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TECHNIQUES USED IN MINE-WATER PROBLEMS
OF THE
EAST TENNESSEE ZINC DISTRICT

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ABSTRACT

A study of ground water as related to mining in cavernous limestones and dolomites in eastern Tennessee was made in 1946 by the U. S. Geological Survey. Surface and subsurface mapping indicated the geologic control of underground channels. Several methods of tracing water were tried and new techniques in using these methods evolved from the work. Rainfall data,

when correlated with ground-water volumes and velocities, gave much information as to expected pumping volumes for any period. The use of fluorescein dye for tracing the flow of the water is described and other methods are discussed briefly. Four examples, each from a different mine, are discussed in detail and some remedies for the problems are suggested.

INTRODUCTION

Mine-water problems merit far more attention than has been generally granted, and a search through the literature reveals only a few scattered references to methods of solving such problems. Most of the articles seen emphasize costs of pumping volumes pumped, and the mechanical details of how the water was handled, whereas relatively few record data on the source of the water, the geologic conditions controlling its movement and how they were determined, or how such a study might aid in developing preventive methods at the source.

As early as 1906 excessive water caused at least two mines in the east Tennessee zinc district to be abandoned. As the years passed and more mines were opened, and as larger areas of ground were cut, the costs of pumping large quantities of ground water rose to the point where one mine became almost uneconomical to operate. Another mine operated under great difficulties because of excessive flooding during periods of very heavy rainfall. In a third, a valuable ore body was made valueless because development workings tapped a huge volume of water under great pressure. These incidents, coupled with many others, brought the acuteness of the problem to the attention of the mine owners and later to members of the U. S. Geological Survey who were engaged in studying the zinc deposits of the district. A special study of the mine-water problems was undertaken by the Survey as an engineering-geology project. This study yielded information that was applicable to the immediate problem, and led to the development of techniques that will be useful in solving similar problems elsewhere.

The field work was done from January to June and from late September to early December of 1946. The writer wishes to acknowledge the complete cooperation of E. B. Jennings, General Manager of the Universal Exploration Co., and his staff; and of H. A. Coy, General Superintendent of the American Zinc Co., of Tennessee, and his organization. A. S. Fry, M. A. Churchill, and B. C. Moneymaker of the Tennessee Valley Authority contributed much time, equipment, and valuable technical assistance throughout the project, as did many of their staff members. A. O. Patterson, R. A. Laurence, and A. L. Brokaw of the U. S. Geological Survey helped much during the study.

GENERAL GEOLOGIC RELATIONS

Stratigraphy

This paper is primarily concerned with the techniques used during the study and includes only that discussion of the geology necessary for understanding the methods used in studying the mine-water problems.

All the mines studied are in Cambrian and Ordovician limestones and dolomites, and present problems peculiar to rocks of these types. The limestones seem to be more soluble, although the dolomites also contain extensive solution cavities. Less soluble beds generally contain large quantities of massive or nodular chert.

Structure

All the mines are located on the southeast sides of isoclinal folds that are typical of the whole zone of Appalachian faulted folds comprising much of eastern Tennessee. Northeast-trending thrust faults with large throws bound these folds on their northwest and southeast sides and pass near or through some of the mines. Related minor tear and reverse faults accompany the thrust faults. Each mine has its own fracture system and most of the mines expose small local flexures plunging at varying angles down the dip. The strike of the formations is generally northeast and the dip ranges from almost vertical in one place to an average of 5° to 10°SE. in the larger mines.

Solution control

The interconnected system of faults, fractures, and bedding planes has allowed the development of an extremely ramiform system of solution cavities. These range from openings of a fraction of an inch to those more than 100 feet high and may extend for many miles over diverse routes. Diamond drilling has proved that a fault may be "tight" in one place even though large caves are developed along it a few feet away. Deep weathering is characteristic and the clayey overburden averages 50 feet in thickness. Oxidation, generally accompanied by solution openings, commonly extends to depths of 500 feet and in one place to a depth of 900 feet. The rainfall percolates through the overburden and the open cavities beneath it furnish a ready drain into the mines. These cavities often divert streams from their channels into the mines.

Detailed geologic mapping gave information on the location of open fault zones or caves; the techniques used in tracing the movement of water along these zones is described below.

PRECIPITATION

Amount

The mean annual precipitation for this area averages more than 50 inches. Precipitation occurs during every month of the year, but is heaviest during late summer and winter. Commonly 1 to 3 inches of rain falls in one 24-hour period, which may or may not follow a period of light, soaking rains.

Measurement

Early recognition of the relation between rainfall and the amount of mine water led to the use of gages to measure relative amounts of precipitation and runoff. The following types of measuring devices were used in this study:

Standard can gage. The standard can gage 1/ records rainfall in hundredths of an inch by actual measurement in a standard cylinder equipped with a standard measuring stick.

¹U. S. Dept. Commerce, Weather Bur., Instructions for cooperative observers, Circulars B and C, Instrument Div., 9th ed. (rev. 1941).

Friez recording gage.—The Friez recording gage is a 7-day, automatically recording gage, of the weighing type, which requires only 10 minutes of service a week. It records total rainfall on a graph, and the completed chart can be read to 0.01 inch.

INSTRUMENTS FOR MEASURING FLOW

Current meters 2/

Geological Survey standard and pygmy current meters were used to measure velocities in streams in order to determine rates of flow at various points along the streams.

Weirs 3/

Standard 2- and 4-foot rectangular weirs were used to measure flow underground and on the surface. The weir plates were constructed of 1/8 inch steel plate with the downstream edge beveled to a 45-degree angle. These plates were punched for screw holes and mounted on wooden dams already set in the stream. The labor charge for five weirs set in underground ditches was \$15.00 apiece, and the material cost \$10.00 per weir.

Parshall flume 4/

A Parshall flume, a specially designed flume used widely for measuring flow of water in irrigated districts of the West, was installed in one mine. This flume required 300 board feet of 2- by 6-inch and 2- by 12-inch seasoned pine lumber, and was lowered into the shaft and installed on the sump level. The advantages of the Parshall flume are that it creates a minimum of backwater, that it carries a flow ranging from 150 gallons per minute up to a maximum of 5,100 gallons per minute through a throat width of 1 foot, and that slimes do not affect its operation. The accuracy of the flume is not affected much by the rate of flow of the approaching water, and it is reliable enough for mine purposes. It is easily read with a simple staff gage, retains its accuracy through continued use over long periods, and may be constructed of wood, metal, or concrete.

METHODS OF TRACING WATER

The two principle methods tested for tracing water were the direct method involving fluorescein dye and the indirect method of comparing volumes of flow at different points and of relating rainfall to volume of flow. Different methods of introducing the dye into the water were tried, and a sampling system for detecting dye in the water was developed. 5/ Some alternative methods of tracing flow are discussed briefly below.

²Corbett, D. M., and others, Stream-gaging procedure: U. S. Geol. Survey Water-Supply Paper 888, 245 pp., 1943.

³Corbett, D. M., and others, "op. cit."

⁴Parshall, Ralph L., Improving the distribution of water to farmers by use of the Parshall measuring flume: Colorado Agr. Exper. Sta. Bull. 488, p. 54, 1945.

⁵Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 72-74, 1942.

FLUORESCIN DYE

Fluorescein dye is a dark-red organic crystalline compound ($C_{20}H_{12}O_5$) derived from coal tar. It is harmless in dilute solution. Because the color can be detected at great dilutions it has long been used as an agent for tracing water, being so used by the Germans as early as 1877. The dye does not fluoresce in the solid state but, when added to water, colors the water green and fluoresces green under an ultraviolet light. The effectiveness of fluorescein is greatly reduced in highly acid waters through loss of color in a rather short period of time. The source of the ultraviolet light used in this study was a portable battery-powered Mineralight, manufactured by Ultra-Violet Products, Inc., Los Angeles, Calif. The dye can be purchased in small quantities from any pharmacist, and ready and comparatively cheap sources of volume purchases are available.

Amount of dye used.—The amount of dye used with each test differed according to the volume of water, the distance it had to travel, and the probable time of travel. Some experimentation was necessary to obtain satisfactory results. In general, when looking for leaks from stream beds, a solution of 1 pound of dye per thousand gallons of water per minute per mile of probable underground travel was adequate.

Methods of introducing the dye into the water. 6/—Four methods were used for the introduction of the dye. The first, that of putting the powder directly into a stream, was ineffective because all the dye did not go into solution rapidly and wind distributed the powder unevenly. This often led to contamination of the final samples, as powder would be carried on the person of the sampler.

It was found that for best results the dye should first be dissolved completely in water. This was the second method used. Alkalies, such as lye, make the dye more soluble. The mixing of dye, lye, and water in pails before putting it in a stream worked well if only one concentrated test was necessary to determine actual speed of passage. If the mixture was distributed evenly, this method worked for tests requiring dyeing throughout half-hour or hourly periods.

In the third method the dye and lye solution was poured into an ordinary hand-pumped 3-gallon orchard sprayer. This was adapted for use by the removal of the small disc in the spray head which causes the spray. The sprayer then ejected a small stream having an effective range of 30 feet. The advantages are obvious for the dyeing of streams,

⁶Stabler, Herman, Fluorescein an aid to tracing waters underground: U. S. Bur. Reclamation, The Reclamation Record, vol. 12, no. 3, pp. 122-123, March 1921.

Fuller, M. L., and others, Underground-water papers: U. S. Geol. Survey Water-Supply Paper 160, pp. 73-85, 1906.

Meinzer, O. E., Outline of methods for estimating ground-water supplies: U. S. Geol. Survey Water-Supply Paper 638-C, pp. 99-144, 1931.

Wenzel, L. K., Methods for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 887, pp. 72-74, 1942.

sinkholes, or even larger bodies of water. One charge, using a pound of dye, a pound of lye, and 2 gallons of water will dye a 6,000 gallon-per-minute stream for 25 or 30 minutes.

The fourth method used was for diamond drill holes, drilled at the surface or underground. As it was not always possible for a geologist or engineer to supervise the dyeing of drill holes the apparatus shown in figure 1 was made for use by the driller. In use the upper valve is opened, the cylinder filled with dye, and the valve is closed. If the drill enters a cavity and loses drill water the driller shuts off his machine, opens the relief valve, and closes the cut-off valve. The drain valve below the cylinder is also opened to allow the water to drain from the hose, and then is closed. Then the lower valve on the dye apparatus is opened and the column of the water pipe is allowed to fill with dye, after which the valve is closed. With the closing of the relief valve and opening of the cut-off valve the dye is forced into the hole under pressure. The driller then sends his helper to notify the nearby mine officials to start sampling in the mine.

Sampling. - Reliable results may be expected only if samples are taken carefully and at regular intervals. In the procedure used, one man made a circuit of the sampling places each hour, taking samples of the water and noting the time each was taken. Racks containing sets of 24 one-inch pyrex test tubes 12 inches in length were used. Corex tubes of ultraviolet-transmitting glass, which were not available at the time, should be used if possible. Each rack was numbered, corresponding to the place used, and the corks in the tubes were painted with consecutive numbers to avoid confusion on recapitulation of sampling results. The sampler generally was not the same person who originally dyed the water, thus dye pollution from clothes, boots, and hands was avoided. If the same person had to do both jobs, he changed clothes and examined his hands under the Mineralight before sampling, to avoid pollution and subsequent error in the results. Records of all tests included time of dyeing, rate of flow in stream, time the dyed sample first appeared, relative strengths of dyed samples, and time the dyed samples stopped appearing.

Use of ultraviolet light. - The Mineralight was used to detect fluorescein in all samples. Occasionally the dye was strong enough to be seen with the unaided eye, but this was unusual. The sampling was started as soon as the dye had been introduced into a stream suspected to be leaking into a nearby mine. The best procedure was first to dye the full length of such a stream from a point at its head. This insured that the most distant points of access of water had been dyed, and therefore that the maximum travel time from stream to sampling point was determined. The samples were taken to a perfectly dark place, and were best viewed by holding the Mineralight over the mouth of the container. If the Mineralight was held against the side of the tube most of the ultraviolet light was reflected, refracted, or absorbed by the glass and a dilute solution containing dye could not be recognized. With the light over the mouth of the tube the fluorescein emits visible light in all directions and the resultant zone of light is seen easily. The added depth of sample allows identification of more dilute solutions. Experience with the use of the light

develops proficiency in the recognition of minute quantities of dye. With the type of samples taken in this study the unaided eye was unable to determine concentrations of less than 1 part in 50 million but with the aid of the light 1 part in 40 billion was visible in the tubes. It is estimated that under the most favorable conditions, namely, a still deep pool in an underground stream, solutions as dilute as 1 part in 200 billion could be recognized by holding the Mineralight over the pool. A viewing box for daylight examination may be easily constructed with apertures for the insertion of the light and specimen and for observing the effect of the ultraviolet light. This method is not as accurate as the use of a place where the eyes can become accustomed to complete darkness.

Comparative-flow method

Weirs were installed underground for the purpose of measuring rates at which water entered a mine. By the use of several weirs it was possible to apportion the total flow into rates of flow from each section and level of the mine. Surface weirs at the end of the pump-discharge lines gave a check of both pump capacity and of the total flow at underground weirs. Hydrographs of discharge showing the rates of flow for the mine and for each weir were made from measurements taken at 24-hour intervals over a 4- to 6-week period in each place. These curves, when correlated with rainfall curves, gave a check on the lag in time between rainfall and the maximum increase of flow in the mines. Information regarding time required for transmission of the pressure effect caused by adding water, as compared with travel time of the water itself, was gained by adding volumes of water and dye simultaneously at one entry point.

A study of 6 years' records of one mine was made because of the construction of a large flood-control and power reservoir in a nearby river valley. Geologic conditions indicated no direct subsurface connection between mine and lake. The curves for daily rainfall, pumping at the mine, and lake levels, when superimposed, showed that after the closing of the gates of the dam the pumping volumes were much greater during the wet winter season. The water table rose along the sides of the valley as the lake filled. During periods of excessive rainfall the water table would normally rise temporarily, and the resultant surplus water would then drain into the river through springs. When the reservoir became filled this water would not drain off as readily, and the water table rose above the level of the mine workings. This rise in the ground-water level probably explains the large increase in volumes of water pumped during the times of heaviest precipitation. Application of the weir method is discussed in the description of mine studies further on in this report.

Other methods of tracing flow

Some variations of methods of tracing the flow of underground water are the use of sodium chloride or other salts, alkalies, bacteria, radioactive materials, and other dyes, detected by appropriate analytical, electrical, or visual methods.^{7/}

^{7/}Churchill, M. A., personal communication, 1946.
Wenzel, L. K., op. cit.

Increase in the concentration of chloride created by the addition of large quantities of salt may be detected quickly and simply. Samples must be collected at the probable underground source and a check made on the natural chloride content prior to the use of this method. Preliminary tests may indicate that a natural condition exists, such as surges of chloride-charged water released from flood-control dams, which may allow sampling without raising the chloride content artificially. The relative concentrations are plotted on curves and compared for similarity with native water. Alkalies can be used in the same manner as salts. Measurements of electrical conductivity of the solutions may be used to detect the presence of greater-than-normal concentrations of electrolytes.

Another method applicable to the field would be the introduction of small amounts of radioactive materials into the water to be studied. Samples of the solution containing such material would then give positive reactions when tested with a Geiger counter.

Other dyes such as methyl umbelliferone (blue) and rhodamin (red) could be used and the sampling procedure would be the same as that used with fluorescein dye.

Maps

The records of all test work included a set of maps which show mine workings, drill holes, and streams, sinkholes, and other topographic features. All pertinent data relating to dyed localities, leaks, points of entry of dye into mine, and direction of flow between points were plotted. Significant geologic data were entered on these maps, and sections were made showing in three dimensions the solution channels in the rocks.

Records

Rainfall records, daily and hourly, were maintained in permanent form, together with all other records such as rates of flow over weirs, times at which flow occurs, daily volumes of water entering and leaving areas, and pumping records of mines by totals, levels, and areas. The engineers used these records for reasons other than water problems, such as checks of pump efficiency and studies of ditch capacities.

Applications

The above techniques were applied in the studies of four different mines described below.

Mine A.—An underground stream fed directly into the workings of mine A, and attempts were made to determine something about the nature of the stream itself. A hole in a stream bed 5,200 feet upstream from the mine portal was proved, by means of a dye test, to have a direct connection with this mine; so in a subsequent test 150 gallons per minute of water was diverted into the hole and at the same time this water was dyed with fluorescein. Constant watch at a weir in the mine showed that 30 minutes was required for the pressure effect to register, whereas 7 hours 48 minutes was required for the dye to appear. The difference in elevation was 130 feet. Research by the Hydraulic Data Division of the Tennessee Valley Authority has shown that a short time of wave travel and a much

longer period for the actual passage of the water, in any given section of stream, ditch, or pipe, indicates that a high percentage of this body of water is pool. The above data were turned over to Mr. Churchill of the Hydraulic Data Division, who, by comparing these figures with those for known streams, estimated an average cross section of 7.48 square feet for this stream. He also estimated that 90 percent of the length of the stream might be pool. Later exploration proved this estimate to be correct.

Flash floods in the mine often resulted in flows increasing from 300 gallons per minute to 15,000 gallons per minute. An interpretation of rainfall and flow data showed this water to be entering the ground over an area of some 825 acres, not directly over the mine, and then finding its way through a cave system to the mine. No preventive method could be used at the source. The safety factor of knowing when flooding would occur was important, however, and examination of the correlation of rainfall and flow curves revealed that, under conditions of maximum overburden saturation, the mine water would start to rise 2 hours after the beginning of rainfall. Depending upon the amount of rainfall, the mine would be flooded 6 to 8 hours later. By keeping a close check on rainfall the operators would thus have time to move men and equipment before mining became too dangerous.

Sinkholes, as well as deep dry gullies, were tested by adding dye during periods of heavy rain. This dye showed up in the mine in from 50 to 70 hours after it was put into sinkholes 2 miles from the mine.

A large creek flowed near the mine, and geologic evidence led to the belief that leaks from the creek contributed directly to the mine water. A discharge profile of the stream was made on the basis of a series of discharge measurements and two places were discovered where there were measurable losses in volume. These were checked with dye, and a direct connection was shown between these places and the mine. This is a quick and economical method of locating leaks of more than 100 gallons per minute in small streams. A. O. Patterson of the U. S. Geological Survey, who made the discharge profile, estimated a 5 percent limit of error in the determinations of stream flow, which ranged from 650 to 2,000 gallons per minute.

Mine B.—During heavy rainfall a sinkhole on mine B property collected a large amount of water which gradually drained into the ground. A comparison of surface and underground maps indicated that a heavily oxidized fault zone in the mine would, if projected, pass through the sinkhole. Much water came into the mine along this fault. Flourescein dye was added to the stream of water flowing into the sinkhole during a heavy rain, and the leaks along the fault were checked underground with the Mineralight. The dye came through from the surface in 4 hours. The flotation process was used at this mine for milling ore, and the water for the milling came from the mine. After this water had passed through the mill the surplus was discharged into a ditch which carried it to the sinkhole described above. It was suggested that elimination of this recirculation of water would save some pumping expense. In 1948, a storm sewer was constructed to carry discharge from this mill beyond the sinkhole and into a creek, so that the water no longer recirculated.

Mine C.—Mine C was the largest mine dye-tested during this investigation. It consists of 125 acres of stope ground in gently dipping beds. The workings extend from the surface to a depth of 1,000 feet. Here, measuring the flow of the water was made complex by very erratic distribution of ditches, which necessitated the installation of several weirs. In addition, three main levels contributed water to these ditches. Water pumped from the lower level was added to that from the upper levels. The times of pumping for the lower level varied from day to day, and a separate record of these was maintained. Checks made every 24 hours for a month revealed a lag of 4 hours between heavy rainfall and entry of the excess water into the uppermost level; this lag seemed to increase proportionately with depth. The short time of transit indicates the open, or cavernous, condition of the ground. The weir discharges were plotted individually on a common sheet, using a different color for each weir, and another curve represented the total discharge for the mine.

Normally dry sinkholes were tested by introducing fluorescein dye during heavy rains, but all tests were negative. However, many sinkholes remain to be tested and these should show some positive results. Dye tests were made in the major streams and the water-plant canal. In one stream, which had already been partly lined with reinforced concrete, a test showed a leak just below the lower end of the lining which, when time-tested with dye, carried water to an upper level of the mine in 45 minutes. This leak was temporarily blocked by diverting a stream of tailings into this section of the creek, but a reinforced concrete pad over the danger area would provide a permanent remedy.

A large river flows over part of the mine, and it was thought that this river might contribute heavily to the mine water. A test was made when the river was flowing at the rate of 6,000 cubic feet per second (nearly 3,000,000 gallons per minute). Thirty pounds of dye was used and this allowed a continuous test over a 1-hour period. The dye was found in the samples 57 hours later, after it had traveled 3 miles downstream, dropped 500 feet along fractures and a tear fault into the mine, and returned to the sampling point through one intermediate sump and along 7,500 feet of ditch. The dye was not visible to the unaided eye in this test.

During the tests at this mine a set of 5 racks, holding 24 tubes each, was employed. One man made the rounds every hour and the actual time needed for a complete circuit of the route was 30 minutes. Four men, including a relief man, did the work on a 24-hour basis for 5 weeks and checked weir readings at the same time. The total cost of the labor for the period was \$20.40 per day and \$737.00 for the job. The sampler gathered up all the racks after the last sample and brought them to the shaft where they could be examined by the geologist or engineer and dumped before he started his next round, making it unnecessary to provide two racks for each sample point.

Mine D.—Mine D was the last mine studied, and although the work was not completed, many new facts were learned. Results of the work proved that direct connections existed between a nearby creek and the mine, and some of these were blocked later. New

methods were used for accurately dyeing sections of a flowing stream. The possibility of dyeing drill holes was studied, and an apparatus was devised for the introduction of the dye into the holes. A study of topography and subsurface geology indicated zones that might prove to be most favorable for the passage of underground water.

The mine produces a volume of water far out of proportion to its size, and if this condition increases the mine will become uneconomical to operate, as pumping costs will exceed profits. Influx of ground water at this mine due to the raising of the water table by construction of a dam nearby has been discussed earlier in this paper. The topography over the mine is much like that at the other mines, but the mine-water problems are more difficult because there is no surface drainage above the mine except through sinkholes. However, 2,000 feet south of the mine a large creek crosses the formation in which the mine is located. This stream emerges from one spring area which has flowed at rates ranging from 1,500 to 80,000 gallons per-minute, depending on the seasonal rainfall.

This creek was dyed at its source and dye was found in the mine by means of the Mineralight in 8 hours. The next step was to survey the stream in sections 200 feet in length, and plot these points on a map. Then dye tests were made of each section, starting at the lower end and working upstream until the dye was found in the mine. This method succeeded only until one test was positive, for dye introduced upstream from this point would have come into the mine through this same point. Steps were taken to isolate the leaking area. The water in this section was diverted and the holes were located, and closed by grouting and other concrete work. Closing the holes proved to be unsuccessful, for the water soon found new openings. However, diversion of the stream proved to be successful, for dye tests of the diverted section showed no leaks and the tests were resumed upstream. Such a procedure can be carried on at little expense until the extent of the cavernous area is determined, and then an over-all program, such as flume or pipe, grouting, or concrete-pad work, can be planned and carried out.

Floods occur during many periods of the year and an attempt was made to simulate the conditions produced by floods. A Parshall measuring flume was installed in the mine; lack of head and large amounts of slimes prohibited the use of another kind of weir. The surface stream was diverted from sections of its bed containing known leaks. Then water was turned into these sections and a close watch was kept for an increase in flume readings, which came in 12 hours. Another plan was to dam a section of the stream, causing low flood lands along the creek to be covered with water. This was accomplished by installing temporary wooden gates on culverts which carried the creek under a railroad spur. The water pressure held them in place and, as the creek had a very slight fall in this section, within 24 hours a foot of water backed up over the area to be tested. The rise in the flume reading in the mine was noted at the end of the period. Dye tests during this period showed that water came from the stream into the mine. During the tests on this creek the sprayer described earlier proved very successful because of its long effective range, its economical use of dye, and its portability.

These tests also indicated that a large volume of water, not connected with the creek, came from another source. When all known creek openings were blocked a considerable amount of water continued to come into the mine. Also, some leaks in the mine never contained dye even though others did.

A program was devised to study possible channels of flow. The apparatus described above for use with the diamond drill (fig. 1) was made to introduce the dye, and it was planned to test each cavity encountered in drilling— checking points of entry, time of flow, and relative strengths of dye sampled. A chart was kept of all results, and this will ultimately show the paths of flow between certain cavernous areas and the mine. Careful study has shown that a possible solution of the problem of a particularly "wet" block of ground might be the laying down of a grout curtain through the same drill holes.

The company controlling this property followed all work closely, assigning a special geologist or engineer to observe and cooperate on all operations. They propose to continue the work on a yearly basis, following a plan drawn up as a result of the above studies.

CONCLUSIONS

The above methods were used to trace the flow of ground water in the area around the mines described. The dyeing and comparative-flow techniques provide a cheap, rapid, and effective means of determining the sources and routes of travel of troublesome mine water in cavernous limestone and dolomite terrain. The aid these methods give in directing preventive measures far outweighs the cost of making a survey. Some of the techniques employed might be easily adapted to studies of mine-water problems under different geographic conditions.

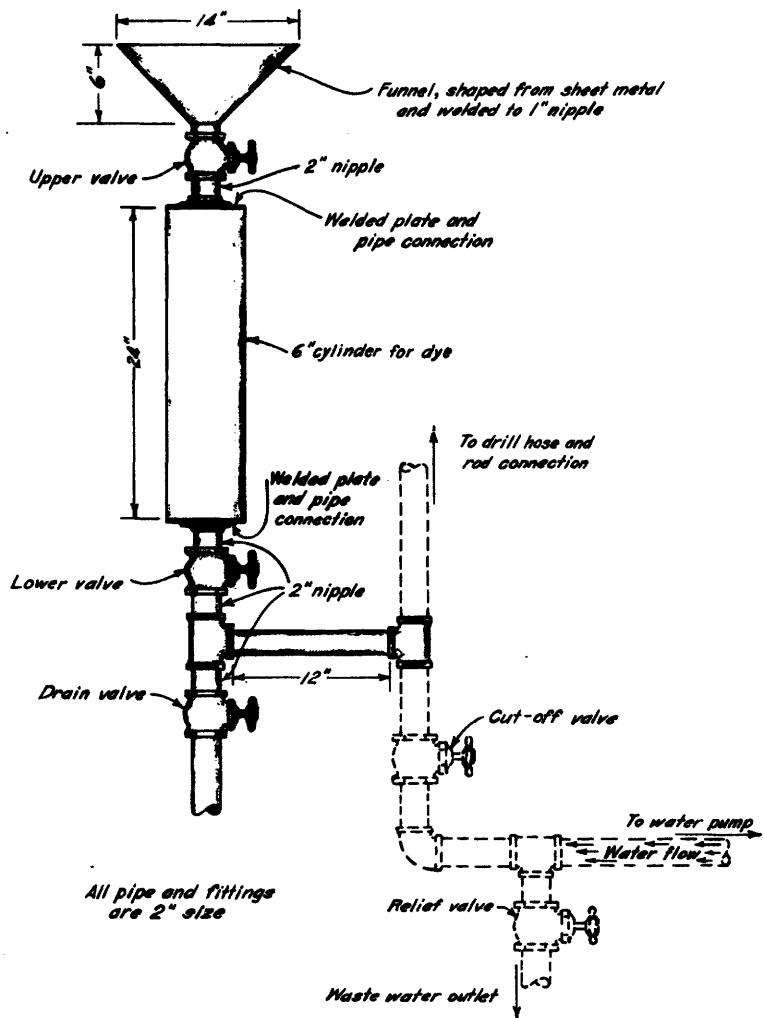


FIGURE 1
APPARATUS FOR INTRODUCING DYE INTO
DIAMOND DRILL HOLES

