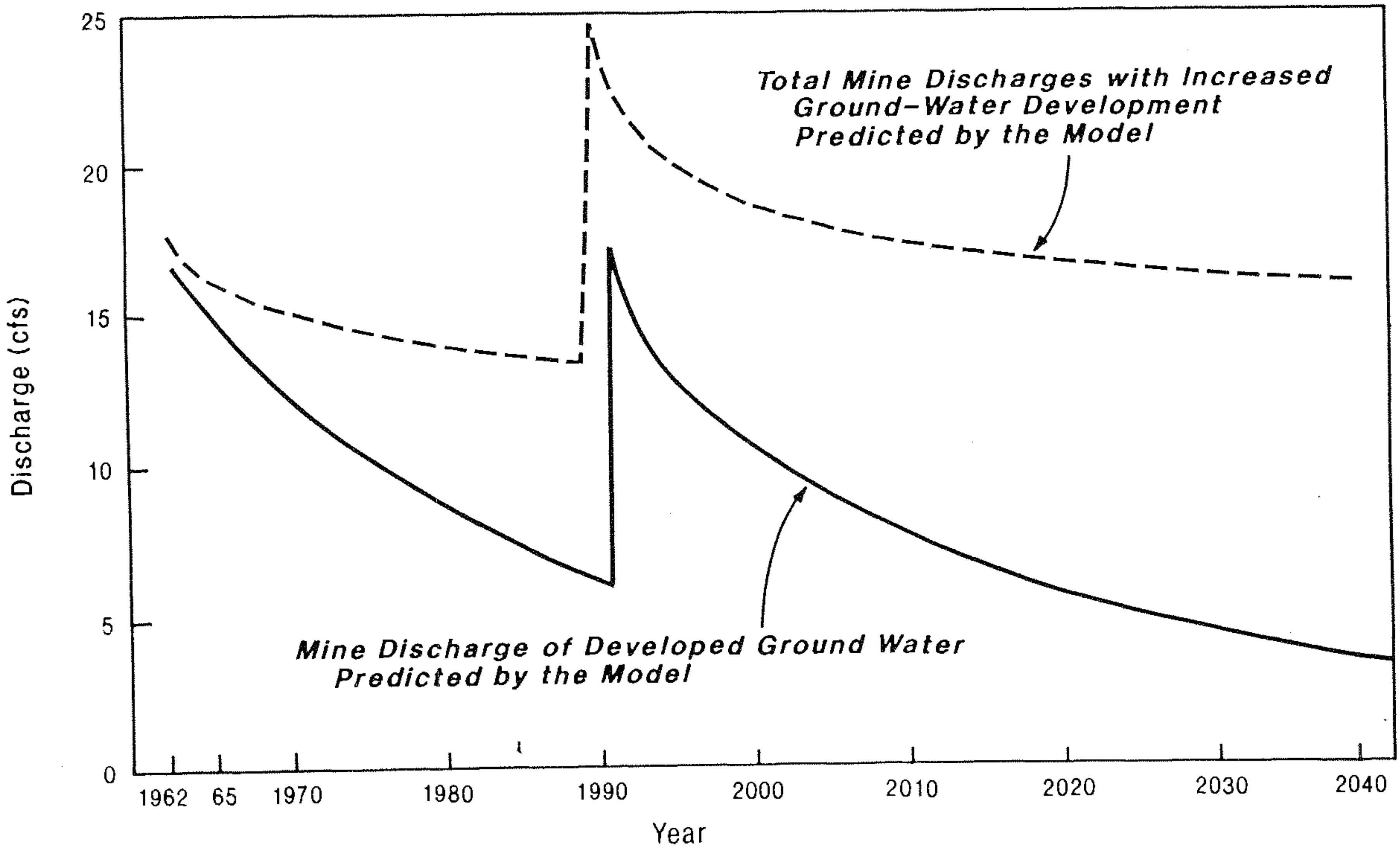


HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 2-6-90	LONG-TERM PREDICTIONS of MINE DISCHARGES	FIGURE 13
	BY: GDN	DRAWN: JF / RM		
	CHKD: JWA	REV: 5-17-90		



HCI HYDROLOGIC CONSULTANTS, INC.	JOB NO: HCI-531(5)	DATE: 5-17-90	LONG-TERM PREDICTIONS of DEVELOPED GROUND-WATER DISCHARGE
	BY: JWA	DRAWN: JF	
	CHKD:	REV: 7-12-90	

FIGURE 14



HCI HYDROLOGIC CONSULTANTS, INC.	JOB NO: HCI-531(5)	DATE: 5-17-90	LONG-TERM PREDICTIONS of DEVELOPED GROUND-WATER DISCHARGE with INCREASED GROUND-WATER DEVELOPMENT	FIGURE 15
	BY: JWA	DRAWN: JF		
	CHKD:	REV: 7-12-90		

TABLE 1

PERTINENT HYDROGEOLOGIC DATA CONCERNING PINE CREEK MINE

Uppermost wet level of mine: 1500 level	Elevation 9,450 ft
Uncorrected average outflow from 1500 haulage ("Zero Adit") 1961 - 1963	8.7 cfs[1]
Corrected[2] average outflow from 1500 haulage ("Zero Adit"), 1961 - 1963	4.0 cfs
Uncorrected average outflow from EZ-Go, 1964 - 1989	13.0 cfs
Corrected[2] average outflow from EZ-Go, 1964 - 1989	12.5 cfs
Average outflow from EZ-Go, 1989	13.0 cfs
Diamond-Drill Exploratory Borehole Results	
Location	**Pressure[3]**
EZ-Go sumps (end of EZ-Go)	120 psi
Bend drift	40 psi
9,000 level diamond-drill station (water encountered at 20 ft)	55 psi

NOTES:

1. Flow rates in cubic feet per second (cfs).
2. See Section 2.1.2 in text for an explanation of outflow corrections.
3. Pressures encountered during drilling ranged from 70 to 200 pounds per square inch (psi).
4. Flow rates from cased boreholes range between 30 - 100 gpm.

TABLE 2

FEATURES OF THE PINE CREEK WATERSHED ABOVE ROVANA GAGE

Drainage Area: 36.4 square miles

Percent above Rovana gage	(elev. = 5,100) ...	100%
Percent above mill	(elev. = 8,000) ...	90%
Percent above tree line	(elev. = 10,800) ...	50%

Basin Perimeter: 32.2 miles

Elevation Range:

Minimum ... 5,100 feet (Rovana gage)
Average ... 10,400 feet
Maximum ... 13,748 feet (Mount Morgan)

Principal Tributaries: Morgan and Gable Creeks

STATISTICS OF ANNUAL SURFACE RUNOFF FROM PINE CREEK ABOVE ROVANA (including mine drainage)

Flow	Annual Average (cfs)	Year	Base Flow Average[2] (cfs)	Year
Minimum	20.0	1931	13	1931
Mean	47.4	1922-88	23	1922-88
Maximum	93.2	1983	35	1946

NOTES: 1. Sources: USGS (1922-1970) & LADWP (1945-1989).

2. Base flow calculated as the average flow for the months of November through March in a given water year.

TABLE 3

FEATURES OF THE ROCK CREEK WATERSHED ABOVE LITTLE ROUND VALLEY GAGE

Drainage Area: 35.8 square miles				
Percent above gage (elev. = 7,450) ... 100% Percent above Rock Creek Lake (elev. = 9,695) ... 40% Percent above tree line (elev. = 10,800) ... 30%				
Basin Perimeter: 31.1 miles				
Elevation Range: Minimum ... 7,450 feet (gage) Average ... 10,200 feet Maximum ... 13,748 feet (Mount Morgan)				
Principal Tributaries: none				
STATISTICS OF ANNUAL SURFACE RUNOFF FROM ROCK CREEK ABOVE GAGE				
Flow	**Annual Average (cfs)**	**Year**	**Base Flow Average[2] (cfs)**	**Year**
Minimum	12.7	1977	8	1988
Mean	32.0	1922-88	14	1918-88
Maximum	67.2	1938	24	1946

NOTES: 1. Sources: USGS (1918-1970) & LADWP (1947-1988).

2. Base flow calculated as the average flow for the months of November through March in a given water year.

TABLE 4

OROGRAPHIC CONTROL OF PRECIPITATION, EASTERN SIERRA NEVADA IN VICINITY OF PINE CREEK

Reporting Station	Years of Record	Elevation (ft NGVD)[1]	Average Annual Precipitation (in)
Benton	1965-68	5,461	7.6
Bishop Airport	1934-89	4,108	5.8
Bishop Creek	1931-41	8,390	16.6
Bishop Creek Intake	1931-41 1961-70 1987	8,154	11.7
Bishop Union Carbide	1961-68	9,390	15.1
Cain Ranch[2]	1931-64	6,880	11.1
Ellery Lake	1931-60	9,600	23.7
Florence Lake[3]	1951-60		
Gem Lake	1931-87	8,970	21.7
Mono Lake	1951-68	6,450	12.5

Orographic Relation:

$$P = 2.373 \times 1.000225^{z}$$

where

P = precipitation (in)
z = elevation (ft)

Correlation: $r^2 = 0.859$

NOTES:
1. Elevations relative to National Geodetic Vertical Datum of 1929 (equivalent to mean sea level).
2. Cain Ranch reporting station property of Los Angeles DWP; all others in National Climatic Data Center reporting system.
3. Florence Lake located on western slope of Sierra Nevada; Florence Lake data not included in calculation of orographic relation.

TABLE 5

SUMMARY RESULTS OF STREAM DISCHARGE ANALYSIS FOR PINE CREEK

Time Period	Pine Creek Actual Mean Annual Discharge (cfs)	Pine Creek Discharge Corrected by Mono/Bear Regression (cfs)	Excess Pine Creek Discharge[2] (cfs)	Mean Annual Excess Pine Creek Discharge[2] (ac-ft/yr)
Pre-mining Time 1922 - 1945	42.9	43.0	-0.1	-36
Zero Adit Time 1946 - 1964	43.9	41.6	2.4	1700
EZ-Go Adit Time 1965 - 1988	55.2	49.9	5.3	3800
Total of Mining Period 1946 - 1988	50.2	46.2	4.0	2900

NOTES:

1. Sources: LADWP (1948-1988); USGS (1920-1970); USGS (1971-1987)
2. See Section 3.1.2 in text for an explanation of statistical streamflow corrections.
3. Excess discharge in Pine Creek corresponds to flow that can be ascribed to mine discharge of developed ground water. Excess discharges for the years 1922-1945 are considered to be negligible, as expected (pre-mining).
4. Corrected base flow estimated using a similar procedure is 20 cfs.

TABLE 6

CALCULATED EVAPOTRANSPIRATION RATE FOR PINE CREEK CANYON, 1989

Vegetated Area[1] (acres)	k (see note 2)	Month	Avg. Temp. (°F)	Daylight (hrs/day)	U (see note 2)
223	1.15	May	54.0	9.88	0.44
		June	59.7	9.89	0.48
		July	5.4	10.05	0.54
		August	59.7	9.44	0.46
		September	54.0	8.37	0.37
				TOTAL	2.29

Total Evapotranspiration: 510 acre-feet/year (0.7 average cfs)

NOTES: 1. Vegetated acreage above the mouth of Pine Creek canyon (Sample Location 3).

2. A complete explanation of the variables used in the evapotranspiration calculations is given in Section 3.1.3.

k = Blaney - Criddle coefficient
U = Consumptive Use

TABLE 7

CALCULATED EVAPOTRANSPIRATION RATE FOR ROCK CREEK CANYON, 1989

Vegetated Area[1] (acres)	k (see note 2)	Month	Avg. Temp. (°F)	Daylight (hrs/day)	U (see note 2)
21	1.15	May	54.0	9.88	0.44
		June	59.7	9.89	0.48
		July	65.4	10.05	0.54
		August	59.7	9.44	0.46
		September	54.0	8.37	0.37
				TOTAL	2.29

Total Evapotranspiration: 48 acre-feet/year (0.07 average cfs)

NOTES: 1. Vegetated acreage above the inlet to Rock Creek Lake (Sample Location J).

2. A complete explanation of the variables used in the evapotranspiration calculations is given in Section 3.1.3.

k = Blaney - Criddle coefficient
U = Consumptive Use

TABLE 8

FEATURES OF THE PINE CREEK WATERSHED ABOVE STATION 3[1]

Sub-basin Area: 35.1 square miles		
Percent above Station 3 (elev. = 6,180) ... 100% Percent above mill (elev. = 8,000) ... 90% Percent above tree line (elev. = 10,800) ... 60%		
Sub-basin Perimeter: 30.8 miles		
Elevation Range: Minimum ... 6,180 feet (Station 3) Average ... 10,400 feet Maximum ... 13,748 feet (Mount Morgan)		
Principal Tributaries: Morgan and Gable Creeks		
ESTIMATION OF ANNUAL SURFACE RUNOFF FROM PINE CREEK ABOVE STATION 3 (including mine drainage)		
Flow	Pine Creek Above Rovana[2]	Pine Creek Above Station 3
August, 1989 (cfs)	39 (see note 3)	45 (see note 3)
August Average (cfs)	56	65 (see note 4)
Base Flow Average (cfs)	23	26 (see note 4)
Mean Annual (cfs)	47	53 (see note 4)

NOTES:
1. Sampling Station 3 is located just above the mouth of Pine Creek canyon (HCI, 1989a; ibid., 1989b).
2. Sources (unless otherwise noted): USGS (1922-1960) & LADWP (1945-1989).
3. HCI, 1989b.
4. Estimated value; see Section 3.1.5 in text for an explanation of estimation procedure.

TABLE 9

FEATURES OF THE ROCK CREEK WATERSHED ABOVE INLET TO ROCK CREEK LAKE[1]

Sub-basin Area: 10.1 square miles		
Percent above Rock Creek Lake (elev. = 9,695) ... 100% Percent above tree line (elev. = 10,800) ... 70%		
Sub-basin Perimeter: 14.6 miles		
Elevation Range: Minimum ... 9,695 feet (lake) Average ... 11,500 feet Maximum ... 13,748 feet (Mount Morgan)		
Principal Tributaries: none		
ESTIMATION OF ANNUAL SURFACE RUNOFF FROM ROCK CREEK ABOVE ROCK CREEK LAKE		
Flow	**Rock Creek at Little Round Valley Gage[2]**	**Rock Creek at Inlet to Rock Creek Lake**
August, 1989 (cfs)	27	17 (see note 3)
August Average (cfs)	39	24 (see note 4)
Base Flow Average (cfs)	14	8 (see note 4)
Mean Annual (cfs)	32	20 (see note 4)

NOTES:
1. Inlet to Rock Creek Lake is Sampling Station J (HCI, 1989b)
2. Sources: USGS (1918-1978) & LADWP (1979-1989)
3. HCI, 1989b.
4. Estimated value; see Section 3.1.5 in text for an explanation of estimation procedure.

TABLE 10

PRECIPITATION AND DISCHARGE FOR
PINE CREEK AND ROCK CREEK DRAINAGE SUB-BASINS

	Pine Creek Sub-Basin Above Station 3	Rock Creek Sub-Basin Above Inlet to Rock Creek Lake
Sub-Basin Area:	35.1 sq. mi.	10.1 sq. mi
1. Mean Annual Surface Discharge[1]:	53 cfs	20 cfs
2. Estimated[2] Mean Annual Underflow:	30 cfs	≈ 0 cfs
3. Total Mean Annual Discharge (1 + 2):	83 cfs	20 cfs
4. Equivalent Annual Precipitation[3]:	32 in	27 in
5. Calculated[4] Total Annual Average Discharge:	74 cfs	22 cfs
6. Developed Ground-Water Contribution from Mine[5]:	4 cfs	--
7. Calculated Total Annual Evapotranspiration in Sub-Basin[6]:	0.7 cfs	0.1 cfs
8. Calculated Mean Annual Discharge (5 + 6 - 7):	77 cfs	22 cfs
9. Total Calculated Equivalent Annual Precipitation (required to produce 8):	30 in	28 in
10. Estimated Total Annual Sublimation from Snow[7]:	2.5 in	2.5 in
11. Calculated Equivalent Annual Precipitation (9 + 10):	32 in	30 in

TABLE 10

PRECIPITATION AND DISCHARGE FOR PINE CREEK AND ROCK CREEK DRAINAGE SUB-BASINS

NOTES:

1. Estimates presented in Tables 8 & 9.
2. Estimated during mill discharge investigation (HCI, 1989a; ibid., 1989b).
3. Precipitation evenly-distributed across the total sub-basin area required to produce the observed mean annual discharge.
4. Calculations based on basin areas and isohyets shown on Sheet 6.
5. Average developed ground-water contribution from the mine over the period 1946 - 1988 (Table 5).
6. Calculations presented in Tables 6 & 7; evapotranspiration areas shown on Sheets 7 & 8.
7. Croft & Monninger, 1953.

TABLE 11

ORIENTATIONS OF PRINCIPAL PERMEABILITIES OF HYDRAULIC CONDUCTIVITY TENSOR[1]

Hydrogeologic Unit	Principal Permeabilities		
	Kxx	Kyy	Kzz
Alluvium	(Isotropic)		
Metasomatic Rocks	S22E/21SE (see note 2)	S80W/28SW	N36E/54NE
Granodiorite	N25W/7NW	S62W/24SW	N81E/65NE
Quartz Monzonite	S69W/4SW	N18W/31NW	S28E/58SE

NOTES:

1. Hydraulic conductivity tensors calculated using Snow's method (Bianchi, 1968)
2. Orientation given as bearing/plunge of hydraulic conductivity vector

TABLE 12

HYDRAULIC PARAMETERS USED IN NUMERICAL MODEL

Hydrogeologic Unit	Specific Yield Sy	Specific Storage S_s (ft^{-1})	Hydraulic Conductivity Tensor[1] K (ft/day)
Alluvium	0.25	0.00007	50 0 0 50 0 (isotropic) 50
Metasomatic Rocks	0.04	0.0004	0.07 0.05 0.045 0.180 -0.03 0.165
Granodiorite	0.02	0.000008	0.03 0.06 -0.02 0.124 0.008 0.147
Quartz Monzonite	0.02	0.000008	0.06 -0.005 0.003 0.05 0.0001 0.06

NOTES: 1. Hydraulic conductivity tensor is an upper-diagonal matrix of the form:

$$\begin{matrix} K_{xx} & K_{xy} & K_{xz} \\ & K_{yy} & K_{yz} \\ & & K_{zz} \end{matrix}$$

TABLE 13

HYDROLOGIC PARAMETERS USED IN NUMERICAL MODEL

	Pine Creek Sub-Basin Above Station 3	Rock Creek Sub-Basin Above Inlet to Rock Creek Lake
Complete Sub-Basin Area[1]:	35.1 sq. mi.	10.1 sq. mi.
Sub-basin Area Within Model Boundaries[1]:	20 sq. mi.	5.7 sq. mi.
Percent of Sub-Basin Area Within Model Boundaries:	57%	56%
Base Flow for Total Sub-Basin	20 cfs	8 cfs
Ground-water Underflow for Total Sub-Basin	30 cfs	≈0 cfs
Base Flow into Modeled Area[2]	3.3 cfs	0 cfs
Evapotranspiration Losses for Total Sub-Basin	0.7 cfs	≈0.1 cfs
Mean Discharge for Total Sub-Basin (Base Flow + Underflow - Base Flow Inputs - ET)	46 cfs	8 cfs
Mean Discharge Scaled to Modeled Area:	26 cfs	4.5 cfs
Recharge (as percentage of precipitation) Required to Sustain Observed Base Flows:	60%	60%

NOTES:

1. Sub-basin areas and model boundaries presented on Sheet 9.

2. Base flow into Pine Creek sub-basin is base flow in Pine Creek at western model boundary, estimated from August 1989 streamflow measurement at Station 29 (HCI, 1989b).

TABLE 15

RESULTS OF PREDICTIVE TRANSIENT SIMULATION,
YEARS 1990 - 2040

Year	Calculated Flows in Pine Creek[1] (not incl. mine discharges) (cfs)	Calculated Total Flows in Pine Creek[1] (incl. mine discharges (cfs)	Base Flows in Rock Creek at Little Round Valley (cfs)	Base Flows in Morgan Creek (cfs)	Total Mine Discharge[2] (cfs)	Mine Discharge from Ground-Water Storage[3] (cfs)
1991	18.8	32.1	13.5	0.4	13.3	5.6
1995	18.4	31.5	13.4	0.3	13.1	5.0
2000	17.8	30.7	13.3	0.1	12.9	4.3
2005	17.3	30.1	13.2	0.0	12.8	3.8
2010	16.9	29.5	13.0	0.0	12.7	3.4
2015	16.5	29.1	12.8	0.0	12.6	3.0
2020	16.2	28.7	12.5	0.0	12.5	2.7
2025	16.0	28.4	12.3	0.0	12.4	2.4
2030	15.8	28.2	12.2	0.0	12.4	2.2
2035	15.6	27.9	12.0	0.0	12.3	2.0
2040	15.5	27.8	11.8	0.0	12.3	1.8

NOTES:

1. Flows calculated in Pine Creek for the modeled area are equivalent to base flow plus ground-water underflow, less evapotranspiration. Pine Creek base flow includes water captured from Rock Creek drainage.

2. Intercepted ground water plus developed ground water.

3. Developed ground water.

TABLE 16

RESULTS OF PREDICTIVE TRANSIENT SIMULATION
WITH INCREASED GROUND-WATER DEVELOPMENT, YEARS 1990 - 2040

Year	Calculated Flows in Pine Creek[1] (not incl. mine discharges) (cfs)	Calculated Total Flows in Pine Creek[1] (incl. mine discharges) (cfs)	Base Flows in Rock Creek at Little Round Valley (cfs)	Base Flows in Morgan Creek (cfs)	Total Mine Discharge[2] (cfs)	Mine Discharge from Ground-Water Storage[3] (cfs)
1991	18.8	43.5	13.5	0.4	24.6	17.0
1995	18.4	38.8	13.4	0.3	20.4	12.3
2000	17.8	36.6	13.3	0.1	18.8	10.3
2005	17.3	35.2	13.2	0.0	17.9	8.7
2010	16.9	34.2	13.0	0.0	17.4	7.5
2015	16.5	33.5	12.8	0.0	17.0	6.5
2020	16.2	32.9	12.5	0.0	16.7	5.6
2025	16.0	32.4	12.3	0.0	16.4	4.9
2030	15.8	32.0	12.2	0.0	16.2	4.3
2035	15.6	31.7	12.0	0.0	16.0	3.8
2040	15.5	31.4	11.8	0.0	15.9	3.4

NOTES:

1. Flows calculated in Pine Creek for the modeled area are equivalent to base flow plus ground-water underflow, less evapotranspiration. Pine Creek base flow includes water captured from Rock Creek drainage.

2. Intercepted ground water plus developed ground water.

3. Developed ground water.

TABLE 14

RESULTS OF TRANSIENT SIMULATION CALIBRATED TO HISTORICAL OUTFLOWS

Year	Calculated Flows in Pine Creek[1] (not incl. mine discharges) (cfs)	Calculated Total Flows in Pine Creek[1] (incl. mine discharges) (cfs)	Base Flows in Rock Creek at Little Round Valley (cfs)	Base Flows in Morgan Creek (cfs)	Total Mine Discharge[3] (cfs)	Mine Discharge From Ground-Water Storage[4] (cfs)
1946	25.9	31.5	14.0	4.6	5.6	5.5
1950	25.7	29.5	14.0	4.4	3.8	3.5
1955	25.4	28.8	14.0	4.2	3.3	2.8
1960	25.2	28.3	13.9	4.0	3.1	2.3
1961	25.1	28.2	13.9	4.0	3.1	2.2
1962	25.1	28.1	13.9	3.9	3.0	2.1
1963	24.2	43.4	13.9	3.2	19.2	16.8
1964	23.9	41.6	13.9	2.8	17.8	15.2
1965	23.6	40.5	13.9	2.6	16.9	14.3
1970	22.4	37.6	13.9	1.9	15.2	11.6
1975	21.3	35.8	13.8	1.4	14.5	9.6
1980	20.3	34.2	13.7	0.9	13.9	8.0
1985	19.5	33.1	13.6	0.7	13.6	6.8
1990	18.9	32.2	13.6	0.6	13.3	5.8

NOTES:

1. Flows calculated in Pine Creek for the modeled area are equivalent to base flow plus ground-water underflow, less evapotranspiration. Pine Creek base flow includes water captured from Rock Creek drainage.

2. Steady-state flow in Pine Creek for the modeled area is 26 cfs (Table 13).

3. Intercepted ground water plus developed ground water.

4. Developed ground water.

Mean Annual Discharge Rates Computed From Monthly Totals

Water Year	PINE CREEK Mean Annual Discharge (ac-ft)	ROCK CREEK Mean Annual Discharge (ac-ft)	BISHOP CREEK Mean Annual Discharge (ac-ft)	BISHOP CREEK CORRECTED (1) Mean Annual Discharge (ac-ft)	BEAR CREEK Mean Annual Discharge (ac-ft)	MONO CREEK Mean Annual Discharge (ac-ft)
1920	- -	1933	- -	- -	- -	- -
1921	- -	2018	- -	- -	- -	- -
1922	3587	2633	- -	- -	6823	11631
1923	2596	1692	- -	- -	5083	8798
1924	1332	938	- -	- -	1763	3189
1925	2195	1407	- -	- -	5631	9356
1926	2028	1389	- -	- -	4245	7104
1927	3253	2565	- -	- -	6792	11923
1928	2325	1806	- -	- -	4220	7643
1929	1798	1388	- -	- -	3523	5972
1930	1560	1215	- -	- -	3133	5633
1931	1184	886	- -	- -	2019	4063
1932	2946	2013	- -	- -	6249	11262
1933	1972	1386	- -	- -	3992	7331
1934	1410	1080	- -	- -	2530	4450
1935	2331	1560	- -	- -	5752	9319
1936	2963	2015	5675	5664	6707	10654
1937	3199	2180	6487	6468	6510	10949
1938	4640	3896	9196	9170	10058	16183
1939	2308	1914	5216	5204	3488	5719
1940	2956	2121	5443	5435	6598	10807
1941	3962	2780	7997	7959	8411	13398
1942	3254	2262	6989	6964	6867	11481
1943	2865	2235	6331	6307	5886	11108
1944	2254	1750	5121	5103	4293	6709
1945	3311	2436	7133	7108	6767	11297
1946	3673	2551	6544	6520	6214	10113
1947	2640	1795	5138	5122	4505	7391
1948	2223	1153	4016	4008	4154	7068
1949	2121	1295	4879	4874	3814	6441
1950	2096	1468	4665	4659	4596	8092
1951	2613	1776	5052	5044	6248	10898
1952	3880	2692	7999	7960	8051	14001
1953	2367	1569	5474	5453	4308	7558
1954	2245	1494	5158	5145	4400	8208
1955	2260	1445	4853	4844	4299	6724
1956	3665	2660	7111	7088	8653	15358
1957	2868	1822	5373	5369	5163	8089
1958	3842	2208	7195	7167	7802	12905
1959	2147	1129	4392	4393	2965	4442
1960	1838	954	3376	3374	3036	4878
1961	1658	904	3473	3469	2727	4219
1962	2847	1687	5724	5718	6200	10666
1963	3172	1901	6386	6368	6456	11203
1964	2238	1194	4195	4183	3418	5554
1965	3106	1773	5821	5793	6874	11122
1966	2532	1149	4089	4077	4126	6778
1967	4294	2628	8617	8567	9488	13173
1968	2521	1072	4471	4460	2831	5365
1969	5389	3380	21976	10087	11906	20471
1970	3125	1635	11663	5585	5255	8403

APPENDIX B

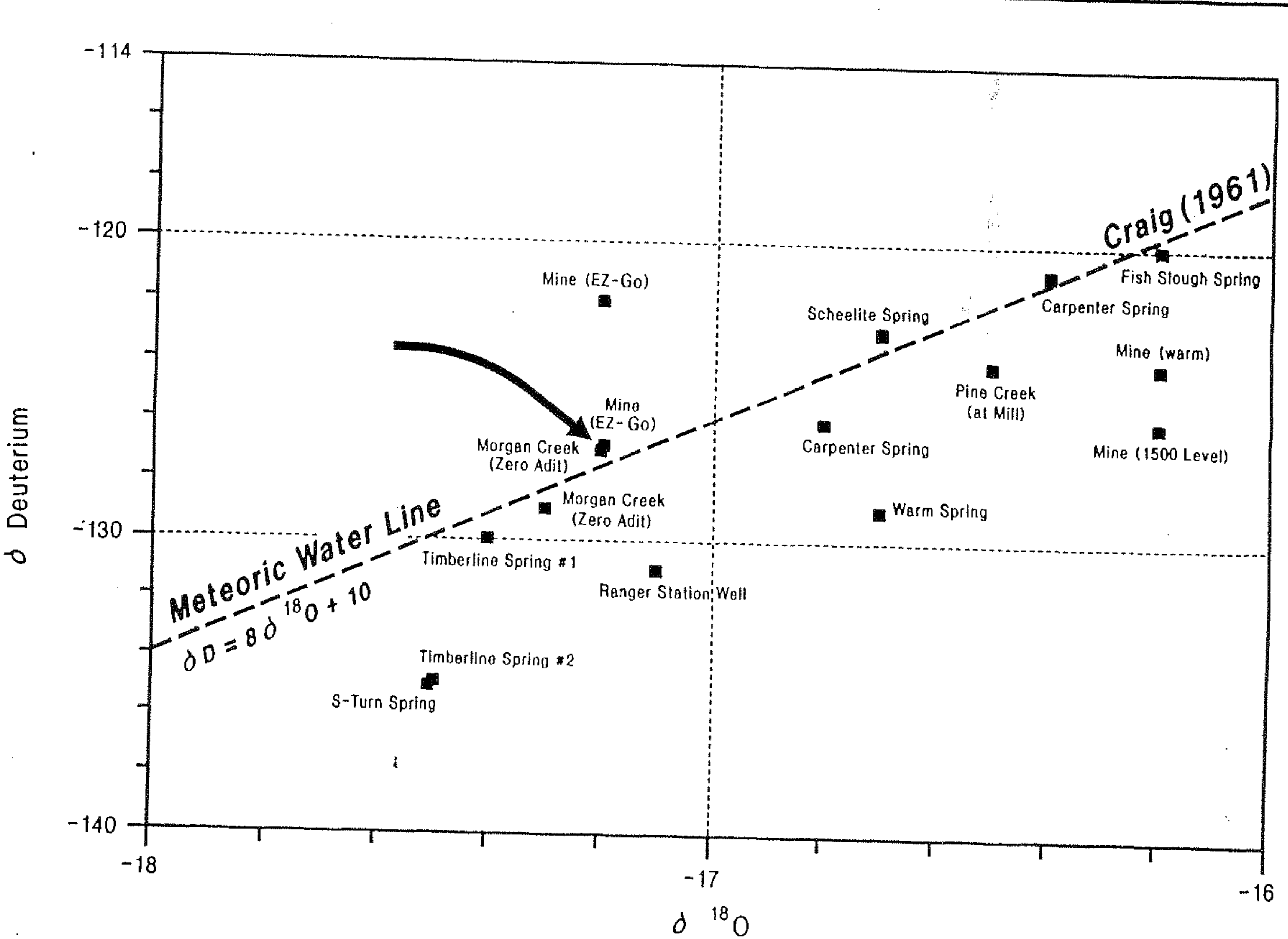
ENVIRONMENTAL ISOTOPE ANALYSES

TABLE B-1

RESULTS OF ENVIRONMENTAL ISOTOPE ANALYSES

SAMPLE LOCATION	del-D[1]	del-^{18}O[1]	T.U.[2]
Fish Slough Artesian Well	-120	-16.2	-
Ranger Station Well	-131	-17.1	-
Warm Spring Artesian Well	-129	-16.7	-
Timberline Spring #1	-130	-17.4	-
Timberline Spring #2	-135	-17.5	-
S-turn Spring	-135	-17.5	-
Morgan Creek	-129	-17.3	18.6
Morgan Creek (duplicate)	-127	-17.2	-
Mine, Lower Level	-127	-17.2	20.4
Mine, Lower Level (duplicate)	-122	-17.2	-
Mine, 1500-level	-126	-16.2	-
EZ-Go, Warm Seep	-124	-16.2	-
Carpenter Spring	-126	-16.8	-
Carpenter Spring (duplicate)	-121	-16.4	-
Scheelite Spring	-123	-16.7	16.9
Pine Creek at Mill	-124	-16.5	-

NOTES:
1. Deuterium (D) and oxygen-18 (^{18}O) reported as per mille relative to Standard Mean Ocean Water (SMOW).
2. Tritium Units.



HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 1-23-90	PLOT of del-D vs. del-^{18}O for PINE CREEK WATERS	FIGURE
	BY: JWA	REV: 2-5-90		B-1
	CHKD: JTF	DRAWN: JF		

Appendix B

Environmental Isotope Analyses

Environmental Isotopes

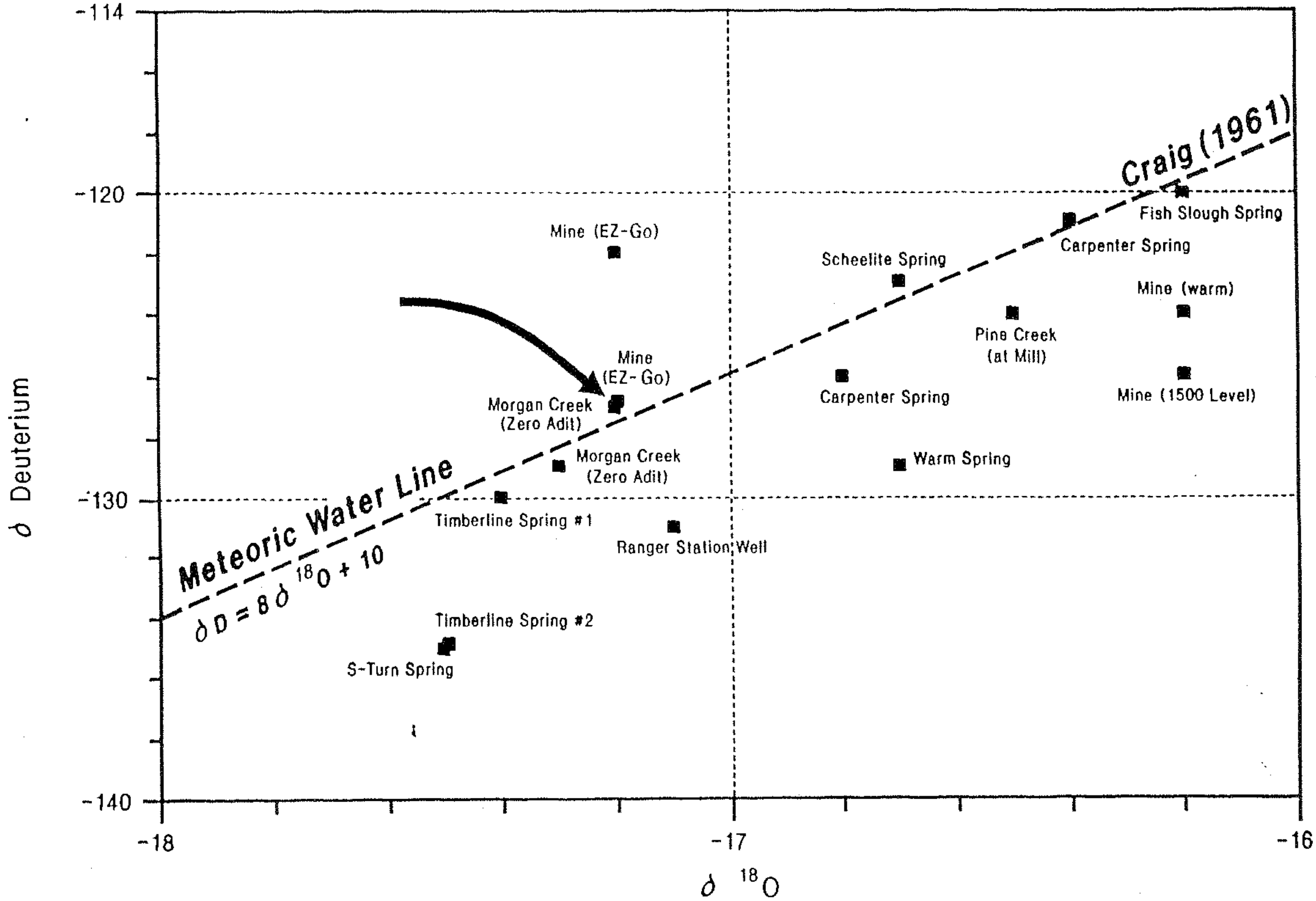
Environmental isotope analyses were conducted on several water samples that had been collected at various locations in the Pine Creek region and within the mine itself (Table B-1), in an attempt to assess the interactions between the ground-water and surface-water systems in the study area. The samples were submitted to a laboratory for procedures that included analysis for deuterium (del-D), oxygen-18 (del-^{18}O) and tritium. These isotopes occur naturally in precipitation and are commonly used as tracers in hydrologic investigations. Because all three isotopes occur as components of the water molecule, and are typically unaffected by subsurface movement over short periods of time, an "isotopic signature" is assumed to be locked into the water when it infiltrates a porous medium (Freeze and Cherry, 1979).

Elevated tritium concentrations (greater than 2 Tritium Units - T.U.) are indicative of water that has been recharged since the advent of open-air nuclear testing in 1953.

Results

The results of these analyses are presented in Table B-1; del-D is plotted versus del-^{18}O for each sample in Figure B-1. All waters analyzed for tritium show evidence of recent (post-1953) recharge. These include the samples from Morgan Creek, Scheelite Spring and the mine (lower level). This finding indicates a relatively short residence time for water discharging into the EZ-Go adit.

The stable isotope analyses appear to confirm that some water in this region of the mine has a recent origin as surface water, as the isotopic signature of the mine lower-level water is similar to water from Morgan Creek (arrow in Figure B-1). It should be noted that the mine lower-level sample was collected from a freely-flowing fracture near the point at which the EZ-Go adit passes beneath Morgan Creek. However, results from other areas of the mine appear to delineate water that was derived from a different source. In particular, water taken from a warm seep in the EZ-Go adit and water from the 1500-level in the mine are more enriched in del-^{18}O than are waters from the lower mine level. The del-^{18}O enrichment probably resulted from oxygen exchange between the meteoric ground water and carbonates of the metasomatic pendant rocks around the mine; this indicates a longer residence time for these waters than for waters from the lower mine level.



HCI HYDROLOGIC CONSULTANTS, INC.	HCI-531(1)	DATE: 1-23-90	PLOT of del-D vs. del-^{18}O for PINE CREEK WATERS	FIGURE B-1
	BY: JWA	REV: 2-5-90		
	CHKD: JTF	DRAWN: JF		

APPENDIX A

Mean Annual Discharge Rates Computed From Monthly Totals

Water Year	PINE CREEK Mean Annual Discharge (ac-ft)	ROCK CREEK Mean Annual Discharge (ac-ft)	BISHOP CREEK Mean Annual Discharge (ac-ft)	BISHOP CREEK CORRECTED (1) Mean Annual Discharge (ac-ft)	BEAR CREEK Mean Annual Discharge (ac-ft)	MONO CREEK Mean Annual Discharge (ac-ft)
1973	3256	1856	6693	6693	6479	11827
1974	3527	2038	6840	6840	6705	12328
1975	2716	1479	6070	6070	5577	8443
1976	1899	980	3463	3463	2549	6247
1977	1712	808	3009	3009	2119	2895
1978	4090	2449	8187	8187	10740	15999
1979	3238	1643	5811	5811	6150	8572
1980	4389	2736	7947	7947	8905	15318
1981	2846	1302	5372	5372	4552	6048
1982	4648	2904	8591	8591	10102	18550
1983	5629	3477	10083	10083	12131	21732
1984	3768	2370	7834	7834	6837	12065
1985	2822	1573	5651	5651	4335	6672
1986	4661	2936	10408	10408	8451	15135
1987	2513	1049	5304	5304	3259	4630
1988	2328	885	4287	4287	3623	5722
1989	1325	- -	- -	- -	- -	- -
1990	- -	- -	- -	- -	- -	- -

Notes: 1. Bishop Creek corrected (years 1969-1971) using multiple regression on Bear and Mono Creeks.

2. Sources: LADWP (1948-1988); USGS (1920-1970); USGS (1971-1987)

3. A dash (- -) indicates no data reported

APPENDIX A

MEAN ANNUAL DISCHARGE RATES COMPUTED FROM MONTHLY TOTALS (IN ACRE-FEET)

Creek (Name of gage)

1. Pine Creek (at division box, at Rovana, near Bishop, CA)
2. Rock Creek (at Little Round Valley, near Bishop, CA)
3. Bishop Creek - actual (below power plant no. 6, near Bishop, CA; natural flow)
4. Bishop Creek - corrected (years 1969 - 1971 re-computed using a regression between Bear and Bishop Creeks)
5. Bear Creek (1922 - 1954, near Vermilion Valley; 1955 - present near Lake Thomas A. Edison)
6. Mono Creek (1922 - 1954, near Vermilion Valley; 1954 - present computed from Lake Thomas A. Edison near Big Creek, CA and Mono Creek below Lake Thomas A. Edison)

June 29, 2006 Project No. 3.30716

Pine Creek Development
126 Old Mammoth Road
Mammoth Lakes, CA 93546

Attention: Mr. Douglas Hicks

Subject: **SEDIMENT ACCUMULATION BEHIND CONRETE BULKHEAD**
Pine Creek Mine – Easy Go Adit
Pine Creek, California

Dear Mr. Hicks:

The following response is provided pursuant to the comments letter sent to Pine Creek Development from the USFS, specifically Paragraph 3, dated April 5, 2006. It is our understanding that the USFS feels that the existing concrete bulkhead could serve as an impoundment/trap for sediment which could potentially block water flow, thereby increasing water levels and thus pressures on the bulkhead leading to a catastrophic failure. Based upon our review of information provided by Pine Creek Development, specifically design details of the bulkhead, and recent water quality records of the mine water discharge, the potential for the bulkhead to act as a sediment trap thereby leading to failure of the plug is considered remote.

Erosion within the mine system and therefore sediment accumulation behind the bulkhead, excluding sediment and debris dislodged during seismic events, is limited due to the geology. Water discharge records from 2004 corroborate the low sediment levels within the system. Turbidity levels were measured at less than 5 NTU each day during drainage indicating that sediments in the water discharged are minimal (see attached water quality records).

The bulkhead was designed by James Thompson Civil Engineer and Andrew Nasser Structural Engineer in 2002 to withstand a pressure force of 866 psi against sliding, which is equivalent of approximately 2,000 feet of impounded water. We understand from conversations with you that impound test data from 2003 showed water levels reached a maximum recorded height of approximately 1,219 feet of head (528 psi), which is approximately 281-feet below the maximum impoundment height where water can exit to daylight from the adit 1,500 above the bulkhead.

Although initial structural design calculations did not include additional pressures from sediment accumulation, we have included additional pressures from a theoretical full width and height sediment buildup behind the plug to see if the additional load would have a negative impact on the bulkhead. An accumulation of sediment to 15'x 15' x 100' behind the bulkhead would impose a pressure force of roughly 35 psi or an added 4.0% of design limit (see attached calculations).

If sediment were to accumulate to roughly this assumed theoretical value while water was fully impounded to the maximum recorded level, the maximum pressure force exerted on the bulkhead would be approximately 563 psi or 65% of the design value.

We appreciate the opportunity to be of service to you. Should you have any questions regarding this letter, please do not hesitate to contact us.

Respectfully,

SIERRA GEOTECHNICAL SERVICES, INC.

Thomas A. Platz
President
PE C41039

Joseph A. Adler
Principal Geologist
CEG 2198

(2) Addressee

SIERRA GEOTECHNICAL SERVICES INC.
P.O. BOX 5024, MAMMOTH LAKES, CALIFORNIA 93546
(760) 934-3992; (760) 934-8832 Fax

Bulkhead Stability Calculations (Sediment Impoundment)

Project: Pine Creek Mine

Givens: Theoretical Sediment buildup 15' x 15' x 100'
Bulkhead Resistance Pressure 867 psi

Soil Parameters: Avg. unit wt. of sediment = 130 pcf
Internal angle of friction ø = 30º

Lateral Earth Pressure behind Bulkhead (per unit foot)

Sediment height ≤ 15' h

$\frac{1 - \sin ø}{1 + \sin ø}$ x Unit wt. of soil = 43.3 pcf/ft depth

15' x 43.3 pcf = 650 psf @ 15'

Pa (stress acting on a point 1/3 the height of bulkhead) = 1/2 h (650 psf) = **4871 lbs** per unit foot or **35 psi**