Pollution of the Coeur d'Alene River and Adjacent Waters by Mine Wastes

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1932.

Anon gift.

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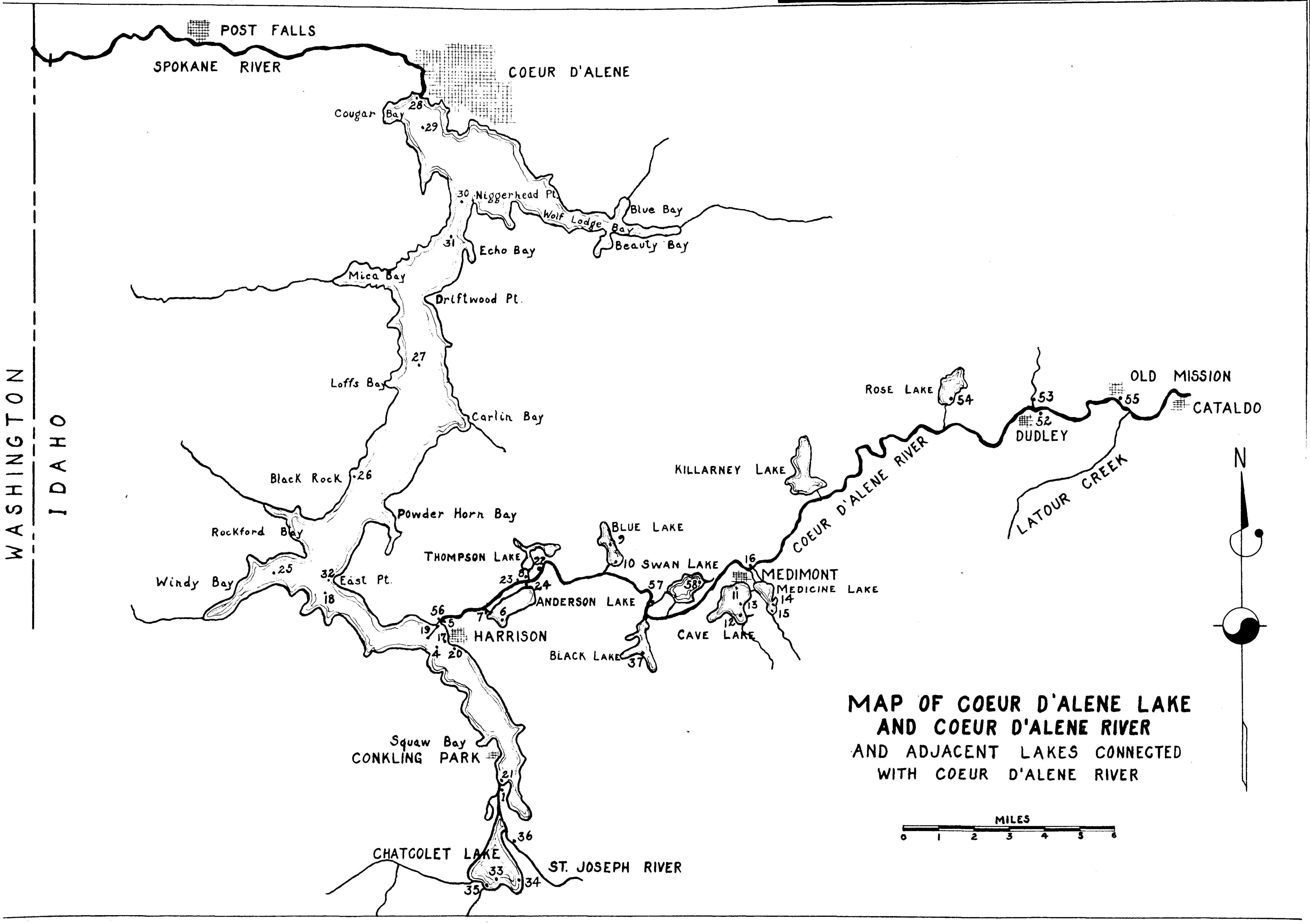


MAP OF COEUR D'ALENE LAKE AND COEUR D'ALENE RIVER AND ADJACENT LAKES CONNECTED WITH COEUR D'ALENE RIVER

Authorization of Present Survey

In view of the reopening of the pollution problem by residents along the lower part of the Coeur d'Alene River during the last few years as a result of the increase in mine slimes and alleged toxic substances reaching their lands, the State of Idaho through its legislature, authorized and financed a commission to make a series of investigations of the pollution problems in the Coeur d'Alene District not only from a standpoint of property damage and alleged injuries to stock and land but from all angles affecting the State or its assets. This commission consists of the Honorable Fred Babbcock, Attorney General, State of Idaho (as chairman), Mr. E. O. Cathcart, County Commissioner of Kootenai County, Idaho (the county including most of the waters and lands damaged by the mine wastes) and Mr. E. L. Taylor, County Commissioner of Shoshone County (the county in which the mines are located). This commission has reviewed the local aspects of the problem and has called upon various state and federal bureaus for advisory aid concerning particular problems. Through Congressman Burton L. French, of the First Idaho District, the Idaho Pollution Commission presented a request to the United States Bureau of Fisheries for an investigation of this particular mine waste problem as effecting fisheries interests, and the present survey was authorized by Mr. Henry O'Malley, United States Commissioner of Fisheries.

Extent of Present Survey

Following the authorization of this survey by Commissioner O'Malley the writer at the suggestion of Congressman French wrote Commissioner E. O. Cathcart, Secretary of the Idaho Pollution Commission, at Harrison, Idaho concerning our needs and Mr. Cathcart assembled certain specimens and material from time to time for this survey in advance of our actual arrival in Idaho. It was planned to begin the field work around the first of June but following correspondence with the Idaho Commission this was found to be impracticable owing to the high stage of water, and the actual field work was postponed until we were notified that conditions were favorable for field work.

Saturday, July 9. Our party of four arrived at Harrison, Idaho, in the afternoon and were met by Mr. Cathcart who had already received our laboratory equipment and had placed it in suitable quarters for our work. A boat house with ample bench space was provided in which our field laboratory was set up. A small cabin launch large enough to carry all of our party and the necessary field equipment was placed at our disposal and a local man familiar with the rivers and lakes detailed to run this launch for us wherever we saw fit. Subsequently this launch was fitted with suitable tackle for sounding and dredging operations, and with apparatus for the field chemical work.

The city of Harrison, Idaho in cooperation with the Idaho Commission ran a special power line into the boat house providing electricity needed in our chemical operations.

<u>Sunday, July 10</u>. Our party worked up the St. Joseph River to a point beyond St. Maries, Idaho. The entire day was taken to this field work, the trip being made by launch. Examination of map will show that the St. Joseph River and the Coeur d'Alene River rise very close to each other, both flowing in a westerly direction and both emptying into Coeur d'Alene Lake. These two rivers are separated from each other by but a single height of land, in places the divide being little more than a ridge, and in other places consisting of high mountains. On the St. Joseph River no mining operations have been conducted but this river has been used as a water-way for the transportation of log booms and the traffic incident to the logging industry. The same conditions also obtain on the Coeur d'Alene River with the addition of the mining activities. The study of the St. Joseph River, therefore, was made to establish a normal for streams flowing into the Coeur d'Alene Lake and this river was used as typical of the general conditions in the Coeur d'Alene River before the introduction of mine waste.

<u>Monday, July 11</u>. Work was begun in the Coeur d'Alene Lake proper in the vicinity of Harrison. The mouth of the Coeur d'Alene River was examined and a trip up the Coeur d'Alene

River made for sampling of Anderson Lake, Thompson Lake and Blue Lake, lateral lakes directly connected with the Coeur d'Alene River and at times subject to pollution through the back-waters from the Coeur d'Alene River.

Tuesday, July 12. Work was continued up the Coeur d'Alene River visiting Cave Lake and Medicine Lake and various parts of the Coeur d'Alene River as far up stream as Medimont, Idaho.

Wednesday, July 13. Work was continued in Coeur d'Alene Lake particularly that portion between the mouth of Coeur d'Alene River and East Point.

Thursday, July 14. Work continued in Coeur d'Alene Lake particularly that portion in front of Harrison, Idaho and up the lake to the mouth of St. Joseph River. One party worked on the Thompson Lake Flats.

Friday, July 15. Dredgings and soundings were made across Coeur d'Alene Lake from Harrison, Idaho to the mouth of Spokane River a distance of some 25 miles. Water and silt samples were taken and the line of current followed.

Saturday, July 16. Work was carried on in Coeur d'Alene Lake near Conkling Park, at the mouth of the St. Joseph River, and up the St. Joseph River in Lake Chatcolet.

Sunday, July 17. Work was carried up Coeur d'Alene River and into Black Lake and back again.

Monday, July 18. Left Harrison, Idaho early in the morning by auto with field equipment driving up the Coeur d'Alene River on the south bank. The extent of mine waste deposits was observed, samples taken at various intervals particularly at Latour Creek and at Bradley, Idaho. Arrived at Wallace, Idaho for the night.

Tuesday, July 19. Worked the Coeur d'Alene River and tributaries in the vicinity of Kellogg and Wallace, Idaho obtaining samples of the water directly after the introduction of mine waste, and from the various mines and mills.

Wednesday, July 20. Returned by auto with field equipment down the north bank of the Coeur d'Alene River making special examinations at Mission Flats in the vicinity of Cataldo, at Dudley, at Fourth-of-July-Creek, and in Rose Lake. Returned to Harrison late that night.

Thursday, July 21. Continued the dredging and chemical work in Lake Coeur d'Alene.

Friday, July 22. Worked up Coeur d'Alene River, into Swan Lake and return.

Saturday, July 23. At the request of the Idaho Commission, our party with suitable field equipment left for British Columbia by auto. The object of this side trip was very specific. At Kimberley, British Columbia the same type of ore, processed by the same treatment, is being handled in enormous quantities and no stream pollution resulting. Due to the strict rulings of the Dominion Government of Canada and the Provincial Government of British Columbia against stream pollution the great Sullivan Mines and Mills of Kimberley, British Columbia have worked out a suitable and economical method of disposal for same sort of mine waste as that now polluting the waters in Coeur d'Alene River in Idaho. It was the request, therefore, of the Idaho Commission that our party make the same sort of examinations in the streams into which the Sullivan Mining Company in British Columbia pours its purified wastes as those we were making in the Coeur d'Alene District and that we become familiar with the processes involved in Canadian purification system so that we could give an intelligent opinion concerning the efficacy of this method. On this trip we were accompanied by Mr. E. O. Cathcart who represented the Idaho Commission. On crossing the border we were shown every courtesy by the Dominion officials and most cordially welcomed by the mine officials themselves at Kimberley, British Columbia.

During the morning of July 23, continued our dredgings and work on Coeur d'Alene Lake leaving Harrison, Idaho by auto with field equipment about three in the afternoon, arriving at Bonners Ferry, Idaho for the night, making examinations of the Pend Oreille River while enroute.

Sunday, July 24. Left Bonners Ferry, Idaho early in morning and proceeded to Kimberley, British Columbia arriving there shortly after noon. During the trip up studies were made of the Moyie River, the stream into which the waste waters from the Sullivan Mines plant at Kimberley flow. Spent the afternoon of July 24 in company with Mr. Banks of the Kimberley Mines studying the tailings deposits, at the Kimberley Mill.

Monday, July 25. Devoted the entire day to sampling, chemical work, and examination of the Sullivan Company's plants in and about Kimberley, British Columbia, particular attention being given to the method of waste disposal and the character of effluent leaving the waste basins.

Tuesday, July 26. Left Kimberley early in the morning, working at St. Marys, British Columbia where the purified waste from the mines enter the St. Mary's River which in turn flows into the Moyie River. Following the St. Mary's and Moyie Rivers back to the United States boundary, we crossed over into Kootenai River drainage, continued down the Kootenai River to Bonners Ferry, Idaho and returned to Coeur d'Alene City, Idaho for the night.

Wednesday, July 27. Our party was joined at Coeur d'Alene City, Idaho by Mr. F. S. Babbcock, Attorney General, State of Idaho and chairman of the Idaho Pollution Commission. In company with the Attorney General and Commissioner Cathcart our party proceeded by autos down the Spokane River which is the outlet of Coeur d'Alene Lake, to Post Falls, Idaho where an examination of the river was made. The object of this part of the trip was an examination of the Post Falls Power Dam which has been placed across the Spokane River by the Washington Light and Power Company, (a concern supplying the mines of north Idaho, various cities of north Idaho, and Spokane, Washington District with power and light). It is the contention of some that the erection of Post Falls, Idaho Dam has greatly increased the extent of the pollution in Coeur d'Alene Lake and the Coeur d'Alene River, in that, the dam has raised the water level in Coeur d'Alene and St. Joseph Rivers and has caused a backing up and flooding of certain lands previously not inundated. After visiting the Post Falls, Idaho, Dam, our party continued across the Idaho-Washington State Line into what is known as the Green Acres Irrigation Project. This project derives its water from the Spokane River which as previously noted is the outlet of Coeur d'Alene Lake. The contention has been raised by some that the finely divided mine slimes now carried by the Coeur d'Alene River, since the introduction of the floatation process at the mines in the Kellogg-Wallace District, have worked across Coeur d'Alene Lake without settling and that these slimes are passing out of Coeur d'Alene Lake and down the Spokane River across the State line into the State of Washington. In company with the Attorney General of the State of Idaho, Commissioner Cathcart and the Washington State Water Master for the Green Acres District our party collected samples from the main Spokane River and the principal irrigation ditches, and also samples of special slimes which had accumulated along the banks of

Spokane River. After completing this work along the Spokane River, in the State of Washington, our party returned to Harrison, Idaho.

Thursday, July 28. Final samples at Harrison, Idaho and vicinity were taken and material shipped back to the Columbia laboratory. Our party in company with Commissioner E. O. Cathcart left Harrison, Idaho at 5:30 p.m. by auto for Seattle, Washington for a conference with U. S. Army Engineer, Lieutenant-Colonel Sturdevant.

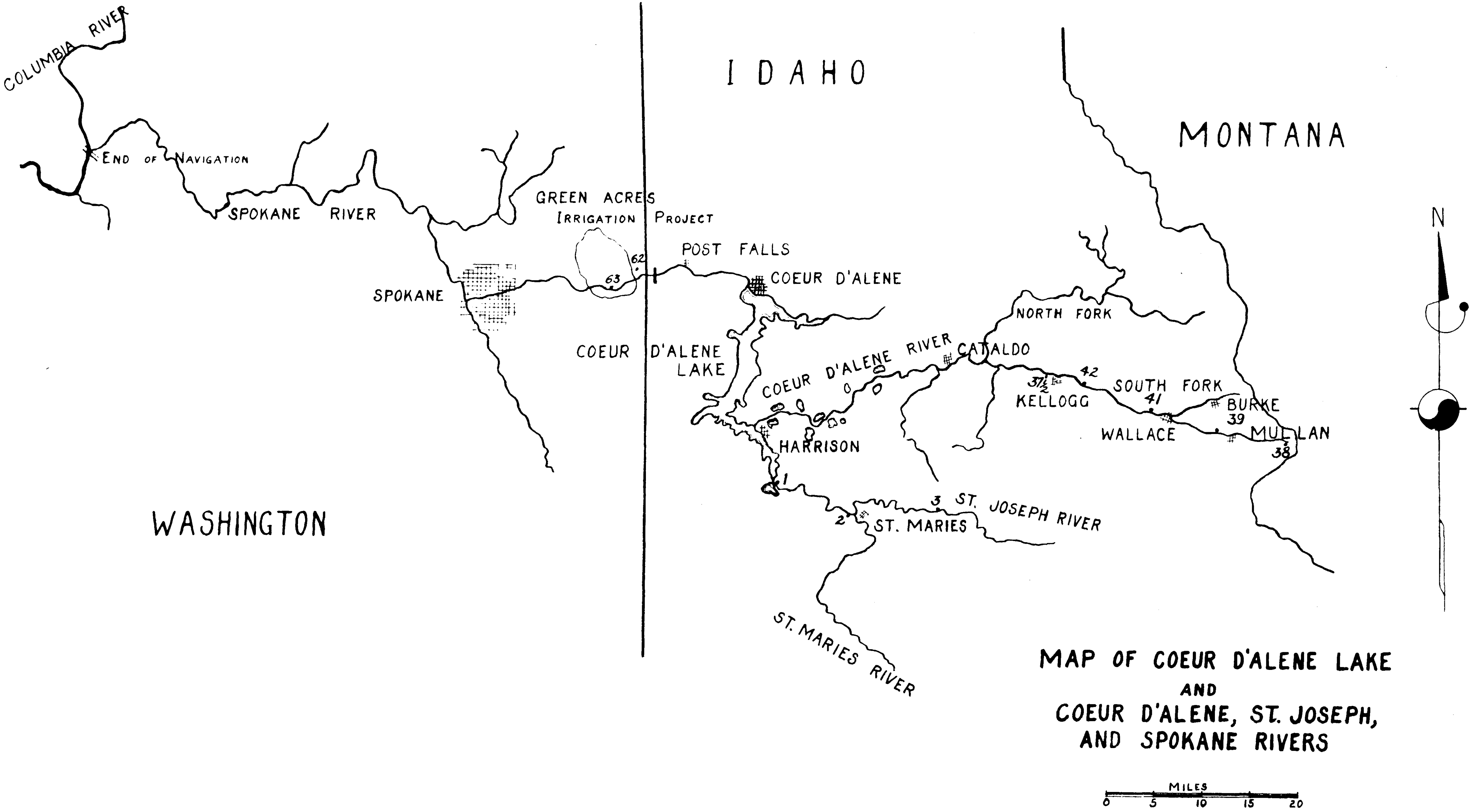
Friday, July 29. Arrived in Seattle.

Saturday, July 30. In conference in Seattle.

Monday, August 1. Completed work in Seattle and returned to Spokane.

Tuesday, August 2. Worked in Spokane River near Spokane.

Wednesday, August 3. Left for east.



MAP OF COEUR D'ALENE LAKE
AND
COEUR D'ALENE, ST. JOSEPH,
AND SPOKANE RIVERS

Localities of Coeur d'Alene Investigations

July, 1932

Locality Number	Description of Locality
C1	Coeur d'Alene Lake; at mouth of St. Joseph River, a little below Ramsdale, along the log boom.
C2	St. Joseph River; along the log boom at St. Maries near Powell Sanders Co. store; depth 4.6 meters.
C3	St. Joseph River; 10 miles above St. Maries and a little below Rochett Creek at foot of St. Joe Baldy.
C4	Coeur d'Alene Lake; in front of Harrison, Idaho, a series of six stations in a line from 500 feet to one-half mile from Andy Botham's boat house; depth 3, 6, 9, 12, 15, and 18 meters.
C5	Coeur d'Alene River; along log boom at Export Mill, near mouth of the river.
C6	Anderson Lake; near south end; water sparkling, clear brownish.
C7	Anderson Lake Ditch; half way between lake and Coeur d'Alene River; water not sparkling, ditch water with yellow-green cast of the river water.
C8	Thompson Lake and ditch.
C9	Blue Lake; about the middle of the lake.
C10	Blue Lake; in <u>Sagittaria</u> and grass near margin.
C11	Cave Lake; in front of John Snider's boat house at Medimont, Idaho; water sparkling, clear, brownish.
C12	Cave Lake, deepest place in the lake, three-fourths miles south of Medimont, in a bay with a wall of lava and basalt rock some ten feet above the lake surface to the west; depth 6 meters.
C13	Cave Lake; alongside a bed of <u>Nupar</u>, across the lake from Medimont.

C14	Medicine Lake; deepest place in the lake, east of the center of the south end of the lake; depth 6 meters. A series of 5 bottom samples in the immediate vicinity were at depths 4, 3, 2, and 1 meters.
C15	Medicine Lake; at mouth of small inlet stream; depth 1 meter.
C16	Coeur d'Alene River; at lower Medimont Ferry, in midstream; depth 12 meters.
C17	Coeur d'Alene River; just inshore from Andy Botham's boat house at Harrison, Idaho.
C18	Coeur d'Alene Lake; about mid-lake opposite Farmington Landing, between the landing and East Point; depth 22 and 25 meters.
C19	Coeur d'Alene Lake; mid-lake two miles west from mouth of Coeur d'Alene River.
C20	Coeur d'Alene Lake; 100 yards off shore at Harrison, pumping station.
C21	Coeur d'Alene Lake at mouth of St. Joseph River, alongside the sorting boom on the east side of the river.
C22	Piling at Springston Mill beside Coeur d'Alene River.
C23	Thompson Flat; alongside of Thompson Lake ditch.
C24	Coeur d'Alene River, just below mouth of Thompson Lake Ditch; depth 17 meters.
C25	Coeur d'Alene Lake; in center of Windy Bay; depth 32 meters.
C26	Coeur d'Alene Lake, off Balck Rock; depth 39 meters.
C27	Coeur d'Alene Lake; between Lofts Bay and Bellegrove Bay, opposite Turner's Bay and Spokane Mountain; depth more than 50 meters.
C28	Coeur d'Alene Lake; along the boom one-half mile above Blackwell's Mill at the foot of the lake; depth 5 meters.

C29	Coeur d'Alene Lake; half way between Clackwell's Mill and Three Mile Point; depth 16 meters.
C30	Coeur d'Alene Lake; mid-channel at Niggerhead Point; depth 49 meters.
C31	Coeur d'Alene Lake, mid-channel between Echo Bay and Bellegrove, out from the reef; depth 60 meters.
C32	Coeur d'Alene Lake; near shore at East Point.
C33	Lake Chatcolet; off Rocky Point; depth 11 meters.
C34	Lake Chatcolet; across bay from Rocky Point, alongside a weed bed; depth 2.5 meters.
C35	Lake Chatcolet; at the west end of the lake just off mouth of Plummer Creek; depth 2 meters.
C36	St. Joseph River; just above outlet from Lake Chatcolet; depth 6 meters.
C37	Black Lake; off Foster Point; depth 5 meters.
C37.5	Bradley, Idaho; just below Bunkerhill Mills, on flat 200 yards from South Fork of Coeur d'Alene River.
C38	South Fork of Coeur d'Alene River; one-fourth mile above Larson, Idaho. Above the mines, river a cold, swift mountain stream; depth 1 meter.
C39	South Fork of Coeur d'Alene River below Golconda Mill; depth 0.6 meters. This station is also below Morning Mill and Mullan but as these mills were not in operation at the time samples were taken (July, 19), the river was clear.
C40	Placer Creek; just above Wallace, Idaho, a little above the swimming pool, source of Wallace water supply, shallow.
C41	South Fork of Coeur d'Alene River; near Wallace, Idaho just at the bridge east of the County Hospital; depth 8 inches. This is below Wallace and the stream was turbid with mine waste. Considerable floating garbage was noted a mile upstream from this point.

C42	South Fork of Coeur d'Alene River; just above the bridge below which the Sunshine waste flume empties into the River; depth 7 meters.
C43	South Fork of Coeur d'Alene River; 240 feet below the mouth of the Sunshine waste flume; depth 6 inches.
C44	Hecla Mill; above Wallace, Idaho.
C45A	Hecla Mill; above Wallace, Idaho.
C45B	Hecla Mill; above Wallace, Idaho.
C46	Canyon Creek; at the dam, above Wallace, Idaho.
C47	Gem Mine; (inactive) on Canyon Creek.
C48	Tiger Mine; (inactive) on Canyon Creek.
C49	Morning Mine Tunnel; Morning, Idaho.
C50	South Fork of Coeur d'Alene above Deadman, Idaho.
C51	South Fork of Coeur d'Alene below Deadman and above Mullan, Idaho.
C52	Coeur d'Alene River; under bridge and opposite Dudley, Idaho (Kootenai County).
C53	Fourth-of-July Creek; opposite Dudley.
C54	Rose Lake; at swimming beach near Rose Lake, Idaho.
C55	Old Mission Slough; flows into Coeur d'Alene River at Old Mission near Cataldo, Idaho.
C56	Coeur d'Alene River; one-fourth mile above the mouth of the river and a little below the Export Mill, along the log boom; depth 9 meters.
C57	Coeur d'Alene River; at mouth of Swan Lake Ditch, alongside the sheer boom.
C58	Swan Lake; in the open water of the main lake basin, water not very clear looks like the water and bottom of the river; depth 4.5 meters.

C59	Sullivan Mine, Kimberley, British Columbia.
C60 a & b	Sullivan Mill, Kimberley, British Columbia, just below the south dam of the settling basin below the iron sulphide pile.
C60c	Sullivan Mill, Kimberley, British Columbia, waste flume as it leaves the mill.
C61	Little stream carrying settled out run-off from the Sullivan Mill settling basins bound for St. Mary's River, a point where the stream crosses the Kimberley-Cranbrook road near the school house west of St. Marys, British Columbia.
C62	Corbin Irrigation ditch from Spokane River where the 'feeder' crosses the second road south of the Idaho-Washington state line, about one-fourth mile east of "Apple Road ".
C63	Flat below the bridge over the Spokane River on the "Apple Road". This is in Green Acres Irrigation Project, Washington.
C64	Pool in Canyon Creek back of water-supply dam above Burke, Idaho; depth approximately 4 meters.
C65	Conkling Park, Coeur d'Alene Lake.

Hazards Presented to Aquatic Life by the Coeur d'Alene Mining Operations

The pollution problems incident to the mining operations in the Coeur d'Alene District are of a scant 50 years standing. The discovery of gold by A. J. Pritchard on the North Fork of the Coeur d'Alene River in 1883 (Stoll, 1932) was responsible for the first rush of miners into this region, but the extensive mining operations of today in the Coeur d'Aldnd District date back to the Bunker Hill Strike in 1885. With the development of the "Bunker Hill", the "Morning", the "Hecla", the "Star", the "Golconda", the "Sunshine" and other mining properties in this region the tonnage of rock handled annually rose rapidly and the quantities of mine tailings and mine waters poured into the South Fork of the Coeur d'Alene River increased accordingly as these operations assumed the proportions of a large industry.

The ore deposits in Coeur d'Alene District are primarily sulphides, chiefly sulphides of lead and zinc, associated with which are deposits of silver, cadmium, bismuth, arsenic, antimony and iron. The bulk of the ore now being mined occurs as sphalerite (zinc sulphide), marmotite (iron-zinc sulphide) and galena (lead sulphide), through which usually are rather intricately mixed varying amounts of arsenic, antimony, cadmium, cobalt and silver depending upon the lode.

For the first 30 to 35 years of these operations the ore was concentrated by the "stamp-mill and jig-table" process. In this method the ore bearing rock is reduced to a rather fine powder are then separated by gravity and water on the "jig-table". The jig-table operations therefore, contribute large volumes of waste waters carrying the pulverized rock together with some particles of the ore which escape from the grooves on the jig-table. This suspension of powdered rock runs rather high in magnesium, manganese, and silica.

As the mining operations became more extensive the stopes were enlarged and mine waters were encountered. These natural waters in running out of the mines pass over various rocks as well as the ore deposits and become a pollution hazard, particularly if they flow over iron deposits. The mine water run-off removed from the mines of the Coeur d'Alene District daily amounts to thousands of gallons.

The mixtures of mine waters and the waters from jig-tables of the mills constituted the bulk of the waste entering the South Fork of the Coeur d'Alene River during the first 30 to 35 years of these mining operations. Because of the location of these mines, in the rough, mountainous district near Wallace and Kellogg, Idaho, the most obvious channel for the disposal of this pulverized waste rock and used water was the Coeur d'Alene River. During the First 30 or 35 years of the active operation of the Coeur d'Alene District, the mine wastes, primarily the jig-table wastes as previously noted, were turned, therefore, into the Coeur d'Alene River without restriction and enormous quantities of finely powdered rock were deposited in the upper reaches of the South Fork of the Coeur d'Alene River. Because of the nature of the stamp-mill-jig-table process the individual particles of rock although small were not colloidal in nature and these particles of rock settled rather rapidly by their own weight in the upper parts of the stream. Visible pollution of the main Coeur d'Alene River, that is the river below the junction of the North and South Forks, by the mine wastes was therefore not evident for more than eight or ten miles down stream during the earlier period of these operations. However, as time went on and the mining operations increased, the mine wastes, settlings and tailings were carried farther down the main Coeur d'Alene River to Mission Flats near Cataldo, Idaho, a distance of some 20 miles below the mines. Here the river widens slightly and a natural sedimentation area was developed. In the region of Cataldo and Mission Flats large quantities of mining tailings settled out and the deposits in the river channel itself and along its banks where the wastes have settled out during high water are today acres in extent. In fact the entire Mission Flats of several square miles is now (1932) very largely covered with these tailings and slimes. (See Figures 3 and 4).

According to various steamboat captains operating boats on the Coeur d'Alene Lake and the St. Joseph, St. Maries and Coeur d'Alene Rivers, the Coeur d'Alene River was formerly navigable to a point above Mission Flats. These steamboat men

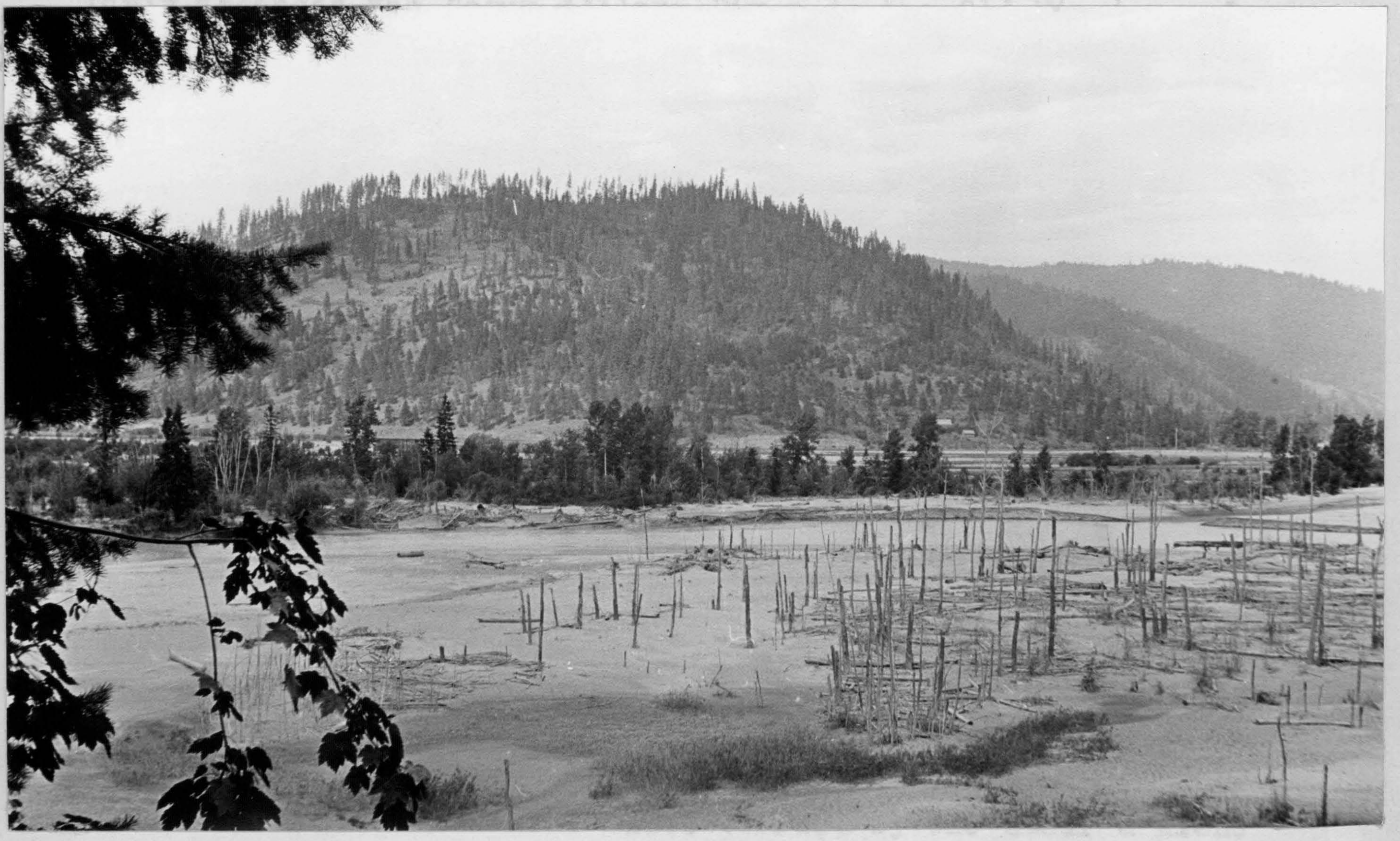


Figure 3.

Mission Flat near Cataldo, Idaho showing timber killed by the deposits of mine slimes on the bank of the Coeur d'Alene River. The Coeur d'Alene overflows the area in the immediate foreground during each period of high water depositing mine slimes well back from the bank of the river as marked in low water.

repeatedly assured the writer that 15 to 20 years ago steamboats carrying passengers and tug boats moving log rafts regularly ascended the Coeur d'Alene River to the Old Mission and that the channel carried from 40 to 50 feet of water in this part of the river. The writer's own soundings during the month of July, 1932 showed only 12 to 15 feet of water in the main channel in this region, both the channel and main stream being obstructed here and there by large bars of mine wastes and tailings.

The continued operation of the mines in the upper Coeur d'Alene District so loaded the South Fork of the Coeur d'Alene River with mine wastes that masses of rock powder not only covered the Mission Flats but were carried down stream beyond Mission Flats and Cataldo (see map, Figure 2) gradually contaminating the entire Coeur d'Alene River between Mission Flats and its mouth near Harrison, Idaho.

The amount of mine waste carried by the Coeur d'Alene River at its junction with Coeur d'Alene Lake was very considerable even in 1911 as may be seen from the following statement made by Kemmerer (1923, p. 80) concerning the conditions which he found when surveying Coeur d'Alene Lake in 1911, "------at Harrison it (the Coeur d'Alene Lake) receives the muddy waters of the Coeur d'Alene River, which drains an immense area, including the famous Coeur d'Alene mining district. These waters are so laden with

Figure 4.

Mission Flat near Cataldo, Idaho showing enormous deposits of mine slimes along the bank of the Coeur d'Alene River.

silt that they may be traced far out into the clear water of the lake".

It is readily recognized that the enormous amounts of finely divided rock which have been poured into the river in such quantities as to form bars and shore deposits along the banks of a stream for over 50 miles must constitute a very definite hazard to certain forms at least of aquatic life because of the mass of material involved, regardless of the chemical composition of the rock powder.

As the jig-table method did not recover all of the ore considerable quantities of lead and zinc ore were lost in these tailings and mine wastes and were carried by the water with the other rock particles to be deposited along the course of the Coeur d'Alene River. No effort was made during the first 25 years of these operations to use certain zinc ores because under the former method of separation these ores could not be profitably smelted, and such ores when mined were also turned into the stream, so that the tailings up to a few years ago were fairly rich in both zinc and lead sulphides.

During each high water, particularly during the spring run-off, the Coeur d'Alene River spreads out over the low lands along each bank, flooding many acres which are under cultivation. As the mine slimes became more and more abundant in the lower part of the river, deposits of these rock powders were left on the flooded land after the recession of the water. These mine slimes were thus exposed to the action of sun, rain, and air, and such disintegration products or compounds as might be formed by such action could easily be returned to the stream by rain run-off or during the next period of high water.

Some 15 years ago suit was brought against the mines by the residents of the lower part of the Coeur d'Alene Valley for alleged damages resulting to their lands by the deposition of finely divided rock and other mine wastes upon the land by the Coeur d'Alene River during periods of high water, which deposit produced serious changes in the condition of the soil. These complaintants also set forth that the rock powder deposited on their lands by the river, that is the mine wastes, was of a highly toxic nature and that normal vegetation, crops and hay were killed out and the the stock particularly horses, and to some extent cattle, dogs and chickens were killed by the substances left upon the grass and along the shore of the river after the water receded. These plaintiffs also stated further that the substances brought down from the mines and deposited by the river on the lands, produced certain toxic substances when exposed to the air, for which the stock, particularly the horses, developed a fondness. These toxic substances when eaten by stock speedily produced death. The complaints may be summarized as calling for the destruction of valuable agricultural land, the killing off of crops, and the poisoning of live stock.

Throughout all of this legal action stress was laid on the formation of toxic crystalline substances from the mine wastes in the soil and along the river bank after the recession of the river. These crystalline substances which developed from the mine wastes were popularly referred to as "lead". Therefore in the lower Coeur d'Alene District the laymen refer to "leaded waters", "leaded hay" and "leaded soil" in connection with soil or vegetation which has been submerged or otherwise subjected to the action of the water of the Coeur d'Alene River and the suspended mine waste which that river is carrying. The next point of contact, therefore, in connection with these pollution studies is the so-called "crystalline lead" which develops in the areas which have been flooded by the polluted waters. The writer saw large masses of this so-called "lead", and this material forms the basis of some of the experimental studies presented in this report (v.i.).

The next phase of this pollution problem developed some five years ago when the Coeur d'Alene mines installed floatation plants. The floatation process which is one of newer developments in lead and zinc mining, has several points of contact with the pollution problem. The ore is reduced in ball mills to a powder so fine that 90 percent or more of the particles will readily pass through a 200 mesh screen, that is 200 meshes to an inch, and a large portion of the crush ore-bearing rock will pass through 250 to 500 mesh screen. At one mine the writer was assured by the chemist in charge, and shown laboratory proof of the statement, that a considerable percent of the particles would pass through a 1,000 mesh screen. The ore-bearing rock is therefore reduced to a powder much finer than the powder formerly used on the jig-tables and so fine that when shaken in water a considerable portion becomes a true colloidal suspension. The separation of the ore from the worthless rock in the floatation process is accomplished by bubbling and stirring an aqueous suspension of this rock powder after it is taken from the ball mills, to which suspension several chemicals are added. By means of the proper adjustment of these chemicals the floatation process now makes it possible to separate intricate mixtures of lead and zinc ores and the reclamation of the ore itself is very much more complete than under the former jig-table system of operations. The floatation process, however, has greatly increased the pollution problem in the following ways:

(1) Ore of much lower grade can be profitably handled by the floatation process so that the amount of rock powder added to the mine run-off is much greater than under the jig-table system in which only relatively high grade ore could be used.

(2) The rock powder discharged from the floatation mills is very much finer than that discharged from the jig-tables and is so fine that it does not readily settle out, being carried much farther by the river currents.

(3) Although the actual amounts of ore lost in the mine wastes is much less from the floatation process, the ore particles which do escape are much finer than those lost from the jig-tables; consequently the ore particles from the floatation process are carried much farther by water currents, and because of the very small size of these floatation ore particles they are much more susceptible to chemical change.

(4) The floatation process calls for the use of various amounts of sodium carbonate, copper sulphate, zinc sulphate, and potassium dichromate and although these substances are in part neutralized or otherwise removed from the wastes, portions of these chemicals (a very large proportion of the sodium carbonate) and a portion of their disintegration products, are included in the mine wastes, presenting another pollution hazard.

(5) The floatation process requires the use of certain "float substances", that is substances promoting the bubbling and frothing of the mixture of pulverized ore-bearing rock and water, and otherwise aiding in the separation of the minute ore particles. Tar oil, croesilic acid and potassium xanthate are the "floats" commonly used and although they are added in only small quantities to the suspension of the rock and ore in water, these "float" substances are to a large extent carried away with the waste water, so that the characteristic odors of the xanthate, croesilic acid and tar oil are readily detectable in the mine waste water at some distance from the flumes pouring this material into the river. The toxic actions of these float substances are also discussed in the experimental section.

With the introduction of floatation process in the Coeur d'Alene District the visible pollution of the streams greatly increased as the finely divided rock was carried in suspension much farther than before. The finely divided float wastes, which are locally referred to in the mine district as "mine slimes" have spread down the entire length of the Coeur d'Alene

River to its mouth in Coeur d'Alene Lake near Harrison, Idaho. The water of the Coeur d'Alene River in July, 1932 when the mines were running only part time, was distinctly turbid and of greenish cast due to these suspended slimes, even at the point where the river enters the Coeur d'Alene Lake. Local residents informed the writer that at times this same suspension of mine slimes discolored the entire surface of Coeur d'Alene Lake as far as Coeur d'Alene City, Idaho some 22 miles up the lake from the point at which Coeur d'Alene River enters the Coeur d'Alene Lake. These statements were verified by boat captains who regularly ply on the Coeur d'Alene Lake. The writer himself observed no such discoloration of the lake water during his stay on the lake but was assured that the lake was clear at the time owing to the small output of the mines during the past few months (June and July, 1932). Since the installation of the floatation process in the upper Coeur d'Alene District the damage to agriculture and stock has been reported as serious.

These slimes as deposited in the lower part of the Coeur d'Alene valleys constitute an additional pollution hazard in that as left on the banks and low lands the slimes are subsequently returned to the stream in part by rains and winds, constituting a repolluting of the river by material which it has deposited. In addition crystalline substances, freely soluble in water, are formed in these slimes when they are exposed to the action of air on the low flats after the recession of the river, and these soluble substances also are washed back into the stream by each rain.

From the standpoint of fisheries problems the mine wastes from the Wallace-Kellogg District constitute definite pollution hazards which may be tabulated as follows:

(1) The introduction of large quantities of very finely divided rock present pollution hazards of the same general sort as those presented by erosion material or erosion silt elsewhere.

(2) The presence of the sulphides of various heavy metals, the soluble salts of which are toxic, constitutes a pollution hazard in that these sulphides in the presence of water and air may change over to other compounds more dangerous than the sulphides themselves.

(3) From the disintegrating rock powder, the ore particles, and the chemicals introduced in the mining process itself, certain other chemical compounds can be formed which present pollution hazards.

(4) The finely divided material introduced from the floatation plants is carried in a colloidal suspension long dis-

tances down stream and out into the adjacent lakes, and may effect the chemical and physical condition of the water so polluted, to the detriment of plankton and other organisms on which fish life depends.

(5) Certain specific substances of possibly toxic nature are introduced into the stream directly as the result of these mining operations.

All of these above contacts have been considered in the present survey.

Fish Fauna of the Coeur d'Alene Basin, 1932

In the course of a survey of the Coeur d'Alene River during the month of July, 1932, no live fish of any species were found in the Coeur d'Alene River from its mouth near Harrison to the confluence of the North and South Forks above Cataldo, nor in the South Fork from its junction with the North Fork to a point above Wallace, that is, that portion of the Coeur d'Alene River (the main stream and the South Fork) carrying the mine wastes and mine slimes was without a fish fauna as far as could be determined. This stretch of river is some 50 miles in length. The same survey found bass and perch in all of the small lakes tributary to the Coeur d'Alene River below Cataldo; trout and suckers in Latour Creek (see map, Figure 2), a tributary stream entering the Coeur d'Alene River near the Old Mission; trout and dace in Deadman's Creek and other tributaries of the South Fork above Wallace; and trout, bass, perch, and dace in the St. Joseph River, an unpolluted stream entering Coeur d'Alene Lake south of Harrison and comparable in many ways with the Coeur d'Alene River.

As several species of fish were found regularly in the unpolluted streams and lakes of the region and as fish were taken in streams and lakes tributary to the Coeur d'Alene River quite close to their junctions with the River, although

Figure 5.

Coeur d'Alene River just below Export Mill near Harrison, Idaho, about one mile from the mouth of river. The river at this point is deep with little current and distinctly turbid.

always above the backwater from the Coeur d'Alene, the correlation between mine waste pollution and the distribution of fish in the Coeur d'Alene District is an evident one. Local residents stated that at times fish had been seen to enter the polluted portion of the Coeur d'Alene River from tributary streams, and that dead or dying fish were often found in the Coeur d'Alene River just below the mouths of tributary streams, but that there was no evidence that fish entering that portion of the Coeur d'Alene River carrying mine wastes ever survived any length of time. This statement was confirmed experimentally by the writer (see page 73).

Perch were reported from certain backwaters in the Mission Flats area, although no specimens were seen by the writer, but it is not at all unlikely that small numbers of fish may be able to live at various points along the Coeur d'Alene River in restricted areas where the fish are protected by local conditions, even though no such areas were found during this survey. However, the striking observation to be made from the field studies in the Coeur d'Alene District is that the 50 miles of the Coeur d'Alene River carrying mine wastes are essentially without a fish fauna. There is no reason to believe that this portion of the Coeur d'Alene River possesses some natural peculiarity which makes it impossible for fish to line in these waters as fish are found in the South Fork above the polluted area and in the unpolluted North Fork. Twenty years before the mines on the South Fork were opened the Coeur d'Alene River in the vicinity of Mission Flats was contributing through its fish to the maintenance of a tribe of some 300 Indians, for Captain John Mullan, U. S. A., (1863, p. 49) who made the Old Mission near Cataldo one of his bases of operations during his surveys of this section of the country between the years of 1854 and 1862, wrote that "The Coeur d'Alanes (Indians) number about 300, live at the Mission, and along the Coeur d'Alene and St. Joseph Rivers. They live by hunting, fishing and cultivating the soil". Stoll (1932, p. 4) in describing the Coeur d'Alene country just prior to the gold strike of 1883 states that "its (Coeur d'Alene District) rivers teemed with trout". From these and other references it is certain that fish were formerly found in the Coeur d'Alene River so that inspite of various other factors which also may have contributed to the elimination of the fish fauna of the polluted portion of the Coeur d'Alene River the present sterile conditions of that part of the river must be associated with the mine wastes and mine slimes which have been poured into that stream.

In Coeur d'Alene Lake no fish were found in the immediate vicinity of the mouth of the Coeur d'Alene River, additional evidence that the mine wastes and mine slimes are at present in some way detrimental to fish or conditions supporting fish life. However, along the bathing beach in front of Harrison, and around the lake to the mouth of the St. Joseph River many schools of young perch were often seen, as well as here and there a few dace minnows. At Conklin Park across the Lake from Harrison, and south toward the mouth of the St. Joseph, many bass were seen in the shallows close to shore. That there has been a decline in the trout fishing in Coeur d'Alene Lake from the days of Captain Mullan (1863, p. 16) who in 1858 described Coeur d'Alene Lake as "a noble sheet of water ---- filled with an abundance of delicious salmon trout", to the present time, when trout are rarely caught off Harrison, can not be denied, but many causes have contributed to this change in the fish population of this lake. Nearly all of these western lakes which in the early days supported large numbers of trout have been modified by deforestation, by the cultivation of land draining into them, and by other conditions incident to the advance of civilization, so that the chemical and physical features of these lakes now present a complex much less favorable to trout than formerly, although these same lakes may at present support both bass and perch. This phase of lake modification has already been pointed out by Kemmerer (1923) for various Idaho Lakes. In addition the sudden temporary changes in lake conditions often greatly disturb trout, as for example the specific case of the construction work up the St. Joseph River by the Milwaukee Railroad in 1911

Figure 6

Coeur d'Alene looking down on Beauty Bay during which operations so much mud was sluiced into the St. Joseph River that the trout were driven out of the upper end of Coeur d'Alene Lake (Kemmerer, l.c., p. 83). Changes in the trout fauna alone of Coeur d'Alene Lake therefore can not be used as significant indices of the pollution of that Lake by mine wastes from the Coeur d'Alene River until various other factors have been evaluated.

Plankton and Other Fish Food Found in the Coeur d'Alene River and Adjacent Waters, 1932

A. Plankton

The importance of plankton plants and animals as the basic links in the food chains of all fishes and other aquatic animals is so well established that the abundance and even the survival of fishes in any given stream or lake is known to be dependent upon the abundance of the proper species of plankton organisms.

No phyto-plankton nor zoo-plankton were found in the waters of the main stream of that portion of the Coeur d'Alene River carrying mine wastes, that is the Coeur d'Alene River and the South Fork from above Wallace to the mouth of the river near Harrison. The backwaters also, as far as examined, with the single exception of a slough near the Old Mission, contained no free-living plankton. In the waters of this slough near the lower end of Mission Flats a few copepods (less than 500 per cubic meter of water) were found, but as this slough received spring water and other unpolluted waters from small lateral streams, the waters of this slough were not directly comparable with those of the polluted river. Above Burke (Locality C64), in Canyon Creek, the untreated waters of which are used for drinking water in Burke as this stream is an unpolluted tributary of the South Fork, copepods and cladocerans, together with numerous nauplii were found in abundance (copepods, 8,000 or more per cubic meter of water) showing that the quieter portions of this unpolluted stream were supporting a plankton fauna of at least average magnitude for such waters.

In contrast to the practically plankton-free condition of the polluted portion of the Coeur d'Alene River are the plankton findings in the lakes adjacent to the Coeur d'Alene River, and in the St. Joseph River and Chatcolet Lake. Killarney Lake was not visited so can not be discussed in this connection, but from five of the eight remaining major lakes along the Coeur d'Alene River between Cataldo and Harrison, good to very good plankton catches were taken. The zoo-plankton in these lakes consisted primarily of copepods both adults and nauplii, and cladocerans, and the phyto-plankton of diatoms, with some other forms of algae. For comparison the copepod counts from these five lakes, together with the copepod counts from Coeur d'Alene Lake, the St. Joseph River, and Chatcolet Lake have been summarized in Table 1. The actual numbers of adult copepods per cubic meter of water in the surface zone, i.e. between the surface and the two-meter level, are given.

Using the copepod counts as indices Anderson Lake and Black Lake can be rated as very good, Rose Lake and Cave Lake as good and Medicine Lake fair to good, as regards plankton fauna, by comparison with other western lakes (see Kemmerer, 1923). In this connection the plankton taken at Station C7 in the ditch connecting the Coeur d'Alene River with Anderson Lake should be noted. At the point where this catch was made the clear water of Anderson Lake was mixing with turbid greenish water backed up from the Coeur d'Alene River, the current moving from the lake toward the river. In these mixed waters the copepod count dropped from 14,400 per cubic meter (Anderson Lake) to 1,600 per cubic meter, and 100 yards downstream from Station C7, at a point where the water from the lake was completely mixed with that of the Coeur d'Alene River, no plankton was found.

In the waters of Swan Lake, Blue Lake, and Thompson Lake very few plankton animals were taken, and the total amount of plankton in these lakes was so small as to be negligible as a source of fish food, in fact in most of the tests of the waters of these lakes no plankton of any sort was found during the month of July, 1932.

Following the Coeur d'Alene River out into the Coeur d'Alene Lake the absence of plankton of the mouth of the Coeur d'Alene River (Station C19) and along the east shore of the lake, i. e., in front of Harrison was conspicuous. Near East Point in Coeur d'Alene Lake small catches of plankton were made (copepods, 500 per cubic meter of water) and off Niggerhead Point fair plankton catches were made (copepods 1,000 per cubic meter). It must be pointed out, however, that off Niggerhead Point water from Wolf Lodge and Beauty Bay mixes with the water from the south end of the lake. The Wolf Lodge section of Coeur d'Alene Lake receives no mine wastes, and in the vicinity of Beauty Bay there are several areas of aquatic vegetation which contribute a considerable amount of plankton to this portion of Coeur d'Alene Lake. All of the plankton catches taken from Coeur d'Alene Lake during July, 1932 averaged much lower than those taken by Kemmerer (1923) from this lake in 1911. Much the same distribution of plankton in the lakes was noted in 1932 as was recorded by Kemmerer, who in 1911 remarked that the plankton counts in the vicinity of the mouth of the Coeur d'Alene River and near Harrison were lower than elsewhere in the lake. As has already been pointed out in the present discussion (page 22) Kemmerer reported in 1911 that the suspended matter carried by the waters of the Coeur d'Alene River could be traced well out into the lake.

Near the mouth of the St. Joseph River at the south end of Coeur d'Alene Lake the plankton count rose, because of the contributions made by the waters of the St. Joseph River, the copepod count at Station C21 being 1,500 per cubic meter and in the St. Joseph River at Station C2, 3,000 per cubic meter. The waters of Chatcolet Lake, a tributary of the St. Joseph River were rich in plankton, the copepod count running 9,200 per cubic meter, and associated with these copepods were large numbers of cladocerans, diatoms and various species of micro-algae.

The field observations on plankton present definite evidence that the mine wastes and mine slimes are detrimental to plankton organisms, the polluted portion of the Coeur d'Alene River being essentially plankton free as well as Swan, Blue, and Thompson Lakes, which at the time visited showed evidence of pollution from the Coeur d'Alene River. The plankton findings in the Anderson Lake, Anderson Lake Ditch and the Coeur d'Alene River at its junction with Anderson Lake Ditch confirm the general findings in a specific case, and the absence of plankton in Coeur d'Alene Lake near the mouth of the Coeur d'Alene River, and off Harrison in a section of the lake more or less polluted by the waters of the Coeur d'Alene River, is at least suggestive in this connection.

Table 1

Copepod count per cubic meter of water, surface to two meters depth, July, 1932

Locality	Name of Station	Adult copepods per cubic meter
C6	Anderson Lake	14,400
C37	Black Lake	12,000
C54	Rose Lake	8,000
C13	Cave Lake	6,400
C14	Medicine Lake	2,800
C7	Anderson Lake Ditch	1,600
C19	Coeur d'Alene Lake, mouth of Coeur d'Alene River	none
C17	" " " , off Harrison	none
C18	" " " , near East Point	500
C30	" " " , off Niggerhead Point	1,000
C21	" " " , mouth of St. Joseph River	1,500
C2	St. Joseph River	3,000
C34	Chatcolet Lake	9,200

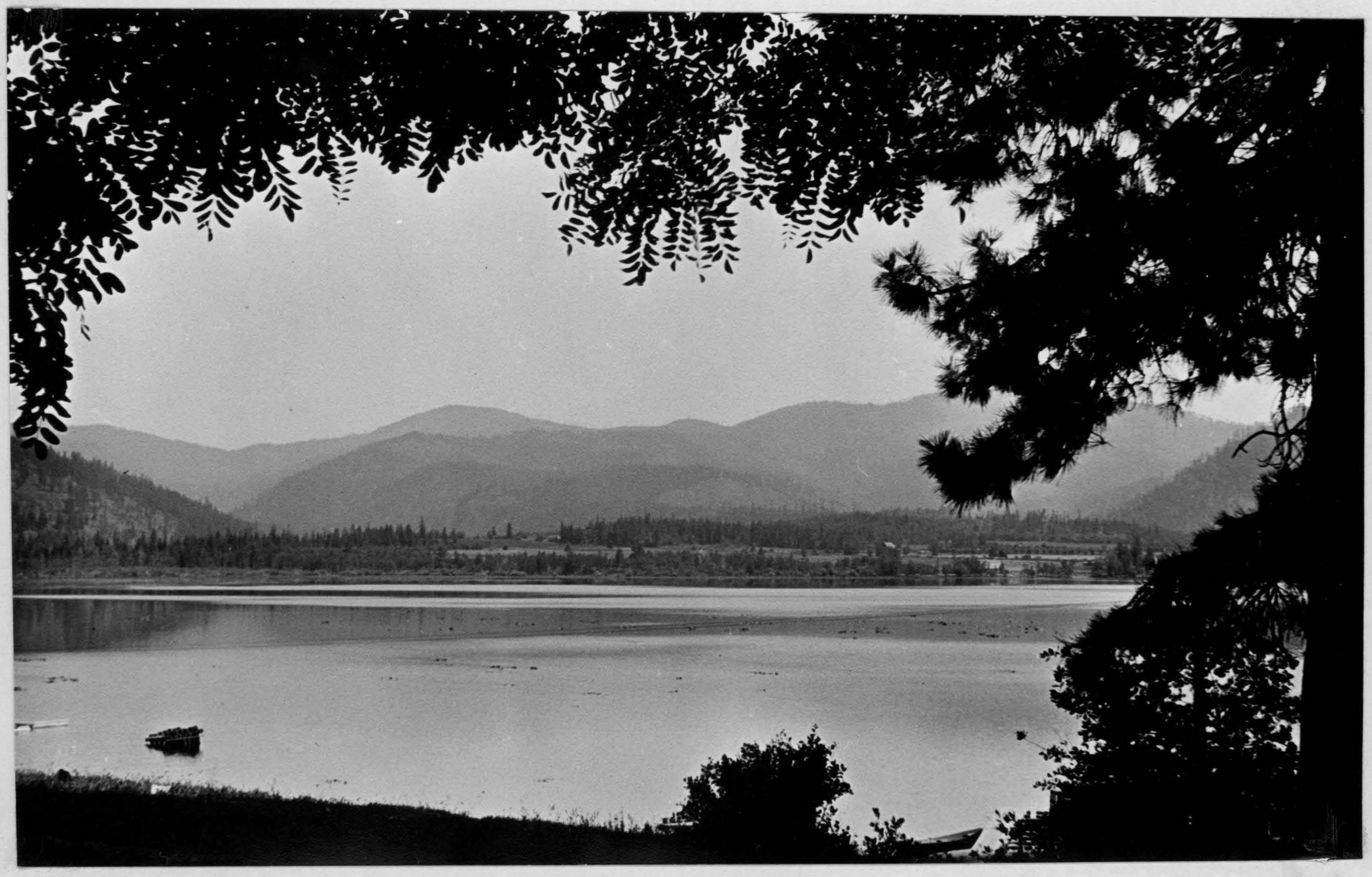


Figure 7.

Cave Lake as seen from Medimont, Idaho. This is a typical example of the lateral lakes adjoining the Coeur d'Alene River.

B. Bottom fauna

A second important source of fish food is the bottom fauna, consisting in most streams and lakes primarily of insects, both larvae and adults, together with various species of worms, mollusca and entomostraca. In the survey of the Coeur d'Alene District bottom samples were obtained by dredging at all of the principal stations, and these samples subjected to both biological and chemical examinations.

The polluted portion of the Coeur d'Alene River, as previously defined, was found to be practically devoid of bottom fauna. Only in the immediate vicinity of the mouths of unpolluted streams joining the Coeur d'Alene River, and not always there, were any of the forms of aquatic insect larvae commonly representative of the bottom fauna in unpolluted streams and lakes, taken in the bottom samples. The few forms collected at such stations were obviously inhabiting the delta formations of these lateral streams and therefore were not subject to the true river environment. No bottom animals were found close inshore in the river proper nor on any of the flats or bars of mine wastes in the Coeur d'Alene River or along its banks.

In and on the mud and debris at the bottoms of Anderson Lake, Black Lake, Cave Lake and Rose Lake many aquatic organisms of various species were maintaining themselves. In Black Lake.

and Anderson Lake midge larvae (Chironomids and related forms) were particularly abundant in the bottom zone, and in all of the four lakes named a productive bottom fauna was flourishing. Below the aquatic vegetation in these lakes numerous dragon-fly nymphs (both Zygoptera and Anisoptera), beetle larvae, and bottom plankton forms were taken. Although a representative bottom fauna was found in Medicine Lake, fewer individuals were noted in the samples collected.

The bottom fauna in Swan, Blue and Thompson Lakes at the time of this survey was very meagre, the samples from even the more favorable stations near aquatic vegetation yielding only a few blood-worms (Chironomus).

Above Wallace, that is above the polluted portion of the Coeur d'Alene River, a rich bottom fauna was found in the South Fork and in its unpolluted tributaries. Large numbers of caddis-fly larvae (Trichoptera) encrusted the submerged stones in these streams, and stone-fly larvae (Plecoptera) and may-fly nymphs (Ephemerida) were abundant. Many of the submerged rocks were covered with mats of the smaller species of algae, and these mats sheltered a diverse fauna of rotifers, flat-worms, small insect larvae and protozoa. All types of bottom aquatic life expected in clear, cold stream water were found in quantity.

The same general type of bottom fauna in equal abundance was found in the more rapid parts of the St. Joseph River above

St. Maries. From St. Maries down river to the mouth at the south end of Coeur d'Alene Lake the caddis-fly larvae became less abundant but were replaced by midge larvae, dragon-fly nymphs and beetle larvae as the water became deeper and the current less rapid. A good bottom fauna typical of the local stream conditions was found at all stations on the St. Joseph River. At St. Maries many fresh-water sponges and small colonies of algae were seen on sunken logs.

The bottom fauna of Chatcolet Lake was characteristic of lakes with mud floors and with small amounts of dissolved oxygen in the lower strata of the lake water (See Table 2, Part VI of dissolved gases). Large numbers of Chironomid larvae and other aquatic Diptera were collected from the bottom samples dredged in this lake, and at stations where the aquatic vegetation was abundant the usual assortment of dragon-fly nymphs, beetle larvae and annelid worms was collected.

In Coeur d'Alene Lake the bottom fauna taken in the dredgings consisted entirely of several species of Diptera larvae belonging to those groups which regularly inhabit the floors of deep lakes. The total number of individuals collected after many hauls was however quite small. As various conditions may increase or reduce the productiveness of the floor of a large deep lake like Coeur d'Alene, particularly the amount of available organic matter, too much stress in connection with the pollution problem must not be placed on the small number of animals found in the bottom zone of the Coeur d'Alene Lake. This phase of the problem will be discussed in the section dealing with the composition of the bottom muds. Near the piling at the mouth of the Coeur d'Alene River (Station C19) and off the Harrison Pumping Station (C20) a few Chironomid larvae were taken at depths ranging from 5 to 16 meters. Off East Point (C32) and near Black Rock (C26) no living organisms of any sort were found in samples at 15 and 29 meters respectively. At Station C30, near Niggerhead Point from a depth of 49 meters a few midge larvae were dredged. No bottom animals were recovered at Stations C28 and C29, off Coeur d'Alene City toward the outlet end of Coeur d'Alene Lake. At the time of this survey, July, 1932, therefore, the bottom fauna of Coeur d'Alene Lake was poor both in quality and quantity.

Physical and Chemical Status of the Coeur d'Alene River and Adjacent Waters with Reference to Fisheries Problems, 1932

The biological findings which have just been reviewed demonstrated that the Coeur d'Alene River between Wallace and Coeur d'Alene Lake, that is the portion of the river carrying mine wastes, was practically devoid of aquatic animal life, although fish and the aquatic animals essential to fish life were thriving in adjacent unpolluted waters in the Coeur d'Alene District. With these observations in mind physical and chemical studies were made covering certain conditions known to affect fish life and which might be modified by the mine wastes, quite aside from any specific toxic action of the mine wastes themselves.

A. Dissolved gases and pH.

In Table 2 the individual data dealing with dissolved oxygen, carbon dioxid, both fixed and free, and pH, have been assembled. It is evident from these data that the mine wastes introduced into Coeur d'Alene Lake have made no appreciable changes in the waters of that Lake during the past 20 or 21 years as regards dissolved oxygen and carbon dioxid. The amounts of dissolved oxygen in the waters of Coeur d'Alene Lake during July 1932, check very closely with those reported from Coeur d'Alene Lake by Kemmerer, (1923) from observations made in July and August of 1911 and 1912. Not only do the actual amounts of dissolved oxygen found by Kemmerer agree very closely with those found

Table 2. Water temperatures, dissolved gases and pH

Part I. Coeur d'Alene Lake

Locality number	Locality****	Date	Depth in meters	Temperature degrees C.	pH value	Carbon dioxid cc. per liter		Dissolved Oxygen	
						Free	Fixed	Parts per million	Percent saturation*
C1	At mouth of St. Joseph River	July 10	S*	18.0	6.9	--	--	7.6	86.46
"	" " "	" "	B**12	16.75	--	--	--	7.7	72.27
C21	Mouth of St. Joseph River	" "	S	18.4	7.1	0.9	4.9	8.4	96.62
"	" " "	" "	B 12	14.0	6.7	0.9	4.2	7.8	81.90
C4	Off Harrison, Idaho	" 11	S	19.3	--	--	--	8.4	98.67
"	" "	" "	3	19.0	--	--	--	8.4	97.82
"	" "	" "	6	17.8	--	--	--	8.3	93.61
"	" "	" "	9	14.8	--	--	--	7.8	82.32
"	" "	" "	12	14.6	--	--	--	8.0	85.27
"	" "	" "	15	11.7	--	--	--	7.4	73.51
"	" "	" "	18	11.6	--	--	--	7.7	72.98
C17	Boat landing, Harrison, Idaho	" 13	S	18.5	--	1.6	4.2		
C20	Off Harrison Pumping Station	" 14	S	18.3	7.0	0.5	4.9	8.5	97.07
"	" " "	" "	B 15	13.8	6.7	1.2	4.1	8.0	82.15
C18	Between Farmington Landing and East Point	" "	22	11.1	--	--	--	8.1	79.51
"	" " "	" "	25	10.6	--	1.4	4.2	8.5	82.58
C25	Center of Windy Bay	" 15	S	18.25	7.2	0.5	4.4	7.5	86.33
"	" "	" "	B 32	10.25	6.7	1.2	4.3	8.4	81.09
C26	Off Black Rock	" "	S	18.5	--	0.5	4.2	7.7	88.04
"	" "	" " "	B 39	9.75	6.7	1.2	4.2	8.5	81.31
C27	Between Loffs Bay and Turner Bay	" "	S	19.5	7.1	0.5	3.9	7.6	89.15
"	" " "	" "	B 50	9.0	6.7	1.1	3.9	8.6	80.96
C28	Half mile up lake from Blackwell's Mill	" "	S	20.25	7.3	0.7	4.0	8.1	96.97
"	" " "	" "	B 5	19.0	7.1	0.6	4.1	8.5	99.09
C29	Half way between Blackwell's Mill and Three-Mile Point	" "	B 16	12.0	6.7	--	--	7.4	74.02
C30	Mid-channel off Niggerhead Point	" "	S	21.25	7.1	0.6	4.2	7.4	89.57
"	" " "	" "	B 49	10.7	6.7	1.2	4.2	8.0	78.26
C31	Between Echo Bay and Bellegrove	" "	S	19.5	7.1	0.5	4.2	8.4	98.77
"	" " "	" "	B 60	9.75	6.7	1.2	4.2	8.4	80.34

* S - Surface

** B - Bottom

*** Percent saturation has been corrected for altitude

**** For details see locality list.

Table 2. Continued

Part II. Coeur d'Alene River below Cataldo, Idaho

Locality number	Locality	Date	Depth in meters	Temperature degrees C.	pH value	Carbon dioxid cc. per liter		Dissolved oxygen	
						Free	Fixed	Parts per million	Percent saturation
C5	Near Export Mill, Harrison, Idaho	July 11	S	--	6.8	--	--	--	--
C7	Anderson Lake Ditch	" "	S	--	7.1	--	--	--	--
C24	Near mouth Thompson Lake Ditch	" 14	S	18.5	7.1	1.1	5.9	7.5	86.77
"	" " "	" "	B 17	18.76	7.0	1.0	5.7	5.5	53.84
C16	Lower Medimont Ferry	" 12	B 12	18.0	6.9	--	--	6.1	69.72
C57	Mouth of Swan Lake Ditch	" 22	S	18.6	7.1	--	--	6.8	78.67
C52	Opposite Dudley, Idaho	" 20	S	--	--	1.8	6.7	--	--

Part III. South Fork of Coeur d'Alene River.

C43	200 feet below mouth of Sunshine Mine Flume, above Kellogg, Idaho	July 19	S	16.5	6.9	1.1	11.5	4.7	53.08
C42	Just above Sunshine Mine Flume, above Kellogg, Idaho	" "	S	17.0	7.3	1.8	10.4	6.1	69.18
C41	2 miles below Wallace, Idaho	" "	S	14.5	7.5	1.2	12.5	5.0	54.43
C39	Just below Golconda Mill, below Mullan, Idaho	" "	0.6	12.5	7.0	0.5	7.5	7.4	77.04
C51	Above Mullan, Idaho	" "	S	--	7.3	0.6	11.0	--	--
C50	Above Deadman Creek	" "	S	--	7.2	0.6	8.9	--	--
C38	Above Larsen, Idaho	" "	0.3	9.0	7.1	0.5	5.5	9.8	93.76
C40	Placer Creek, Wallace, Idaho	" "	S	13.0	7.5	0.5	9.6	9.5	99.08
C46	Canyon Creek, above Wallace, Idaho	" "	S	--	7.1	0.4	3.3	--	--

Part IV. Mine Waters

C44	Hecla Mill above Wallace, Idaho	July 19	S	--	7.5	0.6	25.6	--	--
C45a	" " "	" "	S	--	7.5	0.0	22.1	--	--
C45b	" " "	" "	S	--	--	0.7	12.7	--	--
C47	Gem Mine on Canyon Creek	" "	S	--	6.7	9.9	19.5	--	--
C48	Tiger Mine on Canyon Creek	" "	S	--	6.7	14.9	48.6	--	--
C49	Morning Mine, Morning, Idaho	" "	S	--	7.5	1.8	34.0	--	--

Table 2. Continued

Part V. Lakes adjacent to Coeur d'Alene River.

Locality number	Locality	Date	Depth in meters	Temperature degrees C.	pH value	Carbon dioxid cc. per liter		Dissolved Oxygen	
						Free	Fixed	Parts per million	percent saturation
C6	Anderson Lake	July 11	S	--	7.5	--	--	--	--
C8	Thompson Lake	" "	S	--	6.6	--	--	--	--
C9	Blue Lake	" "	S	21.0	6.5	--	--	7.9	95.12
"	" "	" "	B 4	18.1	6.5	--	--	6.8	77.97
C37	Black Lake	" 17	S	--	7.0	0.5	4.5	7.7	
"	" "	" "	B 6	19.0	6.8	1.5	4.7	3.0	33.66
C58	Swan Lake	" 22	S	18.3	--	1.0	5.5	--	--
"	" "	" "	B 4.5	18.0	--	1.0	5.6	7.9	88.84
C12	Cave Lake	" 12	S	23.0	7.1	0.9	3.8	6.4	80.05
"	" "	" "	B 6	21.0	7.0	1.0	4.5	5.0	60.11
C14	Medicine Lake	" "	S	--	6.9	--	--	--	--
"	" "	" "	1	23.25	6.9	--	--	7.4	93.45
"	" "	" "	2	21.0	6.7	--	--	7.6	91.82
"	" "	" "	3	19.75	6.7	--	--	6.4	76.04
"	" "	" "	4	14.00	6.4	--	--	1.0	10.31
"	" "	" "	B 6	13.75	6.4	5.7	5.0	0.4	3.40
C15	" "	" "	1	23.80	6.7	--	--	7.5	95.06
C54	Rose Lake	" 20	S	--	7.3	0.4	3.8	--	--
C53	Fourth-of-July Creek	" "	S	--	--	1.5	6.6	--	--
C55	Old Mission Slough	" "	S	--	6.9	1.6	6.3	--	--

Table 2. Continued

Part VI. St. Joseph River and Chatcolet Lake

Locality number	Locality	Date	Depth in meters	Temperature degrees C.	pH value	Carbon dioxid cc. per liter		Dissolved Oxygen	
						Free	Fixed	Parts per million	Percent saturation
C1	Mouth of St. Joseph River	July 10	S	18.0	6.9	--	--	7.6	86.46
C21	" "	" 14	S	18.4	7.1	0.9	4.9	8.4	96.62
"	" "	" "	B 12	14.0	6.7	0.9	4.2	7.8	81.90
C36	St. Joseph River just above outlet of Lake Chatcolet	" 16	S	21.75	7.5	1.1	5.4	7.1	87.04
"	" "	" "	B 6	19.25	6.9	1.0	5.7	7.7	89.35
C2	St. Joseph River, St. Maries, Idaho	July 10	S	19.0	7.0	--	--	7.9	91.47
"	" "	" "	B 5	17.5	7.0	--	--	7.7	86.56
C3	St. Joseph River, ten miles above St.Maries	" "	S	18.0	7.1	--	--	7.2	82.17
"	" "	" "	B 7	17.5	6.9	--	--	8.0	89.94
C33	Chatcolet Lake, off Rocky Point	" "	S	21.5	7.1	0.4	4.3	8.3	101.31
"	" "	" "	B 11	13.25	6.4	1.9	4.2	2.7	28.16
C34	" "	" "	S	22.0	7.3	0.2	4.3	8.4	102.91
"	" "	" "	B 2.5	19.8	7.5	0.2	4.4	9.0	105.80
C35	Chatcolet Lake, north of Plummer Creek	" "	B 2	21.75	7.1	1.1	6.5	7.1	87.04

in the present survey during 1932, but the maximum and minimum values, that is the limits of dissolved oxygen in Coeur d'Alene Lake were practically the same in 1911 and 1912 as in 1932, the differences being well within the expected variations.

The free carbon dioxide values reported by the Kemmerer survey are slightly higher than those found in 1932, the average value for free carbon dioxid found in Lake Coeur d'Alene during the summer of 1932 being 0.905 cc. per liter, ranging from 0.5 cc. to 1.5 cc. per liter, as compared with values varying from 0.5 cc. to 2.8 cc. per liter reported by Kemmerer (see p. 115, l.c.). This difference in free carbon dioxid is quite small and may not be significant but it is well to point out here that the waters of the Coeur d' Alene River when carrying a large amount of the more concentrated mine wastes contained little free carbon dioxid. The fixed carbon dioxid values given by Kemmerer are very much the same of those of the present survey, his values varying from 2.5 cc. to 5.1 cc. per liter and those of the 1932 survey, from 3.9 cc. to 4.9 cc. per liter, the average for 1932 being 4.24 cc. per liter.

The pH values of the waters of Coeur d'Alene Lake at all levels were fairly close to neutrality in 1932, the reaction in general, however being slightly acid as the actual values ranged from 6.7 to 7.3.

Summarizing the dissolved oxygen, carbon dioxid and pH data from Coeur d'Alene Lake it may be said that the conditions as far as these three variables are concerned were satisfactory for fishes, and the various plankton organisms and insects on which fishes depend so largely for food, in July, 1932, and also that as regards dissolved gases the waters of this lake had essentially the same saturations in 1932 as those reported by the independent observers 20 and 21 years previous. It may be noted in this connection that Kemmerer on page 80 of his report on Coeur d'Alene Lake states that, "At the southern end, or head, the lake is fed by the St. Joe River, and at Harrison it receives the muddy waters of the Coeur d'Alene River, which drains an immense area, including the famous Coeur d'Alene mining district. These waters are so laden with silt that they may be traced far out into the clear waters of the lake, the bottom of which showed the effect of the sediment from both rivers. The depth of water gradually increases from the head of the lake to within three miles of the outlet, where it begins to decrease. The deepest place, 56 meters, is at once of the narrowest parts of the lake."

From these observations it is evident that considerable quantities of mine slimes were being carried well out into the Coeur d'Alene Lake by the waters of the Coeur d'Alene River even in 1911. As Kemmerer's dissolved gas data tally very closely with those of the present survey the mine wastes entering Coeur d'Alene Lake have not created an oxygen demand or produced any conspicuous change in the carbonate-acid balance of waters of this lake in the past 20 years.

The dissolved oxygen values for the Coeur d'Alene River between Cataldo and its mouth near Harrison also indicate that the mine wastes are not producing any marked change in the dissolved oxygen of these waters. Both fixed and free carbon dioxid are higher in the river waters than in the lake waters but there is nothing unusual about the balance of carbon dioxid, dissolved oxygen and pH in the Coeur d'Alene River and were these the only factors to be considered the waters of this part of the stream would be reported as suitable for fish and the organisms forming fish food. The relatively low oxygen reported from Station C24 near the mouth of Thompson Lake Ditch is readily explained as due to the current of outbound lake waters, as it may be seen from examination of Part V, of Table 2, that the lakes waters in some cases were very low in dissolved oxygen.

Above Cataldo, that is above the Mission Flats the South Fork of the Coeur d'Alene River is heavily charged with mine wastes, a considerable portion of which settles out on the Mission Flats so that the analyses of waters of this portion of the river are particularly significant. The fixed carbonates in the river water after it has received the mine wastes were conspicuously higher than the fixed carbonates in either the river below Cataldo or in Coeur d'Alene Lake. As the milling operations in connection with the floatation process of ore separation require the use of considerable quantities of sodium carbonate and as the powdered waste rock from the mills contains large amounts of carbonates, both calcium and magnesium, the rise in fixed carbonates and the slight alkalinity of the waters as shown by the pH values in this part of the South Fork was to be expected after the introduction of mine wastes. However, even after the addition of the mine wastes to the river water, neither the pH values, which ranged from 6.9 to 7.5 in the South Fork, nor the volumes of fixed carbon dioxid which varied from 5.5 cc. to 12.5 cc. per liter were unusual or excessive. Unpolluted river waters frequently have a pH value of from 7.4 to 7.8 and the fixed carbon dioxid volumes in lakes supporting an abundant fish fauna are often 20 cc. or more per liter. Aside from the samples taken in the immediate vicinity of the mine flumes, that is at points where the large volumes of mine waters and mine slimes have not mixed completely with the waters of the river (see localities C43, C42, and C41, in Part III, Table 2) the oxygen percents saturation in this part of the river were reasonably satisfactory for fish life. Even in the vicinity of these emptying flumes the oxygen percents saturation only drop to around 50.

As the mine waters that is, the natural waters leaving the mines through the drainage or pumping systems pass over exposed bodies of ore and rock, and constitute a separate pollution hazard from the mill and floatation waters, a series of samples of mine waters (Table 2, Part IV) were tested for pH values, free carbon dioxid and fixed carbon dioxid. The dissolved oxygen was not determined in these samples because these waters are agitated by various pumps and other mechanical devices, so that the oxygen figures would not be significant. These analyses showed the mine waters to be high in fixed carbonates, 12.5 cc. to 48.6 cc. per liter but these values are well within the limits tolerated by ordinary aquatic life. In no case was the pH value of these mine waters dangerously acid or alkaline, the range being pH 6.7 to pH 7.5.

The lakes adjacent to the Coeur d'Alene River are definitely involved in this pollution problem since the waters of the Coeur d'Alene River during high water on occasion back up into some of these lakes, and during low water, waters from all these lakes drain into the Coeur d'Alene River. These lakes showed nothing unusual as regards pH, free carbon dioxid or fixed carbon dioxid. In general the surface waters were near neutrality, or very slightly acid, and the bottom waters in those lakes having large masses of aquatic vegetation, as was to be expected were more acid than the surface waters, the range being from pH 6.4 to pH 7.3. The bottom samples contained more free carbon dioxid and more fixed carbon dioxid than the surface waters but no surprising or excessive values were found.

The dissolved oxygen at the surface and in the upper layers of each of these lakes adjacent to the Coeur d'Alene River was high, approaching complete saturation, the percent saturation decreasing however toward the bottom of the lake. In Medicine Lake which was almost filled with large masses of vegetation the dissolved oxygen dropped to 0.4 parts per million, which value at that altitude and under the existing conditions of temperature and pressure represented a 3.4 percent saturation. The conditions as regards dissolved gases and pH, noted in the several lakes examined however presented nothing unusual or peculiar, for it is well known that lakes having considerable quantities of vegetation along their shores or in their back waters frequently show an oxygen supersaturation in their surface waters yet have sufficient decomposing organic material at the bottom to produce a definite oxygen demand which often reduces the available oxygen to near the zero point. Bottom samples (to be discussed later) from these lakes showed quantities of organic debris and as these lakes were too shallow to present any constant thermoclinal stratification of waters, the small amounts of dissolved oxygen and the large quantities of fixed carbon dioxid found in the waters near the bottoms of these lakes were ascribed to the decomposing organic material on the floors of these lakes. No hazards in dissolved gases, pH and temperature conditions, to fish life or to plankton fauna supporting fish life were noted in any of these lakes.

Since the St. Joseph River receives no mine wastes but supports lumber industries and other activities similar to those found in the Coeur d'Alene River, and since the St. Joseph River rises in the same general mountain group as the Coeur d'Alene River and travels a westerly course paralleling that of the Coeur d'Alene River from which it is separated by only one definite height of land, a comparison of the St. Joseph River with the Coeur d'Alene River seems a valid one, with the pollution resulting from the mine wastes as the principal point of difference. The oxygen saturations and the range of pH values of the waters of the St. Joseph River were essentially the same as those of the Coeur d'Alene River and Coeur d'Alene Lake. The fixed carbon dioxid volumes were slightly higher in the St. Joseph River although the actual differences were probably too small to be significant. The maximum of 5.7 cc. per liter from the St. Joseph River at Station C36 near the mouth of Chatcolet Lake presents nothing unusual in connection with fisheries problems.

Chatcolet Lake, a lake tributary to the St. Joseph River and adjacent to that river was used for comparison with the lakes adjacent to the Coeur d'Alene River which have been previously discussed. Chatcolet Lake contained much aquatic vegetation and the surface waters were found to be supersaturated with oxygen at three stations. This is not an unusual condition for waters in lakes having vigorous growths of aquatic vegetation as has been noted repeatedly by limnologists. Owing to the amount of decomposing vegetation found at the bottom of this lake it was not surprising that the oxygen was reduced to 2.7 parts per million at a depth of 11 meters in Chatcolet Lake. Kemmerer (1923) who visited this lake in 1911 found no oxygen at the depth of 11 meters, suggesting that conditions were essentially the same in Chatcolet Lake during the summer of 1932 as in 1911.

To summarize all of the data on dissolved gases and pH values from the waters of the Coeur d'Alene District, the statement may be made that the mine wastes have not disturbed the balance of dissolved gases, carbonates and acids to any critical degree, except in the immediate vicinity of the flumes emptying these wastes into the river. Indirectly the mine wastes which have eliminated to a large extent the aquatic vegetation and algae from the Coeur d'Alene River, may be the cause of the slightly lower oxygen saturation of the waters of the Coeur d'Alene River as compared with the unpolluted St. Joseph River. However, the absence of a fish fauna and of the various groups of organisms on which fish depend directly or indirectly for their food, in the polluted portion of the Coeur d'Alene River can not be ascribed to oxygen saturation, carbonate balance or relative acidity in that part of this river.

B. Specific conductance.

As both the quantities of salts dissolved in natural waters and the chemical nature of these salts may be critical factors in determining the survival of aquatic organisms, the specific conductance of various natural and waste waters in the Coeur d'Alene District was measured. The specific conductance values which make possible comparisons of the relative amounts of "total salts", i.e. electrolytes in solution in these waters, together with the pH and fixed carbonate readings, have been assembled in Table 3. To aid in the interpretation of these figures similar determinations on mine wastes from British Columbia and on natural waters from the Mississippi River and the Gulf of Mexico have been added.

All of the natural waters tested by this survey in the Coeur d'Alene District, both polluted and unpolluted, were found to have very low specific conductance as compared with sea water or with Mississippi River water, that is, the relative amounts of dissolved salts in these waters from the Coeur d'Alene region were small.

These findings are in accord with the well-known fact that natural surface waters in mountainous areas are usually "soft". If Section I of Table 3 be examined, however, it will be noted that the specific conductance of water from the polluted

Table 3. Specific conductance of various waters from Coeur d'Alene District, 1932

Locality number	Locality	Date	Depth in meters	Specific conductance x 10^6 at 25°C.	pH value	Fixed carbon dioxid cc. per liter
	I. Natural waters, Coeur d'Alene District					
C46	Canyon Creek, above Burke	July, 19, 1932	S*	20.0	7.1	3.3
C50	South Fork, above Deadman's Gulch, above Mullan	" " "	"	51.1	7.2	8.9
C52	Coeur d'Alene River at Dudley	" 20 "	"	100.5	6.9	6.7
C53	Backwater Coeur d'Alene River at mouth of Fourth-of-July Creek	" " "	"	99.7		6.6
C56	Coeur d'Alene River near Harrison	" 21 "	9	94.3	6.8	5.9
C4	Coeur d'Alene Lake off Harrison	" " "	14	55.0	6.9	4.9
C54	Rose Lake	" 20 "	S	56.7	7.3	3.8
	II. Mine waters and mine wastes, Coeur d'Alene District					
C48	Mine water, Tiger Mine, not operating	July 19, 1932	S	349.0	6.7	48.6
C47	" Gem Mine " "	" " "	S	491.9	6.7	19.5
C49	Waste water, Morning Mine, operating	" " "	"	1,174.7	7.5	34.0
C43	Flume run-off, Sunshine Mine, operating	" " "	"	196.8	6.9	11.5
C45B	Waste water, Zinc jig-tables, Hecla Mine, operating	" " "	"	255.0		12.7
C44	" Lead floatation, Hecla Mine, operating	" " "	"	363.3	7.5	25.6
C45A	" " " " " " "	" " "	"	411.4	7.6	22.1
	III. Mine wastes, Kimberley, British Columbia					
C60C	Waste water, Sullivan Mill, operating	July 25, 1932	S	1,119.6	--	--
C61	" " Kimberley Settling Area	" 26 "	"	1,880.6	--	--
	IV. Other natural waters for comparison**					
632 633	Mississippi River, near Hannibal, Missouri	August 30, 1932	S	319.5	7.6	34.3
80	" " " Lake Keokuk, Iowa	June, 1932	"	300.2***	7.5	27.0
546	Gulf of Mexico, Pensacola, Florida	December 31, 1931	"	47,680.0	8.1	34.1

* - Surface
** - From other investigations for the U. S. Bureau of Fisheries
*** - Average of 40 determinations

Coeur d'Alene River at Dudley is approximately two times the specific conductance of the water from the unpolluted South Fork above Mullan, and five times the specific conductance of the water in Canyon Creek above Burke, that is, the specific conductance of the river water rose 100 percent or more after the introduction of the mine wastes. Measurements of samples from other stations on the river show that this new level of specific conductance was maintained all the way down stream to the mouth of the Coeur d'Alene River.

These determinations of specific conductance point out first that the mine wastes contain relatively little soluble material and therefore do not overwhelm the river fauna by causing a rise in dissolved salts to a concentration detrimental to aquatic life because of osmotic changes, as is the case in some types of river pollution. The specific conductance values also show, however, that the mine wastes do produce a definite rise of approximately 100 percent in the specific conductance of the waters of the entire Coeur d'Alene River below the point at which these wastes are introduced into the stream. Although specific conductance is not a straight line function of the percent of total salts in solution, such a rise in the specific conductance of the river water indicates a definite change either in the total amount of dissolved salts or in the chemical composition of the salts in solution in the river. The biological significance of the particular change in salt content in the Coeur d'Alene River apparently rests on the toxic nature of the salts introduced by the wastes as is discussed in the section on experimental tests, (see page 100 et seq.).

The specific conductance of the water from Coeur d'Alene Lake was approximately the same as that of the unpolluted South Fork above Mullan and of Rose Lake, and shows that the water carried by the Coeur d'Alene River was not producing any noticeable change in the total amount of salts dissolved in the waters of Coeur d'Alene Lake during July, 1932. The possible toxic action of the water of Coeur d'Alene River on organisms in Coeur d'Alene Lake is discussed in another section.

From a review of Sections II and III in Table 3 it may be seen that all of the mine wastes and mine waters carried appreciable although not excessive amounts of salts in solution. As might be expected the waters from the mines and mills in active operation contained more soluble material than the other mine waters. These specific conductance determinations are given merely to show that soluble materials are added to the stream with the mine wastes, but the dilution of these soluble substances in the river water after receiving the mine wastes has already been discussed.

C. Bottom and shore conditions.

One of the most obvious results of the pollution of the Coeur d'Alene River by mine wastes is the blanketing of the bottom of that river, and to some extent portions of the floor of Coeur d'Alene Lake, with enormous quantities of very fine rock powder. This rock powder, which is a mixture of the various matrix rocks surrounding the ore veins, together with small amounts of the ores themselves, is produced during the milling operations by the stamp mills and the ball mills. Being relatively insoluble in water this rock powder has been deposited in such quantities in the Coeur d'Alene River during the past 30 years or more, that the entire bed of that stream is covered with layers of pulverized rock from the points where these wastes are poured into the river to its mouth near Harrison. During the course of this survey bottom samples taken at various stations along the Coeur d'Alene River between Wallace and Harrison showed this deposit of powdered rock to be in general many feet thick.

Because of the very small size of the rock particles composing these mine slimes this blanket of rock powder is more or less mobile, and is constantly shifting in the stream bed, forming bars and other temporary deposits which are subsequently cut away by changes in current or during periods of high water. As a result conditions at the bottom of the Coeur d'Alene River are very unstable and do not come to balance because of the constant streams of mine westes carrying more rock powder which are poured in from the mills.

Leaving out of consideration for the time any possible toxic action of the components of this rock powder on aquatic life, these constantly shifting masses of pulverized rock have overwhelmed the bottom fauna so completely in this river, that as previously noted (see page 43) no bottom fauna of any consequence was found in the 50 miles of polluted river between Wallace and Harrison. The continuous movement of the rock powder not only prevents any adjustments on the part of animals living at the bottom or those which use the bottom for spawning grounds, but it also buries any deposits of organic debris on which bottom animals would feed. A condition comparable to the acute erosion disturbances now menacing many natural waters in deforested areas has been established in the Coeur d'Alene River, with this difference that the silt supplied by natural erosion elsewhere is being supplied to the Coeur d'Alene River by the stamp and ball mills. A similar case of artificial erosion has been studied by the writer in Southern Indiana, the contiminating silt which had wiped out the bottom fauna in those waters being limestone powder from the limestone cutting mills. A comparison of the Indiana situation with that of the Coeur d'Alene is pertinent in this, a considerable part of the damage to fish and fisheries interests in the Coeur d'Alene has resulted directly or indirectly from the mere mechanical action of the enormous quantities of powdered rock flumed into this stream, as similar changes in certain Indiana streams have been produced by the relatively innocuous limestone powder. This statement does not of course preclude the possibility that the rock powder from the mines in the Coeur d'Alene District may also have some toxic properties.

As the finer particles of this rock powder are carried in a colloidal suspension it was not surprising to find deposits of this rock powder, or mine slimes (as designated locally) on the floor of Coeur d'Alene Lake. Dredgings from the bottom of this lake showed that the mine slimes brought into the lake by the Coeur d'Alene River could be recognized both chemically and microscopically, often macroscopically as well, in the deposits on the floor of the lake. As a result of an extended series of dredgings in Coeur d'Alene Lake at various stations from the mouth of the St. Joseph River on the south, up lake to the outlet to the west of Coeur d'Alene City it may be stated that mine slimes, that is deposits of the very fine particles of rock powder received by the Coeur d'Alene River in the mine wastes, could be detected over practically the entire lake floor. These slimes were easily recognizable, in fact constituted the major part of the bottom samples from the mouth of the Coeur d'Alene River to East Point, and off Harrison south to the vicinity of the Harrison Pumping Station. Farther south, that is, toward the mouth of the St. Joseph River mud, sand and logging debris (bits of disintegrating bark and wood) became more and more dominant in the samples, although bands and streaks still indicated deposits of mine slimes. These gross findings have been of course verified by laboratory tests.

From East Point to Niggerhead Point the bottom samples contained mica sands and off Black Rock, black sands, as well as the rock powder from the Coeur d'Alene River. Off Coeur d'Alene City and west toward the outlet of the lake the bottom was covered with a mixture of sands, clay and some organic matter, chiefly saw mill waste, although streaks of slimes were still detectable (confirmed by laboratory tests).

The dredging work in Coeur d'Alene Lake showed conclusively that the mine slimes have been deposited over the entire floor of the Lake from Harrison to the outlet west of Coeur d'Alene City (no dredgings were made up Wolf Lodge Bay), and that from time to time when certain conditions arise these slimes are being deposited in considerable quantities on certain parts of the lake floor, as the streaks of slimes in many bottom samples testify. However, various other inorganic deposits as mud and sand from the St. Joseph River, mica sands from Windy Bay and other parts of the west shore, and black sands from the vicinity of Black Rock are also contributing to the filling up of the lake bottom. All of these deposits including the mine slimes are covering over the small amount of organic debris which could be used as food by animals of the bottom fauna in this lake. Therefore as the slime deposits from the Coeur d'Alene River form only a part of the whole mass of inorganic waste which is gradually filling up this lake, the biological importance of these mine slimes which are distributed all over the lake floor lies not so much in the actual mass of these slimes but in the toxic properties of some of the components of these slimes. This phase of the problem is discussed in the section on experimental tests.

The mobility of the mine wastes and mine slimes carried by the Coeur d'Alene River has made possible the pollution of considerable lateral areas, as the flats and low lands adjacent to the river, because large quantities of these wastes are swept out onto the flats during high water, and left there as the river recedes. The extent and size of these deposits of mine wastes and mine slimes can be seen in Figures 3 and 4. In addition to forming a constant source of material with which the stream can be repolluted through the action of rain and wind, these exposed masses of mine slimes present a new hazard to aquatic life because of the chemical nature of several of the substances comprising these particular mine wastes. The sulphides of heavy metals, lead, zinc, iron and others, when exposed to air in the presence of sunlight and moisture can be changed into sulphates and various other compounds, that is, the small particles of ore together with various other substances in these mine wastes, when exposed to the joint action of air, light and moisture can produce a whole series of new compounds some of which may affect aquatic life quite differently from the mine wastes as originally poured into the stream. It is in this way the masses of so-called "crystalline lead" or "lead stone" which are found on these flats, after each period of high water, are formed.

During the present survey this crystalline crust was collected at Mission Flats, Dudley, near Medimont, near Black Lake Ditch, and on Thompson Flats near Harrison, in fact it was found at practically every station on the Coeur d'Alene River from Cataldo to Harrison. This material varied in color from pure white to a dirty slate gray or a yellowish brown in various parts of the same area. It often formed a crust an eighth of an inch or more in thickness over areas an acre or more in extent, and was so firm that, without cracking, it would support the weight of a man. Some times this crystalline material, instead of forming a crust over the ground, was mixed through the top six inches or more of the soil or mine wastes on the flat, forming a partial binder which prevented the soil from crumbling readily. Broken bits of the impregnated soil sparkled with the crystals of this material when exposed to sunlight. On the flats which were covered with this crystalline substance no vegetation was growing and the little pools of water held in the depressions of these flats, contained no animal life. The toxic action of this crystalline material is discussed in the experimental section.

Deposits of very fine mine slimes were also found around the shore of Coeur d'Alene Lake, for although the heavier particles settled out along the course of the Coeur d'Alene River, to a large extent, much of the mine wastes material is so fine that it is carried by the river water as a colloidal suspension which does not settle out so readily. It is well known to local residents that "clouds" of these colloidal slimes drift across the lake moving in one direction or another, depending upon the volume of wastes coming down the Coeur d'Alene River and the air and water currents acting on and in the lake at the time. The movements and volume of the colloidal clouds of mine slimes is attested by the deposits of these slimes at Black Rock, where during high water the slimes are deposited on the black rocks from which Black Rock Point takes its name. As the slimes are light in color they are easily photographed (see Figure 8) on the black rock background.

The volume and extent of these shore deposits of slime along the margins of Coeur d'Alene Lake were trival as compared

Figure 8.

Black Rock on Coeur d'Alene Lake. Note the white line on the base of the rock showing the deposit of slimes left there at high water when the lake was turbid.

with the pollution of the flats along the Coeur d'Alene River, but these findings along the shores of Coeur d'Alene Lake were significant in that they show that the finer mine slimes are readily carried across and up the lake. This fact has already been brought out in the discussion of the bottom dredgings.

Experimental Tests

Since evidence pointing to the toxic action of some substance or substances in the mine waste complex on aquatic life accumulated during the field work, several series of experiments were conducted to determine the toxic action, if any, of the several components and products of the mine wastes. In these studies fish and plankton crustacea were used as test animals in the survival and toxicity experiments, and fish, frogs, turtles and fresh-water mussels in the experiments dealing with specific physiological effects. As the technical data from these experiments are quite voluminous the various tests have been summarized in this report and the several waters and materials used discussed in special sections.

A. Coeur d'Alene River and Coeur d'Alene Lake Waters.

1. Fish.

It is the current belief among the residents along the polluted portion of the Coeur d'Alene River that the waters of this part of the river are toxic , that is they contain something derived from the mine wastes of a rather actively poisonous nature. To test this point as bearing on aquatic animals survival experiments using native fish were conducted in the Coeur d'Alene River at a point about one-quarter of a mile upstream from its mouth, (C56) and in Coeur d'Alene Lake near Harrison Beach, (C17).

On July 16, 1932, 20 minnows of two species, the long-nosed dace, Agosia nubila (Girard) and the dace minnow, Leuciscus (Richardsonius) balteatus (Richardson), were obtained from Coeur d'Alene Lake in the vicinity of Conkling Park, (C65). Both of these species are native in Coeur d'Alene Lake and the Columbia River system (Jordan and Evermann, 1896, pp. 238 and 311), and the individuals selected averaged about 3 inches in length (Agosia) and 5 inches (Leuciscus). As may be noted from the map (see Figure 2) Conkling Park is on the west shore of Coeur d'Alene Lake near the south end.

Placed in live-buckets at the point of capture these fish were transported by launch at once to the two test stations, namely up the Coeur d'Alene River about one-quarter of a mile and off-shore in Coeur d'Alene Lake near the Harrison Beach. At each station the fish were placed in large wooden live-boxes, the sides of which were made of metal screen and these boxes after being properly sealed and weighted were lowered to the depth of about 3 meters. Each live-box was moored with ropes to prevent swinging and anchored to a piling, about one meter above the bottom.

On July 17, that is after a 24-hour exposure to the water at the test station the boxes were raised and all fish at both stations found alive and apparently as active as when first placed in the live boxes. The boxes were returned at once to their moorings without taking the fish from the water. On July 19, after a 72-hour exposure to the river water, all of the fish at the Coeur d'Alene River station were dead. Each individual was covered with a heavy coating of mucous slime and the gills were choked with mucous, the filaments being in some cases matted together. All of the fish at the Coeur d'Alene Lake station were active and in good condition. Those in the lake series were continued another 48 hours, making a total of 120 hours exposure to the lake water just off Harrison, without casualties. All of the fish in the lake series were active and apparently uninjured at the end of the test. These experiments were discontinued at the end of 120 hours as their object was the determination of acute conditions, if they existed.

The death of all of the fish in the river tests during the first 72 hours can not be ascribed to low oxygen, high carbon dioxid, high osmotic tension or a temperature differential in the Coeur d'Alene River water as shown by the chemical and physical data, and as borne out by the fact that there were no deaths in the series during the first 24 hours. The heavy secretion of mucous by these fish during the next 48 hours points very definitely to an irritation, either chemical or mechanical, or possibly both, as the secretion of mucous is one of the protective reactions of living fish. It is evident therefore, that the mine wastes carried by the Coeur d'Alene River in

July, 1932 were sufficiently harmful because of this mechanical action, chemical toxicity, or both, to kill native minnows in 72 hours, while controls from the same lot of fish lived without a casualty under identical conditions of confinement in the waters of Coeur d'Alene Lake. As the fish in the Coeur d'Alene River tests were suspended above the bottom and were not subjected to strong current action, the mechanical irritation produced by the slimes seems the less probable of the two factors causing the death of these fish. The fact remains, however, that exposure to the Coeur d'Alene River water did kill these native fish in 72 hours, regardless of the specific nature of the lethal factor.

2. Plankton.

As an additional check on the Coeur d'Alene River water living plankton crustaceans were exposed to the action of Coeur d'Alene River water from Dudley, Idaho (C52) and from the station one-quarter of a mile above the mouth of the river near Harrison, (C56); of water from Coeur d'Alene Lake off Harrison, (C4); and of water from Canyon Creek, above Mullan, Idaho, (C46).

For these series (and subsequent series in which this form of biological assay was used) wild strains of copepods and cladocerans were obtained from marshy pools and transferred to battery jars in the laboratory. When needed for experimentation the animals were concentrated and sorted as to size by filtering the water containing the plankton through bolting cloth and organdie screens, care being taken to keep the screens submerged so that the animals would not be crushed or injured. In these particular studies the animals used, both cladocerans and copepods, ranged in general from 500 to 800 micra in length. Many copepod nauplii were included among the test animals. Pyrex Erlenmeyer flasks having a capacity of 50 cc. were used as containers for the individual runs. Into each flask 25 cc. of the water to be tested, was placed, and this water (or solution in some of the other experiments) aerated by shaking the unstoppered flask vigorously. Trial samples were analysed for dissolved oxygen after this treatment and approximately complete saturation demonstrated. Immediately after aeration one to ten drops (depending on the series) of the concentrated and graded plankton animals were added to the water in each flask, and the flask immediately sealed with a cork stopper which previously had been sterilized and dried. At no time during the experiment did the test fluid containing the plankton animals come in contact with the cork stopper. Control flasks for each series, containing the same number of drops of plankton animals, in 25 cc. of glass-distilled water and in 25 cc. of tap water, were carried as checks against the physiological conditions of the plankton animals at the time of exposure to the test solutions. On an average each flask contained approximately 100 animals, representing a mixture of cladocera, copepods and copepod nauplii. During the experimental periods the flasks containing the plankton animals were kept in subdued light and at a temperature of approximately 20° Centigrade.

The results of the experimental exposures of plankton to water from the Coeur d'Alene River were striking in view of the absence of any natural plankton fauna in the polluted portion of this river at the time of this survey, and considering the small plankton fauna in the waters of Coeur d'Alene Lake near the mouth of the Coeur d'Alene River as reported in 1911 by Kemmerer (1923) and as found by the writer during July, 1932. All of the plankton animals placed in water from the Coeur d'Alene

River, Station C56, were dead in 18 hours or less, and those added to water from the river near Dudley, Station C52, died in 36 hours or less. As the samples of river water used in these tests were allowed to settle before using and only the clear, supernatant water drawn off for the plankton flasks, the death of the plankton animals when placed in the river water can not be ascribed to the suspended matter which the river water was carrying, that is to any mechanical action of suspended mine slimes. Dissolved gases, particularly dissolved oxygen, and pH, as causes of death were eliminated by the analyses of samples of the water tested and by the chemical and physical data on the river water. The conductivity data showed that the water was by no means hypertonic and as an additional check on the osmotic conditions it must be noted that the controls carried in glass-distilled water lived for five days, which answers the question of hypotonicity as a factor. The controls carried in tap water (the water added to the stock cultures of plankton being free from the organic wastes present in the culture jars) were all alive and active at the end of 14 days when the experiments on these samples were completed, so that the physiological condition of the animals at the beginning of all these tests was good. The conclusion that the Coeur d'Alene River water contained salts or other substances in solution during July, 1932, which were quite toxic to plankton animals is evident. Mixtures of equal parts of Coeur d'Alene River water and tap water (as defined above) were also toxic, killing all plankton placed in such mixtures in 48 hours or less. No definite explanation of the apparently higher toxicity of the Coeur d'Alene River water near the mouth as compared with water from the same stream at Dudley can be given, but the following suggestion is offered. The lower reaches of the stream near the mouth had received the leachings from more flats covered with exposed mine slimes, and as the "crystalline lead" or "lead rock" produced on these exposed flats was found to be very toxic to plankton and as Thompson Flat, only a few miles upstream from Station C56 in the Coeur d'Alene River, was covered at the time these samples were taken from the Coeur d'Alene River, with large masses of "lead rock" which were leaching into the river, it seems probable that the water near the mouth of the river had received more of the toxic material from the exposed flats.

Plankton placed in water from Canyon Creek above Mullan (C46) that is in water taken from the head-waters of the South Fork above the mine pollution were carried through these tests without casualties, which of course was to be expected since plankton crustacea were living in this water at the time it was collected. The Canyon Creek tests, however, are good confirmatory controls, showing that the plankton placed in the polluted water from Harrison and Dudley, died as the result of the lethal properties of the water and not as a result of the experimental procedure.

Exposures to settled water, that is water free from suspensoids, taken from Coeur d'Alene Lake at Station C4, off Harrison, also killed most of the plankton animals placed in this water in from 48 to 72 hours, the younger and smaller animals having the higher mortalities. In no test with this water were all of the animals killed, and some of the cladocerans and copepods continued to live in this water throughout the experiment (ten days), but the average casualties ran 80 percent or higher during the first three days of exposure to this lake water. When the lake water was diluted with equal parts of tap water the mortality of the plankton animals was reduced to about 25 percent, the deaths occurring during the first three days. The toxicity of the Coeur d'Alene Lake water off Harrison for plankton crustacea was therefore much less than that of the Coeur d'Alene River water, at stations where it was carrying mine wastes.

Reviewed collectively, the various series of plankton tests show that the waters of the polluted portion of the Coeur d'Alene River were quite toxic to plankton animals during July, 1932, and that the toxicity was due to substances in solution, for the waters were toxic after the removal of the suspensoids, by sedimentation. The rather high toxicity of these waters is evident by comparison with the work of Warren (1900) who found that it required on an average 75 hours to kill cladocerans (Daphnia magna) by exposure to a 1.2 percent solution of sodium chlorid (common salt) at room temperature (21° Centigrade), and 22 hours by exposure to a two percent solution of sodium chlorid. Although the comparison can only be a gross one the magnitude of the toxicity of the Coeur d'Alene River water for plankton crustacea was similar to that of a two to 2.5 percent sodium chlorid solution, although the specific conductance of the river water was only 94.3 (K x 10^6, see Table 3). In view of this toxicity of the Coeur d'Alene River water, the abrupt drop in the plankton fauna of the ditches bringing water from the plankton producing lakes into the Coeur d'Alene in the zone where the lake waters mix with those of the polluted river, is easily understood (See Anderson Lake Ditch, under plankton discussion). The toxicity of the Coeur d'Alene River water for plankton may also account for the small plankton fauna off Harrison in Coeur d'Alene Lake and the lethal action of this lake water on a high percent of the plankton animals exposed to it. The effect of the pollution of Coeur d'Alene Lake waters by the waters of Coeur d'Alene River, as regards plankton, will be discussed in the summary after other experimental tests have been presented.

B. Mine Wastes

The toxic action of the water from the polluted portion of the Coeur d'Alene River, as demonstrated on fish and plankton crustaceans, could be produced by the presence in the mine wastes of substances which are specifically toxic to protoplasm in general; by the introduction through the mine wastes of sufficient quantities of relatively innocuous compounds which are toxic to aquatic life when not balanced against proper amounts of certain other materials; and by various combinations of the two kinds of toxic agents acting simultaneously. Biological and physiological tests on fish and other animals have been made therefore using representative components of the mine wastes and also some of the unaltered mixtures of mine wastes, (that is, the wastes as collected from the mills and flumes), as checks on the synergistic and antagonistic actions of the several compounds comprising these wastes. For convenience in discussion, these experiments have been grouped under four headings with regard to the source of the material tested.

In the fish survival experiments goldfish, Carassius carassius L. were used, as this fish is superior to ordinary stream fish for many laboratory tests, particularly in that it does not require constant aeration of the water and is very tolerant of confinement. The use of the goldfish as a test animal in toxicity experiments is amply justified by previous experimental work (Powers, 1917; Baudin, 1932). In the more technical physiological tests the leopard frog, Rana pipiens Shreber; painted turtle, Chrysemys picta (Herm.); the channel catfish, Ictalurus punctatus (Rafinesque); the short-nosed gar, Lepisosteus platostomus Rafinesque; the quillback, Carpiodes velifer (Rafinesque); the large-mouthed black bass, Micropterus salmoides (Lacepede); the washboard mussel, Amblema gigantea (Barnes); the river mucket, Lampsilis carinata (Barnes); the three-ridge, Amblema costata, Rafinesque; and the yellow sand-shell, Lampsilis teres (Rafinesque) were used as experimental animals.

1. Milling Chemicals

In the floatation process various chemicals are added to the aqueous suspension of pulverized ore and rock to facilitate the separation of the valuable ore particles from the waste rock powder. Although the floatation procedures vary slightly in the different mills, the chemicals currently used are the following:

1. Copper sulphate.
2. Sodium dichromate.
3. Sodium cyanid.
4. Sodium carbonate.
5. Water gas tar.
6. Coal tar creosote.
7. Cresylic acid (Cresol)
8. Potassium xanthate (ethyldithiocarbonate).

The first three of these compounds, although known to be extremely toxic to many forms of aquatic life, can be eliminated from the present pollution problem because these salts are broken down during the course of the floatation operations, and practically all of the copper recovered. No evidences of copper poisoning were seen, and the samples of mine slimes collected in the Coeur d'Alene River and Coeur d'Alene Lake gave no tests for copper, confirming the reports of O'Keeffe and Ziegler (1930) who (p. 2) list copper only as a "trace" in their samples of inorganic solids from Coeur d'Alene River and Coeur d'Alene Lake after the insoluble suspensoids had been removed. Little if any sodium cyanid or sodium dichromate as such leaves the mill and as very small quantities of these two compounds are used in the floatation work their decomposition products are almost negligible.

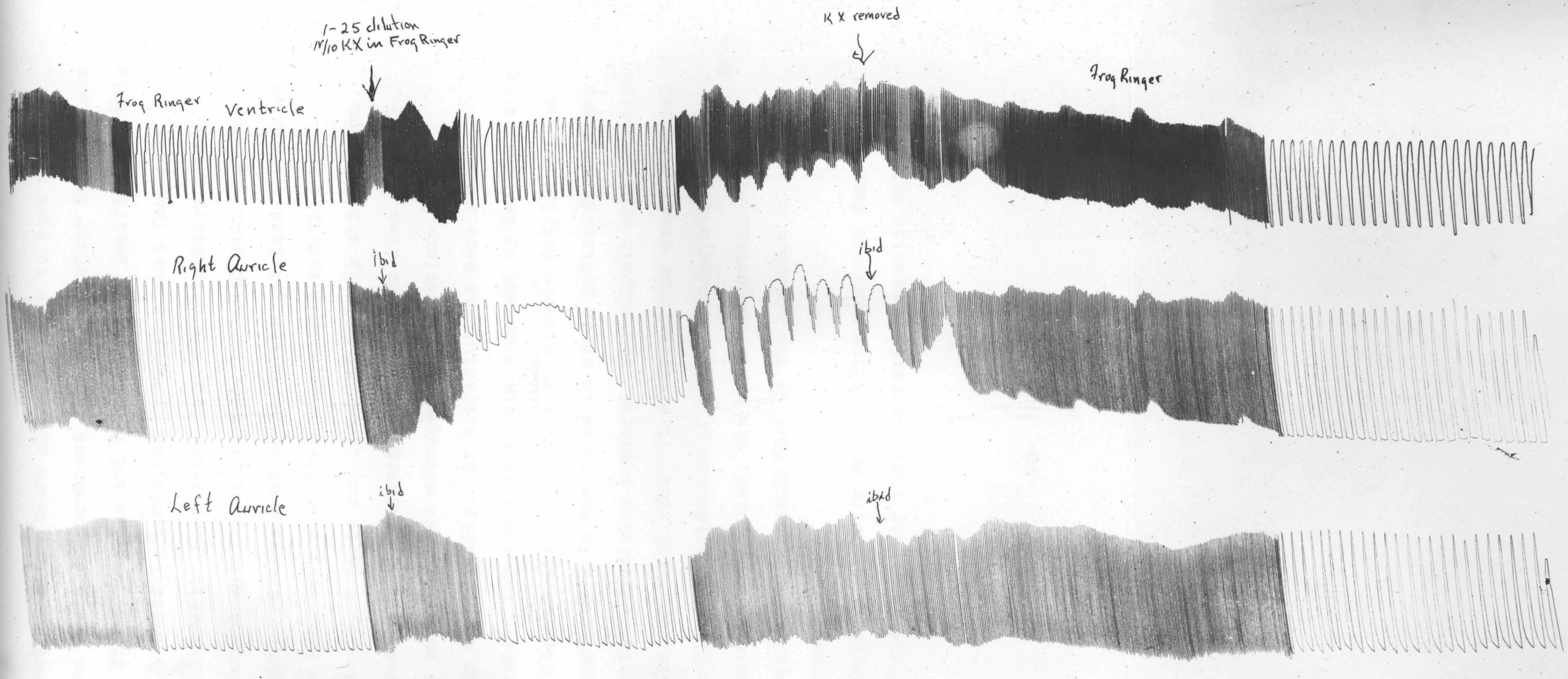
The fourth chemical, sodium carbonate is used in quantities ranging from 3 to 5 pounds per ton of milled ore, and when mixed with the waters of the floatation plant and the other waste waters from the mines is reduced to a dilution of plus or minus 1:1,000. This dilution ratio is not exact, but rather a gross approximation computed from various figures supplied by some of the mine officials. As the amount of water varies considerably this ratio is merely given to suggest the general order of magnitude of the sodium carbonate dilution in the flume water, were all of the sodium carbonate used in the floatation process removed unchanged. The carbonate in the flume water is of course diluted still more when this flume water mixes with the river water. In such dilutions sodium carbonate is not immediately toxic to the larger aquatic animals as fishes, although sodium carbonate in dilutions even less than 1:1,000 may affect both fishes and plankton animals in long exposures (several days to several weeks) if not properly balanced by small amounts of potassium and calcium salts. Garrey (1916) has shown that in general fresh-water fishes can tolerate the common sodium, potassium, calcium and magnesium salts in properly balanced mixtures of these salts if the osmotic pressure of the mixture does not exceed that of fish blood (circa 0.5 percent sodium chlorid; 0.03 percent potassium chlorid; 0.026 percent calcium chlorid; and 0.002 magnesium chlorid), but that any one of these elements may be quite toxic to fresh-water fish in much higher dilutions if not properly balanced by the presence of the other salts. The continued addition of sodium carbonate and other sodium salts to the river by the mine wastes even if these salts be quite dilute might create therefore pollution conditions detrimental to aquatic animals in the upper reaches of the polluted portion of the Coeur d'Alene River, but this sodium hazard is probably negligible in view of the calcium and magnesium salts supplied by the rock powder from the ball mills.

The sodium carbonate used in the floatation process presents indirectly another hazard to aquatic animals exposed to the action of these mine wastes, particularly in those parts of the stream where mine wastes are not greatly diluted, in that sodium carbonate combines rather readily with various sulphur compounds. As the ores handled in the Coeur d'Alene District are largely sulphids, in the course of different interreactions between these ores, the water, the dissolved gases in the water and the sodium carbonate, small quantities of a variety of sulphur compounds are formed including sulphates, sulphites, soluble sulphids, sulphur dioxid and even hydrogen sulphid.

Sodium sulphate is not a toxic compound in the usual sense, and plankton animals lived in a 0.1 percent solution of sodium sulphate for five days during tests made in this investigation, so that the action of small amounts of sodium sulphate on aquatic animals is much the same as that of sodium carbonate in dilute solutions, namely, a disturbance of the normal salt balance, which may in time produce death. Sulphites are quite toxic to aquatic animals, the sulphite wastes from paper mills being a conspicuous example, and soluble sulphids, particularly hydrogen sulphid and sulphur dioxid are extremely toxic not only to aquatic animals but to many other forms of life, even in very high dilutions. A dilution of 5:1,000,000 of sulphur dioxid will kill trout in an hour (Weigelt, 1903). The sulphurous odor of the wastes from the floatation mills and of water from the Coeur d'Alene River some distance below the mouths of the flumes emptying these wastes into the river indicated the presence of these various sulphate and sulphid compounds in sufficient quantities to be a hazard to both the plankton and fish in the polluted portion of the South Fork. Laboratory tests on plankton confirmed these observations.

Water gas tar, coal tar creosote and Cresylic acid (chemicals 5, 6, and 7) pharmacologically may be grouped as aromatics. These substances are all quite toxic to fish in very small quantities (Shelford, 1917) and tests on plankton crustaceans made by the writer using Cresol, showed that 0.001 percent Cresol was fatal to these crustaceans in 2 hours. As the odor of these aromatic substances was readily detectable in mine waste samples and in some of the samples of river water taken near the flume outlets, these aromatics although present in very small quantities may be factors in the destruction of the plankton fauna in the river near the mouths of the flumes. As these organic compounds are soon oxidized and otherwise destroyed in the stream, they probably are of little consequence in the present pollution problem below the South Fork, as the total amount of all three substances is not large (less than one pound per ton of milled ore, on an average.

As the potassium xanthate odor (chemical 8) was very evident in certain mine wastes from mills using this compound, even though it had been added to the floatation suspension in very small quantities (0.02 pounds per ton of milled ore), the toxic action of potassium xanthate alone and in combination with some of the sulphid ores, was tested on both plankton and fish. As Muir and Swezey (1926), working on sugar cane pests in Hawaii showed that insects and other soil-inhabiting animals were readily killed by spraying this compound over the surface of the ground, it seemed probable that potassium xanthate would prove toxic to aquatic animals. In the present tests it was found that one part of potassium xanthate in 12,500 killed all goldfish subjected to this concentration in 36 hours or less, and that one part in 3,175 was fatal in 5 to 8 hours. As the xanthate undergoes decomposition rather rapidly when exposed in dilute solutions one part in 100,000 was not fatal to goldfish unless renewed. If replaced daily with fresh solution, the toxic action of potassium xanthate on goldfish was evident in dilutions as high as 1:10,000,000. This compound speedily produced an irritation of the alimentary canal in fish subjected to xanthate even in very dilute solutions. Long strings of mucous were voided and the poisoned fish showed difficulty in feeding or refused food entirely. Physiological records demonstrated (see Figure 9) that this compound affects the heart, particularly the right auricle, causing the heart to beat irregularly and finally stop. If only very small amounts



Toxic action of Potassium Xanthate on turtle heart *in situ*

Top graph, ventricle
Middle graph, right auricle
Bottom graph, left auricle

Solution applied by internal perfusion in normal Ringer's solution
Dilution tested 1/400 normal, approximately 4 parts per million.

of xanthate were used the heart might continue to beat for a time but showed signs of permanent damage even after the xanthate was removed. Frogs, turtles and fishes were so sensitive to this compound that 4 parts in 1,000,000 produced almost immediate stopping of the heart. When taken into the alimentary canal, or when the stomach and intestines were perfused with similar dilutions a prompt paralysis of these organs resulted. Plankton crustacea were also very sensitive to minute quantities of potassium xanthate, 8 parts per 1,000,000 killing all plankton crustacea tested with this strength in 5 days or less without renewal of the solution, and stronger concentrations killed correspondingly more rapidly. If the solutions were renewed daily to compensate for the loss of the compound by decomposition dilutions as high as 1:100,000,000 were clearly detrimental to the plankton crustacea. In the tests in which potassium xanthate was added to water containing powdered lead sulphid ore, powdered zinc sulphid ore, or "lead rock" (the crystalline crust material from Thomspons Flat) no evidences of either synergistic or antagonistic actions were noted, the toxic properties of the xanthate apparently being unmodified by the presence of these other substances.

The experimental work on potassium xanthate demonstrated that this compound is highly toxic to various aquatic animals both vertebrates and invertebrates, and that the introduction of even very small quantities of this salt into the stream with mine wastes constitutes a hazard to aquatic animals, except that this substance in dilute solutions decomposes rather rapidly into products much less toxic than the original compound. No evidences of xanthate action were found in the field work except in the immediate vicinity of the emptying flumes.

The experiment work on the various milling chemicals may be summarized as showing that these several chemicals with the exception of sodium carbonate, are quite toxic to aquatic animals. However, because of the methods followed in the floatation process, of the small quantities of these substances used, and of the chemical nature of the substances themselves or of their reaction products, these milling chemicals are not responsible for the pollution of the Coeur d'Alene River miles down stream, and constitute only small pollution hazards in the upper part of the polluted portions of the South Fork. Both the experimental evidence and the field data particularly on pH and conductivity, also indicate that sodium carbonate as such is not the immediate cause of the toxicity of the Coeur d'Alene River water to aquatic animals.

2. Milling Products.

The reduction of the ore-bearing rock to a powder in the ball mills releases, after the separation of the ore particles by the floatation process, enormous quantities of rock powder, the most bulky of the mine wastes. As this waste rock powder consists primarily of compounds of calcium, magnesium, iron and manganese for the most part in the carbonate or silicate forms, both because of the particular elements concerned and because of the relative insolubility of these compounds, these rock powders would hardly be suspected as the source of the toxic material in the Coeur d'Alene River water. Actual tests of this material on plankton and fish showed it to be quite harmless when free from ore particles, except as it disturbed the salt balance, pH and osmotic pressure conditions. The field data showed that once well mixed with the waters of the main stream this rock powder did not cause any marked rise in conductivity or pH. The rock powder did cause a rise in fixed carbonates in the test water, and the production of a slightly more alkaline reaction, a combination of changes, which, in view of the work of Wells (1915 a and b) who found that carbonates in general do not effect fishes detrimentally if the water is acid, and that slightly alkaline water lessens the activity of fishes and increases the mortality, would be regarded as of an unfavorable order. However, the actual field tests of the river water after the rock powder was well mixed with the water of the stream (see Table 3 Part II) showed that although there was a rise in fixed carbonates, the pH values due to the balance of various factors, remained much the same as in the unpolluted portion of the river or if anything became slightly more acid. The rock powder (not ore particles) therefore was not producing any detrimental chemical changes at the time the river was studied (1932). The mechanical effects, as discussed in a previous section (page 65), of this powder are of course quite another consideration.

3. The Ores.

Because of the well known toxic properties of many compounds of the heavy metals, particularly those of lead, both fish and plankton were exposed to the action of the lead and zinc ore concentrates. The finely powdered ore as recovered by the floatation process was washed thoroughly with clear tap water to remove any freely soluble substances. The ore was then washed in 95 percent alcohol and violently agitated so that each particle would be cleansed of any material soluble in alcohol. After several extractions with alcohol, the old fluid being decanted off each time before fresh alcohol was added, the alcohol was removed and the ore powder washed through five separate treatments of glass-distilled water. The water was finally drained off and the prepared ore, which will be referred to hereafter as "washed ore powder", put aside in pyrex vessels. These washed ore powders consisted essentially of lead sulphid or zinc sulphid, together with small amounts of other metallic sulphids which are associated with these two ores in the ore-bearing rock.

a. Lead ore.

To test the action of the natural ore unmodified by exposure or weathering single goldfish were placed in glass battery jars each containing 4 liters of tap water (water from the same source as that flowing through the large tank in which these fish were living prior to the experiment). This tap water contained small amounts of calcium carbonate and magnesium sulphate but no salts of heavy metals (as shown by analyses of this water made by the Department of Physical Chemistry, University of Missouri). To each jar 25 grams of washed lead ore powder was added, and the ore, being quite insoluble in water, sank at once forming a thin layer over the bottom of the jar. Control jars with goldfish but without lead ore were carried under identical conditions and the dissolved oxygen, carbonates, pH and temperature followed as a routine for all jars of the series, but the water was not changed during the test. Under these conditions there were no casualties in any of the jars of this series during the 31 days this experiment was maintained. All of the fish were fed regularly every day and those fish in the jars containing the washed ore took food with apparently the same interest as those in the control jars. At the end of the experiment, therefore, the fish living in the presence of the lead ore seemed to be in quite as good condition as the controls. In the course of the month during which these animals were under observation there were no abrupt changes in the dissolved oxygen or pH of the surrounding water, although the fixed carbon dioxid rose throughout the experiment from 20 cc. per liter to 74 cc. at the end.

These fish tests brought out two points namely, that the lead sulphid ore is not immediately toxic to fish and that it is not transformed into more toxic compounds in sufficient quantities to produce an immediate toxicity of the water, by the excretory products of the fish, even when these products are allowed to accumulate. These results were expected in view of the fact that lead sulphid has a very low solubility coefficient and that small quantities of many heavy metal salts can be precipitated as albuminates by mucous slime. It was evident that some such precipitation was occurring in these experiments as small masses of slightly opaque, flocculent coagulum were seen on the bottoms of the jars in the lear ore series.

Plankton crustaceans carried in tap water to which the washed lead ore powder had been added (1 gram to 25 cc. of water - there is no significance in the amount, other than that an ample excess was provided) died in 48 hours or less, the deaths occurring in the second 24-hour period and the young dying earlier than the adults. Control plankton animals in lead-free tests maintained under the same conditions at the same time were active and vigorous for 10 days when they were discontinued. In these tests it was not determined whether the plankton animals died from the ingestion of tiny particles of the ore powder or as the result of dissolved lead in the water. It must be pointed out here, however, that although lead sulphid is very insoluble in distilled water, various other substances in the water materially increase the solubility of this compound. Kolthoff (1931) who has recently reviewed the solubilities of sulphids finds that lead sulphid is soluble in pure distilled water (conductivity water) only to the extent of $10^{-9.65}$ mols per liter, that is approximately one part in 50,000,000 but that water which is in equilibrium with the carbon dioxid of the air will dissolve $10^{-8.62}$ mols per liter or roughly one part in 5,000,000. Although this second value is still extremely small it is nearing the magnitude of toxicity dilution for several known poisons. Besides lead sulphid is readily attacked by various body fluids and digestive juices forming lead compounds much more water soluble than lead sulphid. Even in tap water in the presence of dissolved oxygen, lead sulphid is oxidized into lead sulphate which according to Orestano (1931) has a solubility of 0.000161 mols per liter or roughly one part in 20,000, and as will be shown in a following section one part in 100,000 of lead acetate is violently toxic to fish stomachs. It is not surprising therefore that the plankton crustaceans which do not have an elaborate mucous protective coat like fishes, died after 48 hours exposure to well-aerated water containing lead sulphid ore powder. The factor significant to the present pollution discussion is the short time in which these plankton animals were killed by exposure to the ore powder water mixture.

b. Zinc Ore.

Fish and plankton series directly comparable in every detail with washed lead ore tests except that washed zinc ore powder was used in place of the washed lead ore powder, were carried simultaneously with the washed lead ore experiments.

Thirty-one days exposure to washed zinc ore powder in unchanged water did not produce any casualties among the goldfish so treated. All fish in these experiments were active and vigorous at the end of the tests, and there was nothing in their daily behavior to suggest that the presence of the zinc ore in the jar was disturbing in the least. One difference was noted, however, between the lead and zinc ore series, namely that little if any of the flocculent coagulum found at the bottom in the jars contain fish exposed to lead ore, was seen in the jars which held the fish exposed to the zinc ore. This observation suggests that more mucous was secreted by the fish exposed to the lead ore and points to a slightly irritating action of the water in the jars containing lead ore powder.

The plankton crustacea placed in water to which washed zinc ore had been added not only did not die in 48 hours (see lead series) but were active and apparently unaffected by the zinc ore powder at the end of 8 days when the experiments were discontinued. It was evident, therefore, that the washed zinc ore powder was at least not immediately toxic to plankton crustacea.

4. Mine and Flume Waters.

Although several of the components of the mine wastes when tested separately were shown to be very toxic to aquatic animals, particularly plankton, there is always the possibility that miscellaneous mixtures of such toxic substances may be less toxic than the individual compounds, as the result of chemical recombination. Samples of mine waters from six stations (see Table 2, Part IV), flume water from the Sunshine Mine, and flume water from the waste flume of the Sullivan Mills, Kimberley, British Columbia, (C60c) were tested and found to be quite toxic to plankton, the survivals in these various waters being 48 hours or less. No evidence of any reduction in toxicity due to the mixing of the various mine wastes was found.

C. Waste incrustations from banks and flats.

Many areas, some of them acres in extent, along the banks and flats between Cataldo and the mouth of the Coeur d'Alene River were covered at the time of this survey (July, 1932) with incrustations of a crystalline material varying from pure white to dull gray or dirty brown in color. This material, as has been discussed in the section on bottom and shore conditions (page 64) was always found on deposits of mine wastes and mine slimes, or in soil heavily impregnated with these slimes. Careful investigation in the field left no doubt but that these incrustations had been produced by the weathering of the exposed mine wastes which are subject to a variety of conditions conducive to chemical changes as moisture, light, heat and oxidation. Some of this crust material was freely soluble in water and other portions sparingly so, and leachings from these crusts were being carried into the Coeur d'Alene River by every rain and high water, in addition the rather continuous return to the river of the mine wastes and their porudcts from these flats and banks by wind and stream action. The gross bulk of the exposed incrustations in July, 1932 was surprisingly large amounting to the enormous weight of 27 to 28 tons per acre of surface incrusted. Since areas of these incrustations acres in extent were observed, particularly at Thompson Flat and near Dudley and as practically every exposed mass of mine slime deposits along the river from Cataldo to the mouth, was more or less covered with these incrustations, the total amount of this crust material along the banks and flats of the polluted portion of the Coeur d'Alene runs into amazing figures. As the values for the weight of the incrustation per acre were obtained from the average weights of measured specimens of the crust which could be lifted en masse from the surface of the mine slime deposits on the flats, no account was taken of the large amounts of this crust-forming material which could be seen in the underlying and nearby soils and which could be readily leached from such soils by water as was shown by laboratory tests. Such quantities of almost any substance with even mildly toxic properties would constitute a pollution hazard when freely available through the action of wind, rain and current.

Analyses of various samples of these incrustations collected during July, 1931 and 1932 have been summarized in Table 4. From this table it may be seen that the items of primary interest in connection with the present fisheries problem are zinc, lead and sulphates. Variations in the components of these soil crusts, particularly in the iron and water-soluble fractions, were to be expected as natural correlaries of the differences in weathering of the mine slimes at various stations up and down the Coeur d'Alene River. However, in these incrustations the regular occurrence of zinc, lead, and sulphates in quantities large enough to be of biological significance, Table. - 4. General chemical composition of soil incrustations along the Coeur d'Alene River as shown by analyses of samples from near Harrison, Idaho, from Thompson Flat, and from Bradley, Idaho during July, 1931* and 1932**.

Total zinc as Zn	5.0 to 12.0 percent
" lead as Pb	0.3 " 0.8 "
" iron as Fe	trace " 9.0 "
" manganese as Mn	" " 4.0 "
" copper as Cu	traces in some samples
" arsenic as As	" " " "
Material freely soluble in water	3.0 to 39.0 percent
Soluble zinc as zinc sulphate	60 to 85 percent of soluble fraction
Other soluble sulphates, computed as sodium sulphate	5 " 20 " " " "
Soluble chlorids	small amounts
Solubla carbonates	small amounts

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* Analysis from laboratory of the Division of Soils Chemistry and Physica, United States Department of Agriculture.

** Analyses from laboratories of U. S. Bureau of Fisheries, Columbia Field Station, and from Department of Physical Chemistry, Unitersity of Missouri indicates that regardless of local conditions, the oxidation of sulphid ore particles was taking place rather continuously in these deposits of mine wastes, and also that considerable amounts of these sulphid ore particles have been lost in the milling operations and carried down stream in the mine slimes which formed these deposits on the flats and banks.

For the experimental studies the incrustation material from Thompson Flat was chosen as typical of the "lead rock" found along the lower part of the Coeur d'Alene River, and the samples of white crystalline crust obtained from the surface of the piles of mine wastes on the banks of the South Fork near Bradley, Idaho as typical of the incrustation material in the immediate vicinity of the mills.

1. Thompson Flat "lead rock" crust.

Several pounds of the soil crusts were collected from different locations on Thompson Flat and all of the material obtained dried, ground to a fine powder and thoroughly mixed. This process gave what was considered a representative sample of the incrustation substances as found on Thompson Flat during July, 1932. The material just described when extracted with distilled water yielded a water-soluble fraction representing 3.3 percent of the total weight. This soluble fraction consisted of 62 percent zinc sulphate; 30 percent other soluble sulphates calculated as sodium sulphate (primarily a mixture of sodium and magnesium sulphates); approximately 0.05 percent lead calculated as Pb, and 0.32 percent organic matter. The remainder of the soluble fraction was composed chiefly of manganese and iron compounds. The insoluble fraction carried approximately 3 percent zinc as Zn and 0.4 percent lead as Pb.

a. Fish survival tests.

Goldfish, as previously described, were placed in battery jars containing three liters of water to which definite amounts of either the water-soluble fraction or of the entire crust samples were added. The results obtained from these exposures can be divided very definitely into "immediate" and "cumulative".

The immediate effects were apparently produced by the water-soluble fraction for the responses varied according to the amount of water-soluble fraction present, whether it were used alone or accompanied with the insoluble fraction. If the soluble fraction were present in concentrations of 0.01 percent or stronger a profuse secretion of mucous by the fish was induced in the course of the first six hours or less depending upon the concentration of the soluble fraction used. This heavy secretion of mucous continued for about 24 hours at which time conspicuous masses of flocculent coagulum were found at the bottom of the jar. By the end of the fourth day of exposure to these high dilutions (water was not changed and no material added during this time) the mucous secretion had ceased and the fish seemed quite normal again.

If sufficient quantities of the whole incrustation powder or of the water-soluble fraction alone were used to give a concentration of 0.18 percent or stronger, of the water soluble fraction, the mucous secretion began very shortly after the fish were placed into the mixture and continued voluminous for 24 hours or more. Within 4 hours after exposure to these stronger concentrations was begun, the fish showed difficulty in swallowing, and were often unable to take food. As in the case of the higher dilutions, these immediate symptoms cleared up during the third day and by the end of the fourth day the secretion of mucous had stopped and the fish appeared normal.

Concentrations of the water-soluble fraction, with or without the insoluble fraction, of 0.33 percent or stronger produced even more severe symptoms of the types described, and were often accompanied by sluggishness of movements or almost stupor inside of five hours. Concentrations up to and including 1.6 percent of soluble fraction were tested, and if the soluble substance were not renewed, that is, if but a single quantity of the soluble fraction were placed in the water, the fish were able to recover in four days. If the soluble fraction were renewed daily, the secretion of mucous and the inability to swallow continued and the fish died in four to six days.

In other series the individual goldfish were placed in jars containing three liters of water and 10 grams of the whole incrustation powder added. The water-soluble fraction from this amount of whole powder produced a concentration of 0.33 percent water soluble fraction, a strength causing immediate responses of considerable severity, and the insoluble fraction weighing some 9.67 grams sank to the bottom of the jars. These fish passed through the cycle of responses previously described under the discussion of the immediate responses, and by the end of the fourth day seemed quite recovered. Between the fourth and tenth days the fish were active, ate regularly and were apparently without hold-over effects from the first set of responses. After the tenth day one by one the fish became less active and in the fins, around the nares and particularly in the region of any small injury as a tear in a fin, black deposits began to appear. From the 12th day on the fish began to die, although controls carried under identical conditions save for the presence of the incrustation powder, were healthy and active. The survival time averaged about 20 days in the presence of 9.67 grams of the insoluble fraction.

At the end of the 31st day the few surviving fish of this series were transferred to fresh-water for four days and then subjected to the action of various detrimental salts. Without exception the fish which had been exposed to action of the insoluble fraction for 31 days succumbed much more readily to harmful salts than did normal control fish without exposure to the incrustation powder.

Reviewing all of these tests on goldfish the "immediate" or "acute" responses present a complex of specific irritation to the mucous cells which constitute one of the main defenses of the fish against both chemical irritation and bacteria. The actual responses made by these fish can be duplicated by similar dilutions of zinc sulphate or of several other salts, and as zinc is not a cumulative poison, being readily excreted even when ingested in rather large amounts without leaving any general toxic effects (Drinker, Thompson and Marsh, 1927) the irritation produced by the 0.01 to 1.6 percent solutions of the soluble fraction are of little significance unless the irritation is continued for some time. In the experimental tests in which but a single quantity of the soluble material was placed in the jar with the fish, recovery followed in four days but if the soluble material were renewed constantly as it would be in the run-off from these flats of mine waste the fish would soon succumb to the chemical irritation just as they did in the daily renewal tests in the present experimental series.

The cumulative effects of the incrustation material from Thompson Flat are more significant perhaps than the immediate effects. The appearance of black deposits, which were chemically identified as lead, in the fins of the fish exposed to this crust powder points specifically to lead poisoning in these fish, as Hammett (1928) has shown that lead is deposited in regions of active cell division as a dense brownish-black accumulation, even from dilutions as high as 10^{-4}, i.e. 0.001 percent. Growth and ability to regenerate are well established characteristics of fish fins, especially of goldfish, and the deposits of lead in the fins of these particular goldfish are not surprising in view of the presence of lead in both the soluble and insoluble fractions of the incrustation material, in amounts in excess of 0.001 percent. Lead is known to be a cumulative poison and the general symptoms of the fish during the second half of these survival experiments were at least suggestive of lead poisoning.

It may be pointed out that the amount of lead in the soluble fraction was quite small and that this lead may have been precipitated out of solution by the fish mucous in the form of lead albuminate during the first part of the experiment when the zinc sulphate and other components of the soluble fraction were producing the irritation resulting in a profuse flow of mucous. Granting that all of the lead in the soluble fraction has been precipitated down, lead compounds were still present in the insoluble fraction and the fact remains that lead deposits appeared in the test fish. This lead may have entered the bodies of the fish in either of two ways. The term "insoluble" is only relative. Even lead sulphid (lead ore) is very slightly soluble in water and lead sulphate, the form in which at least part of the lead occurs in the insoluble fraction of these incrustations, is soluble in water to the extent of 1:20,000, as has been pointed out in a previous section. This quantity is very small, but as Porritt (1931) has demonstrated, very minute quantities of lead may produce cumulative lead poisoning, 1:5,907,000 being sufficient to cause cumulative lead poisoning in man if the exposure be prolonged. The solvent action of the water on the lead compounds in the insoluble fraction would maintain the saturation level for these lead compounds in the water surrounding the fish. Part of this lead would be reprecipitated by the mucous of the fish but water containing lead would be swallowed each time the fish fed, for no matter how much lead were precipitated down the solution equilibrium would be maintained since the undissolved lead compounds are in excess in slimes at the bottom of the jar. The second and more probable source of the lead stored by these fish is in the undissolved lead as lead compounds, in the slimes, that is in the insoluble fraction. Minot (1924) has pointed out that the gastro-intestinal

tract is the principal portal of entry for lead into the bodies of living animals and this is particularly true of fish, which have no lungs (as lead is taken in as dust by air breathing animals). Small particles of lead compounds even though insoluble in the general sense of that term, were taken into the alimentary canal of these goldfish while feeding and supplied a source of material from which lead could have been absorbed, leading ultimately to cumulative lead poisoning. Porritt (l.c.) notes that it is not essential that the "infinitesimal doses" of lead be in a soluble form to produce cumulative lead poisoning when taken into the alimentary canal, and Magath (1931) reports acute and fatal lead poisoning in wild ducks which have swallowed shot picked up in the course of feeding.
It is evident in view of the existing literature on lead poisoning and the analyses of the incrustation material from Thompson Flat, that ample lead is present in the incrustation powder to produce cumulative lead poisoning in fishes if the exposure be long enough.

It is well to compare the action of the whole incrustation material with the action of washed lead-ore powder (see page 94) on fish. In the tests with lead-ore powder goldfish were kept in jars containing undissolved washed lead-ore powder (lead sulphid) for 31 days without casualties. The water in these jars was in solution equilibrium with the lead sulphid, very minute quantities of which are soluble, and these fish were also subject to the hazard of the lead particles which might be swallowed when these goldfish fed. The goldfish in the incrustation material series, in the presence of actually much less lead (weight for weight as the lead ore runs roughly 85 percent lead) began dying at the end of the tenth day although some fish in the series continued to live the full 31 days of the test. At least three factors contribute to these differences: (1) time, (2) the synergistic action of the substances other than lead in the incrustation material, and (3) the presence in the incrustation material of other compounds of lead besides lead sulphid. The acute reactions of the fish during the first few days of exposure to the incrustation powder indicated severe physiological disturbances at the time, and it is a well established principle in physiological investigations that previous exposures to detrimental substances often enhance the toxic action of subsequent exposures to other substances of relatively low toxicity. Besides, various substances in the insoluble fraction may have contributed to the solution and absorption of the lead after it was taken into the body of the fish. Weathering on the flats changes part at least of the lead sulphid to lead sulphate, and a variety of other lead compounds may be formed during the course of the disintegration and recombination of the ore particles.

in the exposed mine slimes, so that the solution and absorption possibilities of the lead compounds in the mine slimes after exposure to weathering are quite different from those of bright, washed lead ore particles, as these particles leave the mill.

The experiments on goldfish, which it must be remembered are more resistant to environmental vicissitudes than trout and many other fishes, demonstrated that the incrustations which formed on the exposed masses of mine slimes spread out over the flats and the banks along the Coeur d'Alene River are highly toxic to fish life. Various immediate reactions to the incrustation material which were fatal to the fish if prolonged by repeated exposure to the freely soluble portion of these incrustations, were observed, and prolonged exposures to even very small amounts of the whole incrustation material produced cumulative poisonings in which lead storage was one of the manifestations. The immediate effects were apparently caused, primarily by the soluble zinc salts, and the cumulative effects by the concerted action of the various components of these incrustations with lead as the outstanding toxic agent.

b. Physiological assays of incrustation material.

As disturbances in swallowing, swimming and gill movements, followed by sluggishness and even coma were observed as immediate symptoms in fish exposed to the action of the incrustation material, several rather extensive series of physiological tests were made on fish, frogs, turtles and fresh-water mussels (see page 84 for list of species used) to ascertain more specifically the nature of this immediate toxic action. These rather technical experiments may be summarized briefly here as showing (see Figures 10 and 11) that high dilutions of the soluble fraction of the Thompson Flats incrustations

(1) produced immediate paralysis of the stomach and intestines of fishes, frogs and turtles, in dilutions as high as 1:100,000 and that even higher dilutions were destructive to peristalsis and the harmonious functioning of the parts of the alimentary canal in these animals. The damage resulting from exposure to this material was very largely irreversible, that is, there was little or no recovery.

(2) caused immediate disturbances in the heart beat of fishes, frogs, turtles and fresh-water mussels which shortly resulted in complete cessation of heart beat, when dilutions as high as 1:100,000 were used. These cardiac changes were also attended by permanent alteration of the physiological activities of the heart.

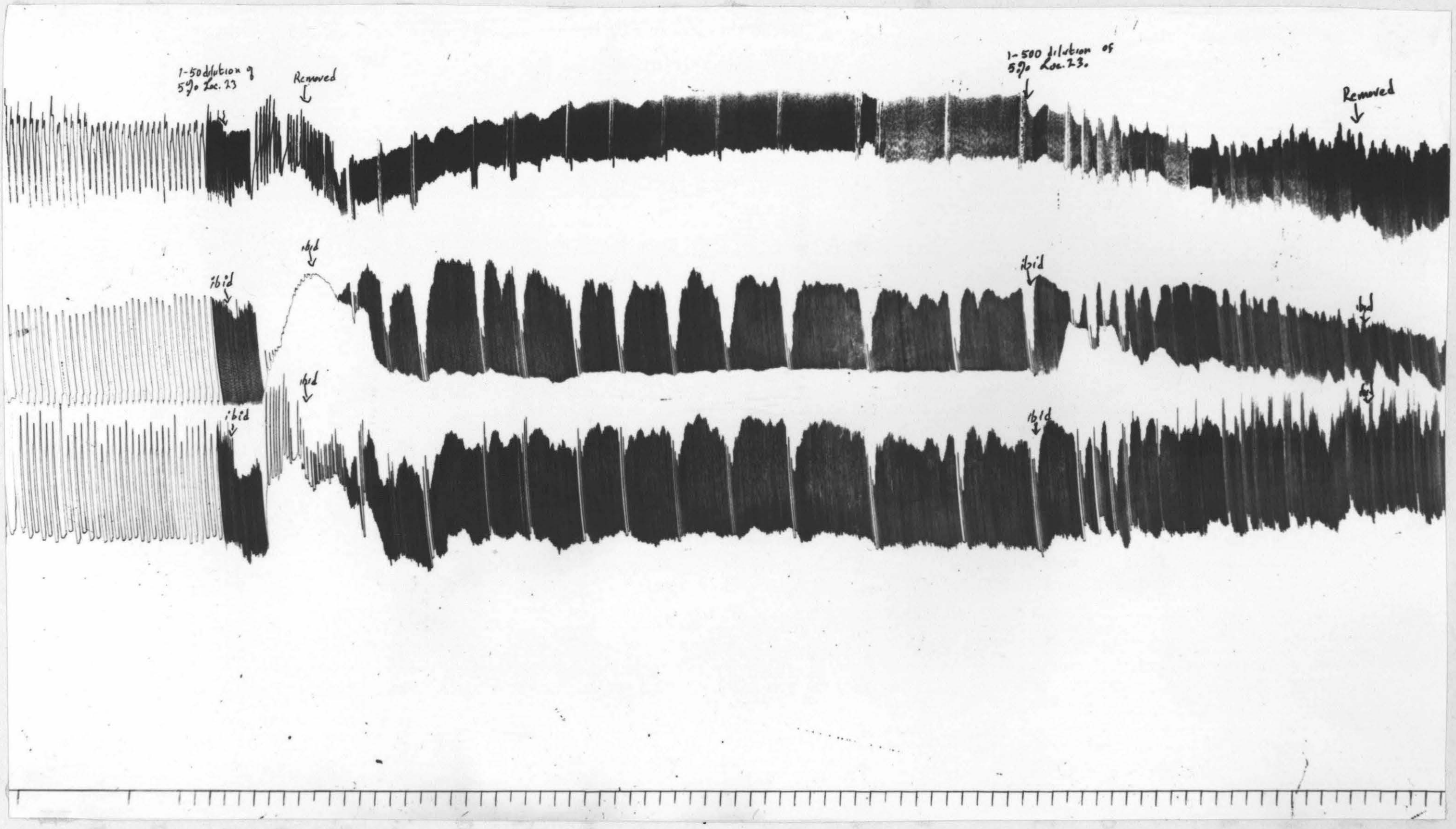


Figure 10

Toxic action of soluble material from Thompson Flat (Locality C23) on turtle heart _in situ_.

Top graph, ventricle
Middle graph, right auricle
Bottom graph, left auricle
Bottom line, time in 30 second intervals.

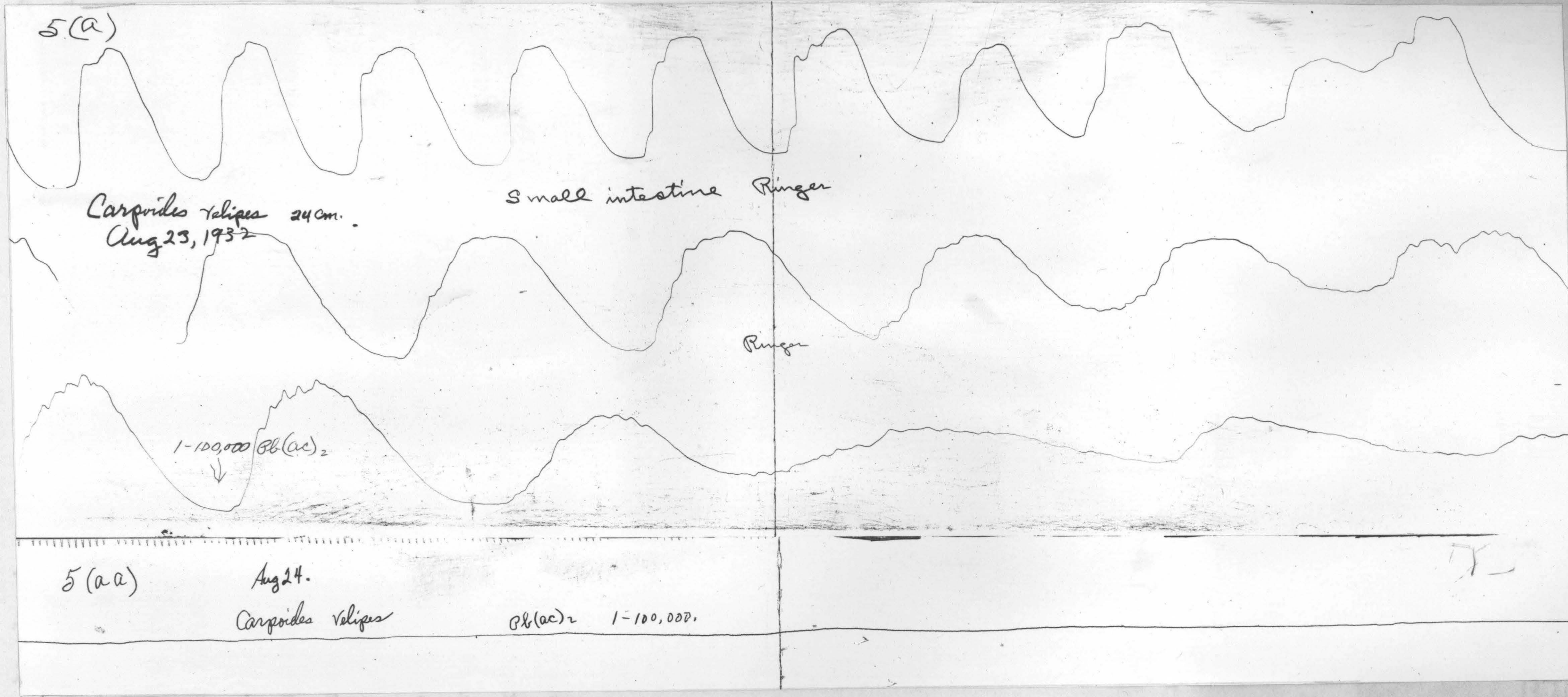
Solution applied by internal perfusion in normal Ringer's solution
First perfusion with 1 to 1,000 concentration. (1-50 dilution of 5%).
Second perfusion with 1 to 10,000 concentration. (1-500 dilution of 5%)/

(3) induced changes of much the same order of magnitude as those produced by lead poisoning with lead acetate in dilutions of 1:100,000, (see Figure 11). (Harnack, 1878).

The physiological assays collectively substantiate the findings in the survival experiments that the soluble fraction was highly toxic to fishes, frogs, turtles and fresh-water mussels if the exposure were long enough to allow even very small quantities of this soluble fraction to be absorbed, taken into the alimentary canal, or otherwise brought to the vital organs.

c. Plankton tests.

Following the procedure used in previous plankton tests the soluble fraction from the Thompson Flat incrustations was added to the water in which plankton crustacea were living and found to be very toxic,dilutions stronger than 1:1,000 killing all plankton crustacea exposed in less than five hours and dilutions as high as 1:100,000 proving fatal in 24 hours or less. Obviously such short survivals did not offer time for cumulative effects, so the high toxicity of this soluble fraction to plankton was ascribed to the soluble sulphates, particularly those of zinc and other heavy metals present in the soluble fraction of the incrustation material. This conclusion was verified by simultaneous tests of the soluble fraction, of zinc sulphate, of sodium sulphate and of



Toxic action of lead in the form of lead acetate on small intestine of the Quillback, *Carpiodes velifer.*
Internal perfusion through living intestine in tact. Perfusion 1 to 100,000 lead.
Time intervals, five seconds; large breaks, one minute.

mixtures of zinc and sodium sulphates. Pure zinc sulphate was found to be almost as toxic to the plankton crustacea as the soluble fraction of the incrustation material, as a dilution of 1:100,000 of zinc sulphate proved lethal to these animals in less than 24 hours and 1:10,000,000 was distinctly toxic in longer exposures. These values are practically the same as those for the fatal dilutions of the soluble fraction. Sodium sulphate on the other hand was tolerated by plankton crustacea in concentrations up to 1:1,000 with very few casualties, although a mixture of equal parts of sodium and zinc sulphates in a dilution of 1:100,000 was almost as toxic as the same dilution of zinc sulphate alone. The high toxicity of the soluble fraction for plankton seems, therefore, to be largely due to the zinc sulphate present in the incrustation material.

2. Bradley incrustations

As large masses of incrustations were seen on the piles of mine wastes along the Coeur d'Alene River near the mills, a composite sample of incrustation material prepared like the composite sample from Thompson Flat, was collected from mine wastes along the river at Bradley. It seemed desirable to compare these incrustations forming on wastes near the source of the wastes with the incrustations forming on mine slimes fifty miles or more down stream at Thompson Flat.

The composite sample from Bradley was of a dirty white color and carried some 39 percent of freely soluble material, running higher in both lead and zinc than the composite sample from Thompson Flat. From tests on fish and plankton the Bradley incrustations were found to possess the same toxic properties as those displayed by the Thompson Flat material, producing a profuse flow of mucous, incoordinate movements, sluggishness and death when fish were exposed to concentrations as low as 1:16,000 of the soluble fraction. Plankton animals were even more sensitive to this incrustation powder and dilutions of 1:100,000 and 1:1,000,000 of the soluble fraction were usually fatal in less than 24 hours. On the whole the Bradley incrustations were conspicuously more toxic than those from Thompson Flat.

General Discussion

Reviewing all the data, both field and experimental, it is evident that as far as fisheries are concerned the mine wastes poured in the South Fork in the Wallace-Kellogg area have reduced the fifty odd miles of the South Fork and main Coeur d'Alene River from above Wallace to the mouth of the river near Harrison, to a barren stream practically without fish fauna, fish food or plankton, and with enormous lateral supplies of potentially toxic materials which as they now stand (1932) will continue to poison the waters of the Coeur d'Alene River for a considerable period of time. In addition the stream bed and banks of the polluted portion of this river are covered with large masses of relatively non-toxic rock powder which because of their mechanical and physical properties have produced conditions which practically prevent the maintainance of any sort of a bottom fauna.

The acute pollution conditions in the Coeur d'Alene River, particularly at its mouth where it flows into Coeur d'Alene Lake, present another fisheries problem, namely one concerned with the effects of these mine slimes and toxic substances which the waters of the Coeur d'Alene River are projecting into Coeur d'Alene Lake, on the biota of that lake.

In the present survey mine slimes were found to be distributed over the floor of Coeur d'Alene Lake, in varying amounts from the mouth of the Coeur d'Alene River to the outlet of the lake west of Coeur d'Alene City. Chemical tests of these bottom samples showed that they contained small amounts of lead, zinc and other heavy metals. Soil samples from the flats along the stream bed of the Spokane River near Green Acres, Washington, at points where the waters of the river had recently receded also contained traces of lead, zinc and copper when subjected to chemical analyses. The evidence, both chemical and microscopical seemed conclusive that the mine slimes more or less mixed with various soil elements as sands and clays, have spread over most of the floor of the lake in the path of flow between the mouth of the Coeur d'Alene River and the outlet west of Coeur d'Alene City. In view of these findings in the lake, the analyses of soil from the river flats near Green Acres, Washington, although by no means conclusive, are suggestive at least that some of the mine slimes or their products are being carried out of the lake and down the Spokane River. However, the data from the bottom samples, and from slime deposits along the shore of Coeur d'Alene Lake, as at Black Rock, indicate that at times large areas of Coeur d'Alene Lake are exposed to clouds of highly dilute mine slime suspensions, and that deposits of these slimes are being incorporated in the floor of the lake. The solid matter composing the clouds of mine slimes carries according to the analyses given by O'Keeffe and Ziegler (1930, p. 2) from 0.25 to 0.45 percent lead as Pb and from 1.7 to 2.3 percent zinc as Zn. The biological hazards resulting from these clouds of mine slimes in the lake water depend largely upon the amount of material in suspension and the duration of the clouding of the lake with these slimes. During July, 1932 the turbidity of the lake was little if at all effected by mine slimes beyond East Point, so that these suspensoids at that time were highly dispersed. It must be remembered however, on the basis of existing analyses of these suspensoids that if the mine slime suspension rose to a concentration of only 50 parts per 1,000,000 there would be sufficient lead present in the lake water to produce cumulative lead poisoning according to the findings of Porritt, (1931), without considering the possibility of lead in solution. Suspensions of mine slimes of this degree of concentration and higher were found in the Coeur d'Alene River water near Harrison during July, 1932 and have been reported by O'Keeffe and Ziegler (1930) from the same locality in 1930. The pollution of the water of Coeur d'Alene Lake, therefore, by these mine slimes will vary directly with the flowage of the Coeur d'Alene River and the output of the mines.

The effect of the mine slimes on the bottom fauna of Coeur d'Alene Lake has already been discussed in the section on bottom conditions, and from the findings in those studies it can be stated that the slime deposits form only a portion of the material which is covering the floor of the lake with layers of inorganic silt.

Summarizing the findings in Coeur d'Alene Lake during July, 1932 the water conditions dependent upon dissolved gases, and carbonates were food and apparently had not changed during the past 20 years, judging from Kemmerer's report (1923) on conditions in Coeur d'Alene Lake during 1911; the bottom fauna was declining; and the plankton catches gave definite evidence of the detrimental effects of the water from the Coeur d'Alene River as far out in the lake as East Point. In the main the pollution from the Coeur d'Alene River is only one factor, in the present complex of conditions which are reducing the fishing in Coeur d' Alene Lake. The mine slimes do present a potential hazard which might at any time become serious if the quantities of mine wastes were increased beyond the volumes seen in July, 1932. The cumulative effects of these slimes on Coeur d'Alene biota if present conditions are maintained are only speculative.

Recommendation

From the viewpoint of fisheries interests one recommendation is obvious as a result of this survey. However, anyone familiar with the Coeur d'Alene district must recognize at once that many other interests, some commercial, some of human hazard, some recreational, are involved in this particular pollution problem. The following suggestions are offered therefore strictly as remedial to the fisheries problems, and the bearing of these suggestions on other matters of human welfare and activities must be decided by those to whom the administration of this district and the waters are entrusted, although the writer has not been unmindful of these complications.

Collectively the mine wastes in the Coeur d'Alene River have destroyed the fish fauna and the plants and animals on which fishes feed, first because the enormous masses of rock powder have overwhelmed everything in the stream with shifting deposits of inorganic waste; and second because the weathering mine slime on the flats and banks produce substances which when leached back into the stream are highly toxic to plankton and other organisms which supply the basic food and to the fish themselves. These conditions in the Coeur d'Alene River not only have made that river barren, but they are threatening all of the lakes adjacent to the Coeur d'Alene River, and constitute constant menace to Coeur d'Alene Lake. There is only one complete solution to this problem and that is the exclusion of all mine wastes from the Coeur d'Alene River. Even if this is done, it will take the river some time to rid itself of the masses of powdered rock in the stream bed and of the weathering deposits of mine slimes along its banks, so that several years will elapse before a natural fauna will reestablish itself in the now polluted portion of the Coeur d'Alene River.

The exclusion of the mine wastes from this stream immediately brings up the question of mine waste disposal, if the mines are not permitted to use this river. Although this is an engineering problem rather than a fisheries matter, the writer visited the Sullivan Mines and Mills at Kimberley, British Columbia, where a successful disposal system for mine wastes from the same sort of ore as those in the Coeur d'Alene District and milled by the same methods, has been worked out. As the Dominion and Provincial laws prohibit the dumping of mill wastes into the natural waters of Canada (a letter from the Deputy-Attorney General of the Province of British Columbia refers to paragraph 332 of the Water Act, as covering this case}, a settling system has been perfected by the Sullivan Mills which handle an ore tonnage comparing favorably with that of the Coeur d'Alene District, for all of the mill wastes at Kimberley. The writer was informed during his visit in Kimberley that the original cost of this settling system was not prohibitive and that the up-keep was nominal.

The mine wastes are conveyed by wooden flumes (see figures 12 and 13) to a settling basin. These flumes are so placed that the wastes

Figure 12.

Margin of settling basin for mine wastes, Sullivan Mining and Milling Company, Ltd. near Kimberley, British Columbia. The main settling area can be seen toward the background in the right half of the picture. The wooden flume carrying the waste slimes passes along the left of the picture. The masses of white material in the foreground having the appearance of snow are crystals of waste substances forming on the surface of the slimes recently discharged from the flume.

run into this basin from several points and the deposits form the dam for the basin holding back the waste waters until the rock powder has settled out and forcing the waste waters to filter back through the deposits. From the first settling basin the now clear water passes to a second settling basin, where the process of settling and filtering is repeated, with the result that the volume of water is greatly reduced by evaporation and the mine chemicals and other substances in solution are very largely destroyed before the water leaves the second settling basin.

Although the banks of the first settling basin were heavily frosted with incrustations (see figure 12) like those forming on the mine slimes in the Coeur d'Alene District and which were found to be quite as toxic as the incrustations at Bradley, by the time the water left the second settling basin it was so reduced in volume and so purified that within a few yards of the mouth of the outlet ditch carrying this waste to the St. Marys River, plankton, algae, aquatic insects and fish were found in the St. Marys River.

Various tests of the mine slimes, the mine waters and the purified water after leaving the settling basins were made and the problem of the Kimberley Mills found to be the same as that of the Coeur d'Alene Mills, with the settling basin system providing a practical solution for the waste disposal without stream pollution.

As a partial solution to the existing conditions in the Coeur d'Alene District some of the mine officials have recently

Figure 13.

Another view of the settling basin for mine slimes on the Sullivan Mining and Milling Company, Ltd. properties near Kimberley, British Columbia. The main wooden flume for the distribution of these slimes crosses the background of the picture.

constructed a suction dredge which is to pump out the mine slimes from the Coeur d'Alene River near Mission Flats and deposits these slimes on the land nearby, which has been acquired for the purpose. This procedure will undoubtedly reduce the amount of mine slimes carried to the lower river but as the finer particles will not settle out even in Coeur d'Alene Lake the pollution of the lower river will not be corrected, but merely modified. Of course, this pumping out of mine slimes will be helpful to some extent but it will not solve the pollution problems in the Coeur d'Alene River for fisheries.

Summary of 1932 Investigations

1. The polluted portion of the Coeur d'Alene River, that is the South Fork from a short distance above Wallace, Idaho to its junction with the North Fork above Cataldo, and the main Coeur d'Alene River from the junction of the forks to its mouth near Harrison, Idaho was found (July, 1932) to be practically devoid of fish fauna, bottom fauna or plankton organisms.

2. The unpolluted small lakes adjacent and tributary to the Coeur d'Alene River between Cataldo and Harrison, were supporting normal fish fauna of bass, sunfish, perch and minnow, together with ample aquatic vegetation and plankton fauna.

3. Thompson Lake and Swan Lake, both rather heavily polluted by recent backwaters from the Coeur d'Alene River were almost without plankton fauna.

4. The plankton fauna of Coeur d'Alene Lake as a whole was rather sparse, and particularly poor at the south end. No plankton were taken off Harrison and at the mouth of the Coeur d'Alene River; and very few as far up the lake as East Point. A comparison of the plankton data obtained by Kemmerer in 1911 with those collected in 1932 showed a decline in the plankton fauna, but the same general distribution, Kemmerer having noted the poor plankton fauna near the mouth of the Coeur d'Alene River.

5. The bottom fauna of Coeur d'Alene Lake was very meagre, and seemed to be declining.

6. Minnows, dace, bass, and perch were found, and trout reported, as living in Coeur d'Alene Lake.

7. The decrease in the numbers of trout living in Coeur d'Alene Lake during recent years, should not be attributed to mine wastes alone as various other factors have been operative to cause these fish to become less plentiful in this lake.

8. The St. Joseph River and Chatcolet Lake were maintaining good plankton, bottom insect, and fish fauna. Bass, trout, perch, minnows and dace were all found in these waters.

9. No significant differences in dissolved gases, pH, carbonates, and other factors dependent upon these were found between the waters of the polluted portion of the Coeur d'Alene River, and those of the St. Joseph River or of the unpolluted portions of the South Fork. The specific conductance of the polluted water was higher than that of the unpolluted water but did not indicate an excessive amount of soluble material in the polluted water.

10. Comparisons of the dissolved gases, relative acidity, and carbonates in Coeur d'Alene Lake during July, 1932 with the analyses made by Kemmerer in this lake in 1911 showed the values

reported by both surveys to be essentially the same, indicating little change in the condition of the Lake with regards to these factors over a period of 20 years.

11. The bottom of the polluted portion of the Coeur d'Alene River was deeply covered with shifting deposits of very fine powder which not only overwhelmed the bottom fauna but prevented the development of any bottom consocies of animals either adult or immature.

12. Along the polluted portion of the Coeur d'Alene River the banks, flats and low lands were covered often to a depth of several feet with deposits of mine slimes which had been left there during high water and which were continually being returned to the river by wind, rain and current action, thus producing a constant repollution of the river with the slimes previously dropped by the river.

13. Deposits of mine slimes more or less mixed with other soil components, were dredged from the floor of Coeur d'Alene Lake at various stations, showing that the mine slimes have spread rather generally over the bottom of Coeur d'Alene Lake, particularly in the line of flow between the mouth of the Coeur d'Alene River and the outlet of Coeur d'Alene Lake west of Coeur d'Alene City. These bottom deposits contained lead and zinc in small amounts, and soil samples from the banks of the Spokane River near

Green Acres, Washington also contained traces of lead, zinc and copper, suggesting that some of the mine slimes or their products are not only carried across the lake but out of the lake and down the Spokane River.

14. Dace and minnows living in Coeur d'Alene Lake near Conklin, Park, when transferred to live cages in the Coeur d'Alene River a short distance above the mouth of the river died in 72 hours while controls under the same conditions of confinement showed no ill effects after 120 hours exposure to the lake water off Harrison.

15. Water from the polluted portion of the Coeur d'Alene River near Harrison was definitely toxic to plankton crustacea killing all plankton animals placed in this water in 18 hours or less.

16. All of the milling chemicals with the exception of sodium carbonate were very toxic to both fish and plankton. The milling chemicals, however, do not present any particular pollution hazard except in the immediate vicinity of the emptying flumes as only part of these milling chemicals leave the mill and the organic derivatives as potassium xanthate and the cresols are soon broken down in the stream.

17. The milling products, that is the rock powder and sodium compounds were relatively non-toxic except as they disturbed the natural salt balance in the river water. Plankton animals were fairly sensitive to such changes.

18. The washed sulphid ores of both lead and zinc were non-toxic to fish in 31 day exposures, but the washed lead ore was quite toxic to plankton.

19. Mine waters and flume waters were quite toxic to plankton.

20. Large amounts of incrustations were observed on the exposed mine slimes on the flats along the polluted portion of the river and in soils more or less impregnated with mine slimes. The incrustations formed hard coatings over the soil in many places and often covered several acres of surface at any given station. In July, 1932 these incrustations amounted to 27 tons per acre on the Thompson Flats.

21. The incrustations were composed of a soluble fraction (3 to 40 percent) which was largely zinc sulphate, and an insoluble fraction carrying zinc and lead compounds.

22. The soluble fraction of these incrustations was highly toxic to fish, frogs, turtles, fresh-water mussels and plankton crustacea.

23. Exposures of 12 to 31 days to high dilutions of these incrustations were fatal to fish, the animals showing among other symptoms black deposits of lead in the fins and elsewhere about the body, indicative of cumulative lead poisoning.

24. The acute pollution conditions existing in the Coeur d'Alene River as resulting from the enormous deposits of rock powder and from the toxic substances produced by the weathering of the exposed mine slimes on the flats, are threatening the small lakes along the Coeur d'Alene River, and also Coeur d'Alene Lake.

25. There is but one solution for this pollution problem as far as fisheries are concerned, namely, the exclusion of all mine wastes from the Coeur d'Alene River.

26. A practical system for the disposal of mine wastes without river pollution, now in operation in British Columbia, is discussed.

Acknowledgement

The writer wishes to acknowledge the generous co-operation given to the Fisheries party during the course of this survey by the Idaho Pollution Commission, by the Consolidated Mining Interests of the Coeur d'Alene District, and by the Sullivan Mines and Milling Company, Ltd. of Kimberley, British Columbia. Particular thanks are due to Commissioner E. O. Cathcart who accompanied us on many of the field trips and greatly expedited the investigations both through his personal knowledge of the roads, streams and lakes, and through his unselfish and unbiased interest in the work; to Messrs. W. L. Ziegler and E. C. O'Keeffe of the Consolidated Mining Interests who personally facilitated our work in the Wallace District, and who made it possible for us to secure many important samples; to Mr. Montgomery, General Superintendent of the Sullivan Mines and Milling Company of Kimberley, British Columbia who, as officer in charge of this entire project, authorized his subordinates to help us in every way possible and who placed laboratory analyses and other important data at our disposal and to Mr. Henry Banks, Assistant Superintendent of the Sullivan Mills, and Mr. A. Loansbrough Jones, Superintendent of operations of the Sullivan Mills, who personally aided us in many ways in the taking of samples and in the examinations of the Sullivan mining operations.

Bibliography

BAUDIN, LOUIS.

1932. Action de la tricaine sur la consommation d'oxygen de *Carassius auratus*. Comptes rendus des Seances de la Societie de Biologie, tome 109, 1932, pp. 731-733.

CUSHNY, ARTHUR H.

1906. A text book of pharmacology and therapeutics. Lea Brothers, Philadelphis and New York, pp. 1-752.

DRINKER, KATHERINE R., PHEBE K. THOMPSON and MARION MARSH.

1927. An investigation of the effect upon rats of long-continued ingestion of zinc compounds, with especial reference to the relation of zinc excretion to zinc intake. American Journal of Physiology, Vol. 81, 1927, pp. 284-306.

FAIRHALL, L. T. and C. P. SHAW.

1924. The deposition of lead salts, with a note on the solubility of di-lead phosphate in water at 25° Centigrade and of di-lead and tri-lead phosphates in lactic acid at 25° Centigrade. Journal of Industrial Hygiene, Vol. 6, 1924, pp. 159-168.

GARREY, WALTER E.

1916. Resistance of fresh-water fish to changes of osmotic and chemical conditions. American Journal of Physiology, Vol. 39 for 1915-16(1916), pp. 313-329.

HAMMETT, FREDERICK S.

1928. The localization of lead within the cell of the growing root. Protoplasmia, Vol. 5, 1928. pp. 135-141.

HARNACK, ERICH VON

1878. Uber dis Wirkungen des Bleis auf den thierischen Organismus. Archives fur Pathologie und Pharmakologie, Vol. 9, 1878, pp. 152-225.

JORDAN, DAVID STARR and BARTON WARREN EVIRMANN.

1896. The fishes of North and Middle America, Part I. Bulletin United States Natural Museum, No. 47, 1896, pp. 1-1240.

KEMMERER, GEORGE, J. F. BOVARD and W. R. BOORMAN

1923. Northwestern lakes of the United States; biological and chemical studies with reference to possibilities in production of fish. Bulletin United States Bureau of Fisheries, XXXIX for 1923-24, (1923), pp. 51-140.

KOLTHOFF, I. M.

1931. The solubilities and solubility products of metallic sulphides in water. Journal of Physical Chemistry, Vol. 35, Pt. 2, 1931, pp. 2711-2721.

LOCKE, F. S.

1895. On a supposed action of distilled water as such on certain animal organisms. Journal of Physiology, Vol. XVIII, 1895, pp. 319-331.

MAGATH, THOMAS B.

1931. Lead poisoning in wild ducks. Proceedings of the Staff Meetings of the Mayo Clinic; Vol. 6, 1931, pp. 749-752.

MINOT, A. S.

1924. Distribution of lead in the organisms after absorption. Journal of Industrial Hygiene, Vol. 6, 1924, pp. 125-148.

MUIR, F. and O. H. SWEZEY.

1926. Preliminary work with soil fumigants. Proceedings Hawaiian Sugar Planters Association, 45th Annual Meeting (1925), (1926), pp. 300-301, Honolulu.

MULLAN, JOHN

1863. Report on the construction of a military road from Fort Walla-Walla to Fort Benton. Senate Document Government Printing Office, 1863, pp. 1-363.

O'KEEFE, EDWARD C. and W. L. ZIEGLER.

1930. Condensed report of investigation on pollution of Coeur d'Alene River and Lake Coeur d'Alene. June 11 to Sept. 10, 1930. A typewritten report issued by the Federal Mining and Semlting Company and Wallace Testing Plant, Wallace, Idaho, Sept. 30, 1930, pp. 1-30.

ORESTANO, G.

1931. Azione farmacologica del solfuro di-piombo colloidale. Archives internationales de Pharmacodynamie et de Therapie, Vol. XLI, 1931, pp. 309-344.

PORRITT, N.

1931. Cumulative effect of infinitesimal doses of lead. British Medical Journal, Vol. 2, 1931, pp. 92-94.

POWERS, EDWIN B.

1917. The goldfish (Carassius carassius) as a test animal in the study of toxicity. Illinois Biological Monographs, Vol. IV, No. 2, October, 1917, pp. 3-73.

SHELFORD, VICTOR E.

1917. An experimental study of the effects of gas waste upon fishes, with special reference to stream pollution. Bulletin Illinois State Laboratory of Natural History, Vol. XI, 1917, pp. 381-412.

STOLL, WILLIAM T.

1932. Silver Strike, The True Story of Silver Mining in the Coeur d'Alenes, Little Brown and Company, Boston, pp. 1-273.

WARREN, ERNEST.

1900. On the reaction of <u>Daphnia</u> <u>magna</u> (Straus) to certain changes in its environment. Quarterly Journal of Microscopical Science, Vol. XXXXIII, 1900, pp. 199-224.

WEIGELT, C.

1903. L'assainissement et la repeuplement des rivieres. Memoires couronnes et autres memoires de l'Academy Royal de Belgique, Tome LXIV, 1903.

WELLS, M. M.

1915a. Reactions and resistance of fishes in their natural environment to acidity, alkalinity and neutrality. Biological Bulletin, Vol. 29, 1915, pp.221-257.

1915b. The reaction and resistance of fishes in their natural environment to salts. Journal of Experimental Zoology, Vol. 19, 1915, pp. 243-283.