THE ECOLOGY OF WATER AREAS ASSOCIATED WITH COAL STRIP-MINED LANDS IN OHIO[1]

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INTRODUCTION

With the advent of the open-pit method of coal mining in Ohio in 1914, commonly referred to as strip mining, a new ecological habitat developed in the state. For a period of 35 years, subsequent to that date, the majority of the spoil banks created were left ungraded. In the ravines between the spoil banks, in the final cuts and in valleys of old fields where haul roads were established, small lakes, ponds, pools and marsh habitats developed. In ungraded strip lands a great number of aquatic habitats now exist in various stages of ecological succession. Some are 45 years of age. Relatively small excavating equipment, available prior to World War II, limited the stripping to areas of shallow overburden. These early operations ranged over widely dispersed coal fields in the southeastern counties of Ohio. The result was the development of aquatic habitats in a variety of overburden conditions. Thus, the physico-chemical aspects as well as the biota of the aquatic habitats are varied. Use of larger and more powerful machinery, in recent years, has resulted in larger continuous blocks of strip-mined land including a greater number of water impoundments having essentially similar watersheds.

Some isolated reclamation work on strip land areas was initiated in 1923 in Ohio, but large scale planting and seeding did not begin until 1940. Research pertaining to forest reclamation potentialities of the strip lands was started in 1937 by personnel of the Central States Forest Experiment Station of the U. S. Forest Service in southern Ohio (Chapman, 1944). Studies pertaining to wildlife utilization of such reclaimed areas were conducted by Yeager (1941) in Illinois. Wildlife population and utilization studies on reclaimed Ohio coal strip lands were conducted by Riley in 1947, 1952, and 1954. The ecology and management of strip mine aquatic habitats were also studied, especially the flora and fauna of such areas and the effect of the various overburden materials on the acidity of the water. Additional information concerning the ecology of such water impoundments has resulted from studies in Iowa (Ruhr, 1952), in Illinois (Bell, 1956; Arata, 1957; Lewis and Peters, 1954; Maupan, Wells, and Leist, 1954), and in Missouri (Heaton, 1951; Parsons, 1956).

OBJECTIVES

The data presented in this paper are part of an extensive study conducted during the period from August, 1946 to October, 1951. Data from additional research conducted during the period from June, 1952 to October, 1957, are also included. Aquatic habitats were studied in 15 counties of Ohio located within each of the several spoil districts (fig. 1). Several strip mine ponds were observed in Indiana and Illinois, but data on these are not included in this paper.

The objectives of the study were: (1) to identify and determine ecological relations of plants and animals inhabiting the water and its environs, (2) to determine which materials of the overburden were important contributors to the

[1]The majority of data are from research conducted by the author for the doctoral dissertation in the Graduate School of The Ohio State University under the direction of Dr. Charles A. Dambach, then Associate Professor, Dept. of Zoology and Entomology. During the study the author held a Wildlife Research Fellowship provided by the Ohio Cooperative Wildlife Research Unit. Additional financial aid was furnished by the Ohio Reclamation Association through The Ohio State University Development Fund.

TABLE 1
Fertility of Lower Kittanning spoil from Wayne Twp., Tuscarawas County, Ohio

Sample site	pH	Active Calcium	Available Phosphorous	Available Potassium
South slope	5.3	L*	L	L
South slope	7.0	L	L	L
North slope	7.3	H	M	H
North slope	4.8	M	M	L
North slope	4.5	L	L	L
Ravine	7.2	H	M	M
Ravine	7.5	M	M	L
Ridge	4.0	L	L	L
Ridge	4.3	L	L	L
Ridge	4.9	L	L	L
Ridge	3.5	L	L	L
Ridge	3.9	L	L	L
Ridge	4.0	L	L	L
Lake bottom	5.7	L	L	L
Lake bottom	5.9	L	M	L

*(L)—Low (H)—High (M) medium.

formation of acid present in many strip ponds, and (3) to determine practical methods of managing the watershed and the pond.

EXTENT OF COAL STRIP MINING IN OHIO

Strip mining of coal occurs in 27 counties, chiefly in unglaciated southeastern Ohio (fig. 1). During the year 1956, this method of mining accounted for approximately 24,606,104 tons out of the total of 39,758,986 tons produced in Ohio, or approximately 61 percent of all coal mined in the state. Of the 27 counties in which strip mining occurs, three contiguous counties, Belmont, Jefferson, and Harrison, produced 44 percent of all coal strip-mined (Ohio Dept. of Industrial Relations, 1956).

Strip mining operations, according to the bulletin cited above, had affected 82,115 acres of land from January 1, 1948 to January 1, 1957. This acreage has been or is to be graded and reclaimed as required by the *Coal Strip Mine Land Reclamation Act*, enacted by the 98th Ohio General Assembly, 1949–1950. Prior to January 1, 1948, an estimated 42,000 acres had been affected but left largely ungraded (Ohio Dept. of Industrial Relations, 1955). Thus, in January, 1957, Ohio had approximately 124,115 acres of coal strip lands interspersed with numerous aquatic habitats.

Although these areas are quite scattered throughout southeastern Ohio, rather large local concentrations exist. For example, in January, 1950, approximately 42 percent of the strip lands were located in Jefferson and Harrison counties (Riley, 1957). Other rather large units of coal strip lands were located in Tuscarawas County—4,452 acres, Columbiana County—4,049 acres, and Perry County—3,770 acres.

STRIP MINING METHODS AND POND FORMATION

The open-pit method of mining coal is done with power shovels, draglines, and tractor-drawn scoops, each having different effects upon the deposition of the overburden forming the watershed, the future physico-chemical conditions of the water and the physical characteristics of the pond. The majority of the stripping is done with power shovels and draglines. In shovel stripping, the equipment rests on the coal seam, and the excavating bucket is moved upward from the exposed coal to the top of the overburden material. The mixed material is then placed in a spoil bank which parallels the exposed cut. Thus, the toxic materials near the coal are mixed with the nontoxic materials near the surface. There is thus less chance of having the acid material deposited in patches.

During dragline stripping, the equipment rests at a higher elevation, and the overburden is removed in layers resulting in the lower, more acid materials being removed last and being placed on top of the spoil bank. With methods used prior to 1948, these patches remained in rather small areas, but under present grading operations, this material is now spread over much larger areas. In some instances operators may partially bury the more toxic materials. Thus, of these two methods, shovel operations are usually superior to those of draglines since the latter places large masses of acid material near or on the surface of the pond watershed. Oxidation of toxic material in the presence of water releases sulfuric acid (H_2SO_4) which accumulates in impoundments. Prior to 1948, rather small lakes and ponds formed between the spoil banks, while long, narrow ponds formed in the final cut. When larger equipment was used in areas of low overburden, a rather broad, oval-shaped impoundment remained.

During tractor and scoop operations, the top strata of the overburden are removed from rather large areas and this nontoxic material is placed on the bottom of the spoil pile, whereas the very acid material from layers directly above the coal seam are placed upon the surface of the spoil. Here grading can do little to cover or bury the acidic spoil. The lakes and ponds formed as a result of this type of operation usually are final cut lakes or oval inter-bank lakes, the latter being similar to many farm ponds. Still another type of pond is formed in valleys across which haul roads have been established. Much of the watershed for this type of pond usually consists of strip lands.

Following the removal of the coal from the pit area, either dams are constructed or sloughing of the highwall tends to cut off drainage from the area, thus creating an inpoundment. Encouragement has been given to the operators to impound water where ever possible by recent amendments to the *Coal Strip Mine Land Reclamation Act* by the 101st Ohio General Assembly. The water areas created usually ranged from a fraction of an acre up to 13 acres with one extreme of 100 acres. Watersheds ranged from one to 30 acres with vegetative cover on the watershed ranging from 25 to 100 percent. Vegetation consisted largely of a mixture of trees, shrubs, and herbs. Some exceptions were found, however, in which either trees or grasses and legumes were dominant. Most of the lakes were less than 25 ft deep, with one mine water supply lake having a depth of 40 ft. In final cut lakes the vertical highwall and the spoil bank are soon modified by erosion and sloughing. In oval-shaped lakes, where the overburden was shallow, the sides were gently sloping and a rather dense cattail community developed.

The water holding capacity of the lake basin depends largely upon the disintegration of the clays and shales present. Finely disintegrated material aids in sealing the porous structure of the spoil bank. The most desirable impoundment sites are those consisting of clay, such as that found in the bottom of the final cut. In the ravines between the spoil banks, the spoil structure is very porous, a condition which decreases greatly during the first few months after stripping due to the settling of the spoil, the disintegration of clays and shales and the attendant erosion of these particles from the adjacent slopes. Although basins are developed in these areas, they do not retain water as readily as those in final cuts. They are, however, more productive of plant and animal life, especially during the first few years, due to rapid erosion and the leaching of various chemical elements from the slope.

GEOLOGY OF THE STRIP MINING AREA OF OHIO

Coal stripping operations occur largely within the Pennsylvanian System; some stripping occurs in a narrow belt of the Permian System along the upper reaches of the Ohio River. The latter system is in parts of Belmont, Monroe, Washington, and Meigs Counties. The Pennsylvanian System, covering an estimated 12,340 sq miles (Stout, 1944), consists of some 50 coal seams interlain with thin bedded to massive sandstone, clays, iron ore bands, limonitic godes, shales (fossiliferous, calcareous, acid and carbonaceous in character), and thin to relatively thick beds of limestone. Along the north and west edge of the strip mine region small amounts of glacial till are also found.

The geologic strata overlying the various coal seams are referred to as overburden. Upon removal, this overburden is deposited in linear piles called spoil. Due to physical and chemical differences in the geologic strata, the spoil material pH, texture, structure, rate of weathering and overall chemical and plant growth factors exhibit a considerable range of variation. As a result of these differences and their effect on reclamation practices and management, including both land and water areas, the strip mining region of southeastern Ohio has been divided into eight districts (Limstrom and Merz, 1949) (fig. 1).

Nine seams of major importance are strip-mined in the eight districts. There are many instances were overburden materials, similar in their characteristics, will be found occurring in more than one specific district. On the other hand,

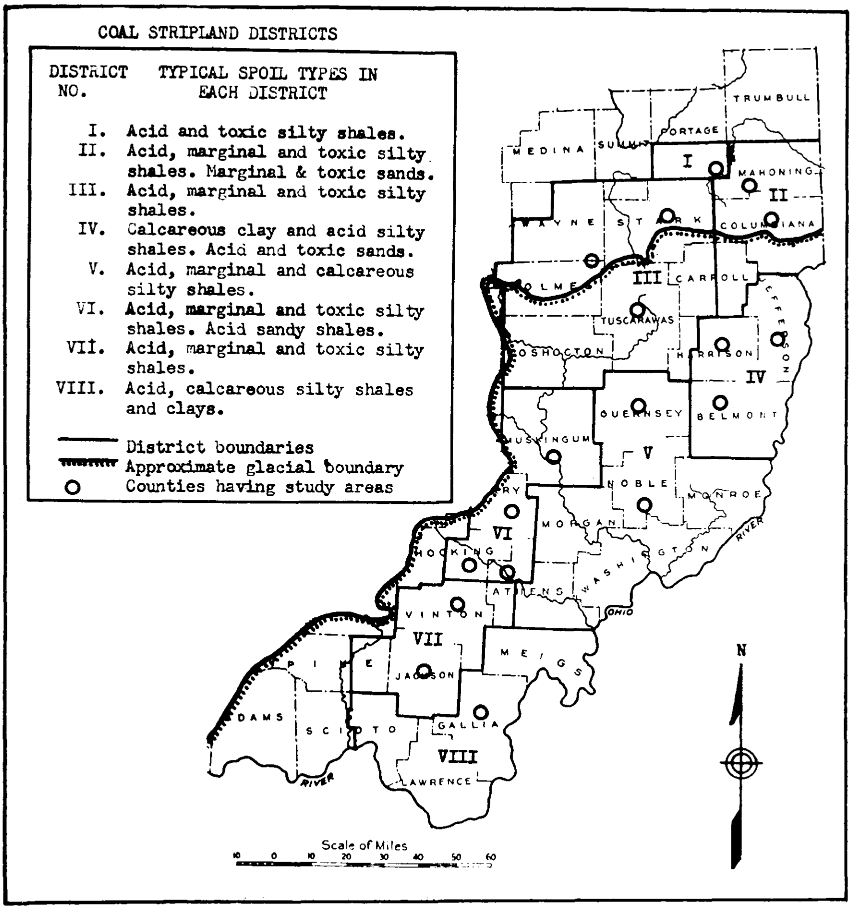

FIGURE 1. Ohio coal strip mining counties.

TABLE 2 *Effect of Lower Kittanning overburden materials on the pH of distilled water*

	Jan.	(1950)		Feb.				Mar.					Apr.				May					June		July	Aug.			
Date of pH test	11	18	25	1	8	15	22	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	31	7	14	21	28
Overburden Material*																												
FeS_2	3.4	3.2	3.1	3.0	3.0	2.6	2.7	2.5	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.3	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4
FeS_2+O_2	3.2	3.0	3.0	2.9	2.8	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.3	2.4	2.4	2.4	2.6	2.6	2.5	2.6	2.5
Cal. Shale	7.4	7.5	7.6	7.7	7.7	7.8	7.7	7.7	7.6	7.7	7.7	7.5	7.5	7.6	7.7	7.7	7.9	7.9	7.9	7.9	7.7	7.7	7.7	7.9	7.9	7.9	7.9	7.9
Cal. Shale$+O_2$	7.4	7.7	7.9	7.7	7.8	8.0	7.8	7.9	7.8	8.0	7.9	7.8	7.9	7.8	7.9	7.9	8.0	8.0	7.9	7.9	7.8	7.7	7.8	7.7	7.7	7.7	7.8	7.8
# 5 Coal	6.0	5.8	5.1	5.1	5.1	5.3	5.1	5.1	6.2	6.8	7.0	6.8	5.0	5.2	6.4	6.8	6.8	6.8	6.2	6.2	5.5	5.6	5.6	4.9	5.0	5.0	5.0	5.0
# 5 Coal$+O_2$	5.8	5.8	5.1	5.1	5.1	5.4	5.3	5.1	6.1	6.8	7.0	7.0	7.0	6.9	6.8	6.9	6.8	6.8	6.1	6.1	4.8	4.8	4.8	4.8	4.9	4.9	4.9	4.8
Carb. Shale	5.9	6.2	6.0	6.1	6.2	6.3	7.6	7.9	7.6	7.6	7.6	7.6	7.5	7.4	7.4	7.3	7.3	7.3	7.0	7.0	6.9	6.8	6.9	6.9	6.9	6.9	6.8	6.9
Carb. Shale$+O_2$	6.3	6.8	6.4	6.3	6.1	6.1	7.3	7.6	7.4	7.4	7.2	6.8	6.9	6.7	6.6	7.0	7.0	7.0	6.9	6.9	6.9	6.7	6.8	6.7	6.8	6.7	6.7	6.8
Blue Shale	7.2	7.5	7.7	7.7	7.7	7.8	7.7	7.7	7.7	7.9	7.7	7.6	7.5	7.5	7.6	7.6	7.7	7.7	7.7	7.7	7.6	7.6	7.6	7.7	7.7	7.7	7.8	7.8
Blue Shale$+O_2$	7.6	7.8	7.9	7.7	7.8	7.9	7.8	7.8	7.7	7.9	7.8	7.7	7.7	7.6	7.6	7.6	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.6	7.6	7.6	7.7	7.7
$FeCO_3$ 1949	7.6	7.4	7.7	7.7	7.8	7.7	7.7	7.8	7.7	7.7	7.7	7.6	7.6	7.6	7.8	7.7	7.7	7.7	7.9	7.9	7.7	7.7	7.7	7.9	7.8	7.9	7.8	7.8
$FeCO_3+O_2$ 1949	7.6	7.6	7.7	7.7	7.8	7.9	8.0	8.1	7.9	8.0	7.9	7.9	7.9	7.8	8.0	7.9	7.9	7.9	7.7	7.7	7.9	7.8	7.9	8.0	7.9	7.9	7.9	7.9
$FeCO_3$ 1922	7.0	6.9	7.4	7.7	7.7	7.8	7.6	7.7	7.7	7.7	7.8	7.7	7.7	7.8	7.7	7.9	7.9	7.9	7.9	7.9	7.7	7.8	7.7	7.9	7.9	7.7	7.7	7.7
$FeCO_3+O_2$ 1922	7.0	7.1	7.9	7.7	7.7	7.7	7.7	7.8	7.6	7.7	7.7	7.6	7.6	7.6	7.7	7.9	7.9	7.9	7.9	7.9	7.6	7.8	7.6	7.9	7.9	7.9	7.9	7.9
Sandstone	6.2	5.3	5.0	5.1	5.2	5.2	5.8	6.1	6.0	6.1	6.1	6.1	6.0	6.0	5.8	5.8	5.8	5.8	5.9	5.9	5.8	5.8	5.8	6.1	6.1	6.1	6.1	6.1
Sandstone$+O_2$	6.6	5.5	5.0	5.1	5.2	5.2	5.8	6.1	6.1	6.2	6.3	6.5	6.4	6.4	5.7	5.9	5.9	5.9	5.9	5.9	5.7	5.7	5.7	6.1	6.2	6.2	6.1	6.1

*A duplicate sample of each material was aerated to determine effects of added oxygen. Temperature maintained between 82° and 84° F.

TABLE 3 *Effect of Lower Kittanning overburden materials on the pH of distilled water*

	Jan.	(1952)	Feb.				Mar.				Apr.				May					June				July			
Date of pH test	18	25	8	16	22	29	7	14	21	28	4	11	18	25	2	9	16	23	30	6	13	20	27	4	11	18	25
Overburden Material*																											
FeS_2	2.3	2.1	1.8	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.7	1.8	1.7	1.6	1.6	1.7	1.6	1.7	1.7	1.6	1.4	1.3	1.4	1.4	1.4	1.3
FeS_2+O_2	2.1	2.8	2.8	2.7	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.6	2.4	2.6	2.6	2.4	2.6	2.6	2.6	2.5	2.3	2.5	2.4	2.4	2.4
Cal. Shale	7.0	7.3	7.9	7.9	7.9	7.9	8.0	7.9	8.0	8.0	7.8	7.7	7.8	7.8	7.7	7.8	7.7	7.8	7.8	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Cal. Shale$+O_2$	7.4	7.4	7.8	7.7	7.8	7.8	7.8	7.8	7.8	7.9	7.8	7.8	7.8	7.8	8.0	8.0	8.0	7.9	7.9	7.9	7.9	7.9	7.9	7.8	7.8	7.9	7.8
# 5 Coal	4.5	4.1	3.6	3.5	3.4	3.4	3.4	3.4	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9
# 5 Coal$+O_2$	4.9	4.8	4.6	4.7	4.7	4.8	4.9	4.9	4.6	4.5	4.5	4.6	4.5	4.5	4.4	4.5	4.5	4.5	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Carb. Shale	4.7	5.1	6.1	6.2	6.1	6.1	6.3	6.4	6.3	6.3	6.2	6.2	6.2	6.2	6.1	6.2	6.2	6.2	6.1	6.2	6.1	6.1	6.2	6.1	6.1	6.1	6.1
Carb. Shale$+O_2$	5.2	5.2	5.8	6.5	5.7	5.6	5.8	5.8	6.1	6.2	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	5.9	5.9	5.7	5.8	5.7	5.7	5.7
Blue Shale	7.7	7.6	7.9	7.9	7.9	7.8	8.0	8.0	8.0	8.0	7.7	7.8	7.8	7.8	7.7	7.8	7.7	7.7	7.6	7 6	7.8	7.8	7.9	7.8	7.9	7.9	7.9
Blue Shale$+O_2$	7.5	7.4	8.0	8.0	8.0	7.9	7.9	7.9	8.0	8.0	7.9	8.0	8.0	8.0	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
$FeCO_3$ 1949	7.1	7.2	8.1	8.1	8.2	8.2	8.2	8.2	8.3	8.2	8.0	8.0	8.0	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.2	8.2	8.1	8.1	8.1	8.1
$FeCO_3+O_2$ 1949	7.3	7.3	7.9	7.9	7.9	7.8	8.0	8.0	8.1	8.0	7.9	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.1	8.1	8.1	8.1	8.1	8.1
$FeCO_3$ 1922	7.1	7.3	7.9	8.0	8.1	8.0	8.1	8.0	8.2	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.4	8.4	8.4	8.4	8.4	8.4
$FeCO_3+O_2$ 1922	7.3	7.5	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.2	8.2	8.3	8.3	8.3	8.3	8.3
Sandstone	4.1	4.1	3.8	3.7	3.6	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.5	3.4	3.5	3.5	3.5	3.5
Sandstone$+O_2$	4.2	4.3	4.2	4.3	4.3	4.4	4.4	4.4	4.3	4.3	4.3	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.4	4.5	4.5	4.5	4.5	4.5

*Overburden material collected from same highwall used in experiment of table 2.

within any one district, extreme variations of pH, plant toxicity, soil structure and texture may occur; in some instances these variations may be present on an area no larger than one acre. Sometimes the variations are due to differences in the geologic strata, whereas in others it may be due to the method of stripping.

Research conducted by personnel of the Central States Forest Experiment Station indicates that the textural classification of Ohio spoil was ten percent sand, sandy shales and sandstones, about 42 percent silty shales and loams and 48 percent clay and limestone. The last-named textural type was found largely in Belmont, Harrison, and Jefferson Counties. Less than four percent of the spoil material in Ohio was classed as toxic, six and one-half percent as marginal, 47 percent acid, and slightly more than 40 percent calcareous.

Production by seams during 1956 was 986,593 tons of numbers four and four A, 1,294,228 tons of number five, 3,104,871 tons of number six, 9,825,808 tons of numbers eight and eight A, and 2,777,504 tons of number nine. (The figures given here are approximate, since some operators report total tonnage for as many as three or four seams with no individual breakdowns.) During the same year, 44 percent of the coal produced by strip mining came from the three counties mentioned above, an area with considerable limestone, marly clay, and calcareous shale overburden (Ohio Dept. of Industrial Relations, 1956).

EFFECT OF OVERBURDEN MATERIALS ON THE pH AND FERTILITY OF LAKE WATER

Water supply for the impoundments in the strip lands results from run-off and springs or in some instances as overflow from flooded streams, the latter occurring when the stripping is done on lower coal seams in the valleys.

The chemical condition of the impounded water, especially the pH, as reported in this paper is largely the result of the reactions of three or four materials found in the overburden or the coal seam. Due to the youthfulness of these impoundments, the small amounts of organic matter present probably exert little influence on pH. The acid produced by the organic matter is of minor significance to the aquatic organisms except perhaps when the critical pH is reached for a particular species. Grading operations and extent of vegetative cover on the watershed can be influential, however, in controlling the rate of oxidation and release of certain acidic materials.

Overburden materials having important effects on the pH of water include acid and marly clays, sandy shale, sandstone, limestone, siderite ($FeCO_3$) and marcasite (FeS_2). Siderite, commonly called iron carbonate, occurs in abundance as various sized concretions in layers above the number five or Lower Kittanning coal seam. Marcasite is commonly called iron sulphide, "gob" or iron pyrite, and may occur as layers one to five in. thick in the coal seam or as crystals distributed throughout the overburden. Actually, pyrite differs from marcasite in that the latter alters much more readily to melanterite ($FeSO_4 \cdot 7H_2O$) and limonite ($Fe_2O_3 \cdot nH_2O$) upon oxidation. Of the group of overburden materials tested under laboratory conditions, marcasite produced a pH that would seriously affect the water and the succeeding ecological events. Very small amounts of marcasite crystals in shale may produce relatively acid substrate in contrast to a nearly neutral substrate in their absence. The deleterious effects of marcasite are often increased by operational activities such as disposing of the waste "gob" somewhere on the watershed and leaving it uncovered. Frequently the "gob" may be gleaned from the coal and left in the bottom of a "dry" pit. Upon oxidation, the toxic wastes are carried from the pit into nearby streams or impoundments by run-off. Other materials such as the calcareous shale, marly clay, limestone and siderite tend to buffer, to a degree, the acidity produced by marcasite bearing material. The former materials tend to produce a neutral to slightly alkaline pH.

The chemical reactions of the overburden materials tested are as follows:

Marcasite (FeS_2)—alters to ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4) and later to hydroxide pseudomorph such as limonite ($Fe_2O_3 \cdot nH_2O$) or melanterite ($FeSO_4 \cdot 7H_2O$) (Kraus, Hunt and Ramsdell, 1936). (A pseudomorph results from chemical alterations such as hydration or oxidation while retaining its external features).

Siderite ($FeCO_3$)—forms a pseudomorph after limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) and usually contains some limestone ($CaCO_3$) and/or rhodocrosite ($MnCO_3$). Chemical decomposition products are limonite, hematite (Fe_2O_3) a micaceous oxide, and magnetite (Fe_3C_4).

Limestone ($CaCO_3$)—occurs in calcareous shales and marly clays or as a layer one to several feet in thickness in the overburden of the Harrison-Jefferson-Belmont County region. Contained in the same material may be varying amounts of magnesium, iron and manganese which may replace the calcium. Resulting chemical changes produce the pseudomorph dolomite ($CaMg(CO_3)_2$) which is a carbonate of calcium and magnesium in a ratio of one to one.

TABLE 4

Effect of Lower Kittanning overburden materials on the pH of distilled water

Date of pH reading	Jan. 23	(1953) 30	Feb. 6	13	20	27	Mar. 6	13	20	27	Apr. 3	10
Overburden Material*												
FeS_2	1.4	1.8	1.8	1.8	1.6	1.7	1.8	1.8	1.7	1.7	1.8	1.8
FeS_2+O_2	2.4	2.6	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.6	2.6
Cal. Shale	7.3	7.4	7.5	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Cal. Shale$+O_2$	7.4	7.5	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
# 5 Coal	3.2	3.5	3.3	3.3	3.3	3.3	3.2	3.3	3.3	3.3	3.3	3.3
# 5 Coal$+O_2$	3.3	4.4	4.5	4.5	4.4.	4.5	4.4	4.5	4.5	4.5	4.5	4.5
Carb. Shale	5.3	5.0	5.1	5.1	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Carb. Shale$+O_2$	4.6	4.6	4.6	4.6	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Blue Shale	7.2	7.1	7.1	7.1	7.2	7.2	7.2	7.2	7.2	7.2	7.1	7.1
Blue Shale$+O_2$	6.7	7.3	7.3	7.3	7.5	7.5	7.5	7.5	7.5	7.5	7.4	7.4
$FeCO_3$ 1949	7.9	7.6	7.7	7.7	7.7	7.7	7.7	7.6	7.6	7.6	7.7	7.7
$FeCO_3+O_2$ 1949	7.6	7.8	7.8	7.8	8.2	8.1	8.1	8.1	8.1	8.1	8.2	8.2
$FeCO_3$ 1922	7.6	7.8	7.8	7.8	7.7	7.7	7.7	7.7	7.8	7.8	7.7	7.7
$FeCO_3+O_2$ 1922	7.6	7.7	7.7	7.7	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Sandstone	4.3	4.4	4.3	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Sandstone$+O_2$	4.6	4.5	4.6	4.6	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2

*Same material used in experiment of table 3, after drying for five months. Water added January 16, 1953.

Chemical reactions occurring may be the oxidation of marcasite (FeS_2) to ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4). The carbonates, limestone ($CaCO_3$) and siderite ($FeCO_3$), tend to react with the water to form calcium hydroxide ($Ca(OH)_2$) and carbon dioxide (CO_2) which acts upon the $FeSO_4$ to from ferrous hydroxide ($Fe(OH)_2$) and calcium sulphate ($CaSO_4$). The $Fe(OH)_2$ forms flakes while the calcium sulphate ($CaSO_4$) is relatively insoluble and both precipitate out. The sulfuric acid (H_2SO_4) ionizes readily and produces a great number of free hydrogen ions, increasing the pH considerably. The carbonate ($CaCO_3$) acts upon sulfuric acid to produce carbonic acid (H_2CO_3) and $CaSO_4$, with the former breaking down into water and carbon dioxide.

In recent years Temple and Koehler (1954) have studied the role of certain bacteria in the production of acid mine water. The two bacteria *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* have been found to have important roles in sulphur and iron oxidation respectively. Apparently, considerably more research is needed before their significance as agents is completely understood.

The fertility of the spoil material found in the Allegheny Formation from above the number five coal seam is rather low as revealed by results of fifteen samples analyzed by the Dept. of Agronomy, the Ohio State University (table 1). Samples were collected from the surface six inches of spoil that had been deposited by strip mining in 1919 (Riley, 1947).

Recent analysis of spoil samples following grading operations on weathered spoils, similar in age to those discussed in this paper, indicate that the available phosphorous and potash tend to leach several feet down into the spoil material. Thus, these nutrients would be a factor influencing the chemical condition of the water during the early years, but would be of greatest significance to vegetation on the watershed at a later time.

EFFECTS OF OVERBURDEN MATERIALS ON THE pH OF WATER UNDER LABORATORY CONDITIONS

Duplicate samples of eight different kinds of overburden materials, and number five coal, were collected from a highwall within the Allegheny Formation in Wayne Twp., Tuscarawas County, Ohio. Two samples of iron carbonate ($FeCO_3$) were collected from spoil that had weathered for 28 and 30 yr, respectively. During the first test series, January 11, through August 28, 1950 (table 2), 100 gm of each overburden material were crushed to two mm mesh size and placed in battery jars containing 2500 cm^3 of distilled water (pH 6.5). Each sample of overburden material was checked for purity. The water level was kept constant throughout the entire period of eight months and the first test, in which a Beckman pH meter was used, was made 24 hr after initiation of the experiment and subsequently at intervals of one week. The top of the jar of one sample of each overburden material was covered with a cellophane cap to simulate conditions on the bottom of a strip mine pond. The duplicate sample of each material was aerated, using a small air pump, to simulate conditions where the water level covers only part of the coal face or acid overburden material and where additional oxygen may tend to increase the rate of oxidation and consequent release of acid.

Following the first series of tests, a second series was run from January 18, through July 25, 1952 (table 3), and from January 23, through April 10, 1953 (table 4). During the second experiment, 20 gm of each overburden material, two mm mesh, were placed in battery jars containing 500 cm^3 of distilled water (pH 6.06). The temperature for all test solutions ranged from 82° to 84° F. During the period of the second test series (1952–1953), the water was completely removed from each sample on August 2, 1952, and the remaining solids permitted to air dry until January 23, 1953, when the tests were resumed for three and one-half months.

Data resulting from the two series of tests indicate the effect of the marcasite (FeS_2) and other materials of the overburden on the pH of distilled water (tables 2, 3 and 4). During the first test series the marcasite lowered the pH of distilled water from 6.5 to 3.2 and 3.4 in 24 hr. Recent tests have indicated this extreme pH change occurs during the first hour after the marcasite is placed in the water. It is interesting to note that when completely fresh marcasite is removed from the interior of a solid "gob ball," or nodule, where there is little chance of the bacteria *T. thiooxidans* and *T. ferrooxidans* being present, this same rapid reduction in pH occurs. It is evident that, at least initially, the release of acid is largely the result of a chemical reaction which takes place without the presence of bacteria.

In the second test series, of seven months duration, using less solute and solvent (20 gm of marcasite and 500 cm^3 of water), the pH of the solution ranged between 1.3 and 2.8 (table 3). After testing the second series for seven months, then air drying the materials in each sample for approximately five and one-half months, tests were resumed for a period of three and one-half months during which the pH ranged between 1.4 and 2.6 (table 4). Only very slight differences in pH were registered as a result of aeration.

Of the remaining overburden materials used, from the Allegheny Formation, the pH measurements of three samples indicate they may contain a sufficient amount of marcasite to be a factor in depressing the pH (tables 2, 3, and 4). The samples of number five coal produced fairly acid conditions in both test series. In the first coal series, pH tests ranged from 4.8 to 7.0 while in the second series the pH ranged from 2.9 to 4.9. The first test series of carbonaceous shale gave a

TABLE 5

Plankton of six coal strip mine lakes

Age of lakes	22 yr	22 yr	20 yr	10 yr	1 yr	1 yr
Spoil district	III	III	IV	IV	IV	III
Dissolved O_2 ppm	9.1	9.1	10.7	7.7	6.9	8.1
CO_2 ppm	26.1	23.0	0	204.0	0	125.8
pH	5.5	6.5	7.0	4.0	7.0	4.0
Animals						
Protozoa						
Difflugia spp.		C				
Dinoflagellate spp.		A				
Rotifera						
Anurea spp.			C		R	
Cathypna spp.		C				
Synchaeta spp.			R			
Unknown spp.				R		
Arthropoda						
Cyclops spp.		C				
Plants						
Chlorophyceae						
Ankistrodesmus		R				
Chaetosphaeridium spp.		R				
Closterium spp.		R			R	
Cosmarium spp.	R	A				
Desmids	R	A	A	R		
Gonatozygon spp.		R				
Gonium spp.		R				
Hormidium spp.			A			
Microthamnion spp.		R				
Mougeotia spp.		R				
Oedogonium spp.		C				
Pleurotaenium spp.	R	A				
Spirogyra spp.		R				
Zygogonium spp.	R					
Bacillarieae						
Cymbella spp.			R			
Diatoma spp.		R		R		
Eunotia spp.				R		
Gomphonema spp.		R				
Navicula spp.	R	R	A	A		A
Synedra spp.			C			
Tabellaria spp.		R				
Euglenophyceae						
Euglena spp.			A	R		
Trachelomonas spp.			R			
Myxophyceae						
Arthrospira spp.			R			
Oscillatoria spp.			C			
Unknown spp.				R		
Dinophyceae						
Peridinium spp.		A				
Chrysophceae						
Dinobryon spp.					A	
Heterokontae						
Tribonema spp.			C			

(A) Abundant. (C) Common. (R) Rare.

pH range from 5.9 to 7.9 while in the second series the range was 4.4 to 6.4. Tests of the lower Freeport sandstone gave a pH range for the first series of 5.0 to 6.6 while in the second series the range was 3.4 to 5.2. The variation in pH between materials from the same overburden used in the two test series could be attributable to variation in amount and concentration of marcasite present.

The other three samples tested, namely hard calcareous shale, soft blue shale, and siderite (1922 and 1949), produced a pH consistently neutral to slightly alkaline. In the case of siderite, samples of two different ages were used; one sample was taken from a concretion that had weathered since 1922, the other from a highwall where it had been sealed off completely from air.

TABLE 6

Results of test netting a six acre Ohio strip mine lake

Species	Average length (standard) in inches	Length maximum (in.)	Length minimum (in.)	Total number measured
Sucker	13.1	16.0	9.5	52
Bluegill	5.5	10.0	4.0	43
Largemouth black bass	9.3	13.0	6.0	16
Brown bullhead	8.5	10.0	7.0	8
Warmouth bass	6.0	6.0	6.0	3

As a result of the series of tests, four overburden materials of the Allegheny Formation, namely coal, sandstone, carbonaceous shale and marcasite, appeared to be responsible for the production of the acid condition associated with water impounded in the coal strip lands. In each instance, marcasite (FeS_2) is the causative agent. In the first three overburden materials discussed above, this mineral is present in varying degrees while "gob" is almost entirely marcasite.

Prior to 1952, I observed a total of nine buried "gob" dumps on the watersheds of a similar number of ponds. Each had been buried with an average of three ft of nontoxic spoil material and each pond contained water suitable for a variety of plant and animal life. I have observed lakes with a concentration of "gob" on the watershed, having water with a pH of 2.4, while 100 ft away where no concentration of "gob" existed, the pH of the water tested 6.1 (Riley, 1952). In recent years the burial of the "gob" with nontoxic spoil material or submergence of "gob" and toxic carbonaceous shales by impoundment have proven to be very practical and economical methods of eliminating the production and release of acid. By eliminating through burial or submergence those overburden materials containing concentrations of marcasite, the acid released by the marcasite contained in other overburden materials is buffered sufficiently to be inconsequential to animal and plant life.

THE EFFECT OF ACID RELEASED FROM OVERBURDEN MATERIALS ON FISH

At the conclusion of the pH tests on the first series of overburden materials, one bluegill fingerling (*Lepomis m. macrochirus*) was placed in each water sample. The individuals placed in the marcasite samples, pH 2.4 and 2.6, were dead in exactly 20 min, while those individuals in all other samples were still in excellent condition at the end of 96 hr. The mucus on the fingerlings in the marcasite began to coagulate in four min; the individual in the coal sample, (pH 4.9), appeared to suffer no ill effects. In additional tests using the common shiner (*Notropus cornutus frontalis*), individuals in the marcasite samples were dead in 22 min, while those in the remaining samples appeared to be in good condition at the end of 96 hr. Even aeration of the water containing the marcasite failed to increase the survival time for either of the two species of fish. While it may appear that death resulted from coagulation of the mucus on the gills, thus impairing respiratory efficiency, one cannot be sure. Temperature, dissolved oxygen, water hardness, species of fish used, and a host of other factors might have been responsible. Recent work by Doudoroff and Katz (1950) indicate that under otherwise favorable conditions water having a pH range of 5.0 to 9.0 is not lethal for most fully developed fresh water fishes. These authors also indicate that a more extreme pH, perhaps below 4.0, can be tolerated indefinitely by resistant species. However, tolerance to low pH values by a desirable species of fish is only part of the problem in management of such waters; there is also the effect of the low pH on the entire biota and the influence on the production of food for the desirable species.

SURVEY OF AQUATIC LIFE IN COAL STRIP LAND LAKES AND PONDS

Thirteen lakes and ponds were surveyed in Columbiana, Harrison, Jefferson, Tuscarawas, Muskingum, and Jackson Counties. The density of the flora of the lakes was found to be dependent on age, water depth, fertility, spoil type, pH and degree of slope of the lake basin. One very shallow lake in Muskingum County, for example, contained a large amount of the white water lily (*Nymphea tuberosa*) covering 90 percent of the water surface. Emergent aquatics included the narrow-leaf cattail (*Typha angustifolia*), common cattail (*T. latifolia*), arrowhead (*Saggitaria latifolia*), fox sedge (*Carex vulpinoidea*), sharp-fruited rush (*Juncus acuminatus*), soft rush (*J. effusus*), burreed (*Sparganium* spp.), and bulrush (*Scirpus cyperinus*). Submerged aquatics included curly pond weed (*Potamegeton crispus*), needle spike rush (*Eleocharis acicularis*), water-starwort (*Callitriche* spp.), common waterweed (*Elodea canadensis*), coontail (*Cerataphyllum* spp.) (Muenscher, 1944), and the alga (*Chara* spp.) (Smith, 1933). A moss (*Drepanocladus fluitans*) (Conard, 1944) was found in one lake in Tuscarawas County. Curly pond weed was found in two alkaline lakes (pH 7.5) in Jefferson County while coontail and water weed were found in two alkaline lakes of Harrison and Jefferson counties. Within the 13 lakes studied narrow-leaf and common cattail were by far the most common vascular plants.

Plankton samples were collected from six of the 13 lakes ranging from one to 22 yr old to determine the variety of microorganisms associated with this type of aquatic environment. Identification of the samples revealed a total of seven classes of algae including 29 genera, two Protozoa, four Rotifera and one Arthopoda. The samples were collected on May 1, 1948; thus, the data merely reveal what was present on that particular day, and it should not be inferred that this sample is representative of organisms found throughout the year. Table 5 reveals the various genera of plankton identified, the age of the body of water, pH, dissolved oxygen and free carbon dioxide. Plankton counts indicated a scarcity of numbers when compared to those in many nonstrip mine impoundments. It is interesting to note that one 22-yr-old lake, with a slightly acid pH (6.5), had the greatest number of genera of algae (17), two Protozoa, one Rotifera and one Arthropoda. In an earlier study of this same lake 14 species of aquatic insects were collected and identified (Riley, 1947). They included the following Coleoptera: (*Berosus striatus*), (*Enemidotus edentulus*), (*Enemidotus muticus*), (*Coptotomus interrogatus*), (*Dineutes americanus*), (*Dytiscus fasciuentris*), (*Tropisternus* spp.) (Blatchley, 1910); order Hemiptera, (*Aretocorive parshley*), (*Belostoma fluminea*), (*Pelacoris femoratus*), (*Sigara atopodonta*) (Blatchley, 1926); order Odonata, (*Aeshna sitchensis*), (*Aeshna* spp.), and (*Arglatibialis* spp.) (Wright and Peterson, 1944).

Within the 13 lakes studied in Ohio, a total of 15 species of fish were collected and identified. (Species were collected and identified by test netting, fly and bait casting and personal observation of catch records by responsible lake owners.) Included within this group were the bluegill, largemouth black bass (*Micropterus* *salmoides*), white crappie (*Pomoxis annularis*), black crappie (*P. nigromaculatis*), brown bullhead (*Ictalurus n. nebulosus*), smallmouth black bass (*Micropterus d. dolomieu*), channel catfish (*Ictalurus lacustris punctatus*), gizzard shad (*Dorosoma cepedianum*), warmouth bass (*Chaenobryttus gulosus*), carp (*Cyprinus carpio*), red-horse sucker (*Moxostoma* spp.), common white sucker (*Catostomus c. commersonnii*), horny head chub (*Hybopsis biguttata*), blue catfish (*Ictalurus furcatus*) and the common shiner (Hubbs and Lagler, 1949). In addition the brown trout (*Salmo trutta*), rainbow trout (*S.gairdneri*), yellow perch (*Perca flavescens*) and redear sunfish (*Lepomis microlophus*) have been introduced in four coal strip mine lakes of Harrison County. The first three have been successful in the "stock and take" program but did not reproduce while redears have reproduced prolifically.

During the fall of 1950, one six-acre unmanaged lake in Jefferson County was test-netted for a period of 96 hr with the nets being lifted every 24 hr. Five species, including a total of 122 individuals, were netted. Included were 52 white and red horse suckers, 43 bluegills, 16 largemouth black bass, eight brown bullheads and three warmouth bass (table 6).

No information was available on the original stocking, such as species composition, size of stock and date of stocking; thus, the data are not considered too significant.

Other data concerning populations and size included largemouth black bass, 27 in., bluegills, nine in., brown bullheads, 11 in., smallmouth black bass, 20 in., common suckers, 16 in. and channel catfish, 15 lb from a lake in Muskingum County. In one Jackson County strip mine lake largemouth black bass, 22.5 in., gizzard shad, ten in. and bluegills, eight in. were removed.

During October, 1947, a one-acre strip mine lake in Tuscarawas County (pH 5.5 to 6.5) was stocked with 889 bluegills (1 in.–2 in.) and 134 largemouth black bass (1 in.–3 in.). The lake was observed approximately twice per month; bluegills reproduced during the spring and summer of 1948 while bass were not observed after ice formed on the lake in November, 1948. In 1949, 100 bluegills were removed averaging six in. in length (5.5 in.–6.5 in.) while 85 were removed during May and June, 1950, averaging the same as in the former year. In 1951, 175 bluegills were removed averaging 4.5 in. (3.5 in.–6.0 in.).

An additional 500 bass (2.5 in.–4 in.) were stocked in the same lake in October 1952 and 500 again in August, 1955 (2.5 in.–3.5 in.). The first bass spawn were observed in May, 1954. Since the summer of 1955, bass (10 in.–18 in.) and bluegills (5.5 in.–9.5 in.) have been harvested from this lake. During the summer of 1958, 114 bluegills were removed within the latter size range.

Amphibians collected and identified included the common toad (*Bufo americanus*), green frog (*Rana clamitans*), leopard frog (*R. pipiens*), pickerel frog (*R. palustris*) and the cricket frog (*Acris crepitans*) (Walker, 1946). Eighty bullfrog tadpoles (*R. catesneiana*) were stocked in one Ohio strip mine pond in May, 1951. Three adult bullfrogs and numerous tadpoles were observed in the same pond in June, 1958. Of the amphibians the green frog was by far the most abundant.

Three species of reptiles were identified including the snapping turtle (*Chelydra serpentina*), painted turtle (*Chyrsemys belli marginata*), and the water snake (*Natrix sipedon*) (Pratt, 1935).

Fifteen species of waterfowl and eight species of shorebirds were observed on or around strip mine impoundments. Twelve of the 15 waterfowl species were observed on two small lakes in Tuscarawas County. Species observed and identified included the Canada goose (*Branta c. canadensis*), common mallard (*Anas p. platyrhynchos*), common black duck (*Anas rubripes*), gadwall (*Anas strepera*), baldpate (*Mareca americana*), blue-winged teal (*Anas discors*), wood duck (*Aix sponsa*), red head (*Aythya americana*), canvasback (*Aythya valisineria*), American golden-eye (*Glaucionetta clangula americana*), bufflehead (*Glaucionetta albeola*), hooded merganser (*Lophodytes cucullatus*), American merganser (*Mergus merganser* *americanus*), horned grebe (*Colymbus auritus*) and the pied-billed grebe (*Podilymbus p. podiceps*). Shorebirds included the green heron (*Butorides v. virescens*), great blue heron (*Ardea herodias*), American bittern (*Botaurus lentiginosus*), woodcock (*Philohela minor*), Wilson's snipe (*Capella gallinago delicata*), killdeer (*Charadrius v. vociferus*), greater yellow-legs (*Totanus melanoleucus*), and lesser yellow-legs (*Totanus flavipes*) (Peterson, 1939).

During the migratory seasons fairly large populations of waterfowl were observed on the strip mine lakes. In September, 1949, 43 mallards were observed on seven acres of water, and in October, 100 wood ducks were identified on the same area. During August, 1949, six wood ducks were observed on a 13 acre strip mine lake. Waterfowl were present in greatest numbers during the migratory seasons although three species were found nesting around or near strip mine ponds. During 1948 and 1949, two broods of mallards were observed on a Jefferson County pond; one brood of blue-winged teal was observed on a pond in Harrison County during 1955 and 1956; a brood of wood ducks in 1956 and one brood of mallards in 1956, 1957 and 1958, all in the latter county.

During the summer of 1949, 18 nests of the red-wing black bird (*Agelaius p. phoeniceus*) containing young were observed around one seven-acre lake.

Mammals living in or near the aquatic strip mine habitats were the muskrat (*Ondatra z. zibethica*), beaver (*Castor c. canadensis*), raccoon (*Procyon l. lotor*), and mink (*Mustela v. vison*) (Bole and Moulthrop, 1942). Both the muskrat and raccoon were present in fairly large numbers with the latter utilizing such areas in search of food. The muskrat was found in nearly every type of strip mine lake or pond and the numerous paths observed by the investigator indicated considerable inter-pond movement. In recent years the beaver has become very numerous in strip mine ponds in Columbiana County. The acidity of the water seemed to have little effect on the use of such areas by the muskrat. This species was inhabiting ponds having a pH as low as four. Dens were usually present in lakes having steep sided basins while houses were more numerous in shallow ponds less than two ft in depth. Bank dens were usually very shallow, and in the spring usually caved in, possibly due to the spoil material being fairly loose. Fifteen and 13 dens, respectively, were observed along 200 ft of shoreline of two lakes in Harrison County. Two landowners in Muskingum County harvested 40 muskrats from 13 acres of water and 50 from six acres in 1948.

SUMMARY

1. The open-pit method of coal mining initiated in Ohio in 1914 had affected approximately 124,115 acres of land in 27 counties as of January 1, 1957.

2. As a result of the stripping operations, hundreds of acres of water were impounded in final cuts, behind haul roads across old fields or between the spoil banks. Within the strip lands, aquatic habitats included marshes, ponds and lakes. They ranged in age from one to 45 years and up to 13 acres in surface area. The extreme was one lake of 100 acres. Depths usually were less than 25 ft; however, one had a depth of 40 ft.

3. Watersheds ranged from one to 30 acres and had from 25 to 100 percent of the spoil surface covered by vegetation. Since the geological strata or overburden above the coal seams varied throughout the 27 counties, the physicochemical conditions of the watershed soil and impounded water were greatly modified, resulting in ecological conditions quite different from those in noncoal strip mine ponds.

4. The type of soil making up the lake basin varied from clays in final cuts to clay, silty or sandy shales, sandstones and limestones of inter-spoil basins to undisturbed soil where lakes were formed as a result of a haul road being constructed across a valley. Clay provided an almost impervious basin, thus reducing the possibility of water loss through leakage.

5. Stripping methods, depending on the type of machine used in overburden removal, influenced the physico-chemical complex of the impounded water. Stripping shovels usually produced well mixed spoil material for the watershed while draglines and scoops tended to remove the acid carbonaceous shales from immediately above the coal seam last and place them on top of the less toxic materials of the watershed.

6. The textural classification of the spoil material forming the watersheds of strip land ponds and lakes has been categorized as ten percent sand, sandy shales and sandstone, about 42 percent silty shales and loams and 48 percent clay and limestone. Less than four percent of the spoil material was classed as toxic, six and one-half percent as marginal, 47 percent acid and slightly more than 40 percent calcareous.

7. Water supply for these impoundments usually came from run-off or from springs. Occasionally when the stripping was done in a valley, overflow from a nearby stream was the principal source. The pH, fertility, and productiveness of the impounded water was greatly influenced by the particular geological strata of the watershed. Watershed spoil removed from above coal seam four (Brookville) and eight (Pittsburgh) usually contained sufficient calcareous material resulting in water having an alkaline pH, while water flowing over spoil material from the other seams was usually acidic. Productiveness of the pond was influenced not only by pH and fertility of the spoil, but also by the rate of disintegration of spoil, leaching, amount of silting and age of the impoundment.

8. Fifteen soil samples from number five spoil (27 years old) in the Tuscarawas County area were analyzed. The pH of the soil samples ranged from 3.5 to 7.5. Tests for active calcium, available phosphorous and available potassium were generally low.

9. Overburden materials deposited as spoil and influencing the pH included acid and marly clay, sandy, silty or carbonaceous shale, sandstone, limestone, siderite ($FeCO_3$) and marcasite (FeS_2). Limestones, various shales and sandstone produced a pH range from medium acid to slightly alkaline.

10. Laboratory tests of eight different overburden materials above the number five coal seam, and including the coal itself, indicated that marcasite (FeS_2) was largely responsible for the toxic condition present in many ponds associated with this coal seam. Other materials releasing considerable acid and consequently producing a fairly low pH were number five coal and sandstone associated with this seam. The various shales and siderite ($FeCO_3$) produced a pH range from medium acid to slightly alkaline. Aeration of the control sample did not produce any great differences in pH.

11. At the conclusion of the first series of tests on overburden materials, one bluegill fingerling was placed in each sample. Those individuals placed in the marcasite samples (pH 2.4 and 2.6) were dead in 20 min, while those in the remaining samples appeared to be in excellent condition at the end of 96 hr. The mucus on the bluegills, in the marcasite samples, coagulated in four min and their erratic behavior indicated respiratory difficulties and possible irritation of the skin. A second species, the common shiner, was used and death resulted in exactly 22 min in the marcasite samples. In the remaining samples no difficulties were apparent at the end of 96 hr. Aeration of one sample of marcasite did not increase the survival period for the test specimen.

12. In 13 strip mine lakes surveyed in Columbiana, Harrison, Jefferson, Tuscarawas, Muskingum, and Jackson Counties, narrow-leaf and common cattail and arrowhead were the most abundant species of vascular plants. Submergent aquatics included five species of vascular plants, and one species of moss.

13. Studies of plankton samples collected from six ponds ranging in age from one to 22 yr included two genera of Protozoa, four of Rotifera, 29 of algae and 15 Arthropoda consisting of 14 species of Insecta and one of Crustacea. Of the

six lakes from which plankton samples were collected, the most productive was a 22-yr-old lake associated with the number five coal seam having acid overburden materials.

14. A total of 15 species of fish were collected and identified within 13 lakes of six counties. Four species of frogs and one species of toad were found, while the bullfrog was introduced into one pond by the author. The snapping turtle, painted turtle and common water snake were identified as inhabitants of these aquatic habitats.

15. Fifteen species of waterfowl and eight species of shorebirds were observed either on the lakes or along the shore areas. The mallard, wood duck and blue-winged teal all were observed nesting on or near strip mine ponds in Harrison County.

16. Four mammals, all fur-bearers of importance, were inhabiting the marsh and pond areas. Of the four, the muskrat was the most numerous inhabitant and was taken in greatest numbers by trapping. Muskrat production based on trapping results for one final cut lake and one marsh in Muskingum County was three and 8.3 rats per acre.

17. A practical management measure to reduce the production and release of acid was burial of the more toxic materials. "Gob," coal gleanings and acid carbonaceous shale when buried under three feet of nontoxic materials released very little acid. Acid formation from these same materials, if in the bottom of the pit, was minimized by raising the water level well over the face of the coal seam and the carbonaceous shale immediately above the coal.

18. Vegetation, well adapted to the varied sites of the watershed, rapidly growing and producing an abundance of leaf litter also aided in reducing oxidation and the consequent release of acid. Black locust (*Robina pseudoacacia*) and sweet clover (*Melilotus* spp.), while not always as desirable to the landowner as other species, are adapted to a wider range of sites than most other plants. Both species were not only adapted to a variety of sites, but they grew very rapidly and provided a mat of organic matter over the spoil surface in a relatively short time.

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LITERATURE CITED

Arata, A. A. 1957. Trapping the strip-lands. Illinois Wildlife 12: 5–6.

Bell, R. 1956. Aquatic and marginal vegetation of strip mine waters in southern Illinois. Trans. Illinois Acad. Sci. 48: 85–91.

Blatchley, W. S. 1926a. Coleoptera of Indiana. Nature Publishing Co., Indianapolis, Indiana. 1385 pp.

———. 1926b. Heteroptera of Eastern North America. Nature Publishing Co., Indianapolis, Indiana. 1116 pp.

Bole, J. B. P., Jr. and **P. N. Moulthrop.** 1942. The Ohio recent mammal collection in the Cleveland Museum of Natural History. Sci. Pub. Museum Nat. Hist. 6: 181.

Chapman, A. G. 1944. Forest Planting on Strip-mined Coal Lands with Special Reference to Ohio. Tech. Paper No. 104, Central States For. Exp. Sta., U. S. For. Service, Columbus, Ohio. 25 pp.

Conard, H. S. 1944. How to Know the Mosses. Wm. C. Brown Co., Dubuque, Iowa. 166 pp.

Doudoroff, P. and **M. Katz.** 1950. Critical Review of Literature on the Toxicity of Industrial Wastes and Their Components to Fish. I. Alkalies, Acids and Inorganic Gases. Reprinted from "Sewage and Industrial Wastes." 22(11): 1432–1458.

Heaton, J. R. 1951. The Ecology and Succession of a Group of Strip Mine Lakes in Central Missouri. Unpublished Master of Arts Thesis, Graduate School. University of Missouri, Columbia, Missouri. 143 pp.

Kraus, E. H., W. F. Hunt and **L. S. Ramsdell.** 1936. *Mineralogy.* An Introduction to the Study of Minerals and Crystals. 3rd Ed., McGraw-Hill Book Co., Inc., New York. 638 pp.

Lewis, W. M. and **C. Peter.** 1954. Physico-chemical characteristics of ponds in the Pyatt, Desoto and Elksville strip-mined areas of southern Illinois. Trans. Amer. Fish. Soc. 84: 117–124.

Limstrom, G. A. and **R. W. Merz.** 1948. Extent, Character and Forestation Possibilities of Land Stripped for Coal in the Central States. Tech. Paper No. 109, Central States For. Exp. Sta., U. S. For. Service, Columbus, Ohio. 79 pp.

Maupan, J. K., J. R. Wells, Jr., and **C. Leist.** 1954. A preliminary survey of food habits of the fish and physico-chemical conditions of the water of three strip mine lakes. Trans. Kansas Acad. Sci. 57: 164–176.

Muenscher, W. C. 1944. Aquatic Plants of the United States. Comstock Pub. Co., Inc., Cornell University, Ithaca, N. Y., 374 pp.

Ohio Department of Industrial Relations. 1956. Annual coal and non-metallic mineral report. Div. of Labor Statistics, State of Ohio, Columbus, Ohio. 226 pp.

Ohio Department of Industrial Relations. 1955. Annual coal and non-metallic mineral report. Div. of Labor Statistics, State of Ohio, Columbus, Ohio. 145 pp.

Parson, J. D. 1956. The effects of acid strip mine pollution on the ecology of a central Missouri stream. Disserration Abstr. 16: 1301–1302.

Peterson, R. T. 1939. A Field Guide to the Birds. Houghton-Mifflin Co., Boston, Mass. 180 pp.

Pratt, W. S. 1935. Vertebrate Animals of the United States. Second Edition, P. Blakiston's Son and Co., Philadelphia, Pa. 416 pp.

Riley, C. V. 1947. An Ecological and Economic Study of Coal Stripped Land in Eastern Ohio. Unpublished Master of Science Thesis. The Graduate School, The Ohio State University, Columbus, Ohio. 204 pp.

———. 1952. An Evaluation of Reclaimed Coal Strip-Mined Lands as Wildlife Habitat. Unpublished Doctoral Dissertation, Graduate School, The Ohio State University, Columbus, Ohio. 257 pp.

———. 1954. The utilization of reclaimed coal strip lands for the production of wildlife. Trans. N. Amer. Wildlife Conf. 19: 224–337.

———. 1957. Reclamation of coal strip-mined lands with reference to wildlife plantings. J. Wildlife Management 21: 402–413.

Ruhr, E. 1952. Fish Population of a Mining Pit Lake. Unpublished Master of Science Thesis, Graduate School, Iowa State College, Ames, Iowa. 78 pp.

Smith, G. M. 1933. The Fresh-Water Algae of the United States. First Edition. McGraw-Hill Book Co., Inc., New York. 716 pp.

Stout, W. 1944. Sandstones and conglomerates in Ohio. Ohio J. Sci. 44: 88.

Temple, K. L. and **W. A. Koehler.** 1954. Drainage from Bituminous Coal Mines. West Virginia University Bulletin, Eng. Exp. Sta., Morgantown, West Virginia, Research Bull. No. 25. Series 54, No. 4–1: 35 pp.

Trautman, M. B. 1957. The Fishes of Ohio. The Ohio State Univ. Press, Columbus, Ohio. 683 pp.

Ward, H. B. and **G. C. Whipple.** 1918. Freshwater Biology. John Wiley and Sons, Inc., New York. 1111 pp.

Wright, M. and **A. Peterson.** 1944. A key to the anisopterous Dragonfly nymphs of the United States and Canada (Odonata—Sub-order Anisoptera). Ohio J. Sci. 44: 151–168.

Yeager, L. E. 1941. Wildlife management of coal stripped lands. Trans. N. Amer. Wildlife Conf. 5: 348–353.