EFFECTS OF OILFIELD BRINES

JAMES R. CHARLES

Kentucky Department of Fish and Wildlife Resources
Frankfort, Kentucky

CONTENTS

ABSTRACT

Oilfield brines wasting into the Green River created an acute pollution problem over 100 miles in extent. Before August, 1958, the water was moderately hard, of the calcium magnesium bicarbonate type, and had an average chloride concentration of less than 10 ppm. With the disposal of brines coincident with the rapid development of the Greensburg oilfield in the spring of 1958, the water became very hard, changed to a sodium chloride type, and chloride concentrations frequently exceeded 1,000 ppm. The effects this pollution had on the water quality, fish fauna, and macro-invertebrate bottom fauna were determined and evaluated in a study that began in the summer of 1960 and continued through 1963.

Domestic and industrial use of the water was seriously affected, as were private springs and wells. Ground water contamination was concentrated in the areas of greatest brine production in Green and Taylor Counties, but was noticeable as far as Brownsville, 100 miles downstream. The two large springs in Mammoth Cave National Park, known as Echo River and Styx River, also became contaminated.

Population sampling showed that the Green River supported an extremely rich and varied fish fauna, especially in the unpolluted sections. One hundred seven of the 177 species known to occur in Kentucky were identified from the river during the 4-year study. As the brine pollution diminished from its peak intensity in 1960, the number of species occurring exclusively in the unpolluted section decreased from 27 in 1960 to 13 in 1963. The unpolluted section supported an average annual standing crop ranging between 85 and 156 pounds per acre. The standing crop in the polluted section increased from 10 pounds per acre in 1960 to 47 pounds per acre in 1963.

The effects of brine pollution on the macro-invertebrates were just as pronounced. The upstream, unpolluted section of the river supported a rich and varied bottom fauna. Productivity in this section averaged 90 organisms and 1.78 cc, per square foot, over the 4-year period. Productivity values in the polluted section during the year of greatest pollution ranged from an average of 26 organisms and 0.18 cc at Station +6.2 (closest to pollution source) to 78 organisms and 0.64 cc at Station +80.4 (farthest from pollution source). The quality (i.e., as potential fish food) of the bottom fauna in the polluted section was extremely poor. However, both quality and productivity showed improvement as the brine pollution gradually diminished.

INTRODUCTION

Enlightened stream management entails more than regulation of creel and season limits, artificial replenishment, population sampling, creel surveying, or habitat alteration. It requires constant vigilance to the ever-growing threat of stream pollution. The situation faced today by most states is not one of adding more miles of fishable streams to their inventories, but instead, one of trying to prevent further losses to pollution. Pollution is a serious problem in certain Kentucky streams, and its effects upon biological productivity were largely unknown. This paper reports the results from one phase of a Dingell-Johnson project that investigated the effects of oilfield pollution on biological productivity. Oilfield brines wasting into the Green River created an acute pollution problem over 100 miles in extent. The specific objectives sought from this study, which began in the summer of 1960 and continued through December, 1963, were:

1. To determine the effects of oilfield brine on the water quality.
2. To determine and evaluate the effects of oilfield brine on the fish fauna.
3. To determine and evaluate the effects of oilfield brine on the macro-invertebrate bottom fauna.

ACKNOWLEDGEMENTS

Although many published titles bear the name of a single author, it has been the experience of this writer that few papers are the result of only one person's efforts. Certainly this is true of this particular publication. Much credit is due Charles Gorham, the writer's assistant, for a job well done in both the field and the laboratory. Few tasks in fishery biology are more tedious and time-consuming than collecting, sorting, and processing some 92,000 bottom organisms that resulted from this and other phases of the project—much less learning to pronounce their scientific names. Charlie ably assisted in all phases of the investigation, and the drafting of the figures was done by him.

Appreciation is extended to the other employees of the Kentucky Department of Fish and Wildlife Resources, especially the staff fishery biologists and the conservation officers, for assistance both indoors and out. William R. Turner either identified or confirmed all preserved fish. Conservation Officer Merl Toms was especially helpful whenever we worked in Casey County.

I am grateful to certain citizens of the Commonwealth who helped us in many ways. More than once, farmer friends brought their tractors

and tow chains to the rescue of our stuck vehicle.

I wish to thank members of the Louisville District Office of the U. S. Army Corps of Engineers ,and particularly their Lock and Dam employees, for the courteous and cordial cooperation they invariably gave us.

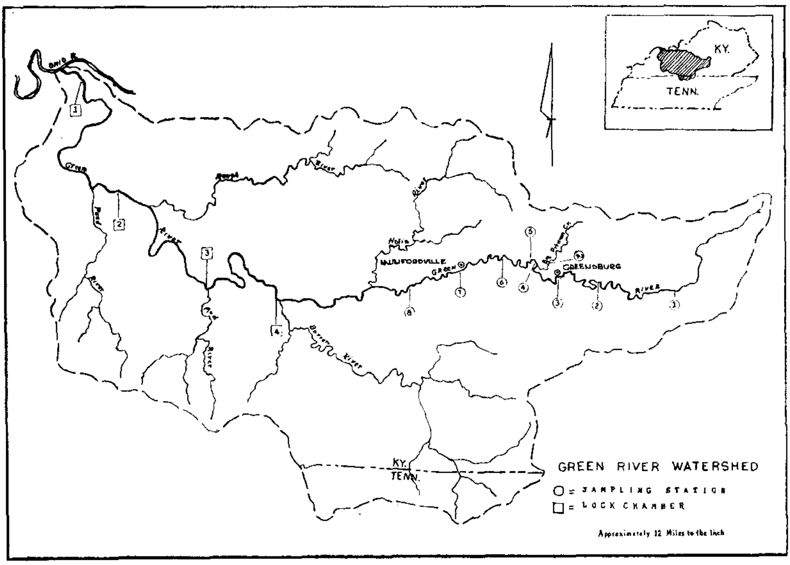
METHODS AND EQUIPMENT

Little difficulty was encountered in locating suitable data stations on the Green River since it is well served by all-weather roads. The coding system used to identify data stations employs plus (+) and minus (—) signs before the mileage number. Station —8.9, for example, indicates that the station was 8.9 miles upstream from the uppermost source of brine pollution. Station +6.2 means the location was 6.2 miles downstream from the uppermost pollution source. For station identification purposes, the uppermost source of pollution is the 0.0 mile point; for all other mileage designations, the mouth of the stream is considered the 0.0 point. Trace Creek, which enters the Green River at Mile 282.8, was the uppermost tibutary discharging brine pollution of any magnitude.

Water-Quality Determinations

Water-quality sampling stations on the Green River coincided in location with the stations selected for bottom fauna sampling (Fig. 1). Water-quality analyses were performed seasonally during 1960 and 1961. The writer then recommended that the permanent data stations be reduced in number, and that they be visited once monthly throughout

Fig. 1 Green River Watershed



the year, rather than seasonally as called for in the original work plans. The recommendations were accepted; three stations located above the pollution source, and five stations below it, were sampled monthly during 1962 and 1963. No water samples were taken, however, during those months when the river stage was too high for bottom fauna sampling. A single permanent data station on Big Pitman Creek, the primary source of brine pollution to the Green River, was used throughout the investigation.

A Hach portable battery-powered colorimeter was used to make turbidity, iron, sulfate, ortho-phosphate, nitrate, nitrite, and pH determinations. Separate kits were necessary for determining total alkalinity and dissolved oxygen. A battery-powered solubridge with paired conductivity cells enabled specific conductance values between 40 and 40,000 micromhos to be measured. The solubridge also measured water temperature.

Fish Fauna Studies

Fish population sampling areas in the Green River were located above and below the sources of oilfield pollution, and in the navigation lock chambers (Fig. 1: lower 150 miles) which were far enough downstream in the recovery zone to be supporting a normal population. Population studies also were made in Big Pitman Creek, the prime source of brine pollution from the Greensburg oilfield. Emulsifiable rotenone (5%) was the only fish toxicant used during 1960, 1962, and 1963. A powdered form of potassium permanganate was used as the detoxifying agent. Sodium cyanide also was used upon occasion during 1961 as the fish toxicant. It proved unsatisfactory, as explained below, for this phase of the investigation.

The stream sampling methods used in studying the fish populations of the Green River and Big Pitman Creek are those that have become, through experimentation, more or less standardized, and are based on many years' experience by staff biologists of this Department. The same sampling procedure was followed, in essence, at each study site (a more detailed discussion of the sampling techniques and data processing methods used is given in an earlier interim report: Charles, 1962).

Sodium cyanide bricks (about the size and shape of charcoal briquets) were used experimentally as a fish toxicant in 1961. Prior to its actual use in the field, the writer had been led to believe that NaCN was non-selective as to species, quickly dissipated downstream from the study area (and therefore required no detoxifying agent), and mortality was practically nil if affected fish were promptly removed from the area treated. Field experienc proved that only the first of these premises was always true. NaCN was non-selective as to species, but extensive downstream kills resulted nearly every time it was used, and it proved impractical to net affected fish and carry them upstream to a live-box when sampling a stream section of average length. Neither did it give a complete kill in the deeper water, as proven by follow-up applications of rotenone. For qualitative spot-sampling of fish populations, however, NaCN is very effective and useful. Used judiciously, excellent results may be had in collecting specimens from riffles and other shallow areas, without the usually-attendant extensive downstream mortality.

Bottom Fauna Studies

Since only riffle areas were sampled at all the stations, the standard Surber square-foot bottom sampler (brass frame, canvas sides, and bolting-cloth bag) was used exclusively during 1961-1963. Both Ekman and Petersen dredges were used briefly in 1960 in pool areas having mud bottoms. Neither dredge was satisfactory because of continual clogging caused by woody debris and pebbles. While suitable substrate for dredge operation was often hard to find, riffle areas abounded in the Green River. Three square-foot samples were collected at each station. An attempt was made to randomly sample the bottom out from the left bank, in the center of the stream, and out from the right bank.

Each collected sample was thoroughly washed and strained through a square twinned-sieve constructed of ¼″-mesh hardware cloth on the top half and 60-mesh bronze screen on the bottom half. All samples were sorted in the field at the station while the organisms were alive and mobile. Sorting was done in a white-enameled pan of the type used by photography shops. A snow-white background that does not glare and reflect light is deemed highly essential for precise and thorough sorting of bottom samples which may contain organisms as small as water mites and larval diptera, to animals as large as crayfish and mussels. Sorted samples were preserved in vials of 80% ethyl alcohol.

In the laboratory, each sample was processed individually using essentially the techniques described by Ball (1948) and by Hunt (1953). The organisms were identified at least to order, counted, and the volume determined for each order by the water displacement method. It has been established (Ball, 1948; Hunt, 1953; and others) that the specific gravity of most macro-invertebrates is so near that of water, that, for all practical purposes, 1.0 cubic centimeter of preserved volume is equal to 1.0 gram live weight. Despite its inappropriate-sounding title, the excellent text edited by Usinger (1956) was the most helpful single volume in matters pertaining to aquatic insect identification.

DESCRIPTION OF THE GREEN RIVER

Geography and Topography

The Green River and its watershed form the largest river basin in Kentucky (Fig. 1). It is the second largest southern tributary of the Ohio River and amounts to about 23 per cent of Kentucky's drainage area. The basin covers 9,222 square miles, a small part of which is in north-central Tennessee. Occupying the heart of the western half of the state, the basin is approximately 160 miles long and from 60 to 80 miles wide. The topography varies from the rugged hilly terrain in the eastern section of the basin, bordering the southern part of the Bluegrass Region, to the Karst topography, deep valleys, and cavern areas of the central section, to the swampy and wide alluvial flood plains of the Ohio River in the western and northern sections. The principal tributaries are the Barren, Nolin, Rough, Mud, and Pond Rivers. The headwaters of the Barren River drain that portion (380 square miles) of the Green River basin in Tennessee. Navigation is maintained on the lower 150 miles of Green River by 4 locks and dams. Two more locks and dams, no longer in operation, impound the river for an additional 49 miles upstream.

The Green River drains a small part of the Knobs, most of the Western Coal Field, and a portion of the Mississippian Plateau Regions. The rocks exposed include limestones, shales, fine-grained sandstones, loess and alluvium. The watershed is rolling with occasional large hills. The tributary rivers in some places have cut deep gorges of from 100 to 200 feet. Large sections of the basin are underlain by cavernous limestone. These regions have no well-defined drainages, and land depressions or sink holes are numerous. The Mammoth Cave area is noted for its limestone caverns. Ground water flow is extensive and many springs are evident. During dry weather the flow of Green River is sustained by the discharge of ground water. Most of the soils that have developed are suited to woodland and pasture. Many areas contain soils that are poorly drained. However, along some of the rivers, especially the upper terraces and on some of the level uplands, well-drained fertile soils occur.

The river rises in Lincoln County at an elevation of 1275 feet and enters the Ohio River at an elevation of 337 feet, an average gradient of 2 feet per mile. From its source it flows southwestward for about 50 miles to the vicinity of Dunnville, Kentucky. Here the river bends westward and flows 200 miles to its junction with the Barren River. From this point, the Green River follows a generally northwestern direction for 150 miles to its confluence with the Ohio River, 8 miles upstream from Evansville, Indiana and 197 miles above the junction of the Ohio and the Mississippi. Including its headwaters, the Green River is approximately 400 miles long.

Gradient

The stream gradient from the headwaters of the Green River in Lincoln County to Greensburg, a distance of 142 miles, averages 5.5 feet per mile. In the next 60 miles downstream, between Greensburg and the last true riffle, the average slope is 1.3 feet per mile. From the head of the slack water created by Lock and Dam No. 6, to the mouth in the Ohio River, the average gradient is 0.45 foot per mile. These data are depicted below. The last riffle downstream is at Mile 198 and

Figure 2.—Annual mean discharge

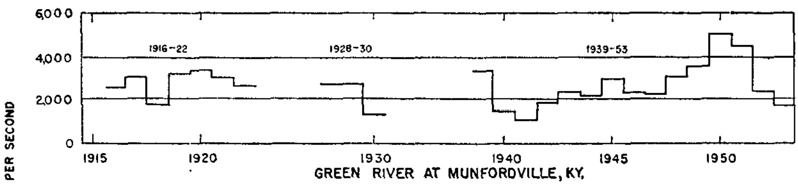


Figure 3.—Minimum daily and monthly discharge

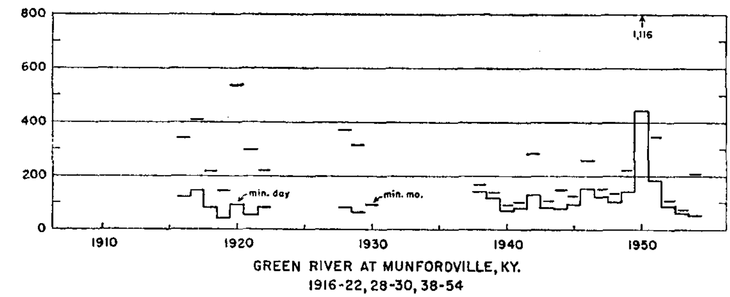
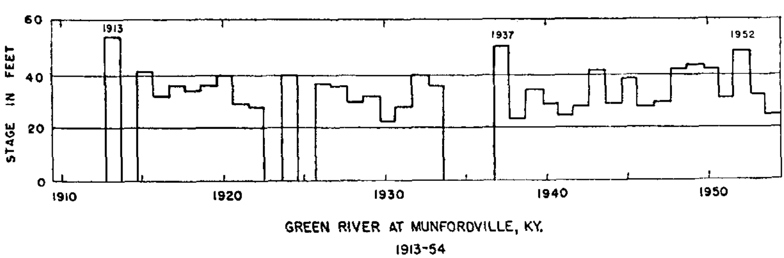


Figure 4—Maximum annual stages



was the location of our lowermost water quality/bottom fauna sampling station.

Mouth		Lock & Dam No. 6		Last riffle		Greensburg	
	0.45′/mi.		1.2′/mi.		1.3′/mi.		5.5′/mi.
0		0		0		0	
	182 miles		16 miles		60 miles		142 miles

Water Discharge

The annual mean discharge of the Green River at Munfordville (Station +49.7), based on records of the U. S. Geological Survey covering a 25-year period, is 2,588 cubic feet per second. The variation in the annual mean discharge is depicted graphically in Figure 2, which (along with Figues 3 and 4) was taken directly from the bulletin, *Streamflow in Kentucky* (Ky. Dept. of Econ. Development, 1956). Figure 3 shows the lowest daily flow and the lowest monthly flow in each calendar year during the period of record. The minimum daily flow during the period of record was 42 cfs in 1919; the minimum monthly flow was 69.7 cfs in 1953. Figure 4 shows the crest stage attained by the highest flood in each calendar year of record and for known high floods prior to the period of record. Notable floods occurred in 1913, 1937, and 1952. The Green River reached a stage of 50.40 feet at Munfordville in 1937, discharging 72,200 cubic feet of water per second. The maixmum known flood stage was 54.0 feet in 1913, when the discharge approximated 87,000 cubic feet per second. The drainage area of the Green River above Munfordville covers 1790 square miles.

Climate

The region has a humid, temperate type of climate and lies in the path of moisture-bearing storms which move from the Gulf of Mexico to the North Atlantic coast. The mean annual temperature is 56.6° with a summer mean of 75.9° and a winter mean of 35.5°. The average annual frost dates are October 15 to 20 and April 12 to 17. The recorded temperature extremes are 108° and −28°.

Precipitation (in the Greensburg area) averages 44 inches per year. Normal precipitation computed by the U. S. Weather Bureau from 30 years of record ranges from a high of 5.6 inches in March to a low of 2.4 inches in October (Hopkins, 1963). Practically all of the precipitation is in the form of rain, since temperatures generally are above freezing during the day.

EFFECTS OF BRINE ON WATER QUALITY

Development of the Greensburg Oilfield

The Greensburg oilfield is in central Kentucky. With the exception of a small area southwest of Greensburg, this field is within the upper Big Pitman Creek drainage basin. Hopkins (1963) states that the area of major oil production extends from a point south and west of Greensburg, the county seat of Green County, north-northeastward into Taylor County, and terminates near Mt. Carmel Church 10 miles northwest of Campbellsville, the county seat of Taylor County. The published dimensions of this oilfield vary, depending upon the publication consulted. One source says the field is approximately 15 miles long and 3 miles wide (45 square miles); another source says it is 25 miles long and 7 miles wide (175 square miles). There is universal agreement, however, based on the size of the tributary creeks and their chloride content, that the vast bulk of waste brine in the Green River comes from Big Pitman Creek.

The Greensburg gas field was drilled between 1920 and 1930 in Green and Taylor Counties. It was depleted and abandoned shortly before 1940. This gas field produced no salt water. The newer oilfield, lying just west of the old gas field, has been developed largely since January, 1958, and maximum oil production was from the fall of 1958 through the summer of 1960 (Table 1). Large amounts of brine were associated with the oil withdrawn from the Laurel Dolomite of Silurian age. Some of the wells produced salt water for several months before oil production started. On a field basis, water production has been estimated to be from 3 to 20 times as great as oil production during the peak oil production period (National Park Service, 1960).

The brines were first simply wasted to sinkholes, drainage ways, and hastily dug ponds. Regulations of the Kentucky Water Pollution Control Commission in October, 1958, required brines to be injected into disposal wells 175 feet or deeper. Pressure disposal into porous zones below the New Albany Shale of Devonian age was permissible from March, 1959 to March, 1960. The Louisville Limestone of Silurian age underlying the New Albany Shale became a major brine disposal zone at this time. This formation had been penetrated, however, by several abandoned gas- and oil-test wells, drilled in the 1920's and 1930's, which allowed the brines to move upward and contaminate the fresh-water zones above. The brines changed the potable ground water from a calcium bicarbonate type, containing moderate amounts of magnesium and sulfate, to a sodium chloride type. Chloride concentrations prior to oil production generally were less than 60 ppm; after oil pro-

Table 1. Oil production, in barrels, of Green and Taylor Counties, Kentucky, compiled by the Kentucky Geological Survey.

Month	1958	1959	1960	1961
January	5,454	613,715	533,787	152,292
February	5,674	587,121	465,148	130,414
March	8,009	806,791	421,891	132,609
April	8,450	1,178,581	478,575	107,753
May	18,216	1,421,608	482,377	117,166
June	21,054	1,234,957	401,624	105,249
July	30,270	1,044,346	345,847	97,939
August	63,107	882,044	307,178	92,862
September	162,244	794,080	268,488	79,476
October	308,860	809,407	235,934	77,417
November	468,529	655,946	190,296	64,551
December	556,181	588,682	157,021	53,418
Totals	1,656,052	10,617,278	4,288,166	1,211,146

Table 2. Maximum, minimum, and modal concentrations and properties of dissolved constituents, Green River at Munfordville.

	Oct. 1, 1950—Sept. 30, 1957				Oct. 1, 1958—Sept. 30, 1959			
(Parts per million)	No. of Samples	Max.	Min.	**Mode**	No. of Samples	Max.	Min.	Mode
Silica (SiO_2)	197	18	3.5	8.8	—	—	—	—
Iron	197	0.36	0.00	0.05	—	—	—	—
Calcium (Ca)	258	52	14.0	33.0	50	152	24	66
Magnesium (Mg)	258	9.4	1.0	5.9	50	52	4.4	15
Sodium (Na)	181	13	1.2	3.9	—	—	—	—
Potassium (K)	181	4.3	0.2	1.4	—	—	—	—
Bicarbonate (HCO_3)	258	186	36.0	104.0	50	154	72	118
Sulfate (SO_4)	258	39	6.2	13.0	34	29	10	17
Chloride (Cl)	258	45	0.5	3.9	358	1700	20	257
Fluoride (F)	202	0.5	0.0	0.1	—	—	—	—
Nitrate (NO_3)	258	7.0	0.2	2.4	49	8.5	0.8	4.0
Dissolved solids (Res. on evap. at 180°C)	258	254	73.0	139.0	50	2700	137	451
Hardness as $CaCO_3$	258	166	44.0	108.0	50	594	80	190
Noncarbonate hardness as $CaCO_3$	258	30	0.0	13.0	50	480	21	107
Specific conductance (micromhos at 25°C)	2551	523	58.9	229.0	362	4650	190	865
pH	258	8.6	6.8	7.6	50	7.9	6.6	7.5
Color	258	32	0.0	4.0	50	25	3	6

duction, chloride concentrations were as high as 51,000 ppm (Hopkins, 1963).

The history of the Greensburg oilfield is a sorry tale; a graphic footnote appears in the National Park Service report (1960): "The field was first developed by local operators, promoters and exploiters with utter disregard for the principles of oil conservation or the right of neighboring lease owners. A major economic asset of the State has been irreparably damaged by unregulated competition. Much of the oil in the formation will never be recovered because of the practices used to recover as much oil as possible in the shortest time."

Chemical Quality Prior to Oilfield Development

Water-qualiy studies, based on daily sampling of the Green River at Munfordville, Kentucky (Station +49.7 in this report) by the U. S. Geological Survey from October, 1950 through September, 1957, provide a 7-year continuous record against which can be measured the subsequent effect of brine pollution from the Greensburg oilfield (Table 2). Krieger and Hendrickson (1960) state that before August, 1958, the water at Munfordville was generally a moderately hard water of the calcium magnesium bicarbonate type, and had an average chloride concentration of less than 10 ppm. With the disposal of brines coincident with the rapid development of the Greensburg oilfield in the spring of 1958, the water changed to a sodium chloride type and chloride concentrations frequently exceeded 1000 ppm. For the period 1950-1957, the maximum sodium and chloride concentrations were only 13 and 45 ppm, respectively, with modal concentrations of 3.9 ppm for both sodium and chloride. The water had the characteristic chemical quality of a stream draining an area containing much limestone and calcareous shale. Usually the water of the Green River was lowest in dissolved salts during the period of high runoff from about December to about April (Krieger and Hendrickson, 1960).

Chemical Quality Subsequent to Oilfield Development

Topography and the porous nature of the limestone surrounding the Greensburg oilfield favored the rapid movement of brines to the streams. The U. S. Geological Survey's daily sampling schedule at Munfordville proved very useful in studying the effects of waste brines on the Green River .With daily determination of specific conductance and chlorides, and a continuous record of water discharge, they were able to calculate the daily discharge of brine from the Greensburg field. Daily analysis also showed the daily variation in the brine load, the effect of flood flows and low flows on the brine concentration, and the change in attendant chemical quality of the water.

According to Krieger and Hendrickson (1960), the effect of waste brines did not become readily apparent until the low water of July and August of 1958. However, a hint of things to come appeared in the relatively high chlorides in late summer and early fall of 1957. High flows during the winter of 1957 and 1958 masked these effects for almost a year. The 1959 water year (October 1, 1958 to September 30, 1959) was the first full year of noticeable brine contamination, as shown in Table 2. Table 2 was taken directly from the report of Krieger and Hendrickson. The data are based on chemical analyses of composites of daily samples, except the specific conductance and chloride values are based on daily samples. Average concentrations are given as the mode (the most frequently occurring value) since they believe that the mode gives the best expression of a significant value for data with such skewed and extreme values.

The Green River at Munfordville became a sodium chloride type water, usually very hard and usually very high in dissolved salts. Domestic and industrial use of the water was seriously affected, as were private springs and wells. Ground water contamination was con-

Table 3. Chemical characteristics, in parts per million, of Green River water analyses made above (—) and below (+) mouth of Trace Creek, 1960.

Station	Date	Sp. cond. (micromhos)	Tot. alk.	Iron	Ortho-phosphate	Sulphate	pH	Tur-bidity
—82.6	Oct. 11	158	—	—	—	—	—	—
—80.9	Oct. 11	165	—	—	—	—	—	—
—77.3	July 19	—	86	—	—	—	—	—
—77.3	Aug. 11	—	103	0.09	—	20	—	50
—35.9	Aug. 10	—	86	0.18	0.10	12	—	25
—34.7	July 20	—	86	—	—	—	—	—
—21.5	Oct. 5	180	—	—	—	—	—	—
— 8.9	Aug. 9	—	120	—	—	—	—	—
— 8.9	Aug. 23	190	—	—	—	—	—	—
— 8.9	Aug. 25	170	103	0.15	0.10	10	7.0	10
— 8.9	Sept. 27	—	120	0.25	0.10	12	6.7	13
+ 1.8	Aug. 23	400	—	—	—	—	—	—
+ 1.8	Aug. 25	400	—	—	—	—	—	—
+ 1.8	Sept. 27	950	—	—	—	—	—	—
+ 4.8	Aug. 17	342	120	0.25	—	17	—	20
+ 5.9	Aug. 17	1750	—	—	—	—	—	—
+ 5.9	Aug. 19	2025	—	—	—	—	—	—
+ 9.3	Oct. 4	4500	137	—	—	—	—	—
+37.0	Aug. 25	1000	—	—	—	—	—	—
+49.7	Aug. 29	1050	137	0.17	0.17	10	7.0	15
+49.7	Aug. 30	1100	—	—	—	—	—	—
+52.1	Aug. 30	900	—	—	—	—	—	—
+79.8	Sept. 1	900	154	—	—	—	—	—
+80.4	Sept. 1	850	—	0.14	0.12	13	6.9	—
+98.3	Aug. 31	750	—	—	—	—	—	—
+113.2	Sept. 22	440	137	—	—	—	—	—
+133.8	July 6	—	111	—	—	—	—	—
+174.3	July 7	—	120	—	—	—	—	—
+273.7	Sept. 6	500	154	0.50	0.25	28	7.0	35

Table 4. Chemical characteristics, in parts per million, of water analyses from Green River tributary streams.

Green River Mile No. (at tributary mouth)	Date	Sp. cond. (micromhos)	Tot. alk.	Iron	Ortho-phosphate	Sulfate	D.O.	pH	Turbidity
Russell Creek—Mile 288.8									
0.0 (mouth)	Aug. 25	210	137	1.40	0.35	18	*	7.0	80
0.05 mi. from mouth	Aug. 9	—	154	1.50	0.30	25	*	*	90
0.1 " " "	Aug. 23	180	—	—	—	—	—	—	—
0.1 " " "	Sept. 27	240	—	—	—	—	—	—	—
Trace Creek—Mile 282.8									
0.5 mi. from mouth	Aug. 25	17,000	—	—	—	—	—	—	—
0.5 " " "	Sept. 27	25,000	—	—	—	—	—	—	—
Big Pitman Creek—Mile 277.4									
0.2 mi. from mouth	Aug. 17	10,000	86	0.20	—	48	*	*	20
0.3 " " "	Aug. 24	15,000	86	0.28	0.20	58	10.5	6.3	30
2.9 " " "	Aug. 24	15,000	120	0.28	0.16	69	*	6.1	30
2.9 " " "	Sept. 27	12,000	—	—	—	—	—	—	—
2.9 " " "	Sept. 28	12,000	171	0.25	0.25	70	10.0	7.1	20
10.5 " " "	Aug. 19	40,000+	—	—	—	—	—	—	—
10.5 " " "	Aug. 23	14,000	154	0.25	—	60	*	*	10
10.5 " " "	Aug. 25	—	137	0.25	0.25	43	6.8	7.0	15
10.5 " " "	Sept. 27	40,000+	—	—	—	—	—	—	—
Little Barren River—Mile 260.4									
6.2 mi. from mouth	Aug. 25	380	—	—	—	—	—	—	—
6.2 " " "	Aug. 27	750	—	—	—	—	—	—	—
Boiling Spring Branch—Mile 236.9									
0.6 mi. from mouth	Aug. 25	350	—	—	—	—	—	—	—
Nolin River—Mile 186.5									
0.8 mi. from mouth	Aug. 31	280	171	0.22	0.15	14	—	7.1	11

* Inaccurate detremination due to unknown causes.
+Beyond scale of solubridge.

Table 5. Average characteristics, in parts per million, of Green River water analyses made seasonally in 1961 (upper values), during 5 months of 1962 (middle values), and during 10 months of 1963 (lower values).

				Big Pitman Creek			a		b
Station	–77.3	–34.7	–8.9	(2.9)	+6.2	+9.3	+28.3	+49.7	+80.4
	15	10	20	5	10	5	25	19	28
Turbidity	29	35	45	12	27	29	10	23	42
	20	30	28	7	71	66	49	15	21
Total	109	96	86	144	123	137	110	137	144
alkalinity	100	81	92	153	121	110	151	141	134
	88	89	91	157	107	109	126	129	134
Specific	180	180	165	2988	1000	850	600	450	390
conductivity	160	148	148	1450	700	513	525	350	367
(micromhos)	166	159	199	2143	709	659	597	476	397
	13	15	14	21	23	25	16	13	18
Sulfate	36	37	30	45	38	43	49	35	42
	42	40	43	69	49	45	35	41	40
Dissolved	8.0	9.8	8.5	9.2	9.6	8.5	8.4	9.0	9.6
oxygen	6.2	7.2	6.8	9.1	6.3	6.9	6.8	7.3	7.2
	7.5	7.9	7.7	8.2	7.7	7.7	8.0	7.9	7.9
	6.5	6.6	6.7	5.7	5.7	7.0	6.3	6.8	6.9
pH	6.9	7.1	7.0	7.1	7.0	7.3	7.2	7.0	7.0
	6.8	6.8	6.9	7.2	7.2	7.2	7.2	7.1	7.2
Ortho-	1.0	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2
phosphate	2.5	1.3	2.0	1.9	1.5	1.5	1.0	1.0	0.6
	1.5	1.6	1.9	2.4	1.8	1.6	1.5	1.9	0.8
	0.19	0.20	0.24	0.10	0.22	0.15	0.22	0.25	0.20
Iron	0.32	0.30	0.41	0.18	0.30	0.28	0.25	0.32	0.30
	0.43	0.33	0.38	0.22	0.32	0.32	0.27	0.25	0.24
	0.05	tr.	0.24	0.59	0.10	0.00	0.29	0.25	0.25
Nitrate	0.18	0.33	0.48	1.45	0.49	0.71	1.28	1.48	1.24
	0.75	0.92	0.56	0.87	0.56	0.61	0.79	0.61	0.73
	0.00	0.00	tr.	0.01	—	—	—	—	tr.
Nitrite	tr.	0.01	tr.	0.00	tr.	tr.	0.03	tr.	tr.
	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.

a—upper (1961) values in this column obtained at Sta. +19.1
b—upper (1961) values in this column obtained at Sta. +174.1

centrated in the areas of heavy brine production in Green and Taylor Counties, but was noticeable as far downstream as Brownsville, about 100 miles below the area of greatest oil production. The two large springs in Mammoth Cave, known as Echo River and Styx River, also became contaminated.

According to Krieger and Hendrickson (1960), in the 1957 water year, more than 10,600 tons of chloride were discharged at Munfordville with about 1,822,800 acre-feet of water. In the 1958 water year, this increased to over 27,000 tons with 2,548,000 acre-feet of water. The discharge of chloride in the 1959 water year increased to over 305,000 tons, although water discharge was about half that of the 1958 water year. Thus, the daily chloride load of more than 830 tons per day exceeded the total monthly chloride load of 7 months in the 1957 water year.

The results of our own water quality determinations made during the 4-year study are summarized in Tables 3-5. These data are understandably much less extensive and precise than those collected by the USGS and cooperating agencies, since many of the determinations require elaborate equipment and laboratory conditions not normally found in the field. The values listed for each station in Table 5 were derived by averaging the monthly analyses.

Specific conductance values ranged between annual means of 148 and 199 micromhos per cubic centimeter in the unpolluted section of the Green River. Total alkalinity during the 4-year study showed an annual mean range of 86 to 109 ppm. The lowest pH value recorded was 6.1 and the highest was 7.7. Dissolved oxygen content was never critical in the unpolluted section. Values from the other determinations fell within the expected range (Tables 3 and 5).

A considerable difference was noted in the water quality of Big Pitman Creek between 1960 and 1963 (Table 4). During the first year the specific conductance ranged from never lower than 10,000 micromhos to over 40,000 micromhos (beyond the scale of our solubridge). The average conductivity was in the range of 12,000 to 15,000 micromhos. During 1961 specific conductance dropped in Big Pitman to between 2775 and 3200 micromhos. (Krieger in a personal communication, however, reported a value of 9600 micromhos for October 3, 1961 when he visited Big Pitman Creek. He also recorded that day 3130 ppm chloride; 0.14 ppm iron; 7.0 pH; 10.8 D. O.; 95 ppm sulfate; 5580 ppm dissolved solids; and 164 ppm bicarbonate.) During 1962 specific conductance ranged from 950 to 1850 micromhos. The annual mean value was 1450 micromhos, a definite improvement over the preceding year, and a drastic improvement over the first year. During the final year of the study, specific conductance averaged 2143 micromhos, reflecting not an actual increase in the amount of brine reaching this tributary, but the lack of dilution water caused by below-normal rainfall. Interfering substances in Big Pitman Creek made water analysis difficult and results were often questionable.

The section of Green River subject to brine pollution showed slight improvement in 1961, compared to 1960, as shown by our water quality analyses (Tables 3 and 5). Specific conductance values in 1960 showed an irregular decline, as dilution began taking effect, from a maximum of 4500 micromhos at Station +9.3, to a minimum of 440 micromhos registered at Station +113.2. The highest conductance value recorded in 1961 was 2240 micromhos at Station +9.3; the lowest found was 333 micromhos at Station +219.7. Krieger (personal communication of March 30, 1962) stated U. S. Geological Survey records showed continued improvement in Green River, although the rate of improvement was less rapid than between October, 1960 and April, 1961. Further improvement was noted at the five stations below the mouth of Trace Creek during 1962. The highest annual mean was 700 micromhos at Station +6.2 and the lowest mean was 350 at Station +49.7. Unaccountably, the lowermost station (+80.4) had an annual mean of 367 micromhos that year. Specific conductance averaged slightly higher the last year of the study because of deficient rainfall and consequent lack of dilution water. The other water quality characteristics of this section over the 4-year study period are shown in Tables 3 and 5.

EFFECTS OF BRINE ON FISH FAUNA

Population sampling showed that the Green River supported an extremely rich and varied fish fauna, especially in those sections not contaminated by oilfield pollution. The check-list of fishes known to occur in Kentucky comprises 26 families, 67 genera, and 177 species. The list of fishes identified from the 1960-1963 Green River population studies included 18 families, 42 genera, and 107 species. Additional species, although not represented in our collections, are known to occur. Table 6 lists all the species collected from the Green River and shows their occurrence either above, within, or below (navigation lock chambers) the polluted section.

Unpolluted Section Fish Fauna

Fifty-two species of fishes, listed below, were identified from the 1960 population studies conducted in the upstream, unpolluted section of the Green River (Fig. 5). The 27 starred (*) species occurred exclusively in the unpolluted section and were not found in the polluted section samples (the lock chamber studies will be compared separately, as will be the Big Pitman Creek studies, since the former sampled completely different type of fish habitat).

*Least brook lamprey
Longnose gar
*Gizzard shad
*Grass pickerel
Stoneroller
*Goldfish
*Carp
Bigeye chub
*Hornyhead chub
Streamline chub
*Popeye shiner
Emerald shiner
Common shiner
Spotfin shiner
Mimic shiner
Stargazing minnow
Bluntnose minnow
Northern hog sucker
Spotted sucker
Shorthead redhose
Black redhorse
Golden redhorse
*Black bullhead
*Yellow bullhead
Channel catfish
*Carolina madtom
*Brindled madtom
*Freckled madtom
*Green River madtom
Flathead catfish
*Northern studfish
Rock bass
Green sunfish
Bluegill
Longear sunfish
*Hybrid sunfish
*Smallmouth bass
Spotted bass
*Largemouth bass
*White crappie
Greenside darter
Rainbow darter
*Bluebreast darter
*Fantail darter
*Stripetail darter
*Speckled darter
Logperch
*Bluestripe darter
*Longhead darter
*Slenderhead darter
*Dusky darter
*Banded sculpin

The 1960 population composition and standing crop values were determined by sampling 4.91 acres (3 different areas: Stations –95.7, –90.2, and –21.5). The standing crop averaged 420 fish and 156 pounds, per surface acre, with an A_t value of 73. These data are summarized in Appendix Table 1, which also shows that all groups in both the Piscivorous and Non-Piscivorous categories were represented by all size-classes, except no fingerling predatory fishes were recovered (Appendix Fig. 1).

Again in 1961, 52 species were identified from the unpolluted section samples (Fig. 5). However, 14 of this number, listed below, were not represented in the previous year's collection from this section

River chub	River redhorse	Blackside darter
Rosyface shiner	Slender madtom	Sauger
Steelcolor shiner	Warmouth	Walleye
Bullhead minnow	Redear sunfish	Brook silverside
Creek chub	Black crappie	

The following 24 species were found only in this section that year:

Gizzard shad	River redhorse	Hybrid sunfish
Grass pickerel	Black bullhead	Smallmouth bass
Bigeye chub	Yellow bullhead	Largemouth bass
River chub	Slender madtom	White crappie
Popeye shiner	Brindled madtom	Back crappie
Steelcolor shiner	Green River madtom	Dusky darter
Bullhead minnow	Warmouth	Walleye
Creek chub	Redear sunfish	Brook silverside

Table 6. List of fishes collected from Green River, 1960 - 1963. This list comprises 18 families, 42 genera, and 107 species.* Symbols denote occurrence above (—) polluted section; in (+) polluted section; and below (0) pollution in the navigation lock chambers.

PETROMYZONTIDAE

		0	*Ichthyomyzon unicuspis* Hubbs and Trautman	Silver lamprey
—			*Lampetra aepyptera* (Abbott)	Least brook lamprey

POLYODONTIDAE

		0	*Polyodon spathula* (Walbaum)	Paddlefish
		0	*Lepisosteus oculatus* (Winchess)	Spotted gar
—	+	0	*Lepisosteus osseus* (Linnaeus)	Longnose gar
		0	*Lepisosteus platostomus* Rafinesque	Shornose gar

AMIIDAE

		0	*Amia calva* Linnaeus	Bowfin

CLUPEIDAE

		0	*Alosa chrysochloris* (Rafinesque)	Skipjack herring
—	+	0	*Dorosoma cepedianum* (LeSueur)	Gizzard shad
		0	*Dorosoma petenense* (Gunther)	Threadfin shad

HIODONTIDAE

		0	*Hiodon alosoides* (Rafinesque)	Goldeye
	+	0	*Hiodon tergisus* LeSueur	Mooneye

ESOCIDAE

—		0	*Esox americanus vermiculatus* LeSueur	Grass pickerel
	+		*Esox masquinongy chioensis* Kirtland	Ohio muskellunge

CYPRINIDAE

—	+	0	*Campostoma anomalum* (Rafinesque)	Stoneroller
—			*Carassius auratus* (Linnaeus)	Goldfish
—	+	0	*Cyprinus carpio* Linnaeus	Carp

		0	*Hybognathus nuchalis* Agassiz	Silvery minnow
	+	0	*Hybopsis aestivalus Girard*	Speckled chub
—	+		*Hybopsis amblops Rafinesque*	Bigeye **chub**
	—	0	*Hybopsis biguttata* (Kirtland)	Streamline chub
—	+		*Hybopsis dissimilis* (Kirtland)	Hornyhead chub
—			*Hybopsis micropogon* (Cope)	River chub
	+	0	*Hybopsis storeriana* (Kirtland)	Silver chub
		0	*Notemigonus crysoleucas* (Mitchill)	Golden shiner
—			*Notropis ardens* (Cope)	Rosefin shiner
—	+		*Notropis ariommus* (Cope)	Popeye shiner
—	+	0	*Notropis atherinoides* Rafinesque	**Emerald shiner**
—			*Notropis boops Gilbert*	Bigeye shiner
	+	0	*Notropis buchanani Meek*	Ghost shiner
—	+	0	*Notropis cornutus* (Mitchill)	Common **shiner**
—			*Notropis leuciodus* (Cope)	Tennessee shiner
—	+		*Notropis photogenis* (Cope)	Silver shiner

CYPRINIDAE (continued)

—	+	0	*Notropis rubellus* (Agassiz)	Rosyface shiner
—	+	0	*Notropis spilopterus* (Cope)	Spotfin **shiner**
—	+	0	*Notropis volucellus* (Cope)	Mimic **shiner**
—		0	*Notropis whipplei* (Girard)	Steelcolor shiner
—		0	*Opsopoeodus emiliae* Hay	Pugnose minnow
—	+		*Phenacobius uranops* Cope	Stragazing minnow
—	+	0	*Pimephales notatus* (Rafinesque)	Bluntnose **minnow**
	+		*Pimephales promelas* Rafinesque	Fathead minnow
—	+	0	*Pimephales vigilax* (Baird and Girard)	Bullhead minnow
—			*Semotilus atromaculatus* (Mitchill)	Creek **chub**

CATOSTOMIDAE

		0	*Carpiodes carpio* (Rafinesque)	River carpsucker
		0	*Carpiodes cyprinus* (LeSueur)	Quill**back**
		0	*Carpiodes velifer* (Rafinesque)	Highfin carpsucker
—			*Catostomus commersoni* (Lacepede)	White sucker
—	+		*Hypentelium nigricans* (LeSueur)	Northern hog sucker
		0	*Ictiobus bubalus* (Rafinesque)	Smallmouth buffalo
		0	*Iciobus cyprinellus* (Valenciennes)	Bigmouth buffalo
		0	*Ictiobus niger* (Rafinesque)	Black buffalo
—	+	0	*Minytrema melanops* (Rafinesque)	Spotted sucker
—	+	0	*Moxostoma anisurum* (Rafinesque)	Silver redhorse
—	+	0	*Moxostoma breviceps* (Cope)	Shorthead redhorse
—	+	0	*Moxostoma carinatum* (Cope)	River redhorse
—	+		*Moxostoma duquesnei* (LeSueur)	Black redhorse
—	+	0	*Moxostoma erythrurum* (Rafinesque)	Golden redhorse

ICTALURIDAE

		0	*Ictalurus furcatus* (LeSueur)	Blue catfish
—		0	*Ictalurus melas* (Rafinesque)	Black bullhead
—		0	*Ictalurus natalis* (LeSueur)	Yellow bullhead
—	+	0	*Ictalurus punctatus* (Rafinesque)	Channel catfish
—			*Noturus eleutherus* Jordan	Mountain madtom
—			*Noturus exilis* Nelson	Slender madtom
—			*Noturus furiosus* Jordan and Meek	Carolina madtom
—		0	*Noturus miurus* Jordan	Brindled madtom
—		0	*Noturus nocturnus* Jordan and Gilbert	Freckled madtom
—	+		*Noturus* species	(Green River system)
—	+	0	*Pylodictis olivaris* (Rafinesque)	Flathead catfish

* Nomenclature throughout this paper complies with recommendations of the Committee on Names of Fishes, American Fisheries Society.

ANGUILLIDAE				
		0	*Anguilla rostrata* (LeSueur)	American eel
CYPRINODONTIDAE				
—			*Fundulus catenatus* (Storer)	Northern studfish
—	+		*Fundulus notatus* (Rafinesque)	Blackstripe topminnow
SERRANIDAE				
		0	*Roccus chrysops* (Rafinesque)	White bass
CENTRARCHIDAE				
—	+	0	*Ambloplites rupestris* (Rafinesque)	Rock bass
—		0	*Chaenobryttus gulosus* (Cuvier)	Warmouth
—	+	0	*Lepomis cyanellus* Rafinesque	Green sunfish
CENTRARCHIDAE (continued)				
		0	*Lepomis humilis* (Girard)	Orangespotted sunfish
—	+	0	*Lepomis macrochirus* Rafinesque	Bluegill
—	+	0	*Lepomis megalotis* (Rafinesque)	Longear sunfish
—		0	*Lepomis microlophus* (Gunther)	Redear sunfish
—		0	*Lepomis* sp. x sp.	Hybrid sunfish
—	+		*Micropterus dolomieui* Lacepede	Smallmouth bass
—	+	0	*Micropterus punctulatus* (Rafinesque)	Spotted bass
—	+	0	*Micropterus salmoides* (Lacepede)	Largemouth bass
—	+	0	*Pomoxis annularis* Rafinesque	White crappie
—		0	*Pomoxis nigromaculatus* (LeSueur)	Black crappie
PERCIDAE				
—	+	0	*Etheostoma blennioides* Rafinesque	Greenside darter
—	+		*Etheostoma caeruleum* Storer	Rainbow darter
—	+		*Etheostoma camurum* (Cope)	Bluebreast darter
—			*Etheostoma flabellare* Rafinesque	Fantail darter
—	+		*Etheostoma kennicotti* (Putnam)	Stripetail darter
	+		*Etheostoma maculatum* Kirtland	Spotted darter
—			*Etheostoma nigrum* Rafinesque	Johnny darter
—			*Etheostoma obeyense* Kirsch	Barcheek darter
—	+		*Etheostoma stigmaeum* (Jordan)	Speckled darter
—	+		*Etheostoma zonale* (Cope)	Banded darter
—	+	0	*Percina caprodes* (Rafinesque)	Logperch
	+		*Percina copelandi* (Jordan)	Channel darter
—	+		*Percina cymatotaenia* (Gilbert and Meek)	Bluestripe darter
—	+		*Percina macrocephala* (Cope)	Longhead darter
—	+	0	*Percina maculata* (Girard)	Blackside darter
—	+		*Percina phoxocephala* (Nelson)	Slenderhead darter
—	+	0	*Percina sciera* (Swain)	Dusky darter
—	+	0	*Stizostedion canadense* (Smith)	Sauger
—	+	0	*Stizostedion vitreum vitreum* (Mitchill)	Walleye
SCIAENIDAE				
	+	0	*Aplodinotus grunniens* Rafinesque	Freshwater drum
COTTIDAE				
—	+		*Cottus carolinae* (Gill)	Banded sculpin
ATHERINIDAE				
—		0	*Labidesthes sicculus* (Cope)	Brook silverside

The 1961 productivity values for the unpolluted section were derived from sampling 4.00 acres (Station —90.2 and —34.7). The standing crop averaged 528 fish and 94 pounds, per acre, with an A_t value of 78 (Appendix Table 2). For the second year, all groups were represented by all size-classes, except no fingering predatory fishes were recovered.

The number of species collected from the unpolluted section during 1962 rose to 64 (Fig. 5). Twelve of this number, listed below, were taken for the first time.

Rosefin shiner	Pugnose minnow	Blackstripe topminnow
Bigeye shiner	White sucker	Johnny darter
Tennessee shiner	Silver redhorse	Barcheek darter
Silver shiner	Mountain madtom	Banded darter

The following 30 species occurred exclusively in this section of the river:

Grass pickerel	River redhorse	Hybrid sunfish
Goldfish	Black bullhead	Largemouth bass
Silver chub	Yellow bullhead	Rainbow darter
Rosefin shiner	Mountain madtom	Bluebreast darter
Bigeye shiner	Slender madtom	Fantail darter
Tennessee shiner	Brindled madtom	Stripetail darter
Steelcolor shiner	Green River madtom	Johnny darter
Pugnose minnow	Northern studfish	Barcheek darter
Creek chub	Blackstripe topminnow	Bluestripe darter
White sucker	Redear sunfish	Brook silverside

The 1962 productivity values for the unpolluted section were derived from sampling 4.75 acres (Stations –90.2, –82.7, and –34.7). The standing crop averaged 932 fish and 85 pounds, per acre, with an A values of 65 (Appendix Table 3). For the third year, all groups in both major fish categories were represented by all size-classes, except fingerling predatory fishes were absent.

Only 42 species were taken from the 1963 unpolluted section samples (Fig. 5). All of the 42 had been collected from this section in other years. The 13 species listed below did, however, occur exclusively in the unpolluted section.

Least brook lamprey	Black bullhead	Fantail darter
Gizzard shad	Yellow bullhead	Stripetail darter
Grass pickerel	Brindled madtom	Bluestripe darter
Goldfish	Warmouth	
White sucker	Hybrid sunfish	

The 1963 population composition and standing crop values were determined by sampling 4.30 acres (Stations –95.7 and –90.2). The standing crop averaged 630 fish and 105 pounds, per acre, with an A_t value of 70 (Appendix Table 4). The fingerling size-class of two groups—food fishes and predatory fishes—were not recovered the fourth and final year of the project.

Polluted Section Fish Fauna

The 35 species listed below were taken from the 1960 population studies conducted in the polluted section of the Green River (Fig. 5). The 10 starred species occurred exclusively in the polluted section and were not found in the clean-water samples that year.

Longnose gar
Stoneroller
Bigeye chub
Streamline chub
*Silver chub
Emerald shiner
Common shiner
*Silver shiner
*Rosyface shiner
Spotfin shiner
Mimic shiner
Stargazing minnow
Bluntnose minnow
*Bullhead minnow
Northern hog sucker
Spotted sucker
*Silver redhorse
Shorthead redhorse
Black redhorse
Golden redhorse
Channel catfish
Flathead catfish
*Blackstripe topminnow
Rock bass
Green sunfish
Bluegill
Longear sunfish
Spotted bass
Greenside darter
Rainbow darter
*Banded darter
Logperch
*Channel darter
*Sauger
*Freshwater drum

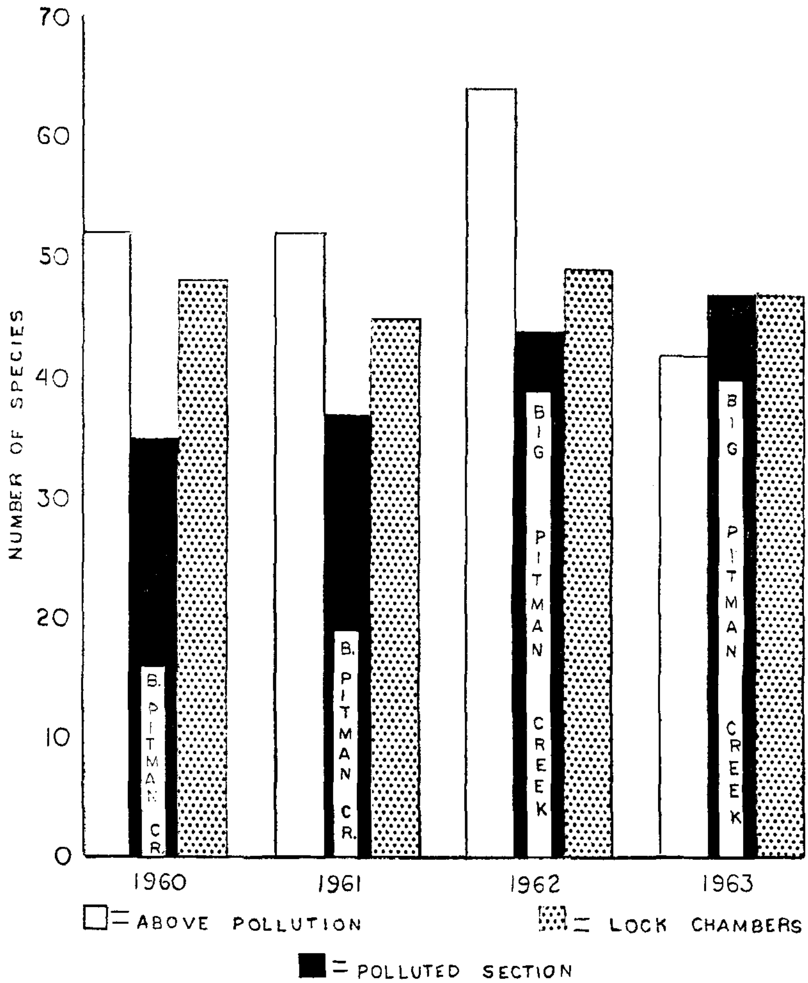


Fig. 5. The number of species of fishes collected from polluted and non-polluted sections of Green River and from Big Pitman Creek during the years 1960 - 1963. The lock chamber samples were located far enough downstream in the recovery zone to support a normal fish population.

The 1960 productivity values were derived from sampling 6.35 acres (Stations +4.8 and +9.3). The standing crop averaged only 85 fish and 10 pounds, per acre, with an A_t value of 66. These data are summarized in Appendix Table 5, which also shows that several size-classes and groups of both major fish categories were either absent or poorly represented. Fin damage (described in the Big Pitman Creek sub-section) was observed on many of the species recovered from this section.

Thirty-seven species were identified from the polluted section sample taken in 1961 (Fig. 5). Eight of this number, listed below, were not found here the previous year.

Stripetail darter	Bluestripe darter	Slenderhead darter
Spotted darter	Longhead darter	Banded sculpin
Speckled darter	Blackside darter	

The following nine species occurred exclusively in the polluted section:

Stoneroller	Stargazing minnow	Speckled darter
Silver chub	Rainbow darter	Banded darter
Silver shiner	Spotted darter	Banded sculpin

The 1961 productivity values were derived from sampling 4.59 acres (one area). This area was one of the two sampled in 1960 and was located 9.3 miles downstream from the mouth of Trace Creek and 3.9 miles below the mouth of Big Pitman Creek. (Another study was attempted in this polluted section, using sodium cyanide as the toxicant, but the results were considered unreliable and the resulting data were used qualitatively only.) The standing crop of 300 fish and 12 pounds, per acre, with an A_t value of 52, showed some improvement numerically, but little change in the total weight being supported. Practically the same size-classes in the same groups were again absent (Appendix Table 6). Fin damage was noticeably reduced, both in numbers of fish affected and severity of affliction.

The number of species collected from the polluted section during 1962 increased to 44 (Fig. 5). Eight of this number, listed below, were taken for the first time.

Gizzard shad	Popeye shiner	White crappie
Mooneye	Ghost shiner	Dusky darter
Carp	Smallmouth bass	

The following 10 species occurred exclusive in the polluted section during 1962:

Mooneye	Ghost shiner	Sauger
Carp	Bullhead minnow	Freshwater drum
Silver chub	Slenderhead darter	
Emerald shiner	Dusky darter	

Two population studies were attempted in 1962 in the polluted section of the Green River during the time scheduled for sampling this section. Both were quantitative failures, the first because of a rising river stage and the second because of low water temperature (58°-59°F.). High and turbid river stages prevailed during the remainder of the time allotted for sampling this section. Fin damage was restricted to a few of the larger (older age-classes) species.

Forty-seven species were identified from the 1963 samples taken in the polluted section (Fig. 5). Eight of this number, listed below, were collected from this section for the first time.

Ohio muskellunge	River redhorse	Bluebreast darter
Speckled chub	Green River madtom	Walleye
Fathead minnow	Largemouth bass	

The following 18 species occurred exclusively in the polluted section during the final year of the project:

Mooneye	Rosyface shiner	Bluebreast darter
Ohio muskellunge	Stargazing minnow	Longhead darter
Speckled chub	Fathead minnow	Slenderhead darter
Streamline chub	Bullhead minnow	Dusky darter
Silver chub	River redhorse	Walleye
Popeye shiner	Green River madtom	Freshwater drum

The 1963 productivity values were derived from sampling 6.45 acres (Stations +7.1, +8.6, and +9.3). The standing crop averaged 229 fish and 47 pounds, per acre, with an A_t value of 77 (appendix table predatory fishes and "harvestable" (above forage size)) forage fishes were absent. Fin damage was not observed.

Big Pitman Creek Fish Fauna

Big Pitman Creek supported a standing crop in 1960 of only 22 fish per acre and 3.5 pounds per acre, with an A_t value of 84 (Appendix Table 8). Two areas (at Mile 0.0 and Mile 2.9) totaling 2.25 acres were sampled. Several size-classes of various groups were either absent or poorly represented. No predatory fishes of any size-class were found in the samples. Only 9 of the 49 fish taken were of harvestable size; 4 were of intermediate size; and the remaining 36 fell into the fingerling size-class. Sixteen species, representing 9 genera from 4 families, were recovered from the population studies (Fig. 5; Table 7).

Extensive fin damage was noted on several species from both Big Pitman Creek studies in 1960. The first study encompassed 1.00 acre just inside the mouth of the creek. Two fingerling yellow bullhead were observed that had badly eroded fins; in fact, the caudal fin on each was absent. The single black redhorse (11″) had eroded margins on its ventral fins. The fins on the other 19 fish from this study were unaffected and the fish appeared healthy in every respect. It is likely that some of the unaffected specimens were a transient segment of the population, having emigrated from the Green River. The second study encompassed 1.25 acre 2.9 miles above the mouth. The single carp taken (2.5″) had only a stump for a caudal fin. The other 26 fish from this study showed no fin damage at all .

The fish population in Big Pitman Creek, determined by sampling 1.00 acre (at Mile 2.9), showed some improvement in 1961. A standing crop of 820 fish and 3.6 pounds, per acre, was found (Appendix Table 9). No harvestable-size fishes were taken from the single study. Neither were any predatory fishes of any size taken. Ninety-six per cent of all fish recovered belonged to the forage fish group. This group accounted for 87 per cent of the total weight. Nineteen species, representing 11 genera from 6 families, were identified (Fig. 5; Table 7). Ten of the 19 species did not occur in this stream the previous year and are listed below.

Bigeye chub	Creek chub	Greenside darter
Streamline chub	Northern hog sucker	Banded sculpin
Spotfin shiner	Black bullhead	
Mimic shiner	Longear sunfish	

The drastic change in number of fish per acre from 22 in 1960 to 820 in 1961 is attributed to a corresponding change in brine content.

Table 7. List of fishes collected from Big Pitman Creek, 1960 - 1963. This list comprises 7 families, 21 genera, and 48 species. An x denotes occurrence that year.

1960	1961	1962	1963	
				LEPISOSTEIDAE
		x		*Lepisosteus osseus*
				CYPRINIDAE
x	x	x	x	*Campostoma anomalum*
x		x	x	*Cyprinus carpio*
	x	x	x	*Hybopsis amblops*
	x	x	x	*Hybopsis dissimilis*
			x	*Notropis ardens*
			x	*Notropis atherinoides*
x				*Notropis blennius* (Girard)*
x	x	x	x	*Notropis cornutus*
x		x	x	*Notropis photogenis*
x	x	x		*Notropis rubellus*
	x	x	x	*Notropis spilopterus*
	x	x	x	*Notropis volucellus*
x	x			*Notropis whipplei*
		x	x	*Phenacobius uranops*
x	x	x	x	*Pimephales notatus*
x				*Pimephales vigilax*
	x	x	x	*Semotilus atromaculatus*
				CATOSTOMIDAE
		x	x	*Catostomus commersoni*
	x	x	x	*Hypentelium nigricans*
		x	x	*Minytrema melanops*
		x	x	*Moxostoma anisurum*
		x	x	*Moxostoma breviceps*
			x	*Moxostoma carinatum*
x			x	*Moxostoma duquesnei*
			x	*Moxostoma erythrurum*

1960	1961	1962	1963	
				ICTALURIDAE
	x	x	x	*Ictalurus melas*
x		x	x	*Ictalurus natalis*
x	x	x	x	*Ictalurus punctatus*
		x		*Noturus* species
x		x	x	*Pylodictis olivaris*
				CENTRARCHIDAE
		x	x	*Ambloplites rupestris*
		x	x	*Lepomis cyanellus*
x	x	x	x	*Lepomis macrochirus*
	x	x	x	*Lepomis megalotis*
x	x	x	x	*Micropterus dolomieui*
x	x	x	x	*Micropteruc punctulatus*
		x	x	*Micropterus salmoides*
				PERCIDAE
	x	x	x	*Etheostoma blennioides*
		x	x	*Etheostoma caeruleum*
		x		*Etheostoma maculatum*
		x	x	*Etheostoma stigmaeum*
		x	x	*Etheostoma zonale*
		x	x	*Percina caprodes*
		x		*Percina cymatotaenia*
			x	*Percina macrocephala*
		x	x	*Percina maculata*
				COTTIDAE
	x	x	x	*Cottus carolinae*

* River shiner. This is the only species not represented in the Green River collections.

Specific conductance values in Big Pitman Creek ranged from never lower than 10,000 micromhos to over 40,000 during 1960. During 1961 the range was between 2775 and 3200 micromhos. Fin damage was much reduced over that observed the first year.

Big Pitman Creek supported a standing crop in 1962 of 1105 fish and 13 pounds, per acre, with an A_t value of 36 (Appendix Table 10). Two areas (Mile 0.0 and Mile 2.9), totaling 2.25 acres, were sampled. Thirty-nine species, representing 21 genera from 7 families, were recovered—a definite improvement in the population structure (Fig. 5; Table 7). The 17 species listed below were taken for the first time.

Longnose gar	Green River madtom	Speckled darter
Stargazing minnow	Rock bass	Banded darter
White sucker	Green sunfish	Logperch
Spotted sucker	Largemouth bass	Bluestripe darter
Silver redhorse	Rainbow darter	Blackside darter
Shorthead redhorse	Spotted darter	

Several size-classes of various groups were either absent or poorly represented in the 1962 population. Nearly 15 per cent of the total weight recovered was comprised of piscivorous species. Game fishes made up 12 of that 15 per cent. Extensive fin damage was again noted on several species of fish. Most of the fin erosion was restricted to the caudal fin. Some specimens of fingerling channel catfish had only stumps for caudal fins. Redhorse species were also observed with affected caudal fins. However, fin damage was observed to gradually diminish, both in kinds and numbers of fishes involved and severity of affliction, as the pollution diminished.

All aspects of the fish population in Big Pitman Creek showed decided improvement during 1963, the final year of study. The same two areas were again sampled with resulting standing crop values of 1034 fish and 46 pounds, per acre (Appendix Table 11). An A value of 22 was derived. Some size-classes were still either absent or weakly represented; but, compared to the 1960 population, Big Pitman Creek was well on the way to complete recovery. Forty species were recorded from the stream, 5 species, listed below, for the first time (Fig. 5; Table 7). Nineteen genera from six families were represented.

Rosefin shiner	Golden redhorse
Emerald shiner	Longhead darter
River redhorse	

No noticeable fin damage was observed while processing the fish from the 1963 studies in Big Pitman Creek.

Lock Chamber Fish Fauna

Seven population studies were conducted in the lower four navigation lock chambers of the Green River during 1960 (Lock No. 4 is 133.8 miles downstream from the mouth of Trace Creek, Lock No. 3 is 174.3 miles downstream, Lock No. 2 is 219.7 miles downstream, and Lock No. 1 is 273.7 miles downstream). The lower 150 miles of the Green River in which these lock chambers are located apparently supported a normal fish population. The combined acreage of the seven lock studies was 4.26 acres. The standing crop averaged 748 fish and 274 pounds, per acre, with an A_t value of 88 (Appendix Table 12). Only fingerling predatory fishes were absent from the lock chambers. The 48 species listed below were recorded from the 1960 lock chamber studies (Fig. 5). The 22 starred species were unique to this section of the river that year.

*Silver lamprey	*Pugnose minnow	*White bass
Longnose gar	Bluntnose minnow	*Warmouth
*Bowfin	Bullhead minnow	Green sunfish
*Skipjack herring	*River carpsucker	*Orangespotted sunfish
Gizzard shad	*Quillback	Bluegill
*Threadfin shad	*Highfin carpsucker	Longear sunfish
*Goldeye	*Smallmouth buffalo	*Redear sunfish
*Mooneye	*Bigmouth buffalo	Spotted bass
Grass pickerel	Spotted sucker	Largemouth bass
Carp	*Blue catfish	White crappie
Silver chub	Black bullhead	*Black crappie
*Golden shiner	Yellow bullhead	Greenside darter
Emerald shiner	Channel catfish	Dusky darter
*Ghost shiner	Brindled madtom	Sauger
Spotfin shiner	Freckled madtom	Freshwater drum
*Steelcolor shiner	Flathead catfish	*Brook silverside

Eight population studies were conducted in the same four lock chambers (each was sampled twice) during 1961. The combined acreage of the 8 studies was 5.52 acres. The average standing crop was 3089 fish and 519 pounds, per acre, with an A_t value of 75 (Apuendix Table 13). All size-classes of all groups were represented.

Forty-five species were identified from the lock studies of 1961 (Fig. 5). The seven species listed below were not recovered from here the previous year.

Paddlefish	Silver redhorse	Walleye
Shortnose gar	Shorthead redhorse	
Black buffalo	Logperch	

The following 20 species were unique to the 1961 lock studies.

Paddlefish	Carp	Black buffalo
Shortnose gar	Golden shiner	Silver redhorse
Bowfin	Ghost shiner	Blue catfish
Skipjack herring	River carpsucker	White bass
Threadfin shad	Quillback	Orangespotted sunfish
Goldeye	Smallmouth buffalo	Freshwater drum
Mooneye	Bigmouth buffalo	

Six population studies were conducted in the lower four lock chambers (Locks 3 and 4 were sampled twice) during 1962. The combined acreage was 3.02 acres. The average standing crop was 1142 fish and 405 pounds, per acre, with an A_t value of 93 (Appendix Table 14). Fingerling-size predatory fishes were not represented this year.

Forty-nine species were identified from the 1962 lock chamber samples (Fig. 5). The 10 species listed below were not recovered from here in previous years.

Spotted gar	Common shiner	Hybrid sunfish
Stoneroller	Rosyface shiner	Blackside darter
Silvery minnow	Mimic shiner	
Speckled chub	American eel	

The following 14 species were unique to the lock chambers in 1962:

Spotted gar	Smallmouth buffalo	Warmouth
Skipjack herring	Blue catfish	Orangespotted sunfish
Silvery minnow	Freckled madtom	Black crappie
Speckled chub	American eel	Walleye
River carpsucker	White bass	

Eight population studies were conducted in the lower four lock chambers (each was sampled twice) during 1963. The average standing crop from the 5.52 acres sampled was 1083 fish and 379 pounds, per acre, with an A_t value of 87 (Appenwix Table 15). All size-classes of all groups were represented, except fingerling predatory fishes.

Forty-seven species were identified from the final-year lock chamber studies (Fig. 5). Only three new species were recorded for the first time: river redhorse, golden redhorse, and rock bass.

The following 18 species were unique to the lock chambers in 1963:

Shortnose gar	Quillback	American eel
Skipjack herring	Smallmouth buffalo	White bass
Threadfin shad	Bigmouth buffalo	Orangespotted sunfish
Ghost shiner	Black buffalo	Redear sunfish
Steelcolor shiner	Blue catfish	Black crappie
River carpsucker	Freckled madtom	Sauger

EFFECTS OF BRINE ON BOTTOM FAUNA

Bottom fauna sampling showed that the Green River supported a rich and varied macro-invertebrate population, especially in the section unaffected by brine pollution. Twenty-one major taxonomic categories of bottom-dwelling organisms were identified from the stations located in the clean-water section during the 4-year study. This diversity of macro-invertebrate forms was not found in the polluted section. However, as the brine pollution subsided, after 1960 and 1961, the variety of organisms in this section approached that found at the upstream stations. The bottom fauna of Big Pitman Creek was even more adversely affected, since brine contamination was greatest in this tributary, but gradual improvement was noted as the brine load diminished. Annual relative abundance of the major taxonomic groups of macro-invertebrates at the various sampling stations is shown in Appendix Tables 16-22.

Unpolluted Section Bottom Fauna

A summary of the mean numbers and mean volumes of bottom organisms collected during 1960-1963 from the Green River stations located upstream from brine pollution is presented in Table 8. However, at this point, an explanation regarding the analysis and evaluation of the bottom sample data is in order. Early in the field work while collecting and sorting the bottom samples from the Green River, and later in the laboratory while counting and weighing the organisms, it became apparent that comparison of *total* productivity between the unpolluted and polluted sections of the river would be misleading, although basically correct. This situation stemmed from the fact that both gastropods (snails) and pelecypods (mussels) in the unpolluted section, and gastropods in the polluted section, occurred in such abundance that their numbers and bulk obscured the effect that brine pollution was exerting on the other macro-invertebrates. Excepting larger decapods (crayfish), practically all of the other macro-invertebrates were equally available at any stage in their life cycle as forage for most all size-classes of fishes. This certainly was not true of the snails and mussels, since many were too large for ingestion by even harvestable-size fishes; and to what extent the various fish species utilize smaller snails and mussels is not well known. Drum, which are known to utilize them, were not found in appreciable numbers in the section of the river where the snails and mussels were most abundant. To illustrate the disparity between total productivity (all organisms included) and modified productivity (snails and mussels excluded), the mean total productivity of the unpolluted section in 1960 was 109 organisms and 5.18 cc, per square foot.

Table 8. Mean number and volume of macro-invertebrates* collected at sampling stations in Green River located upstream from oilfield brine pollution, 1960 - 1963.

Year	Number of Stations	Sq. Ft. Sampled	Number of Organisms	Volume (cc)	Mean Number per sq. ft.	Mean Volume per sq. ft.
1960	7	25	2198	67.30	87.6	2.68
1961	8	27	2502	56.45	91.4	2.06
1962	3	45	3041	73.68	67.6	1.64
1963	3	81	8263	120.25	102.0	1.48
Totals		178	16,004	317.68		
Mean (all years combined)					89.7	1.78

* Gastropoda (snails) and Pelecypoda (mussels) deleted.

Table 9. Mean number and volume of marco-invertebrates* collected at the sampling station on Big Pitman Creek (primary source of brine pollution) 1960 - 1963.

Year	Sq Ft. Sampled	Number of Organisms	Volume (cc)	Mean Number Per Sq.Ft.	Mean Volume Per Sq.Ft.
1960	9	558	1.20	62.0	0.13
1961	3	435	0.84	145.0	0.28
1962	15	1686	4.17	112.4	0.28
1963	27	8356	12.37	309.5	0.46
Totals	54	11,035	18.58		
Mean (all years combined)				210.2	0.34

* Gastropola and Pelecypoda deleted.

Excluding the snails and mussels, these mean values were revised downward to 88 organisms and 2.68 cc. In the polluted section that same year, the mean total productivity was 321 organisms and 12.30 cc, per square foot. Excluding snails and mussels, the modified productivity values became 120 organisms and 0.76 cc. These illustrations not only show the extreme abundance of brine-tolerant gastropods in the polluted section, but they also show the distortion that would result if total productivity was the sole criterion used to evaluate the effects of brine pollution on bottom organisms. Unless specifically stated otherwise, modified productivity values have been used throughout this report, both in the text and in the figures. Also, all productivity values were computed and are reported on a per square foot basis.

Productivity in the clean-water section fluctuated from a low annual mean of 56 organisms in 1961 to a high mean of 120 organisms in 1963 (mean annual production at all the sampling sattions is graphically compared in Appendix Figs. 2-5). The lowest mean volume was 1.48 cc in 1963 and the highest was 2.68 cc in 1960. The overall 4-year mean for this section was 90 organisms and 1.78 cc.

Practically every year, the same nine taxonomic groups of macro-invertebrates dominated the benthos in the unpolluted section. Those 9, listed below, accounted for never less than 97.8 per cent of both the total number and total volume of the combined samples.

Oligochaeta	Megaloptera (Corydalidae)	Coleoptera
Gastropoda	Plecoptera	Diptera
Pelecypoda	Trichoptera	
Ephemeroptera		

Individually, the other 12 taxonomic groups seldom comprised as much as 1.0 per cent of either the total number or volume. Mayfly nymphs predominated over all the other groups each year; 30 to 40 per cent of all macro-invertebrates belonged to this single order. Snails were the second most abundant group each year, accounting for 16 to 26 per cent of all organisms collected. Caddisfly nymphs usually ranked third in relative abundance, followed by larval dipterans or adult and immature beetles. Mussels, while annually comprising only 4 to 9 per cent of the numerical total, ranked second only to the snails volumetrically by making up from 6 to 12 (per cent) of the total volume. The dense-shelled snails accounted for never less than 42 per cent nor more than 69 per cent of the total volume. Crayfish, during two of the four years, shared second-place volumetric rank with the mussels. The decapods comprised from 8 to 24 per cent of the total volume each year. Caddisfies ranked fourth volumetrically the last two years of the study. The other taxonomic groups shifted from year to year in relative abundance, as shown in Appendix Table 16. The presence of a diverse bottom fauna existing in moderate abundance, both numerically and volumetrically, typified the normal macro-invertebrate complex to be expected in a stream of this type. Thus, the above productivity values were a valid index against which the effects of brine pollution could be measured.

Polluted Secion Bottom Fauna

The annual mean numbers and mean volumes of macro-invertebrates tabulated from samples collected during 1960 - 1963 at the 5 stations located within the polluted section are compared in Table 10. The overall 4-year mean from this section was 44 organisms and 0.55 cc, about one-half and one-third, respectively, of the overall mean number and mean volume recorded from the unpolluted section. However, the reduction in productivity was much greater at most of the polluted section stations the first two years. At Station +6.2 (closest to pollution source), a mean of only 26 organisms and 0.18 cc was found in 1960; the 1961 figures were 4 organisms and 0.43 cc. At Station +80.4 (farthest from pollution source), the 1960 production values averaged 78 organisms and 0.64 cc. Although there was considerable variation from year to year and from station to station in bottom fauna productivity, as the organisms responded to fluctuating water quality levels, the pattern of increasing productivity in relation to decreasing pollution was clearly evident (Table 10). Another factor to be considered was the sampling schedule, since the bottom samples were collected seasonally in 1960 and 1961, and monthly in 1962 and 1963. River stage permitted samples to be taken once a month from May through October (except September) of 1962 and from April through December of 1963. The monthly sampling schedule undoubtedly permitted better interpretation of variation in the composition and productivity of the bottom fauna in relation to seasons of the year and

Table 10. Mean number and volume of macro-invertebrates* collected at sampling stations in Green River located downstream from oilfield brine pollution (+ = miles below), 1960 - 1963.

Station No. 4 (+6.2)

Year	Sq Ft. Sampled	Number of Organisms	Volume (cc)	Mean Number Per Sq. Ft.	Mean Volume Per Sq. Ft.
1960	3	78	0.55	26.0	0.18
1961	3	13	1.28	4.3	0.43
1962	15	330	8.84	22.0	0.59
1963	27	1130	9.89	41.9	0.37
Totals	48	1551	20.56		
Mean (all years combined)				32.3	0.43

Station No. 5 (+9.3)

1961	4	487	0.98	121.8	0.25
1962	15	169	13.01	11.3	0.87
1963	27	1302	18.14	48.2	0.67
Totals	46	1958	32.13		
Mean (all years combined)				42.6	0.70

Station No. 6 (+28.3)

1962	9	294	10.06	32.7	1.12
1963	27	1122	6.74	41.6	0.25
Totals	36	1416	16.80		
Mean (all years combined)				39.3	0.47

Station No. 7 (+49.7)

1960	6	1360	7.65	226.7	1.28
1962	15	328	4.39	21.9	0.29
1963	27	855	15.50	31.7	0.57
Totals	48	2543	27.54		
Mean (all years combined)				53.0	0.57

Station No. 8 (+80.4)

1960	5	388	3.21	77.6	0.64
1962	15	424	10.15	28.3	0.68
1963	27	1644	14.30	60.9	0.53
Totals	47	2456	27.66		
Mean (all years combined)				52.3	0.59

* Gastropoda and Pelecypoda deleted.

degree of pollution (a separate report covering seasonal variation in bottom fauna productivity will be published later.

The composition and relative abundance of bottom organisms in the samples collected from all 5 stations located in the polluted section in 1960 and 1961 differed greatly from the fauna of the clean-water section (Appendix Tables 17 - 21). Fourteen major taxonomic groups in 1960, and 12 in 1961, were identified from the polluted section. The 4 most abundant groups the first year accounted for more than 94 per cent of all organisms collected: Gastropoda, 53%; Diptera, 25%; Pelecypoda, 10%; and Oligochaeta, 7%. The mayfly order, Ephemeroptera, which predominated in the unpolluted section by comprising 40 per cent of the total number, made up only 1.6 per cent in the salt water section. Two of the aforementioned groups, Gastropoda and Pelecypoda, together accounted for nearly 94 per cent of the total volume. Gastropoda alone made up 73 per cent of the total bulk. Mayflies ranked very low in volume, accounting for only 0.26 per cent of the total collections. While some shifting in relative abundance and volume was noted in 1961, the same groups again predominated. The 4 most abundant groups accounted for 99 per cent of the total number: Gastropoda, 60%; Diptera, 17%; Oligochaeta, 13%; and Pelecypoda, 9%. Snails and mussels made up 95 per cent of the total volume that year. No mayflies were recorded from this section in 1961.

Relative abundance and composition of the bottom fauna in the salt-water section of the river continued to differ greatly from the fauna of the clean-water section during 1962 and 1963. Definite improvement in the fauna was noted, however, as the brine contamination gradually diminished. Eighteen major taxonomic groups of macro-invertebrates were found here the last two years of the investigation (Appendix Tables 17 - 21). Crayfish were taken for the first time, although this group accounted for only 0.3 per cent of the total number collected in 1962. Mayflies, occupying only 1.6 per cent of the total number in 1960, and absent altogether in 1961, made up 7 per cent in 1962, and 12 per cent in 1963, of the total fauna. The percentage of two-winged flies in the samples varied from 25 per cent in 1960, to 17 per cent in 1961, to 7 per cent in 1962, to 15 per cent in 1963. The other important insect orders that gained a slightly stronger foothold in the bottom fauna the ast two years were Trichoptera, Coleoptera, and Plecoptera. The other taxonomic groups exhibited little change in their relative positions in the bottom fauna population. Snails continued to dominate the benthos. Seventy-two of every 100 organisms sampled in 1962 were gastropods; this figure decreased to 54 in 1963.

By virtue of their numerical superiority and dense shells, snails made up 86 per cent of the total volume recorded from the polluted section in 1962. Only three other taxonomic groups contributed as much as one per cent to the total volume that year. They were Decapoda (7%), Pelecypoda (3%), and Corydalidae (1.5%). During the final year of the study, snails made up 89 per cent of the total volume of all samples. The two groups that exceeded one per cent of the total bulk that year were Decapoda (4%) and Pelecypoda (4%).

Big Pitman Creek Bottom Fauna

Bottom fauna productivity in this tributary to the Green River averaged less each year than that of most of the polluted section stations, and much less than that of the clean-water section of the river. Table 9 clearly shows the effects of brine pollution on benthic productivity and the response of macro-invertebrates to diminishing levels of contamination. An average production of 62 organisms and only 0.13 cc, per square foot, was recorded from this tributary in 1960. The following year these values rose to 145 organisms and 0.28 cc; the third year they were 112 organisms and again 0.28 cc. The final year of the study the productivity increased to 310 organisms and 0.46 cc, a great relative improvement, but still a poor showing compared to the unpolluted areas in the Green River. The overall 4-year mean production rate was 210 organisms and 0.34 cc.

Ten major groups of macro-invertebrates were recorded from Big Pitman Creek in 1960 (Appendix Table 22). Members of the Diptera order, mainly tendipedids, accounted for 93 per cent of the total number and 44 per cent of the total volume that year. Most of the other groups were represented in the bottom samples by only one or two specimens. The following year only four taxonomic groups were taken from here. Dipterans again predominated over the other groups by accounting for 98 per cent of the total number and 87 per cent of the total volume. A definite improvement was found in the composition and relative abundance of the bottom fauna during 1962. While dipterans (mainly midge larvae) continued to be the most abundant group, mayflies, appearing for the first time, made up 34 per cent of the total number, and the number of groups represented rose to 11. During the final year 14 taxonomic groups were found, but dipterans once again overshadowed all the other groups with their numerical superiority, accounting for 85 per cent of the total. Mayflies decreased the last year to 4 per cent of the total number. Big Pitman Creek was apparently too salty for even the brine-tolerant snails during 1960 and 1961. While their bulk accounted for 65 and 76 per cent, respectively, of the total volume in 1962 and 1963, they comprised only 25 per cent of the total volume in 1960 and 8 per cent in 1961.

DISCUSSION

The effects of brine pollution on biological productivity described so far were drastic in nature and clear cut in consequences. The damage to the river was not, however, restricted to those effects previously discussed. Other factors, some obvious, some subtle, were involved in the degradation of the Green River by brine contamination.

No reports mentioning dead or dying fish in the polluted section were ever received from either the local conservation officers or citizens. Surprisingly, there was even an absence of rumors concerning fish kills in this section. Some complaints were registered by commercial fishermen that fishing success became poorer after the oil strike. The standing crop figures from the polluted section supported the often-heard contention that the salt water had "driven all the fish out of Green River." Many species did move downstream until they found water in which the brine contamination had been reduced by dilution to tolerable levels.

There was universal agreement along the river that fish from the polluted section, after being cooked, had an oily taste. Consequently, fishing pressure was practically nil, at least during the life of this project. This was unfortunate, for while the oily taste did exist during the years of peak brine contamination, the rumor persisted long after the objectionable taste had disappeared and very few fishermen availed themselves of the recovering fish population in this section of the river.

Mussels, very sensitive to brine pollution in view of their virtual absence in the polluted section during 1960 and 1961, began the slow process of repopulating the areas which they formerly occupied. Vast numbers of empty mussel shells littering the riffles of Green River bear mute testimony to their former great abundance. Although outside the province of fisheries biology, and this particular investigation, the writer is compelled to at least mention the apparent role of mussels in the diet of stream-loving mammals. Many of the riffles which were not too near the works of man were quite often covered with freshly shucked mussel shells. As the mussels reinvaded their former territories, it was observed that they were quickly utilized, probably by raccoons. A riffle devoid of fresh mussel shells usually indicated that the bivalves were still absent from the bottom faunal complex.

The fin damage observed on fish from the polluted section and from Big Pitman Creek was not restricted to a particular species or group of species. Neither was the damage peculiar to a certain size class nor to any certain fin. It was not possible to differentiate between recent fin damage and older damage on fins of the older age groups. The number of fish affected each year, and the severity of affliction, seemed to keep pace with the diminishing brine contamination. The component(s) of the brine responsible for the fin damage were never ascertained.

In summation, one of Kentucky's most valuable natural resources was seriously damaged by the Greensburg oil strike and the ensuing brine contamination, but, ironically, the same factors that caused the damage were responsible for the problem curing itself: poor conservation practices.

SUMMARY

1. Oilfield brines wasting into the Green River in the Greensburg vicinity created an acute pollution problem over 100 miles in extent. The effects of brine contamination on the water quality, fish fauna, and macro-invertebrate bottom fauna were determined and evaluated in a study that began in the summer of 1960 and continued through 1963.

2. The Greensburg oilfield was developed and exploited between 1958 and 1961. Maximum oil production was from the fall of 1958 through the summer of 1960. Oil production increased from 5,454 barrels in January, 1958 to 1,421,608 barrels in May, 1959. Production steadily decreased to 53,418 barrels in December, 1961.

3. Brine production accompanied oil production and very often the wells produced salt water for several months before oil production started. On a field basis, water production was estimated to have been from 3 to 20 times as great as oil production during the peak production period. Based on the size of the tributary creeks and their chloride content, it was evident that the vast bulk of waste brine reached the Green River via Big Pitman Creek.

4. Before August, 1958 Green River water was moderately hard, of the calcium magnesium bicarbonate type, and had an average chloride concentration of less than 10 ppm. With the disposal of brines from the Greensburg oilfield, the water became very hard, changed to a sodium chloride type, and chloride concentrations frequently exceeded 1,000 ppm.

5. Domestic and industrial use of the water was seriously affected, as were private springs and wells. The brines changed the potable ground water from a calcium bicarbonate type, containing moderate amounts of magnesium and sulfate, to a sodium chloride type. Chloride concentrations prior to oil production generally were less than 60 ppm; after oil production, chloride concentrations were as high as 51,000 ppm.

6. Population sampling showed that the Green River supported an extremely rich and varied fish fauna, especially in the unpolluted sections. One hundred seven of the 177 species known to occur in Kentucky were identified from the river during the 4-year study.

7. As the brine pollution diminished from its peak intensity in 1960, the number of fish species occurring exclusively in the clean-water section decreased from 30 to 13. The number of species found in the polluted section increased from 35 in 1960 to 47 in 1963.

8. The unpolluted section supported an average annual standing fish crop ranging between 85 and 156 pounds per acre. The standing crop in the polluted section increased from 10 pounds per acre in 1960 to 47 pounds per acre in 1963.

9. Only 16 fish species, representing 9 genera from 4 families, were recovered from Big Pitman Creek in 1960. During the last year

of the study the number of species inhabiting this tributary had increased to 40, and 19 genera from 6 families were represented. The standing crop was 3.5 pounds per acre in 1960; by 1963 it had expanded to 46 pounds per acre.

10. The fish population found in the navigation lock chambers, located in the lower 150 miles of the Green River and far enough downstream in the recovery zone to be supporting a normal population, nearly matched the diversity found in the clean-water section. Between 45 and 48 species were identified each year from the lock studies. The mean annual standing crop varied from 274 to 519 pounds per acre.

11. A rich and varied macro-invertebrate bottom fauna was found in the unpolluted section of the Green River. Twenty-one major taxonomic categories were identified during the 4-year study. This diversity of macro-invertebrate forms was not found in the polluted section or in Big Pitman Creek.

12. Productivity in the clean-water section fluctuated from a low annual mean of 56 organisms in 1961 to a high mean of 120 organisms in 1963 (per square foot basis). The lowest mean volume was 1.48 cc in 1963 and the highest was 2.68 cc in 1960. The overall 4-year mean for this section was 90 organisms and 1.78 cc.

13. During the first 2 years of peak contamination, the number of taxonomic groups found at the sampling stations in the polluted section ranged from as few as 5 to no more than 12. The quality of the bottom fauna as potential fish food was extremely poor. As the pollution subsided, the variety of organisms in this section approached that found at the upstream stations.

14. Productivity values in the polluted section ranged from a low annal mean of 26 organisms and 0.18 cc in 1960 at the station nearest the pollution source, to a high mean of 61 organisms and 0.53 cc in 1963 at the station farthest from pollution. The overall 4-year mean for the section was 44 organisms and 0.55 cc, about one-half and one-third, respectively, of the clean-water production rates.

15. Bottom fauna productivity in Big Pitman Creek averaged less each year than that of most of the polluted section stations, and much less than that of the clean-water section of the river. The annual mean production recorded for 1960 was 62 organisms and 0.13 cc. The final year of the study the productivity increased to 310 organisms and 0.46 cc. The overall 4-year mean production rate was 210 organisms and 0.34 cc.

LITERATURE CITED

Ball, Robert C. 1948. Relationship between available fish food, feeding habits of fish and total fish production in a Michigan lake. Techn. Bull. 206, Michigan State College Agr. Exp. Sta., 59 pp.

Charles, James R. 1962. Project Progress Report, D-J Project F-18-R (1 & 2). Ky. Dept. Fish and Wild. Res., 84 pp.

Hopkins, Herbert T. 1963. The effect of oilfield brines on the potable ground water in the Upper Big Pitman Creek basin, Kentucky. Rept. of Invest. 4, Series X, Ky. Geol. Surv., in coop. U. S. Geol. Surv., 36 pp.

Hunt, Burton P. 1953. The life history and economic importance of a burrowing mayfly, *Hexagenia limbata*, in southern Michigan lakes. Bull. 4, Inst. Fish. Res., coop. Univ. Michigan, 151 pp.

Kentucky Dept. Econ. Development. 1956. Streamflow in Kentucky. In coop. U. S. Geol. Surv., Louisville Dist., 91 pp.

Krieger, R. A., and G. E. Hendrickson. 1960. Effects of Greensburg oilfield brines on the streams, wells, and springs of the Upper Green River basin, Kentucky Rept. of Invest. 2, Series X, Ky. Geol. Surv., in coop. U. S. Geol. Surv., 36 pp.

National Park Service. 1960. A study of oilfield pollution and its relation to Green River and Mammoth Cave National Park. U. S. D. I., in coop. with various State & Fed .agencies, 57 pp.

Usinger, Robert L. 1956. Aquatic insects of California. Univ. of Calif. Press, 508 pp.

APPENDIX—Figures 1-5—Tables 1-22

Figure 1. Kentucky's Standard Method for Reporting Fish Population Data.

	FINGERLING SIZE			INTERMEDIATE SIZE			HARVESTABLE SIZE		
SPECIES	Range	Number per acre	Pounds per acre	Range	Number per acre	Pounds per acre	Min. inch group	Number per acre	Pounds per acre
(A) GAME FISHES									
Ohio muskellunge	0-4			5-23			24		
Chain pickerel	0-4			5-11			12		
Grass pickerel	0-4			5-9			10		
White bass	0-4			5-8			9		
Yellow bass	0-4			5-6			7		
Sauger	0-4			5-11			12		
Walleye	0-4			5-11			12		
Largemouth bass	0-4			5-9			10		
Smallmouth bass	0-4			5-9			10		
Spotted bass	0-4			5-9			10		
Black crappie	0-4			5-7			8		
White crappie	0-4			5-7			8		
TOTALS									
(B) FOOD FISHES									
Blue catfish	0-4			5-9			10		
Channel catfish	0-4			5-9			10		
Flathead catfish	0-4			5-9			10		
TOTALS									

SPECIES	FINGERLING SIZE			INTERMEDIATE SIZE			HARVESTABLE SIZE		
	Range	Number per acre	Pounds per acre	Range	Number per acre	Pounds per acre	Min. inch group	Number per acre	Pounds per acre
(C) PREDATORY FISHES									
Skipjack herring	0-4			5-9			10		
Goldeye	0-4			5-9			10		
Mooneye	0-4			5-9			10		
Longnose gar	0-4			5-23			24		
Shortnose gar	0-4			5-23			24		
Spotted gar	0-4			5-23			24		
Bowfin	0-4			5-13			14		
American eel				8-15			16		
TOTALS									
(D) PANFISHES									
Rock bass	0-2			3-5			6		
Bluegill	0-2			3-5			6		
Green sunfish	0-2			3-5			6		
Hybrid sunfish	0-2			3-5			6		
Longear sunfish	0-2			3-5			6		
Redear sunfish	0-2			3-5			6		
Warmouth	0-2			3-5			6		
TOTALS									

SPECIES	FINGERLING SIZE			INTERMEDIATE SIZE			HARVESTABLE SIZE		
	Range	Number per acre	Pounds per acre	Range	Number per acre	Pounds per acre	Min. inch group	Number per acre	Pounds per acre
(E) COMMERCIAL FISHES									
Sturgeons	0-7			8-23			24		
Paddlefish	0-7			8-23			24		
Buffalofishes	0-4			5-11			12		
Carpsuckers	0-4			5-11			12		
Hogsucker	0-4			5-11			12		
Redhorses	0-4			5-11			12		
White sucker	0-4			5-11			12		
Spotted sucker	0-4			5-11			12		
Carp	0-4			5-11			12		
Bullheads	0-4			5-9			9		
Drum	0-4			5-9			10		
TOTALS									

SPECIES	FINGERLING SIZE			INTERMEDIATE SIZE			ABOVE FORAGE SIZE		
	Range	Number per acre	Pounds per acre	Range	Number per acre	Pounds per acre	Min. inch group	Number per acre	Pounds per acre
(F) FORAGE FISHES									
Lampreys	0-3			4-7			8		
Gizzard shad	0-3			4-7			8		
Threadfin shad	0-3			4-7			8		
Notropis spp.	0-3			4-7			8		
Other cyprinids	0-3			4-7			8		
Madtoms	0-3			4-7			8		
Topminnows	0-3			4-7			8		
Darters	0-3			4-7			8		
Orangespotted sunfish	0-3			4-7			8		
Brook silverside	0-3			4-7			8		
Sculpins	0-3			4-7			8		
TOTALS									
GRAND TOTALS									

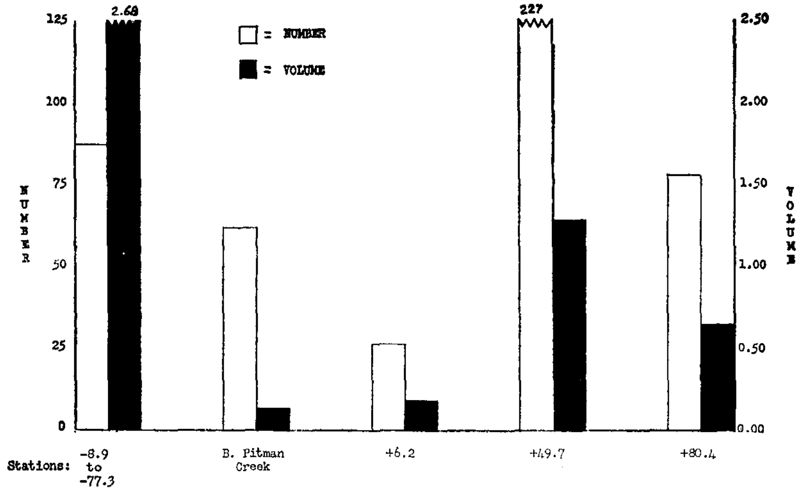


Fig. 2. Mean number and mean volume, per square foot, of macro-invertebrates collected in 1960 from Green River and Bit Pitman Creek. Seven stations were located upstream (- = miles above) and three stations were located downstream (+ = miles below) from the oil field pollution. A single station was located on Big Pitman Creek, the prime source of oil field brines.

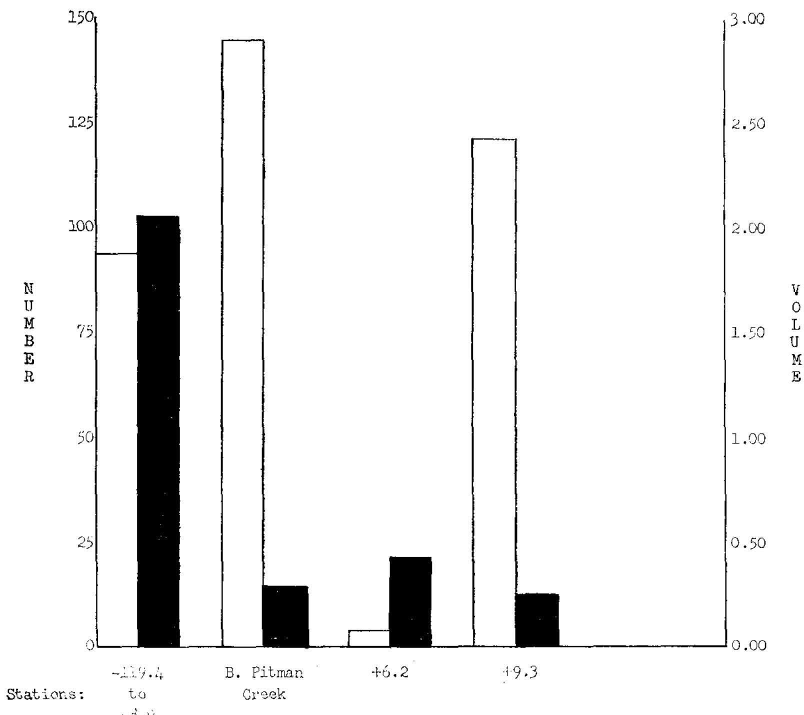


Fig. 3 . Mean number and mean volume, per square foot, of macro-invertebrates collected in 1961 from Green River and Big Pitman Creek. Eight stations were located upstream (- = miles above) and two stations were located downstream (+ = miles below) from the oil field pollution. A single station was located on Big Pitman Creek, the prime source of oil field brines.

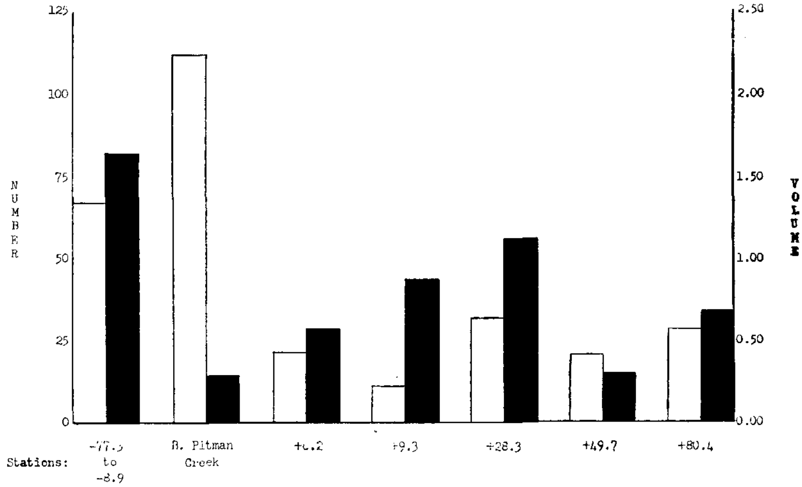


Fig. 4. Mean number and mean volume, per square foot, of macro-invertebrates collected in 1962 from Green River and Big Pitman Creek. Three stations were located upstream (- = miles above) and five stations were located downstream (+ = miles below) from the oil field pollution. A single station was located on Big Pitman Creek, the prime source of oil field brines.

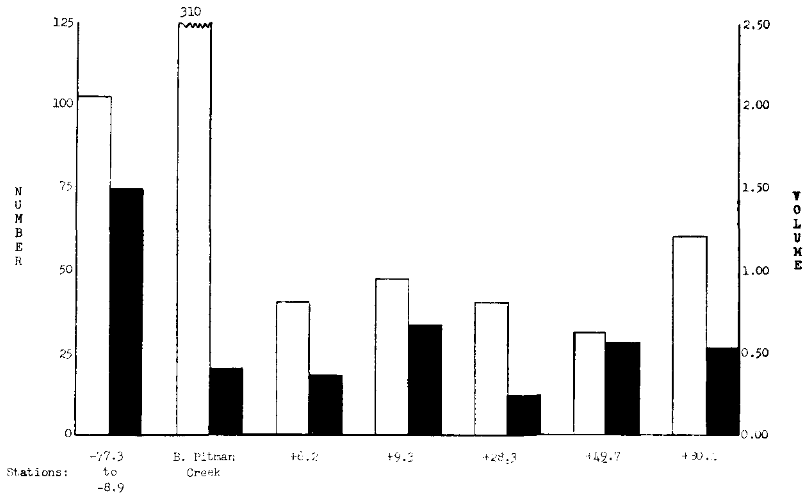


Fig. 5. Mean number and mean volume, per square foot, of macro-invertebrates collected in 1963 from Green River and Big Pitman Creek. Three stations were located upstream (- = miles above) and five stations were located downstream (+ = miles below) from the oil field pollution. A single station was located on Big Pitman Creek, the prime source of oil field brines.

Table 1. Composition of the 1960 standing fish crop in the unpolluted section of Green River, determined by sampling 4.91 acres (3 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	6	0.1	13	2.4	9	7.0	28	9.4	6.5	6.1
Food Fishes	1	tr.	1	0.2	7	14.6	9	14.9	2.1	9.5
Predatory Fishes	—	—	22	14.4	8	10.6	30	25.0	7.1	16.0
Totals (Piscivorous)	6	0.1	36	17.0	24	32.2	66	49.3	15.7	31.6
Panfishes	10	tr.	67	3.4	24	6.3	101	9.7	24.1	6.3
Commercial Fishes	13	0.3	79	21.3	40	67.9	132	89.5	31.5	57.5
Forage Fishes	110	0.5	1	tr.	9	6.6	120	7.2	28.6	4.6
Totals (Non-Piscivorous)	133	0.9	148	24.8	72	80.8	345	106.5	84.2	68.4
GRAND TOTALS	140	0.9	184	41.8	96	113.0	420	155.7	100.0	100.0

Standing Crop = 420 fish per acre; 156 pounds per acre. A_t = 72.6

Table 2. Composition of the 1961 standing fish crop in the unpolluted section of Green River, determined by sampling 4.00 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	3	tr.	15	2.3	13	11.3	31	13.6	5.9	14.6
Food Fishes	1	tr.	1	0.1	4	4.7	5	4.8	0.9	5.2
Predatory Fishes	—	—	1	0.1	tr.	0.3	1	0.4	0.1	0.4
Totals (Piscivorous)	4	tr.	16	2.5	17	16.3	37	18.8	6.9	20.1
Panfishes	31	0.3	59	2.9	35	9.1	125	12.2	23.6	13.1
Commercial Fishes	5	0.1	75	13.2	50	45.1	130	58.4	24.6	62.5
Forage Fishes	228	1.6	8	0.3	1	2.1	237	4.0	44.8	4.3
Totals (Non-Piscivorous)	264	2.0	142	16.4	86	56.3	491	74.6	93.0	79.9
GRAND TOTALS	268	2.0	158	18.9	103	72.6	528	93.5	100.0	100.0

Standing Crop = 528 fish per acre; 94 pounds per acre. A_t = 77.7

Table 3. Composition of the 1962 standing fish crop in the unpolluted section of Green River, determined by sampling 4.75 acres (3 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	18	0.2	10	1.8	8	5.5	36	7.5	3.9	8.9
Food Fishes	1	tr.	1	0.1	6	9.0	8	9.1	0.8	10.8
Predatory Fishes	—	—	4	1.2	1	1.7	5	2.8	0.5	3.3
Totals (Piscivorous)	19	0.2	15	3.1	15	16.2	49	19.4	5.2	23.0
Panfishes	26	0.2	159	6.2	32	6.1	216	12.4	23.2	14.7
Commercial Fishes	107	0.7	75	17.1	37	31.8	218	49.6	23.4	58.6
Forage Fishes	424	2.1	26	0.6	tr.	0.5	449	3.2	48.2	3.7
Totals (Non-Piscivorous)	557	3.0	260	23.9	69	38.4	883	65.2	94.8	77.0
GRAND TOTALS	576	3.2	275	27.0	84	54.6	932	84.6	100.0	100.0

Standing Crop = 932 fish per acre; 85 pounds per acre. A = 64.5

Table 4. Composition of the 1963 standing fish crop in the unpolluted section of Green River, determined by sampling 4.30 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	1	tr.	13	2.5	12	11.0	26	13.5	4.2	12.9
Commercial Fishes	—	—	1	tr.	1	3.7	1	3.7	0.2	3.5
Predatory Fishes	—	—	4	1.5	2	2.2	6	3.6	0.9	3.5
Totals (Piscivorous)	1	tr.	18	4.0	15	16.9	33	20.8	5.3	19.9
Panfishes	61	0.5	155	5.7	16	3.5	231	9.6	36.7	9.2
Commercial Fishes	20	0.2	131	19.6	40	52.3	190	72.1	30.2	68.6
Forage Fishes	150	0.8	24	0.5	1	1.1	175	2.4	27.8	2.3
Totals (Non-(Piscivorous)	231	1.5	310	25.8	57	56.9	496	84.1	94.7	80.1
GRAND TOTALS	231	1.5	327	29.7	71	73.9	630	105.0	100.0	100.0

Standing Crop = 630 fish per acre; 105 pounds per acre. $A_t = 70.4$.

Table 5. Composition of the 1960 standing fish crop in the polluted section of Green River, determined by sampling 6.35 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre) Number	Pounds	INTERMEDIATE (per acre) Number	Pounds	HARVESTABLE (per acre) Number	Pounds	TOTALS (per acre) Number	Pounds	PER CENT OF TOTAL Number	Pounds
Game Fishes	tr.	tr.	tr.	0.1	tr.	0.1	1	0.1	0.7	1.4
Food Fishes	tr.	tr.	—	—	4	5.3	4	5.3	4.8	51.1
Predatory Fishes	—	—	1	0.4	—	—	1	0.4	0.9	4.3
Totals (Piscivorous)	tr.	tr.	1	0.5	4	5.3	6	5.8	6.4	56.8
Panfishes	2	tr.	1	tr.	—	—	2	tr.	2.8	0.3
Commercial Fishes	2	tr.	5	2.6	1	1.4	8	4.0	9.1	39.1
Forage Fishes	65	0.3	4	0.1	—	—	69	0.4	81.6	3.8
Totals (on-Piscivorous)	68	0.4	10	2.6	1	1.4	79	4.5	93.5	43.2
GRAND TOTALS	69	0.4	11	3.2	6	6.8	85	10.3	100.0	100.0

Standing Crop = 85 fish per acre; 10 pounds per acre. $A_t = 65.7$

Table 6. Composition of the 1961 standing fish crop in the polluted section of Green River, determined by sampling 4.59 acres (1 area) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	2	tr.	tr.	0.1	1	0.4	3	0.5	1.1	4.1
Food Fishes	6	tr.	1	0.1	1	0.8	8	0.9	2.6	7.5
Predatory Fishes	—	—	tr.	tr.	—	—	tr.	tr.	0.1	0.3
Totals (Piscivorous)	8	0.1	2	0.2	2	1.2	12	1.4	3.8	12.0
Panfishes	2	tr.	3	0.1	tr.	0.1	6	0.2	2.0	1.3
Commercial Fishes	6	0.1	12	4.1	5	5.0	23	9.2	7.8	75.5
Forage Fishes	228	1.1	32	0.3	—	—	260	1.4	86.4	11.3
Totals (Non-Piscivorous)	236	1.2	47	4.4	6	5.1	289	10.7	96.2	88.1
GRAND TOTALS	245	1.2	49	4.7	7	6.3	301	12.2	100.0	100.0

Standing Crop = 30 fish per acre; 12 pound per acre. A_t = 51.5

Table 7. Composition of the 1963 standing fish crop in the polluted section of Greeen River, determined by sampling 6.45 acres (3 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	3	tr.	5	0.9	3	2.6	11	3.5	4.9	7.5
Food Fishes	3	tr.	9	1.0	10	14.6	22	15.6	9.5	33.0
Predatory Fishes	—	—	2	0.9	1	0.6	3	1.4	1.3	3.0
Totals (Piscivorous)	6	0.1	16	2.7	14	17.7	36	20.5	15.8	43.5
Panfishes	10	0.1	15	0.7	2	0.4	27	1.2	11.8	2.5
Commercial Fishes	19	0.3	42	6.3	17	18.3	78	24.8	34.1	52.6
Forage Fishes	81	0.4	7	0.3	—	—	88	0.7	38.3	1.4
Totals (Non-Piscivorous)	110	0.7	63	7.3	20	18.7	193	26.7	84.2	56.5
GRAND TOTALS	116	0.7	79	10.0	34	36.5	229	47.2	100.0	100.0

Standing Crop = 229 fish per acre; 47 pounds per acre. $A_t = 77.3$

Table 8. Composition of the 1960 standing fish crop in Big Pitman Creek, determined by sampling 2.25 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	tr.	tr.	tr.	0.2	tr.	0.2	1	0.4	6.1	12.2
Food Fishes	tr.	tr.	—	—	2	2.3	2	2.3	10.2	67.2
Predatory Fishes	—	—	—	—	—	—	—	—	—	—
Totals (Piscivorous)	1	tr.	tr.	0.2	2	2.6	3	2.8	16.3	79.4
Panfishes	—	—	1	0.1	2	0.3	3	0.4	12.2	12.8
Commercial Fishes	1	tr.	tr.	0.2	—	—	2	0.2	8.2	6.3
Forage Fishes	14	0.1	—	—	—	—	14	0.1	63.3	1.6
Totals (Non-Piscivorous)	15	0.1	1	0.3	2	0.3	18	0.7	83.7	20.6
GRAND TOTALS	16	0.1	2	0.5	4	2.9	22	3.5	100.0	100.0

Standing Crop = 22 fish per acre; 3.5 pounds per acre. $A_t = 83.6$

Table 9. Composition of the 1961 standing fish crop in Big Pitman Creek, determined by sampling 1.00 acre (1 area) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	9	tr.	—	—	—	—	9	tr.	1.1	0.6
Food Fishes	—	—	1	tr.	—	—	1	tr.	0.1	1.1
Predatory Fishes	—	—	—	—	—	—	—	—	—	—
Totals (Piscivorous)	9	tr.	1	tr.	—	—	10	tr.	1.2	1.7
Panfishes	—	—	16	0.2	—	—	16	0.2	2.0	5.0
Commercial Fishes	4	tr.	2	0.2	—	—	6	0.2	0.7	6.3
Forage Fishes	759	2.6	29	0.6	—	—	788	3.2	96.1	87.1
Totals (Non-Piscivorous)	763	2.6	47	1.0	—	—	810	3.6	98.8	98.4
GRAND TOTALS	772	2.6	48	1.0	—	—	820	3.6	100.0	100.0

Standing Crop = 820 fish per acre; 3.6 pounds per acre. $A_t = 0.0$

Table 10. Composition of the 1962 standing fish crop in Big Pitman Creek, determined by sampling 2.25 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	7	0.1	5	0.8	1	0.7	13	1.5	1.2	11.8
Food Fishes	18	0.1	1	0.2	—	—	20	0.3	1.8	2.3
Predatory Fishes	—	—	1	0.1	—	—	1	0.1	0.1	0.8
Totals (Piscivorous)	25	0.2	7	1.1	1	0.7	34	1.9	3.1	14.9
Panfishes	3	tr.	18	1.3	11	2.2	32	3.5	2.9	26.5
Commercial Fishes	118	0.9	12	1.6	2	1.8	132	4.3	11.9	32.8
Forage Fishes	893	2.9	14	0.4	—	—	907	3.4	82.2	25.8
Totals (Non-Piscivorous)	1014	3.8	44	3.3	13	4.0	1071	11.2	97.0	85.1
GRAND TOTALS	1039	4.0	51	4.4	14	4.7	1105	13.1	100.0	100.0

Standing Crop = 1105 fish per acre; 13 pounds per acre. A_t = 35.9

Table 11. Composition of the 1963 standing fish crop in Big Pitman Creek, determined by sampling 2.25 acres (2 areas) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fihses	16	0.1	8	1.6	2	1.6	27	3.3	2.6	7.2
Food Fishes	—	—	**2**	**0.2**	1	0.7	3	0.9	0.3	2.0
Predatory Fishes	—	—	—	—	—	—	—	—	—	—
Totals (Piscivorous)	16	0.1	10	1.8	3	2.3	29	4.2	2.9	9.2
Panfishes	17	0.2	66	2.8	14	3.0	96	6.0	9.3	13.1
Commercial Fishes	29	0.3	190	23.7	4	4.7	223	28.7	21.6	62.3
Forage Fishes	555	3.3	130	3.8	—	—	685	7.1	66.3	15.5
Totals (Non-Piscivorous)	601	3.7	385	30.3	18	7.7	1004	41.8	97.1	90.8
GRAND TOTALS	617	3.9	395	32.1	21	10.0	1034	46.0	100.0	100.0

Standing Crop = 1034 fish per acre; 46 pounds per acre. $A_t = 21.7$

Table 12. Composition of the 1960 standing fish crop in lower Green River, determined by sampling 4.26 acres (7 studies in 4 navigation lock chambers) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	4	0.1	8	1.7	5	3.3	17	5.1	2.3	1.9
Food Fishes	25	0.2	41	4.4	28	18.0	94	22.6	12.6	8.3
Predatory Fishes	—	—	5	1.6	3	3.5	8	5.1	1.0	1.9
Totals (Piscivorous)	29	0.3	54	7.7	37	24.8	120	32.8	15.9	12.0
Panfishes	2	tr.	7	0.4	5	1.0	13	1.4	1.8	0.5
Commercial Fishes	56	0.4	59	12.3	55	162.7	170	175.4	22.7	64.1
Forage Fishes	184	06	143	10.4	118	53.1	445	64.1	59.5	23.4
Totals (Non-Piscivorous)	242	1.0	208	231.	178	216.8	628	240.9	84.0	88.0
GRAND TOTALS	271	1.3	262	30.8	215	241.6	748	273.7	100.0	100.0

Standing Crop = 748 fish per acre; 274 pounds per acre. $A_t = 88.3$

Table 13. Composition of the 1961 standing fish crop in lower Green River, determined by sampling 5.52 acres (8 studies in 4 lock chambers) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	2	tr.	29	3.2	11	5.4	41	8.6	1.3	1.7
Food Fishes	26	0.5	99	6.2	11	8.1	137	14.7	4.4	2.8
Predatory Fishes	1	tr.	3	0.6	5	3.0	9	3.5	0.3	0.7
Totals (Piscivorous)	29	0.5	131	9.9	27	16.5	186	26.8	6.0	5.2
Panfishes	1	tr.	23	1.5	12	2.6	35	4.1	1.1	0.8
Commercial Fishes	142	3.8	463	32.8	151	271.4	756	308.1	24.5	59.4
Forage Fishes	452	1.3	1312	79.3	348	99.0	2111	179.5	68.4	34.6
Totals (Non-Piscivorous)	594	5.1	1799	113.5	510	373.1	2902	491.7	94.0	94.8
GRAND TOTALS	623	5.6	1930	123.4	537	389.5	3089	518.5	100.0	100.0

Standing Crop = 3089 fish per acre; 519 pounds per acre. A_t = 75.1

Table 14. Composition of the 1962 standing fish crop in lower Green River, determined by sampling 3.02 acres (6 population studies in 4 lock chambers) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	5	0.1	11	2.2	8	5.0	24	7.3	2.1	1.8
Food Fishes	14	0.1	37	4.1	25	29.1	76	33.3	6.7	8.2
Predatory Fishes	—	—	37	1.6	2	1.2	39	2.8	3.5	0.7
Totals (Piscivorous)	19	0.2	85	7.9	35	35.3	139	43.4	12.3	10.7
Panfishes	51	0.1	8	0.5	3	0.6	61	1.2	5.3	0.3
Commercial Fishes	61	0.5	122	17.5	92	319.3	275	337.3	24.1	83.4
Forage Fishes	562	1.6	31	1.8	74	19.4	667	22.8	58.4	5.6
Totals (Non-Piscivorous)	674	2.2	161	19.8	169	339.3	1003	361.3	87.8	89.3
GRAND TOTALS	693	2.4	246	27.7	204	374.6	1142	404.7	100.0	100.0

Standing Crop = 1142 fish per acre; 405 pounds per acre. A_t = 92.6

Table 15. Composition of the 1963 standing fish crop in lower Green River, determined by sampling 5.52 acres (8 studies in 4 navigation lock chambers) with rotenone.

GROUP	FINGERLING (per acre)		INTERMEDIATE (per acre)		HARVESTABLE (per acre)		TOTALS (per acre)		PER CENT OF TOTAL	
	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
Game Fishes	1	tr.	13	2.2	11	7.0	25	9.2	2.3	2.4
Food Fishes	33	0.5	172	12.3	32	20.7	234	33.5	21.9	8.9
Predatory Fishes	—	—	5	0.7	3	1.5	8	2.2	0.7	0.6
Totals (Piscivorous)	34	0.5	190	15.2	46	29.2	269	44.9	24.8	11.9
Panfishes	8	0.1	16	1.0	6	1.2	30	2.2	2.8	0.6
Commercial Fishes	29	0.6	158	15.3	83	250.5	270	266.4	24.9	70.4
Forage Fishes	103	0.3	282	17.0	130	74.6	514	65.0	47.5	17.2
Totals (Non-Piscivorous)	140	1.0	456	33.3	219	299.3	814	333.6	75.2	88.1
GRAND TOTALS	174	1.5	645	48.5	264	328.5	1083	378.5	100.0	100.0

Standing Crop = 1083 fish per acre; 379 pounds per acre. $A_t = 86.8$

Table 16. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Green River upstream from oilfield brine pollution.

Year:	1960		1961		1962		1963	
Total number - volume:	2733-129.84		3490-291.78		4632-305.28		10,992-512.72	
Taxonomic group	Relative abundance (percentage of total number—total volume)							
Turbellaria (flatworms)	—	—	—	—	—	—	0.1	tr.
Nemata (nemas)	tr.	tr.	—	—	—	—	—	—
Oligochaeta (earthworms)	6.7	1.7	4.6	1.2	1.1	0.4	1.4	1.1
Hirundinea (leeches)	0.1	tr.	0.1	0.1	—	—	0.1	tr.
Isopoda (sowbugs)	tr.	tr.	0.1	tr.	tr.	tr.	tr.	tr.
Amphipoda (scuds)	—	—	0.1	tr.	tr.	tr.	tr.	tr.
Decapoda (crayfish)	0.7	23.8	1.3	7.5	0.8	9.8	0.6	11.5
Gastropoda (snails)	16.1	41.8	23.4	69.2	25.6	61.2	18.5	66.0
Pelecypoda (mussels)	3.5	6.3	4.9	11.5	8.8	14.7	6.3	10.5
Hydracarina (water mites)	0.1	tr.	0.1	tr.	—	—	0.1	tr.
Ephemeroptera (mayflies)	40.4	19.3	30.4	5.4	31.5	3.6	36.3	3.1
Odonata								
Anisoptera (dragonflies)	0.2	1.0	0.3	0.1	0.3	0.1	0.1	0.2
Zygotera (damselflies)	tr.	tr.	0.5	0.2	0.2	0.1	0.2	0.1
Megaloptera								
Sialis (alderflies)	0.4	0.3	0.1	tr.	0.2	tr.	0.2	0.1
Corydalidae (dobson/fishflies)	1.7	2.4	0.6	0.5	2.7	3.5	1.4	2.7
Plecoptera (stoneflies)	1.4	0.4	6.1	1.0	4.1	0.4	7.1	0.9
Trichoptera (caddisflies)	5.9	1.6	6.6	1.0	11.6	5.0	13.3	3.0
Coleoptera (beetles)	7.4	0.7	11.3	1.0	8.5	1.0	5.6	0.6
Hemiptera (bugs)	tr.	tr.	—	—	—	—	—	—
Lepidoptera (caterpillars)	0.1	tr.	—	—	—	—	—	—
Diptera (flies)	14.7	0.7	9.5	1.5	4.7	0.3	8.7	0.3
Unidentified	0.6	tr.	tr.	tr.	—	—	—	—

Table 17. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Green River 6.2 miles (Sta. 4) below oilfield brine pollution.

Year:	1960		1961		1962		1963	
Total number - volume:	132-7.75		205 - 13.45		879 - 51.02		2249 - 167.58	
Taxonomic group	Relative abundance (percantage of total number—total volume)							
Turbellaria	—	—	—	—	—	—	tr.	tr.
Nemata	3.8	tr.	—	—	0.1	tr.	0.4	tr.
Oligochaeta	49.2	1.3	—	—	1.1	0.1	0.8	0.1
Hirundinea	—	—	—	—	0.2	tr.	—	—
Decapoda	—	—	—	—	1.1	14.4	0.9	3.4
Gastropoda	40.2	90.3	93.7	90.5	62.0	82.5	49.4	93.9
Pelecypoda	0.8	2.6	—	—	0.5	0.2	0.4	0.2
Hydracarina	—	—	—	—	—	—	0.2	tr.
Ephemeroptera	0.8	tr.	—	—	11.5	0.5	14.4	0.7
Odonata								
Anisoptera	1.5	0.7	1.0	8.9	0.5	0.1	0.3	0.1
Zygoptera	—	—	—	—	—	—	0.3	tr.
Megaloptera								
Sialis	—	—	—	—	0.2	tr.	0.2	tr.
Corydalidae	0.8	5.2	—	—	1.1	0.4	0.6	0.2
Plecoptera	—	—	0.5	0.2	0.5	0.1	4.7	0.2
Trichoptera	—	—	—	—	0.7	0.5	2.4	0.3
Coleoptera	—	—	0.5	tr.	5.2	0.8	5.2	0.2
Hemiptera	—	—	—	—	0.1	tr.	—	—
Diptera	3.0	tr.	4.4	0.5	15.1	0.5	1.97	0.6

Table 18. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Green River 9.3 miles (Sta. 5) below oilfield brine pollution.

Year:	1961		1962		1963	
Total number - volume	2155 - 44.05		2109 - 124.40		2390 - 136.38	
Taxonomic group	Relative abundance (percentage of total number - total volume)					
Turbellaria	—	—	—	—	tr.	tr.
Nemata	0.1	tr.	0.1	tr.	0.6	0.1
Oligochaeta	—	—	0.4	tr.	4.3	tr.
Hirundinea	0.3	0.4	0.1	tr.	—	—
Decapoda	—	—	0.2	6.0	1.1	9.6
Gastropoda	78.3	97.8	90.9	88.9	45.4	86.6
Pelecypoda	—	—	1.1	0.7	0.1	0.1
Hydracarina	—	—	—	—	0.1	tr.
Ephemeroptera	—	—	2.1	0.1	21.5	1.0
Odonata						
Anisoptera	0.3	0.1	1.7	1.5	1.5	0.9
Zygoptera	—	—	—	—	0.4	0.1
Megaloptera						
Sialis	—	—	0.1	tr.	tr.	tr.
Corydalidae	tr.	tr.	0.7	2.3	0.1	3.0
Plecoptera	—	—	0.2	tr.	5.1	0.4
Trichoptera	tr.	tr.	0.6	0.4	0.5	0.1
Coleoptera	0.1	0.1	0.6	0.1	3.7	0.2
Diptera	21.6	1.6	1.0	tr.	15.6	0.4

Table 19. Relative abundance of each major taxonomic group of *macro-invertebrates occurring in riffle samples from Green* River 28.3 miles (Sta. 6) below oilfield brine pollution.

Year:	1962		1963	
Total number - volume	758 - 47.73		2680 - 141.27	
Taxonomic group	Relative abundance (% of total No. - total vol.)			
Turbellaria	—	—	0.1	tr.
Nemata	—	—	0.1	tr.
Oligochaeta	—	—	0.2	0.1
Hirundinea	—	—	0.1	tr.
Decapoda	0.3	16.6	tr.	6.0
Gastropoda	60.2	78.2	51.1	84.9
Pelecypoda	1.1	0.7	7.1	10.3
Hydracarina	—	—	0.5	tr.
Ephemeroptera	5.7	0.4	10.4	0.7
Odonata				
Anisoptera	3.2	1.8	1.5	0.4
Zygoptera	—	—	0.1	tr.
Megaloptera				
Sialis	0.1	tr.	tr.	tr.
Corydalidae	3.3	0.5	0.9	1.3
Plecoptera	6.6	0.2	10.2	1.0
Trichoptera	5.7	0.7	1.3	0.2
Coleoptera	4.0	0.4	3.8	0.2
Diptera	10.0	0.5	12.6	0.3

Table 20. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Green River 49.7 miles (Sta. 7) below oilfield brine pollution.

Year:	1960		1962		1963	
Total number - volume:	4073 - 125.93		1641 - 111.88		4164 - 324.33	
Taxonomic group	Relative abundance (percentage of total number - total volume)					
Nemata	—	—	—	—	tr.	tr.
Oligochaeta	0.7	0.3	1.1	0.3	0.2	0.1
Hirundinea	—	—	—	—	tr.	tr.
Amphipoda	—	—	—	—	0.1	tr.
Decapoda	—	—	—	—	0.6	3.5
Gastropoda	66.3	77.0	73.9	87.7	74.2	88.8
Pelecypoda	0.3	17.0	6.1	8.3	5.3	6.5
Hydracarina	tr.	tr.	—	—	0.1	tr.
Ephemeroptera	1.5	0.1	4.8	0.3	6.9	0.2
Odonata						
Anisoptera	0.1	0.4	1.5	0.5	0.4	0.2
Zygoptera	—	—	0.1	tr.	tr.	tr.
Megaloptera						
Corydalidae	0.7	1.7	0.3	1.5	0.1	tr.
Plecoptera	0.1	0.3	1.4	0.6	5.1	0.6
Trichoptera	3.3	1.9	5.1	0.3	1.0	0.1
Coleoptera	0.3	tr.	2.2	0.2	1.4	tr.
Diptera	26.6	1.5	3.5	0.1	4.5	0.1

Table 21. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Green River 80.4 miles (Sta. 8) below oilfield brine pollution.

Year:	1960		1962		1963	
Total number - volume	852 - 72.11		689 - 80.25		2488 - 163.72	
Taxonomic group	Relative abundance (percentage of total number-total volume)					
Nemata	—	—	0.1	tr.	0.1	tr.
Oligochaeta	2.2	0.8	2.5	0.4	1.3	0.2
Isopoda	0.1	tr.	—	—	—	—
Amphipoda	—	—	0.1	tr.	—	—
Decapoda	—	—	0.6	6.7	0.3	4.4
Gastropoda	51.4	63.9	37.4	86.7	33.5	90.7
Pelecypoda	3.1	31.6	1.0	0.6	0.4	0.6
Hydracarina	0.1	tr.	0.1	tr.	0.2	tr.
Ephemeroptera	3.4	0.1	26.9	1.9	12.7	0.5
Odonata						
Anisoptera	0.1	tr.	0.6	0.1	0.2	0.1
Megaloptera						
Sialis	—	—	0.3	tr.	—	—
Corydalidae	2.0	2.8	1.5	1.6	1.6	1.7
Plecoptera	0.1	tr.	3.5	0.5	7.9	0.5
Trichoptera	0.8	tr.	3.5	0.6	4.5	0.3
Coleoptera	2.1	0.2	6.4	0.6	6.3	0.4
Diptera	34.5	0.5	15.5	0.3	31.0	0.7

Table 22. Relative abundance of each major taxonomic group of macro-invertebrates occurring in riffle samples from Big Pitman Creek (primary source of brine pollution).

Year:	1960		1961		1962		1963	
Total number - volume:	577 - 1.60		440 - 0.91		1803 - 12.03		9130 - 51.79	
Taxonomic group	Relative abundance (percentage of total number - total volume)							
Nematata	—	—	—	—	0.1	tr.	tr.	tr.
Oligochaeta	0.2	tr.	0.2	1.1	1.8	1.5	0.1	tr.
Hirundinea	—	—	—	—	0.1	0.3	tr.	0.1
Gastropoda	3.1	25.0	1.1	7.7	6.5	65.3	8.5	76.0
Pelecypoda	0.2	tr.	—	—	—	—	tr.	0.1
Hydracarina	0.2	tr.	—	—	—	—	0.1	tr.
Ephemeroptera	—	—	—	—	34.3	12.6	3.7	0.7
Odonata								
Anisoptera	0.2	tr.	—	—	0.2	2.2	tr.	0.9
Zygoptera	0.3	tr.	—	—	—	—	tr.	tr.
Megaloptera								
Corydalidae	1.0	28.1	—	—	0.3	1.5	0.3	0.4
Plecoptera	—	—	—	—	0.1	tr.	0.4	tr.
Trichoptera	—	—	—	—	0.2	0.1	1.7	2.3
Coleoptera	1.2	3.1	0.9	4.4	1.6	1.8	0.5	0.4
Hemiptera	0.5	tr.	—	—	—	—	—	—
Diptera	93.1	43.8	97.7	86.8	54.8	14.7	84.7	19.1