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MINE-WASTE POLLUTION OF BEAR BUTTE CREEK, BLACK HILLS, SOUTH DAKOTA

BY

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INTRODUCTION

In the course of a general investigation of mine wastes affecting fish and other aquatic life in the streams of western United States, effluents leaving the Gilt Edge Mining properties in the Black Hills near Deadwood, S. Dak., were collected during April 1940. Field studies of these effluents and of the streams receiving them were made at the time and subsequently laboratory assays and analyses have been completed on samples returned to the Columbia (Mo.) Laboratories of the Fish and Wildlife Service.

Data from this particular case of mine waste pollution are presented here in advance of the general report on mine effluents at the request of officials of the State of South Dakota. The pollution of Bear Butte Creek is a recent development as the wastes from the Gilt Edge holdings had been turned into Bear Butte Creek only a little over 2 months before the present studies were made. However, the polluted waters had entered Boulder Canyon below Deadwood early in April, 1940, and were moving down this canyon at the time of these investigations.

The Gilt Edge Mill is located at the head of a gulch which drains into Bear Butte Creek near Galena, S. Dak. From Galena, Bear Butte Creek follows a meandering course to the northeast entering Boulder Canyon about 6 miles east of Deadwood. Thence Bear Butte Creek continues down this canyon leaving the hills near Sturgis and after passing through plains country for about 12 miles enters the Belle Fourche River near Volunteer, S. Dak.

Above Galena, that is, upstream from the junction with the gulch receiving the wastes from the Gilt Edge properties, the waters of Bear Butte Creek are clear, sparkling and cold, and possess the general characteristics of a typical mountain meadow or mountain park trout stream fed by springs, snow, and mountain run-off waters.

Chicago, 1943
1945

Below Burchett Springs in Boulder Canyon, east of Deadwood, Bear Butte Creek is dry for a considerable portion of the year but a well-defined stream bed extends from Boulder Canyon to the Belle Fourche River. This lower portion of Bear Butte Creek carries the waters of heavy rains and other sudden run-offs from Boulder Canyon together with any waters that come down Bear Butte Creek from the hills, east into the Belle Fourche River.

THE MINE WASTES

The effluent from the Gilt Edge Mill at the time of this investigation was a grayish fluid carrying a large quantity of rock powder together with spent chemicals from the oil floatation process used in the separation of gold. This waste was flumed from the mill into the gulch, down which flowed a small stream draining huge piles of "sands", that is, crushed rock wastes left by previous cyanide-process operations. The run-off water from these old cyanide dumps was yellowish brown in color and heavily loaded with very fine rock powders. Waters pumped from the mine constituted a third source of possible pollution in this complex.

The mixture of these three waters, namely, the effluent from the oil floatation mill, the run-off from the old cyanide dumps, and the waters pumped from the mine, produced a yellowish-gray stream of opaque fluid which flowed rapidly down the steep gulch and joined Bear Butte Creek near Galena, S. Dak.

The hazards to fish and other aquatic organisms from oil-floatation wastes can be classified as those resulting from the rock powder carried in the effluent, and those due to the toxic action of various chemicals from the floatation operations. The oil-floatation effluent from the Gilt Edge Mill as collected directly from the mouth of the flume emptying into the gulch stream (No. 2101 in table 1) carried 295,260 p.p.m. (parts per million) suspended solids by weight, and 750 p.p.m. of dissolved solids. The suspended solids in this effluent together with the water which they occluded constituted 56 percent of the mixture by volume after 1 hour sedimentation.

Further analyses of these suspended solids showed that the maximal particle size in this floatation waste was approximately 1,500 micra and that during the first 30 minutes of sedimentation the coarse particles which constituted 13 percent of the effluent settled out rapidly (Alpha layer) and that in a second layer (Beta layer) comprising 43 percent of the effluent by volume, all of the finer particles down to the size of 20 micra were deposited during 1 hour of sedimentation. The supernatant fluid of this effluent after 1 hour sedimentation therefore constituted only 44 percent by volume, had a residual turbidity of 105 United States Public Health units and carried only 90 p.p.m. by weight of rock powder having a maximal particle size of less than 20 micra.

Table 1. Summarized data from various samples collected during a study of the pollution of Bear Butte Creek, South Dakota

Item	Locality No. 1/					
	2104	2101	2102	2103	2106	2105
Solids, p.p.m. by weight						
Suspended						
All	Trace	295,260	88,780	13,836	14,380	2,59
After 1 hr. sedimentation	---	90	160	848	440	66
Dissolved	140	750	660	320	420	21
Total	140	296,010	89,440	14,156	14,800	2,83
Suspended solids by percentage volume						
After 30 min. sedimentation						
Alpha layer	---	13.00	4.75	0.70	0.05	0.06
Beta layer	---	48.00	32.25	3.50	21.45	2.24
Total	---	61.00	37.00	4.20	21.50	2.30
After 1 hr. sedimentation						
Alpha layer	---	13.00	4.75	0.70	0.05	0.06
Beta Layer	---	43.00	29.25	4.05	19.95	2.91
Total	Trace	56.00	34.00	4.75	20.00	3.00
Suspended solids, maximum particle size (Micra)						
All	10	1,500	1,500	700	20	20
After 1 hr. sedimentation	10	20	20	5	5	5
Residual turbidity after 1 hr. sedimentation (U.S.P.H.units)	1---	105	305	2,420	5,000	1,250
Hydrogen-ion concentration (pH)	7.98	7.29	7.45	7.60	7.47	7.50
Specific conductance (mho x 10 - 6 at 25° C.)	204	1,782	680	307	435	339

1/ 2104 : Bear Butte Creek, 300 yds. above junction with Gilt Edge Gulch stream.
2101 : Flume effluent from flotation process, Gilt Edge Mill.
2102 : Mixture of run-off from old sand dumps and flume effluent from flotation process, Gilt Edge Mill.
2103 : Bear Butte Creek, 100 yds. below junction with Gilt Edge Gulch stream
2106 : Bear Butte Creek at Burchett Spring in Boulder Canyon, 6 mi. E. of Deadwood.
2105 : Bear Butte Creek, 500 yds. below Burchett Spring, E. of Deadwood.

These determinations on the rock powder in this effluent show that the waste carried approximately 37,000 p.p.m. by weight of coarse rock particles (maximal particle size 1,500 micra) which would settle out quickly in the more quiet portions of the stream; approximately 258,000 p.p.m. of fine rock powder most of which would move or shift readily in a current of 2 miles or more per hour; and only 90 p.p.m. of very fine silt which would tend to coat fish eggs and the more delicate structures such as gills, spiracles and fins both of miscellaneous small aquatic animals and young fish, even if the Alpha and Beta layers were removed.

The chief stream hazard, therefore, of the rock powder leaving the floatation plant of the Gilt Edge Mill is the blanketing action of these rock particles which cover the stream bottom and submerge objects with a shifting layer of fine sand and coarse silt and smother all forms of bottom life. This bottom blanket of rock particles will continue to flow downstream as long as the incoming supply is maintained.

The watery portion of the effluent from the floatation operations of the Gilt Edge Mill had a pH of 7.29 (as determined with the Beckman Glass Electrode), a specific conductance of 1,782 mho x 10-6 at 25°C., (determined by standard conductance cell and micro hummer) and carried 750 p.p.m. of dissolved solids by weight. These values, which indicate a slightly alkaline water carrying only 0.075 percent dissolved solids (largely ionizable salts are within limits readily tolerated by most fish and other aquatic animals if the dissolved substances have no marked specific toxicity. Several of the chemicals used in oil floatation of various ores however are highly toxic in very small quantities to fish. Since both the combinations of these substances and the alterations of the compounds themselves by various materials in the rock powders, vary greatly in different plants because of the differences in individual mill operations, the toxicity of the effluent water must be determined for each case of floatation waste studied. The watery portion of the oil floatation effluent as collected from the Gilt Edge Mill in April 1940, had very low toxicity for fish, which toxicity was largely counteracted by subsequent dilution. Thus the specific toxicity of the fluid portion of this particular effluent may be dismissed as inconsequential if the present composition of that effluent and the present dilution ratio are maintained.

No accumulations of oil were noticed in the polluted portion of Bear Butte Creek and such accumulations could hardly have been expected in April 1940, as only small quantities of oil are used in floatation work and the present routine of floatation operations had been in progress at the Gilt Edge Mill only a few weeks at the time the samples reported on here were taken. However, if evidence from other oil-floatation operations be considered, increasing accumulations of the finely-divided oil on submerged objects over which this effluent flows may be expected if the floatation process is continued long enough. Such oil deposits although actually composed of very small quantities of oil, have become serious hazards to aquatic life of various sorts in other streams, particularly to the small organisms comprising fish food, and to young fish.

As the water pumped from the mine and the run-off waters from the old cyanide "sands" vary in quantity, the mixture of the combined wastes from these two sources together with the floatation effluents from the mill was studied. Samples were collected just below the floatation waste flume after these three wastes were thoroughly mixed by their own currents in the gulch stream (see No. 2102, table 1).

The combined wastes from the Gilt Edge Mining properties, as just described, carried 89,440 p.p.m. by weight of suspended solids and 660 p.p.m. of dissolved solids. After 1 hour, 160 p.p.m. of solids were still suspended producing a residual turbidity of 305 U.S.P.H. units in the supernatant water. The total rock powder in this sample constituted 34 percent by volume of the effluent. The formation of the Alpha and Beta layers during sedimentation showed the same general stratification as that of the effluent from the floatation process and the range of particle size was the same for the mixed waste as for the floatation waste alone. However, the Beta layer of silt was much less stable in this mixture than in the waste from the floatation plant.

These findings demonstrate a dilution of the floatation waste by the waters from the mine and from the old cyanide dumps. The most significant characteristic of the mixed waste as compared with the floatation effluent is the greater residual turbidity of the mixed waste. Although the mixed waste carries fewer parts per million of suspended solids (88,780 as compared with 295,260 in the floatation effluent) it has about three times as great a residual turbidity after sedimentation. This greater turbidity was produced by almost twice the actual load of particles suspended after 1 hour of sedimentation, namely, 160 p.p.m. as compared with 90 p.p.m. in the floatation effluent alone.

This increase in residual turbidity is produced by the fine rock powder carried in from the old cyanide dumps by run-off water. The piles of disintegrating mine "sands" contribute yellowish-brown waters carrying rock powders which, because a large percentage of the suspended particles are 5 micra less in size, spread in density currents or clouds when added to clear water. Owing to the small particle size, rock powders from the old cyanide "sands" settle out very slowly and the layers of finer particles are very unstable, being readily moved by currents of less than 1 mile per hour. The physical characteristics of these particular fine rock powders from the cyanide dumps together with the small size of the suspended particles are such that the wet silts comprising the finer portions of the cyanide dump run-off adhere readily to submerged objects including fish eggs, and the gills and fins of small aquatic animals, and thus produce disastrous effects on the aquatic fauna. The seriousness of the hazard of fine silts to aquatic life has been demonstrated in various parts of the United States, and one example from a nearby stream will suffice. Similar silts from old cyanide wastes at the head of Annie Creek which drains into Spearfish Creek near Cheyenne Crossing are known to have produced catastrophes among the young fish and developing fish eggs at hatcheries located on this stream, several times during recent years.

The introduction of large amounts of very fine silt (particle size less than 10 micra) having high adhesive properties constitutes the chief pollution hazard from the combined wastes of the Gilt Edge Mining Properties and from the cyanide "sands" on those holdings.

The watery portion of the combined wastes below the Gilt Edge Mill had a pH of 7.45, a specific conductance of 680 mho x 10^{-6} at 25°C. and was non-toxic to fish life at the time these samples were taken. However, the toxicity of the watery portion of these combined wastes will vary from time to time, dependent in part on the composition of the mine waters incorporated in this mixture. Mine waters may be little more than seepage from the surface and therefore carry little toxic material. These same mine waters, if allowed to accumulate in the workings or to leach soluble minerals, may become very acid and highly toxic. Observations elsewhere have shown that waters pumped from mines are subject to much variation in composition and should be checked frequently, if aquatic life in the stream receiving such waters is to be protected. Although the combination of wastes as studied in April 1940, at a time when there was much melting snow on the surrounding hills and much surface water moving into the soil, showed no specific toxicity or acid hazards from the mine waters themselves, they should be reexamined in mid-summer before they can be pronounced as not dangerous to aquatic life.

Attention has been directed repeatedly to old cyanide dumps as a possible source of poisonous material which might damage aquatic life. Although cyanides are extremely poisonous to most fish and other aquatic organisms, cyanides in general are subject to rather rapid chemical breakdown when in solution and exposed to air. The waters from the cyanide "sands" on the Gilt Edge properties as tested in April 1940, showed no cyanide, that is, gave no response to tests sensitive to 1 part cyanide in 10,000,000. However, the snow run-off was in progress at that time and the dilution and aeration of the leachings from the cyanide dumps were probably maximal. Consequently before the run-off waters from these piles of "sands" can be dismissed definitely as a possible source of toxic pollution, midsummer samples must be studied for residual cyanides.

POLLUTION OF BEAR BUTTE CREEK

The mixtures of wastes from the Gilt Edge Mining properties flow down a steep gulch, and thus arrive at the junction of this gulch with Bear Butte Creek near Galena, essentially the same as described from the samples below the Mill (No. 2102, table 1). The water of Bear Butte Creek a short distance above the junction with the stream from the gilt Edge gulch was cold, clear, and sparkling. After 24-hours sedimentation only traces of suspended solids (No. 2104, table 1) were found consisting for the most part of fragments of organic detritus from aquatic vegetation. The materials were of the character found in any rapidly moving stream which passes through mountai meadow land, together with some particles of sand and clay which are also to be expected in the waters of rapidly moving streams of this sort. The total volume of suspended material in Bear Butte Creek above the point of introduction of the wastes from the Gilt Edge Mining properties was so small as to be negligible and is therefore listed in table 1 as "trace". The hydrogen-ion concentration of this water gave a pH value of 7.98, that is, the water was feebly alkaline, and the specific conductance of 204 mho x 10^{-6} at 25°C., together with 140 p.p.m. of dissolved solids, indicate the usual load of dissolved carbonates and soil salts expected in such waters. Other analyses not listed in table 1 showed these dissolved salts to be largely carbonates.

Collectively, the analyses of the waters of Bear Butte Creek above the area of mine pollution indicate a very satisfactory water complex for fish and the usual supporting fauna of aquatic larvae and bottom forms. Upstream from the junction with the Gilt Edge Gulch stream the waters had a high content of dissolved oxygen and a desirable quantity of dissolved carbonates.

In the course of 100 yards below the junction with the gulch carrying the wastes from the Gilt Edge Mill, stream conditions in Bear Butte Creek changed abruptly. The water was opaque and of a yellowish-gray color; the suspended solids (No. 2103, table 1) rose from a trace to 13,836 p.p.m. by weight and the dissolved solids from 140 to 320 p.p.m. At the same time the residual turbidity after 1 hour sedimentation increased from less than 1 U.S.P.H. unit to 2,420 U.S.P.H. units, due to a residual load of 838 p.p.m. by weight of silt particles still suspended. This residual silt load was composed of fine silt, the maximal particle size being 5 micra, and many of the particles were much smaller. The bottom fauna had been completely eliminated by a covering of shifting sand and coarse silt on the stream bed and all of the submerged objects together with the creek margins were heavily coated with deposits of very fine silt. The entire stream had been rendered unfit for fish, particularly trout, and the supporting organisms which constitute fish food. These conditions obtained all the way down Bear Butte Creek, approximately 6 miles by stream, to the junction of this creek with Boulder Canyon about 6 miles east of Deadwood.

A review of samples collected at Burchett Spring in Boulder Canyon about 6 miles east of Deadwood, will suffice to show the movements of these mine wastes downstream in Bear Butte Creek as noted during the April 1940, survey. At this point (No. 2106, table 1) the waters of Bear Butte Creek receive some ground water in a small series of spring pools. The rate of flow of Bear Butte Creek is materially reduced in these pools although the waters are agitated to some extent by the inflow from the springs. Even with the dilution afforded by the springs the slowing of Bear Butte Creek at this point had facilitated the accumulation of fine silt (particle size less than 5 micra) so that the suspended solids were found to be 14,380 p.p.m. by weight in the moving water at this location. The marked increase in the number of fine particles in the silt suspension is shown by the residual turbidity of this water, which equalled 5,000 U.S.P.H. units after 1 hour sedimentation, and was produced by a load of 440 p.p.m. by weight of residual suspended solids.

The rapid loss of the larger particles of rock powder from the moving water after the Gilt Edge Mining wastes entered Bear Butte Creek near Galena is seen in the reduction of maximal particle size of the suspended matter in the water at localities 2103 and 2106. At No. 2103 the maximal particle size of the suspended material in the polluted stream had dropped to 700 micra and at Burchett Spring (No. 2106) the maximal particle size in the moving water was only 20 micra. The reduction in the volume of the Alpha layer in the sedimentation tests of samples from these two localities also shows this same loss of large particles from the moving water in the upper levels of the stream. The Alpha layer after 1 hour of sedimentation comprised only 0.7 percent by volume of the sample at No. 2103 and only 0.05 percent at Burchett Spring, No. 2106.

Although the coarser material was being rapidly lost from the moving waters of Bear Butte Creek as these figures show, the deposits of fine sands and coarse silts on the bottom were being moved downstream steadily by current action. An extensive deposit of these heavier particles had already reached Boulder Canyon in April 1940.

Samples taken below Burchett Spring in Boulder Canyon (No. 2105, table 1) from the stream near the east end of water flow at that time, carried 2,590 p.p.m. by weight of suspended solids in the moving water of the top layer. This water had a residual turbidity after 1 hour of sedimentation of 1,250 U.S.P.H. units, due to 660 p.p.m. by weight of silt particles still in suspension. These values, when compared with those obtained at Burchett Spring (No. 2106), demonstrate the "settling basin" effect of the pools in the Burchett Spring area. As soon as these pools are filled with the bottom flow of sands and coarser silts, conditions comparable to those at No. 2103 will appear progressively farther down Boulder Canyon. If the supply of rock powder from the Gilt Edge gulch is maintained these sands and silts ultimately will reach the Belle Fourche River near Volunteer, S. Dak.

EFFECTS OF MINE-WASTE POLLUTION ON BEAR BUTTE CREEK

Already over 6 miles of a fine mountain stream have been rendered unfit for fish and the supporting fish-food organisms. Were the wastes from the Gilt Edge properties excluded from Bear Butte Creek at once it would require several seasons and the snows of several winters to flush out the wastes now deposited in this stream between the junction with Gilt Edge Gulch and Boulder Canyon below Deadwood. Several years would elapse before the stream could be restored to its former usefulness as a recreational asset to the State of South Dakota. However, prompt action now can still save this 6-mile stretch of Bear Butte Creek.

If the wastes now entering Bear Butte Creek from the Gilt Edge Mine properties are permitted continued access to the stream conditions will rapidly become almost irreparable. The accumulation of wastes in Bear Butte Creek will become not only more unsightly but even offensive, and more and more of the marginal vegetation including many fine trees along this stream will be killed. The disfigurement of Boulder Canyon also will proceed along these same lines if the wastes from the Gilt Edge Holdings are allowed exit through Boulder Canyon.

RECOMMENDATIONS

1. All wastes from the Gilt Edge mining properties should be excluded, as soon as possible, from Bear Butte Creek.

2. The floatation wastes from the Gilt Edge Mill should be flumed into a suitable settling basin and only the clear overflow waters allowed to escape. In the case of the floatation wastes from the Gilt Edge Mill, as some of the sedimentation studies presented here have shown, settling will remove almost all of the rock powder in 1 hour if this waste be unmixed with other wastes.

3. The run-off from the cyanide dumps, that is the old "sands", should be impounded and not permitted to enter the gulch stream. Careful ditching and the construction of small earthern-work dams would hold this run-off entirely at the base of these waste piles. Seepage water from such an impoundment probably could be allowed escape.

4. The waters pumped from the mine should be carefully studied and, if found hazardous in mid-summer or any other seasons, properly impounded.

5. The most logical solution for the whole problem would be fluming of all of the wastes from the Gilt Edge Mining properties collectively into the headwaters of Whitewood Creek which is already a heavily polluted and ruined stream carrying loads of mine wastes from various other mining properties.