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# A Survey of the Effects of Metals on Park Lake and Frohner Basin

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# ABSTRACT

A study on water quality was taken over a two year period, 1974 (8) and 1976, ranging from April to November on the Park Lake-Lump Gulch Area in Jefferson County, Montana. Tests were conducted for copper, zinc, iron, lead, pH, specific electrical conductance, temperature, and dissolved oxygen content. Severe winter kills and mortality rates for fish plants were common reports in the previous years, however, neither occurred during the 1976 test season. Conditions were studied for both fish and human safety.

Results showed no single cause as detrimental to the area except in the immediate Frohner Mine area. Some speculation concerning synergistic effects of toxicants, precipitating metals, and other prevalent conditions are made.

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# INTRODUCTION

Park Lake is one of the Helena area recreation sites and is used for fishing and camping. Frohner Basin and Park Lake (Township 8N, Range 5W, Section 13) comprise an area of 3400 acres and is located approximately 13 miles south southwest of Helena. This area has several mines which are for the most part currently inactive. Park Lake was constructed to store and supply water for the mines of the area but is currently owned by the Montana Fish and Game Department. Frohner Mine (Township 8N, Range 5W, Section 15) is above Park Lake and between these there are several beaver ponds and wet meadows which hold water for late season water flow.

Since the water for the lake flows over an area that has mine tailings from the now inactive Frohner Mine and a limited amount of water comes out of the mine tunnel itself this is one factor that must be considered as a possible source of contaminant minerals and pH changes. Another possible contaminant source to be considered is a road that was built for timber access in Frohner Basin above Park Lake. During construction, approximately 1400 cubic yards of mine tailings from the Frohner Mine were used on 0.79 miles of road. This road crosses the creek as it passes through Frohner Meadows (Township 8N, Range 5W, Section 14).

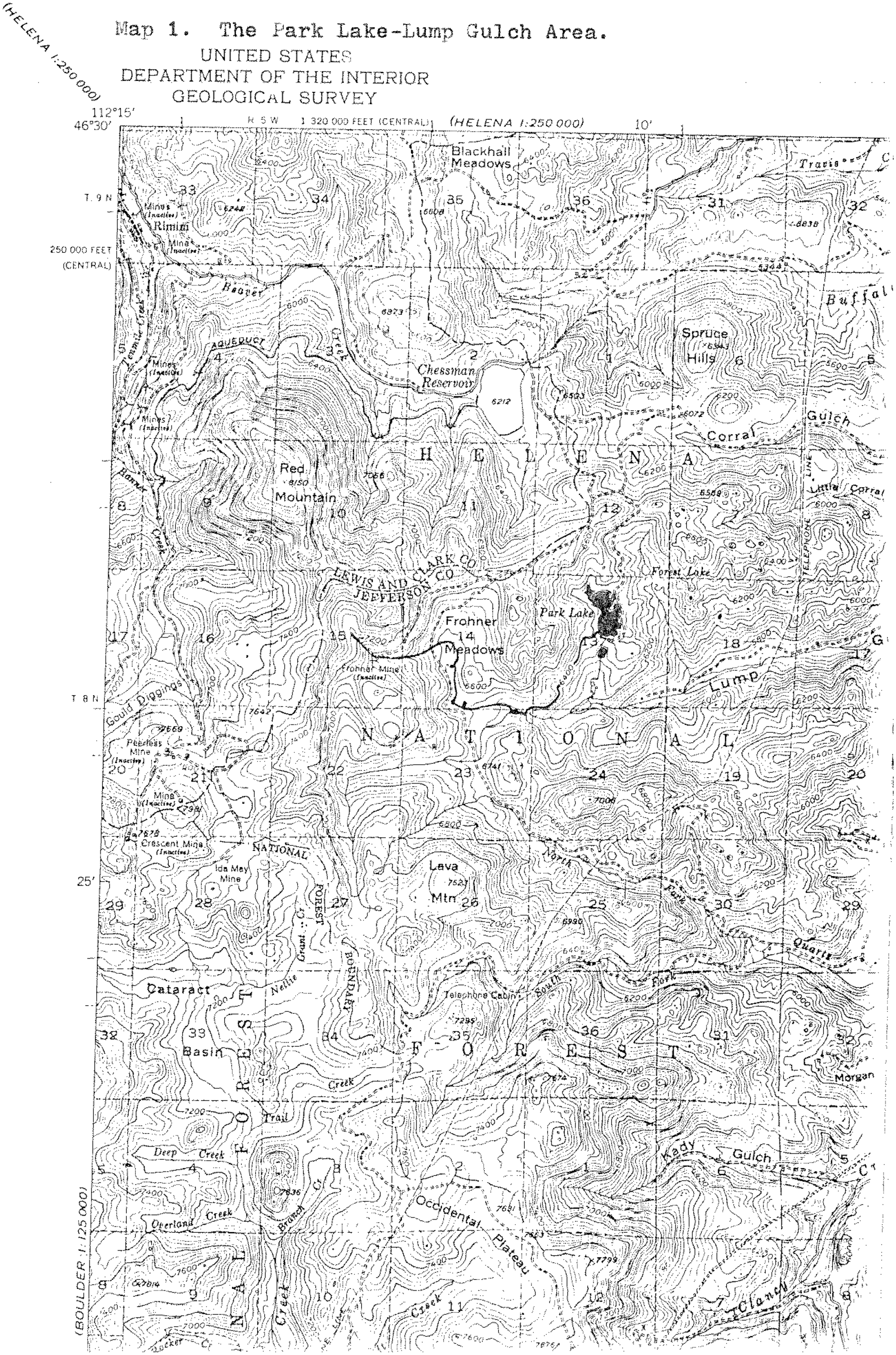
As a result of concern for public health the U. S. Forest Service submitted a report on the effect of mine tailings on the water of Lump Gulch and Park Lake in 1974. (4) In general, this report is concerned with human consumption safety standards as set by the U. S. Public Health Service and concludes that at least under the parameters and sampled flow and runoff conditions there should be no danger to Park Lake or its users. The data resulting from the Forest Service report as well as the data from our own tests, which aren't as extensive as those conducted by the Forest Service, can be interpreted with reference to aquatic life, especially rainbow trout.

In the past there have been problems with fish winter killing during certain winters and also with planted rainbow trout having abnormally high mortality rates within the first few days following the plant. For example, on May 25, 1964 an "estimated couple hundred" rainbow trout were dead around the shore of Park Lake; May 29, 1967, trout winter kill was "extensive" (4). In June 1967 a high mortality rate of planted trout was reported; again in June 1970; and the 1975 plant produced 235 dead fish which prompted the study.

The purpose of this work is to attempt to point out conditions which may be responsible for the winter kill of rainbow trout and for the occasional high mortality rate that occurs when rainbow trout are planted in the lake. We will look at the environmental conditions provided such as mineral content, temperature, pH, and dissolved oxygen levels.

## Map 1. The Park Lake-Lump Gulch Area.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



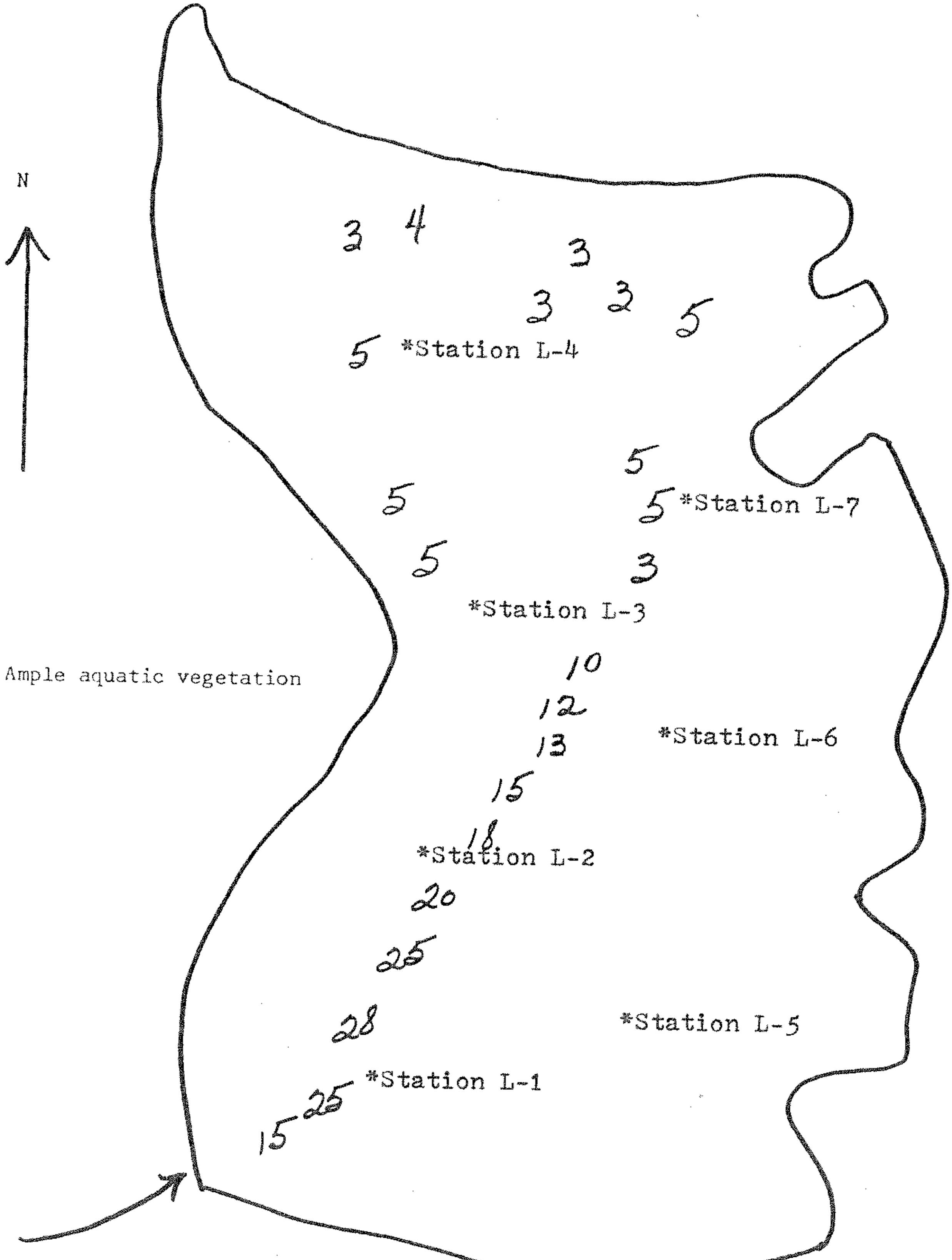
## METHODS and MATERIALS

Our study on the quality of water in relation to animal and human populations ranged from above the Frohner Mine and tailings, along the Lump Gulch Creek, and into Park Lake. There were four test stations along the creek pathway designated C-1 through C-4. C-1 was located above the mine and used as the control for the area. C-2 was at the entrance to the mine tunnel. C-3 was below the mine area, with C-4 at the inlet to the lake. We set up seven stations on the lake, designated as L-1 through L-7. Recordings were taken at both the surface and bottom of these sites. L-1 through L-4 are located on the west portion of the lake going from south to north, respectively. L-5 through L-7 are on the eastern portion, also running from south to north. (See map # 2) Samples were also taken at the lake exit. During the latter stages of the summer the water level dropped considerably, to such an extent where no water left the lake except by means of a few minor seepage points. Samples were discontinued during this time.

We collected a number of raw samples and recorded observations in the field but due to the high cost of the testing process not all of the raw samples were used. If our tests concurred with those in the report by the Helena National Forest Officers, then we took no more time and expense to test again for the same materials. We tried to

Map 2. Park Lake, showing depths and 1976 study stations.

PARK LAKE
17-9376-03



Numbers show depths in feet.
Stars depict 1976 study stations.

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use our data in such a way as to give the best overall view of the 1976 season.

The materials for experimentation were all donated for our use by the Montana Department of Fish and Game. This included all the equipment for the acquisition of samples and for their storage and preparation. Preservatives were also donated.

We used the test for total minerals consistently. This test gives an indication of the total minerals present in the sampling area. In this test, a 1000 ml plastic container was filled with sample water and 5 ml of concentrated nitric acid is added at the time of collection to minimize absorption of the metals on the container walls.

We tested for dissolved minerals. This test represents the minerals found dissolved in the sample water smaller than 45 micron size level. Here a 50 ml glass syringe was attached to a 45 micron filter. The sample passed from the syringe, through the filter, and into a 250 ml plastic container. One ml of nitric acid was added as a preservative.

Both the total and dissolved mineral samples were taken to the State Department of Health and Environmental Sciences laboratory and analysed by the Atomic Absorption Spectrophotometric Method.

Generally, atomic absorption spectroscopy measures the amount of light absorbed through a sample that is aspirated into a flame and atomized. The light beam is directed through the flame into a monochromator, and onto a detector. The amount absorbed by the flame is proportional to the concentration of element in the sample (1).

We tested for hydrogen sulfide ($H_2S$) concentration and for specific conductivity. A 1000 ml plastic container was filled, no preservatives were added. Hydrogen sulfide concentration is measured by the Department of Health and Environmental Sciences laboratory using a colorimetric method. A reaction is produced between paraaminodimethylaniline, ferric chloride, and sulfide ion, resulting in the formation of methylene blue. Ammonium phosphate is added to remove color due to the ferric ion, and color comparison determines the results (1).

The test for specific conductivity was also run by the laboratory. This test gives useful indications of the total concentration of ionic solutes. It is determined by commercially available monitoring equipment.

Dissolved oxygen tests were an important factor in the study. Samples were obtained from various depths of water and drained into a glass container. Here we employed the Azide Modification of the Winkler Method (1) in the the field.

The procedure for this test is as follows. To a 300 ml sample add 2 ml manganese sulfate solution, followed by 2 ml alkali-iodide-azide reagent. Stopper with care not to include air bubbles and mix by inverting the bottle at least 15 times. Wait until a precipitate settles out and add 2 ml concentrated sulfonamic acid ($H_2SO_4$). Mix by gentle inversion until dissolution is complete. Then remove 203 ml of solution for titration. Titrate with 0.0250 N thiosulfate solution to a pale straw color. Add 1 - 2 ml starch solution and continue to titrate until the first disappearance of the blue color. The volume in milliliters of the titration material is the relative amount of dissolved oxygen present.

pH is the measure of the hydrogen ion concentration of the water. Extremely high or low concentrations can adversely effect water quality. A small portion of untreated sample water is tested using a portable pH meter. PH readings were taken in the field. The pH meter included an automatic system where temperature of the water is accounted for.

Temperature of the air, the water, and time of sampling were all recorded.

Materials of our study also includes a report of the Helena National Forest by Richard H. Wheeler, condensed by Parley Waters (8). This report covers the same sampling space, with the exception of Park Lake itself. Tests were run by the same institutions. This report is more extensive than our report. We feel this material is of importance to our thesis.

# LITERATURE CITED

## COPPER

In general, the effects of copper in water are in terms of copper (Cu) or copper salts. Metallic copper is insoluble in water while many copper salts are highly soluble in water. These copper salts occur in natural surface waters only in trace amounts of about 0.05 mg/l and thus higher concentrations are usually due to the copper compounds being added by some source such as industry, insecticides, or fungicides (6-10, 6-27, 6-44).

The chloride, nitrate, and sulfate of divalent copper are highly soluble in water. The carbonate, hydroxide, oxide, and sulfide forms are not soluble in water and therefore cupric ions that are introduced into natural waters at pH 7 or above will precipitate as the hydroxide or as basic copper carbonate ($CuCO_3$, $Cu(OH)_2$ ). This is the reason copper ions are not usually found in natural surface waters or ground water in high concentrations (6).

Copper is probably not a hazard in domestic water supplies because when it is in high enough concentrations to be dangerous to human beings it will also have a disagreeable taste (6). Copper is found in traces in all plant and animal life and in blood-forming organs the physiological function seems to be involved in the metabolism of iron (6-27, 6-44). Most of the copper ingested is excreted by the body with very little being retained, thus copper is not considered to be a cumulative systemic poison as is lead or mercury. Over the years the U. S. Public Health Service (USPHS) has had various drinking water standards with the 1962 standards being a recommended limit of 1.0 mg/l, this limit being set primarily because of the taste problem (6-24).

Fish and other aquatic life have varying levels of copper tolerance which differ from species to species and also with the physical and chemical characteristics of water such as temperature, hardness, turbidity, and carbon dioxide content (6-28, 6-45). Hard water reduces the toxicity of copper salts by the precipitation of copper carbonate or other insoluble compounds (6-11, 6-45). The sulfates of copper and zinc act synergistically to increase their toxic effect on fish (6-9, 6-19, 6-41). Copper concentrations varying from 0.1 to 1.0 mg/l have been found to be non toxic to most fish (6-9, 6-19). It has been demonstrated that the toxic threshold concentrations of copper for rainbow trout were diminished as the dissolved-oxygen tension was lowered (6-1, 6-46, 6-47).

## IRON

Iron can be found in water as the ferric and ferrous salts such as chlorides which are highly soluble in water. Ferrous ions are readily oxidized in natural surface waters to the ferric condition which will then form insoluble hydroxides (6-49) which will precipitate easily in well-aerated waters. For domestic water supplies the USPHS set a recommended limit of 0.3 mg/l in their 1962 drinking water standards. This limit was based on esthetic and taste considerations because even at concentrations as high as 1.0 mg/l would have little effect on the total daily intake of iron.

Because of the ability of ferrous or ferric ions to combine with hydroxyl ions to form precipitates very little of the iron remains in solution. One danger that may arise under the conditions of a high dosage of soluble iron salt and water that is not strongly buffered may be to lower the pH of the water to a toxic level. Iron hydroxides may deposit on the gills of fish and cause irritation and blocking of the respiratory channels. Also, heavy precipitates of ferric hydroxide may be hazardous to fish eggs due to smothering ( 6-8, 6-25, 6-50). Death of pike, tench and trout may occur at an iron concentration of 1-2 mg/l and a pH of 5.0-6.7, however, the toxicity of iron may be dependent on whether or not it is in solution or suspension (6-8, 6-18, 6-20).

## LEAD

Lead may be introduced into the environment as a constituent of many industrial and mining processes. Our report deals directly with effluents of a mining camp.

Lead is a dangerous chemical in the environment for two reasons. First, it has a cumulative effect. Secondly, no one is positive as to the maximum intake levels that are safe for man and animals.

Lead is not considered essential for nutrition of either man or animals. Successive intake of lead accumulates as a poison. This poison is generally deposited in the bones and causes many abnormalities.

No one is positive about the harmful levels of lead. The USPHS Drinking Water Standards states a level of 0.1 mg/l as safe. This is a very difficult figure to accurately interpret. Many factors, such as food intake, inhaled atmosphere, tobacco smoke, drinking water consumption, and sensitivity of the individual to lead concentrations, must be considered. This makes finding a maximum acceptable toxicant concentration level very difficult.

Lead poisoning of fish is generally caused by the amount of dissolved lead in the water. McKee and Wolf (6) have determined the complications of the metal are due to the deposition of lead on the gills of rainbow trout, which eventually causes suffocation. This is a reaction of the mucus layers of the gills with the dissolved lead. However, Davies, Goettl, Sinley and Smith (3) have shown the effects of lead to follow two different channels. One is where lead is thought to have direct or indirect influence on the central nervous system. The other channel is thought to be biochemical inhibition of metabolism. This degeneration is not believed to be solely due to mucus coating by lead, but possibly by direct ingestion of heavy metals or by means of the food chain. It is important to note that symptoms of those channels described by the latter authors have been produced by other means than lead poisoning in separate and unconnected experimentation.

Effects of lead poisoning on rainbow trout generally cause vast physical abnormalities, such as spinal curvatures, paralysis, and darkening of the tail sections. McKee and Wolf (6) site the maximum acceptable toxicant concentration as 0.1 mg/l. Davies, Goettl, Sinley, and Smith (3) have designated 0.018 - 0.032 as the maximum acceptable level. Part of the difference is due to a change in testing procedure by the latter authors. They believe the atomic absorption spectroscopy (which we used) is not as exact as the pulse polorography method. Despite the methods used, this discrepancy is quite large and should be looked into.

It is important to note the toxicity of lead toward rainbow trout increases with a reduction of dissolved oxygen content. This has been determined by the Water Pollution Research Board (6-1, 6-2, 6-46, 6-47).

## ZINC

Zinc has the ability to be highly soluble in water when it is in a salt form such as zinc chloride or zinc sulfate, however, when it is in the form of zinc carbonate, zinc oxide or zinc sulfide it is insoluble in water and will precipitate out of water and may then be found in silt.

A limit of 5.0 mg/l of zinc was set by the USPHS in 1962 because the taste threshold for zinc occurs at the 5.0 mg/l level. Zinc has no know adverse physiological effects upon man unless it is consumed in very high concentrations.

Zinc exhibits its greatest toxicity toward fish and aquatic organisms. In soft water zinc is more toxic than in hard water. It is thought that zinc exerts its toxic action by forming insoluble compounds with the mucous that covers the gills (6-30, 6-34, 6-35), by damaging the gill epithelium (6-56), or possibly as an internal poison (6-26, 6-57).

Fish that survived exposure to dissolved zinc have been less susceptible to additional exposure to zinc, thus indicating that some acclimatization to the presence of zinc is possible. It has also been noted that the effects of zinc poisoning may not become apparent immediatly, i.e. fish removed from zinc-contaminated water after 4-6 hours of exposure may die in zinc free water 48 hours later (6-17, 6-21). The toxicity of zinc salts is increased at lower dissolved oxygen concentrations in about the same proportion as for lead and copper. For example, the lethal concentration at 60% saturation of dissolved oxygen is only about 0.85 of that concentration needed to be lethal at a 100% saturation (6-22, 6-37, 6-46, 6-47, 6-56). If temperature is increased the survival time of rainbow trout in solutions of zinc sulfate in hard water will decrease, but the threshold concentration was not appreciably affected by changes in temperature (6-56). In hard water, zinc concentration of 4.0 mg/l and exposure for three days is lethal for rainbow trout (6-42).

## PH

PH is the measure of the hydrogen ion concentration and is used to measure potential pollutants. PH is especially important because it determines the degree of dissocation of weak acids and bases, some of which are more toxic in the dissolved form than in the ionic form. The toxicity of metals is determined by the pH.

The buffering action of water is essential to the determination of a material's ability to influence the pH of the sample. Domestic sewages generally do not influence pH due to the water's high ability for buffering action. Many industrial or mine wastes are so concentrated, they have a marked effect on the PH.

Of the U.S. waters that support good fish life, 5% have a pH less than 6.7 and 50% have a pH less than 7.6; and 95% have a pH less than 8.3 (6-6).

The U.S. PHS Drinking Water Standard has set no limits as to pH in domestic waters (6-23). Some pH values have been suggested by the Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Comission (6-29). Lethal effects are not produced in the range of 5.0 to 9.5. For best productivity, however, the pH should range from 6.5 to 8.2. Rainbow trout have been reported to tolerate a range from 4.1 to 9.5. The optimum range for fish eggs is 6.0 to 7.2.

The tolerance of fish to varying concentrations of dissolved oxygen changes markedly with pH changes (6-13, 6-51, 6-52).

Natural waters do not dissolve lead if pH values are above 8.0 (6-14). Iron in a concentration of 0.9 mg/l will lethally affect fish life if the pH drops to 5.5 (6-5, 6-13).

## SPECIFIC ELECTRICAL CONDUCTANCE

Specific electrical conductance serves as a quick method of measuring the ion concentration of water which may indicate that the water is polluted by salt concentrations that would be high enough to be harmful to living organisms because of the resultant increase in osmotic pressure. Specific electrical conductance is the reciprocal of the resistance in ohms of a column of solution one centimeter long and with a cross section of one square centimeter, at a specified temperature, which is usually 25° C (6).

The fish can be affected by high osmotic pressure caused by salts in solution. Water may be drawn from the gills and other delicate external organs which will cause damage and sometimes death to the cells. Studies by Ellis (6-4) of inland fresh waters indicate that the specific conductance of streams and rivers that support a good fish life is between 150 and 500 $\mu$mhos at 25° C. A good fish fauna was not found in water with a specific conductance greater than 2000 $\mu$mhos at 25° C. Most types of streams that had specific electrical conductances greater than 1000 $\mu$mhos at 25° C are probably indicative of the presence of acid or salt polution of various kinds. Some more alkaline western streams may have an upper limit of 2000 $\mu$mhos at 25° C for the indicative signs of acid or salt pollution.

## DISSOLVED OXYGEN

Since oxygen is important to so many life processes the concentrations of dissolved oxygen plays an important part in determining the suitability of an aquatic environment. The dissolved oxygen content of water at equilibrium with the atmosphere is a function of the temperature and salinity of the water. The dissolved oxygen concentration will decrease with increases in temperature or dissolved solids (6).

In dealing with fish it is hard to make a general statement about a minimum level of dissolved oxygen needed to support life. This is because the oxygen requirements vary with age, species, prior acclimatization, temperature, and the concentration of other substances. Temperature affects the amount of available dissolved oxygen and the rate at which it will be used by fish. The higher the temperature, the more oxygen required by the fish. For example, the minimum concentration at which trout are asphyxiated at 10° C is 1.16 mg/l and at 18° C it raises to 2.14 mg/l (6). These results must be looked at while keeping in mind the fact that within certain limits fish can adjust their rate of respiration to compensate for changes in the concentration of dissolved oxygen. Besides temperature, the deadly effect of low dissolved oxygen concentrations seems to be increased by the presence of toxic substances such as carbon dioxide, ammonia, cyanides, zinc, lead, copper, or cresols (6-3, 6-25, 6-38, 6-40, 6-46, 6-48, 6-43).

The Water Pollution Research Board of England (6-36) found the minimum oxygen tensions at which rainbow trout could survive for 84 hours to be:

10° C - 1.89 mg/l
16° C - 3.00 mg/l
20° C - 2.64 mg/l

The 20° C figure contradicts the theory that a rise in temperature leads to a rise in oxygen demand but maybe this can be accounted for by the adaptability of the fish. According to Ellis (6-4, 6-7), under average stream conditions, a dissolved oxygen level of 3.0 mg/l or less should be considered hazardous or lethal to fish. In quoting other authorities (6-15), Ellis reports that sustained dissolved oxygen levels of 3.5 mg/l will be lethal to most species of fish but it has also been reported (6-12) that in winter, fish can tolerate dissolved oxygen levels of 1.0 to 2.0 mg/l for short periods of time. Hatching of fish eggs may be delayed under conditions that have near zero dissolved oxygen.

Some logical recommendations for dissolved oxygen have been set up by the Aquatic Life Advisory Committee of ORSANCO (6-29). The recommendations are for warm water fish populations and to sustain a coarse fish population; the dissolved oxygen concentration may be less than 5 mg/l for not more than 8 hours out of any 24-hour period but the concentration should at no time be lower than 2 mg/l.

## TEMPERATURE

Because the effects of temperature on water in relation to human use is lengthy and somewhat irrelevant to the main theme, we will limit our discussion to fish and temperature interactions and in particular rainbow trout.

Temperature acts to change water conditions in the following ways (6):

1) Higher temperature decreases the availability of dissolved oxygen.
2) Higher temperatures increase the metabolism, respiration, and oxygen demand of fish.
3) Higher temperatures may act to intensify the

toxicity of many substances.

4) There are maximum temperatures that each species of fish can tolerate.

The maximum temperatures an adult fish can withstand will vary not only with the species but also with prior acclimatization, oxygen availability, and synergistic effects of other pollutants. The median tolerance limit for common brook trout (Salvelinus fontinalus) as reported by the Freshwater Biological Association (6-32) in 1961 was 25.0° C while the median tolerance limit for lake trout (Lalvelinus namaycush) was reported by Gibson and Fry (6-53) to be 23.5° C. Garside and Tait (6-54) report that the preferred temperature for rainbow trout is 13° C. Much lower than median tolerance limit temperatures are needed for spawning and hatching of eggs. For example, trout eggs will not hatch in temperatures over 14.4° C (6-33).

Sudden changes in temperature can be harmful to fish life; i.e. abrupt changes of 5° C or greater are likely to be harmful (6-31). It was also found that rainbow trout that were acclimatized to 12° C could not withstand an 11° C temperature shock while rainbow trout that were acclimatized to 10° C could tolerate a temperature shock of 8° C (6-55).

## FISH HABITS

The fish which were of major importance to us were the Rainbow Trout and Artic Greyling.

The natural range for rainbow trout extends from southern California to the Gulf of Alaska (2). Rainbow hybridizes readily with cutthroat trout, thus introducing many intermediates into streams and lakes. For this reason, pure strains are difficult to isolate. Due to the great adaptability to temperature and other conditions, rainbow have extensively invaded western Montana. Rainbow are more widely propagated than any other trout in Montana for sporting and commercial purposes.

The rainbow are used as plant fish for western Montana. On June 4, 1976, the Montana Department of Fish and Game planted 2999 fish in Park Lake. On June 7, 1976, 1000 more rainbow were added. These rainbow were from the Washoe Park Hatchery in Anaconda.

Rainbow usually mature sexually in 2-3 years. Females produce 800-1200 eggs per pound of fish. Spawning usually occurs from April to July, depending on the water temperature. Eggs hatch in about 50 days at $50^\circ$ F ($10^\circ$ C).

Rainbow do not necessarily migrate upstream, although many still do. Rainbow in lakes or reservoirs must move into a tributary to spawn successfully. One male accompanies each female and defends their position from other fish intruders. Redds are built in the gravel beds, 3 to 6 inches deep, by the female. The eggs are fertilized by the male as they are deposited into the intersticies of the gravel in the redd.

Rainbow seldom live past 5-6 years old. Rainbow up to 20 pounds have been found in Montana.

Artic greyling range from eastern Siberia, along North America to Hudson Bay, Minnesota, Montana, and British Columbia (2). Greyling are cold water stream fish but live in lakes except for spawning purposes.

Greyling mature sexually in 2 years. Females produce from 7000 to 12000 eggs, depending on their weight. Greyling spawn usually from late March to early June, this depending on water temperature. Hatching time varies from 11 to 22 days. In some mountain lakes, runs begin immediately when the ice goes off. Spawning occurs in the streams. There seems to be less discrimination between partners of artic greyling than for the rainbow trout. Females dig no redds and the drop spots for the eggs vary from sand to coarse rubble.

Greyling usually live six years, but in a few instances have lived up to 10 years. The largest greyling caught in Montana was 2.5 pounds. Greyling are not nearly as extensive in Montana as are rainbow.

# RESULTS

## COPPER

The concentrations of copper over the 1974 and 1976 study periods ranged from less than 0.01 mg/l to 0.14 mg/l. In the majority of the cases, the concentration of copper was 0.02 mg/l or less.

At the mine tunnel the concentration clearly indicates some outside addition to the creek, other than natural sources. This is expected due to the input of materials from the mine tunnel. The concentration readily decreases, however, and has always dropped below 0.04 mg/l at Station C-3, located below the mine area, indicating the quick removal of the copper substance. One unexpected concentration of 0.14 mg/l was found once at Station C-4, the inlet to Park Lake. This occurred in late May, 1974, and is probably due to the high runoff.

Except for the three isolated instances, the level for copper was well below the USPHS standards. The hard water of our sample area reduces toxicity of copper also, therefore we cannot foresee any harmful effects resulting from excess levels of copper.

Copper and zinc are known to produce a synergistic effect for toxicity in fresh waters. No evidence of any harmful consequences were discovered.

## IRON

The iron concentration data is not as clear cut as most of the other results. The USPHS drinking standard level for humans use 0.3 mg/l mainly for taste reasons. It has been determined that a level of 1.0 mg/l would have little harmful effect on man. Outside of the immediate mine area, iron concentrations range from less than 0.01 mg/l to 1.2 mg/l. The 1.2 mg/l was at Park Lake at the 24 feet level of Station L-1. The next highest level is 0.79 mg/l. Most of the readings approach 0.3 mg/l but never surpass it. Outside of taste abnormalities, the iron concentration is not harmful to man.

At the mine area however, concentrations run as high as 33.0 mg/l, but generally stay between 1.0 and 8.1 mg/l. These levels are high for iron safety levels. It is true that the iron concentration drops off quickly from the mine tunnel to Station C-3, below the mine. Our data shows a general decrease to about 1.0 to 2.1 mg/l here.

This high concentration of iron in this mine area probably contributes significantly to the severe drop in pH recorded there.

Iron readily precipitates in well aerated water, leaving little concentration in solution. This might have a detrimental effect on fish eggs. At Station L-1 on Park Lake, a concentration of 0.17 mg/l at the top contrasts with a concentration of 1.2 mg/l at the bottom.

High iron concentrations have been found to be harmful to fish eggs. This is of concern to us because it is felt that rainbow trout aren't reproducing at normal rates in the lake and the increased iron levels are near the potential spawning area. Our data on this subject is too limited to make any conclusions, but suggest a need for further study.

Levels of 1.0 to 2.0 mg/l of iron have been found harmful to fish. This concentration of iron is found only at the bottom of the lake at Station L-1. Although it might present a danger to fish of that immediate area, we feel that iron is not harmful to the area as a whole.

## LEAD

The controversy between the maximum acceptable toxicant concentration is the key behind our study on lead concentrations. Throughout the 1974 and 1976 periods on which we have data, only two stations have exceeded the level of 0.1 mg/l as set by the USPHS. This was at the Frohner Mine tunnel where the 0.1 mg/l level was exceeded one time by a factor of 23 on May 29, 1974, and below the Frohner Mine area, where the level reached a concentration of 0.14 mg/l on this same date. This data was somewhat expected due to the setup of the area. For example, the mine tunnel water contains many minerals, and the water then runs ½ mile through mine tailings and is measured again.

However, following the guidelines set by Davies, Goettl, Sinley, and Smith (3) of 0.018-0.032 mg/l as safe for fish life, one must be more concerned. With the exception of the control above the mine area, every other station, including the lake sites, have at one time or another reached a level of 0.05 mg/l. 0.05 mg/l was the recording at two sites, L-1 and L-2 on the lake, both at the surface and at lower depths.

The general trend for all reports at all stations, seems to be a decreasing concentration as the summer goes on until late August where the level at Stations C-2, C-3, and C-4 move upward.

It is important here to note that no fish, with the exception of one that died during the plant, was ever found on the surface of the water gaping as though it was dying from lack of oxygen and no obvious physical abnormalities on any fish were found.

We could find no means to measure the effects of varying dissolved oxygen levels in reaction to lead toxicity. However, using the same criterion of the physical status of the fish at Park Lake, we feel this did not have a detrimental effect in the Park Lake area over the 1974 and 1976 seasons.

The general lead concentrations for the two periods were usually lower than 0.05 mg/l, many of them less than 0.01 mg/l. This is a safe level for humans and fish relative to both safety level systems.

From our comparison of test results with available literature we feel that lead is not detrimental to the fish or humans in the area by the actions of lead alone.

## ZINC

Seepage from the Frohner Mine tunnel definitely increases the concentrations of zinc in the water flow. Our data shows increases of over 100 times the concentrations of our control station, C-1. The zinc concentrations drop quickly, however, and are always less than 1.0 mg/l below the mine area.

The USPHS sets safety standards for human consumption at a level of 5.0 mg/l. Rainbow have been known to die within three days at a zinc concentration of 4.0 mg/l. Excluding the immediate mine area, zinc concentrations of our samples are never this high. It is a rare occurance for our samples to exceed a level of 1.0 mg/l.

Fish effected by this mineral are usually found gaping, indicating zinc coating their gills. None of the fish that were caught or spotted swimming in shallow water showed these symptoms.

Zinc may precipitate out and be found in the stream silt. This might present a problem for fish in their spawning, however, we have nothing to indicate this is what is happening.

Increases in temperature and thus decreases in dissolved oxygen with high levels of zinc are conditions for a potential hazard for some fish. We found no evidence that the zinc concentrations and temperature increases would be of magnitude to create a hazard for the fish.

## PH

As expected, the pH at the mouth of the tunnel is the lowest, ranging only from 2.8 to 3.1 over the seven month, two year sample period. This water probably contains all the metals that have washed from the abandoned mine. Immediately below the mine, pH ranged from 3.6 to 6.5. This pH level is also very low. However, where the water enters the lake, pH ranged from 6.8 to 7.4. This is good considerating a pH of 7.0 is neutral. These pH's at the lake entrance resemble those of Station C-1, the control whose range is from 6.3 to 7.6 over the sample period.

Although the concentration of ions coming from the mouth of the mine are high, the creek seems to buffer the system well enough to balance the pH.

The lake pH's vary from 7.3 to 7.8. This data, however, is for one test period only, therefore it is not a good indication of the whole season.

USPHS cites no specific level for safe drinking water, believing the bad taste will protect the consumer.

Hopefully, this is the case at the immediate mine area. There is a possibility the pH might be slightly high to meet ideal conditions for fish egg progression. This could be a factor influencing the lack of reproductive ability of the lake rainbow trout. Except for egg progression conditions, it seems as though the pH stays within ideal levels. It is within the general productivity range for fish life. The pH never drops low enough outside the mine area to harm fish or human life.

## SPECIFIC ELECTRICAL CONDUCTANCE

Generally a good fish fauna is not found with specific conductivity levels above 2000 μmhos. Levels greater than 1000 μmhos are indicative of acid or salt pollution. In our results, levels over 1000 μmhos were found only at the Frohner Mine tunnel, where a level indicating pollution would be expected. All other stations recorded values below 1000 μmhos, thereby indicating the Park Lake area to be free of salt or acid pollution.

Ideal conditions for fish generally range between 150 and 500 μmhos. Specific conductances for Stations C-1 and C-4 were in this range or below it. We have no data for the lake. This evidence seems to show good living conditions for the fish of the area.

## DISSOLVED OXYGEN

Dissolved oxygen data was taken only at the lake because there is little danger of a low dissolved oxygen level occuring in a fast moving stream such as the one that feeds Park Lake. Several low dissolved oxygen concentrations were recorded during April and May of 1976 with 1.03 mg/l being recorded at the 24 foot level of Station L-1, 0.87 mg/l being recorded at the 18 foot level of Station L-2, and 2.46 mg/l being recorded at the 15 foot level of Station L-5 on April 21, 1976. Temperatures at these stations ranged from 3 - 4° C.

These concentrations are low by the numerous safety standards described in the literature and could be harmful to fish. However, these low readings are at places that are prime low dissolved oxygen areas. The life on the bottom of the lake uses up the dissolved oxygen during the iced over winter months, a time when dissolved oxygen replacement is limited. Other stations in the lake had dissolved oxygen levels that were around 8 mg/l and therefore the fish would not be restricted to a low dissolved oxygen environment. Fish also have the ability to adjust to low dissolved oxygen levels, within limits, during the winter months. Dissolved oxygen levels rise quickly, and by May 30, 1976, the lowest recordings were 5.9 and 7.3 mg/l with all other stations recording dissolved oxygen concentrations greater than 8.0 mg/l; which is a safe level by all standards cited.

The oxygen intake increases for fish as the temperature increases. We found no evidence indicating that fish were suffering due to low oxygen levels.

Hatching of eggs will be postponed until a sufficient concentration of dissolved oxygen is present. The dissolved oxygen level rises so quickly as shown by data from April to May, 1976, that we feel this is not happening at Park Lake.

## TEMPERATURE

There are many factors intricately involved with temperature, such as oxygen availibility, synergistic effects of pollutants, and ability of temperature to intensify toxicity. Therefore, it is difficult to clearly state the effects of temperature on fish life.

The maximum temperature brook trout can tolerate has been set at 25° C, and 23.5° C is maximum for lake trout. At no time during our study did we record temperatures over 21° C. This temperature was recorded on July 10, 1976 at the surface of Park Lake Station L-1. On the same date a recording of 19° C was taken at the inlet to Park Lake, at Station C-4. All temperatures reached a maximum around July.

A temperature of 13° C is preferred for rainbow trout. Our data shows that on an average, temperatures stayed around this mark or slightly cooler.

We therefore do not believe a high temperature is adversely effecting the mature fish in Park Lake.

However, we do have some concern over the fish eggs of the area. Rainbow eggs will not hatch in temperatures over 14.4° C. Rainbow usually spawn from April to July, depending on the water temperature. In our data of the two year season, we have temperatures of 19 and 21° C recorded on July 10, as previously stated. We feel that this might have a harmful effect in seasons where the spawn runs into July since Rainbow Trout eggs take about 50 days at 10° C to develop. Unfortunately, we have no temperature data for June. But at Station C-4, the inlet to Park Lake, the temperature rises 11° C to 19° C from May 30 to July 10, 1976. This is a substantial increase in a short time. We feel this might be a subject to be looked into in more detail in future seasons.

# CONCLUSION

From our results it cannot be concluded that any one of the many prevalent toxicants are lethal for the fish of the area. The metals were generally all within safe concentrations when considered individually with the main exception being at or near Frohner Mine. The dissolved oxygen levels were low in some isolated cases but returned to safe levels quickly so as to present little danger to the fish. The temperature and pH were also within tolerance limits for fish. Also the fish have the ability to acclimatize to the conditions of the lake as is shown by the fish that have lived through stress periods.

Reports of past fish winter kill, high mortality rates for planted fish, and possible low reproduction rates might be accounted for by a synergistic action of the metals that are present in the area, low dissolved oxygen levels at stress periods, or a combination of these. Temperature also plays a role in the toxicity of metals. Combinations of toxic elements such as metals plus low dissolved oxygen levels may be producing the occasional winter kill or metals plus warmer temperatures may be making it harder for the planted fish to acclimatize to the lake. These combinations may explain the inconsistency of winter kill and plant kill. A kill might or might not occur, depending on the combination that is present at the time of the plant or during the stress periods of the winter.

Another consideration is the possibility that the lake might be acting as a settling pond for the upstream metals. This is indicated in the results by higher metal concentrations at the bottom of the lake than at the top. This would also seem logical since the water outflow of the lake is very limited and evaporation along with natural settling would tend to concentrate the metals at the bottom of the lake.

We would like to recommend that:

(1) The Fish and Game continue using caution in planting fish in the lake, especially with regard to temperature shock and allowing the lake to aerate sufficiently before planting.

(2) If further studies are made of the lake, soil sediment samples be taken from the bottom of the lake and analyzed to determine if this might be a source of toxic levels of metals during winter stress periods.

(3) In the event that a fish kill occurs in the future, some of the fish should be analyzed to determine if toxic levels of lead, zinc, arsenic, iron or copper are present and in what amounts.

(4) A sign cautioning the public of the potentially harmful conditions of the water at the immediate mine area should be placed in an obvious location at the mine and/or at the mine tailings.

APPENDIX I

Table 1**

| Sampling Date | Time | Water Temp. | EC | pH | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| 5/20/76 | 1215 | | 64 | 6.9 | .01 | .14 | <.05 | .03 |
| 5/29/74* | 1130 | 2 | 45 | 6.3 | .02 | .14 | <.01 | .01 |
| 6/ 6/76 | 1200 | | | 7.6 | | | | |
| 7/10/76 | 1200 | | | 7.5 | | | | |
| 7/20/74* | 1140 | 10 | 77 | 7.7 | .01 | .08 | <.01 | .02 |
| 8/ 7/74* | 1115 | 7 | 107 | 7.1 | <.01 | <.01 | <.01 | <.01 |
| 8/28/74* | 1300 | 6 | 87 | 7.5 | .01 | .01 | <.03 | .04 |
| 9/21/76 | 0715 | | | 7.3 | | | | |
| 9/21/74* | 1135 | 4 | 94 | 7.4 | <.01 | .02 | <.01 | .02 |
| 10/23/74* | 1020 | 4 | 96 | 7.6 | .01 | .04 | <.01 | .02 |
| 11/27/74* | 1255 | | 58 | 7.0 | <.01 | .02 | <.01 | .02 |

Table 1 represents data tabulations for Station C-1, Lump Gulch above the Frohner Mine.

* This data has been taken from a report to the Helena National Forest on the effect of mine tailings on the water of Lump Gulch and Park Lake, prepared by Richard H. Wheeler, for and condensed by Parley W. Waters (8).

** All samples analyzed by the Department of Health and Environmental Sciences.
All data recorded as mg/l unless otherwise noted.
Water temperature recorded in °F and converted to the nearest whole °C.
Electrical conductance (EC) recorded in umhos per cm at 25°C.
PH recorded as standard units.
Dissolved mineral figures were considered in the data, but are not listed here.
All tables follow this same format.

## Table 2

Data tabulations for Station C-2, Frohner Mine Tunnel.

| Sampling Date | Time | Water Temp. | EC | pH | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| 5/29/74* | 1145 | 4 | 590 | 3.2 | .13 | 3.6 | 2.3 | 6.1 |
| 6/ 6/76 | 1230 | | | 2.8 | | | | |
| 7/20/74* | 1145 | 5 | 708 | 3.0 | .13 | 33.0 | .38 | 11.5 |
| 8/ 7/74* | 1145 | 4 | 1036 | 2.8 | .04 | 22.0 | .07 | 17.0 |
| 8/28/74* | 1310 | 4 | 1028 | 2.8 | .08 | 5.8 | .04 | 11.0 |
| 9/21/74* | 1140 | 3 | 1010 | 2.9 | .03 | 8.1 | .38 | 7.3 |
| 10/23/74* | 1030 | 4 | 892 | 3.1 | .01 | 7.3 | .12 | 11.0 |
| 11/27/74* | 1300 | 4 | 800 | 2.9 | .02 | 3.5 | .80 | 7.5 |

## Table 3

Data tabulations for Station C-3, Lump Gulch below Frohner Mine.

| Sampling Date | Time | Water Temp. | EC | pH | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| 5/20/76 | 1250 | | 76 | 6.6 | .01 | .84 | .05 | .28 |
| 5/29/74* | 1400 | 5 | 217 | 3.6 | .01 | 1.0 | .14 | .80 |
| 6/ 6/76 | 1300 | | | 6.2 | | | | |
| 7/10/76 | 1310 | | | 6.2 | | | | |
| 7/20/74* | 1320 | 13 | 150 | 4.7 | .02 | 1.5 | .12 | 1.60 |
| 8/ 7/74* | 1140 | 9 | 183 | 4.5 | .01 | 1.0 | .02 | 2.20 |
| 8/28/74* | 1330 | 7 | 195 | 4.5 | .04 | 2.1 | .02 | 2.00 |
| 9/21/76 | 0745 | | | 6.9 | | | | |
| 9/21/74* | 1155 | 4 | 175 | 4.6 | .02 | 1.5 | .05 | 1.50 |
| 10/23/74* | 1040 | 4 | 160 | 5.0 | .01 | 1.3 | .03 | 2.30 |
| 11/27/74* | 1310 | | 137 | 5.8 | .02 | 1.4 | .01 | 1.70 |

Table 4

Data tabulations for Station C-4, Park Lake Ditch, at the inlet to Park Lake.

| Sampling Date | Time | Water Temp. | EC | pH | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|
| 5/20/76 | 1430 | | 68 | 7.2 | .01 | .26 | .05 | .11 |
| 5/29/74* | 1535 | 8 | 46 | 6.8 | .14 | .20 | <.01 | .60 |
| 6/ 6/76 | 1350 | | | 7.0 | | | | |
| 7/10/76 | 1350 | | | 7.3 | | | | |
| 7/20/74* | No flow recorded | | | | | | | |
| 8/ 7/74* | 1540 | 14 | 84 | 7.4 | .01 | .02 | <.01 | .06 |
| 8/28/74* | No flow recorded | | | | | | | |
| 9/21/76 | 0900 | | | 7.2 | .01 | .79 | .05 | .07 |
| 9/21/74* | 1550 | 8 | 162 | 6.9 | .01 | .08 | <.01 | .20 |
| 10/23/74* | No flow recorded | | | | | | | |
| 11/27/74* | No flow recorded | | | | | | | |

Table 5

Data tabulations for Station L-1, Park Lake at the southwest corner, near the creek inlet.

| Sampling Date | Time | Sample Depth | Water Temp. | pH | $DO_2$[+] | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 4/21/76 | 1630 | Surface | 2 | | 9.50 | | | | |
| 4/21/76 | 1630 | 24 ft. | 4 | | 1.03 | | | | |
| 5/30/76 | 1330 | Surface | 12 | | 8.50 | | | | |
| 5/30/76 | 1330 | 24 ft. | 10 | | 8.10 | | | | |
| 7/10/76 | 1400 | Surface | 21 | 7.3 | | | | | |
| 7/10/76 | 1400 | 24 ft. | 19 | 7.3 | | | | | |
| 10/ 5/76 | 1000 | Surface | 8 | | 8.7 | .01 | .17 | .05 | .08 |
| 10/ 5/76 | 1000 | 24 ft. | 4 | | 8.2 | .02 | 1.2 | .05 | .06 |

[+] Dissolved Oxygen

## Table 6

Data tabulations for Station L-2, Park Lake along the southwest shore, north of Station L-1.

| Sampling Date | Time | Sample Depth | Water Temp. | pH | $DO_2$ | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 4/21/76 | 1550 | Surface | 2 | | 8.51 | | | | |
| 4/21/76 | 1550 | 18 ft. | 4 | | 0.87 | | | | |
| 5/30/76 | 1330 | Surface | 12 | | 8.7 | | | | |
| 5/30/76 | 1330 | 18 ft. | 8 | | 5.9 | | | | |
| 6/ 6/76 | 1150 | Surface | 13 | 7.8 | | | | | |
| 6/ 6/76 | 1150 | 18 ft. | 13 | 7.8 | | | | | |
| 10/ 5/76 | 1230 | Surface | | | 8.6 | .01 | .20 | .05 | .01 |
| 10/ 5/76 | 1230 | 18 ft. | | | 8.5 | .03 | .44 | .05 | .09 |

## Table 7

Data tabulations for Station L-3, Park Lake along the northwest shore, north of Station L-2.

| Sampling Date | Time | Sample Depth | Water Temp. | $DO_2$ |
|---|---|---|---|---|
| 4/21/76 | 1515 | Surface | 2 | 8.59 |
| 4/21/76 | 1515 | 8 ft. | 4 | 8.71 |
| 5/30/76 | 1330 | Surface | 12 | 8.4 |
| 5/30/76 | 1330 | 8 ft. | 12 | 8.4 |

Table 8

Data tabulations for Station L-4, Park Lake along the northwest corner.

| Sampling Date | Time | Sample Depth | Water Temp. | $DO_2$ |
|---|---|---|---|---|
| 5/30/76 | 1430 | Surface | 12 | 8.1 |
| 5/30/76 | 1430 | 6 ft. | 12 | 8.3 |

Table 9

Data tabulations for Station L-5, Park Lake along the southeast corner.

| Sampling Date | Time | Sample Depth | Water Temp. | $DO_2$ |
|---|---|---|---|---|
| 4/21/76 | 1445 | Surface | 2 | 9.13 |
| 4/21/76 | 1445 | 15 ft. | 3 | 2.46 |
| 5/30/76 | 1230 | Surface | 12 | 8.8 |
| 5/30/76 | 1230 | 15 ft. | 10 | 8.1 |

Table 10

Data tabulations for Station L-6, Park Lake midway along the east shore.

| Sampling Date | Time | Sample Depth | Water Temp. | $DO_2$ |
|---|---|---|---|---|
| 5/30/76 | 1530 | Surface | 13 | 8.7 |
| 5/30/76 | 1530 | 6 ft. | 11 | 7.3 |

Table 11

Data tabulations for Station L-7, Park Lake along the northeast corner.

| Sampling Date | Time | Sample Depth | Water Temp. | $DO_2$ |
|---|---|---|---|---|
| 5/30/76 | 1500 | Surface | 12 | 8.6 |
| 5/30/76 | 1500 | 6 ft. | 12 | 8.5 |

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