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A Survey of Pollution on Selected Streams in the Black Hills of South Dakota

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A SURVEY OF POLLUTION ON SELECTED STREAMS IN THE BLACK HILLS OF SOUTH DAKOTA

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A SURVEY OF POLLUTION ON SELECTED STREAMS IN THE BLACK HILLS OF SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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A SURVEY OF POLLUTION ON SELECTED
STREAMS IN THE BLACK HILLS
OF SOUTH DAKOTA
Abstract

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Under the supervision of Dr. John Nickum

Seven streams in the Black Hills of South Dakota were surveyed to determine the influence of suspected sources of pollution on these streams.

The sources of pollution included both sewage treatment plant effluents and mining wastes. A comparison of the benthic fauna community below a pollution source to that above it was the primary basis for evaluating the effect of the pollution source on the stream.

The results of the benthic fauna samples indicated that the streams surveyed were being polluted. The degree of pollution of each stream was also indicated by these results. Chemical analysis were used to verify the results of the benthic fauna samples. These analyses concurred with the benthic fauna results and indicated the streams were being polluted.

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I want to thank R. Keith Stewart for his advice and counsel. His knowledge and experience of the Black Hills, which he generously shared, were helpful in initiating and conducting the study.

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The microphotographs of representative macroinvertebrates shown in Figures VII, VIII, IX, and X were taken by Roger Woo, of the University of Minnesota, Limnological Research Center.

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INTRODUCTION

Gold mining was the first major cause of widespread pollution in the Black Hills. More recently activities associated with mining, construction, waste disposal, and land and forest utilization (Figures I and II) have resulted in water pollution. A loss of over 1,000 miles of streams from the trout fishery in the last twenty years may be attributed to pollution (Stewart, 1961).

The major pollution problem currently degrading streams appears to be organic pollution. The sources of this pollution are stream-side homes and municipalities with insufficient sewage treatment facilities. Many homes adjacent to streams have only crude facilities for waste treatment. The wastes reach the stream either by direct deposition or indirect leaching. Community growth in the Black Hills area has resulted in the overloading of municipal sewage treatment facilities. This problem is compounded by an influx of tourists during the summer. When sewage treatment plants become overloaded, operators are forced to either partially treat wastes or allow raw sewage to by-pass the plant. These partially treated or raw wastes contain organic matter and toxic substances which reduce water quality (Figure I).

Consolidation of gold mining operations in recent years has limited pollution from this source to one drainage. However, potential mining pollution problems have been created in other drainages by reopening old gold mines with the expectation of discovering new minerals. Bog iron mining, recently made profitable by new advances in mining and new uses of this ore, has created a new pollution threat.

These mining operations are located adjacent to streams, where careless exploitations of their minerals could result in the destruction of several miles of streams.

Construction of roads and homes also has augmented the demise of streams. Roads designed to follow streams can be built at lower costs than those involving construction through mountainous terrain. Construction and maintenance of stream-side roads result in the introduction of large amounts of silt. This type of construction often necessitates direct modification of stream channels, such as rechanneling and straightening, resulting in a loss of stream length. Many of these modifications also result in accelerated erosion because flow rates of water are increased and vegetative cover that stabilizes stream banks is destroyed (Figure II). Construction of homes, primarily excavation and landscaping, also adds silt into the stream as excess soils are usually deposited in or adjacent to streams to avoid removal expenditures (Figure II).

Pollution from all these sources is intensified by reduced stream flows because pollutants are not adequately diluted. Orr (1959) reported a trend towards reduced stream flow caused either by dog-hair stands of ponderosa pine (Pinus ponderosa) or changes in precipitation patterns. Moisture is retained in the branches of dog-hair timber, where it evaporates and is prevented from reaching the ground; consequently, this moisture cannot reach the stream (Figure III). Drouth conditions can also result in reduced stream flows and intensify pollution because of the lack of dilution. Further evidence of reduced stream flows is recorded in the files of Cleghorn Springs Trout Hatchery located on Rapid Creek. These records show a reduction in flow from nine million gallons per day in 1928 to four million gallons per day in 1964.

Although pollution is generally apparent in the Black Hills, studies concerning the problem have been limited. The South Dakota Department of Health has reported pollution findings on Whitewood Creek (Anonymous, 1959); the Belle Fourche River (Anonymous, 1960); and Rapid Creek (Anonymous, 1964). The primary information reported in these studies concerns environmental health, and specific information regarding bottom organisms is briefly summarized or appended to chemical data. Other studies dealing with pollution have been reported by Stewart and Thilenius (1964) and Thilenius (1965).

The objectives of this study were: (1) to survey suspected sources of organic and mining pollution on major Black Hills' streams; (2) to determine the effect of these suspected sources on the streams by using benthic organisms as the main indicator of stream conditions; (3) to determine the practicality of using macroinvertebrates as a method of determining and monitoring stream conditions in the Black Hills.

The importance of macroinvertebrates as a tool in pollution investigation was emphasized by Hynes (1965) when he stated that a very simple study of the invertebrates can be used to determine the extent of pollution. Hynes (1960) also pointed out that some of the advantages of using macroinvertebrates in studying pollution are: (1) a single series of samples reveals the state of animal communities (2) animal communities provide a more or less static record (3) biological records show the result of intermittent pollution. It should be pointed out that macroinvertebrates are considered just one tool for pollution investigation, with best results obtained by using both biological and chemical methods.

Figure I. Upper photo showing cattle grazing on streambanks. Lower photo showing effluent release from Rapid City Sewage Treatment Plant.

Figure II. Upper photo showing stream-side road construction. Lower photo showing stream-side home construction.

Figure III. Top photo showing a stand of dog hair timber with a snow depth of 1.5 feet. Lower photo showing open area with a snow depth of 3.0 feet.

THE STUDY AREA

The Black Hills is a mountainous area lying along the South Dakota-Wyoming border. It encompasses an area of approximately 20,600 square miles of which 12,700 square miles are in South Dakota. The area is drained by a large number of relatively small streams (Black Hills Area Resources Study, Anonymous, 1967). In the South Dakota portion of the area streams radiate from the main divide, which is along the crest of the limestone plateau that is generally adjacent and parallel to the South Dakota-Wyoming border (Newport, 1956). Figure IV graphically represents the geologic formations of the South Dakota portion of the Black Hills and also the location of sampling sites.

The following major streams in the Black Hills were surveyed: Spearfish, Rapid, Castle, Spring, Battle, and French Creeks, and Fall River. The geology of the region influences the physical, chemical, and biotic characteristics of these streams. The central portion of the Black Hills is composed of granite, and is surrounded by concentric rings of slates, limestones, and sandstones. Streams originating in limestone formations are more productive than those originating in granitic or slaty outcrops. All streams sampled originate in limestone except French and Battle Creeks. Only Rapid Creek and Fall River flow continuously to the Cheyenne River, while others studied become subterranean when they reach the eastern limestone rim.

Rapid Creek has the largest area of any drainage system in the Black Hills, and an average stream flow of 30.9 cubic feet per second (cfs). (Detailed information regarding stream flows is presented in

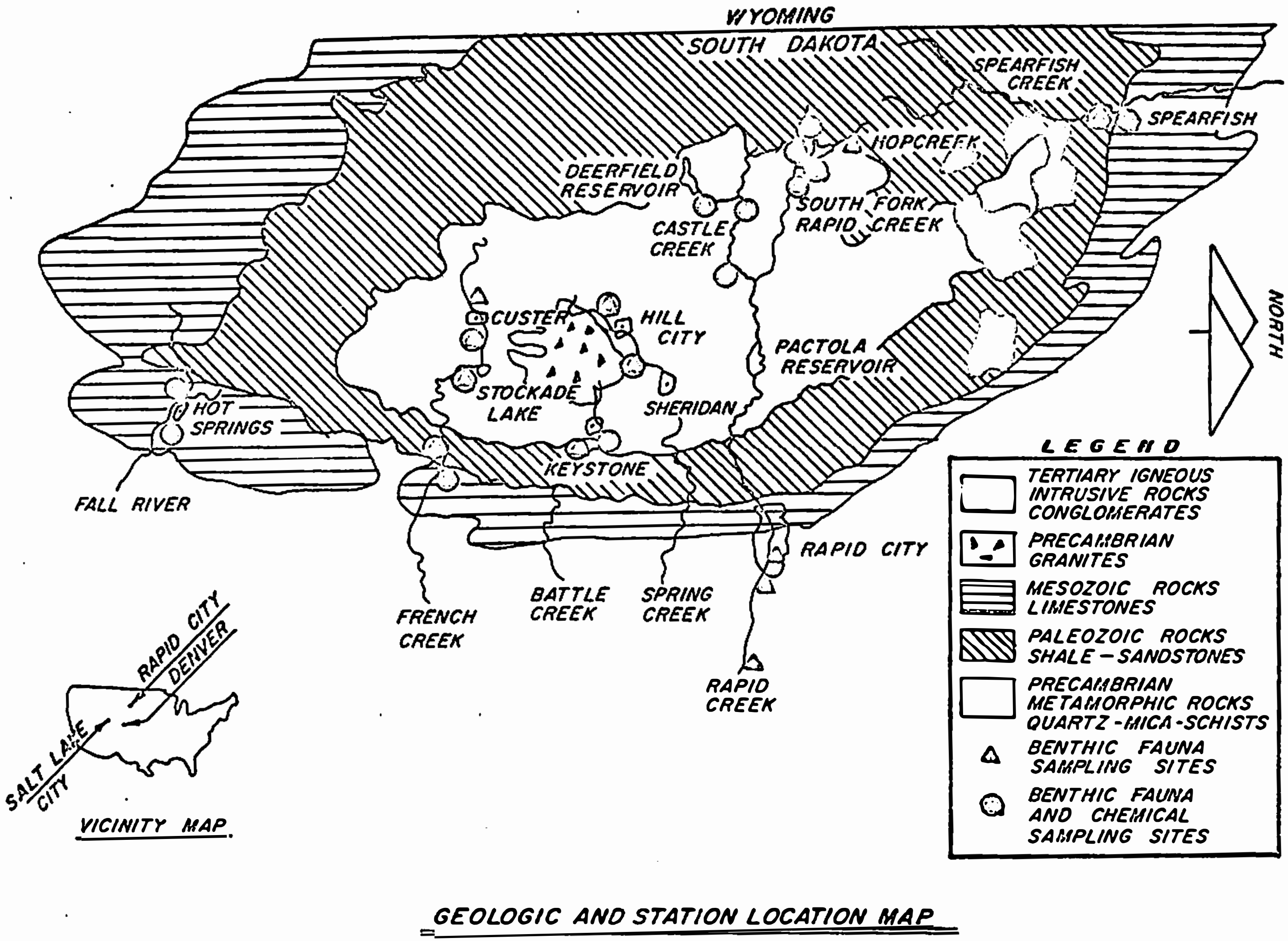


Figure IV. Geologic and Station Location Map.

Table 1.) Rapid City uses this stream as a water supply source and also for waste removal from the municipal sewage treatment plant. (Detailed information regarding sewage treatment plants is presented in Table 2.) The sewage treatment plant has a capacity of 4×10^6 gallons per day. When the load exceeds this maximum, partially treated and raw sewage are allowed to by-pass the plant. Three sampling stations were established on lower Rapid Creek--one above and one below the sewage treatment plant, and one ten miles downstream. The downstream station was established to measure stream recovery. Small amounts of vegetation, mostly periphyton were present in the upper and lower stations. Large deposits of organic sludge were common in eddy waters below the sewage treatment plant, but fast-flowing water kept riffle areas relatively free from sludge accumulations.

Spearfish Creek is considered by biologists and many fishermen as the best stream in the Black Hills, having an average stream flow of 42.3 cfs. It flows throughout its entire course over limestone formations, with surface flow being maintained by a series of diversion dams and piping. Stream water is used by the town of Spearfish for potable water and to remove effluent from the Spearfish sewage treatment plant. One station was established above and one below the effluent outfall. The bottom at both stations was composed primarily of rubble with small amounts of sand and silt.

Spring Creek flows into Sheridan Lake, one of the most popular recreation areas in the Black Hills. Average stream flow is 3.7 cfs. This stream receives wastes from the sewage treatment plant in Hill

City. Two stations, one above and one below the sewage treatment plant, were established in the stream. Rubble was the predominant bottom material at both stations, with silt and aquatic vegetation present only at the lower stations.

French Creek flows only a short distance from its source before it flows through the town of Custer. During dry seasons the stream is intermittent above the town and the effluent from the Custer sewage treatment plant comprises the entire stream flow. Four miles downstream from Custer the stream enters Stockade Lake, which acts as a stabilization pond for any untreated wastes. Water released from Stockade Lake continues flowing until it reaches an area known locally as "the narrows". At this point it goes underground, but later resumes a surface flow for a short distance before it again becomes subterranean.

Five stations were established on French Creek to determine the modifying influences of an impoundment and underground flow on stream recovery following organic pollution. Sampling stations were located as follows: above Custer, below Custer, below Stockade Lake, above "the narrows" and below "the narrows". Bottom types were composed of rubble above and below the sewage treatment plant with sand at the other stations. Small amounts of aquatic vegetation were present above and below the sewage treatment plant and abundant below Stockade Lake.

Fall River is located in the southern part of the Black Hills. This stream originates in warm springs and has an average stream flow of 27.1 cfs. The streambed is composed entirely of limestone formations. The town of Hot Springs adds effluent from its sewage treatment plant. One station was established above and one below the effluent outfall. The bottom at both stations is comprised primarily of sand which has been slightly solidified by calcarious deposits and a small amount of silt was also present.

The possible influence of bog iron mining on macroinvertebrates was investigated on the south fork of Rapid Creek. Two deposits of bog iron have been mined--one is adjacent to the south fork, and the other is on Hop Creek, a small tributary to the south fork (Figure V). Five stations were established in the mining area, including one above and one below both mining areas which are located approximately one-half mile from the confluence of the south fork with Hop Creek, and one station was established one-quarter mile below the confluence. The bottom type of the south fork is rubble and sand with no aquatic vegetation. The bottom type in Hop Creek was sand and silt at the sampling stations, but bedrock constitutes the bottom in the mined area.

Castle Creek is a primary tributary to Rapid Creek. It flows through extensive areas of unmined bog iron deposits. Three stations were established in Castle Creek to check the possible influence of these unmined deposits on macroinvertebrates. Stations were located above, in, and below the main bog iron deposits.

Battle Creek is a small stream located in an abandoned gold field. Recently one of the old mines was reopened to mine beryllium, from which mine tailings are being deposited adjacent to the stream (Figure V). Stations were located above and below the mine. The bottom of both stations is almost entirely sand with no aquatic vegetation at either station.

Figure V. Upper photo showing Hop Creek mining area. Lower photo showing the beryllium mining area on Battle Creek.

Table 1. Population, Sewage Treatment Plant Capacity, Type Treatment, and Flows Through Sewage Treatment Plants of Streams Involved in the Study

City	RAPID CITY	SPEARFISH	HILL CITY	CUSTER	HOT SPRINGS
Population	49,000	4,000	483	2,105	4,943
Sewage treatment plant capacity	4 million g/d	210,000 g/d	125,000 g/d	500,000 g/d	750,000 g/d
Type treatment	Secondary	Secondary	Secondary	Secondary	Secondary
Year of operation	***1963	***1964	**	**	***1963
Treatment of sewage	Processed-By pass	Processed	Processed	Processed	Processed
Flows through sewage treatment plants	Jan. 6.20- 0	Jan.-	Average annual	Average annual	Jan.-
	Feb. 6.15- 0	Feb.-	flow--	flow--	Feb.-
	March 6.83-437,000	March-	70,000 g/d	200,000 g/d	March-
	April 7.25-632,820	April-			April-
	May 7.24-2.33	May- 400,000	Average summer	Average summer	May-
	June 7.93-3.08	June-600,000	flow--	flow--	June- 500,000 g/d
	July 7.84-3.00	July-	100,000 g/d	300,000 g/d	July- 600,000 g/d
	*Aug. 7.59-2.86	*Aug.-			*Aug.- 550,000 g/d
	Sept. 7.25-1.50	Sept.-	Average winter	Average winter	Sept.-300,000 g/d
	Oct. 6.69- 47,334	Oct.-	flow--	flow--	Oct.- 300,000 g/d
	Nov. 6.59- 0	Nov.-	55,000 g/d	165,000 g/d	Nov.-
	Dec. 6.32- 0	Dec.-200,000			Dec.-

All flows shown in gallons per day (g/d)
* Indicates sampling months
** Flows not actually recorded, but estimated by plant operators
*** Flows recorded by equipment

Table 2. Monthly Average Maximum and Minimum Flows of Streams Involved in the Study

	Fall River***		Battle Creek***		French Creek**		Spring Creek***	
	1963	1964	1963	1964	1963	1964	1963	1964
Jan.	24.1	22.0	1.25	1.94			1.74	1.94
Feb.	23.8	22.5	2.11	3.03		1.9	1.90	3.03
March	25.6	23.4	7.11	2.57			2.05	2.57
April	23.6	24.5	19.4	5.82			3.47	5.82
May	21.3	26.1	22.9	12.5			12.9	12.5
June	23.6	24.0	85.5	29.1			94.3	29.1
July	22.5	22.6	21.3	25.7			29.7	25.7
Aug.	22.3	22.6	3.9	6.16	3.7		5.27	4.16
Sept.	27.6	23.8	6.1	1.81			2.93	1.81
Oct.	26.5	24.0	2.93	1.25			2.93	2.80
Nov.	25.6	25.1	3.0	1.32			3.0	1.89
Dec.	24.5	22.9	2.24	1.32			2.24	1.52
Maximum discharge	74	44	300	131			171	33
Minimum discharge	16	18	0.8	0.4			0.5	0.8
Mean discharge	24.3	23.6	14.8	7.54			13.5	2.89
Annual Average discharge	27.1		*				3.79	
Drainage area	137 sq. mi.		66 sq. mi.				199 sq. mi.	

Table 2. (continued)

	Castle Creek***		Hop Creek**		Spearfish Creek***		Rapid Creek in Rapid City***	
	1963	1964	1963	1964	1963	1964	1963	1964
Jan.	2.02	2.34			25.9	39.5	16.3	29.8
Feb.	2.11	2.32		1.0	30.4	38.4	19.0	27.6
March	2.26	2.17			36.8	37.6	21.2	31.1
April	2.0	13.2			109	60.7	27.6	65.6
May	2.17	21.2			105	88.6	40.1	107.0
June	9.17	26.5			111	172.0	106	190.0
July	8.29	18.4			57.5	69.9	121	115
Aug.	7.66	22.2	2.3		40.3	59.1	55.1	73.8
Sept.	7.65	23.9			41.8	50.4	54.8	46.0
Oct.	2.37	12.8			38.2	50.3	39.0	49.6
Nov.	2.38	2.20			35.4	49.6	30.8	33.8
Dec.	2.18	2.47			36.7	49.0	29.6	32.5
Maximum discharge	14	64			438	1,480	180	250
Minimum discharge	1.9	2.0			20	31.0	12	9.4
Mean discharge	4.19	12.5			55.7	63.7	46.8	66.8
Annual average discharge	8.68				43.3		60.3	
Drainage area	96 sq. mi.				168 sq. mi.		410 sq. mi.	

All flow values shown in cubic feet per second (c.f.s.)

* Information unavailable
** Information compiled from Surface Water Records of North and South Dakota, 1962, 1963, 1964
*** Records not available; flow determined at the time of sampling only

METHODS AND MATERIALS

Twenty-four sampling stations were established in the study area. Bottom samples were collected from riffle areas with a square foot Surber bottom sampler. The Bioassay and Pollution Ecology, Training Course Manual (Anonymous, publishing date unknown), states: (a) the riffle is one of the most satisfactory habitats for comparing stream conditions at different points; (b) the well-known square foot Surber sampler is one of the best quantative collecting devices from riffle areas; (c) at least two or three square foot samples should be taken at each station to insure that a reasonable percentage of the species present will be sampled. An attempt to reduce variation was made by selecting sampling sites with as many similar characteristics as possible. Cordone and Kelley (1961) list depth, velocity and substrate type as the significant features when considering sampling sites. Gaufin, Harris and Walter (1956) suggest that bottom forms are not randomly distributed and that bottom types to be sampled must be carefully selected if a small number of samples are to present a comprehensive picture of the fauna.

Two series of samples were collected for the study. One series of samples was collected during August, 1963 (summer samples). The summer samples consisted of one Surber sample collected from each site. Another series of samples was collected during February, 1964 (winter samples). Two Surber samples were collected on consecutive days at each station during the winter period.

After collection, organisms were sorted from debris by using a U. S. Standard Sieve Series, and preserved in a formalin solution. Final processing included separation, identification, and enumeration of individual organisms.

References used for identification included Review of Ephemeridae (Ephemeroptera) in the Missouri River Watershed with a Key to Species (Hamilton, 1959), Fresh-water Biology (Edmondson, 1959), Larvae of Insects, an Introduction to Nearctic Species (Peterson, 1960), and Aquatic Insects of California with Keys to North American Genera and California Species (Usinger, 1963). Nomenclature of organisms is according to Fresh-water Biology (Edmondson, 1959). No attempt was made to identify any adult forms such as Coleoptera and Hydracrina collected incidentally with bottom organisms.

Pollution evaluation by means of macroinvertebrates is simplified by establishing groups of organisms that react with some degree of similarity when affected by pollution. Three categories--pollution sensitive, intermediate, and tolerant--were established to evaluate this study. Organisms were classified on the basis of other studies, including Thelenius (1965), South Dakota Department of Health on Rapid Creek (Anonymous, 1964), and Brinkhurst (1963). These studies were used as a basis of comparison because they involved sources of pollution similar to those being investigated in this study. Studies on the environmental requirements of Plecoptera (Gaufin, 1965); Ephemeroptera (Leonard, 1965); Tricoptera (Robak, 1965); midges (Curry, 1965); and Tubificidae (Brinkhurst, 1965), were also considered in classifying organisms. These studies described the effects of factors such as dissolved oxygen, siltation, current, etc., on macroinvertebrates under both field and laboratory conditions.

The similarity between samples was determined by using Sorensen's coefficient of similarity

$$K = \frac{2w}{a + b}$$

where w equals the total of the smaller number of individual organisms taken at both stations; a equals the total number of organisms at the first station; and b equals the total number of organisms at the second station (Phillips, 1959). Samples having completely different numbers and kinds of organisms would have a similarity index of zero; samples which were identical in both numbers and kinds of organisms would have a similarity index of 100.

Indices of similarity were determined between samples taken above and below suspected pollution sources for both summer and winter samples. Winter samples taken from the same relative location on consecutive days were also analyzed to determine similarity indices.

Chemical data, presented in the results section, was collected in association with other stream studies in the Black Hills area. This data is presented only from samples which were taken from stations that closely coincided with bottom sampling stations; therefore, data is lacking for some stations.

Water samples were analyzed by Inland Analytical Laboratories, Inc., in Rapid City, South Dakota, using methods described in Standard Methods for the Examination of Water and Wastewater for the following:

1-T.S.	Total solids
2-T.F.S.	Total filterable solids
3-pH	pH
4-P.A.	Phenolphthalein Alkalinity
5-M.O.A.	Methyl Orange Alkalinity
6-TURB.	Turibidity
7-Cl	Chloride as Cl
8-SO_4	Sulfates as SO_4
9-mg	Magnesium as Mg
10-Ca	Calcium as Ca
11-Na	Sodium as Na
12-K	Potassium as K
13-T.Fe	Total iron
14-C.H.	Calculated hardness
15-T.PO_4	Total phosphates from filtered samples
16-NH_4	Nitrogen as NH_4
17-O.N.	Nitrogen - Organic
18-NO_2	Nitrogen as Nitrite
19-NO_3	Nitrogen as Nitrate
20-S.C.	Specific Conductance @ 25^{o}C in MMHOx10^{-6}

Figure VI shows typical winter and summer sampling sites. Figures VII, VIII, IX, and X are microphotographs of some of the representative organisms that were sampled.

Figure VI. Upper photo showing typical summer sampling site. Lower photo showing typical winter sampling site.

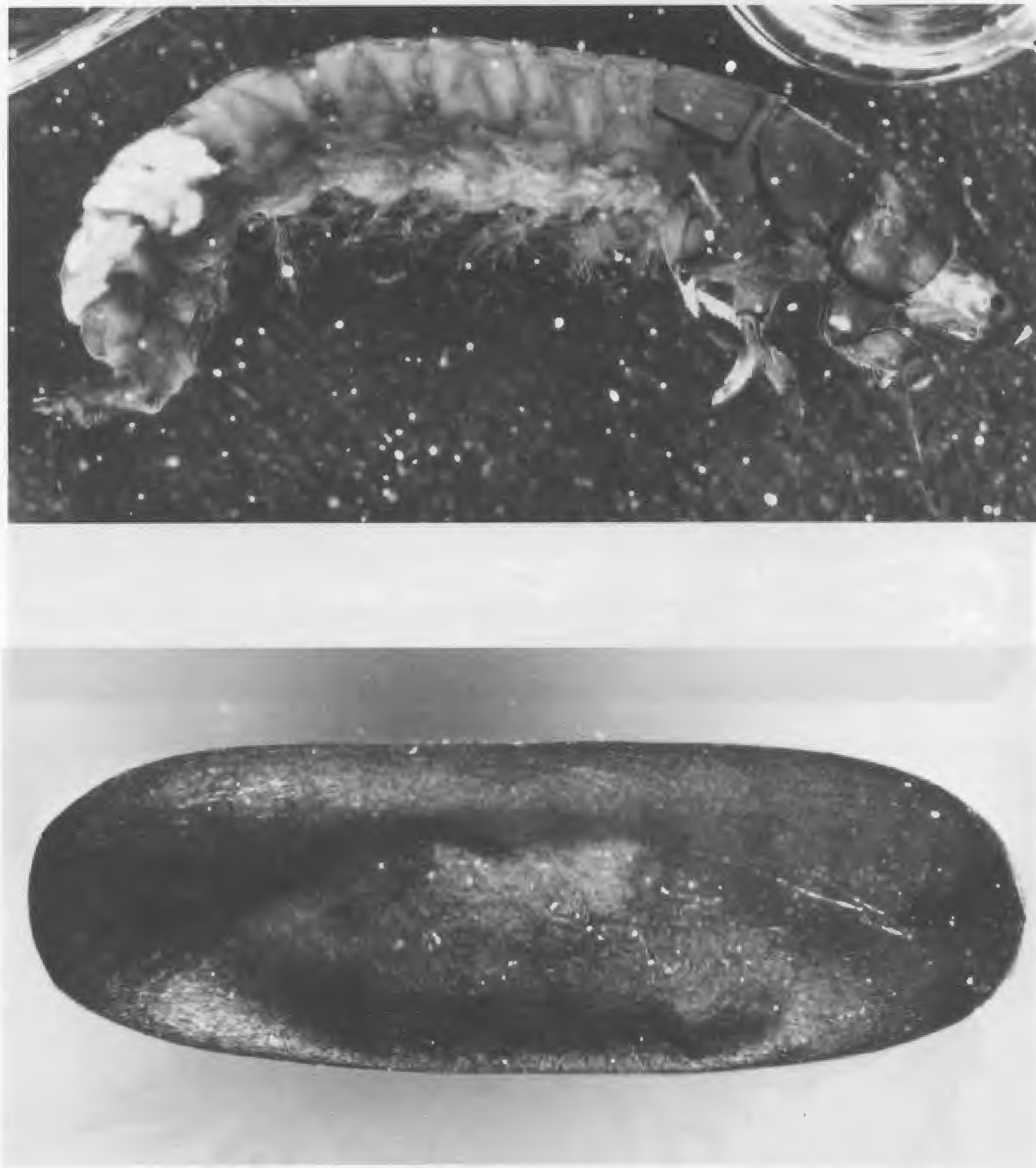


Figure VII. Microphotographs of Tricoptera. Top photo showing <u>Hydropsyche</u>. Lower photo showing <u>Glossosoma</u> enclosed in a case.

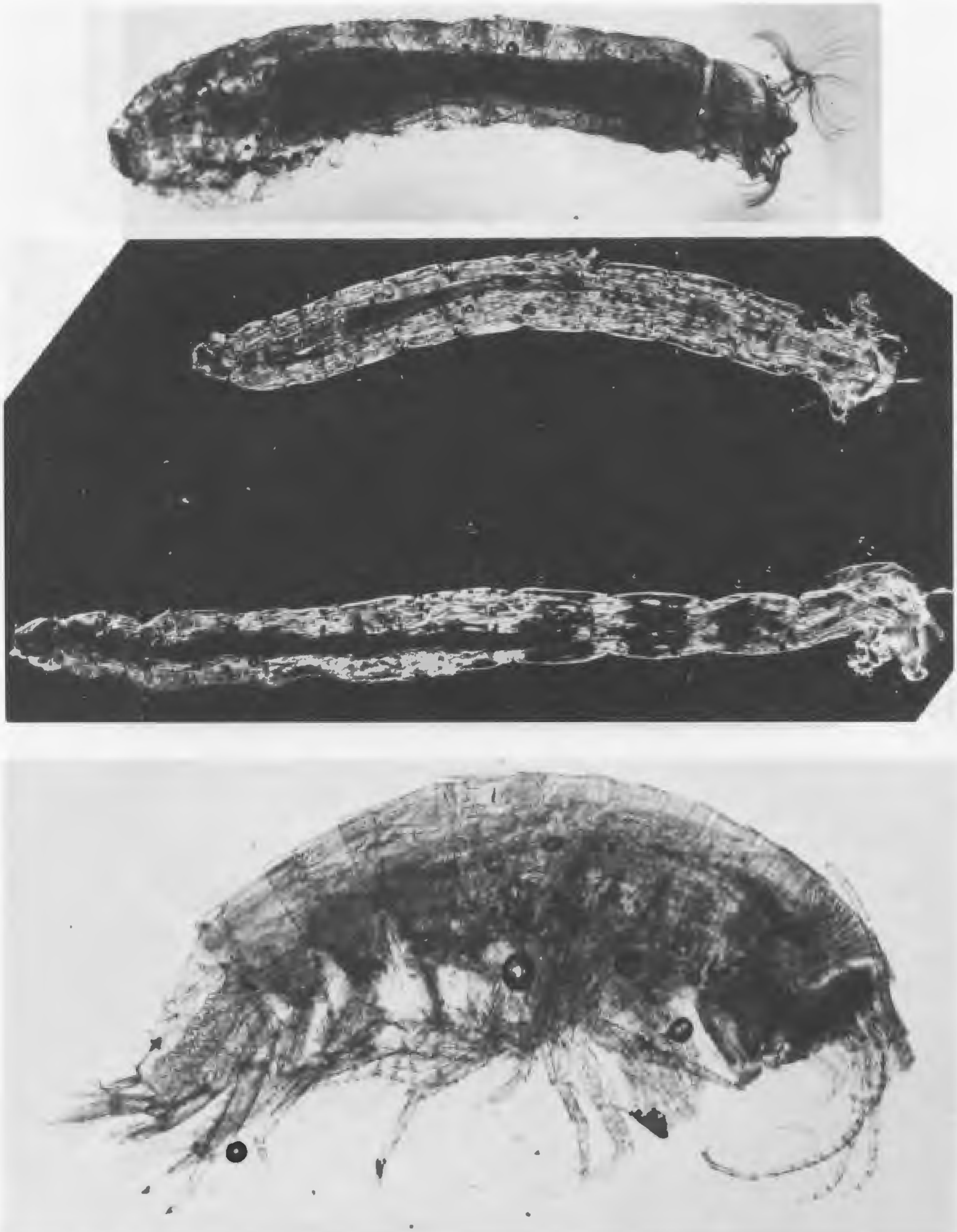


Figure VIII. Microphotographs of Diptera and Crustacea. Top photo showing Simuliidae larva. Middle photo showing two forms of tendipeds. Lower photo showing the Crustacea Hyallela.

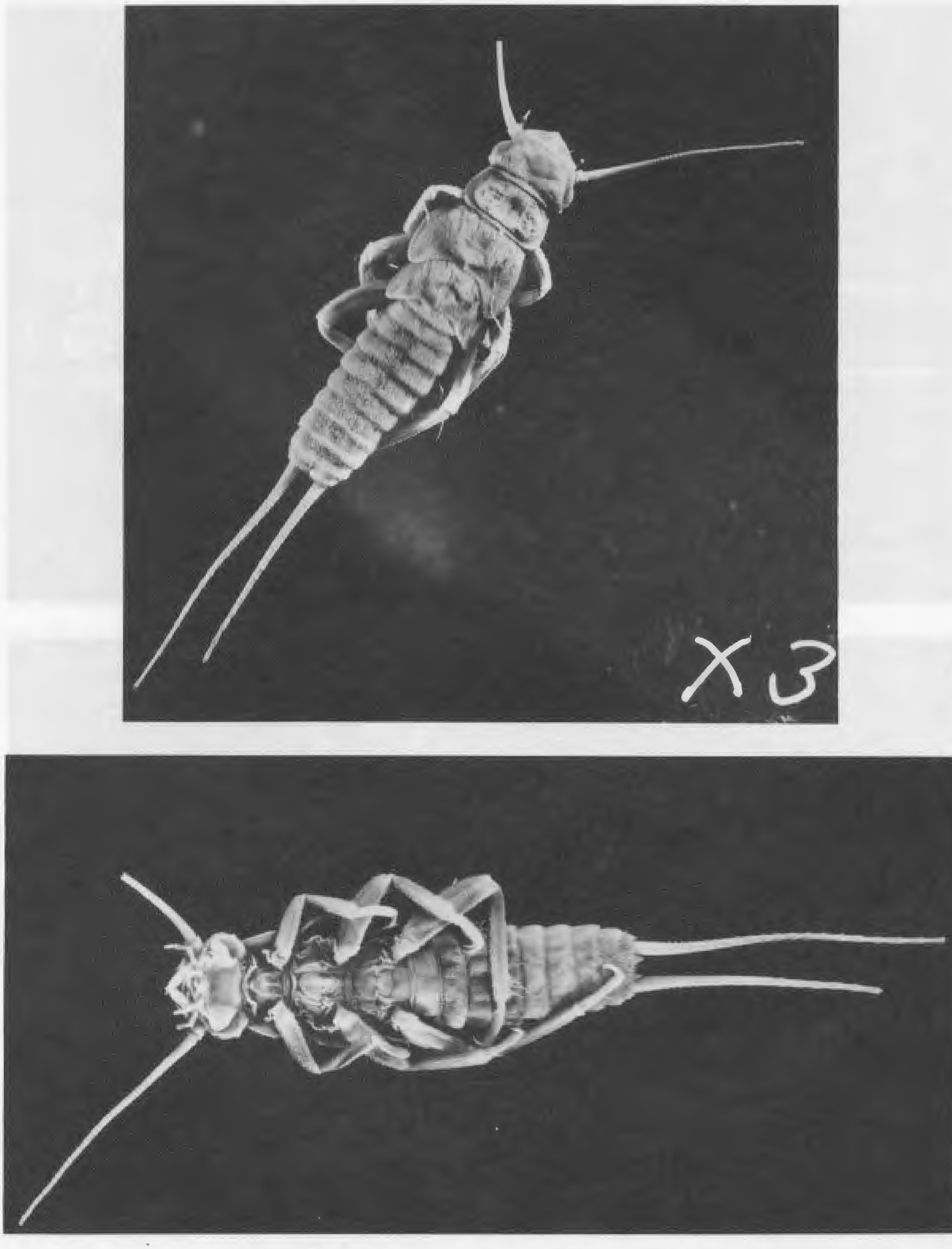
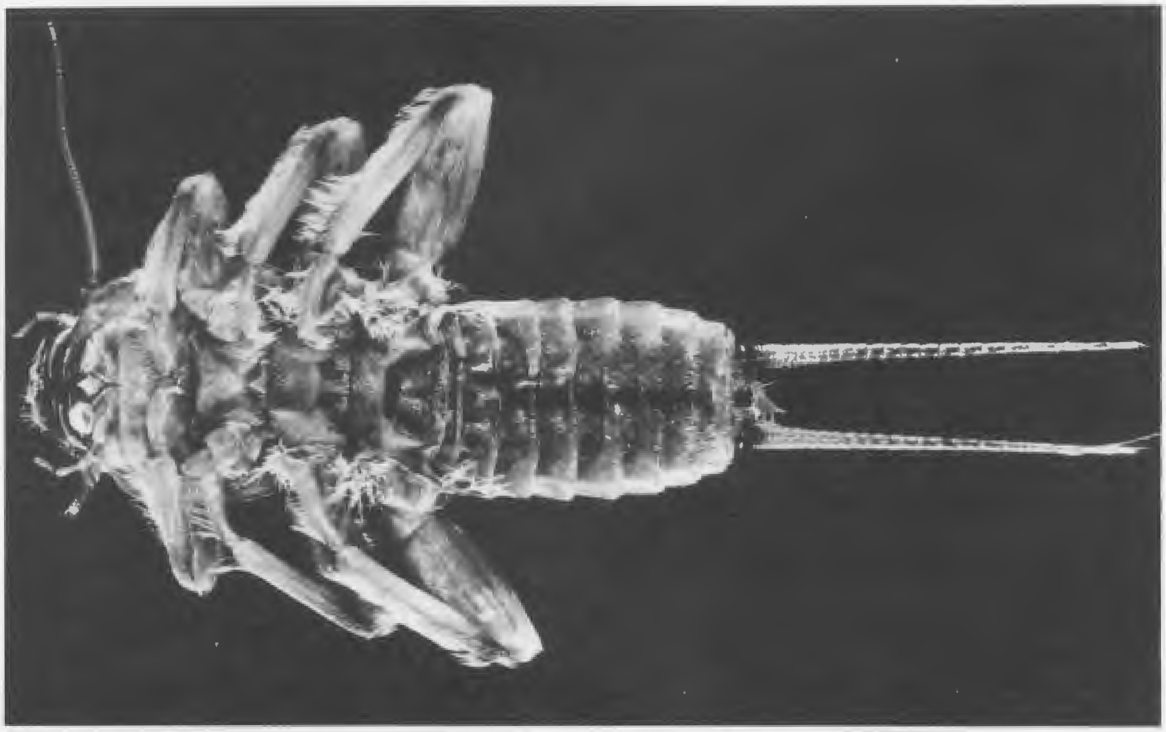


Figure IX. Microphotographs showing dorsal view (upper photo) and ventral view (lower photo) of the Mayfly nymph, <u>Ameletus</u>.



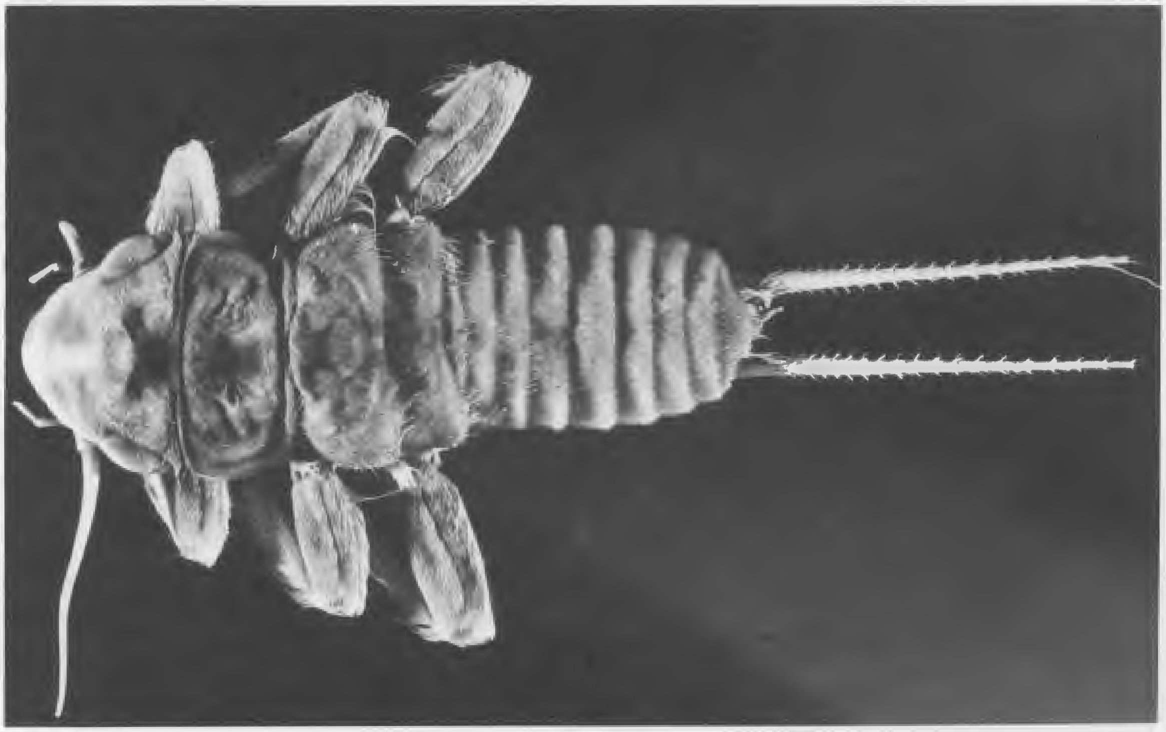


Figure X. Microphotographs showing dorsal view (upper photo) and ventral view (lower photo) of the Stonefly nymph, Acroneuria.

RESULTS

Summer samples collected from Rapid Creek above the Rapid City sewage treatment plant contained three sensitive genera: Tricorythodes spp. Ulmer, Centroptilum spp. Eaton, and Baetis spp. Leach. One intermediate form Lumbricidae also appeared above the plant. These organisms were all eliminated below the plant. Tolerant organisms including Glossiphonia spp. Johnson, Limnodrilus spp. Claparede, Psychoda sp. Latreille, and tendipeds (Family Tendipedidae--midge larvae) with anal gills were present below the plant. Tendipeds were divided into two groups--those with gills on the tenth abdominal segment, and those without such gills. According to Stewart (1965), these abdominal gills enable tendipeds to withstand much lower dissolved oxygen concentrations typical of polluted areas. Tendipeds with abdominal gills were classified as pollution tolerant, while those without were considered intermediate. At the station established ten miles downstream, sensitive genera of Tricorythodes spp. and Paraleptophlebia spp. Lestage returned and Neocloeon spp. Traver and Hydropsyche spp. Pictet appeared. Intermediate forms present at the downstream station were Hyallela sp. Saussure and tendipeds without anal gills.

Winter samples were similar to those collected during the summer; sensitive organisms sampled above the plant were Tricorythodes spp., Baetis spp., and Hydropsyche spp. These organisms were absent below the plant. Intermediate forms including Simuliidae, Hyallela sp., and tendipeds without anal gills were found above the plant. Intermediate forms present below the plant were Eclipidrilus sp. Eisen and tendipeds without anal gills. At the downstream station Baetis spp. and Hydropsyche spp. returned and Cheumatopsyche spp. Wallengren was present. Hyallela sp., an intermediate form, also returned. Tolerant genera were found at all three stations. Above the plant, Tubifex sp. Lamarck and Glossiphonia spp. were found, while below larger numbers of these genera and Helobdella sp. Blanchard, Psychoda sp., and tendipeds with anal gills were present. Tendipeds with anal gills and Helobdella sp. disappeared downstream and the numbers of Tubifex spp. and Psychoda sp. decreased. Additional benthic fauna data from the Biological Survey Report on the Rapid Creek Water Pollution Investigation is presented in Appendix A.

The coefficient of similarity indices for the stations above and below the sewage treatment plant are summer 0, winter first day 5, winter second day 5. Indices between the station above the plant and the downstream station are summer 16, winter first day 35, and winter second day 51. Index values on Rapid Creek for the consecutive days with comparable sampling sites are 74 above the sewage treatment plant, 70 below it, and 58 at the downstream station.

Organisms collected from Fall River showed variation above and below the Hot Springs sewage treatment plant. Summer samples showed a reduction of sensitive organisms from four above the sewage treatment plant to two below the plant. One intermediate form was taken above and two were taken below the plant. Winter samples showed a greater variation between stations. Twelve sensitive organisms were sampled above the plant and only two were sampled below. Intermediate forms decreased from two above to one below the plant. No tolerant forms were taken in any of the samples; their absence can be explained by the lack of bottom habitat suitable for these organisms.

Chemical samples collected from Fall River show an increase of total solids from 430 ppm to 940 ppm; chloride from 106 ppm to 171 ppm; sodium from 160 ppm to 300 ppm; total phosphates from .18 ppm to .96 ppm; ammonia from .33 ppm to 1.02 ppm; nitrite from .02 ppm to .10 ppm; and nitrate from .06 ppm to .28 ppm. Complete chemical analysis is shown in Table 8.

The coefficient of similarity indices for the stations above and below the sewage treatment plant are 13 for the summer samples, 4 for the first day and 5 for the second day winter samples. The index values for comparative location samples on Fall River are 88 above the plant and 64 below it.

French Creek samples above and below the Custer sewage treatment plant showed only a slight variation in types of organisms. Summer samples showed a decrease in sensitive organisms from six above the sewage treatment plant to two below it. Winter samples did not show this variation; only the numbers of tendipeds without anal gills showed a decrease below the plant. Numbers of sensitive organisms increased at stations below Stockade Lake and in "the narrows" area. Kinds and numbers of intermediate and tolerant species did not vary appreciably in the French Creek stations.

A comparative chemical sample was not available from the station above the sewage treatment plant, but other stations showed a general decrease of constituents at each station below the sewage treatment plant. Selected chemical values for French Creek stations are shown in Table 3. Additional chemical data from French Creek is presented in Appendix B.

Table 3. Comparison of Selected Chemical Constituents of the French Creek Stations

	Below Sewage Treatment Plant	Below Stockade	Above Narrows	Below Narrows
Total Solids	482.0	182.0	197.0	135.0
Turbidity	179.0	118.0	143.0	112.0
Sulfate	78.0	28.0	32.0	26.0
Phosphate	15.3	2.94	.23	.36
Nitrite	.59	.08	.03	.02
Nitrate	1.12	.46	.09	.07

Index of similarity values of the French Creek winter samples with similar locations are above the sewage treatment plant 64, below the plant 44, below Stockade Lake 79, above "the narrows" 79, and below "the narrows" 70. Table 4 shows the index of similarity values for the French Creek stations compared to the station above the sewage treatment plant.

Table 4. Index of Similarity Comparisons for the French Creek Stations

	Above S.T.P.* Below S.T.P.	Above S.T.P. Below Stockade	Above S.T.P. Above Narrows	Above S.T.P. Below Narrows
Summer	22	17	56	37
Winter, first day	10	21	16	10
Winter, second day	18	15	17	8

*Sewage Treatment Plant

The reaction of the benthic community in Spring Creek below the Hill City effluent outfall was generally one of increase in both numbers and kinds of organisms when compared to the station above the sewage treatment plant. Sensitive organisms increased from four above the sewage treatment plant to six below it. Winter samples showed an even greater increase of from nine above the plant to 11 below it. Numerical increases of other forms are exemplified by Hydropsyche spp., which increased from 120 organisms above the plant to 1,399 below it, and by Cheumatopsyche spp., which increased from 97 above to 571 below. Intermediate and tolerant forms reacted to the Hill City effluent the same way as the sensitive organisms showing increases in kinds and number of organisms.

Results of chemical analysis also showed increase in most constituents below the plant. Total solids increased from 102 ppm to 307 ppm; total phosphate remained the same; ammonia increased from .80 ppm to 2.02 ppm.

Indices of similarity values comparing the station above the plant to the one below are summer sample 13, winter sample first day 28, winter sample second day 17. Values comparing the same sites on consecutive days are 74 for the station above the sewage treatment plant and 86 for the station below it.

Samples from Spearfish Creek in general were very similar to those from Spring Creek. Sensitive organisms again showed increases in kinds and numbers. Intermediate forms also showed slight increases in kinds and numbers while tolerant species were almost entirely lacking.

Simuliidae showed large increases in the summer sample, from 200 to 2,306, and tendipeds with anal gills showed a similar increase in the winter samples, 45 to 331, above and below the effluent outfall.

Chemical data concurs with biological data and does not show any large increases in chloride, sodium, nitrite, nitrates; phosphates did show a slight increase from .10 ppm above the plant to .66 ppm below it. Additional chemical data from Spearfish Creek is presented in Appendix C.

Indices of similarity values comparing the station above the plant to the one below it are summer 16, winter first day 24, and winter second day 16. The index of similarity value for samples taken above the plant on consecutive days is 63, while the value for samples taken below the plant is 91.

Complete biological results for stations associated with organic pollution are shown in Tables 5, 6, and 7. Table 8 shows the complete chemical analysis for the stations associated with organic pollution.

Bog iron mining operations in the south fork of Rapid Creek and Hop Creek areas were sampled both biologically and chemically. Bottom samples above and below the mine on the south fork were similar. No macroinvertebrates were collected in the lower Hop Creek station during either sampling period. Organisms were reduced in kinds and numbers in the south fork below its confluence with Hop Creek.

Table 5. Organic Associated - Summer Samples

	FALL RIVER ABOVE SEWAGE TREATMENT PLANT	FALL RIVER BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK ABOVE SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW STOCKADE LAKE	FRENCH CREEK ABOVE NARROWS	FRENCH CREEK BELOW NARROWS	SPRING CREEK ABOVE SEWAGE TREATMENT PLANT	SPRING CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK ABOVE SEWAGE TREATMENT PLANT	RAPID CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK DOWNSTREAM STATION	SPEARFISH CREEK ABOVE SEWAGE TREATMENT PLANT	SPEARFISH CREEK BELOW SEWAGE TREATMENT PLANT	
PLECOPTERA															SENSITIVE
Acroneuria sp.															
Arcynopteryx spp.							11						7		
Isoperla spp.								1					8		
Alloperla spp.															
EPHEMEROPTERA															
Ameletus sp.															
Tricorythodes spp.					22		2			4		1		2	
Paraleptophlebia spp.			1		2				1						
Centroptilium spp.			17				11		3	17		35	1	38	
Neocloeon spp.			4		2		1	4	24			19		2	
Ephemerella spp.														3	
Baetis spp.										21			13	64	
COLEOPTERA															
Narpus spp.							2								
Optioservus spp.															
Zaitzevia spp.															
LEPIDOPTERA															
Elophila sp.	10						2								
TRICOPTERA															
Glossosoma spp.															
Chimarra spp.							1								
Agraylea spp.															
Hesperophylax spp.							4	2							
Limnephilus spp.															
Leptocella spp.															
Oecetis spp.							4								
Triaenodes spp.	1														
Brachycentrus spp.									3				25		
Helicopsyche spp.	3	27	2												
Hydropsyche spp.	19	2	13	29	2	7	63	1	30			7	1	1	
Cheumatopsyche spp.			9	88	2	10	57	1	71						
AMPHIPODA															INTERMEDIATE
Gammarus spp.															
Hyallela sp.			1	37	1							53			
ODONATA															
Gomphus spp.															
Erpetogomphus spp.	1														
Ophiogomphus spp.															
DIPTERA															
Simuliidae													200	2306	
Tendipeds (without anal gills)		11			22			21				46	24	7	
Bezzia sp.		5						1							
Chrysops spp.				1				2							
Tabanus sp.								1							
Tipula sp.															
Hexatoma sp.															
Atherix sp.															
PLESIOPORA															
Eclipidrilus sp.					1		3		8						
PLESIOPORA															TOLERANT
Limnodrilus spp.			3		1										
Tubifex spp.															
RHYNCHOBDELLIDA															
Helobdella sp.					1										
Glossiphonia spp.											3				
DIPTERA															
Tendipeds (with anal gills)													5	10	
Psychoda sp.											5		3		
SENSITIVE	4	2	6	2	5	2	11	5	6	3	0	4	6	6	
INTERMEDIATE	1	2	1	2	3	0	1	4	1	0	0	2	2	2	
TOLERANT	0	0	1	0	2	0	0	0	0	0	2	1	0	0	
TOTAL NUMBER OF ORGANISMS	34	45	67	155	56	17	161	34	141	42	8	171	279	2423	

Table 6. Organic Associated - Winter Samples - First Day

	FALL RIVER ABOVE SEWAGE TREATMENT PLANT	FALL RIVER BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK ABOVE SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW STOCKADE LAKE	FRENCH CREEK ABOVE NARROWS	FRENCH CREEK BELOW NARROWS	SPRING CREEK ABOVE SEWAGE TREATMENT PLANT	SPRING CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK ABOVE SEWAGE TREATMENT PLANT	RAPID CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK DOWNSTREAM STATION	SPEARFISH CREEK ABOVE SEWAGE TREATMENT PLANT	SPEARFISH CREEK BELOW SEWAGE TREATMENT PLANT	
PLECOPTERA															
Acroneuria sp.														2	
Arcynopteryx spp.								38							
Isoperla spp.	1					5	40	5	28				4	4	
Alloperla spp.							14						3		
EPHEMEROPTERA															
Ameletus sp.															
Tricorythodes spp.							1			14					
Paraleptophlebia spp.	10						11		28						
Centroptilium spp.									22						
Neocloeon spp.								4							
Ephemerella spp.					11								38	<200	
Baetis spp.	18					67	10		1	11		3	134	10	
COLEOPTERA															
Narpus spp.	8							8	1					1	
Optioservus spp.							2		5						SENSITIVE
Zaitzevia spp.	7														
LEPIDOPTERA															
Elophila sp.	188	5					2		14						
TRICOPTERA															
Glossosoma spp.								34	4						
Chimarra spp.	15														
Agraylea spp.															
Hesperophylax spp.							9								
Limnephilus spp.									4						
Leptocella spp.	9						2								
Oecetis spp.															
Triaenodes spp.															
Brachycentrus spp.						2	7		20				16		
Helicopsyche spp.	37	5					1								
Hydropsyche spp.	279					153	60	76	645	13		4			
Cheumatopsyche spp.	4		17	3		113	129	64	275			12	3		
AMPHIPODA															
Gammarus spp.															
Hyallela sp.			16	19				48				54			
ODONATA															
Gomphus spp.	3						1								
Erpetogomphus spp.															
Ophiogomphus spp.	6	1				1									
DIPTERA															
Simuliidae						1				3					
Tendipeds (without anal gills)	18		500	10	68	132	42	65	126	42	33	24	28	184	INTERMEDIATE
Bezzia sp.															
Chrysops spp.					1			5	1						
Tabanus sp.								1							
Tipula sp.														4	
Hexatoma sp.															
Atherix sp.									1						
PLESIOPORA															
Eclipidrilus sp.			2			4	6	16	2		1			2	
PLESIOPORA															
Limnodrilus spp.							4							5	
Tubifex spp.					32					2	92	3			
RHYNCHOBDELLIDA															
Helobdella sp.								2			1	2			
Glossiphonia spp.										1					
DIPTERA															
Tendipeds (with anal gills)								10			106				TOLERANT
Psycheda sp.											37				
SENSITIVE	11	2	1	1	1	5	13	7	12	3	0	3	6	5	
INTERMEDIATE	3	1	3	2	2	4	3	5	4	2	2	2	1	3	
TOLERANT	0	0	0	0	1	0	1	2	0	2	4	2	0	1	
TOTAL NUMBER OF ORGANISMS	603	11	535	32	112	478	341	376	1177	86	270	102	226	412	

Table 7. Organic Associated - Winter Samples - Second Day

	FALL RIVER ABOVE SEWAGE TREATMENT PLANT	FALL RIVER BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK ABOVE SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW SEWAGE TREATMENT PLANT	FRENCH CREEK BELOW STOCKADE LAKE	FRENCH CREEK ABOVE NARROWS	FRENCH CREEK BELOW NARROWS	SPRING CREEK ABOVE SEWAGE TREATMENT PLANT	SPRING CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK ABOVE SEWAGE TREATMENT PLANT	RAPID CREEK BELOW SEWAGE TREATMENT PLANT	RAPID CREEK DOWNSTREAM STATION	SPEARFISH CREEK ABOVE SEWAGE TREATMENT PLANT	SPEARFISH CREEK BELOW SEWAGE TREATMENT PLANT	Group
PLECOPTERA															
Acroneuria sp.														2	
Arcynopteryx spp.								53							
Isoperla spp.	3					1	8		70				27		
Alloperla spp.							28						1		
EPHEMEROPTERA															
Ameletus sp.															
Tricorythodes spp.										3					
Paraleptophlebia spp.	3						14								
Centroptilium spp.															
Neocloeon spp.								6							
Ephemerella spp.	2				9		5						18	195	
Baetis spp.	3					22	9		85	13		3	57	6	
COLEOPTERA															
Narpus spp.	21							4	3					2	SENSITIVE
Optioservus spp.							2		5						
Zaitzevia spp.	4														
LEPIDOPTERA															
Elophila sp.	187	3							3						
TRICOPTERA															
Glossosoma spp.								31	8						
Chimarra spp.	5														
Agraylea spp.															
Hesperophylax spp.							4								
Limnephilus spp.									4						
Leptocella spp.	4														
Oecetis spp.															
Triaenodes spp.															
Brachycentrus spp.			4	1		4	1	2	7				11	1	
Helicopsyche spp.	15	11													
Hydropsyche spp.	243					208	115	44	754	22		11	23		
Cheumatopsyche spp.	3		23	1	1	195	215	33	296			33	6		
AMPHIPODA															
Gammarus spp.										2					
Hyallela sp.			70	68			1	24				15			
ODONATA															
Gomphus spp.							1								
Erpetogomphus spp.															
Ophiogomphus spp.									1						
DIPTERA															
Simuliidae									3						
Tendipeds (without anal gills)	10		995	38	99	167	35	44	125	31	8	40	17	147	INTERMEDIATE
Bezzia sp.															
Chrysops spp.							2	6	1						
Tabanus sp.															
Tipula sp.														2	
Hexatoma sp.									1						
Atherix sp.															
PLESIOPORA															
Eclipidrilus sp.					1	1	7	5	5		15			12	
PLESIOPORA															
Limnodrilus spp.							20	2	4					11	
Tubifex spp.				2	17						163	3			
RHYNCHOBDELLIDA															
Helobdella sp.								1							
Glossiphonia spp.												2			
DIPTERA															
Tendipeds (with anal gills)			1	2					1		84				TOLERANT
Psychoda sp.											4				
SENSITIVE	12	2	2	2	2	5	10	7	10	3	0	3	7	5	
INTERMEDIATE	2	0	2	2	2	2	5	4	6	2	2	2	1	3	
TOLERANT	0	0	1	2	1	0	1	2	2	0	3	2	0	1	
TOTAL NUMBER OF ORGANISMS	504	14	1093	110	127	598	467	255	1376	71	274	107	160	378	

Table 8. Chemical Results from Organic-associated Stations

Test made	Spearfish Creek below sewage treatment plant 2/13/63 Amount in ppm	Spearfish Creek above sewage treatment plant 2/13/63 Amount in ppm	Spring Creek below sewage treatment plant 11/62 Amount in ppm	Spring Creek above sewage treatment plant 11/62 Amount in ppm	French Creek below Narrows 3/27/63 Amount in ppm	French Creek above Narrows 2/5/63 Amount in ppm	French Creek below Stockade Lake 2/5/63 Amount in ppm	French Creek below sewage treatment plant 2/5/63 Amount in ppm	Fall River below sewage treatment plant 1/22/63 Amount in ppm	Fall River above sewage treatment plant 1/22/63 Amount in ppm
1-T.S.	310.0	270.0	307.0	120.0	135.0	197.0	182.0	482.0	940.0	430.0
2-T.F.S.	5.0	1.0	2.5	2.0	0.5	50.0	NIL	270.0	10.0	4.0
3-pH	7.2	8.1	8.4	8.1	6.2	7.10	6.50	7.20	7.4	7.6
4-P.A.	0.0	0.0	0.0	0.0	NIL	0.0	0.0	0.0	0.0	0.0
5-M.O.A.	239.0	251.0	101.0	84.0	112.0	143.0	118.0	179.0	252.0	168.0
6-TURB.	NIL	NIL	1.0	1.0	NIL	4.0	14.0	96.0	2.0	NIL
7-Cl	70.0	97.0	29.0	19.0	148.0	133.0	387.0	560.0	171.0	106.0
8-SO4	11.0	10.0	53.0	57.0	26.0	32.0	28.0	78.0	340.0	340.0
9-MG	16.0	3.0	67.0	19.0	NIL	NIL	NIL	NIL	NIL	NIL
10-Ca	57.0	55.0	37.0	31.0	13.0	48.0	32.0	48.0	77.0	111.0
11-Na	37.0	46.0	26.0	30.0	33.0	90.0	229.0	280.0	300.0	160.0
12-K	7.0	6.0	16.0	10.0	6.0	17.0	40.0	27.0	53.0	8.0
13-T.Fe	0.03	0.05	0.18	0.14	0.16	0.66	0.29	0.60	0.09	0.04
14-C.H.	208.0	178.0	368.0	155.0	32.0	121.0	82.0	50.0	192.0	275.0
15-T.PO4	0.66	0.10	0.90	0.90	0.36	0.23	2.94	15.3	0.96	0.18
16-NH4	NIL	0.31	2.02	0.80	0.72	0.33	2.00	7.8	1.02	0.33
17-O.N	0.25	NIL	1.82	1.11	0.13	0.79	1.73	4.76	0.61	0.33
18-NO2	TR.	NIL	NEG	0.04	0.02	0.03	0.08	0.59	0.10	0.02
19-NO3	NIL	NIL	NEG	NEG	0.07	0.09	0.46	1.12	0.28	0.06
20-S.C.	410.0	425.0	285.0	230.0	255.0	320.0	290.0	580.0	1200.0	1200.0

Chemical data from the three stations on the south fork of Rapid Creek show an increase in total solids from 250 ppm at the station above both mines to 303 ppm above Hop Creek and 250 ppm below Hop Creek; pH 7.75 above both mines, 7.8 above Hop Creek, and 7.1 below Hop Creek; sulfates 14 ppm above both mines, 45 ppm above Hop Creek, 63 ppm below Hop Creek; total iron was negligible above both mines, .44 ppm above Hop Creek and .73 ppm below Hop Creek. The station above the mine on Hop Creek did not have a comparable chemical station; however, chemical results below the mine showed 400 ppm total solids, pH of 3.2, 270 ppm sulfates and total iron of 11.2 ppm.

Indices of similarity values comparing the station above both mines to the one above the confluence with Hop Creek are summer 66, winter first day 21, and winter second day 37. Values comparing the station above both mines to the one below the confluence with Hop Creek are summer 0, winter first day 20, and winter second day 9. Index of similarity values for the three stations on the south fork of Rapid Creek are above both mine areas 33, above the confluence with Hop Creek 68, and below the confluence with Hop Creek 33.

Castle Creek was sampled in an unmined bog iron deposit area after trout mortality in the area was reported late in the fall. Samples were collected from Castle Creek only during the winter sampling period. Sensitive organisms did not show any appreciable differences at any of the three stations. Intermediate forms were reduced from 6 above the deposit area to 0 in the deposit area; three intermediate forms were present at the lower station. One tolerant form was present in the upper station; none were present at the other two stations.

Chemical data shows increases in: total solids from 211 ppm to 252 ppm, turbidity 6 ppm to 42 ppm, sulfates 23 ppm to 78 ppm and total iron .04 ppm to 4.5 ppm; from the upper station to the station in the bog iron area. The pH value at the lower station was 7.1 compared to 7.9 at the upper station. Values at the lower station of the constituents listed above returned to those of the upper station except for sulfates, which were 79 ppm.

Index of similarity values for the Castle Creek stations indicate population differences between stations. The values comparing the upper and mid-station are first day 9, second day 11, and those comparing the upper and lower stations are first day 15, second day 12. Similarity values on Castle Creek for the consecutive days with comparable sampling sites are above the bog iron deposits 46, in the deposit area 66, and below the deposit area 57.

Samples collected from Battle Creek showed a reduction in numbers and kinds of organisms below the beryllium mine. All genera of Plecoptera, Ephemeroptera, and Coleoptera present above the mine were absent. Numbers of all other organisms were reduced at the station below the mine. Additional benthic fauna data, collected by South Dakota Department of Game, Fish, and Parks personnel, is presented in Appendix D.

Chemical data from Castle Creek corresponds with the biological data and showed increases in many constituents. Increases from above the mine to below the mine were recorded for the following constituents: total solids 170 ppm to 638 ppm; turbidity 4 ppm to 37 ppm; chloride 120 ppm to 237 ppm; sulfates 25 ppm to 225 ppm. The pH was lowered from 6.3 above the mine to 3.0 below the mine.

Index of similarity values comparing the Battle Creek stations above and below the mine are summer 30, winter first day 31, and winter second day 10. The value comparing similar samples above the mine is 74 and the value comparing stations below the mine is 41.

Complete biological results for stations associated with mining areas are shown in Tables 9, 10, and 11. Table 12 shows the complete chemical analysis for the stations in the mining areas. Table 13 shows the index of similarity values for winter samples taken from the same relative area on consecutive days. Table 14 shows the index of values for stations above and below various suspected sources of pollution.

Table 9. Mining Associated - Summer Samples

	BATTLE CREEK ABOVE MINE	BATTLE CREEK BELOW MINE	CASTLE CREEK ABOVE DEPOSIT AREA	CASTLE CREEK NEAR DEPOSIT AREA	CASTLE CREEK BELOW DEPOSIT AREA	SOUTH FORK OF RAPID CREEK ABOVE BOTH MINE AREAS	SOUTH FORK OF RAPID CREEK ABOVE HOP CREEK	HOP CREEK ABOVE MINE	HOP CREEK BELOW MINE	RAPID CREEK BELOW HOP CREEK	
PLECOPTERA											
Acroneuria sp.							3				
Arcynopteryx spp.	6									3	
Isoperla spp.											
Alloperla spp.											
EPHEMEROPTERA											
Ameletus sp.											
Tricorythodes spp.	11										
Paraleptophlebia spp.	3										
Centroptilium spp.	21					4	4				
Neocloeon spp.	4										
Ephemerella spp.											
Baetis spp.								1			
COLEOPTERA											
Narpus spp.											
Optioservus spp.	2										SENSITIVE
Zaitzevia spp.	2										
LEPIDOPTERA											
Elophila sp.											
TRICOPTERA											
Glossosoma spp.	2										
Chimarra spp.	11										
Agraylea spp.											
Hesperophylax spp.	1										
Limnephilus spp.											
Leptocella spp.											
Oecetis spp.											
Triaenodes spp.											
Brachycentrus spp.		1									
Helicopsyche spp.		5									
Hydropsyche spp.	16	27									
Cheumatopsyche spp.	5										
AMPHIPODA											
Gammarus spp.											
Hyallela sp.											
ODONATA											
Gomphus spp.											
Erpetogomphus spp.											
Ophiogomphus spp.						1					
DIPTERA											
Simuliidae										4	
Tendipeds (without anal gills)	40	7						6			INTERMEDIATE
Bezzia sp.											
Chrysops spp.											
Tabanus sp.											
Tipula sp.	1										
Hexatoma sp.											
Atherix sp.											
PLESIOPORA											
Eclipidrilus sp.	11	4									
PLESIOPORA											
Limnodrilus spp.	1										
Tubifex spp.											
RHYNCHOBDELLIDA											
Helobdella sp.											
Glossiphonia spp.											
DIPTERA											
Tendipeds (with anal gills)											TOLERANT
Psychoda sp.											
SENSITIVE	12	3	No samples	No samples	No samples	1	2	1	0	1	
INTERMEDIATE	2	3				1	0	1	0	1	
TOLERANT	1	0				0	0	0	0	0	
TOTAL NUMBER OF ORGANISMS	136	44				5	7	7	0	7	

Table 10. Mining Associated - Winter Samples - First Day

	BATTLE CREEK ABOVE MINE	BATTLE CREEK BELOW MINE	CASTLE CREEK ABOVE DEPOSIT AREA	CASTLE CREEK NEAR DEPOSIT AREA	CASTLE CREEK BELOW DEPOSIT AREA	SOUTH FORK OF RAPID CREEK ABOVE BOTH MINE AREAS	SOUTH FORK OF RAPID CREEK ABOVE HOP CREEK	HOP CREEK ABOVE MINE	HOP CREEK BELOW MINE	RAPID CREEK BELOW HOP CREEK	
PLECOPTERA											
Acroneuria sp.			3		7						
Arcynopteryx spp.							1				
Isoperla spp.	1			10	35		1				
Alloperla spp.				2	1						
EPHEMEROPTERA											
Ameletus sp.					3						
Tricorythodes spp.											
Paraleptophlebia spp.	4			11	3						
Centroptilium spp.					11						
Neocloeon spp.											
Ephemerella spp.	5		27	8	46	1	9				
Baetis spp.	2		8	6		1					
COLEOPTERA											
Narpus spp.			3			2					SENSITIVE
Optioservus spp.	26										
Zaitzevia spp.											
LEPIDOPTERA											
Elophila sp.											
TRICOPTERA											
Glossosoma spp.	30	10			2						
Chimarra spp.											
Agraylea spp.											
Hesperophylax spp.											
Limnephilus spp.	2										
Leptocella spp.											
Oecetis spp.											
Triaenodes spp.											
Brachycentrus spp.	5		3		5	1	11			3	
Helicopsyche spp.	2	2									
Hydropsyche spp.	227	72	1	6	24	1	3			1	
Cheumatopsyche spp.	43	4			21						
AMPHIPODA											
Gammarus spp.			39								
Hyallela sp.			163								
ODONATA											
Gomphus spp.											
Erpetogomphus spp.											
Ophiogomphus spp.		1			2						
DIPTERA											
Simuliidae			3								
Tendipeds (without anal gills)	106		22								INTERMEDIATE
Bezzia sp.											
Chrysops spp.	1		1				4			1	
Tabanus sp.											
Tipula sp.	1	1			1						
Hexatoma sp.											
Atherix sp.											
PLESIOPORA											
Eclipidrilus sp.	8				3		2				
PLESIOPORA											
Limnodrilus spp.	12		8								
Tubifex spp.											
RHYNCHOBDELLIDA											
Helobdella sp.											
Glossiphonia spp.											
DIPTERA											
Tendipeds (with anal gills)											TOLERANT
Psychoda sp.											
SENSITIVE	11	4	6	6	11	5	5	No samples	0	2	
INTERMEDIATE	4	2	5	0	2	0	3		0	1	
TOLERANT	1	0	1	0	0	0	0		0	0	
TOTAL NUMBER OF ORGANISMS	475	90	281	43	164	6	32		0	5	

Table 11. Mining Associated - Winter Samples - Second Day

	BATTLE CREEK ABOVE MINE	BATTLE CREEK BELOW MINE	CASTLE CREEK ABOVE DEPOSIT AREA	CASTLE CREEK NEAR DEPOSIT AREA	CASTLE CREEK BELOW DEPOSIT AREA	SOUTH FORK OF RAPID CREEK ABOVE BOTH MINE AREAS	SOUTH FORK OF RAPID CREEK ABOVE HOP CREEK	HOP CREEK ABOVE MINE	HOP CREEK BELOW MINE	RAPID CREEK BELOW HOP CREEK	
PLECOPTERA											
Acroneuria sp.	1		7		15						
Arcynopteryx spp.											
Isoperla spp.	17		3	6		1	1				
Alloperla spp.				4							
EPHEMEROPTERA											
Ameletus sp.					5						
Tricorythodes spp.											
Paraleptophlebia spp.	6			1	4						
Centroptilium spp.					6						
Neocloeon spp.											
Ephemerella spp.			4	8	14	24	4				
Baetis spp.	3		13	1		3	1				
COLEOPTERA											
Narpus spp.			2		5	2					SENSITIVE
Optioservus spp.	5										
Zaitzevia spp.											
LEPIDOPTERA											
Elophila sp.						3					
TRICOPTERA											
Glossosoma spp.	18	35									
Chimarra spp.			3								
Agraylea spp.											
Hesperophylax spp.											
Limnephilus spp.											
Leptocella spp.											
Oecetis spp.											
Triaenodes spp.											
Brachycentrus spp.	5	1	5			1	8			1	
Helicopsyche spp.		2									
Hydropsyche spp.	278	16	3	15	43	1	1				
Cheumatopsyche spp.	123	1			26						
AMPHIPODA											
Gammarus spp.			4								
Hyallela sp.			46								
ODONATA											
Gomphus spp.											
Erpetogomphus spp.											
Ophiogomphus spp.	9	2			3						
DIPTERA											
Simuliidae			2								
Tendipeds (without anal gills)	146		56			2					
Bezzia sp.			2								
Chrysops spp.	3	1	2				1				INTERMEDIATE
Tabanus sp.	1						1				
Tipula sp.		4									
Hexatoma sp.	3										
Atherix sp.											
PLESIOPORA											
Eclipidrilus sp.	37					2	2				
PLESIOPORA											
Limnodrilus spp.											
Tubifex spp.	24		4			1	1				
RHYNCHOBDELLIDA											
Helobdella sp.	4										
Glossiphonia spp.											
DIPTERA											
Tendipeds (with anal gills)											TOLERANT
Psychoda sp.											
SENSITIVE	9	5	8	6	8	7	5	No samples	0	1	
INTERMEDIATE	6	3	6	0	1	2	3		0	0	
TOLERANT	2	0	1	0	0	1	1		0	0	
TOTAL NUMBER OF ORGANISMS	633	62	156	35	121	40	20		0	1	

Table 12. Chemical Results from Mining-associated Stations

Test made	South fork of Rapid Creek below Hop Creek 12/13/62 Amount in ppm	Hop Creek below mine 12/13/62 Amount in ppm	South fork of Rapid Creek above Hop Creek 12/13/62 Amount in ppm	South fork of Rapid Creek above both mine areas 12/20/62 Amount in ppm	Castle Creek below deposit area 12/6/62 Amount in ppm	Castle Creek near deposit area 2/27/63 Amount in ppm	Castle Creek above deposit area 3/5/63 Amount in ppm	Battle Creek below mine 1/2/63 Amount in ppm	Battle Creek above mine 5/13/63 Amount in ppm
1-T.S.	250.0	400.0	303.0	250.0	207.0	252.0	211.0	638.0	170.0
2-T.F.S.	5.0	4.0	5.0	11.0	2.5	17.0	2.0	35.0	8.0
3-pH	7.1	3.2	7.8	7.75	8.0	7.1	7.9	3.0	6.2
4-P.A.	0.0	0.0	0.0	0.0	0.0	NIL	NIL	0.0	NIL
5-M.O.A.	257.0	0.0	245.0	267.0	147.0	162.0	243.0	3.0	48.0
6-TURB.	4.0	4.0	2.0	2.0	NIL	42.0	6.0	37.0	4.0
7-Cl	10.0	24.0	13.0	4.0	19.0	56.0	50.0	237.0	120.6
8-SO4	63.0	270.0	45.0	14.0	79.0	78.0	23.0	225.0	25.0
9-Mg	50.0	63.0	12.0	41.0	67.0	12.0	19.0	24.0	4.8
10-Ca	83.0	186.0	33.0	82.0	45.0	58.0	36.0	58.0	19.0
11-Na	13.0	14.0	14.0	9.0	9.0	43.0	71.0	182.0	84.0
12-K	9.0	10.0	12.0	NIL	9.0	NIL	10.0	61.0	19.0
13-T.Fe	0.73	11.2	0.44	NEG	0.11	4.5	0.04	12.8	0.09
14-C.H.	260.0	734.0	133.0	376.0	388.0	201.0	168.0	266.0	68.5
15-T.PO4	0.15	0.46	0.11	0.11	0.18	0.10	0.07	0.25	0.13
16-NH4	0.63	1.11	0.86	0.36	1.11	NIL	NIL	1.8	NIL
17-O.N	0.99	1.08	1.11	0.70	2.50	0.15	1.53	1.4	0.25
18-NO2	NIL	NIL	NIL	NEG	NIL	NIL	0.02	NIL	NIL
19-NO3	NIL	NIL	NIL	0.09	NIL	NIL	0.03	0.39	0.02
20-S.C.	460.0	600.0	470.0	440.0	475.0	280.0	460.0	840.0	900.0

Table 13. Index of Similarity Comparisons Between Winter Samples Taken From Same Relative Area on Consecutive Days

Location of stations	Index of similarity
Fall River above sewage treatment plant	88
Fall River below sewage treatment plant	64
French Creek above sewage treatment plant	66
French Creek below sewage treatment plant	44
French Creek below Stockade Lake	79
French Creek above Narrows	79
French Creek below Narrows	70
Battle Creek above mine	74
Battle Creek below mine	41
Spring Creek above sewage treatment plant	74
Spring Creek below sewage treatment plant	86
Castle Creek above deposit area	46
Castle Creek near deposit area	66
Castle Creek below deposit area	57
South fork of Rapid Creek above both mines	33
South fork of Rapid Creek above Hop Creek	68
South fork of Rapid Creek below Hop Creek	33
Rapid Creek above sewage treatment plant	74
Rapid Creek below sewage treatment plant	70
Rapid Creek downstream station	58
Spearfish Creek above sewage treatment plant	63
Spearfish Creek below sewage treatment plant	91

Table 14. Index of Similarity Comparisons for Stations Above and Below Various Suspected Sources of Pollution

Location of stations	Winter 1st day	Winter 2nd day	Summer
Fall River above-below sewage treatment plant	04	05	13
French Creek above-below sewage treatment plant	10	18	22
French Creek above sewage treatment plant-below Stockade Lake	21	15	17
French Creek above sewage treatment plant-above Narrows	16	17	56
French Creek above sewage treatment plant-below Narrows	10	08	37
Battle Creek above-below mine	31	10	30
Spring Creek above-below sewage treatment plant	28	17	13
Castle Creek above deposit area-near deposit area	09	11	
Castle Creek above deposit area-below deposit area	15	12	
South fork of Rapid Creek above both mines-above Hop Creek	21	37	66
South fork of Rapid Creek above both mines-below Hop Creek	20	09	
Rapid Creek above-below sewage treatment plant	05	05	0
Rapid Creek above sewage treatment plant-downstream station	35	51	16
Spearfish Creek above-below sewage treatment plant	24	16	16

DISCUSSION

Hawkes (1964) discussed various aspects of pollution and macroinvertebrates, including how pollution affects the benthic community and the responses of the benthic community to pollution, which are summarized by the following comments.

Pollution can either affect the organism directly through some metabolic process or indirectly through habitat alteration. Several factors determine the influence of pollution upon the benthic community, including toxicity thresholds of organisms, reduction of food, elimination of predator species, and changes in composition of bottom materials. The riffle community is dependent on materials carried in by the current. Any changes in these materials will affect the community.

Macroinvertebrates react to organic pollution in one of the following ways: 1) Mild pollution results in a general increase in most organisms, except for genera that are highly sensitive which will be eliminated. 2) Additional pollution will eliminate most organisms in the sensitive category, reduce the number of forms in the intermediate category, and those in the tolerant category will increase. 3) Severe pollution will result in the loss of organisms in the intermediate category, and an increase of organisms in the tolerant category.

Toxic and organic wastes usually exhibit similar effects on the benthic community, although certain species may be affected differently. Certain species show more tolerance to toxic wastes, while others show less tolerance; for example, some species of stoneflies are eliminated by a small amount of organic pollution, but can withstand large amounts of heavy metals, and certain species of Diptera have shown just the opposite reaction. However, when considering the entire benthic community, Hawkes concluded, the effects are very similar.

The "Report on Water Pollution Investigation Rapid Creek", December, 1963, page V, by the South Dakota Department of Health, clearly stated that Rapid Creek is polluted below the Rapid City sewage treatment plant:

> "Clean stream water quality in Rapid Creek was found above Rapid City. The sanitary and industrial wastes at Rapid City are only partially treated. Repeated by-passing of raw municipal wastes is contrary to health regulations. Improperly treated waste water from municipal waste treatment facilities creates serious public health hazards and water-course degradation in the receiving stream. The physical, chemical, and biological quality of lower Rapid Creek waters precludes use of this water for safe beneficial purposes."

Because Rapid Creek is known to be polluted, it was used as a standard to determine the effect of pollution on macroinvertebrates and as a comparison for other streams sampled.

The sampling results generally agree with those published by the South Dakota Department of Health. The elimination of sensitive organisms and the occurrence of such species as Psychoda sp. below the sewage treatment plant indicates that Rapid Creek is being polluted by the effluent from the Rapid City sewage treatment plant. The occurrence of sensitive and intermediate organisms at the downstream station indicates that the stream is recovering from the heavy pollution immediately below the sewage treatment plant. The occurrence of these organisms does not infer high quality water as the organisms present are the more resistant organisms.

The results of the French Creek samples indicate a change in water quality below the Custer sewage treatment plant. This minor change in organisms probably does not reflect the full influence of the Custer plant because organisms above the plant are limited by low stream flows. The increase in kinds of organisms at each downstream station reflects the improvement of the water quality. However, water flows at these stations are more consistent because of releases from Stockade Lake and small feeder streams. This improvement may be the result of either distance from the sewage treatment plant as in the case of the downstream station on Rapid Creek or the influence of Stockade Lake.

The improvement in water quality at the station below "the narrows" from that above "the narrows" is probably due to the influence of the underground aquifer as the distance between the stations is approximately one-half mile and it is doubtful if distance alone could result in the improved water quality.

The results of chemical sampling verify those of the biological samples. The high values of total solids, turbidity, sulfates, phosphates, nitrites, and nitrates below the plant show that the Custer sewage treatment plant is adding to the pollution load of French Creek.

The degrading effects of the Custer effluent are not only apparent on French Creek, but also on Stockade Lake, one of the main sources of water-based recreation to visitors at Custer State Park. This lake shows many signs of organic enrichment, or eutrophism, including heavy algal blooms, dense aquatic vegetation, an ooze bottom, and the inability to support a trout population as it once did. Mackenthun, Ingram, and Porges (1964) list one of the main methods of minimizing conditions leading to water enrichment as stopping the discharge of sewage and decomposable organic industrial wastes, which contain high concentrations of nitrogen and phosphorus, which will manifest in nuisance growths of aquatic plants.

The reduction in sensitive organisms below the Hot Springs sewage treatment plant shows that the water quality of Fall River is being lowered by the effluent from the plant.

Chemical samples collected from Fall River support the biological data. The increase in total solids, chloride, sodium, phosphates, nitrites, and nitrates corresponds to the decrease in sensitive organisms.

Spring Creek samples indicate that the effect of the Hill City sewage treatment plant is one of enrichment of the stream. The presence of the stonefly larvae _Isoperla_ spp. Banks indicates that Spring Creek is not being seriously degraded by the Hill City effluent.

Chemical samples did not show any major increases except for total solids and ammonia; and as the biological samples, they indicate enrichment of the stream.

The situation on Spring Creek is similar to that on French Creek in that the Creek flows into a major recreation reservoir, Sheridan Lake. This reservoir is showing signs of eutrophication, especially in the inlet area where dense stands of aquatic vegetation are apparent.

Spearfish Creek samples were similar to those collected from Spring Creek in that the reaction was an increase in total number and kinds of organisms. This increase is indicative of the stream being enriched by the effluent from the Spearfish sewage treatment plant. The occurrence of the sensitive stonefly species *Acroneuria* sp. and *Isoperla* spp. below the sewage treatment plant is further evidence that the effluent is not causing serious degradation of the stream.

Chemical data showed slight increases in some constituents, indicating that the stream is being enriched by the effluent from the sewage treatment plant.

Samples from the bog iron mining area indicates that the mine adjacent to the south fork did not influence the water chemistry to cause any significant changes in the benthic fauna. Chemical samples did show an increase in iron; however, it did not cause the bottom organisms to change.

Samples taken in the Hop Creek area and in the south fork below Hop Creek did show major changes in both the biological and chemical samples. No organisms were taken below the mine in Hop Creek, iron was 11.2 ppm and the pH was lowered to 3.2 ppm.

Data from the station in the south fork below Hop Creek also showed that the Hop Creek mine was influencing the biological and chemical characteristics of the south fork. The elimination of most benthic organisms, the increase in sulfates and iron, and the lowering of the pH in the lower station in the south fork is evidence of the effects of the Hop Creek mine.

The effect of the high iron concentrations especially in feeder streams to reservoirs could result in a general decline in productivity of the reservoirs. Ruttner (1953) states when ferrous iron and phosphate occur together in the hypolimnion of a lake, an insoluable ferric phosphate is precipitated at times. There is some evidence that this phenomenon may be in effect in Pactola Reservoir which is fed by Rapid Creek.

Data from the Castle Creek stations show the effects of bog iron deposits, as did the south fork mining stations. Although no mining has been done in Castle Creek, iron is leaching into the creek from deposits near the creek. Organisms decreased when the iron and sulfate content of the water increased in the iron deposit area. The organisms that appeared to be affected the most by the increased iron were those listed as intermediate. Many of the organisms that were eliminated did recur at the lower station corresponding to a decrease in iron and sulfate at the same station.

Battle Creek samples show the effect of the beryllium mine on the biological and chemical samples. Organisms were reduced in numbers and kinds at the downstream station. Chemical samples showed increases in almost every constituent and correspond with the reduction in benthic fauna to show the effects of the beryllium mine.

SUMMARY AND CONCLUSIONS

Results of macroinvertebrate sampling on each stream reflect changes in water quality; thus, each stream is being polluted by the suspected sources of pollution that were investigated. The reaction of the benthic community not only indicates that the streams are being polluted, but also the degree of pollution of each stream. Rapid Creek shows the greatest reduction in water quality due to organic pollution. Fall River and French Creek are also being severely polluted by organic wastes, although the main effects in French Creek are more serious on Stockade Lake than on the Creek itself. Spearfish Creek and Spring Creek are being only mildly polluted by sewage treatment plant effluents. The pollutants being added to Spring Creek are evidently accumulating in Sheridan Lake; thus, the mild pollution of Spring Creek must be considered as serious.

Mining is also responsible for degradation of streams. Hop Creek is grossly polluted by mining of bog iron, and this pollution is affecting the south fork of Rapid Creek. Castle Creek is being polluted by leaching from bog iron deposits; and if these deposits were to be mined similar to the Hop Creek area, the results could be the same as Hop Creek and the pollution extended further down stream. Beryllium mining and disposal of process wastes is polluting Battle Creek.

Chemical data also indicated that streams investigated are being polluted. This data concurs with and therefore supports the macroinvertebrate data. It is evident that the best pollution investigations involve both biological and chemical evaluation; however, biologists are often limited by time, equipment, and budgets, and are unable to conduct thorough investigations. Macroinvertebrates are one tool that enables biologists to overcome some of the previously mentioned problems, and yet obtain valuable information regarding stream conditions. In many instances pollution investigations based on benthic communities can be simplified by limiting the identification of organisms to the order or family level. However, identification to the genus or species level is necessary in cases of mild pollution.

Macroinvertebrates can indicate the degree of pollution of a stream; however, they cannot indicate the chemical constituents causing pollution. In many instances the type of pollution is evident, such as sewage treatment plant effluents; however, in other instances, the composition of pollutants is unknown and can only be determined by chemical analysis. One of the most beneficial uses of macroinvertebrates would be as a monotoring device in streams; this would involve sampling of specific sites at regular intervals. Any significant changes in the benthic fauna could be an indication of a possible change in water quality, and would necessitate a more intensive investigation.

Records from this type of program would be invaluable for evaluating the effects of new pollution sources or evaluation of remedial measures applied to known pollution sources. For example, Rapid City is currently constructing a new sewage treatment plant, and the effectiveness of this plant could be determined by sampling macroinvertebrates before and after the start of its operation. Also, the recovery of the stream below the old plant could be determined after it is no longer in service.

Detection and curtailing pollution is probably the main problem currently facing fisheries biologists in the Black Hills. Reduction of water quality by pollution has resulted in the loss of many miles of stream from the trout fishery, and impoundments now receive the majority of fishing pressure. Impoundments are also important for recreation, such as water skiing and swimming. These impoundments cannot continue to receive contaminants carried by their feeder streams and still maintain their high quality. This fact is evidenced by Stockade and Sheridan Lakes.

Construction of new dams in the Black Hills is limited in part by pollution. Attempts to select dam sites away from pollution often necessitates selection of sites high on the drainage where the water supply is insufficient or construction costs are prohibitive.

Continued lake pollution will affect the economy in the area of the Black Hills. The Black Hills are popular as a recreational area and also have many points of interest which attract tourists. For example, Mt. Rushmore and Custer State Park both average over one million visitors each year (Appendix E). Degradation of the lakes to the point where they are no longer attractive as a recreational source will decrease the ability of the area to retain people.

Pollution not only affects the recreational aspects of streams and lakes, but also the agricultural aspects. Water polluted by organic or toxic wastes cannot be used effectively for irrigation or livestock.

Towns in the Black Hills use the streams as a water supply source and could be in danger of losing it if pollution continues. The water at least will require additional treatment, resulting in higher costs for potable water. Towns may be faced with not only low-quality water, but also with an insufficient supply, if the trend towards reduced stream flow is continued.

LITERATURE CITED

1. Anonymous. Publishing date unknown. Bioassay and pollution ecology training course manual. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. III-17-2 and 3.

2. ______. 1967. Black Hills area resources study. U. S. Depts. of Interior and Agriculture. 225 pp.

3. ______. 1959. Environmental health investigation, Lawrence County, South Dakota Division of Sanitary Engr., South Dakota Dept. of Health. 45 pp.

4. ______. 1965. Preliminary report, waste water treatment facilities for Spearfish, South Dakota. Prepared by Brady Engr. Company. 57 pp.

5. ______. 1964. Report on water pollution investigation, Rapid Creek, Pactola Reservoir to Cheyenne River, Division of Sanitary Engr., South Dakota Dept. of Health. 61 pp.

6. ______. 1960. Report on water pollution studies, Gold Run Creek--Whitewood Creek--Belle Fourche River--Cheyenne River, Division of Sanitary Engr., South Dakota Dept. of Health. 42 pp.

7. ______. 1962. Surface water records of North Dakota and South Dakota. U. S. Geological Survey, Pierre, South Dakota. 255 pp.

8. ______. 1963. Surface water records of North Dakota and South Dakota. U. S. Geological Survey, Pierre, South Dakota. 255 pp.

9. ______. 1964. Surface water records of North Dakota and South Dakota. U. S. Geological Survey, Pierre, South Dakota. 255 pp.

10. Brinkhurst, R. O. 1963. Observations on the recovery of a British river from gross organic pollution. Dept. of Zoology, Univ. of Liverpool. pp. 9-51.

11. ______. 1965. The biology of the Tubificidae with special reference to pollution. Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 57-65.

12. Cordone, A. J., and D. W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish and Game, Vol. 47, No. 2, pp. 189-226.

13. Curry, L. L. 1965. A survey of environmental requirements for the midge (Diptera: Tendipedidae). Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 127-141.

14. Edmondson, W. T., Editor. 1959. Fresh-water biology. John Wiley and Sons, New York.

15. Gaufin, A. R. 1965. Environmental requirements of Plecoptera. Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 105-110.

16. ______, E. K. Harris, and H. J. Walter. 1956. A statistical evaluation of stream bottom sampling data obtained from the three standard samplers. Ecology, Vol. 37, No. 4. pp. 643-648.

17. Hamilton, E. W. 1959. Review of Ephemeridae (Ephemeroptera) in the Missouri River watershed with a key to species. Iowa State College J. of Sci., Vol. 33, No. 4. pp. 443-474.

18. Hawkes, H. A. 1964. Effects of domestic and industrial discharges on the ecology of riffles in midland streams. Advances in Water Pollution Research, the Macmillan Company. pp. 293-317.

19. Hynes, N. B. 1960. The biology of polluted waters. Liverpool Univ. Press. 202 pp.

20. ______. 1965. The significance of macroinvertebrates in the study of mild river pollution. Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 235-240.

21. Leonard, J. W. 1965. Environmental requirements of Ephemeroptera. Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 110-117.

22. Mackenthun, K. M., W. M. Ingram, and R. Porges. 1964. Limnological aspects of recreational lakes. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 1-176.

23. Newport, C. A. 1956. A history of Black Hills forestry. Doctor of Philosophy, State Univ. College of Forestry of Syracuse, New York. South Dakota Dept. of Game, Fish, and Parks. 112 pp.

24. Orr, H. K. 1959. Precipitation and stream flow in the Black Hills. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, Station Paper No. 44. 24 pp.

25. Peterson, A. 1960. Larvae of insects, an introduction to Nearctic species. Edwards Brothers, Inc., Ann Arbor, Michigan. pp. 1-117.

26. Phillips, E. A. 1959. Methods of vegetation study. Henry Holt and Company, Inc. 107 pp.

27. Roback, S. S. 1965. Environmental requirements of Tricoptera. Biological Problems in Water Pollution, Third Seminar. U. S. Dept. Health, Education, and Welfare, Pub. Health Serv. pp. 118-126.

28. Ruttner, F. 1953. Fundamentals of limnology. Univ. of Toronto Press, Toronto, Ontario. 242 pp.

29. Stewart, R. K. 1961. The loss of 1040 miles of trout stream. South Dakota Conserv. Dig., Summer, 1961, reprint. pp. 1-6.

30. ______. 1965. Personal correspondence regarding identification of tendipeds.

31. ______, and Carol A. Thilenius. 1964. Stream and lake inventory and classification in the Black Hills of South Dakota. Dingell Johnson Project F-1-R-12, Job Numbers 14 and 15. 101 pp.

32. Thilenius, Carol A. 1965. An evaluation of pollution in the Belle Fourche and Cheyenne Rivers due to wastes carried by Whitewood Creek. South Dakota Dept. of Game, Fish, and Parks. 47 pp.

33. Usinger, R. L., Editor. 1963. Aquatic insects of California with keys to North American genera and California species. Univ. of Calif. Press, Berkley and Los Angeles. 508 pp.

APPENDIX

Appendix A. Benthic Fauna from Rapid Creek

	Station #1 above sewage treatment plant	Station #2 below sewage treatment plant	Station #3 downstream from #2	Station #4 downstream from #3
Ephemeroptera				
Baetis	3	0	0	0
Tricorythodes	92	0	0	0
Tricoptera				
Hydropsyche	3	0	0	0
Diptera				
Psychoda	0	0	1,340	12
Tendipes plumose	0	0	4,800	1,712
Unidentified				
Small midge	65	0	0	0
Pulmonata				
Physa	1	7	128	0
Ancylidae	12	0	0	0
Rhynchobdellida				
Leach	5	12	0	56
Turbellaria-Flatworm				
Planaria	0	0	0	12
Oligochaeta				
Oligochaetes	2	0	0	0
Tubificidae	0	0	1,250	2,836
Total species	8	2	4	5
Total number of organisms	183	19	7,518	4,628

Data taken from Biological Survey Report from stations above and below Rapid City sewage treatment plant.

Appendix B. Chemical Data from French Creek

Station	Above sewage treatment plant	Below sewage treatment plant	Inlet to Stockade Lake
Sulfate (SO_4)	59.2	80.0	56.0
Chloride (Cl)	18.0	56.0	39.0
Ammonia (N)	.26	9.8	5.38
Nitrite (N)	.02	.13	.01
Nitrate (N)	.30	1.20	.60
Ortho Phosphate (PO_4)	.02	16.2	.06
Total Phosphate (PO_4)	.02	13.1	4.9
Iron (Fe)	.15	.25	.10
Organic Nitrogen (N)	.55	4.35	1.13

Information obtained from Dept. of Game, Fish, and Parks files. All values in parts per million.

Appendix C. Chemical Information Regarding Spearfish Sewage Treatment Plant Effluent*

	Dec. 20-21 196,000 gal.	Dec. 21-22 225,000 gal.	Dec. 22-23 198,000 gal.	Dec. 23-24 177,000 gal.	Average 197,500 gal.
5 day BOD	61 ppm	44 ppm	40 ppm	45 ppm	46 ppm
Total solids	675 ppm	665 ppm	715 ppm	685 ppm	685 ppm
Suspended solids	25 ppm	50 ppm	65 ppm	15 ppm	40 ppm
Dissolved solids	650 ppm	615 ppm	650 ppm	670 ppm	650 ppm
Settleable solids	ML/LO.3 ppm	LO.1 ppm	LO.1 ppm	0.1 ppm	0.1 ppm

Samples Taken from Spearfish Creek*

	250' below outlet	250' above outlet	½ mile below outlet	250' below outlet
5 day BOD	4.0 ppm	2.0 ppm	3.0 ppm	3.0 ppm
Total solids	335 ppm	370 ppm	270 ppm	235 ppm
Suspended solids	50 ppm	N.A.	50 ppm	N.A.
Dissolved solids	285 ppm	N.A.	220 ppm	N.A.

It can be seen that the existing facility is not meeting public health standards even under the optimum conditions of the test period. A more serious condition prevails during summertime peak loading when the receiving stream is down in flow and sewage flows at a maximum.*

*Information obtained from Preliminary Report, Waste Water Treatment Facilities for Spearfish, South Dakota.

Appendix D. Benthic Fauna Data from Battle Creek*

	Composite of three sq. ft. samples-- April 27, 1965		Composite of three sq. ft. samples-- March 31, 1966		One sq. ft. sample-- April 19, 1967	
	Above	Below	Above	Below	Above	Below
Plecoptera						
Chloroperlidae	30	0	64	0	22	1
Perlodidae	0	1	225	130	60	2
Nemouridae	3	0	0	0	0	0
Ephemeroptera						
Baetidae	0	0	2	5	5	0
Odonata						
Gomphidae	15	1	0	0	0	7
Tricoptera						
Helicopsychidae	7	9	0	0	521	215
Hydropsychidae	449	1	27	51	137	44
Leptoceridae	50	0	0	1	0	8
Limnephilidae	0	0	70	16	31	18
Rhyacophylidae	134	0	26	51	9	5
Hydroptilidae	0	0	0	0	0	0
Coleoptera						
Elmidae	3	0	0	0	57	16
Dytiscidae	1	0	0	0	0	0
Gyrinidae	0	0	0	0	18	0
Diptera						
Tendipeds	5	0	10	22	38	1
Tabanidae	0	1	3	2	0	1
Tipulidae	45	1	11	6	31	3
Oligochaeta-Class	1	1	1	0	0	9
Turbellaria-Class	0	0	0	0	0	0
Mollusca						
Physidae	4	0	0	0	30	5
Total	747	15	469	284	959	335

*Data obtained from Game, Fish, and Parks Dept. files.

Appendix E. Attendance Figures for Leading Tourist Attractions in the Black Hills Area

	Mt. Rushmore*	Custer State Park**	Passion Play***
1961	1,030,428	839,328	81,000
1962	1,209,364	1,630,468	84,000
1963	1,272,758	1,739,842	95,000
1964	1,343,256	1,713,120	98,000
1965		1,912,420	100,000

1963 monthly		1964 monthly	
Jan.-	5,370	Jan.-	6,553
Feb.-	5,877	Feb.-	5,411
March-	13,120	March-	13,342
April-	25,018	April-	21,487
May-	51,287	May-	68,440
June-	237,188	June-	252,982
July-	388,995	July-	391,054
Aug.-	376,794	Aug.-	393,069
Sept.-	119,054	Sept.-	129,947
Oct.-	33,690	Oct.-	44,765
Nov.-	11,026	Nov.-	13,846
Dec.-	5,341	Dec.-	2,360

* Information obtained by personal correspondence with the Superintendent of Mt. Rushmore National Memorial.

** Information obtained by personal correspondence with the Superintendent of Custer State Park.

*** Information obtained from Preliminary Report, Waste Water Treatment Facilities for Spearfish, South Dakota.