Drainage as a factor in the development and operation of a mine

Peter Paul Ribotto

Follow this and additional works at: http://scholarsmine.mst.edu/professional_theses
Part of the Mining Engineering Commons
Department:

Recommended Citation
Ribotto, Peter Paul, "Drainage as a factor in the development and operation of a mine" (1944). Professional Degree Theses. Paper 226.
DRAINAGE AS A FACTOR IN THE DEVELOPMENT AND
OPERATION OF A MINE

BY

PETER P. RIBOTTO

A

THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in fulfillment of the work required for the
Degree of

ENGINEER OF MINES
Ishpeming, Michigan
1944

Approved by
Professor of Mining
CONTENTS

List of Illustrations .......................................................... 11
List of Maps ........................................................................ 11
List of Graphs and Charts ....................................................... 11
Introduction ........................................................................... 1

Section I--A Study of the Factors Influencing the Development and Operation of a Mine.

Topography ........................................................................... 2
Local Geology ......................................................................... 8
Location and Mining of Oreshoots ............................................. 9
Haulage Problems .................................................................. 12
Ventilation and Safety ............................................................ 13
Conclusion ............................................................................. 14

Section II--Control of Surface and Underground Waters.

Surface .................................................................................... 15
Underground ........................................................................... 20

Section III--An Example of a Program of Study and Control of Mine Waters.

The Morris Mine of the Inland Steel Co. at Ishpeming, Michigan.

General Conditions ............................................................... 30
The Water Control Program at the Morris Mine ....................... 41
Conclusion ............................................................................. 70

Bibliography ........................................................................... 71
Index ...................................................................................... 73
### LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Profile showing current flow lines and equipotential lines for resistivity survey</td>
<td>5</td>
</tr>
<tr>
<td>2.</td>
<td>Typical section at Morris Mine</td>
<td>7</td>
</tr>
<tr>
<td>6.</td>
<td>N-S section looking east through a Morris Mine orebody showing effect of mining on surface</td>
<td>57</td>
</tr>
<tr>
<td>10A</td>
<td>Test hole logs</td>
<td>45</td>
</tr>
<tr>
<td>10B</td>
<td>Test hole logs</td>
<td>46</td>
</tr>
<tr>
<td>11.</td>
<td>Morris Deep Well No. 3A--sunk by churn drill</td>
<td>48</td>
</tr>
<tr>
<td>12.</td>
<td>Morris Deep Well No. 8--sunk by hydraulic rotary drill</td>
<td>48</td>
</tr>
<tr>
<td>19.</td>
<td>Pumps and water piping</td>
<td>61</td>
</tr>
<tr>
<td>21.</td>
<td>Types of underground dams</td>
<td>68</td>
</tr>
</tbody>
</table>

### LIST OF MAPS

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Location of Morris Mine</td>
<td>31</td>
</tr>
<tr>
<td>5.</td>
<td>Ledge contours</td>
<td>34</td>
</tr>
<tr>
<td>7.</td>
<td>Location of subsidence profile</td>
<td>40</td>
</tr>
<tr>
<td>9.</td>
<td>Diversion and drainage ditches at Morris Mine</td>
<td>43</td>
</tr>
<tr>
<td>13.</td>
<td>Water Table, October, 1939</td>
<td>49</td>
</tr>
<tr>
<td>14.</td>
<td>Water Table, October, 1940</td>
<td>50</td>
</tr>
<tr>
<td>15.</td>
<td>Water Table, October, 1941</td>
<td>51</td>
</tr>
<tr>
<td>16.</td>
<td>Water Table, October, 1943</td>
<td>52</td>
</tr>
</tbody>
</table>

### LIST OF GRAPHS & CHARTS

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Resistivity profile at above section</td>
<td>7</td>
</tr>
<tr>
<td>8.</td>
<td>Subsidence record form</td>
<td>40</td>
</tr>
<tr>
<td>Fig.</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>17. Portion of deep well and test-hole measurement chart</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>18. Typical graphs of well and test-hole measurements, year 1939</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>20. Graph of total underground pumping</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

Peele's "Mining Engineers' Handbook" lists six of the more vital factors influencing the method of development and operation of a mine. These are (1) topography, (2) local geology, (3) location and mining of oreshoots, (4) haulage problems, (5) drainage, and (6) ventilation and safety. The purpose of this thesis is to provide a scheme for studying the drainage factor and to show how such a scheme works out in actual practice.

Even the casual observer will note the interdependence and interrelationship among the factors listed. So closely tied together are they that a reasonable discussion of an item such as drainage may well be given in terms of the other items. Drainage will be discussed in just that fashion in this paper. A general study of each factor, and a program of water control will be followed by an application of this brief study to the water problem at the Morris Mine of the Inland Steel Company at Ishpeming, Michigan.

1-McClelland: Peele's "Mining Engineers' Handbook", pp. 489-494
SECTION I

A STUDY OF THE FACTORS INFLUENCING THE DEVELOPMENT AND OPERATION OF A MINE

I. TOPOGRAPHY

A. Surface Maps -- A good surface map of the property in question is one of the most desirable requirements. Contours should be shown at a small enough interval to depict all important drainage channels. Even if a water problem is not anticipated, it is still wise to make topographic surveys in great detail. For example, even the kinds of trees should be noted because the nature of the vegetation is indicative of the proximity of the water table and is also somewhat indicative of the kind of country rock.

In many regions of the United States it is possible to obtain aerial photographs as taken by the Department of Agriculture or by the Department of Interior. Such photographs are of inestimable value in finding surface features and they eliminate the necessity of extensive topographic surveys. If the area under consideration is large, it might be worthwhile to contract with some aerial survey concern to have a special survey made.

B. Surface and Sub-surface Waters -- A study of surface and sub-surface water conditions should be a part of the general topographic study. For a detailed investigation, this should involve a study of climatic conditions, quantity and character of precipitation, flow of streams, and nature and depth of overburden.

In dealing with rainfall, the run-off factor must be
considered, since this is a measurable quantity. The remainder of the water either seeps into the ground or evaporates. Run-off is affected by the amount and intensity of precipitation, slope, character of soil, and vegetation. An unfavorable combination of these factors will make rainfall a critical consideration in mine drainage. In cases where dangerous seepage is suspected, it is advisable to make flow studies of streams. Such studies might show too, that seepage is occurring not only from the immediate precipitation, but also directly from the streams.

An accurate weather record for years past is often of value in dealing with a drainage problem. This would show, among other things, the amount of snowfall; which is an important consideration in many regions. The rapidity with which the snow melts in the spring usually has some effect on the amount of water appearing underground.

When water is absorbed into the ground, some of it remains in the pores of the soil at the surface, some goes through into the deeper layers of the overburden, and some percolates still further into the bedrock. The upper limit of the saturated zone is called the water table, and its configuration varies with the elevation at surface, and with the nature of the soil and bedrock. Its depth below surface is variable with the climate. Ground water moves slowly in the direction of the slope of the water table.
Since the nature of the overburden has an important bearing on the water-table, it is often necessary to drill test-holes where cross-sections of the overburden are desired. Test-holing may be minimized where an exploration program has already been initiated, because the diamond drill holes will furnish logs of the surface material.

C. Ledge Contour Maps -- In areas where a water problem is expected, a contour map of the ledge rock is essential. Such a map may be made up from drill hole information or, better yet, from information determined by an electrical resistivity survey.

A simple resistivity survey may be conducted by comparatively inexperienced engineers. Such a survey is based on the principle that the difference in resistance of various soils or rocks is a measurable quantity. In the case of a loose, saturated mantle overlaying a ledge rock, the difference in resistance between the overburden and the ledge is usually of considerable magnitude. This relationship simplifies the interpretation of survey results.

With the general principle of an electrical resistivity survey in mind, if some method is devised of introducing an electrical current into the earth in such a manner that the depth at which the current is functioning may be varied and measured, a measurement of the various layers of material from the surface down, may be thus taken. Operating on this premise, a simplified measuring apparatus would consist of the four electrodes shown in Fig. 1. These electrodes
FIG. 1--PROFILE SHOWING CURRENT FLOW LINES AND EQUI-POTENTIAL LINES FOR RESISTIVITY SURVEY. (FROM "APPLIED GEOPHYSICS"--EVE & KEYS, PG. 95).
are placed at equal intervals in a straight line and at a fixed depth in the soil. The current, which is measured by a milliammeter, enters and leaves the soil by the two outer electrodes, C₁ and C₂. At the same time, a potentiometer measures the difference in potential between electrodes P₁ and P₂. In Fig. 1, the dotted lines represent the current flow and the inverted bowls represent the equipotential areas. The mean resistivity of the ground to a depth about equal to the electrode spacing may be obtained by the modified formula:

\[ \text{Resistivity} = 2 \pi \times \text{electrode spacing} \times \frac{E}{I} \]

Changin the spacing of the electrodes gives the resistivity for a different depth.

The simple resistivity survey described most nearly resembles what is known as the Porous Pot Method. Various other methods follow the same general principle.

Electrical resistivity survey notes may best be interpreted graphically, as shown in Fig. 3. A survey over a typical section such as in Fig. 2, at the Morris Mine of the Inland Steel Co., would produce the profile of Fig. 3. Note that the curve suddenly changes direction when the high-resistance rock is reached. It is this point of change of direction that indicates the depth to the ledge.

D. Effect of Topography on the Mode of Entry. -- One of the phases in mine development affected by topography is the mode of entry; which, in turn, has its effect on drainage. Topography determines whether an adit or a shaft
FIG. 2--TYPICAL SECTION AT MORRIS MINE

FIG. 3--RESISTIVITY PROFILE AT ABOVE SECTION (TYPICAL)
will be driven into the orebody. The advantages of an adit over a shaft for drainage purposes is readily discernible. Further, even though a shaft may be necessary as a primary entrance into a mine, the configuration of the land may permit driving a tunnel for drainage purposes.

II LOCAL GEOLOGY

Information for a good geologic map comes from engineers' topographic surveys and surface maps, from drill holes, from any geophysical work that may be done, from adjoining property owners, and from actual geologic field work. Probably most of the information affecting drainage will be derived from drill hole logs.

A geologic study from the drainage viewpoint should take particular notice of dikes, faults, jointing and fissuring, bedding planes, and permeability characteristics of the various rocks. It is an interesting coincidence that the same factors which are active in assisting in the concentration of ores also often aid in localizing waters in areas where they are least desired. Thus, dikes and faults often conduct mineralizing solutions and also make excellent channels for undesirable surface waters.

The importance of a careful study of outcrops is emphasized because surface inflow through outcrops may be one of the chief sources of detrimental mine waters.
Drill records should be studied to reveal information on the rocks at depth. Crevices and underground cavities encountered in drilling may reflect a general characteristic of the rock. Such cavities may present a serious aspect to underground operations because of the possible sudden influx of water if such crevices are tapped.

III LOCATION AND MINING OF ORESHOOTS

From the characteristics of the orebodies as obtained by exploration and from the other topographic and geologic data on hand, a good idea of the size, shape, and location of the oreshoots can be obtained. Further, from this information it should be possible to determine closely what mining method will be used. This latter is all-important in relation with drainage. Briefly, a mining method which affects the outcrops invites surface waters into the mine; a mining method which leaves a strong caprock will result in relatively less underground water. There follows a brief summary of the various mining methods with emphasis on their relationship to mine drainage.

In their broadest classifications, mining methods resolve themselves into:

(A) Underground metal-mining methods
(B) Open-out methods
(C) Coal-mining methods
(D) Placer-mining methods
A. Underground metal-mining methods -- Under these metal-mining methods there are the following sub-classifications: 5

1. open stopes,
2. timbered stopes,
3. filled stopes,
4. shrinkage stopes,
5. caving methods,
6. a combination of any of the above methods. The method chosen depends on many factors not the least of which should be drainage. From the drainage angle, the question to be asked is, will the method used bring the surface in? If it will, and if there are abundant surface waters, there will be a drainage problem to contend with.

1. Open stopes -- An open stope is one in which the walls are supported by pillars of ore or waste with little or no timber. In many mines, open stopes remain open long after the ore has been removed, such as in the hard iron ore mines of the Marquette Range and the iron ore mines of the Menominee Range. On the other hand, the soft hematite ore open stopes of the Marquette Range cave quickly and are, therefore, of no more advantage in drainage than are the ordinary caving methods. By filling the open stopes with sand or other waste material, caving can frequently be eliminated completely.

2. Timbered stopes -- Timbered stopes, as the name implies, are stopes in which timbering is the predominant feature of the method. Under this method are listed such classifications as square-setting and Mitchell slicing. It is very difficult to maintain such stopes open for much longer than the period of mining. Most timbered stopes

5-McClelland, Peale's "Mining Engineers' Handbook, pp.537-762
are now filled with waste material.

(3) **Filled stopes** -- These are stopes in which support of the wall rock is furnished by some filling material such as waste rock, sand, tailings, and the like. Under this heading come methods such as filled flat back stoping, resuing, and filled rill stopes. These methods are ideal for weak ground where caving is not allowable.

(4) **Shrinkage stopes** -- Shrinkage stopes are overhand stopes in which the ore accumulates under the feet of the miners until the mining has been completed. The applicability of shrinkage stopes is limited by rigid requirements such as steep dip of orebody, regularity of shape of orebody, and strong wall rock. Shrinkage stopes are often narrow enough so that they will not cave after mining is complete. If there is danger of caving it is simple to fill with waste.

(5) **Caving methods** -- As the name implies, caving methods are those in which the back of the working places follows the progress of the mining downward. Sub-level caving, block-caving, and top-slicing are caving methods. A caving-method is considered to be successful if the material above the mining location caves continually up to surface. This eliminates the danger of a cap rock hanging up for a period of years and then letting go with what has often been disastrous results.

B. **Open cut methods** -- With drainage in mind, there is little discussion necessary for open-cut mining. This is an excellent example of the effect location of oreshoots
has on drainage, however. An open cut mine acts as an artificial drainage basin. Climate has a more pronounced effect on the mine waters present.

C. Coal mining methods -- This paper deals mainly with metal mining, so the subject of coal may be passed over with only a few remarks. In general, the advanced stages of underground coal mining bring on subsidence with its attendant water problems. The drainage problems of open-cut coal mines are similar, in many ways, to those of open-cut metal mines.

D. Placer mining -- In placer mining, the surface aspects of drainage come to the fore. The handling of water during the mining of placer deposits is a very specialized procedure since the problem is more often to control or divert waters to the best advantage, rather than to eliminate them completely. Underground placer-mining produces still newer problems in the nature of drainage.

IV HAULAGE PROBLEMS

Although haulage problems may seem somewhat distant in treating of drainage problems, actually, the relationship is quite close. Too many mines minimize this relationship. For example, haulage affects the location of openings. This is especially true in the case of flat-lying orebodies where a shaft or adit entering an orebody at its lowest point, makes for grades in favor of loaded cars and, therefore, also in favor of drainage. Drainage and haulageways most often bear this relationship
to each other. The haulage and drainage problems of a mine also go hand in hand in determining the size and design of openings, such as shafts and drifts.

V VENTILATION AND SAFETY

Problems often arise in the course of mine development and operation where otherwise important factors must be disregarded in favor of ventilation and safety. The best drainage drift might have to be abandoned because of certain ventilation conditions. The positions of vital dams are often selected with an eye to ventilation and, of course, to safety. Quite naturally, almost everything in favor of good drainage also promotes safety.
CONCLUSION

The interdependence of the factors discussed is stressed again. A final program of development and operation of a mine would be one evolved from a proper balance of the information obtained in a study of all those factors. Such a final program would include a new element to be weighed well with the other factors. This new element would be proposed total ore production. It can readily be seen that a water condition which might be serious in a long-lived mine may be at least normal in the same mine with a short life. Assume that two mines have the same ore reserve, and the same daily water flow. If one mine is worked out in half the time of the other, the total cost of drainage will correspondingly be half that of the other mine. This is an especially important consideration in mines where the ratio of water removed to ore removed is 20 or 30 to 1. Quantity production, then, can often be made to carry over properties which might otherwise be marginal because of a bad water problem.

Considering this last point with the factors previously discussed, many eventualities can be prepared for ahead of time. True, as in all mining, there is always the chance factor, but it is an axiom that a correct scientific approach does away with much of the element of chance.
SECTION II
CONTROL OF SURFACE AND UNDERGROUND WATERS

I SURFACE

The study in Section I should produce enough information to show whether or not some form of control of surface waters is necessary on any one particular property. In any event, it should be kept in mind that it is generally much cheaper to catch a quantity of water at surface, than to pump the same water after it has gone underground.

In cases where inflows of water, such as from streams, are localized within small areas, there are relatively simple expedients for controlling the water. These expedients may be diversion ditches, flumes, or slimes and clays. Where troublesome waters are present over a large area such as a swamp or lake, the only good remedy is to drain the area. If possible, this should be done with ditches; otherwise surface deep wells must be used for pumping off the water.

Sometimes bothersome surface waters are only periodic, as with floods. These can be controlled by dams, levees, and other familiar schemes of flood control.

A. Inflows of water from streams -- It is obviously often difficult to determine definitely whether water is seeping into the bed of a stream. Various dyes may aid in finding the seepage zone. In smaller streams, a check may be made by a method taken from the writer's experience. Briefly
stated, the scheme is to place weirs at intervals in the stream, and to note if there is a drop in volume between any two weirs. If there is a decrease, taking into account all tributary streams, of course; there must be seepage into the stream bed.

The writer has found that many contradicting results may be obtained by the method, unless all controlling factors are carefully considered. The location of the weirs is important. Advantage must be taken of the knowledge of the general geology, so that weirs will be placed on both sides of possible porous or cracked formations. Weirs must be placed in tributary streams so that the necessary corrections may be made. Readings must be taken at regular intervals. For best results, even evaporation should be noted. Observers watches should be synchronized, and the rate of flow between weirs should be determined.

When observations have shown that there is seepage between weirs, the troublesome area can be narrowed down by constructing intermediate weirs and repeating the observations. When a seepage zone is found, suitable control measures as discussed below may be taken.

(1) **Diversion ditches and fluming** -- The necessity for a stream to be diverted is sometimes difficult to ascertain. A successful stream diversion is the surest method of eliminating seepage, but the cost of such a project is often not in its favor. Fluming, or the use of slime and clays, when applicable, are cheaper. There are several cases in the writer's experience, where small streams flowed over orebodies to be
mined by the open cut method. In such a case, streams obviously must be diverted.

Insofar as possible, a new stream must be situated where seepage from this same stream will not get back into the workings. In one of the cases mentioned above, sheet piling was driven to the ledge between the diverted stream and the workings, in an effort to intercept persistent seepage. The efficacy of sheet piling, however, is questionable; because of the difficulty of making a good seal at the ledge. A much better alternative might have been to just divert the stream, and then to flume the portion flowing over the seepage zone.

Mining history is replete with interesting cases of stream diversion. At the time of writing, the current diversion project holding considerable interest in the mining world, is that at Steep Rock Lake, Ontario.* Briefly, at Steep Rock, the waters flowing into the lake are diverted completely into another lake. A portion of Steep Rock Lake itself is being pumped dry, while the remaining portion is dammed off at a narrow neck. Open pit ore will be mined from the pumped out lake bed.

Fluming is not always to be discarded in favor of diversion, because the former is much cheaper. Flumes may range from concrete beds for streams to elevated steel channels. Concreting is feasible only where the broken areas are few and small. As has been noted before, fluming is often used in conjunction with diversion to completely eliminate seepage.

---
* Robert K. Bartley - A. I. M. E., T.P. 1543
If the volume of a troublesome stream is small, it may sometimes be feasible to dam the stream above the seepage zone and then to pump the water from the reservoir to some area away from all mining operations.

(2) **Slimes and clays** -- New developments in the chemical industry have encouraged the use of slimes and clays in sealing off porous and leaking stream beds. Since the cost of such methods is comparatively small, it is wise to investigate these possibilities before diverting or completely fluming a stream.

The materials used for sealing streams may be local by-products of mining, such as flotation slimes. Otherwise commercial clays or grouts may be used. There are some properties where there is a natural process of sealing going on in streams carrying silty or slimy mine or mill waters. Many ores in a fine state become almost colloidal in nature and assist in sealing.

Flotation slimes of favorable character may be used either directly on a stream bed or pumped into drill holes in the fractured zone. The effectiveness of the slimes depends not on any colloidal action, but rather on the familiar packing effect displayed by many small-mesh materials.

The clay ordinarily used in sealing off waters is some commercial form of bentonite—a clay that has the unique property of being able to absorb many times its own weight in water, and to swell up to 15 times its original size in the process. This clay never permanently sets
or hardens; its flexible, expanding, and everlasting properties make it ideal for sealing off waters. The clay may be applied simply by sprinkling over a stream bed. If the stream flows too rapidly, the clay should be covered over with sand or soil. The sucking action of water going down into cracks quickly draws the clay down before it has time to expand. When expansion occurs, the crack is completely sealed.

Bentonite and associated clays may also be applied successfully to ponds and lakes.

Cement grouting may be successfully used in sealing off porous measures, but the process is expensive. In some cases, a mixture of a cement grout with a clay or slime is effective, and decreases the cost somewhat.

B. Inflow of water from large areas, such as swamps — When water seeps into underground workings from extensive areas, such as swamps, the only obvious method of control is to attempt to drain the whole area in some manner. Any program of this nature should be expected to be long and expensive with results frequently uncertain.

A large surface area may be partially drained by putting ditches throughout the area and utilizing every inch of drainage grade available. This scheme needs to be followed by a deep-well pumping program designed to drain the area to ledge rock. The principle of such a program is to situate wells in a manner so as to lower the entire water table and also to intercept water flowing in channels in the overburden or on the ledge.

A more complete discussion of the use of deep well pumps
in draining areas is given under Section III, so details of locating, drilling, and pumping of deep wells are omitted here.

Deep wells may be used for draining areas below the ledge rock, also. In some fields where the mining is near surface, a systematic deep-well pumping program drains areas just ahead of the mining.

C. Recording and interpreting surface water control results --

As in all types of engineering projects, substantial methods of checking results are needed in order to insure efficient operation. Routine measurements at all pumps and weirs are essential. Much can be learned by keeping adequate maps, graphs and charts.

Besides regular measurements on operating equipment, there are certain field tests which are applicable under many conditions. There are chemicals such as fluorescein and various dyes which may be used, in following the underground flow of water. Fluorescein can be detected by ultra-violet light when the dilution is extremely great. In making such a test, the chemical is placed in the well, test-hole or crevice, and samples are taken at regular intervals over as wide an area as is feasible. From the results, charts can be made up which will assist in new methods of water control.

II UNDERGROUND

A. Shaft sinking -- Control of water in some of its more difficult aspects appears when shaft sinking begins. That portion of the shaft above the ledge more often produces the water problems, although, there are many water problems encountered when sinking in rock.
(1) Sinking in soft, water-bearing soils -- Peele's classifications of methods of sinking in soft, water-bearing soils are: (1) linings constructed in the shaft as excavation progresses, (2) linings constructed at surface and sunk as excavation progresses, and (3) solidification of the material in advance of sinking.

Linings that are constructed in the shaft as work progresses, are difficult to maintain successfully. Timber is ruled out when there is much water with the soft soil. Sheet-piling is often used to hold back the soil. The piling may be driven either outside the shaft area entirely, or else directly along the outline of the shaft. The use of a steel structure known as a shield is found to have excellent results in the case of particularly soft water-bearing ground. The shield sets on the bottom of the shaft with a sharp shoe along the edge driving into the muck. Shaft lining is added on top as miners excavate dirt from within the shield. Care must be taken so that subsidence will not set in around the outside of shaft linings.

Probably the best and most often used methods of sinking in soft, water-bearing soil are those with linings constructed on surface and sunk as excavation progresses. Open and pneumatic caissons fall under this classification. A caisson is a hollow, pipe-like affair which is sunk by excavating from within. When the water problem is acute, a pneumatic caisson is used, that is, a caisson in which air pressure keeps back water and mud. This method is probably the most successful one of 8-Donaldson & Jarrett--Peele's "Mining Engineers' Handbook pp. 296
sinking a shaft through a water-soaked overburden. It is a very expensive method, because of the special equipment and specially-trained men needed.

The dropshaft also falls under this second classification of shaft-sinking in water-bearing soils. The drop-shaft is sunk by tools similar to a large drill bit and all the work is done from surface. The drop-shaft method may be alternated with a scheme suggested by P. S. Tillinghast. His method consists of dropping a 6-foot shoe down by the usual process of excavating from within, but the lining sets are put in as the shaft progresses, and the shoe is jacked down from the nearest set. At the same time, the sets are all hung from a well-established bearer on surface; and if trouble develops, the method may be altered to a drop shaft.

A freezing process for solidifying surface material before sinking is applicable under conditions similar to those requiring a pneumatic caisson, but where sinking is to continue for a considerable depth. The freezing process consists of pumping a freezing solution into properly spaced holes at the shaft site. When the ground is frozen, any of the usual methods of sinking may be used. For considerable depths, the freezing process is carried on in stages.

In all these methods of sinking in soft, water-bearing soils, the job is not complete until the water is sealed off effectively at the ledge. A solid concrete wall down

9-Tillinghast, P. S. "Mining & Milling Practice." pp.65-70
to ledge is most satisfactory. At the ledge contact, it is recommended that grout should be pumped into drill holes in the rock. Grouting over various portions of the concrete shaft wall might be necessary to effectively seal off water.

(2) Shaft sinking in rock -- After the preliminary phase of sinking the shaft to the ledge, the major water problem is usually under control. There will still be water dropping into the shaft from the wall rock. This may be controlled to a certain extent by, (1) the use of water-rings, (2) diverting dripping water into intermediate reservoirs in the shaft, (3) grouting local fissures carrying water, and (4) completely lining the shaft with an impervious material such as concrete.

A water-ring is a small groove cut around the shaft to act as a miniature sump. Corrugated iron sheets and splashboards may be used in conjunction with water-rings to gather water from the shaft and lead it to a tank and pump. Grouting readily seals troublesome areas, especially if the grout is projected in through long drill holes.

When a shaft must be completely lined, there is a choice of concrete, masonry, or tubing. The tubing has common use in what is known as the Kind-Chaudron shaft sinking process. In this process, the shaft is sunk entirely by a boring tool working under water. When an impervious stratum is reached, the water is sealed off. The shaft is then lined with the steel tubing.

B. Underground pumping -- The most commonly used method
of underground water control is direct pumping. The general scheme of an underground pumping system is one of gathering water from the mining areas to a central reservoir from whence it is pumped to surface. The exact layout of a pumping system depends on factors such as the flow of water, expected depth of the mine, number of levels, etc.

(1) Types of pumps -- Variations from centrifugal to plunger-type pumps present many interesting problems in a pumping layout. The factors to be considered in the choice of a pump are: (1) type of power available, (2) required pumping capacity, (3) head of water to be pumped. When large quantities of water are to be pumped under a high head and with good efficiency, the plunger-type pump is hard to beat. The present trend, however, is more and more to centrifugal, because of their many advantages. They are compact and easy to handle, have very favorable pumping characteristics, and they make for a very elastic pumping system. In addition, the newer types of multi-stage centrifugals can effectively replace most plunger pumps.10

(2) Water column -- When the type of pump has been selected, and preparations are started for the installation, the problem of the choice of a water column appears. The problem is simplified because columns are generally fabricated especially for each job by firms specializing in this work. Care must be used in choosing a column that will be sure to meet future needs.

(3) Sump -- Making a sump of sufficient size to hold all the inflow of mine water over a period of several hours is

10-Slack, F. E., "Modern Mining & Milling Practice", pp. 103-105
essential. There is always the possibility of a sudden large
inflow of water exceeding the capacity of the pumps or a power
breakdown may stop the pumps completely. A large sump is an
excellent safety valve in these cases.

In constructing a sump, the fact that considerable slimes
carried by the water will accumulate in the floor of the sump
must be taken into consideration. The design of the sump must
be such that this accumulation may be readily removed.

(4) **Pumping measurements** -- The quantity of water being
pumped from a mine must be determined continuously. Two
methods are regularly used for doing this. In the first
method, the operating time of each pump is recorded; and since
the capacity of the pump is known, the total volume of water
pumped can easily be computed. It should be noted that the
actual capacity of a pump is nearly always less than its
rated capacity. The actual capacity of a pump should be
computed occasionally to insure accurate measurements. A
second, and auxiliary, method of computing the total amount of
water pumped, is by the use of weirs at the entrance to every
sump. These weirs should either be equipped with automatic
recording devices or else should be read at frequent inter-
vals by some competent person. Except in mines where the
water flow is remarkably uniform, the results obtained from
reading weirs without the use of automatic recorders is, at
best, only approximate.

The results of underground weir readings should be co-
ordinated and compared with all other water measurements, both
surface and underground. The possibilities in weir investigat-
ions are extensive. Weirs can be placed throughout a level to
catch small localized fluctuations in flow. Weir studies can further aid in tracing water flows from surface to the various levels and they can give evidence of how the mining is affecting the inflow of water.

C. Drifting -- In the normal development of a mine, drifting follows the shaft sinking and pump installation. The main drift away from the shaft is driven in only far enough to insure that pipes and the like will not be injured by blasts. A pilot hole some distance ahead of the breast should be drilled before every blast to detect any possible flow of water. This flow is often quite high when an orebody is reached.

From the drainage viewpoint, a drift is simply a water course. The design and grade of a drift must be adjusted with this in mind. Provisions that water will not flow over the track, should be made by a large enough ditch. Timbered drifts through wet areas may be designed so as to deflect dropping water into the ditch rather than on the track area.

The grade of a drift is necessary both to balance the haulage of loaded cars against empty cars, and to enable water to flow toward the sump. From the haulage angle, grades up to 1% are usually sufficiently steep; but, from the drainage angle, grades up to 1% are often not excessive.

D. Miscellaneous devices and Installations

(1) Hoisting water in tanks or skips -- Many times, water may be conveniently removed from a mine by bailing it out with a special tank or a regular skip. This method is especially adaptable in dewatering flooded mines. It is also applicable when an
underground pumping plant is in danger of being flooded out.

(2) **Air lift** -- The air lift has an applicability in the same general field as that of hoisting water in tanks or skips. The air lift operates on the principle that water can be forced up a column by blowing air into the bottom. The air gives an upward pushing effect and, in addition, it reduces the specific gravity of the water in the column. The outside water then pushes the air-water mixture up the inside of the column. S. F. Shaw\(^2\) has found that a properly constructed air lift operates at an efficiency favorably comparable with that of a centrifugal pump.

(3) **Water car** -- The use of a car to remove water is limited to operations where the amount of water is so small that it need only be bailed into a car and hoisted to surface.

(4) **Siphons** -- An obstacle in the way of a normal water flow may often be bypassed by means of a siphon. This situation occasionally occurs in the floor of a drift where a slight rise acts as a dam.

(5) **Acid waters** -- The problem of acid waters is encountered in many mines throughout the country, especially the copper and coal mines. The treatment of such waters is a problem that must be studied very carefully, because the presence of an acid in a mine water does not necessarily require that the water be neutralized before pumping. It may be that non-corrosive metals could be used in the pumping equipment. The metals would need to be only sufficiently non-corrosive to outlast the mine. It might also be pos-

---

sible that renewal of equipment would be cheaper than buying neutralizing agents.

When neutralizing of acid mine waters is essential, the agent used is most often milk of lime. Neutralization may only be partial if partial neutralization will protect the pumping equipment.

(6) Dams and bulkheads — Dams and bulkheads may be of either the temporary or permanent type. Several types are shown in Section III. Permanent bulkheads, carefully situated and installed, may be a major factor in reducing the amount of water pumped. They are of particular value when they keep water out of ore areas. A large flow of water in a waste rock area is often preferable to even a minor flow in an ore area, because of the difficulties in mining and hauling wet ores.

Bulkheads may serve a double purpose by shutting off abandoned areas and decreasing the needed volume of fresh circulating air.

Temporary dams and bulkheads are generally placed near the shaft in a position where they can be closed in a few minutes against sudden onrushing waters. These are also discussed in Section III. Dams of the door-type are replacing others now because a door-type dam can be closed with great rapidity. When waters back of a temporary bulkhead are definitely of flood proportions, a permanent bulkhead must be built further downstream.

E. Unwatering Mines by tunnels — Mining literature is full of many examples of new mining areas opened up because tunnels
have drained the flooded ore areas. The applicability of such a method of draining potential mining areas is obviously restricted to mountainous regions, where the topography permits the driving of a tunnel underneath a sufficiently large tonnage of ore. Mining often proceeds from this same tunnel after the water has been drained.

Immensely amounts of money have been expended on tunnels to gain an apparently small amount in drainage depth. In an article entitled "The Rothschenberger Stollen" an adit is mentioned which was driven for 30 miles to gain 300 to 500 feet in drainage depth. The cost of a tunnel must be balanced with the cost of the pumping which would have been required, had the tunnel not been driven.

14-Trans. A. I. M. E. Vol. VI. "The Rothschenberger Stollen."
15-Comp. Air Magazine: Nov. 1941 pp. 6589-6590
SECTION III

AN EXAMPLE OF A PROGRAM OF STUDY AND CONTROL OF
MINE WATERS

THE MORRIS MINE OF THE INLAND STEEL COMPANY AT
ISHPEMING, MICHIGAN

I. GENERAL CONDITIONS

The Morris Mine is situated on the Marquette Range about
two miles west of Ishpeming, Michigan (see Fig. 4). The pro-
PERTY consists of a number of "40's" lying over the north
limb of a great synclinal basin which pitches to the west with
its axis outcropping in the vicinity of Ishpeming. The basin
is composed of sedimentary rocks which have been intruded and
metamorphosed by basic igneous rocks. Ore occurs on both
the north and south limbs of the syncline in the Negaunee
formation. On the north limb, the ore is soft hematite such
as is at the Morris Mine; and on the south limb, most of the
ore is hard specular hematite and magnetite.

The Morris Mine has been in operation about 30 years.
The mine was first operated by the Cleveland Cliffs Iron
Company, and for the last ten years has been operated under
a leasing agreement by the Inland Steel Company.

A. Topography

(1) General surface -- The mining operations take place
almost entirely under an extensive swamp area, (see Fig. 9)
which is forested with tamarack, spruce, and balsam fir. There
are ledge outcrops at a few spots but most of the swamp area
has from 50 to 150 feet of overburden. When the Inland Steel
FIG. 4 - LOCATION OF MORRIS MINE
Company took over the Morris Mine, the underground workings were just beginning to get wet, so no great concern about draining the swamp area had as yet been shown.

(2) Climate -- The climate of the region is one of cold, snowy days in the winter, and alternate hot and cold spells with intermittent rains in the summer. The total precipitation ranges from 30 to 40 inches per year. Except in extreme cases when there are continual abnormal rains, the effect of rainfall on underground waters appears to be very small. Of a more noticeable effect however, are the spring thaws.

The problem of rainfall and spring thaw effects was brought to the attention of the engineering department in 1940. A record of the underground pumping was compiled for the Morris Mine and for the Lloyd Mine adjoining the Morris on the east. An attempt was then made to correlate these records with the weather and seasons. No reasonable correlation with rainfall could be made. At the Lloyd Mine, the effect of the spring thaw was striking; the small normal flow was almost quadrupled during the several weeks of maximum thaw. At the Morris Mine, the volume of water pumped did not fluctuate with the amount of thawing on surface. There is a satisfactory explanation for this which gives us a better idea of what is essential for control of these waters. At the Lloyd Mine, there is only a negligible amount of water in the overburden, and there is as a result only a small normal underground flow. When the surface
water is increased by the spring thaw, this water goes right through the comparatively dry overburden and into the mine. At the Morris Mine, however, the water table is very near the surface of the overburden material and seepage underground is continuous. The effect of the spring thaw is simply to raise the water table several feet with no appreciable change in the flow underground. Spring thaws, then, do have their effect insofar as the total amount of water to be controlled is concerned. In the same way, accordingly, rainfall has its effect.

(3) Streams -- There is one fair-sized stream flowing over the Morris property. This is the Carp River shown on Fig. 9. There is a possibility of some seepage from the river in the cross-hatched area showing the underground workings. In that area the ledge outcrops at several points. The stream bed, however, is abundantly covered with fine iron oxides which certainly seal most of the possible channels. There have never been any flow studies made of the Carp River and it seems that such a study might be an advisable step in an extended water control program.

(4) Ledge contour map -- The ledge contour map of the Morris Mine area is based on information from all drill hole records. This includes information from the test holes drilled to obtain sections of the overburden. The current ledge contour is shown in Fig. 5. The unfortunate characteristic of this map is that the drilling of a new hole necessitates at least a minor revision of the contours. The usefulness of the ledge contour map is explained under a separate
FIG. 5—LEDGE CONTOURS
MORRIS MINE
SCALE: 1" = 400'

LEGEND
TEST HOLES — O
DEEP WELLS — •

ELEV.
1500-1475
1475-1450
1450-1425
1425-1400
1400-1375
1375-1350
1350-1325
BELOW 1325
The swamp region at the Morris would be an excellent location for conducting an electrical resistivity survey. The data from such a survey should result in a very reliable ledge contour map. It is likely that the engineering departments' proposal for such a survey may be one of the future steps in water control at the Morris Mine.

B. Local Geology -- The dip of the north limb of the Marquette Range syncline is approximately 70° to the south in the Morris area. The dip of the beds undoubtedly has a bad effect on the drainage situation because the bedding planes tend to become natural drainage channels.

Natural trough structures formed by the intersection of faults or dikes with the dipping beds tend to convey waters to ore areas. This structure is most often apparent with dikes rather than faults. The Morris Mine has numerous dikes lying in varied positions and by observation it can be seen that they localize seeping water from surface.

An additional geological factor that should be considered is the permeability of both the rock and the ore. This factor would have a position of greater importance in flat-lying beds, but with dipping beds the water that seeps through is carried mainly by the bedding planes. At the Morris the country rock is fairly impermeable whereas the orebodies are capable of soaking up large volumes of water. This water is not released then until the orebody is first tapped.
The very nature of the iron formation may be the indirect cause for the presence of the Morris swamp area. Note on Fig. 5 that the ledge within the iron formation is, in general, at a lower elevation than that outside the formation. This is due to the fact that the iron formation was more easily eroded than the adjacent formations. Thus, natural basins for the accumulation of water are formed.

C. Location & Mining of oreshoots -- The Morris orebodies have been developed from several hundred feet to a depth of 1800 feet below the collar of the shaft. At that bottom elevation, the ore areas are enclosed within the cross-hatched area in Fig. 9. Most of the mining falls under or near the swamp as outlined in Fig. 9, so there was always potential danger of seepage from the swamp. This seepage was eventually caused by the method of mining the ore.

Soft hematite ore is most readily mined by some caving method such as top-slicing, sub-level caving and block-caving or by an open stope method such as sub-level stoping and shrinkage stoping. In a mine like the Morris, the open stope methods are often applicable, but it should be pointed out that the stopes do not remain open much longer than the period of the mining operation. The net result in all cases, then, is the same; that is, the rock over the stope gradually breaks and works downward with the progress of the mining.

There have been several deviations in mining practice at the Morris Mine but, in general, mining has been done by

15-Crane, A. T. M. E. T.P.1473A & 18391
FIG. 6 - N-S SECTION LOOKING EAST THRU A MORRIS MINE OREBODY SHOWING EFFECT OF MINING ON SURFACE. FOR SUBSEQUENT EFFECT ON DRAINAGE SEE EXPLANATION IN TEXT.
top-slicing and sub-level stoping. The results, taking place over a period of years, are shown in Fig. 6. The figure depicts a cross-section of a top-slice orebody; results are the same for a sub-level stoping orebody. After the mining has proceeded downward for some time, the country cap rock gradually weakens and spills off in successive upward steps as shown in the sketch. Eventually there is a sudden breakthrough to surface producing a visible cave as shown. This is exactly what happened at the Morris in February 1939, when surface cave No. 1 (see Fig. 5) appeared. Cave No. 2 appeared in the spring of 1940 as the result of continued subsidence.

The quantity of water pumped underground increased considerably as soon as the cave occurred. However, the quantity of water had also been increasing gradually for months preceding the cave-in at surface. This is logical because the successive steps in subsidence break up the ground and provide new and better channels for the water.

The final result is that the small underground flow of water coming perhaps along the big dike shown in Fig. 9 has now been increased to a large flow coming from a large shattered area offering comparatively free passage to water right from surface.

After the occurrence of Cave #1, surface subsidence continued at a slow and intermittent rate until finally Cave #2 occurred. Since a cave-in usually results in a quick influx of water, it became necessary to follow the progress of the subsidence more closely in an effort to anticipate another
cave. For this purpose, a series of profile stations as shown in Fig. 7 were laid out near the caves and regular elevation readings were taken to these stations. These were recorded on a chart such as in Fig. 8. The engineering department is continuing this control study. Results to date seem to indicate the same surface happenings as have occurred at other Lake Superior properties. As sketched in Fig. 8, the subsidence proceeds roughly in steps away from the main cave, coming to rest only when mining has finally stopped.

As the subsidence area is enlarged on surface, the territory open to the surface waters increases. This not only tends to increase the water volume underground, but also spreads the water over a larger portion of the mine. As mining proceeds downward, then, more and more mining places become wet.

D. Haulage problems -- At the Morris Mine, haulage and drainage problems are closely tied together and this relationship has been the subject of much engineering discussion. Determination of the proper grade of a drift is very important, because of the necessity for a proper balance between drainage grade and haulage grade. Enough study has been made so that wet areas are well known and predictions can be made as to the condition of the finished drift. The present policy is to use a $\frac{1}{4}$% grade in dry areas and from $\frac{3}{4}$% to $\frac{3}{4}$% in wet areas. Sometimes it is wise to err on the side of too steep a grade.
FIG. 7 - LOCATION OF SUBSIDENCE PROFILE

FIG. 8 - SUBSIDENCE RECORD FORM
II THE WATER CONTROL PROGRAM AT THE MORRIS MINE

A. Surface Control

(1) Control of water from streams -- The problem of further diverting the Carp River is one that has been facing the Inland Steel Company since the Morris Mine was taken over. Previous to that time, too, there had been several diversion and dredging projects. In 1922, (see Fig. 9) the Carp River was dredged so as to lower the level of North Lake 20 feet. This might prevent the lake from being a drainage problem in future mining operations. Also in 1922, two diversion ditches were dug, as shown by the dotted lines in Fig. 9.

In 1934 the Inland Steel Company decided to make a further diversion to insure safety for a long time to come. Accordingly the main ditch shown by the heavy dash line was dug. The lateral ditches "A", "B", and "C" were designed to drain the maximum possible portion of the swamp. All the ditches were put in at minimum allowable grades so as to provide for a maximum depth of drainage.

The Carp River continues as a problem, however, as long as it flows over the orebody area. One never knows when new subsidence may affect the stream bed. The results would be much more disastrous than those produced by any small amount of water now seeping through the stream bottom. The engineering department has laid out a proposed diversion ditch to bring the river still further east. At the same time, an extended field investigation is being made to determine if it is possible to divert the entire Carp River north to a
different watershed, from a point just west of the Morris shaft. Such a step would be ideal, for it would eliminate the Carp River problem completely as far as the Morris Mine is concerned. Results of the survey, however, have not been encouraging. It appears that a ditch long enough to bring the Carp within another drainage area would be much too costly.

A somewhat radical engineering proposal has been made concerning this new drainage area. It is suggested that the river should be dammed just west of the Morris and then the water should be pumped from this reservoir north to another drainage area. A study of this has indicated that the cost again would be prohibitive.

Fluming the river over the mining area would be effective only in preventing stream bed seepage, but would be useless against subsidence.

Another survey started during the summer of 1943, proposes a north-south ditch several miles west of the Morris shaft. This ditch would cut across several tributaries of the Carp River and decrease the flow over the Morris operating area. The results of the preliminary survey have been encouraging.

The problem continues, and it seems that for the present, temporary diversion to the east will be the only logical step, until such time as a permanent change can be worked out.

(2) Control of water from swamps -- Certainly the most interesting phase of the water control program at the Morris
FIG. 9 - DIVERSION AND DRAINAGE DITCHES AT MORRIS MINE

SCALE: 1" = 600'
has been that of the deep well pumping systems. The lateral ditches "A", "B", and "C" removed about 15 feet of the surface water, but did nothing for all the water below the ditches. The only satisfactory method for removing this water was a long-term deep well pumping program. The main engineering problem throughout has been to place these wells in positions where they would do the most good.

To be successful, a deep well must first be situated in a water-bearing gravel. Even though the entire overburden may be saturated with water, a gravel bed should be present to conduct water rapidly enough to the pump. Secondly, a good well must be in a position where it can intercept waters going into the mine. Thirdly, a good well must be situated where it can lower the water table to a considerable extent. A well can be giving both long-term and short-term results; it can be lowering the water-table so as to eventually drain the area completely and it can prevent local flows of water from entering the mine workings.

Since logs of the overburden are necessary before drilling a well, a test hole churn drilling program was started in 1937. Up to 1944, 30 test holes have been drilled, finding satisfactory locations for 10 deep wells. The logs of the test holes are shown in Figs. 10A and 10B. Although several runs of water-bearing material had been encountered in earlier holes, it was decided to attempt a well at the location of test hole 509. (see Fig. 5). This was in an area in the ledge
FIG.10A-TEST HOLE LOGS
FIG. 10B-TEST HOLE LOGS
known to be a basin from early-day exploration drilling.

The first five wells were drilled by a large churn drill and the remainder have been sunk by a hydraulic rotary machine. The wells drilled by the latter method have progressed more rapidly because the heavy clay media used in drilling has held up the walls of the hole better. The two types of completed wells are shown in Figs. 11 and 12. It can be seen that the churn drilled well has more sections because of the necessity of holding up the walls of the hole. The casing is perforated in the expected water-bearing area. The wells are known as the gravel-wall type with a vertical turbine pump installation. The volume of pumping gradually decreases as the water table drops in the region of the well. Pumped water is flumed out of the seepage zone.

Each new test hole and well has given information which helped in the next drilling. In 1940, sufficient information had been gathered to enable the engineering department to construct the previously-discussed ledge contour map (Fig. 5). This map was a great step in the water control program because it would enable the engineers and superintendents to see immediately the slopes of the ledge. Test holes were spotted by the use of this map for three years.

In the fall of 1943, the writer hit on the idea that the contour of the water-table should have much more significance than the contour of the ledge in laying out new wells. The slopes of many water tables often do not follow the configuration of the ledge and, since the ground water flows in the direction in which it slopes, the effect of the ledge slope is
FIG. 11 - MORRIS DEEP WELL NO. 3A.
SUNK BY CHURN DRILL

FIG. 12 - MORRIS DEEP WELL NO. 8.
SUNK BY HYDRAULIC ROTARY DRILL
FIG. 13 - WATER TABLE, OCTOBER 1939
SCALE: 1" = 400'

LEGEND
TEST HOLES — —
DEEP WELLS — —

FLEV.
1500-1475
1475-1450
1450-1425
FIG. 14 - WATER TABLE, OCTOBER 1940
FIG. 15 - WATER TABLE, OCTOBER 1941
LEGEND

TEST HOLES - O
DEEP WELLS - •

ELEV.
1500 - 1475
1475 - 1450
1450 - 1425
1425 - 1400
1400 - 1375
1375 - 1350
1350 - 1325

FIG. 16 - WATER TABLE, OCTOBER 1943
small. Working on this premise, the writer made up the maps shown in Figs. 13, 14, 15, and 16. The data for constructing the maps comes from measurements of the elevation of the water in the test holes. The month of October was used because that is a month when the water table would least be affected by climatic conditions. The year 1942 is omitted because the change from 1941 to 1943 is very uniform. The maps show in a striking manner the results of the deep well pumping program. They show also how much there is yet to be accomplished.

Results of the subsidence are also evident, especially in Fig. 16. The table is low in the region of No. 4 and No. 6 wells, not only because the pumping has been successful, but also because surface cracks are very likely admitting the water underground at a greater rate.

The water-table maps do not destroy the usefulness of the ledge contour map. Rather, coordinating the information on both maps produces the most reliable guide to date in putting in new test holes and deep wells. Using Figs. 5 and 16, one can readily select a number of places where water and ledge slopes are both favorable for wells. Examples of such locations might be just Southeast of No. 6 well, west of No. 8 well, and southwest of No. 1 well. One must remember, however, that a favorable overburden is still essential and at each proposed location test holes must be drilled. A detailed study of all available logs has shown no connection between the various sections of gravel. Apparently the gravel beds consist of many lenses, the occurrence of which would be extremely difficult to predict.
In the next several years, a number of deep wells will be drilled using the location method described above. Results should be better on these wells than past wells and the number of test holes required should be less. The control program at the Morris will continue to progress along the same lines. More and more deep wells will be needed in order to effectively drain the area. The engineering department will continue to improve methods of finding favorable well sites. The deep-well program must be kept well ahead of the subsidence to be at all effective.

(3) Recording and interpretation of results -- No system of control is adequate unless a careful record is kept of the progress of that system. At the Morris Mine, one of the big jobs of the engineering department is keeping a record of the various phases of water control program.

First come the deep well turbine pumps. These pumps must be kept going with a maximum flow. This requires frequent adjustment, as the quantity of water decreases, otherwise surging will result. Surging is that condition where a pump takes large "swallows" of water followed by "swallows" of air. The flow becomes irregular and pumping is inefficient. Surging also results in inaccurate measurements of the quantity of water pumped. The quantity of water is measured by gauging the velocity head on a small hose projecting from the side of the pump discharge pipe. From this reading the gallons per minute are computed. Such readings are taken once a week and recorded on graphs and charts which show at a glance
the trend of the pumping.

Test holes are also measured regularly. This is done by lowering a small-bell shaped pipe at the end of a tape. When the bell hits the water's surface a sharp, reverberating sound is heard. At this point a reading is taken on the tape and recorded. These readings are taken throughout the year and also charted and graphed.

The charts and graphs of the deep-well and test hole readings are shown in part in Figs. 17 & 18. Notice that the volume pumped goes down as the water table is gradually lowered.

The results of the pumping and test hole measurements are finally shown on the previously discussed water-table contour maps. All of these records are correlated insofar as possible with all the underground pumping records.

An improvement has been noted in underground water since the pumping on surface began but how much of this improving is due to the deep-well program is difficult to ascertain. The continual subsidence produces an ever changing condition. At some stages subsidence tends to open up new crevices and at other stages it tends to seal up old ones. Meanwhile surface pumping continues at a steady rate; therefore, the underground results cannot help but be erratic. Time alone will show the true effect of the deep wells.

As an aid in interpreting results and planning for the future of the control set up, experiments have been made by tracing the flow of water with dyes. The first attempt was made at No. 507 test hole. This test hole is just south of the cave area and will not hold water; so it must be directly
<table>
<thead>
<tr>
<th>NO. 1 DEEP WELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>503 504 505</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEVATION OF COLLAR</th>
<th>ELEVATION OF LEDGE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1524.26</td>
<td>1298.0</td>
<td>07-07-37</td>
</tr>
<tr>
<td>1526.38</td>
<td>1350.4</td>
<td>07-07-37</td>
</tr>
<tr>
<td>1503.95</td>
<td>1364.8</td>
<td>07-10-37</td>
</tr>
<tr>
<td>3.3</td>
<td>3.0</td>
<td>09-03-38</td>
</tr>
<tr>
<td>3.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WATER BELOW COLLAR ELEV.</th>
<th>WATER BELOW COLLAR ELEV.</th>
<th>WATER BELOW COLLAR ELEV.</th>
<th>GAUGE, GALS. PER (IN.)</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.4</td>
<td>27.2</td>
<td>8.1</td>
<td>1497.9</td>
<td>1560</td>
</tr>
<tr>
<td>1499.2</td>
<td></td>
<td>1495.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FIG. 17 - PORTION OF DEEP WELL AND TEST HOLE MEASUREMENT CHART.**
FIG. 18 - TYPICAL GRAPHS OF WELL AND TEST-HOLE MEASUREMENTS; YEAR 1939.
over a crack. The experiment was intended to show what areas in the mine were draining water from the No. 507 area. The chemical used was uranin dye, a dye which produces a brilliant green in water and can be easily detected under ultra-violet rays.

A number of places underground where there were pronounced water flows were marked on a map and a schedule for taking water samples regularly over 24-hour periods was made up. A measured quantity of dye was placed in Test Hole No. 507 and washed down with much water. Sampling underground commenced immediately. No dye was detected in any of the samples, although the ultra-violet test was not made. A larger quantity of dye was used the second time and several samples showed a faint coloration. If this survey is repeated, there will undoubtedly be an ultra-violet apparatus for testing the samples. Successful dye tests such as this at the Morris might further localize the area in which deep well pumps are most imperatively needed.

B. Underground Control

(1) Shaft sinking -- The Morris shaft has given no particular water trouble during shaft sinking. The total amount of water dropping in the shaft probably rarely exceeds 40 gallons per minute. The portion of the shaft above the ledge -- approximately 100 feet, was sunk by the pneumatic caisson method and concreted to ledge. The seal apparently was very successful, since there has been no leakage.

The shaft is now down nine levels for total depth of 1850 feet. Levels are the 4th, 5th, 7th, 8th, and 9th. Only
the 8th and 9th levels are operating levels at the time of writing. Most of the water dropping into the shaft comes from points below 4th level.

The last sinking operation was completed several years ago. The shaft was then sunk from the 8th to the 9th level with about 60 feet below the level for skip pockets. During the sinking, control of water in the shaft was accomplished mainly by diverting water into tanks leading to an intermediate pump. Removing the shaft water from the skip pit is accomplished by means of a small Cameron compressed air pump. This pumps the water to the 9th level sump.

As a portion of the problems facing an engineering force during the shaft sinking operations, selection and preparation for installation of a new water column is one of the major considerations. Although the actual design of the column is left to some fabricating company, it is up to the engineers to gather all the necessary data for the column. In the case of the last sinking job at the Morris Mine, it was decided to put in a new column extending from 9th level right to surface. (See Fig. 19) This column was to be also connected with the 9th level pump. Careful elevations were taken at each level and particular attention was given to the elevations of the pump discharge pipes. This information, along with shaft plat maps, and complete specifications of the pumps were sent to a pipe fabricating concern. This concern immediately submitted a proposal in drawing form. This proposal was thoroughly checked and approved by the engineering depart-
ment and fabrication then commenced. When the column was installed, an engineer was on duty to see that all parts were in their proper places.

This gives a general sketch of the engineer's responsibility in the matter of the installation of a water column. The base support for the column usually has to be designed by the mining company; this work also falling to the engineers.

(2) Pumping -- The Morris Mine pumps approximately 800 gallons per minute to surface and has pumped as much as 1200 gallons per minute. The pumping system which takes care of this amount of water, represents the solution of many diverse engineering problems. At the Morris, the present system is depicted in Fig. 19. The layout represents months of study and work by engineers, mechanics, and superintendents, with numberless changes made as time has passed.

The water on the 4th level is a small flow, easily taken care of by either of the pumps shown in Fig. 19. The capacity of the pumps is great enough to take care of the water pumped up regularly from 7th level. In addition, in case of emergency two auxiliary 8th level pumps, No. 9 & No. 4 are arranged to pump to the 4th level. The 7th level sump is equipped with a siphon going to the 8th level in case the 7th level pumps break down. On 8th level, where the water flow is great, pump No. 6 discharges the flow directly to surface. The 9th level also has a small auxiliary centrifugal pump not shown, which can pump water to 8th level in case of necessity. The dominant features of the pumping system are its elasticity and its auxiliary pumps on each level. If a main pump should fail,
PUMPS

1. Prescott, 6½" x 34", 1000 G.P.M., 1000' HD., Doub. Acting Duplex.

FIG. 19 - PUMPS AND WATER PIPING
an auxiliary pump is on hand ready to relay water to another level.

In case of power failure, of course, the safety of the mine depends on the sump storage capacity and the efficacy of the underground dams.

(3) **Recording underground water flow** -- The time of operation of the pumps is all recorded so that the total amount of water pumped from the mine for any period can be calculated by multiplying the time each pump operated by its capacity. In addition, at the Morris there is a weir at the entrance to each sump. The weirs are a standard 90° "V" type; designed, installed, and maintained by the engineering department. A plug is set in the drift floor so that the top is level with the weir notch. The plug must be in an undisturbed zone several feet upstream from the weir. Measurements are taken regularly by gauging the height of water above the top of the plug.

It has been found that water flow varies considerably and weir readings have to be taken as frequently as possible to insure any kind of check with the pumping records. The ideal condition would be that of a weir with an automatic recording device.

Weir recordings are charted and graphed. The graph of the readings is shown on Fig. 20; the curve shows only the total of all the weir readings. This record of underground pumping is compared with the surface pumping to determine the effectiveness of the water control program. The curve can also be correlated with the various water table contour maps.
After surface pumping began in earnest in 1940, the underground water dropped appreciably. The rise of water in 1943 is hoped to be only a spasmodic variation.

On the graph are shown also the time of occurrence of each of the surface caves. A phenomenon that is noted is that each cave has occurred a short time after a sharp rise in water flow. Not enough caves have occurred to establish this relationship as definite but it does have a logical basis. The cave is only the final step in a subsiding action which has been progressing for some time. This preliminary subsiding action must open up some cracks which admit the higher flow of water previous to the occurrence of a cave to surface. If this hypothesis is borne out it may be possible in the future to roughly predict a cave. This would be of value because a cave-in is usually followed by a short-lived onrush of water which might sometimes be dangerous.

(4) Mining -- In the final analysis, no mining company objects completely to pumping a fair amount of water if this water does not hamper mining operations. Waters might conceivably come through fissure areas in drifts or in faulted areas, all entirely away from the actual mining operations. At the Morris Mine, however, most of the water comes directly through the orebodies or along dikes in the orebodies and soaks the working place thoroughly. The nature of the ore is such that water mixed with it produces a heavy mud. The water and ore mix together readily in any proportion. The most undesirable result, from the cost standpoint, is that it be-
comes necessary to scrape all wet ore directly into cars. Wet ore stored in a raise packs unbelievably hard and water running in with it makes a hazard for the chutemen. On the other hand, it is expensive to keep a motor and crew waiting under each wet contract. Furthermore, cars cannot be filled to their rated capacity when the ore is wet.

The problem of finding some way to keep the ore dry is an individual one for each contract. As the mining progresses, steps are taken as the opportunities to eliminate water present themselves. In some contracts, it has been possible to lay out the sequence of mining so that at least a portion of the mining place can be worked dry. A dike passing through an orebody often keeps the water all on one side, leaving the other portion dry. Sometimes the nature of the ore itself keeps a portion of it dry.

A second scheme for draining water from an orebody has been to drop down 20 or 30 feet below a mining sub and dog drift to the wet portion of the orebody. Dog raises are then driven up to tap the working sub. This method has been very effective in some cases in draining water away from ore being mined.

A third scheme which has been successful to some extent in mining wet ore, has been the use of loading drifts just above the main haulage level. This is an adoption of the scraper-loading drift system used at the Montreal Mine at Montreal, Wisconsin. In this system the ore is mined wet and scraped down to the loading drift. The loading drift
is a short drift driven just above the main haulage drift and at right angles to it. The loading drift acts as a storage space for the wet ore and a pipe in the bottom of the drift drains at least a portion of the water off. When the motor crew comes to pull the ore, one of the chutemen operates a scraper on one side of the drift to pull the ore into cars. The big saving is in that no time is lost by either the miners in waiting for the motormen, or by the motormen in waiting for the miners. Several mining places may be served by one loading drift. The loading drift presents perhaps the best plan for handling ore from wet mining places.

Wet open stopes are rare for the simple reason that wet orebodies in the Morris Mine cannot be successfully mined by open stoping. Some open stopes do become partially wet after mining has started and it becomes necessary to control the water so that the ore in the stope will not become wetted. One plan for controlling the water is by permitting it to run down one raise and underneath a false bottom in the main ore transfer drift. Otherwise, a separate small raise at one end of the sub-level stope area can drain the water directly down to the main level.

As mining operations proceed, it is evident that more and more formerly dry places are now becoming wet. This follows logically from the fact that the subsiding area on surface is increasing and thereby distributing water underground over a greater area. Handling the wet ore underground
is as pressing a problem as draining the surface water and new schemes are suggested every day for greater ease in handling the sloppy ore.

(5) **Underground dams** -- There are both permanent and temporary dams in the Morris. Of greatest importance are the permanent dams separating the Morris workings from the Barnes-Hecker Mine workings to the west. The Barnes-Hecker was the scene of a sudden, disastrous inundation in 1926. At that time, natural damming kept the waters out of the Morris Mine long enough to permit a dam to be constructed. All possible avenues for the water were bulkheaded with stoppers of concrete up to 30 feet in thickness.

Besides the permanent dams mentioned, each level has a temporary-type dam a short distance from the shaft. These dams are of importance because of the floods resulting from surface cave-ins. Timber dams as shown in Fig. 21 were used up until the time the 9th level was started. On the 9th level the steel water door dam also shown in Fig. 21 has been constructed. This last type of dam was designed by the Morris engineering department whereas the timber dam is an old standard type.

In the timber dam, the timbers are kept piled up systematically at the side of the drift. In case of a large flow of water, the timbers can all be put in place by an experienced crew in 10 minutes. The construction of the dam is such that the diagonal timbers tighten as the height of water behind the dam increases. The dam is kept up until the pumps have lowered the water below the windbore in the dam.
FIG. 21—TYPES OF UNDERGROUND DAMS
Several years ago it was thought wise to design a better type of dam which could be put in place more quickly. The water door type of dam offered this advantage. This steel door is set in a concrete frame keyed in the drift. The door trolley on the level floor aids in closing the door. In case of a flood, the track is removed, the trolley is cut, and the door is closed -- all in about two minutes.

The dams complete the water control system at the Morris Mine.
CONCLUSION

The Inland Steel Company at its Morris Mine is engaged in a water control program that is somewhat unprecedented in mining operations. Diversion ditches are being planned to keep streams off the mining area. A deep well surface pumping program is intended to eventually drain the entire Morris Mine area above the ledge. As this deep well pumping works toward that goal, it is expected that the underground waters will gradually diminish. Careful records of both surface and underground pumping are being correlated at all times to determine the progress of the program.

The eventual results of the control system, even though negative in some respects, should prove to be a marked accomplishment in mining history and should add much data to the literature on mine water problems.
BIBLIOGRAPHY

(1) A. I. M. E. Transactions, Vol. VI--"The Rothschild-berger Stollen."

(2) American Colloid Company, advertising bulletin: "Effective Water Stoppage."


(4) Compressed Air Magazine--Nov. 1941 "Carlton Tunnel Drains Portland Mine pp. 6589-6590


(10) Layne-Northwest Company--advertising bulletin: "Layne Well Water Systems."

(11) Miller, W. J. "Introduction to Physical Geology."


(14) Slack, E. E.--Modern Mining & Milling Practice, "Pumping Against 3304-Foot Head in a Single Lift." pp. 103-105


(17) Tillinghast, E. S.--Modern Mining & Milling Practice.
"Shaft Sinking in Quicksand." pp. 65-70

(18) Weigel, W. W.--T. P. 1807, A. I. M. E.
"Mine Drainage, Southeast Missouri Lead District."
## INDEX

<table>
<thead>
<tr>
<th>A</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Waters treatment</td>
<td>27</td>
</tr>
<tr>
<td>Aerial Photographs for surface maps</td>
<td>2</td>
</tr>
<tr>
<td>Air Lift principle and use</td>
<td>27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnes-Hecker Mine</td>
<td>67</td>
</tr>
<tr>
<td>Bentonite Clay</td>
<td>18</td>
</tr>
<tr>
<td>use of</td>
<td></td>
</tr>
<tr>
<td>(see also &quot;Clays&quot;)</td>
<td></td>
</tr>
<tr>
<td>Block Caving</td>
<td></td>
</tr>
<tr>
<td>(see also &quot;Stopes&quot;)</td>
<td></td>
</tr>
<tr>
<td>Bulkheads</td>
<td>28</td>
</tr>
<tr>
<td>general</td>
<td></td>
</tr>
<tr>
<td>(see also &quot;Dams&quot;)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caissons</td>
<td>21</td>
</tr>
<tr>
<td>open and pneumatic</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>27</td>
</tr>
<tr>
<td>water car</td>
<td></td>
</tr>
<tr>
<td>Carp River at Morris Mine</td>
<td>33,41,42</td>
</tr>
<tr>
<td>Cave-ins at Morris Mine</td>
<td>38,39,63</td>
</tr>
<tr>
<td>Centrifugal Pumps advantages and ...</td>
<td>24</td>
</tr>
<tr>
<td>disadvantages</td>
<td></td>
</tr>
<tr>
<td>Churn Drilling</td>
<td>43</td>
</tr>
<tr>
<td>test-holes</td>
<td></td>
</tr>
<tr>
<td>deep wells</td>
<td>47</td>
</tr>
<tr>
<td>(see also &quot;Wells&quot;)</td>
<td></td>
</tr>
<tr>
<td>Clays</td>
<td>16,18</td>
</tr>
</tbody>
</table>
Cleveland Cliffs Iron Company ........................................... 30

Climate
   (see "Rainfall," "Snowfall," and "Weather")

Coal Mining
   general ............................................................... 12
   subsidence in .................................................... 12

Column
   choice of water column ......................................... 24
   water column at Morris Mine .................................... 59

Contours
   surface .................................................................. 2
   ledge .................................................................. 4
   water table .......................................................... 47, 53, 62

Dams
   general .................................................................. 28
   at Morris Mine ..................................................... 67, 69

Deep Wells
   (see "Wells")

Ditches
   diversion .............................................................. 16, 17
   at Morris Mine ..................................................... 41

Diversion
   general .............................................................. 16, 17
   at Morris Mine ..................................................... 41
   at Steep Rock Lake ............................................... 17

Drifts
   loading drifts ...................................................... 65
   (see also "Haulage" and "Grades")

Drilling
   (see "Churn Drilling" and "Hydraulic Rotary Drilling")

Drop-shaft
   in shaft sinking .................................................... 22

Dyes
   aid in tracing seepage ........................................... 15, 20
   use at Morris Mine ................................................ 55, 58
   (see also "Fluorescein" and "Uranin"
E

Entry

effect of topography on mode of ............................................ 8

F

Filled Flatback Stopes (see "Stopes")

Filled Rill Stopes (see "Stopes")

Filled Stopes (see "Stopes")

Floation Slimes

use of .................................................................................. 15

(see also "Slimes")

Fluming

general ...................................................................................... 16, 17

at Morris Mine .......................................................................... 42

Flourescein

use of ...................................................................................... 20

Freezing process

in shaft sinking ........................................................................ 22

G

Geology

general ...................................................................................... 8

Marquette Range ...................................................................... 30

Morris Mine ............................................................................. 35

Grades

haulage grades ........................................................................ 12, 26

haulage grades, Morris Mine ................................................... 39

Graphs and Charts

do drainage data .................................................................... 20, 26, 55, 62, 83.

(see also "Weirs")

Gravel Beds

in test holes ............................................................................. 53

Grouting

with cement ............................................................................ 19, 22, 23

H

Haulage

problems related to drainage ................................................... 12, 26

at Morris Mine .......................................................................... 39
Hydraulic Rotary Drilling
(see "Wells")

Inland Steel Company ........................................ 30
Ishpeming, Michigan ........................................ 30

Kind-Chaudron
process of shaft sinking .................................. 23

Ledge
contours of .................................................. 4
contours at Morris Mine .................................. 33, 47

Lift
(see "Air-lift")

Lime
milk of ......................................................... 28

Lloyd Mine
effects of climate ........................................ 32

Loading Drift
described .................................................. 65

Marquette Range
mining ......................................................... 10
geology ....................................................... 30

McClelland
(see "Peele")

Measurements
(see "Weirs")
(see "Graphs and charts")

Mining
at Morris Mine ............................................ 36
control of water in ........................................ 63, 65, 66, 67
(see also "Mining Methods")

Mining Methods
from Peele .................................................. 9, 10, 11

Mitchell Slicing
(see "Stopes")
Neutralization
(see "Acid Waters")

North Lake
Draining of ........................................ 41

Open Caissons
(see "Caissons")

Open-Cut Mining
general .................................................. 11

Open Stopes
(see "Stopes")

Outcrops
study of ................................................ 9

Peale, Robert F.
factors influencing development and
operation of a mine ..................................... 1
mining methods ......................................... 9,10
shaft sinking ............................................ 21

Permeability
of rock and ore ....................................... 35

Photographs
aerial .................................................. 2

Piling, Sheet
in diversion ........................................... 17
in shaft sinking ........................................ 21

Pilot Hole
in drifting ............................................. 26

Placer Mining ......................................... 12

Plunger Jumps
advantages and disadvantages ....................... 24

Pneumatic Caissons
(see "Caissons")

Porous Pot
electrical resistivity method ....................... 5
Production
related to drainage .................................. 14

Profile
for subsidence measurements .......................... 39

Pumping
underground, general .................................. 24
at Morris Mine ......................................... 60
(see also "Wells")

Pumps
centrifugal ............................................... 24
plunger .................................................. 24
turbine .................................................. 47, 54

Rainfall
run-off factor .......................................... 2
in Morris Mine area .................................... 32
(see also "Weather")

Resistivity survey
method of conducting .................................. 4
applicability at Morris Mine ......................... 35
Porous Pot method ..................................... 5

Resuing
(see "Stopes")

Rings
Water (see "Water Rings")

Rotary Drilling
(see "Hydraulic Rotary Drilling")

Rothschenberger Stollen
(see "Tunnels")

Run-off
in rainfall .............................................. 2
factors affecting ..................................... 3

Safety
related to drainage .................................. 14

Seepage
general .................................................. 3, 15
at Morris Mine ......................................... 33, 35, 36
(see also "Dyes")
Shaft Sinking
from Peele ........................................... 21
control of water during .................................. 20
at Morris Mine ........................................... 58,59

Shaw, S. F.
(see "Air Lift")

Sheet Filing
(see "Filing")

Shield
use of in shaft sinking .................................. 21

Shrinkage Stopea
(see "Stopea")

Sinking, Shaft
(see "Shaft Sinking")

Siphon
use of ....................................................... 27
at Morris Mine ........................................... 60

Skips
for hoisting water ........................................ 26

Slimes
use of ....................................................... 16,18

Snowfall
effect on mine drainage .................................. 3
effect at Morris Mine .................................... 32

Square-Setting
(see "Stopea")

Steep Rock Lake, Ontario
diversion at ................................................ 17

Stopea
block caving ............................................... 11
filled ....................................................... 11
filled flat-back .......................................... 11
filled rill .................................................. 11
Mitchell slicing .......................................... 10
open ......................................................... 10
resuing ..................................................... 11
shrinkage .................................................. 11
sub-level caving .......................................... 11
square-setting ............................................ 10
timbered ................................................... 10
top-slicing ................................................ 11
Streams
(see "Seepage," "Carp River")

Sub-level Caving
(see "Stopes")

Subsidence
In coal mining .................................................. 12
at Morris Mine ................................................. 38, 39, 53

Sump
underground, design of ...................................... 24, 25

Surface
caves, (see "Cave-ins")
contours .......................................................... 2
maps ................................................................. 2
Morris Mine ...................................................... 30
vegetation ......................................................... 2

Surging
defined .......................................................... 54

Swamps
control of water in ............................................ 19
at Morris Mine .................................................... 48

Table, Water
(see "Water-Table")

Tanks
for hoisting water ............................................. 26

Test-Holes
when needed ..................................................... 4
(see "churn drilling")
(see "Gravel Beds")

Tillinghast, E. S.
on shaft sinking .............................................. 22

Timber Dams
(see "Dams")

Timbered Stopes
(see "Stopes")

Top Slicing
(see "Stopes")

Topography
effect on mode of entry ...................................... 8
(see also "Surface")
Tubbing
in shafts ........................................ 23
(see also "Kind-Chaudron")

Tunnels
in draining mines .................................. 29
Rothschonberger Stollen ........................... 29

Turbine Pumps
in deep-wells ....................................... 47, 54

Urania
use of at Morris Mine .............................. 58

Vegetation
surface ............................................... 2

Ventilation
related to drainage .................................. 13

Water
acid waters .......................................... 27
car ....................................................... 27
column .................................................. 24
door dam ............................................. 67, 69
surface and sub-surface ............................. 2

Water Door Dam
(see "Dams")

Water Rings
in shafts ............................................. 23

Water Table
defined ............................................... 3
at Morris Mine ..................................... 33, 47, 53, 82

Weather
effect on mine drainage ............................. 3

Weirs
in streams .......................................... 16
underground, general ................................ 25
underground, Morris Mine .......................... 62

Wells, Deep
for drainage, general .............................. 20
at Morris Mine ..................................... 43, 53, 54