Accelerated Erosion Due to Industrial Waste*

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Introduction

The stream studied in this report is Jenny Lind Run which empties into the Ohio River 13 miles above the city of Louisville, Ky. Source of the stream is 1¾ miles south of the town of Charlestown, Ind. The stream course is southerly for 1.8 miles, then turns abruptly east for 1.7 miles where it joins the Ohio.

The government owned powder plant located at Charlestown, Indiana, discharged the waste acid and water used in manufacture into Jenny Lind Run. Since the underlying rock is limestone, the result was a greatly accelerated erosion. It is the object of this report to describe this rapid Karst development.

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The Stream and Region Before Industrialization

Jenny Lind Run is shown as part of the Charlestown, Ind.-Ky. quadrangle published in 1937 by the U. S. Geological Survey. Jenny Lind Run empties into the Ohio River at 420 ft. above sea level when the river is at "normal pool stage." The lower 1.8 miles of the course were mapped as .permanent stream and the upper 1.7 intermittent. Throughout that part of the course mapped as permanent the Run is trenched more than 100 ft. below the general level of the upland; the intermittent portion drops abruptly from the gently rolling upland to this depth. The general level of the upland is 600 feet with gentle rises of 20 feet more or less above the general elevation.

Sinkholes are fairly numerous on the upland, the map showing 12 to 15 to the square mile. Sharp trenching of the streams, as already described for Jenny Lind Run, is characteristic.

Several caves were discovered in the course of preliminary surveying of the area. The longest that could be entered and mapped was less than a mile. In short, the region offers an example of Karst topography in the youthful stage.

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Course Changes Preliminary to Industrial Use

Near the source of the Run a series of long narrow sinkholes extended northwestward. A channel was dug connecting these sinks, thus lengthening the surface course of the stream.

A dam was thrown across the Run 1½ miles above the mouth, impounding a lake about 500 yards long and over 20 feet deep. This lake was designed to serve as a settling basin for plant waste. The spillway of the dam was constructed so that water passing over it was vigorously aereated. The stream was bridged for highways and railroads at several points.

At the head of the artificially lengthened portion of the stream a second basin was also built. This basin received waste from some preliminary steps in manufacture. Its waters were not acidic.

The acid discharge tiles (A of map), sometimes referred to as the outfall of plant effluent, were near the mid-point of the artificially lengthened course and 2.8 miles above the mouth. The dug portion of the valley of the Run seems to have been clayfloored originally; a fact of some significance in this study.

History of Plant Operation

Although manufacture of nitric acid began in April 1941, there was considerable lag before waste began to reach Jenny Lind Run, so that the first acid reached the creek at the beginning of May. Production of powder and hence volume of waste water and of acid varied. There was also a seasonal variation in the amount of water used. The peak flow was reached in early July, 1942, and continued at a high level until August 20, 1945 when production was reduced to ⅙ capacity. Production ceased October 1, 1945. Thus there was a total operating period of 52 months.

Amount and Nature of Acid Waste

Not all water furnished the plant was discharged into the Run, nor were careful measurements made to determine the exact amount that did flow away as waste. Estimates however were furnished the writer, based on the way the plant was constructed and on some partial observations. The average flow was thus estimated at 22,500 gallons per minute with peak flow in late summer reaching 32,000 g.p.m.

When discarded the acid had an hydrogen-ion concentration (pH) of 2.3. Before being dumped into the Run, pulverized limestone was added, changing the pH to 3.2. These pH values remained essentially constant throughout the period of plant operation, according to report. The limestone dissolved from the bed of Jenny Lind Run completed the neutralization of the acids. That such was the case is proved by repeated tests near the mouth of the stream showing a pH of 6.8 to 7.0.

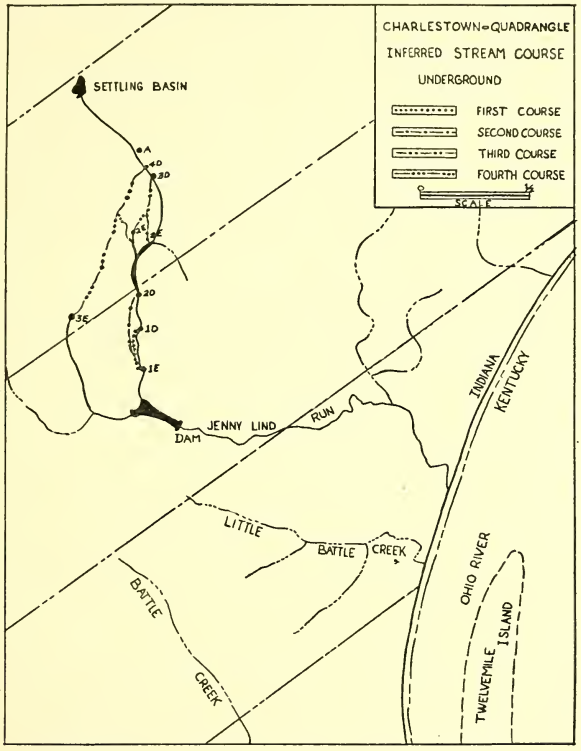
Temperature of water in the Run was about 80 degrees F. due to its use for cooling in certain of the industrial processes.

Stream Changes During Plant Operation

Unfortunately exact dates for stream changes are not available, since in some instances disappearance of the stream was not immediately

discovered. The early swallow-holes appeared in an inaccessible and seldom-visited area. Further, the date when swallow-holes were discovered does not seem to have been recorded in the plant files; at least such could not be found. Approximate dates are available, however since undermining of certain plant routes necessitated changes in operation.

The accompanying diagram show the series of major changes that occurred. One large additional cavern was noted by the writer in his exploration of the stream, but whether this opening was one of emergence or disappearance there seemed to be no way of determining.



The diagram shows the first major change discovered. It occurred in the fall of 1942, probably October. The distance between the swallow-hole (1D) and spring (1E) is 1750 feet as one follows the twists and bends of the channel. The portion of the bed of the stream deserted at this time was not again occupied by plant effluent, so measurements here give an indication of the amount of solution taking place from May 1941 to October 1942—seventeen months. 1D marks point of disappearance, 1E point of emergence, and A the position of out-fall acid effluent. The sides of the stream course were carefully studied to determine the level of the stream before acid attack; and wherever such determination was possible, calculations were made of bedrock removed by factory

waste. A series of measurements taken from 15 to 50 feet above the spring (emergent point 1E), in the abandoned portion of the stream bed showed average erosion of 7 feet 6 inches by 8 feet 6 inches width. Approximately midway of the abandoned section several measurements average 8 feet 1 inch depth by 7 feet 2 inches width. Fifty feet downstream from the swallow-hole, (point of disappearance 1D), acid waste had trenched the bedrock 5 feet 6 inches in depth by 7 feet 5 inches in width.

The conditions shown held for six months, when a new swallow-hole appeared 1000 feet upstream.[1] The stream abandoned a total of 2,750 feet of its original course. Trenching of the limestone downstream from this second swallow-hole (2D on map) was not great. It varied from 2½ feet to 3½ feet depth by 10 feet 6 inches to 10 feet 9 inches width.

Upstream from swallow-hole 2D, trenching was deep; the first exposures show limestone cut 7 feet four inches depth by 8 feet 2 inches width. One hundred and fifty feet above the swallow hole a concrete-floor culvert below a highway shows 6 feet of concrete and limestone removed. This strikingly deep and narrow trenching of limestone is to be expected for this part of the course, since it was occupied longer than any other stretch of valley—thirty-eight months.

In May 1943 a new swallow-hole (3D) appeared, a mere 2 months after 2D just described. This new opening was ¾ mile up valley from 2D and only 800 feet below the outfall of plant effluent (A). It was also but a few yards below a vitrified tile culvert beneath one of the plant railroads. This new disappearance of the stream was the first to produce a marked change in the general pattern of the Run. The stream disappearing at 3D reappeared mostly at 2E and 2E1 but some water also worked to the surface as seepage, making a swampy area between the two points, killing trees ad similar upland vegetation.

From the present aspect, 2E[1], the westernmost opening, carried the most water. This opening is a small cave that existed before the acid waters were thrown into the area.

The stream now had its most complicated pattern. The acid waters joined the Run at A, flowed on the surface for 800 feet, disappeared underground for 1800 or more, emerged at 2E and vicinity to flow for another 800 feet on the surface, only to again go underground at 2D, and finally reappeared at 1E to stay above ground to its mouth.

The section of stream above 2D is especially interesting, since it carried plant waste without interruption for 38 months, as already mentioned. It gives the widest and deepest measurements to be found. The deepest measurement found was 8 ft. 4 in. by 8 ft. 4 in. in width, although 6½ ft. in depth by 9½ ft. in width was more nearly typical.

The latest chapter to date in the evolution of Jenny Lind Run occurred in midsummer of 1944, and was perhaps the most spectacular of

[1] It was this second swallow-hole that focused attention on the activity of the stream. Between the two swallow-holes there is a railroad trestle across the gorge. Fear that solution had undermined the foundations of this high trestle caused it to be abandoned.

all. The first step was a large cave-in 225 feet below the outfall (A). At this point a small ledge of limestone had been exposed when the channel was artificially lengthened. The exposure is scarcely 12 feet long and originally seems to have been about 2 feet high. It made a part of the east bank of the channel way, although the channel proper seems to have been either clay or clay-covered.

The acid waters working on this limestone ledge on the east bank dissolved a channel beneath the stream so that when the cave-in occurred it was on the west bank. Remnants of this pseudo-natural bridge can still be seen. The cave-in is now large, due to repeated collapse of its roof. It measures 45 feet at its widest by 15½ ft. depth, of which depth 12½ feet is in limestone. A further feature of this cave-in is a tile-lined culvert 75 feet downstream (300 feet below outfall) that held the stream to the artificially established grade. This culvert would also tend to inhibit any scour, had such tendency been present. Between cave-in and outfall a conspicuous post-cave-in feature is a falls 8 feet high over hard-packed stratified clay. While the original land form cannot be determined, this packed clay is inferred to be the bottom of an old sink-hole.

Following the cave-in (4D on map) a new spring appeared on a tributary (3E on map). Thus a radically different pattern of underground courses can be inferred, for though the entire flow of the Run disappeared at 4D it reappeared at several places (2E, 2E[1]), the swamp between, and at 3E. This condition held until the close of operation, October 1945—fifteen months.

The opening 3E is a cave, originally mapped as the source of an intermittent stream. The opening had been closed by a concrete wall extending to within a few inches of the roof. This wall was not breached by the acid waters, but the limestone below was dissolved, making a U-shaped cut 56 inches deep by 48 inches wide.

Measurements were made approximately every .1 mile from source to mouth of this new tributary on depth and width of solution. At the source hydraulic churning had deepened the cut slightly, immediately under the concrete wall; clear of obstruction the solution cut was 48 by 48 inches. This gave a transverse lineal measure—side, bottom, side—of 12 lineal feet. This lineal measure seemed to be a rather constant thing for the whole course of the stream. The least lineal measure found was 10 ft. 6 in. and this increased to 11 ft. 10 in. twenty feet upstream.

This more or less constant lineal measure did not, however, reflect a constant ratio of depth to width. For example, near the mouth trenching was but 18 inches deep and the width was 8 feet. Midway of the course, trenching was 3 ft. in depth and 5 ft. in width.

Probably this reflects the lessening acidity of the waters.

Tributary Changes

The accompanying map shows a number of intermittent tributaries entering Jenny Lind Run. These were dry when visited by the writer. There had been some concentration of flow, due to ditching around powder works buildings, in a few of the streams. This did not noticeably affect

the streams, since those not connected with industrial drainage show essentially the same changes as those that are.

The rapid deepening of Jenny Lind Run might be expected to cause hanging valley tributaries, but such is not always the case. Indeed, the first tributary below the outfall enters the Run *at grade*. This tributary is only 1100 feet from the point where acid poured into the Run. Though originally mapped as a dry valley, there is some intermittent flow due to ditching and concentration of flow by a highway culvert. Weathered and broken stone has been removed for 25 feet and deep channeling of bedrock is observable for nearly 100 yards upstream.

The eastward-swinging stream above 2E, mapped as the head of the Run, has cut back 2 feet into the limestone and has removed all loose material for 33 yards above its mouth.

A very short tributary, just above point 1E, cascades into Jenny Lind. This tributary on the steeper part of the slope, is on bedrock, and is little deepened.

The westernmost tributary is uneffected. It empties into New Jenny Lind Run $\frac{7}{10}$ mile below 3E. This part of the Jenny Lind course is clay-floored. Hence, there are no changes in main stream or tributary due to solution.

Solution Patterns

King described the corrosion pattern in a semi-arid region as "shallow, flat-bottomed, sub-circular basins, with their steep and sometimes overhanging, fretted margins".[2] This pattern is not found in Jenny Lind Run but a quite different one. The difference is assumed to be the result of continuous abundant water in the stream.

The bedrock of the now dry stream bed has been etched into random, shallow, saucer-shaped depressions a few inches across, the whole giving a sort of dappled effect. There are no well-defined ripples. The patern is conspicuously interrupted by numerous fossils. These are sufficiently silicified to resist solution and so stand above the surface beautifully clean and free of gangue. Indeed, frequently they are on delicate pedestals that break at the touch of the hand.

The limestone parts of the stream bed are always rough. Clay portions, on the other hand, are smooth or marked by shallow grooves parallel with the stream sides.

Conclusion

Since the concentration of acid in Jenny Lind Run during the operation of the Powder Plant was so greatly in excess of any found in nature, the effects here described cannot be generally encountered. Nevertheless, it is believed that the solution accomplished by the high acid concentrations is, at least in part, comparible to results accomplished by nature in a vastly longer time with waters of lesser acid content.

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[2] King, P. B. Corrosion and Corrasion on Barton Creek, Austin Texas. *Jour. Geol.* v. XXXV #7 Oct.-Nov. 1927, p. 635.