CRITERIA FOR DETERMINING WHEN A BODY OF SURFACE WATER CONSTITUTES A HAZARD TO MINING

Prepared for

United States Department of the Interior
Bureau of Mines

by

ENGINEERS INTERNATIONAL, INC.

2514 Wisconsin Avenue

Downers Grove, Illinois 60515

FINAL REPORT

Contract No. J0285011

August 1979

United States Department of the Interior

BUREAU OF MINES
2401 E STREET, NW.
WASHINGTON, D.C. 20241

IN REPLY REFER TO:

November 10, 1980

Memorandum

To: Chief, Office of Public Information

Through: Deputy Director, Minerals Research

From: Director, Minerals Health and Safety Technology

Subject: Distribution of Contract Report

Approval is requested to place on Open File and with the National Technical Information Service the report titled, "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining." The contractor was Engineers International, Inc. and the Contract No. is J0285011. The TPO was Clarence O. Babcock and the Program Manager was Chi-shing Wang. The contractor has not filed a DI-1217 (invention disclosure form).* Press release recommendation: low.

To make this report available to interested parties, it is recommended that two copies of the report be placed on open file for public review in the Department of the Interior Library; one copy in the Office of Surface Mining Library, South Interior Building, Washington, D. C.; one copy each at Bureau facilities in Albany, Avondale, Denver, Pittsburgh, Reno, Rolla, Salt Lake City, Spokane, Tuscaloosa, Twin Cities, and Boulder City; DOE facilities at Carbondale, Ill., and Morgantown, W. Va.; and the National Mine Health and Safety Academy, Beckley, W. Va.

Since this study was not site specific, no copies will be sent to State Geologists.

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Robert L. Marovelli

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CB Kenahan 11/13/80

Deputy Director, Minerals Research

Approved:

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(no press release)

Enclosures

*If Form DI-1217 has been filed, Solicitor's approval must accompany this document.

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MINERALS RESEARCH CONTRACT REPORT

Report Title "CRITERIA FOR DETERMINING WHEN A BODY OF SURFACE WATER CONSTITUTES A HAZARD TO MINING"

Type of Report--Final, Interim, Etc. FINAL

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I Concur: [signature] Date 11/10/80
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April 17, 1981

Memorandum

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Through: Galen G. Waddell, Research Director, Denver Research Center

From: Verne E. Hooker, Research Supervisor, Mine Design, DRC

Subject: Disposition of Report, "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining," Contract J0285011, dated August 1979.

Enclosed is the subject final report from Engineers International, Inc. A copy of the memorandum to the Chief, Office of Public information, approving open file placement is also enclosed.

Verne E. Hooker

Enclosures

cc: Julie Walker, Avondale, Maryland

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16. Abstract (Limit: 200 words)

This report covers the work on developing criteria for determining when a hazard exists when mining stratified mineral deposits beneath bodies of surface water. The nature of water bodies is considered, the disturbance to the strata induced by mining is described, inundation case histories reviewed, reasonable water inflows derived, and methods of mining to prevent or minimize the hazard are presented. Criteria are given whereby effected industries and agencies can recognize a potential hazard and plan a mine accordingly, releasing considerable mineral reserves otherwise considered unminable.

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FOREWORD

This report was prepared by Engineers International, Inc., under U. S. Bureau of Mines Contract No. J0285011. This contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Denver Mining Research Center with Dr. Clarence O. Babcock acting as Technical Project Officer. Mr. David J. Askin was the Contract Administrator for the Bureau of Mines. This report is a summary of work recently completed as a part of this contract during the periods of 26 September 1978 through 31 August 1979. This report was submitted by the authors on 31 August 1979.

The work on the project was significantly aided by the contributions of the following individuals: Dr. Verne Hooker of DMRC/USBM for technical advice; Messrs. Gerald Davidson and Edward Hollop of MSHA Denver Technical Support; Dr. Kelvin Wu of MSHA Pittsburgh Technical Support, Messrs. R. L. Loofbourow and Fred D. Wright, Project Consultants, and Dr. Zs.G. Kesserü, of the Hungarian Mining Research Institute.

EI staff who also participated on major portions of this project are Mr. Bennie G. Wheelis, Jr., Mining Engineer, and Mr. Stephen E. Sharp, Engineering Geologist.

This project was under the technical supervision of Mr. Francis S. Kendorski, with Mr. Inderjit Khosla as Project Engineer, under the overall direction of Dr. Madan M. Singh, President, who are the authors of this report.

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NOTATION

A = area, L^2

A_c = elastic strain in creep equation at time = 0, dimensionless

a = wall length, L

B = bulking factor, dimensionless

B_c = steady state creep strain, dimensionless

b = wall height, L

C = pillar strength, FL^{-2}

C_c = transient or primary creep, dimensionless

C_D = drag coefficient, dimensionless

c = Chezy roughness coefficient, dimensionless

$\tilde{c}$ = variate of roughness coefficient, dimensionless

D = depth of mining, L

d = depth of surface water body, L

E = strain, dimensionless

E_r = strain rate, T^{-1}

E_t = traveling strain, dimensionless

E_x = extraction ratio, dimensionless

e = base of natural logarithms, dimensionless

F = force acting on person in water, F

f = force on wall, F

f_s = flexural strength, FL^{-2}

g = acceleration due to gravity T^{-2}

H = pillar height, L

H_s = height of sinkhole, L

h = height of water, L

h_l = slope of energy grade line, dimensionless

$\tilde{h}$ = variate of water head, L

i = interest, dimensionless

K = coefficient of permeability (Meinzers), $L^3T^{-1}L^{-2}$

k = subsidence constant, dimensionless

L = length of water pathway, L

l_1 = width of zone of horizontal extension and vertical compression, L

M = width of sinkhole, L

m = volume of mine entry, L^3

M_w = height of wall per square foot, FL^{-2}

N = subsidence factor, dimensionless

$\underset{\sim}{N}$ = variate of number inflows, dimensionless

n = coefficient of roughness, dimensionless

n = (in statistics) a number, dimensionless

P = length of sinkhole, L

P_r = profit, $

P_w = wetted perimeter, L

p = width of mining panel, L

Q = water flow, L^3T^{-1}

$\underset{\sim}{Q}$ = variate of water flow, L^3T^{-1}

q = length of entry intersecting water fissure zone, L

R = hydraulic radius, L

r = radius of critical area, p/2, L

S = vertical subsidence, L

s = width of entry, L

T = time, T

t = mined thickness of seam, L

U_c = volume of void, L^3

U_o = volume of collapsed roof, L^3

V = water velocity, LT^{-1}

v = horizontal displacement, L

W = pillar width, L

$\underset{\sim}{w}$ = variate of fissure or fracture width, L

X = years, T

Y = sum of money, $

Z = wall thickness, L

α = angle of formation dip, degrees

β = correction factor, dimensionless

γ = angle of draw from horizontal, degrees

γ_w = specific weight of water, FL^{-3}

δ = deviation from the average value

ε = creep strain, dimensionless

ζ = angle of draw from vertical, degrees

η = creep exponent, dimensionless

κ = pillar strength constant, dimensionless

λ = inrushes per area, dimensionless

ρ_w = mass density of water, ML^{-3}

σ = normal stress, FL^{-2}

σ_f = flexural stress, FL^{-2}

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1.0 INTRODUCTION

In order to fully realize and recover the nation's reserves of coal, mining must be planned and carried out with safety. In underground mining, a hazard which has always been of great concern is the sudden inrush of water. Since many coal mining areas are overlain by water bodies such as lakes, streams, rivers, ponds, and so on, techniques to assure mine safety when mining beneath water are necessary.

Recognizing this need, the Bureau of Mines supported a program for research on guidelines for mining in close proximity to bodies of surface water. Accordingly, two contracts, both entitled "Guidelines for Mining Near Surface Waters" were awarded, one to Skelly and Loy, Harrisburg, PA (Contract No. H0252083) and one to K. Wardell and Partners, Newcastle, United Kingdom (Contract No. H0252021). The results of the two contracts are published as Bureau of Mines Information Circular 8741, entitled "Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water," reproduced in Appendix A. The guidelines have had limited application, however, because of problems in defining both water bodies of concern and the nature of the strata.

Mining has been conducted and may be planned under large bodies of water such as oceans, large lakes, and rivers or small bodies like streams, farm ponds, and other impoundments. If it is assumed that a hazard always exists while conducting mining under or in the vicinity of surface bodies of water irrespective of their size and geometry, a large percentage of reserves are likely to be left unmined. On the other hand, it is likely that by adopting special mining plans and procedures, it may be possible to release reserves for exploitation which otherwise would have been unmineable under surface bodies of water which are relatively small in size. Accordingly, the present study undertakes to develop criteria for determining whether (or when) a body of surface water constitutes a hazard to mining. This work was carried out under Bureau of Mines Contract No. J0285011 entitled, "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining."

IT SHOULD BE NOTED THAT A SUGGESTED STEP-BY-STEP PROCEDURE FOR HAZARD DETERMINATION HAS BEEN SUMMARIZED AS APPENDIX E OF THIS REPORT AND INCLUDES A SUGGESTED APPLICATION FORMAT TOGETHER WITH SUGGESTED GUIDELINES FOR MINING.

1.1 Scope of Work

This work is restricted to investigation of the exploitation of stratified mineral deposits with overlying surface waters. Vein and disseminated deposits are not covered, nor are breakthroughs into adjacent mines in the same horizon.

1.1.1 Determination of Critical Size of Water Body

Water bodies may be divided into three categories based upon their potential hazard to underlying mining activity:

- catastrophic potential
- major potential
- limited potential

Catastrophic potential would include oceans, large lakes, large inland reservoirs, and rivers that can flood the mine completely in a short time.

Major potential water bodies include lakes and streams which have the potential to flood only portions of the mine and pose a danger to both life and property if not considered in mining plans.

This study has mostly attempted to determine what sizes of such water bodies do not constitute a hazard to mining and how their sizes depend on the special mining plans and procedures.

Limited potential would include finite bodies of water which have a volume considerably smaller than the mine volume, and flowing streams which have a relatively small rate of replenishment which can be dealt with by pumping or isolation in the event they flow into the mine. Such bodies of water may cause an inconvenience such as temporary disruption of production or some damage to the equipment. On rare occasions some personnel injuries may also occur.

1.1.2 Approach

Based on reported surface subsidence measurements, investigation of strata deformations through instrumentation of boreholes in the subsided zone, studies of actual case histories of inundation accidents, and several instances of working under water bodies successfully, a concept regarding the existence of an overlying water barrier of strata (aquiclude) above the mined coal seam has been developed and presented in this report.

Several studies regarding water flow patterns revealed that with proper planning and sequence of mining, mines may be designed to accept considerable quantities of water without causing much damage to the mine and equipment, and at the same time affording safe escape routes or shelters for personnel. It is proposed that the critical size of the water body be fixed depending upon its size in relation to the capacity of the mine volume which can be planned to accept the entire volume of water in the event of an inundation.

Based upon these studies a suitable chart indicating the cover for working below water bodies of major potential size has been developed. It envisages reduction of the cover previously suggested for larger bodies of water depending on the nature of the intervening strata.

The safe cover suggested for working below major potential water bodies is based on judgement and practical experience. Normally, no danger of inundation should exist. However, geological anomalies cannot be ruled out completely. Even if such anomalies exist, and an inundation should take place, the rates of inflow of water at the suggested cover are not likely to be disastrous provided the mine plan has taken this possibility into account. This is further supported by examples of actual inflow rates which are available in case histories. These rates of inflow are not insurmountable and can be taken care of by proper planning of the mine and sequencing of operations.

Based upon the above study consolidated guidelines have been prepared which can be used by the industry to design the mine for working below surface water bodies ensuring maximum resource utilization, and can also be used by regulatory agencies to ensure that all operations are carried out with safety and precautions.

1.2 Prior Work

As already mentioned, prior work related to developing guidelines for mining in the proximity of surface water bodies was carried out by Skelly and Loy, and K. Wardell and Partners. As these works are relevant to this study they are briefly summarized below.

In addition, an inquiry has been carried out by the Government of the State of New South Wales, Australia, on a dispute concerning coal mining beneath water supply reservoirs in a single coal field that involved much study. This work is also summarized.

1.2.1 Summary of Skelly and Loy Report

The Phase I report dealt with the collection of information on mine inundation case histories, description of successful mining under bodies of water at relatively shallow cover without any water inflow, and summaries of regulations and guidelines used in different states and countries.

The Phase II report contained summaries of a number of major inundations which were tabulated, evaluated, and grouped into the four general categories designated - 1) Mining near continental surface waters, 2) Submarine mining, 3) Mining near abandoned workings and water-bearing zones, and 4) Situations in which general mine planning was at fault. Guidelines for each individual category were comparatively analyzed and then subdivided into classes. The different classes represent the effectiveness of the guidelines in terms of safety of workers and of the mine.

Class I guidelines include those which arbitrarily fix the safety zone, safe depth, method of work, percentage recovery, and so on. These are considered to be inadequate and conservative because they do not give consideration to the size of the water body, or to geological factors like competence and permeability of different strata, and special methods of work. They are inherently inflexible.

On the other hand, Class II guidelines require the approval of mining plans on the merits of the individual case. Safety zones are defined and the guidelines are formulated to help layout the mine and to ensure each application is reviewed on an equal basis and that no items are overlooked which may adversely affect safety. Guidelines can then be made flexible, to give consideration to the effects of depth of the seam, mining system, past mining activity, geological factors, thickness of extraction, percentage recovery, gob filling, and other items.

The Phase II report also considered whether the various inundation accidents could have been prevented had applicable guidelines been complied with. Also included are physical and geological characteristics affecting inundation potential within various regions of the country, method of predicting subsidence, and patterns for advance test boreholes in exploratory headings.

Some of the points mentioned are that a 100 acre lake and 15 ft wide stream may present the same inundation hazard but the reserves which may be locked-up are different and the mine planning considerations should be different as well. The depths of the seam, integrity of the strata, method of work, extraction ratio, and the existence of contiguous old workings all need to be considered.

The Phase III report contains Level 1 Guidelines and Level 2 Guidelines which have been primarily based on the guidelines existing in different states and countries.

1.2.2 Summary of K. Wardell & Partners Report

The Phase I report discussed geological and physical factors affecting the risk of inundation of mines from surface waters, particularly the sea. The regulations governing undersea mining in the various countries and the general rationale of these stipulations have also been discussed. The stipulations with respect to minimum thickness of cover between the sea and mine workings in various countries are given here in Table 1. Also, the stipulations regarding the maximum seam thickness which could be mined under the sea and the minimum depth of cover are given in Table 2 for the various countries.

The Phase II report discussed subsidence phenomena and its relevance to mining beneath water. Included was that total extraction over a sufficiently large area causes disturbance of both the immediately overlying strata and the surface. The height of the zone of disturbance in the immediate roof is considered as a function of the height of extraction and the caving characteristics of the roof beds. The intensity of the disturbance at the sea bed is determined by calculating the maximum tensile strain. The formula for calculating maxiumum tensile strain presented has been adopted by the National Coal Board in the United Kingdom and is:

$$E_{max} = k \frac{S_{max}}{D}$$

Where k is a constant whose value is found empirically from local observations. S_{max} is the maximum possible vertical surface subsidence expressed as a fraction of the seam thickness t and D is the depth of mining below the land surface.

Table 1

Minimum Thickness of Cover Stipulated in Different Countries for Any Undersea Mining (after Wardell, 1976)

Country	Minimum Cover to Sea Bed for any Mining	Form of Regulation	Remarks
New South Wales, Australia	120 ft	Statutory & Mandatory (Crown Leases)	For partial extraction only
Nova Scotia, Canada	180 ft	Statutory	For partial extraction only
British Columbia, Canada	180 ft	Statutory	No restriction stipulated
United Kingdom (1)	197 ft	Mandatory (Nat. Coal Board Dir.)	For partial extraction only
Japan (2)	197 ft	Statutory	For partial extraction only
Chile	230 ft	Mandatory (Ser. of Mines Dir.)	For partial extraction only

NOTE: (1) A minimum of 148 ft of the cover must be Carboniferous strata.

(2) This only applies where there are no Quaternary deposits (mostly clays) at the sea bed. If there is at least 33 ft of such deposits and at least 100 ft of solid strata, mining may take place to a minimum depth of 125 ft.

Table 2

Minimum Thickness of Cover Stipulated in Different Countries for Total Extraction Under Sea (after Wardell, 1976)

Country	Minimum Cover Thickness to Sea Bed at Which Total Extraction is Permitted	Maximum Seam Thickness Which May Be Worked at Minimum Depth in One Seam Only	Remarks
Nova Scotia, Canada	700 ft	1 ft of seam for each 100 ft of thickness	Thickness for cover
Vancouver Island, British Columbia, Canada	400 ft	None given	Thickest seam worked averages 6 ft approx.
United Kingdom	345 ft	5.6 ft	Minimum thickness of Carboniferous strata - 197 ft
Japan	197 ft (with no unconsolidated clay deposits)	2.6 ft	Mining must be in sections with dams
Chile	492 ft	No restriction	Thickest available seam is 4.6 ft

S_{max} and D must have the same units. The value of k is generally around 750,000 $\mu\varepsilon$ and that of S_{max} varies from 0.6t to 0.9t in different regions. Assuming average values for k as 750,000 $\mu\varepsilon$ and S_{max} as 0.8t, the relative intensities of disturbance at the sea bed in different countries work out as follows in units of microstrains ($\mu\varepsilon$):

Nova Scotia:	7,710
Vancouver Island:	7,500
United Kingdom:	10,000
Japan:	8,000
Chile:	5,030

The United Kingdom is the only country which specifies a limiting value. The values for the other countries are from other specified or known information (National Coal Board, 1968, 1971).

The Phase III report discussed particulars of incidents of mine flooding both from sea water and inland bodies of surface water or deposits which have a tendency to flow. Summaries of these incidents are given in Table 3 and Table 4 reproduced from the Wardell (1976) report. All such incidents had been reviewed to determine common causative factors.

Factors like strata permeability, the dimensions of mine openings or entries, the support system, the physical properties of the strata, and the time period for which the workings need to be protected against danger of inrush, have been discussed to determine the rationale of a minimum rock cover thickness.

Regarding the stability of room and pillar workings, the work carried out by Holland (1964) based on the laboratory testing of coal samples has been discussed. Other approaches based on statistics by Salamon and Munro (1967), and analytical techniques (Wilson and Ashwin, 1972) were also presented.

TABLE 3- Incidents of Mine Flooding from Sea Water (after Wardell,1976)

MINE	COUNTRY	SEAM THICKNESS (ft)	SYSTEM OF MINING	COVER (TO SEA BED) AT POINT OF INUNDATION (ft)	YEAR OF INCIDENT	LIVES LOST
Mostyn, N. Wales (Inundations - Dee Estuary)	U.K.	9 - 15	Room and pillar 1st working 2nd working locally.	72 - 90	1800 1838 1818 1845 1829 1884	Nil
Isabella Pit Workington, Cumb. (Unundation-Irish Swa	U.K.	10	Room and pillar 1st & 2nd wkg. Typical 1st wk. roads 5 yds. pillars 7-8 yds.	120	1837	27
Lanshipping, Pemb. S. Wales. (Inundation from Tidal River).	U.K.	Not Known	Not Known	60 ft sand 4 ft rock	1843	40
Puchoco, Coronel (Sea Inundation)	Chile	Not Known	No Details	Said to be thin and	1881	Nil
Ferndale. (Inundation from Tidal Creek)	Australia		Room and pillar 50% ext.	Roof fall collapse to base of deposits below tidal creek 65 ft cover (top 23 ft sand and silt).	1886	1
Santagumi (Sea)	Japan	Not Known	Details Unkown	46 ft (inc. 7 ft sea bed deposits).	1900	25
Asturias Mine Co. (Feeder from sea bed, mine abondoned)	Spain	Not Known	Total extraction with waste packing.	Not Known	1905	Nil
Mabou, Nova Scotia	Canada	7	Headway toward sea.	110	1909	Nil

Table 3- Continued

MINE	COUNTRY	SEAM THICKNESS (ft)	SYSTEM OF MINING	COVER (TO SEA BED) AT POINT OF INUNDATION (ft)	YEAR OF INCIDENT	LIVES LOST
Santagumigata	Japan	Not Known	Details Unknown	50 ft (inc. 7 ft sea bed deposits).	1910	75
Port Hood, Nova Scotia (Sea)	Canada	6 - 7	Room and pillar some pillar drawing.	942 ft to 874 ft sandstone, 18 ft sand, then 40 ft shale over coal.	1911	Nil
Higashimisome Coll.Ube, Yamaguchi-ken.	Japan	Not Known	Room and pillar some pillar drawing.	155 ft sandstone, 82 ft alluvium. Water via fault in sandstone.	1915	237
Nishiokinoyama (Sea)	Japan	Not Known	Details Unknown	237 ft(inc. 155 ft sea bed deps) (fault).	1915	?Nil
Shinura (Sea)	Japan	Not Known	Details Unknown	66 ft(inc. 23 ft sea bed deps).	1920	34
Motoyama (Sea)	Japan	Not Known	Details Unknown	50 ft (inc. 46 ft sea bed deps).	1921	Nil
Matsushima (Sea)	Japan	Not Known	Details Unknown	200 ft sea bed deps, (fault). Rock cover unknown.	1934	54
Motoyama (Sea)	Japan	Not Known	Details Unknown	285 ft (inc. 86 ft sea bed deps) (fault)	1936	Nil
Chosei (Sea)	Japan	Not Known	Details Unknown	119 ft (inc.99 ft sea bed deps) (faults)	1942	183
Chosei (Sea)	Japan	Not Known	Details Unknown	65 ft (inc. 27 ft sea bed deps).	1948	Nil
Tokamani (Sea)	Japan	Not Known	Details Unknown	79 ft (inc. 46 ft sea bed deps).	1959	4

Table 4- Incidents of Mine Flooding from Inland Water Bodies(after Wardell,1976)

MINE	COUNTRY	SEAM THICKNESS (ft)	SYSTEM OF MINING	COVER AT POINT OF INUNDATION. (ft)	YEAR OF INCIDENT	LIVES LOST
Clifton Colly. Pendlebury, Lancs(Inrush of Sand/Gravel/ Water).	U.K,	Not known.	No details.	Presumed heading into wash.	1829	Not known.
Scholes Bridge, Wigan.	U.K.		Room and Pillar.	18 - 60	1847	6
Gwendraeth, Glam. (Inundation of quicksand)	U.K.	Not known	Not known.	Not known.	1852	26
Burroughs, Plainsville,Pa. (Inrush of Sand/Water)	U.S.A.	Not known.	Not known.	Break into wash.	1872	Nil.
Wanamie, Pa. (Inrush of Sand and Water).	U.S.A.	Not known.	Not known.	Break into wash.	1874	?Nil.
Troedyrhiew Coll. S.Wales. (Inrush of Moss and Water).	U.K.	Not known.	Not known	Not known.	1877	5
Home Farm, Lanark, Scotland.	U.K.	7.5 - 8 ft (4.8 - 5ft Mined) Roof Coal left.	Room & Pillar.	108 ft- mostly sand and clay, said thin rock cover collapse caused R.Clyde to overflow into collapse adjacent to it.	1877	4

Table 4- Continued

MINE	COUNTRY	SEAM THICKNESS (ft)	SYSTEM OF MINING	COVER AT POINT OF INUNDATION. (ft)	YEAR OF INCIDENT	LIVES LOST.
Maltby, Swoyersville, Pa. (Inrush of Sand and Water).	U.S.A.	Not known.	Not known.	Break into wash.	1882	Not known.
Braidwood, Ill. (Inrush of Water).	U.S.A.	3	Longwall	54 ft sand and drift.	1883	61
Fuller, Swoyersville, Pa. (Inrush of Sand & Water).	U.S.A.	Not known.	Not known.	Break into wash.	1884	Not known.
Nanticoke, Pa. (Inrush of culm bank).	U.S.A.	Not known.	Not known.	Tapped into pothole 200 ft dep with rock cover 22 - 48 ft thick.	1885	26
Tawd Vale, Skelmersdale.	U.K.		Not known.	Inrush via outcrop.	1897	2
Mt. Lookout Mine Wyoming, Pa. (Sand/Water rush).	U.S.A.	Not known.	Not known.	Tapped into wash.	1897	Nil.
Wanamie, Pa. (Sand/Water rush).	U.S.A.	Not known.	Not known.	Tapped into wash.	1898	Not known.
Franklin, Wilkesbarre, Pa. (Sand/Water)	U.S.A.	Not known.	Not known.	Tapped into wash.	1899	Not known.
No. 2 Slope Nanticoke, Pa.	U.S.A.	Not known.	Not known.	Tapped into wash.	1899	Nil.

Table 4- Continued

MINE	COUNTRY	SEAM THICKNESS (ft)	SYSTEM OF MINING.	COVER AT POINT OF INUNDATION. (ft)	YEAR OF INCIDENT.	LIVES LOST.
Bliss Mine, Hanover, Pa. (Sand/Water)	U.S.A	Not known.	Not known.	Tapped into wash.	1899	Not known
Dalmellington Ironworks, Ayrshire, Scotland.	U.K.	Not known.	Not known.	Working holed into gravel below river.	Late 19th century.	2
Donibristle.	U.K.	5.8	Heading driven to the outcrop.	31 ft of Moss/Sand 7 ft of weathered rock	1901	8
Brancepeth Coll	U.K.	Not known	Not known.	Holed into body of water at surface.	1905	Not known.
Roachburn.	U.K.	4.3	Heading driven to the outcrop.	49 ft of Moss/Peat/ Clay.	1908	3
Brereton, Coppice Pit, Staffs. Water/ Gravel.	U.K.	10.8	Longwall	Mining operations contacted the base of thick (200 ft +) water bearing gravels.	1908	3
Superba/Lemont Mines. Evans Stanton, Pa.	U.S.A.	Not known	Room & Pillar.	Within a few feet of wash.	1912	4
Sugar Notch Mine, Pa. (Sand/Clay/ Water Inrush)	U.S.A.	Not known.	Not known.	Break into wash.	1914	Nil.
Sugar Notch No. 9, Pa. (Sand/Water)	U.S.A.	Not known.	Not known.	Tapped into wash.	1914	Not known.
Prospect Coll. Lehigh Valley, Pa.	U.S.A.	Not known.	Not known.	10 ft rock cover overlain by sand/clay/ gravel - stream flooded over superficial deposits prior	1915	Nil.

Table 4- Continued

MINE	COUNTRY	SEAM THICKNESS. (ft)	SYSTEM OF MINING.	COVER AT POINT OF INUNDATION. (ft)	YEAR OF INCIDENT.	LIVES LOST.
Wilkeson Mine, Wilkeson, Pa.	U.S.A.	Not known.	Not known.	Not known.	1917	6
Stanrigg & Arbuckle, Airdrie, Scot. (Moss/Water)	U.K.	1.8 ft - 2.8 ft	Room and pillar/ longwall.	4 ft Moss, clay & Stones; 4.7 ft rock.	1918	19
Carbonado, Wash.	U.S.A.	15 -20	No details.	Breakthrough into 200 ft thick gravel beds.	1927	7
Brancepeth Coll.	U.K.	Not known	No details.	Nil-roadway broke into wash.	1949	Nil.
Knockshinnoch Castle Coll. Ayrshire, Scotland. (Inundation of liquid peat).	U.K.	Heading 18 ft thick 7 ft high	Heading being driven updip at 1 in 2.	36 ft deep - water-logged peat underlain by mud & sand.	1950	13
Omhi	Japan	Not known	Details unknown.	65	1953	8
Lehigh Valley Coal Co. Pittston Coal Co.	U.S.A.	11	Details unknown.	Reported to be 19 ft cover under Susquehanna River	1959	12
Hoshui	Japan.	Not known	Details unknown.	13	1960	67

The strength of a coal pillar is considered a function of a constant κ based on the strength properties of the coal, the minimum width W of the coal pillar or test sample, and the height H of the coal pillar or sample, so that pillar strength = f(κ, W, H). A number of formulas have been produced empirically or mathematically to give a numerical expression to the above relation. The expression

$$C = 1000\ (1/\sqrt{H}) + 20\ (W/H)^2$$

where C is the strength of pillar in psi and H, W are measured in feet,

appears to give satisfactory statistical results and may be used for pillar design with an appropriate factor of safety.

The behavior of the strata overlying totally extracted coal panels (either longwall or room and pillar) has also been discussed. The surface subsidence profiles over a few longwall panels in the United States have been compared with the average profile curve for the United Kingdom coalfields. The limit angles, ground slope co-efficient, and ground curvature have also been compared. The difference in the various co-efficients is attributed to the difference in lithology of the strata found in the United States and the United Kingdom. However, the limitation of the data available for the coalfields of the United States has also been stressed.

The Wardell (1976) research did not reveal any positive evidence, even in the case of relatively shallow total extraction workings, of cracks or fissures being induced which could provide a direct hydraulic connection between underground mine workings and the ground surface. The general conceptualized strata deformation shows zones of increased strata permeability associated with the peripheral tensile areas near the ground surface and an enveloping zone of increased permeability around the totally extracted area. If the thickness of the cover is sufficient (which prevents overlapping of the increased permeability zones) and there exists unaffected intervening strata which are not originally highly permeable, there should be little or no danger of inflow of water from any body of surface water. It would appear that no rapid or massive inflows would take place.

To provide supporting evidence for the above concept, the report refers to methane drainage holes which produced no gas beyond a height of 100 to 150 ft above the extraction area, which has been taken to indicate that the permeability of the strata above this height is apparently unaffected by mining.

Allowable or calculated maximum tensile strain, together with a general indication of the main rock strata sequence are given in Table 5 for the purposes of comparison.

In the Phase III report the potential hazards of working under various bodies of surface water are summarized and presented in Table 6. Based on the concepts developed in Phase I and Phase II reports and the influence from the existing experience of working below bodies of surface water, guidelines have been developed and presented in this report.

1.2.3 Summary of Bureau of Mines Information Circular 8741

Based on the reports prepared by Skelly and Loy (1976) and K. Wardell & Partners (1976), the Bureau of Mines issued Information Circular 8741 entitled, "Results of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water" which has been reproduced in its entirety as Appendix A since this document is necessary to comprehension of the present report. The guidelines recommended in the circular are given below.

WORKING BELOW SURFACE WATERS

Total Extraction Mining

1. Any single seam of coal beneath or in the vicinity of any body of surface water may be totally extracted, whether by longwall mining or by pillar robbing, provided that for each 1 ft thickness of coal seam to be extracted, a minimum of 60 ft of solid strata cover exists between the proposed workings and the bed of the body of surface water.

2. Where more than one seam of coal exists, all may be worked by total extraction provided that for each 1 ft of the aggregate coal and rock thickness of all seams to be extracted, a minimum thickness of 60 ft of solid strata cover exists between the proposed workings in the uppermost seam and the

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Table 5

Allowable or Calculated Maximum Tensile Strain Adopted in Different Countries (after Wardell, 1976)

Country	Allowable or Calculated Max. Tensile Strength	Geological Sequence
Sydney Coalfield of Nova Scotia, Canada	1,710 με	Carboniferous-predominantly shaley with some fireclay and sandstone beds.
Vancouver Island, British Columbia, Canada	7,500 με	Predominently sandstone with some shales and little fire-clay.
United Kingdom	10,000 με	Carboniferous-predominantly shaley with some fireclay and some sandstone beds.
Japan	8,000 με	Predominently sandstone with some shale and fireclay beds. Calculations apply where there is no supposed alluvial cover at the sea bed.
Chile	5,030 με	Predomintently sandstone with some shale and fireclay beds.

Table 6

Different Hazards of Working Beneath Various Bodies of Surface Water (after Wardell, 1976)

BODIES OF SURFACE WATER	HAZARDS				
	MINE	SURFACE			
	PASSAGE OF WATER INTO MINE	IMPAIRMENT OR FAILURE OF IMPOUNDING STRUCTURES	IMPAIRMENT OR FAILURE OF FUNCTION	ENCROACHMENT OF LAND SUR-FACE BY WATER	INSTABILITY TO ADVERSE CHANGES IN HYDROLOGY
NATURAL					
Sea & Tidal Waters	X	-----	-----	X	-----
Lakes & Ponds	X	-----	X	X	X
Marshes	X	-----	-----	X	X
Rivers & Streams	X	-----	X (where navigable)	X	X
ARTIFICIAL					
Impounded Waters	X	X	X	X	X
Canals	X	X	X	X	X

bed of the body of surface water. When subsidence observations have been carried out and satisfactory calculations of surface tensile strain can be made, any number of seams may be mined by total extraction provided that the maximum cumulative, calculated tensile strain beneath a body of surface water will nowhere exceed 8,750 $\mu\varepsilon$.

3. Where a single seam has already been mined by total extraction in accordance with the provision that for each 1 ft thickness of mineral and rock extracted, a minimum of 60 ft of solid strata should exist, no other underlying seam should be mined by total extraction. Where the cover between the two seams is 60 times (or greater) the extractable thickness of the lower seam, such a lower seam should be mined by partial extraction -- in accordance with the subsequent guidelines here stipulated -- as though the upper seam represented a body of surface water.

4. Where wash or other natural deposits, which may be highly permeable or which when wet may flow, exist between bedrock and the bed of a body of surface water, these should be excluded from the thickness of solid strata mentioned, except where it has been demonstrated that such wash or other deposits would not be likely to flow when wet and could be considered as impermeable.

5. Where a fault which might connect mine workings with a body of surface water and which has a vertical displacement greater than 10 ft, is known to exist or an intrusive dike having a width greater than 10 ft, is known to exist or is met with during development, no seam should be totally extracted within 50 ft horizontally on either side of such fault or dike.

Partial Extraction Mining: Room and Pillar

Minimum Depth of Cover

1. No entry should be driven in any coal seam lying beneath or in the vicinity of any body of surface water where the total thickness of solid strata cover above the seam is less than 5 times the maximum entry width (5s) or 10 times the maximum entry height (10t), whichever is the greater. Where at least one competent bed of sandstone or similar material is present within the solid strata and has a thickness at least 1.75 times the maximum entry width, mining at a lesser cover than 5s or 10t may be considered.

2. In the case of drifts or tunnels beneath or in the vicinity of the body of surface water driven through the strata for the purpose of gaining access to a coal seam, the provision of 10t or 5s should also apply unless drifts or tunnels are permanently supported and are so maintained. In the latter event, however, there should be a minimum solid rock cover of 1.75 times the maximum drift or tunnel width.

Pillar Dimensions for First Workings

1. Where room and pillar first working is to be carried out beneath or in the vicinity of any body of surface water and at cover depth greater than the stipulated minimum, the minimum width of pillar should be determined from the equation

$$((W + s)/W)^2 \; 1.5\, D = 1000/\sqrt{t} + 20\, (W/t)^2$$

where W, s, t, and D are pillar width, room width, seam thickness, and depth from surface, respectively. An exception is made where specific local data (including relevant and comparable mining experience) exist which demonstrate that a lesser width could be used with safety.

2. Where an upper seam has been mined by room and pillar first working in accordance with these guidelines, underlying seams should not be mined -- whether by total or partial extraction -- except by considering the upper seam as though it were the bottom of the surface body of water.

3. Where pillar widths are determined in accordance with these provisions, the calculated pillar loading should not exceed the allowable load bearing capacity of the immediate roof and/or floor beds.

Partial Extraction Mining: Panel and Pillar

1. Where the panel and pillar system is to be carried out beneath or in the vicinity of any body of surface water, there should be a minimum solid strata cover thickness of 270 ft or 3p, where p is the width of the panel, whichever is greater.

2. The widths of extraction panels should not exceed one-third the depth of mining, and the widths of pillars between extraction panels should be 15 times their height or one-fifth the depth of mining, whichever is greater.

3. Where more than one seam is to be mined by this system, the panels and pillars in all seams should be superimposed into the vertical direction with the panel widths being determined from the depth to the uppermost seam and the pillar widths being determined by reference to either the thickest or the deepest seam, whichever would give the greater dimension.

4. Where the panel and pillar system of mining has been employed in an upper seam, it should not be permissible to mine by total extraction in any underlying seam except by considering the upper one as though it were the base of the surface body of water.

Safety Zones

Surface Waters

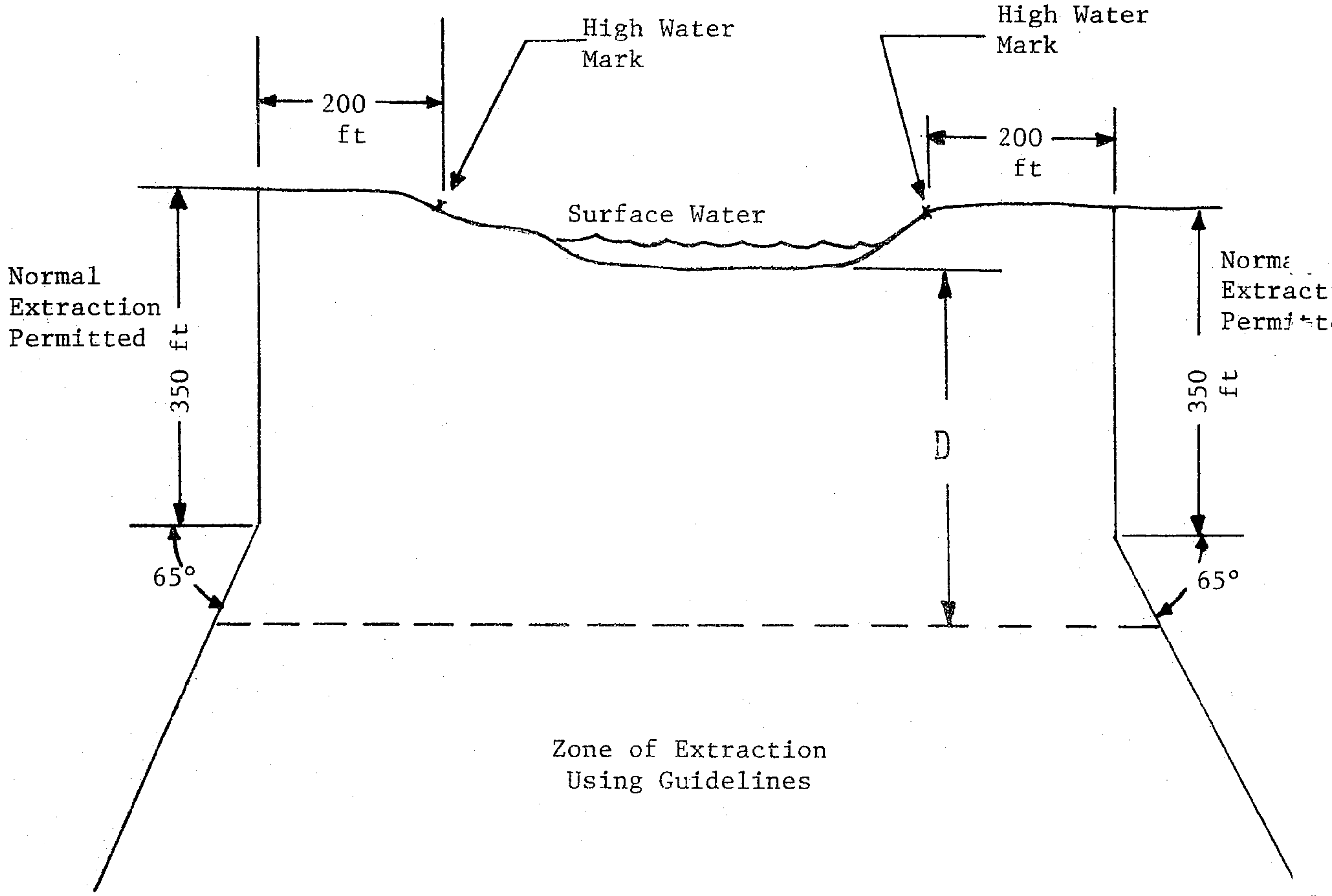
1. Where any body of surface water is present above the potential mine workings, a safey zone around such body of surface water should extend 200 ft horizontally from the high-water mark, or perimeter of the water body, and vertically downward from this point to a depth of 350 ft, then outward at an angle of dip as shown in Figure 1.

2. If mining is considered within such a safety zone, it should be in accordance with the guidelines for mining beneath surface waters.

3. The width of such a safety zone may be increased or decreased if local observations and/or experience justify.

Structures Retaining Water

1. Where any surface structure is impounding a substantial body of surface water and damage to that structure by mine subsidence effects could lead to a risk of structural failure and prejudice to public safety, no mining should be permitted within the safety zones of such a structure.



D is determined from the following table:

	D*
Room and Pillar	5s or 10t
Panel and Pillar	3p or 270 ft
Total Extraction	60t

*Whichever value of D is larger.

Figure 1- Safety Zone Beneath Body of Surface Water (after Babcock and Hooker, 1977)

2. The perimeter of the structure requiring protection should be established by those responsible for its maintenance and safety. The safety zone around the perimeter of protection should extend outward 200 ft in all directions, then downward for 350 ft, and then outward at a dip of 65° from the horizontal as shown in Figure 2. This safety zone is designated as a zone of no extraction. Figure 2 also shows the restriction on mining beneath the impounded water.

3. A greater or lesser distance than that specified in paragraph 2 above may be used where local observations and/or experience so indicate.

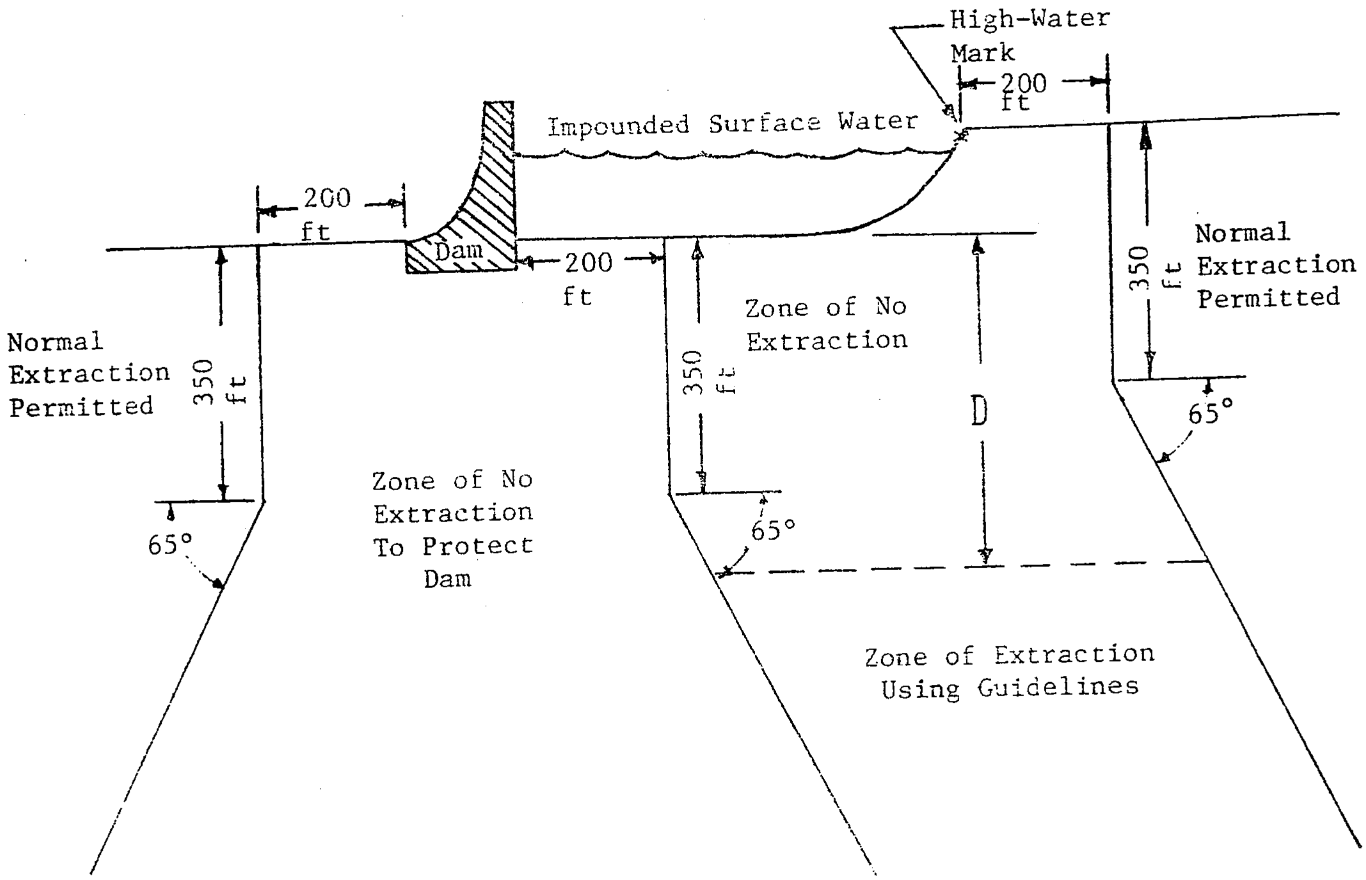
1.2.4 Summary of NSW Inquiry

The report of the inquiry (Reynolds, 1976) is a legal document and not a technical report, so the presentation is not intended as an original work but as a report on the Commissioner of Inquiry's findings and recommendations.

The report begins with a review of the problem, in which it is noted that several underground coal mines have applied to mine beneath stored water in 5 reservoirs. The area is in the Southern Coalfield of New South Wales, Australia. The seams of interest are approximately 9 feet thick at a depth of about 1000 feet. Within the government of the State of New South Wales, the Department of Mines is charged with furthering coal extraction while the Metropolitan Water Sewerage and Drainage Board is charged with maintaining the water supply. Thus the dispute arises between the two conflicting interests.

The coals are generally the Bulli Seam and Wongawilli Seam extracted with a thickness of about 9 feet and are part of the Illawarra coal measures. These are overlain by the Narrabeen Group of sandstones and claystones with some shale which is overlain by the Hawkesbury Sandstone.

A comprehensive review of subsidence phenomena is given, generally following NCB experience. It is acknowledged that whereas the surficial disturbance is well-studied, the changes in strata permeability induced by mining have not been studied. Mining methods are then reviewed, and the panel and pillar system is accepted as the commonly used system in this instance.



D is Determined From the Following Table:

	D*
Room & Pillar	5s or 10t
Panel & Pillar	3p or 270 ft.
Total Extraction	60t

* Whichever Value is Larger

Figure 2- Safety Zone Beneath Surface Structure Impounding Large Body of Surface Water (after Babcock and Hooker, 1977)

It is noted in the report that previous guidelines for mining under water are intended to protect the men and workings, but not the surface waters, which can drain into surficial disturbances without reaching the mine. The various guidelines for undersea and underwater mining that have seen use throughout the world are summarized.

The Commissioner visited several United States and European mines actively working beneath stored waters, and reported on their situations and experiences. Also, the results of methane drainage projects above coal seams are reported.

Field tests were then carried out in which bore holes were drilled from the surface above unmined and mined areas. The field tests allowed only two conclusions: that the mining induced surface fractures did not extend for hundreds of feet into the mining horizon, and that in all cases a retarding layer was present in the strata which prevented vertical migration of significant quantities of water no matter what the mining-induced increase in permeability.

Wet mines in the area were examined and it was determined that drips contained algae species that originated in stored surface waters. Tritium level studies indicated that rainwater rather than stored groundwater was the source of mine water. The inspections and field tests also indicated that below 200 ft (60m) little natural vertical flow of water occured.

Finite element model studies were carried out, and concluded that surface indications of disturbance were not indicative of subsurface disturbances, and that in panel and pillar mining three zones exist from the surface downward: disturbed zones above and below a sensibly undisturbed zone, the three above the mining horizon.

The following intermediate conclusions were reached and it should be noted that only partial extraction mining is contemplated:

Depth of Cover:

1. For Mining under the stored waters it is necessary to ensure that a sufficiently thick sequence of normal strata of the Narrabeen Group which remains sensibly undisturbed lies between the mine opening and the base

of the stored waters. Such a sequence will provide vertical impermeability in a practical sense. It has not been established that any sequence of 200 ft (60 m) of strata, even if undisturbed by mining, will be sufficient to provide layers of low vertical permeability. The experience at Huntley Colliery throws doubt upon an unqualified acceptance of 200 ft (60 m) of undisturbed strata being sufficient.

2. The required thickness of undisturbed Narrabeen sequence is 200 ft (60 m).

Bord and Pillar:

3. Mining by the bord and pillar method with bords no wider than 18 ft (5.5 m) and pillars with a minimum dimension not less than 15 times the height of the extraction or one-tenth of the depth of cover, whichever is the greater, will not cause strata disturbance at the surface and only minor roof disturbance at the seam where the depth of cover is 200 ft (60 m) or more. (The alternative pillar size is stipulated in case mining by bord and pillar is undertaken at great depth.)

4. This type of mining at this depth will at most locations under the reservoirs therefore substantially provide the requisite sequence of undisturbed impermeable strata.

5. At depths of cover of 250 ft (76 m) or more, bord and pillar mining may be undertaken irrespective of the nature of the cover. With depths of cover of 200 ft (60 m) or more to less than 250 ft (76 m) no mining should be undertaken unless the cover includes 200 ft (60 m) of rocks of the Narrabeen Group.

Panel and Pillar:

6. At depths of cover of 300 ft (90 m) or more, by following certain patterns of mining geometry, it is possible to obtain a reasonably high percentage of extraction whilst localising the stresses which are developed and lead to rock fracture or other disturbance to zones near the surface and near the seam.

7. At this minimum depth, if subcritical panels of appropriate width are extracted, the immediate roof beds will generally collapse and fill the void causing a zone of collapse up to five times the height of the extraction but conceivably extending to ten times.

8. Above this zone will be a zone where some fracturing or rock joint opening and some separation of the beds will occur.

9. A level is reached where progressively the strata will begin to behave as a bridge and deflect only slightly.

10. From this level to near the surface the strata will remain sensibly undisturbed except for minor deflection at the centre of the panel of extraction. It will be tightly constrained and its permeability will not be affected.

11. When a series of panels have been extracted under this system separated by pillars of appropriate size a shallow flat bottomed trough of subsidence will be formed. Above the pillars at the limit of such a layout tension effects will occur but only to shallow depths.

12. In normal geological situations the bridging effect will be achieved at a height above the extraction not more than the distance in width of the extracted panel.

13. In the series of substantially parallel panels there must be separation by pillars of a specified width for three reasons:
    (a) to avoid disturbance of the strata above a panel interfering with the stability of the strata arch above adjacent panels.

    (b) to avoid excessive overlapping of subsidence profiles, and

    (c) to provide permanent support to the strata.

14. Pillars of a length co-extensive with the panel length, with a minimum width no less than one-fifth of the depth of cover or 15 times the height of extraction, whichever is the greater, is the appropriate specification.

15. Necessary caution and conservatism demands that any proposal for a chain of pillars be not accepted.

16. At all depths in excess of 300 ft (90 m) if panels not exceeding one-third of the depth of cover are extracted and pillars are of the dimensions specified, there will be provided at least 200 ft (60 m) of undisturbed strata of the Narrabeen Group.

17. Nevertheless, other considerations may demand a more conservative decision as to the minimum depth of cover.

Following this, further items were discussed, such as the marginal zones around reservoirs which have been taken as 26-1/2° from the vertical, and around dams as 35° from vertical. Further, the Full Storage Level (FSL) and not the Top Storage Level (TSL) or flood stage has been taken as defining the reservoir perimeter. The problem of long term stability of pillars was considered, and it was concluded that adequately designed pillars will endure for the lifetimes of the reservoirs, that is, for centuries.

The Commissioner concluded with the following Findings and Recommendations (which it should be noted allow partial extraction only):

(1) I would answer the first question in the terms of reference in the affirmative. I have formed the opinion that, in the public interest, the relevant mining should be permitted because the valuable resource of coal reserves may be mined without endangering the security of the stored waters if the mining is carried out with proper safeguards.

(2) The following paragraphs indicate my views relating to the second question of the terms of reference as to the extent of such mining and the conditions subject to which it should be carried out.

Restricted Mining Only:

(3) Mining under the stored waters must be restricted to specified systems of partial extraction.

(4) There must be a zone around the margin of the stored waters within which only this restricted mining is practised.

(5) Minimum depths of cover for mining must be observed.

(6) No mining or driving of access roads should be permitted at a depth of cover under the stored waters of their marginal zones of less than 200 ft (60 m).

Bord and Pillar Recommendations:

(7) Bord and pillar mining at depths in excess of 200 ft (60 m) should be allowed with bords of a maximum width 18 ft (5.5 m) and pillars of a minimum width 15 times the height of extraction or one-tenth of the depth of cover, whichever is the greater, provided the cover includes not less than 200 ft (60 m) of rocks of the Narrabeen Group.

(8) Where the depth of cover is 250 ft (76 m) or more, bord and pillar mining with bord and pillar sizes as in (7) should be permitted.

(9) Where the depth of cover is in excess of 200 ft (60 m) but less than 250 ft (76 m) but does not include 200 ft (60 m) or more of rocks of the Narrabeen Group, only the driving of access roads should be permitted.

(10) Where two or more seams are worked in the same locality by the bord and pillar system, the pillars in each seam should have the same dimensions and these should be related to the thicker seam. Where the interval between the two seams is greater than five times the thickness of the lower seam the dimensions of pillars in the lower seam may be related solely to the thickness of that seam. Where the pillars are required to be identical in size, the pillars in each seam should be disposed in the same vertical plane.

Panel and Pillar Recommendations:

(11) At depths of cover of not less than 400 ft (120 m) partial extraction of coal by the panel and pillar method may be carried out provided that panel sizes do not exceed one-third of the depth of cover and pillar sizes are of a length co-extensive with that of the panel extracted and of a width not less than one-fifth of the depth of cover or fifteen times the height of extraction, whichever is the greater.

(12) If more than one seam is worked, one above the other, by the panel and pillar system, the smaller panel applicable and the pillar larger in width should be taken to apply in both seams and the pillars should be in the same vertical alignment.

Marginal Zone Recommendation:

(13) The marginal zone around the stored waters should be determined by an angle of draw of 26-1/2° taken from the boundary of the stored water at full storage level.

Dam Wall Recommendation:

(14) There should be no mining or driving of access roadways within a pillar of coal under and surrounding an impounding structure.

(15) The size of the pillar of unworked coal under any impounding structure should be determined by an angle of draw of 35° taken from a line on the surface 650 ft (200 m) from the edge of the concrete or masonry structure. The Minister for Mines and Energy should have power if thought fit in a particular case to increase the distance of 650 ft (200 m).

Further Recommendation:

(16) A detailed plan should be submitted to the Department of all proposed mining under the stored waters and their marginal zones. The Minister should have power to disapprove such a plan in whole or in part, notwithstanding that it complies with these recommendations if, in the opinion of the Minister, it is proper to do so.

(17) In particular, the Department should ensure that the mining plan in so far as it relates to the pattern of extraction at and near the boundary of the marginal zone is such that the integrity and effectiveness of the partial extraction system will not be impaired or reduced.

(18) Periodical inspection of the working under the stored waters or the marginal zones should be allowed by a representative of the Board. Coal which has spalled from pillars the size of which is specified to these recommendations should not be removed. Special powers to halt mining under the stored waters and their marginal zones should be reserved to the Department.

(19) Severe sanction should be imposed for any breach of the mining conditions relating to mining under the stored waters or their marginal zones.

2.0 THE NATURE OF WATER BODIES

The size, geometry, and nature of bodies of surface water are important factors on which will depend the size of the zone in which mining may be restricted. For convenience, bodies of surface water have been grouped into the following three categories.

2.1 Catastrophic Potential Size

In the first category are included those water bodies whose water level is not significantly affected in the event of any loss of water into the mine. Such bodies will include an ocean, the Great Lakes, large rivers, large inland lakes, and reservoirs. They can completely flood the mine workings.

2.1.1 Oceans

Oceans have unlimited water supply and are infinitely larger than the volume of any particular mine. Coal mining beneath the sea has been carried out in the United Kingdom, Canada, Japan, Australia, Chile, and Spain. Records indicate that in the United States some limited mining in the past was carried out beneath Narragansett Bay near Portsmouth, RI (Barton, et al, 1977). Some of the workings in these instances below the ocean extend for a maximum distance of about 5 miles from the shoreline.

Marine environments are generally classified on the basis of depth of water, closeness to shore, and the type of bottom sediments. As seen in Figure 3, depositions at the sea bed in littoral and neritic environments, which extend outward to a point corresponding to a depth of about 600 ft, are important in their potential to seal mining induced cracks that may develop in the ocean floor. It is estimated that about 80% of oceanic sediments are deposited in these environments. Sediments deposited include mud, silt, sand, and lime muds. Sandy sediments generally grade out in the shore region into an area of silty mud. Generally the silt content decreased as the water deepens. Thus muddy sediments predominate in littoral environments. Clay and mud may also be entrapped by vegetation such as sea weed which occurs in

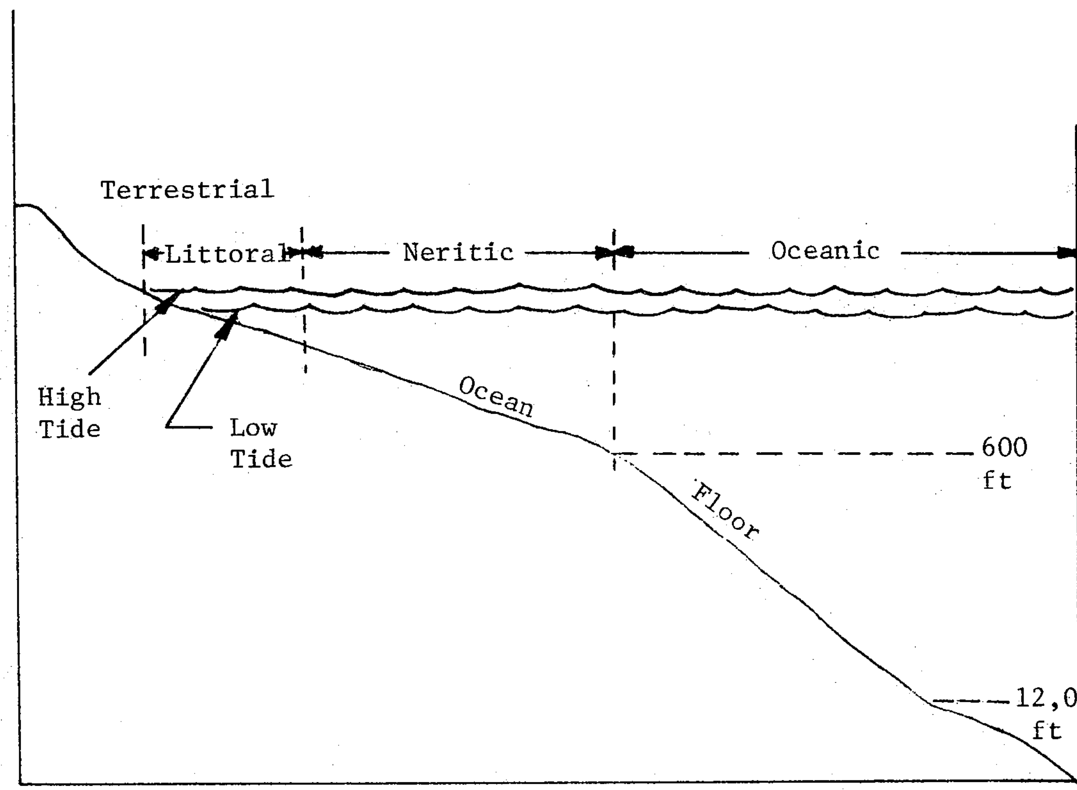


Figure 3 - Schematic Diagram Showing Marine Environment (after Huang, 1962).

abundance in areas of shallow water. However, it may be noted that irregularities of deposition are common in areas of shallow water and it will, therefore, be essential to study individual cases rather carefully.

It is not clear as to what extent any induced fractures are self sealing through weathering and softening and through being covered by clay and silt. It has been suggested that the "ooze" occurring at the sea bed acts as a good filling medium for cracks. Many undersea workings are very dry and it is therefore suggested by some that the fine grained mud and clay deposited on the bed of the sea acts as a layer impermeable to water (Orchard, 1975).

The presence of relatively thick unconsolidated deposits of impermeable clay, silt and marl between bedrock and the sea bed has been considered to be a significant factor in decreasing the risk of inundation in Japan, Chile, Vancouver Island, and Scotland. In formulating regulations, Japan made a specific distinction between the impermeable unconsolidated formations and coal measures, taking into consideration the likely beneficial effects of the presence of the unconsolidated formations (Fawcett, 1973). It is reflected in the Japanese Safety Regulations (issued by The Mine Safety Bureau Ministry of International Trade and Industry) which make a distinction between the thickness of Quaternary and Tertiary formations in the cover. All the coal seams mined in Japan are of Tertiary age. The Tertiary rocks have a general shale, sandstone, sandy shale sequence, while the Quarternary formations consist entirely of impervious muds, clays, silts, sands, or pebbles.

Although the mineable reserves of coal under the oceans may be appreciable in the United States, their potential is not known at the present time.

2.1.2 Very Large Lakes

Like oceans, very large lakes have an unlimited supply and can flood any mine that may be worked under them without there being any significant change in water level. Depositions at the beds of large lakes are similar to that of oceans. However, in the case of some lakes, the strata may contain considerable thickness of glacial material. Glacial material may be highly permeable, and as such, its effect on the requirement of the total thickness of the safe cover warrants special consideration.

In the case of both oceans and very large lakes, the "highest high water level" should be taken as the edge line of the water body and can be determined from the appropriate authorities.

2.1.3 Large Rivers

The water level in large rivers is controlled by its inflow and outflow, thus mine subsidence under the river bed will cause the lowering of the land but not necessarily a lowering of the level of water. A general lowering of relatively flat land surrounding a river may result in considerable increased water intrusion thereby making it wet or swampy. Also, in the event of the land surrounding a river being subject to flooding, mine subsidence could considerably extend the areas of surface flooding.

Large rivers are continuously replenished and can flood a mine completely without there being any permanent change in their level of flow. The flood stage of the river should be taken at the mine or mine panel life flood as in Figure 4. That is, if the expected mine life is 50 years, the flow and lateral extent of the river for hazard determination should be the 50 year flood.

Rivers carry a large quantity of clay, silt, sand and other sediment which may be deposited to a considerable thickness at the river bed and its banks. The thickness of the unconsolidated material should not be taken into consideration while determining the thickness of the cover for working below or in the vicinity of rivers, since this material is often scoured out during flood stage.

2.2 Major Potential Size

The second category will include small rivers, streams, and lakes.

2.2.1 Small Rivers and Streams

Small rivers and streams generally have a great variation in their flow depending on the season. Advantage of this seasonal variation may perhaps be taken to recover considerable additional percentages of reserves of minerals with due regard to safety in the closing years of a mine. This, of

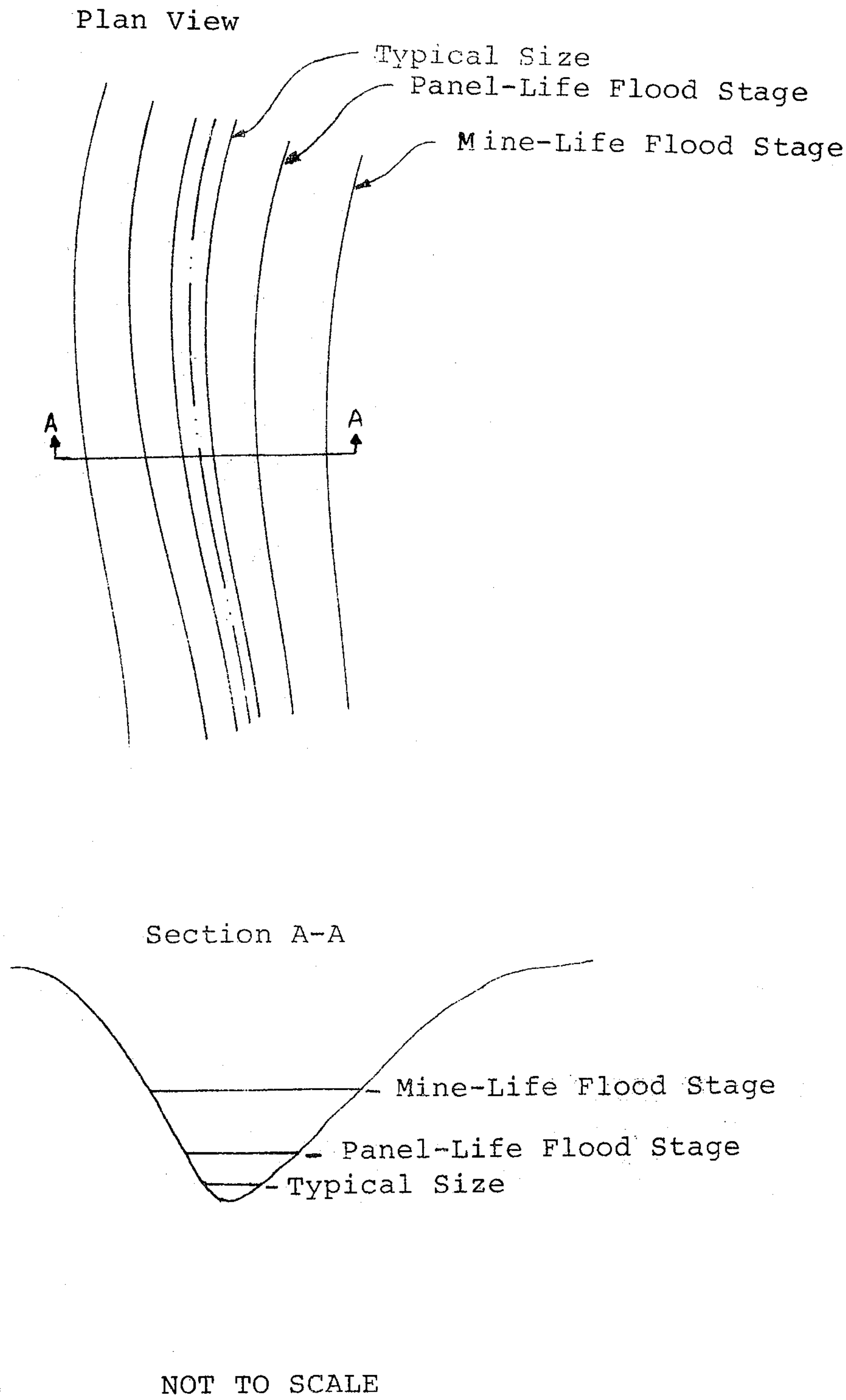


Figure 4 - Mine-life and Panel-life Flood Stages of a River.

course, will call for special mining plans and precautions. However, for all-season operations, adequate precautions in accordance with the suggested guidelines for "catastrophic potential" bodies as discussed above will be necessary because small rivers and streams can completely flood the mine depending on their flow rate. As with rivers, the mine life or panel life should be used to determine the flood stage of the stream. However, the flowing nature of such streams rates out the mine being able to accept any inflow above pumping capacity thus placing flowing bodies in either the Catastrophic or Limited Potential class.

2.2.2 Small Ponds and Lakes

It is likely that the mine volume may be larger than the water volume of a small lake, a farm pond, or a sediment pond on the surface. Thus, even in the event of an inundation, only a part of the mine may be flooded which may not affect either the production or the safety of the mine beyond acceptable limits. If a mine is relatively new, it may be possible to adopt a suitable mining plan which will provide for sufficient water storage capacity in the downdip workings to provide for a cushion in the event of an inundation while working under a water body.

The total available water storage capacity of a mine with respect to a body of surface water has been used to determine its critical size. The size of the water body is critical or of catastrophic potential if its volume exceeds that of the available water storage capacity of the mine, and has been classified as major potential if its volume is less than the available water storage capacity. As before, the mine life years flood stage should be taken for the depth, extent, and volume, as in Figure 5.

2.3 Limited Potential Size

The third category will include water bodies like very small lakes, farm ponds, sediment control ponds, and small seasonal creeks.

If the average flow of a surface creek over the year is sufficiently small, it may be possible to continue mining underneath it as if the creek did not exist. The cut-off flow rate of the creek can be worked out from economic considerations such as the additional cost of pumping and the additional profit that may accrue as a consequence of recovery of additional reserves.

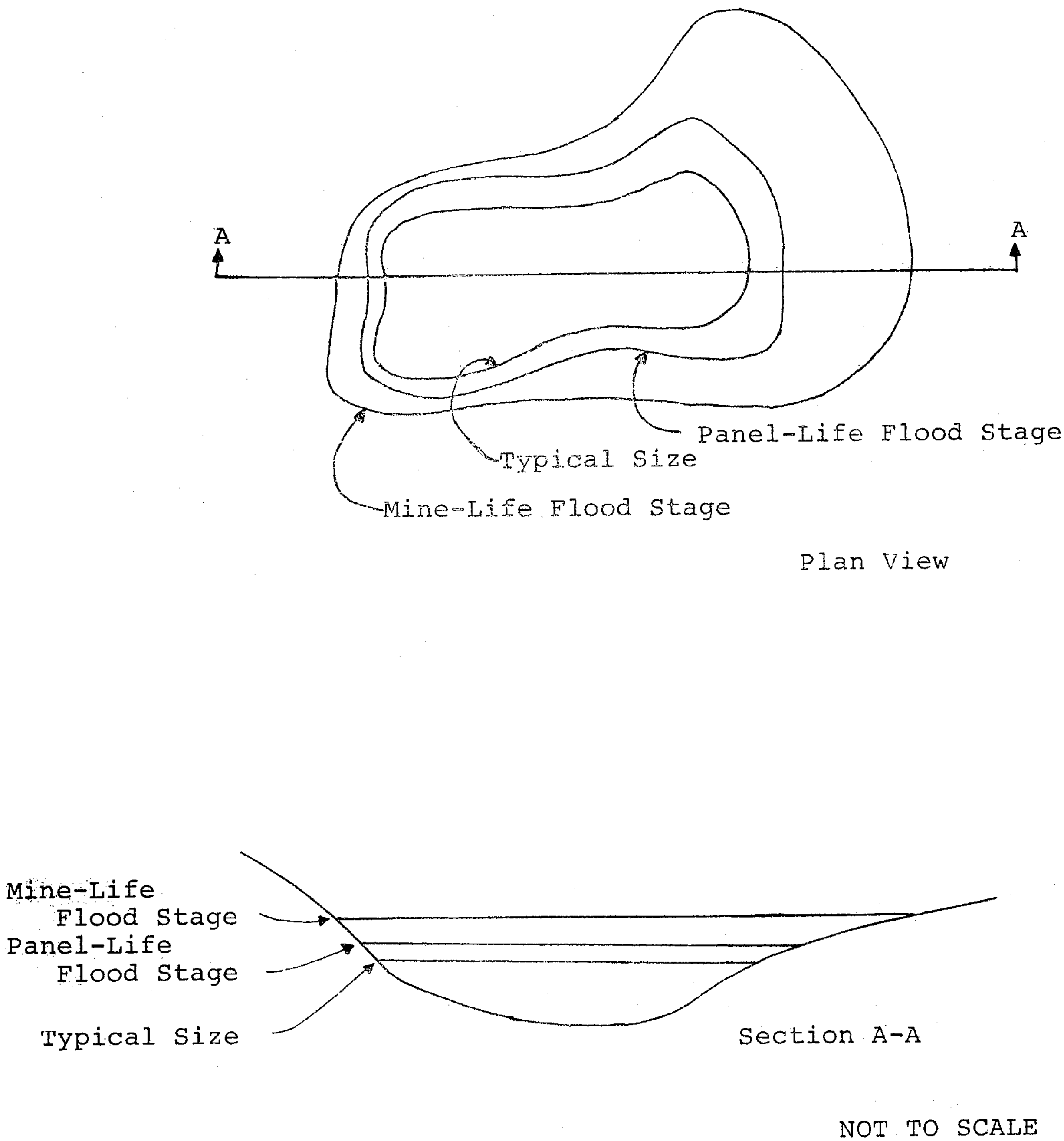


Figure 5 - Mine-life and Panel-life
Flood Stages of a Lake.

It is essential that adequate pumping capacity is provided to deal with the expected peak discharge from a mine lifetime year's flood.

Before undermining such small streams where the thickness of cover is less than laid down in the existing and the proposed guidelines, the legal and social factors which may be affected as a result of draining of these water bodies should be evaluated. It may be possible to make alternative arrangements for supply of water to the owners of affected water rights, or to recharge it on the downstream side with appropriately treated mine drainage or other waters with overall economic gains.

Small non-flowing bodies of water must be recognized on a basis of their likely effect if they enter a mine and must possess a likely inflow rate and volume that would allow persons to avoid problem areas. They could also be drained prior to mining under them.

2.4 Surface Effects

As already mentioned where the surface land is subjected to flooding, mining subsidence may greatly increase the area of flooding mainly as a result of lowering of the ground level. The ground surface is liable to develop cracks as a result of mining subsidence even if the depth of cover is adequate. Small streams of water, if undermined, may be lost due to these cracks whereas bigger streams and rivers retain their water flow level. Of course, surface subsidence cracks give rise to increased seepage thereby wetting the ground near the banks.

As an alternative to working below major or limited potential water bodies with an increased risk of inflow into the mine, their deliberate draining or diversion should be considered which will eliminate the risk altogether. This will have to be decided on the merit of each individual case and other overall considerations.

2.5 Structures Retaining Water

Working below dams and embankments poses a different type of problem altogether. Except in the case of small embankments which impound a relatively small quantity of water, any damage to them may endanger public safety. It has been illustrated by experiments on brick walls in subsidence zones that a horizontal strain of a magnitude of 400 $\mu\varepsilon$ on the surface produced a crack as wide as 0.5 inch to 0.75 inch in the brick wall (Littlejohn, 1974). It shows that even a small but widespread disturbance due to mining may jeopardise the safety of a structure which is not specially designed to accept localized lateral strain.

Total protection of structures of public importance is necessary, which can be achieved best by not allowing any kind of mining in the safety zone surrounding these structures.

Small structures or embankments which impound only a small quantity of water, mud, and silt, even if breached, may not threaten the public safety and health. There are quite a few small embankment type structures underneath which considerable coal reserves may be unmineable if no distinction is made between small and big dams. The standards established by West Virginia Department of Natural Resources (1975) for the design and construction of sediment dams and agricultural dams located in predominently rural or agricultural areas make a distinction between small and big structures. A structure is classified as small when:

1. Failure of the structure would not result in loss of life; in damage to homes, commercial or industrial buildings, main highways, or railroads; in interruption of the use of service of public utilities or damage existing water impoundments; and

2. The contributing drainage area does not exceed 200 acres; and

3. The maximum vertical height of the dam or embankment as measured along the centerline of the embankment to the crest of the spillway does not exceed 15 ft; and

4. The area of the impounded water at the spillway level does not exceed 10 surface acres; and

5. The structure conforms to all applicable laws and regulations pertaining to the storage of water.

Mining beneath these small structures may carried out in accordance with the guidelines proposed herein.

2.6 Multiple Water Bodies

Throughout this report, water bodies are considered singly. It is possible that a single subsidence event could affect several water bodies, but is not likely that they would drain into the mine at the same time. Water bodies that are connected, such as a chain of lakes, or a stream flowing into a lake, must be combined and their combined volume and flow considered.

3.0 THE NATURE OF STRATA DISTURBANCE DUE TO UNDERGROUND MINING

All strata achieve a balance of forces over periods of geologic time by processes of deposition and tectonic change. The natural stress field in the strata is mainly due to the weight of the overlying rocks though some areas have reported active geologic horizontal stresses. The average density of coal measure rocks is 150 lb/cu-ft, therefore, the vertical pressure gradient due to gravity is approximately one psi per foot of depth. The creation of a void in the strata by underground mining produces a disturbance in the natural stress field. The effect of the stress change results in strata deformation which, depending on the dimensions of the excavation, can extend to the surface causing it to subside. Surface depressions, cracks and pits, with or without damage to surface structures, are the common effects of subsidence induced by underground mining.

3.1 Mining Subsidence

For working under bodies of surface water, the study of the nature of strata deformation is particularly important.

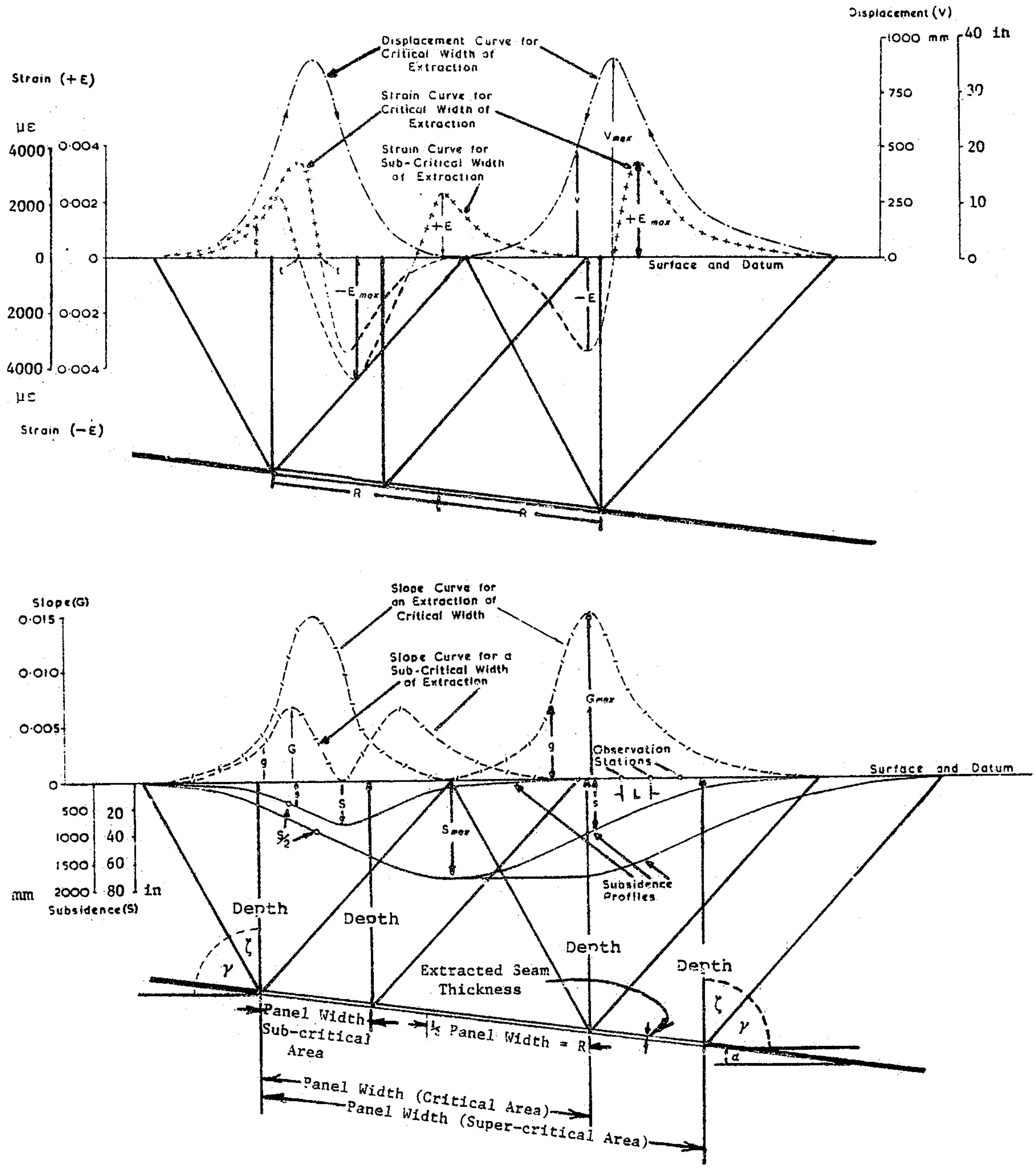
In the absence of extensive field investigations and instrumentation, the nature of strata deformation is generally interpreted from the measurement of surface subsidence or its predicted value. Measurements of mining subsidence in Europe and also to a lesser extent in the United States have made it possible to predict within a reasonable degree of accuracy the effects on surface structures such as buildings, bridges, pipelines, roads, and railroads. Also, in recent years, several studies have been undertaken to determine the effect of geological anomalies such as faults, nature of the water table, and characteristics of the strata on overall structural damage. In underground workings, the convergence of the mine roof and floor, stress distribution, caving characteristics of the immediate roof strata, physical properties of the seam and surrounding strata have also been determined.

Surface subsidence depends on the method of mining in addition to other factors. As mentioned earlier, effects are observed on the surface only if the excavations are made sufficiently wide. Most subsidence studies, therefore, have been confined to total extraction methods by longwall mining. Most subsidence theories based on direct observations have evolved from these studies. However, if pillars are completely extracted in room and pillar mining, the result is total extraction and it has been shown by subsidence measurements that the same theories are applicable (Dahl and Choi, 1974). Figure 6 shows a typical section through workings illustrating the trough subsidence profile with corresponding strain and displacement curves.

3.2 Factors Influencing Subsidence

Tha angle of draw, also called the limit angle, is the angle between the vertical to the edge of the opening and the line connecting the edge of the opening to the point on the surface where the subsidence has dimished to zero (Figure 6). In practice, it is measured up to the point of least measurable vertical movement which is ordinarily 1 mm (0.04 inches) (Wade and Conroy, 1977). It depends mainly on the nature of strata and ranges from 8° to 45°. Commonly measured angles of draw in different coalfields of the United States and some European countries are given below:

Country	Angle of Draw (degrees)
United States	
Eastern	15 - 27
Central	0 - 30
Western	12 - 16
Great Britain	25 - 35
Germany	30 - 45
Netherlands	35 - 45
Northern France	35
Soviet Union	30



LEGEND

α - Angle of dip
ζ - Angle of draw from vertical
γ - Angle of draw from horizontal
R - Radius of critical area
v - Displacement
V_{max} - Displacement (Maximum Possible)
e - Strain
E_{max} - Strain (Maximum Possible)
s - Subsidence
S_{max} - Subsidence (Maximum Possible)
g - Slope
G_{max} - Slope (Maximum Possible)

Figure 6 - Typical Sections Through Workings, Illustrating Subsidence Troughs, and Slope, Strain, and Displacement Curves with their Respective Symbols (from National Coal Board, 1975). Reproduced with permission from National Coal Board Subsidence Engineers Handbook (revised edition 1975).

The maximum possible surface subsidence is given by the relation:

$$S_{max} = tN$$

where t is the seam thickness and N is a subsidence factor which ranges from 0.1 to 0.9 with different gob support methods. Some typical values of subsidence factor measured in the United States and a few European countries are given in Table 7. Some United States case histories giving particulars of surface subsidence measurements and their effects are given in Table 8. Measured and predicted subsidence along with respective lithologies of different coal regions of the United States are given in Table 9.

Other important factors that influence subsidence are width and depth of panels, method of gob packing, seam inclination, and time. Their effects are generally predicted on the basis of empirically derived relationships of several field measurements. Continuum mechanics theories including elastic, visco-elastic and elastic-elastoplastic have also been developed but are not presently used for practical problems because they do not give reliable results (von Schonfeldt, Wright and Unrug, 1979).

3.3 Prediction of Horizontal Strain by the Graphical Method

The extent of fracturing, and therefore, the magnitude of the increase in permeability of the deformed strata, largely depends on the magnitude of the horizontal strain. Therefore, a brief description of the commonly used graphical procedure for determining horizontal strains due to total extraction of a flat seam as developed by the National Coal Board is given by working a hypothetical example, below.

For p = width of panel, 500 ft

D = depth, 400 ft

t = thickness of extraction, 6 ft

S = maximum subsidence, 4.98 ft (from Figure 7)

Table 7

Typical Subsidence Factor (N) Values
Measured in Different Countries
(after Brauner, 1973)

Coal Field and Method of Gob Packing	Subsidence Factor
United States	
Eastern (room and pillar)	0.10 - 0.60
Central (longwall)	0.50 - 0.62
Central (room and pillar)	0.10 - 0.40
Western (longwall)	0.33 - 0.71
Ruhr Coal Field, Germany	
Pneumatic Stowing	0.45
Other solid stowing	0.50
Caving	0.90
North and Pas de Calais Coal Field, France	
Hydraulic stowing	0.25 - 0.35
Pneumatic stowing	0.45 - 0.55
Caving	0.85 - 0.90
Upper Silesia, Poland	
Hydraulic stowing	0.12
Caving	0.70
United Kingdom	
Solid stowing	0.45
Caving or strip-packing	0.90
Soviet Union	
Donbass district	0.80
Lvov-Volyn district	0.80 - 0.90
Kizelov district	0.40 - 0.80

Table 8 - Case Histories Showing Surface Subsidence and Surface Effects

	Mine	Width of Panel (ft) (P)	Depth (ft) (D)	Seam Thickness Mined (ft) (t)	Max. Subsidence (ft) (S)	S/t	Angle of Draw ζ	Maximum Strain (E)	D/t	Remarks
1	Marquette Cement	500	590	3.5	1.847	0.52	24° 25' to	.276	169	The pillars in limestone workings caved and the solid stone cracked resulting in roof falls(Auchmuty, 1931)
2	Marquette Cement	500	450	3.5	1.936	0.55	60° 57'		129	
3	Crucible Mine	1125	550	6.2	3.21	0.52	Not measured	Not measured	89	Highway on the surface developed Cracks (Maize and Greenwald, 1939)
4	Old Ben Mine	400	610	7.0	4.39	0.63	14° - 30°		87	Under Rand Lake (Wade and Conroy,1977)
5	Blacksville No. 1	450	370	6.0	2.30	0.38	Not measured	Not measured	62	(Dahl and Choi, 1973)
6	Humphrey No. 7	300	380	6.5	0.47	0.08	Not measured	Not measured	58	(Dahl and Choi, 1973)
7	Crucible Mine Area 2	900	350	7.2	3.5	0.48	Not measured	1.0	54	(Maize, Thomas and Greenwald, 1941)
8	Crucible Mine Area 2	450	350	7.2	2.9	0.40	Not measured	0.75	49	(Maize, Thomas and Greenwald, 1941)
9	Nemacolin Mine	1300	300	6.5	3.08	0.47	Not measured	Not measured	46	Highway on the surface developed cracks (Maize, Thomas and Greenwald, 1941)
10	Gibson Mine	350	135 to 400	5.3	2.8	0.53	Not measured	1.25	25 to 75	90% coal recovery (surface cracked) (Maize, Thomas and Greenwald, 1940)
11	York Canyon Mine	550	240 to 440	10	7.1	0.71	15.5°		24 to 44	(Gentry and Abel, 1977)
12	Montour No. 10 Mine	150	15 to 70	5.0	3.0	0.60	Not measured	Not measured	3 to 14	3in to 6in cracks on the surface (Maize, Thomas and Greenwald, 1941)

Table 9 - Measured and Predicted Subsidence for Some U.S. Coal Districts (after von Schonfeldt, Wright and Unrug, 1979) Used with permission of the American Mining Congress.

Geographic Location	West Virginia (1)	West Virginia (2)	West Virginia (3)	New Mexico (4)	Illinois (5)	Virginia
Average Overburden, ft, (D)	213	(193-213) 201	183	(73 -226) 150	190	1600-1800
Panel Width/Overburden	.64	.74 -.64	.56	1.72 -.8	.74	1.3
Stratigraphy Sandstone (%)	5	13	20	30	3	47
Limestone (%)	45	42	31	-	3	-
Shale, Mudstone, Siltstone, etc, (%)	50	45	49	70	94	53
Subsidence Ratio (%)	40-47	38	35-38	(50-84) 70	63 - 73	20
NCB Subsidence Prediction (%)	61	63	50	70-88	67	70

(1) Choi and McCain, 1979
(2), (3) Dahl and von Schonfeldt, 1977
(4) Abel and Gentry, 1978
(5) Conroy, 1978

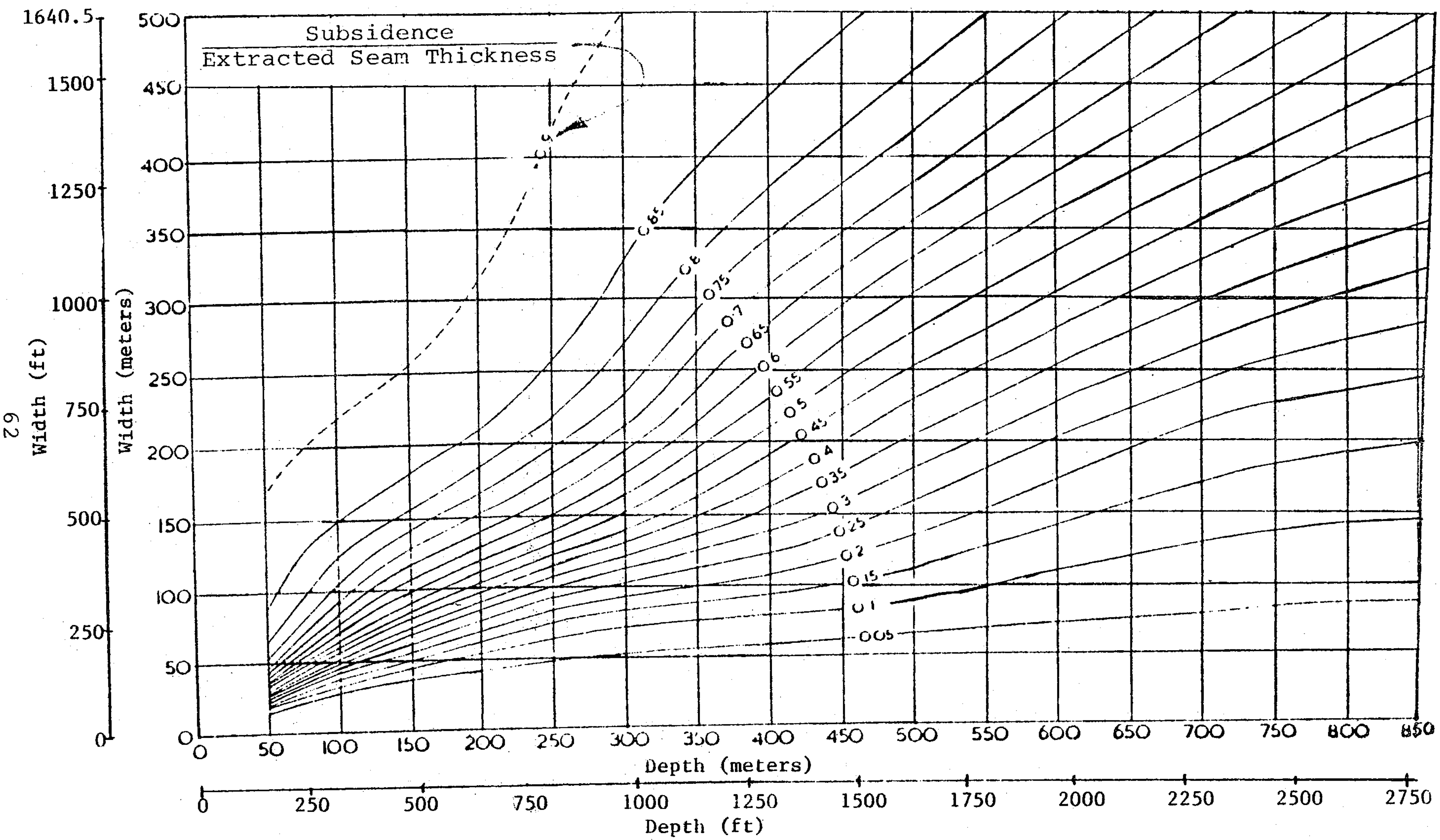


Figure 7- Relationship of Subsidence to Width and Depth.
(from National Coal Board, 1975).
Reproduced with permission from National Coal Board
Subsidence Engineers Handbook (revised edition 1975).

The maximum strain is directly proportional to the maximum subsidence and inversely proportional to the depth of the seam. It is expressed as:

$$E = k\ S/D$$

It may be noted that factor k is different for tensile and compressive strains and is proportional to p/D of the excavation. From Figure 8, compressive and tensile values for k are:

For compressive strain (-E) (using units of microstrains, $\mu\varepsilon$)

$k = 510{,}000$, therefore $-E = kS/D = 6{,}800\ \mu\varepsilon$

and for tensile strain (+E)

$k = 650{,}000$, therefore $+E = k\ S/D = 8{,}100\ \mu\varepsilon$

Table 10 can now be constructed. Row 1 in Table 10 is taken from Table 11. Multiply k S/D by the fractions in row 1 to obtain row 2; obtain row 3 from Table 11 for p/D = 1.25 and multiply row 3 by D = 400 to obtain row 4 which gives distances from the center of the panel. Now plot the strain profile using rows 2 and 4 as shown in Figure 9.

As a result of large number of subsidence and strain measurements, it is now known that the subsidence and strata strains when superimposed on one another due to either working two adjacent panels or multiple seams accumulate algebraically. Figure 10 shows the calculated effect on the strain profile for working two panels adjacent to each other with a 50 ft wide barrier pillar. The algebraic sum of the strata strain is shown by the dotted line. The observations indicate that the ground strain is not relaxed with the passage of time. Therefore, the effects of working underlying or overlying seams or adjacent panels in the same seam when superimposed accumulate algebraically irrespective of whatever may be the time lag. If the ribsides of subsequent workings in overlying or underlying seams coincide with the curvature at the edges of subsidence depression, the curvature becomes sharper and fissuring and fracturing more severe (Orchard, 1975).

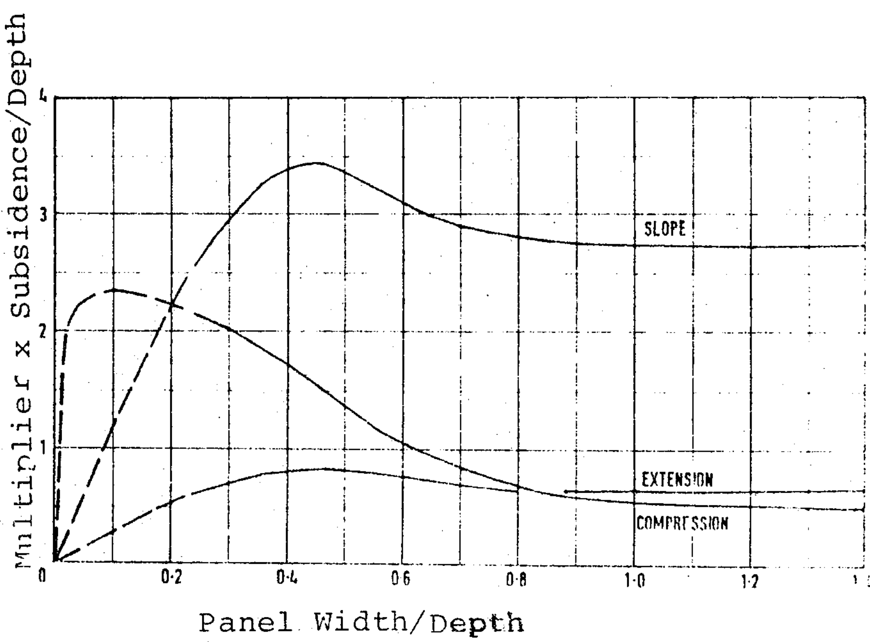


Figure 8 - Graph for Predicting Maximum Slope and Strain for Various Width/Depth Ratios of Panel (from National Coal Board, 1975). Reproduced with permission from National Coal Board Subsidence Engineers Handbook (revised edition 1975),

Table 10- Method of Predicting Strain Profile

	EXTENSION (+E)							COMPRESSION (-E)								
1. E/E_{max}	0	0.20	0.40	0.60	0.80	1.00	0.80	0	0.20	0.40	0.60	0.80	1.00	0.80	0.60	0.40
2. Strain in $\mu\varepsilon$	0	1620	3240	4860	6048	8100	6480	0	1360	2720	4080	5440	6800	5440	4080	2720
3. Distance in terms of D	1.33	0.90	0.79	0.73	0.68	0.63	0.58	0.48	0.46	0.43	0.40	0.37	0.31	0.22	0.15	0.09
4. Distance in feet	532	360	316	292	272	252	232	192	184	172	160	148	124	88	60	36

for p/D=1.25
from Table 11

Table 11 - Relationship for Various Strain Values in a Subsidence Profile (from National Coal Board, 1975).

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Values of $\frac{\text{Strain}}{\text{strain (maximum)}}$

Panel Width / Depth Ratio of Panel	Extension (+E)												Compression (−E)					
	0	0.20	0.40	0.60	0.80	1.00	0.80	0	0.20	0.40	0.60	0.80	1.00	0.80	0.80	0.40	0.20	0
	DISTANCES FROM PANEL CENTRE IN TERMS OF DEPTH																	
3.0	2.2	1.78	1.67	1.61	1.56	1.50	1.46	1.36	1.34	1.31	1.28	1.25	1.19	1.10	1.03	0.96	0.90	0.70
2.6	2.0	1.58	1.47	1.41	1.36	1.30	1.26	1.16	1.14	1.11	1.08	1.05	0.99	0.90	0.83	0.77	0.70	0.50
2.2	1.8	1.38	1.27	1.21	1.15	1.10	1.06	0.96	0.94	0.91	0.88	0.86	0.79	0.70	0.63	0.57	0.50	0.30
2.0	1.7	1.28	1.17	1.11	1.05	1.00	0.96	0.86	0.84	0.81	0.78	0.76	0.69	0.60	0.53	0.47	0.40	0.20
1.8	1.6	1.17	1.07	1.01	0.95	0.90	0.86	0.76	0.73	0.71	0.68	0.65	0.59	0.50	0.43	0.37	0.30	0.10
1.6	1.5	1.08	0.97	0.91	0.85	0.80	0.76	0.66	0.63	0.61	0.58	0.55	0.49	0.40	0.33	0.27	0.20	0.03
1.4	1.4	0.98	0.87	0.81	0.75	0.70	0.66	0.56	0.53	0.51	0.48	0.45	0.39	0.30	0.23	0.17	0.10	0
1.3	1.35	0.93	0.82	0.76	0.70	0.65	0.61	0.51	0.49	0.46	0.43	0.40	0.34	0.25	0.18	0.12	0.05	0
1.2	1.3	0.88	0.77	0.71	0.66	0.61	0.56	0.46	0.44	0.41	0.38	0.35	0.29	0.20	0.13	0.07	0.02	0
1.1	1.25	0.83	0.72	0.66	0.61	0.56	0.52	0.42	0.39	0.37	0.33	0.31	0.24	0.15	0.09	0.03	0	0
1.0	1.2	0.79	0.68	0.62	0.57	0.51	0.47	0.37	0.35	0.32	0.29	0.26	0.20	0.10	0.05	0	0	0
0.98	1.19	0.78	0.67	0.61	0.56	0.50	0.46	0.36	0.34	0.31	0.28	0.25	0.19	0.09	0.04	0	0	0
0.96	1.18	0.77	0.66	0.60	0.55	0.49	0.45	0.35	0.33	0.30	0.27	0.24	0.18	0.09	0.04	0	0	0
0.94	1.17	0.76	0.65	0.59	0.54	0.48	0.44	0.35	0.32	0.30	0.26	0.23	0.17	0.08	0.03	0	0	0
0.92	1.16	0.75	0.64	0.58	0.53	0.47	0.43	0.34	0.31	0.29	0.25	0.22	0.16	0.07	0.02	0	0	0
0.90	1.15	0.74	0.63	0.57	0.52	0.46	0.42	0.33	0.30	0.28	0.24	0.21	0.15	0.06	0.02	0	0	0
0.88	1.14	0.73	0.62	0.56	0.51	0.46	0.41	0.32	0.29	0.27	0.24	0.21	0.15	0.05	0.01	0	0	0
0.86	1.13	0.72	0.61	0.55	0.50	0.45	0.40	0.31	0.29	0.26	0.23	0.20	0.14	0.05	0	0	0	0
0.84	1.12	0.71	0.60	0.54	0.49	0.44	0.39	0.30	0.28	0.25	0.22	0.19	0.13	0.04	0	0	0	0
0.82	1.11	0.70	0.59	0.53	0.48	0.43	0.38	0.29	0.27	0.25	0.21	0.18	0.12	0.03	0	0	0	0
0.80	1.10	0.69	0.58	0.53	0.48	0.42	0.37	0.29	0.26	0.24	0.20	0.17	0.11	0.02	0	0	0	0
0.78	1.09	0.68	0.57	0.52	0.47	0.41	0.36	0.28	0.26	0.23	0.20	0.17	0.11	0.02	0	0	0	0
0.76	1.08	0.67	0.57	0.51	0.46	0.40	0.36	0.27	0.25	0.22	0.19	0.16	0.10	0.01	0	0	0	0
0.74	1.07	0.67	0.56	0.50	0.45	0.39	0.35	0.26	0.24	0.22	0.18	0.15	0.09	0.01	0	0	0	0
.072	1.06	0.66	0.55	0.49	0.44	0.38	0.34	0.26	0.24	0.21	0.17	0.15	0.09	0	0	0	0	0
0.70	1.05	0.65	0.54	0.48	0.44	0.37	0.33	0.25	0.23	0.20	0.17	0.14	0.08	0	0	0	0	0
0.68	1.04	0.64	0.54	0.47	0.43	0.37	0.32	0.24	0.22	0.20	0.16	0.13	0.07	0	0	0	0	0
0.66	1.03	0.64	0.53	0.47	0.42	0.36	0.31	0.24	0.22	0.19	0.16	0.13	0.07	0	0	0	0	0
0.64	1.02	0.63	0.53	0.46	0.41	0.35	0.31	0.23	0.21	0.19	0.15	0.12	0.06	0	0	0	0	0
0.62	1.01	0.63	0.52	0.45	0.41	0.34	0.30	0.23	0.21	0.18	0.15	0.12	0.05	0	0	0	0	0
0.60	1.00	0.62	0.52	0.45	0.40	0.34	0.29	0.22	0.20	0.18	0.14	0.11	0.05	0	0	0	0	0
0.58	0.99	0.62	0.51	0.44	0.39	0.33	0.29	0.22	0.19	0.17	0.14	0.10	0.04	0	0	0	0	0
0.56	0.98	0.61	0.51	0.44	0.39	0.33	0.28	0.22	0.19	0.17	9.13	0.10	0.03	0	0	0	0	0
0.54	0.97	0.61	0.51	0.43	0.39	0.32	0.28	0.21	0.19	0.16	0.13	0.09	0.03	0	0	0	0	0
0.52	0.96	0.60	0.51	0.43	0.38	0.32	0.27	0.21	0.18	0.16	0.12	0.09	0.02	0	0	0	0	0
0.50	0.95	0.60	0.51	0.43	0.38	0.32	0.27	0.21	0.18	0.16	0.12	0.08	0.02	0	0	0	0	0
0.48	0.94	0.60	0.51	0.43	0.38	0.31	0.27	0.20	0.18	0.15	0.12	0.08	0.01	0	0	0	0	0
0.46	0.93	0.60	0.51	0.43	0.38	0.31	0.27	0.20	0.18	0.15	0.11	0.08	0.01	0	0	0	0	0
0.44	0.92	0.60	0.51	0.43	0.39	0.31	0.27	0.20	0.18	0.15	0.11	0.07	0.01	0	0	0	0	0
0.42	0.91	0.60	0.51	0.44	0.39	0.31	0.27	0.20	0.18	0.15	0.11	0.07	0	0	0	0	0	0
0.40	0.90	0.61	0.52	0.45	0.40	0.32	0.28	0.21	0.18	0.15	0.11	0.07	0	0	0	0	0	0
0.38	0.89	0.61	0.53	0.45	0.41	0.32	0.28	0.21	0.18	0.15	0.11	0.07	0	0	0	0	0	0
0.36	0.88	0.62	0.53	0.46	0.42	0.33	0.29	0.21	0.18	0.15	0.11	0.07	0	0	0	0	0	0
0.34	0.87	0.62	0.54	0.48	0.43	0.34	0.30	0.22	0.19	0.15	0.11	0.07	0	0	0	0	0	0
0.32	0.86	0.63	0.55	0.49	0.45	0.35	0.30	0.22	0.19	0.16	0.12	0.97	0	0	0	0	0	0
0.30	0.85	0.65	0.57	0.51	0.47	0.37	0.32	0.23	0.20	0.16	0.12	0.08	0	0	0	0	0	0
0.28	0.84	0.66	0.58	0.54	0.49	0.39	0.33	0.24	0.21	0.17	0.13	0.08	0	0	0	0	0	0
0.26	0.83	0.68	0.60	0.57	0.51	0.41	0.35	0.26	0.22	0.18	0.14	0.09	0	0	0	0	0	0
0.24	0.82	0.70	0.63	0.60	0.54	0.44	0.37	0.28	0.23	0.20	0.15	0.10	0	0	0	0	0	0
0.22	0.81	0.72	0.66	0.63	0.58	0.47	0.39	0.30	0.25	0.21	0.16	0.11	0	0	0	0	0	0
0.20	0.80	0.74	0.69	0.66	0.61	0.49	0.42	0.32	0.27	0.23	0.18	0.12	0	0	0	0	0	0

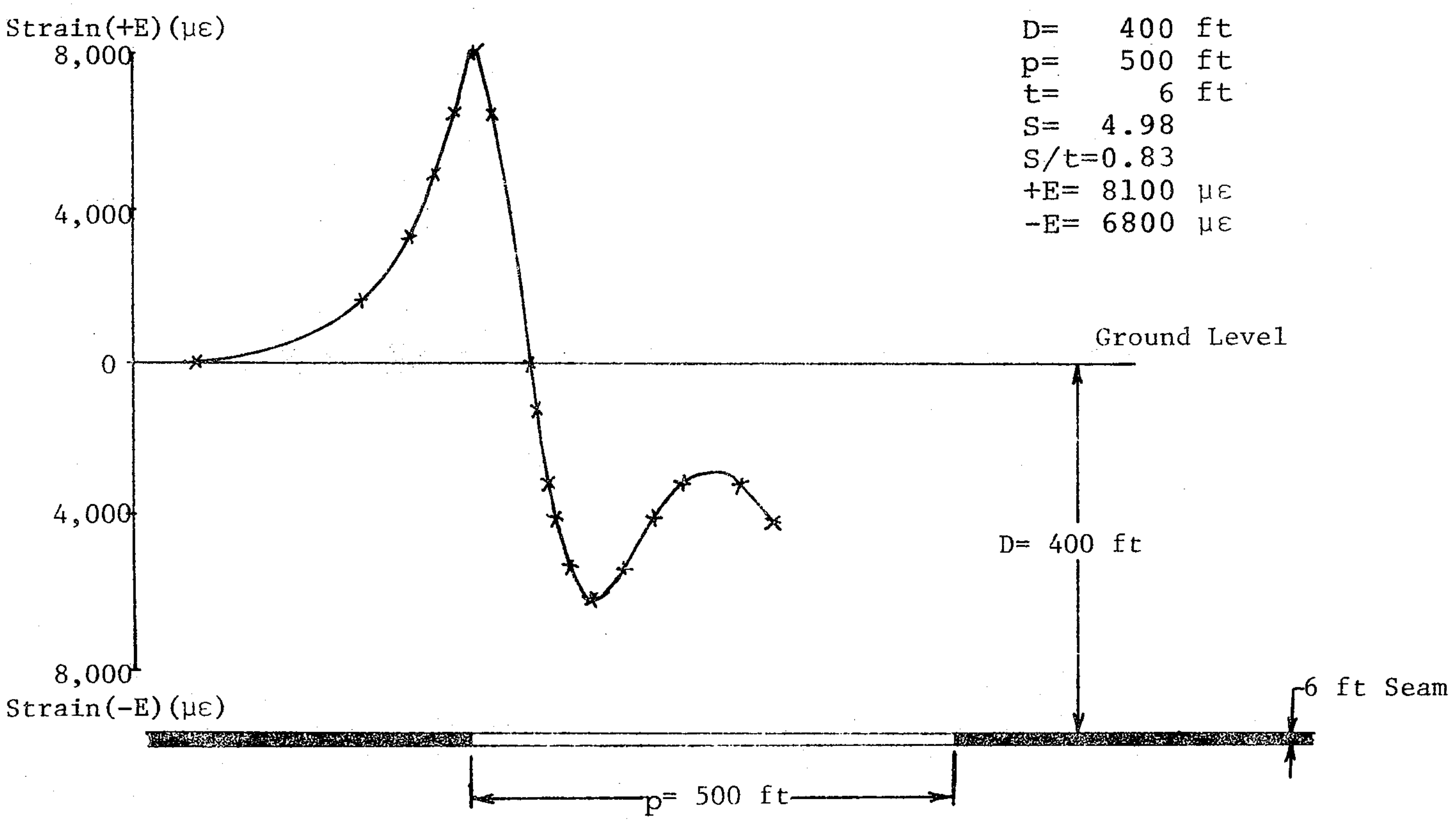


Figure 9- Method of Plotting Predicted Strain Curve

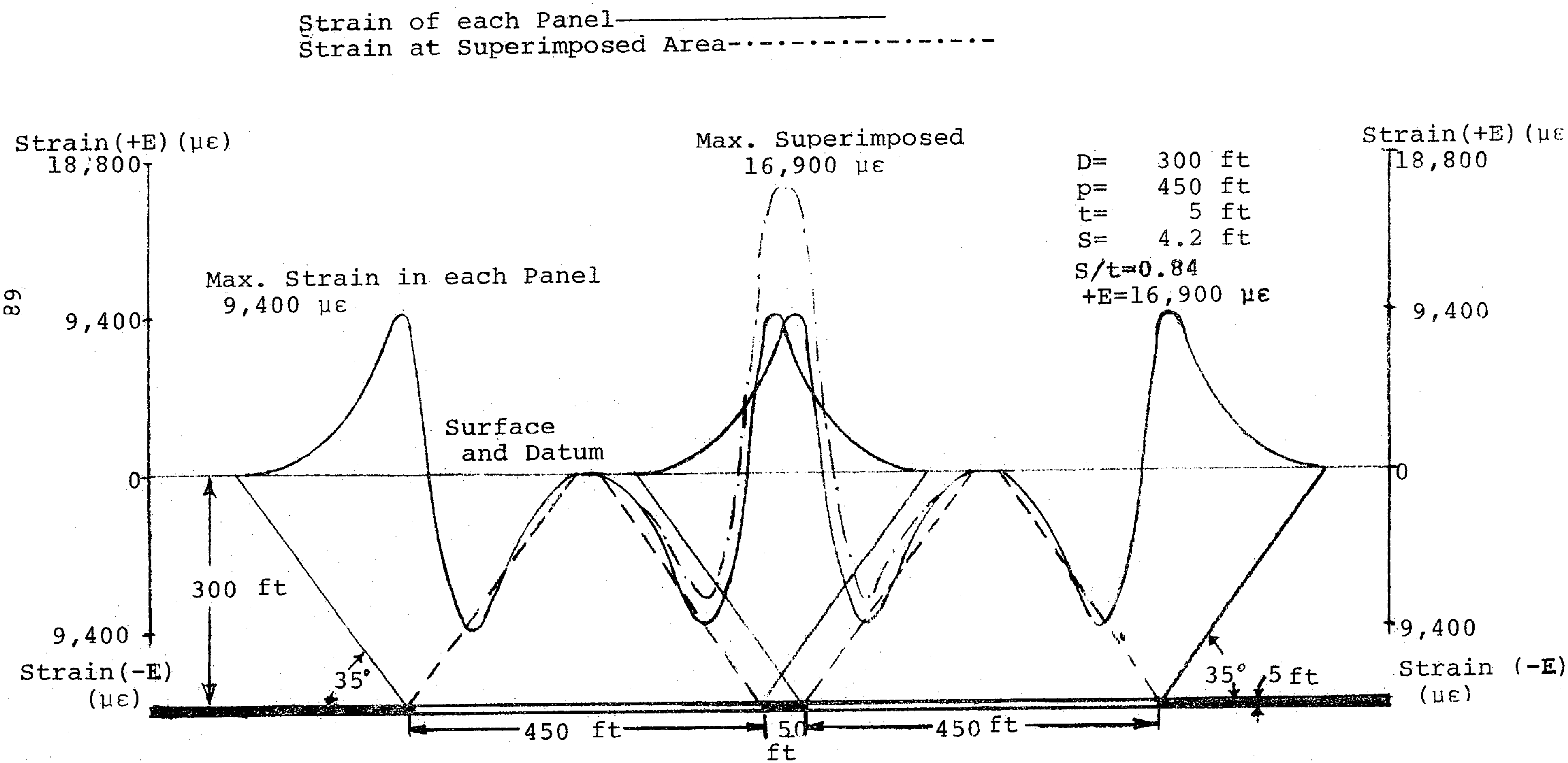


Figure 10- Superimposed Strain Profile of Two Adjacent Panels

3.4 Measurement of Subsidence

According to the guidelines recommended in Bureau of Mines IC 8741 any number of seams may be mined by total extraction provided that the maximum cumulative, calculated tensile strain beneath a body of surface water will nowhere exceed 8,750 $\mu\varepsilon$, when subsidence observations have been carried out and satisfactory calculations of surface tensile strain can be made. It is important that subsidence measurements are carried out with a reasonably high standard of accuracy. Therefore, it is necessary to set up certain minimum standards for setting up survey monuments, including their spacing, the layout of survey lines on the surface, and instruments to be used for measuring distances, angles, and tilt (Panek, 1966, Gentry and Abel, 1977).

3.5 Subsurface Strata Movement Measurements

Subsurface strata movements induced as a result of mining have been measured by instrumenting boreholes drilled from the surface or from below ground. Most measurements made in the United States were of strata separation with respect to the position of the advancing longwall faces. These measurements have provided considerable information on the behavior of the intermediate subsurface strata lying over the caved zone. Some important case studies are discussed below.

At Mine No. 24 of Old Ben Coal Company, a 387 ft long retreating longwall face was worked in Herrin (No. 6) coal bed about 8.5 to 9 ft thick. About 1 to 1.5 ft of coal were left in the floor to avoid exposure of the soft underclay floor. The average thickness of cover above this Panel No 1 was 650 ft. An NX size borehole was drilled from the surface over Panel No. 1 into which a 7/8 inch diameter coaxial cable was grouted. As the longwall face approached the test borehole and passed under it, the damage to the cable was detected by using time domain reflectometry (Wade and Conroy, 1977; Curth, 1978; Curth and Cavinder, 1977). The results of the monitoring are shown in Figures 11 and 12. As shown in Figure 12, the majority of the strata movement was confined to a height of about 175 ft above the coal seam. The subsequent break in the co-axial cable at about 415 ft height above the coal seam was probably on account of bed separation of the subsiding strata. Although these measurements are of

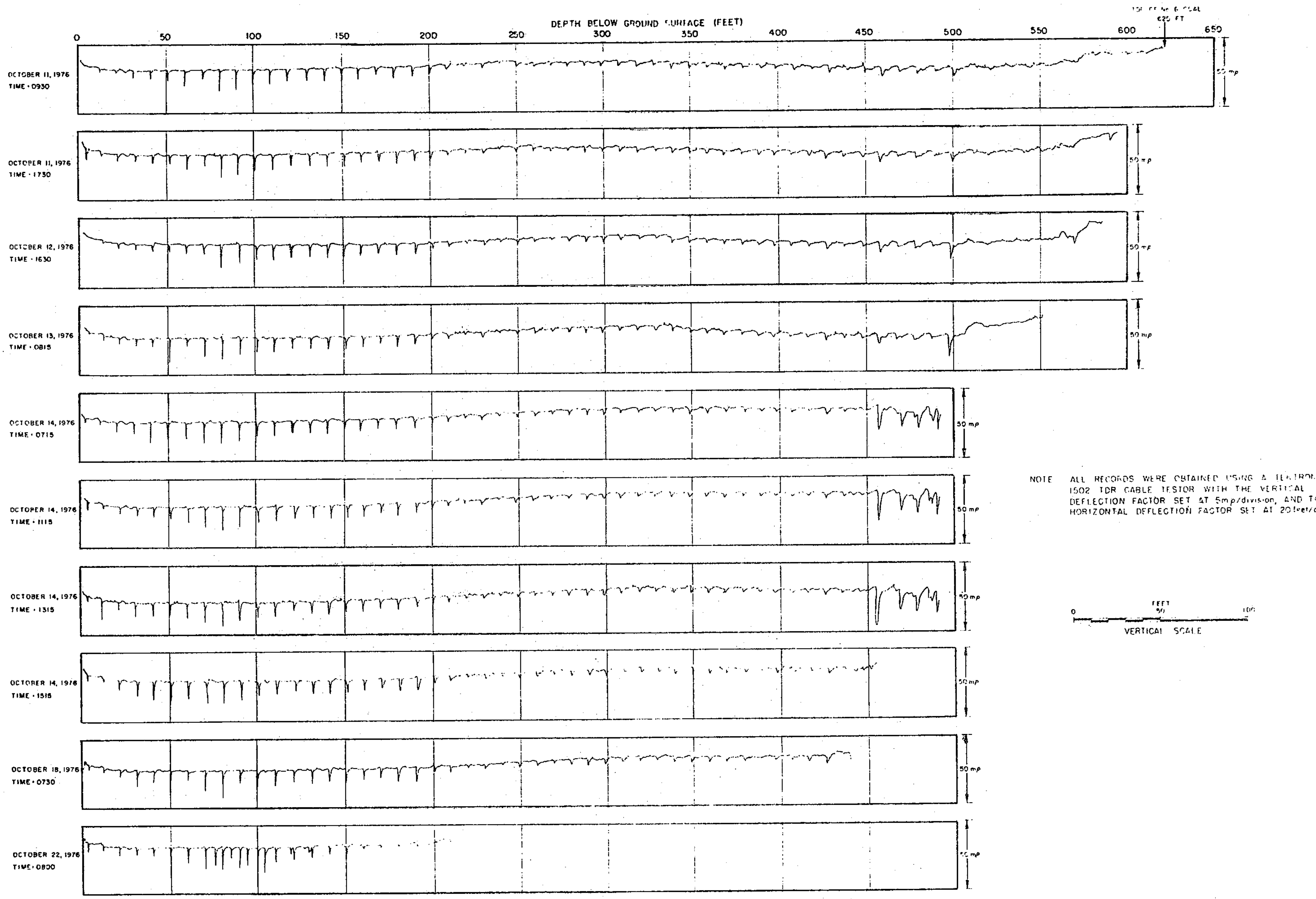


Figure 11- Time Domain Reflectometry Strata Movement Determination at Old Ben Coal Co Mine No. 24 (from Wade and Conroy, 1977)

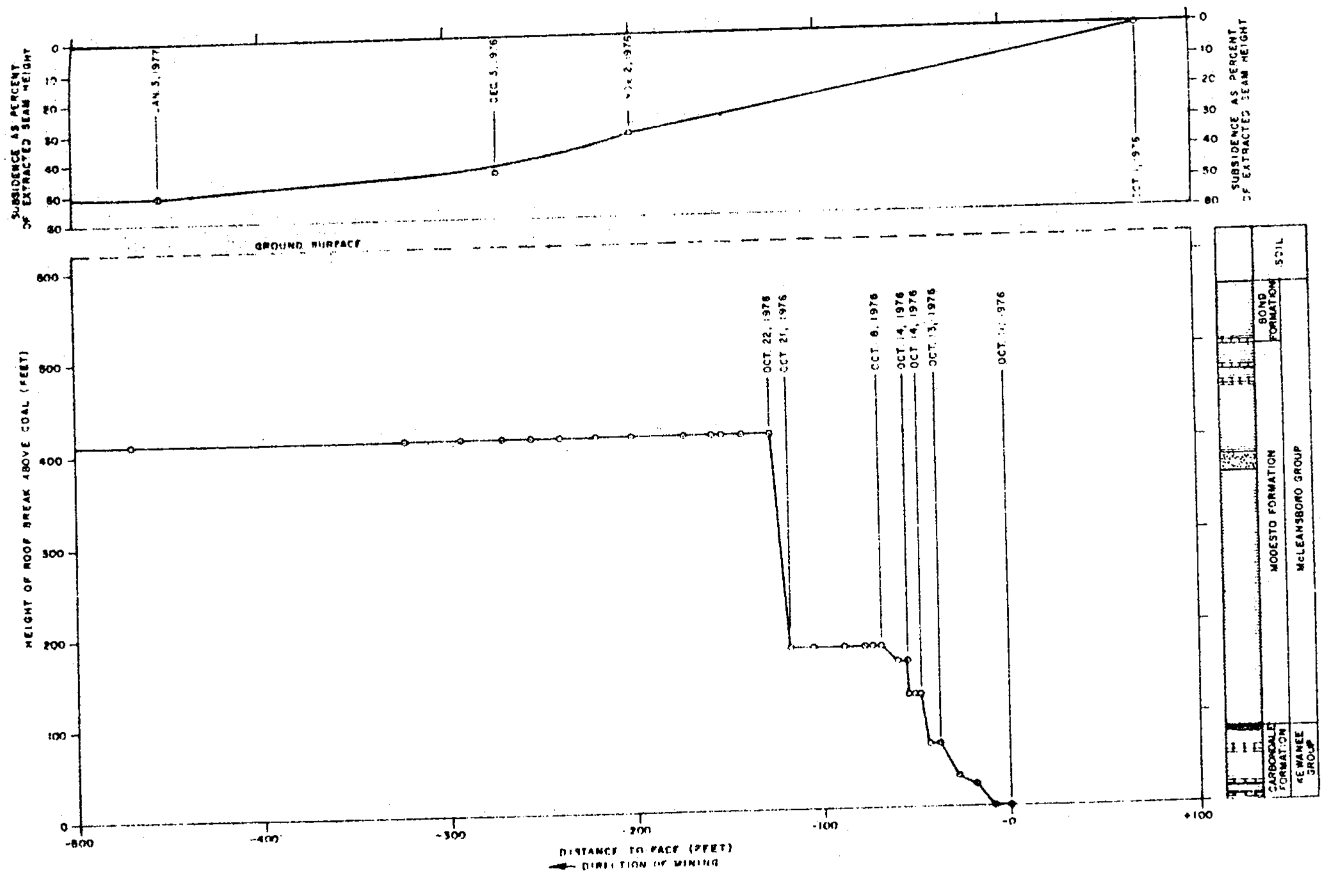


Figure 12 - Results of Time Domain Reflectometry Monitoring Showing Roof Break in Relation to Advance of Face (from Wade and Conroy, 1977)

vertical strata displacement, the study does illustrate that the strata above 175 ft height remained more or less undisturbed except for vertical subsidence and minor bed separation or extension of the strata in the vertical direction.

Time domain reflectometry studies of another test borehole above the adjacent Panel No. 2 at the same mine gave similar results except that the co-axial cable broke at a height of about 90 ft before the longwall face reached a position under the borehole. Strata movements induced ahead of the longwall face are considered responsible. The study does indicate that the major portion of the strata deformation ahead of the face in this case was confined to a height of less than 100 ft about the coal seam.

Strata movements above a longwall face were monitored in the United Kingdom from a roadway driven in the overlying seam above the panel at a parting of 145 ft (King, Whittaker, and Batchelor, 1972; and Whittaker and Pye, 1977). The monitoring of the movements of different strata layers was carried out by determining the movement of anchors fixed in boreholes driven from the roadway in the upper seam under extraction as shown in Figure 13. The displacements of the different anchors at different horizons were measured. It was seen that the relative displacement of the upper most anchor fixed at 140 ft above the seam was 6 inches as compared to the lower most anchor which was fixed at a height of 29 ft above the seam under extraction. The indication is that most of the displacement of the strata is confined to the immediate roof beds.

At York Canyon Mine in New Mexico, three boreholes 4-1/2 inches in diameter in which multiple-position borehole extensometers were installed were placed above a longwall panel. The borehole placed in the center of the panel indicated that the strata above the advancing longwall face was first subjected to large and continuous extension but the observations could not indicate whether this extension was due to bed separation or release of compressive stress (Gentry and Abel, 1977).

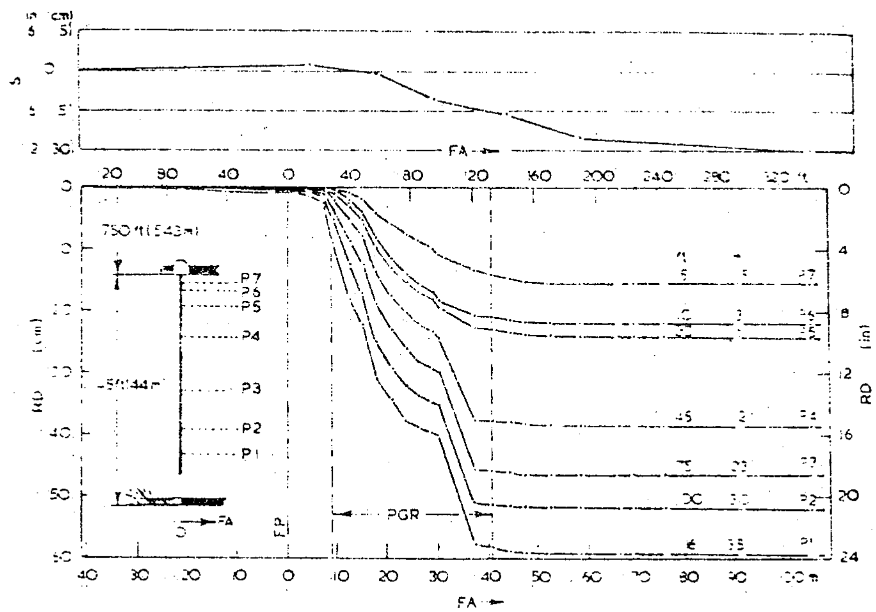


Figure 13- Strata Movement as a Function of Face Location (after Whittaker and Pye, 1975) Used with permission of the American Society of Civil Engineers.

Reference:
Whittaker, B.N. and J.H. Pye. Design and Layout of Longwall Methods of Coal Mining. Design Methods in Rock Mechanics, Proc. 16th Symp. in Rock Mechanics, C. Fairhurst and S.L. Crouch, eds., Am. Soc. Civil Eng., NY, 1977, p.303-314.

At the Shoemaker mine subsurface relative strata movements were measured above a longwall panel using radioactive bullet markers. The results are shown in Figure 14 which also indicates that most of the displacement of the strata, exclusive of subsidence, was confined to a height equal to 35 times the height of extraction above the coal seam. In this case, the longwall face was 450 ft wide and the height of extraction was about 7 ft.

The important findings of time domain reflectometry studies at Old Ben Coal Company Mine No. 24 and radioactive bullet displacement studies at the Shoemaker Mine are given in Table 12. The development of cracks or fissures in different beds of the strata above a coal seam is unlikely without a corresponding measurable relative vertical displacement taking place. It can be concluded from Table 12 that the chances of the strata developing cracks or fissures above 25t to 35t height (where t is the thickness of seam extraction) above the coal bed are small.

3.6 Evidence for Strata Movement Induced Changes in Permeability

It has been observed from methane drainage through boreholes drilled into the strata above mined out areas that little or no gas was produced from boreholes beyond a height of 100 to 150 ft above the extraction area. This implies that the permeability of the overlying strata beyond 100 to 150 ft height (which would represent at the most a height of 30t) was not perceptibly affected.

In New South Wales, Australia, increased permeabilities were measured to a height of 35t above the coal seam in a sequence of shales and sandstones (Williamson, 1978).

In Hungary, the height above the extraction area up to which the permeability of the strata is effected is taken to be 25t (Kesserü, 1977).

In the Soviet Union the height of the disturbed or water-conducting fissure zone above total extraction mining was determined by on-site measurements of water pressure changes in overlying strata and by comparison of specific water infiltrations in strata before and after undermining (Gvirdman et al, 1977).

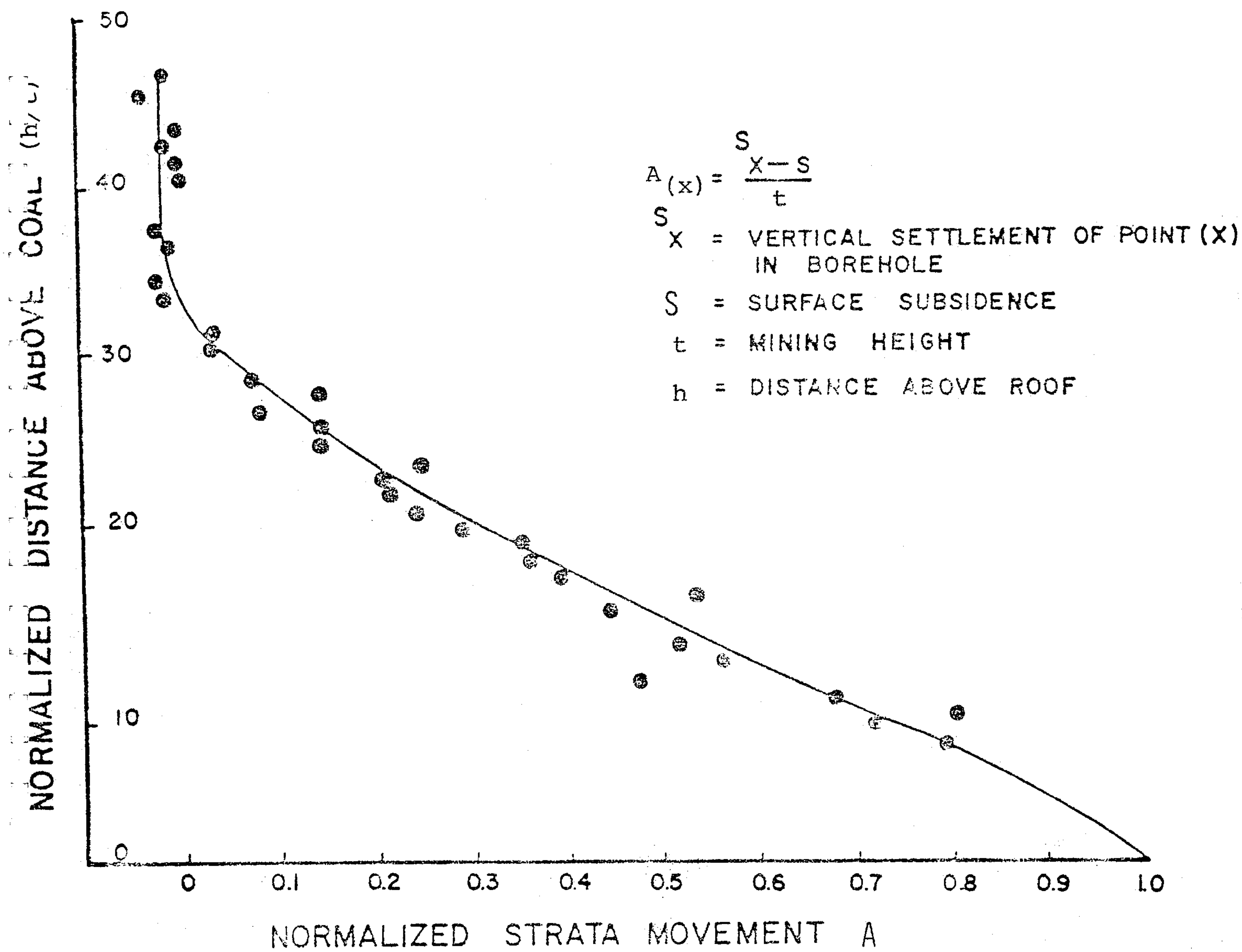


Figure 14- Caving Observation in a Surface Test Borehole Using Radioactive Bullet Markers (after Dahl and von Schonfeldt, 1977). Used with Permission of the Society of Mining Engineers of AIME.

Table 12 - Caving Observations in Strata Above Longwall Panels

Mine	Seam Thickness (ft) (t)	Avg. Depth (D)	Panel Width (W)	Surface Subsidence at Test Hole	D/t	W/D	S/t	Face Adv. Beyond Test Borehole	Height Above Seam of Caved Strata	Remarks
Shoemaker	5.5 (Pittsburgh)	704	450	1.3 (2.4max)	128	0.64	0.44	430	310	*At 200 ft above coal the change was insignificant (less than 0.1 ft) (von Schonfeldt, 1979 and Dahl and von Schonfeldt, 1977)
Shoemaker	5.5 (Pittsburgh)	704	450	0.45 (2.4max)	128	0.64	0.44	90	170	
Old Ben No.24	7 (Herrin)	650	387	4.36 (max)	93	0.60	0.62	65	175	(Wade and Conroy, 1977)
Old Ben No.24	7 (Herrin)	650	387	4.36 (max)	93	0.60	0.62	120	410	The TDR study probably revealed bed separation and not general caving of the strata. The general caving of the strata apparently ceased at 175 ft height above the seam. The relative movement of the strata above this and upto about 410 ft height appears to be insignificant. (Wade and Conroy, 1977)

* A borehole was drilled above the panel 120 ft from the rib and 500 ft from the starting point. The gamma ray survey of the borehole was carried out after the face had passed 90 ft and 430 ft beyond it in order to determine the caving of the intermediate strata.

During total extraction of a coal seam, water-conducting fissures are induced in the strata lying immediately above the seam. These fissures may intersect water bearing strata which then drain or have the pressure reduced. These changes in pressure are observed either with the help of piezometers or during drilling of special monitoring wells. In the former case, a number of boreholes are drilled in the strata to be undermined. Each borehole is connected hydraulically with only one water-bearing horizon, it thus acts as a piezometer. The water level in the piezometer indicates the pressure in the observed water-bearing horizon. The height of the water-conducting fissure zone is determined by observing the water level in the piezometers before, during, and well after they have been undermined.

A large number of boreholes are required for making observations by piezometer method. Alternatively, the height of the water-conducting fissure zone can be determined by observing the pressures in the specified sections during drilling of special hydrogeological boreholes. If hydrogeological data is available from previous observations, only one borehole is required to be drilled over the undermined area. During drilling of this borehole, the pressure is measured in each water-bearing horizon or horizons intersected and having a thickness of 35 to 75 ft and is isolated by packing from the overlying layers of strata. The height of the water-conducting fissure zone is similarly determined as equal to the distance from the roof of the coal seam to the middle of the interval between two neighboring water bearing horizons, in the upper one of which, the natural pressure of the underground water is preserved, while there is a drop in this pressure in the lower horizon.

When the water-conducting fissure zone is higher than the underground water level, it is not possible to use the method of pressure observation to determine its height. In such situations, the method of comparison of specific water infiltrations is used. The method involves drilling two boreholes one above the undermined area and the other over an adjacent undisturbed area. During drilling of these two boreholes, water pressure and specific water infiltrations are determined in each intersected layer or group of layers 35 to 75 ft thick. This is followed by injection of pure water under different pressures to determine specific infiltration of the layer or group of layers. The corresponding increase in water infiltration of the highest layer determines the height of the water-conducting fissure zone.

These on-site determinations were carried out at several mines in the Soviet Union. The results of these studies are given in Table 13. The results are graphically represented in Figure 15. These observations reveal that the height of water-conducting fissures above an extracted area extends from 31 to 62 times the thickness of extraction between 4 and 7 ft, 27 to 37 times the thickness of extraction between 7 and 10 ft, and 22 to 29 times the thickness of extraction between 10 and 12 ft. It indicates that as the thickness of extraction increases, the ratio (h/t) of the height of the water-conducting fissure zone to the height of extraction decreases.

Crane (1927) has noted that when mining bedded iron ore in Alabama using full extraction methods under variable depths of cover, no fracturing of the rock mass extended higher than 400 ft above a 20 ft mined height, for a ratio h/t of 20.

3.7 Method of Work

The nature of strata disturbance and its magnitude depends on the method of work to a large extent. Only those methods of work can be selected for undermining bodies of surface water which will not produce strata disturbance beyond the accepted safe limits. Accordingly, a brief description of each common method and its relevance to the nature and severity of strata disturbance are given below.

3.7.1 Total Extraction Mining

Total extraction coal mining implies excavating a sufficiently large width of a coal seam as in longwall or shortwall mining or extraction of pillars in a room and pillar mining system with essentially concurrent caving of the roof behind the face supports or the line of extraction. The thickness of the coal seam extracted and whether the gob (the void created by the excavation) is stowed or not is not relevant. Also, longwall and shortwall faces of small width flanked with wide barrier pillars in the panel and pillar system of mining are not included in this definition.

Strains in the strata can be reduced considerably by stowing of the voids with a suitable material or materials. The subsidence factor for total extraction without stowing ranges from 0.6 to 0.9. Depending on the compressibility of the stowing material and the manner of stowing, this subsidence factor will be reduced. Values for different stowing methods are as follows:

Table 13 - Results of On-site Determinations of the Height of the Water-Conducting Fissure Zone above the Coal Seam Under Total Extraction (from Gvircman, et al., 1977)

	Mine/Coal Basin	Depth of bed, ft D	Dip angle of bed, degrees	Working thickness of bed, ft t	Thickness of argillite and siltstones, % of the height of the water-conducting fissure zone	Height of the water-conducting fissure zone, ft h	h/t	Method of determining height of water-conducting fissure zone
1	Avangard/Suchan	446	18-25	4.0	20	230	56	Comparison of specific water infiltrations
2	Chertinskaya/ Kuznetsk	328	7	4.5	45	230	50	Comparison of specific water infiltrations
3	Toparskaya/ Karaganda	558	34-43	4.5	70	131	31	Pressure observations during drilling of special boreholes
4	Severnaya/ Suchan	574-656	23	4.5	0	230-262	54-62	Pressure observations during drilling of special boreholes, comparison of specific water infiltration
5	Kirov/Kuznetsk	394	5-6	5.5	67	220	39	Pressure observation during drilling of special boreholes, comparison of specific water infiltrations
6	Pionerka/ Kuznetsk	590	20	6.0	53	243	41	Pressure observations during drilling of special boreholes, comparison of specific water infiltrations
7	Pionerka/ Kuznetsk	689	20	6.0	60	243	41	Pressure observations using piezometers
8	Kapital'naga/ Kuznetsk	1050	8	6.0	20	279	47	Pressure observation using piezometers
9	Severnaya/ Suchan	574-656	23	6.5	0	338	47-51	Pressure observations during drilling of special boreholes, comparison of specific water infiltrations

Table 13 - Results of On-site Determinations of the Height of the Water-Conducting Fissure Zone above the Coal Seam Under Total Extraction (from Gvircman, et al., 1977)

	Mine/Coal Basin	Depth of bed, ft D	Dip angle of bed, degrees	Working thickness of bed, ft t	Thickness of argillite and siltstones, % of the height of the water-conducting fissure zone	Height of the water-conducting fissure zone, ft h	h/t	Method of determining height of water-conducting fissure zone
10	Churubai-Nurinskaya/ Karaganda	722	13-20	6.5	70	230	35	Pressure observations during drilling of special boreholes
11	Kupustin/Donets	705	12-14	8.0	67	302	37	Pressure observations during drilling of special boreholes
12	Stepnaya/ Karaganda	420	5-20	9.5	64	335	35	Pressure observations during drilling of special boreholes
13	Stepnaya/ Karaganda	420	5-20	9.5	64	302	32	Pressure observations during drilling of special boreholes
14	Spepnaya/ Karaganda	528	5-20	9.5	93	253	27	Pressure observations during drilling of special boreholes
15	Kol'chutinskaga/ Kuznetsk	590	6-7	10.0	70	164	17	Pressure observations during drilling of special boreholes, comparison of specific water infiltrations
16	Stepnaya/ Karaganda	476	5-20	12	60	256	22	Pressure observations during drilling of special boreholes
17	Stepnaya/ Karaganda	476	5-20	12	60	328	29	Pressure observations during drilling of special boreholes

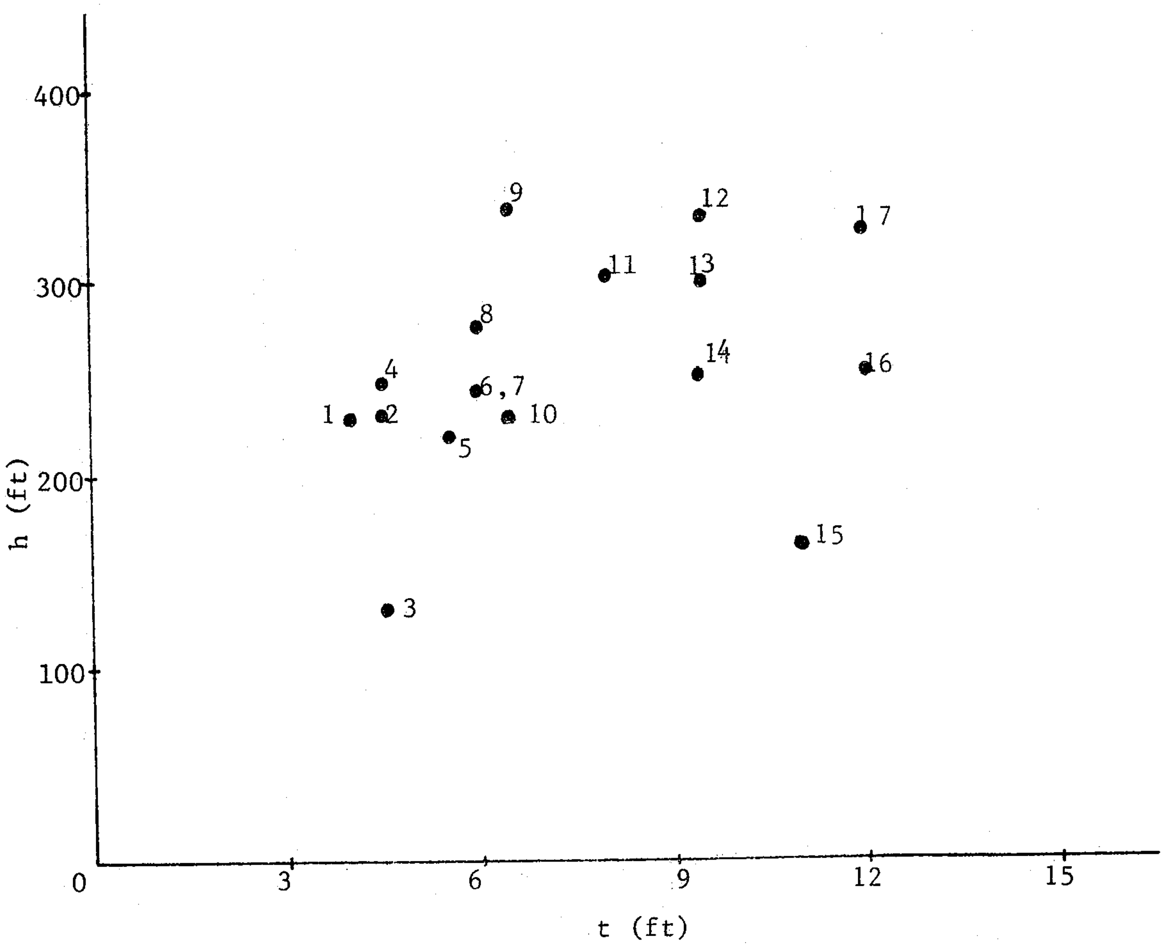


Figure 15- Height of Water-Conducting Fissures Above Mined Out Areas. Numbers are Keyed to Mines in Table 13 (after Gvircman et al, 1977).

Method	Subsidence Factor
Without Stowing	0.6 to 0.9
Strip Packing	0.6 to 0.9
Pneumatic, slusher and manual	0.3 to 0.7
Hydraulic	0.1 to 0.3

This implies that with stowing of the gob, total extraction below bodies of surface water can be resorted to at shallower cover.

Observations in the United States have revealed that with extraction of pillars, subsidence development over room and pillar panels is similar to that over longwall panels (Dahl and Choi, 1973, 1974). Thus, subsidence development can be fairly well predicted on the basis of an average extraction thickness calculated from extraction ratios.

3.7.2 Partial Extraction Mining

A partial extraction system is one in which pillars are deliberately left behind to serve as permanent support for the overlying strata and the land surface. Two such systems are the room and pillar first working and the panel and pillar system.

3.7.2.1 Room and Pillar Method of Partial Extraction

In this system two sets of parallel entries usually at right angles to each other are driven in a seam leaving nearly square coal pillars to support the roof strata. If pillars are to provide permanent support to the strata, they will have to be designed adequately which will depend primarily on the depth of the seam, height of extraction, width of the entries and the nature of overlying strata. The nature of strata should be carefully examined and suitable means adopted in the design of the workings in order to prevent the formation of sinkholes. A system adopted by the National Coal Board to determine the required minimum size of coal pillars considered adequate for long term stability is given in Figure 16 and is applicable for depths down to 1500 ft. This system is based on the following empirical relation (Wilson and Ashwin, 1972):

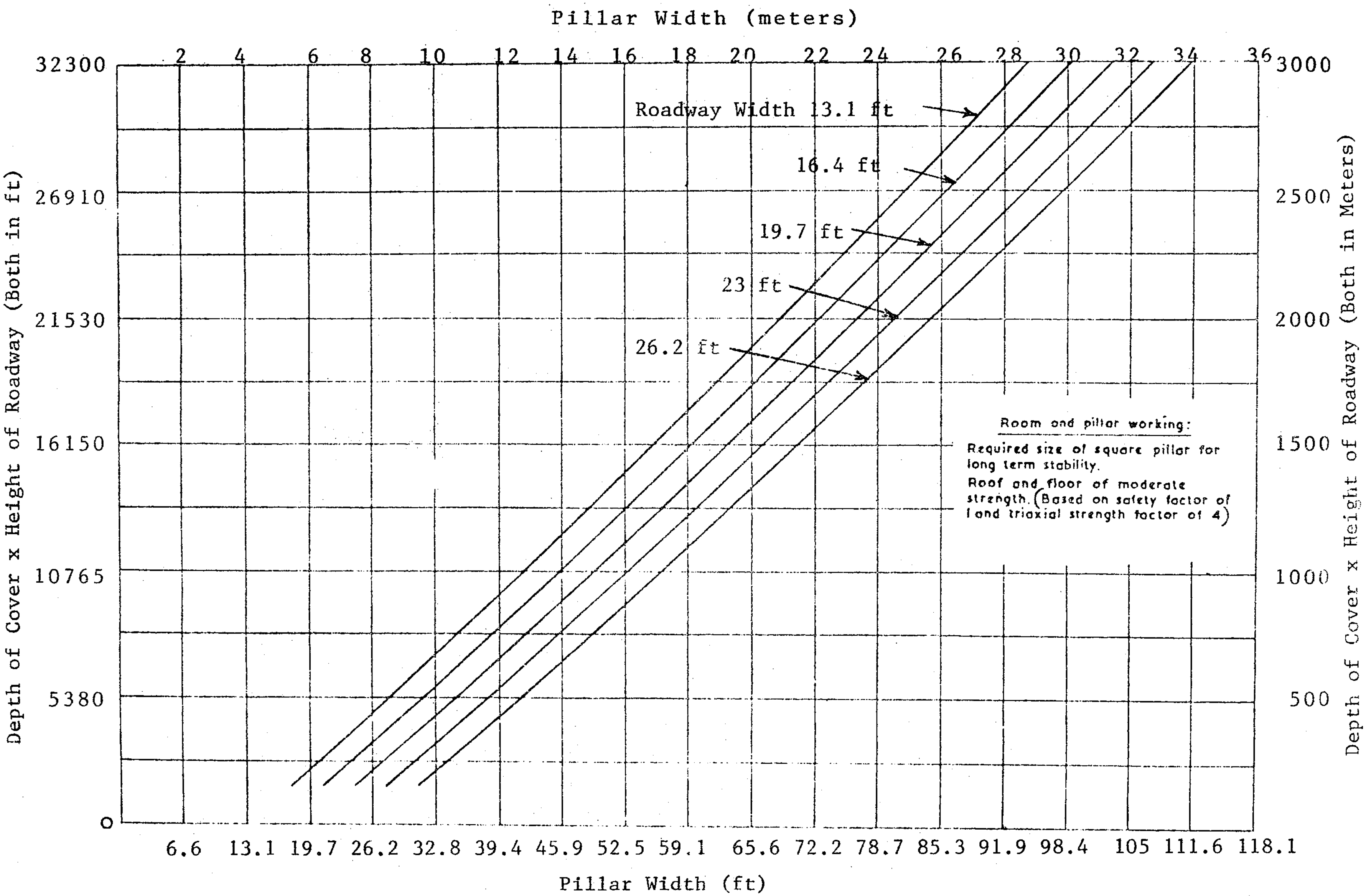


Figure 16- Pillar Sizes in Room and Pillar Working (after Wilson and Ashwin, 1972). Used with permission of the Society of Mining Engineers of AIME.

$$W = [s/3+(2tDx10^{-3})]+ [s/3(2tDx10^{-3})]^2+(s^2/3)-(4t^2D^2x10^{-6}) \text{ ft}$$

where W = width of pillar
s = width of the entry
t = height of extraction
D = depth of cover

This relation is based on the following observations:

(a) a stable pillar consists of a non-yielding core surrounded by a yielding marginal zone equal in width to 0.005td,

(b) because of the lateral constraint afforded by the yielding zone the core of the pillar may be loaded up to 4 times the cover load,

(c) the stress in a pillar increases from 0 at the pillar edge to the cover load at a distance equal to the width of the yield zone.

It should be mentioned that larger pillars result at shallower depths with this method then result from other methods which would be of benefit when mining beneath surface waters; however, the empirical method for pillar design by Wardell (1976), has seen more general use and may be stated as:

$$[(W+s)/W]^2 \; 1.5D=1000/ \; t+20(W/t)^2$$

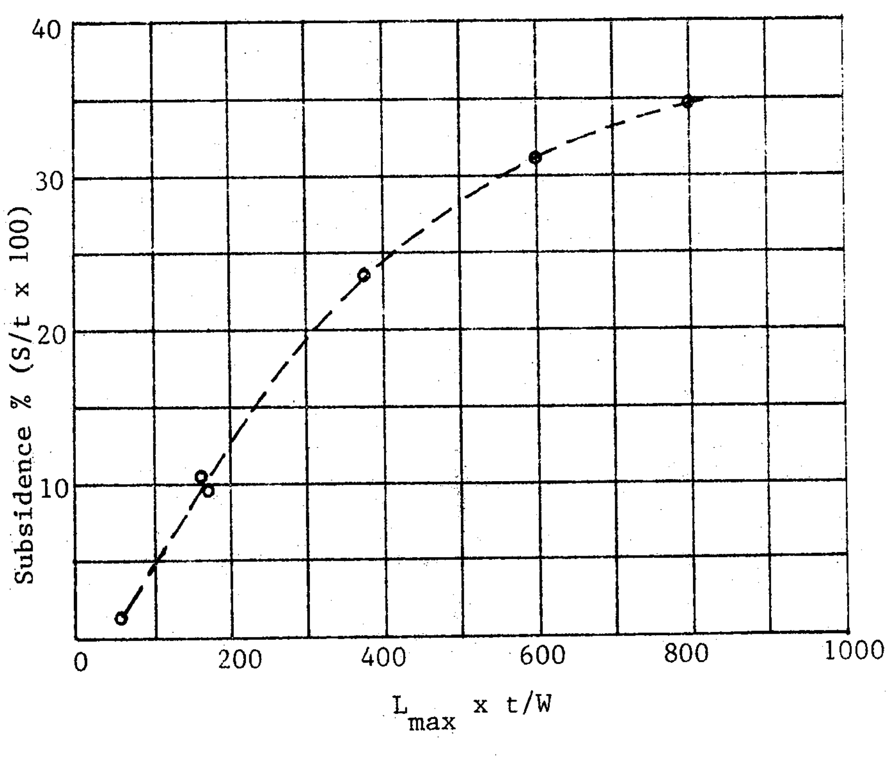
where W, s, t, and D are pillar width, room width, seam thickness, and depth from surface respectively. Until such time as a more generally accepted pillar design criteria is developed, and the Bureau of Mines is actively working toward this end, the above equation (Wardell, 1976) is recommended for use in this present work.

Rock movements outgoing from the individual excavations in the room and pillar system of mining are usually superimposed to give a uniform overall surface subsidence trough free from any undulations except when the cover is shallow. As reported from several European countries, the surface subsidence ranged from 3% to 20% of the seam thickness for an extraction range of 30% to 70% (Brauner, 1973). Analyses of some of the case histories are given in Figure 17 (Wardell, 1969). It may be mentioned that the subsidence factor can be reduced to less than 3% by leaving the pillars unworked and stowing the entries hydraulically.

From the foregoing it will be seen that the design of room and pillar systems for working below bodies of surface water should incorporate the following considerations:

- the suggested minimum strata cover should take only solid rock into account.
- the strata should be properly analyzed and adequate precautions taken to safeguard against any sinkholes that may develop at a later date.

Example	D Depth (ft)	t Seam Thick- (ft)	W Pillar Width (ft)	t/W	s Room Width (ft)	Ex Extrac- tion Ratio	S Subsid- ence (ft)
1	480 to 800	4.50	30	0.150	9	0.41	0.473
2	260	4.25	10	0.425	10	0.70	0.987
3	500	8.00	16	0.500	24	0.69	2.784
4	870	7.00	50	0.140	10	0.31	0.672
5	330	4.25	44	0.097	16	0.46	0.095



Note: $L_{max} = \frac{D}{1 - Ex}$ p.s.i.

All examples were of mined areas with plan dimensions greater than D x D

Figure 17- Percent Subsidence Against Maximum Theoretical Pillar Loading x tW (from Wardell, 1969). Used with permission of the American Mining Congress.

3.7.2.2 Panel and Pillar Method of Partial Extraction

In this method, the workings are laid out in such a manner that substantial pillars are left between panels. The panels may be extracted by longwall or shortwall method or they may be first developed by room and pillar method and subsequently the pillars may be extracted totally by conventional method. The designed width of the barrier pillar is much wider than the minimum required for stability so that no additional subsidence from pillar failure need be allowed for and the law of superposition can be applied. It has been observed that depth (D) as well as the p/D ratio (p is width of the panel) affected the subsidence. More subsidence occurs over a deeper panel than over a shallow panel of the same p/D ratio (Orchard and Allen, 1970). For example, subsidence is 5% at 500 ft depth while it is 18% at 1800 ft depth for a p/D ratio of 0.25 according to the British experience. A much higher percentage of recovery is possible by this method as compared to the room and pillar method for partial extraction. A graph prepared by the British Coal Board is given in Figure 18 which gives the superimposed subsidence percentage for a series of panels for width/depth ratio between 0.25 and 0.33 at different width/depth ratios.

The panel and pillar method is useful for maximizing recovery and at the same time keeping the horizontal strains induced in the strata within permissible limits. It has been used in Europe for working under towns, under the ocean, to avoid drainage problems on the surface, or to avoid adverse public opinion. The method generally yields higher recovery with multiple seam mining as compared to the room and pillar method. In multiple seam mining, best results are obtained by superimposing panels and pillars in all seams in the vertical direction. In this case, the panel width should be determined from the depth to the uppermost seam and the pillar width with respect to the depth of the deepest seam (Orchard and Allen, 1970).

Several alternative layouts have been tried which deviate from the principle of superincumbent verticality of the panels and pillars. They aim either to neutralize induced strain or to minimize it, and the technique is generally referred to as "harmonic extraction" (Lehmann, 1938; Grond, 1957). This technique, in its elementary form, involves extraction of two or more panels simultaneously in one or

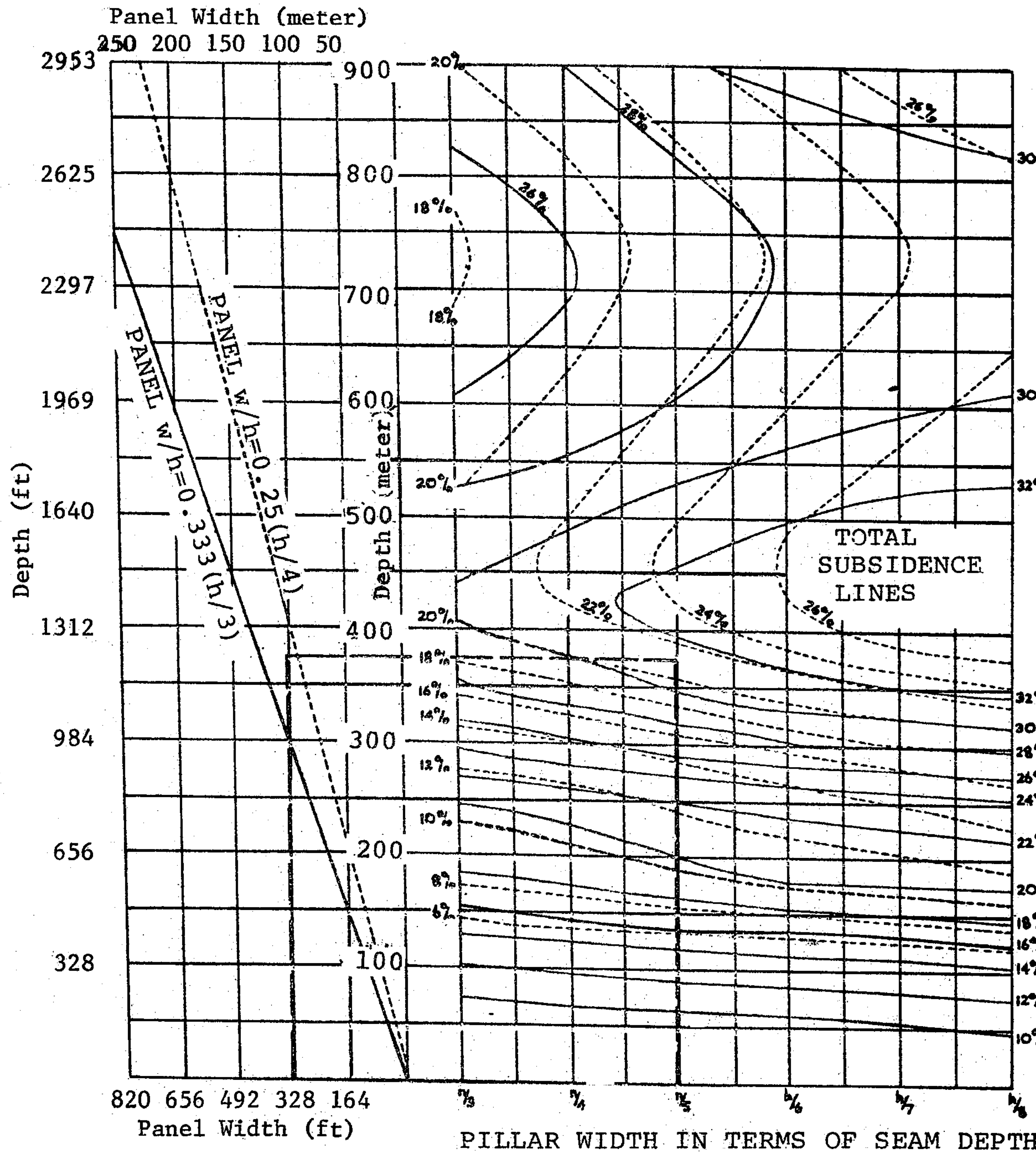


Figure 18 - Partial Extraction Layout Nomogram for Width/Depth Ratio of 0.25 to 0.33 (from National Coal Board, 1975). Reproduced with permission from National Coal Board Subsidence Engineers Handbook (revised edition, 1975).

more seams so that the tensile strain induced by one panel is neutralized wholly or partially by the compressive strain induced by the other panel or panels. The success of this procedure depends on coordination of the face advance in the different panels and as such it is fraught with danger However, it may be adopted for working under small bodies of water after incorporating suitable precautions in the mine plan. In any event, the tensional strain induced at any point on the surface should not exceed the specified safe limits, established for working below bodies of surface water.

3.7.2.3 Rapid Undermining

When a line of extraction or a longwall face advances at a fast rate, the traveling tensional strain is smaller than the maximum static strain as shown in Figure 19. Advantage can be taken of this phenomenon for undermining small sized bodies of surface water. It will essentially involve extracting a supercritical area at a relatively fast speed when the face position is unfavorable with respect to the water body. In this manner, the magnitude of the tensional strain may possibly be kept within safe limits in marginal cases. For example, the value of E_t in Figure 19 must be within safe limits irrespective of the magnitude of E_{max} in this particular case. This method is of some use only for small water bodies to afford an opportunity for planning the mine workings in such a manner that, in the event of the face stopping or slowing down at an unfavorable position, necessary precautions can be taken to guard against an inflow of water.

3.8 Sinkhole Phenomena

Surface damage in northern Pennsylvania is often a result of collapse of the strata overlying old workings at shallow depth (GAI, 1976). The damage shows up in the form of sinkholes, which are also called "crownholes" or "chimneys" in Britain. They are generally less than 15 ft in diameter and 3 to 4 ft deep, but some of them are up to 45 ft deep giving the appearance of a pipe. Therefore, this phenomena is also called "piping."

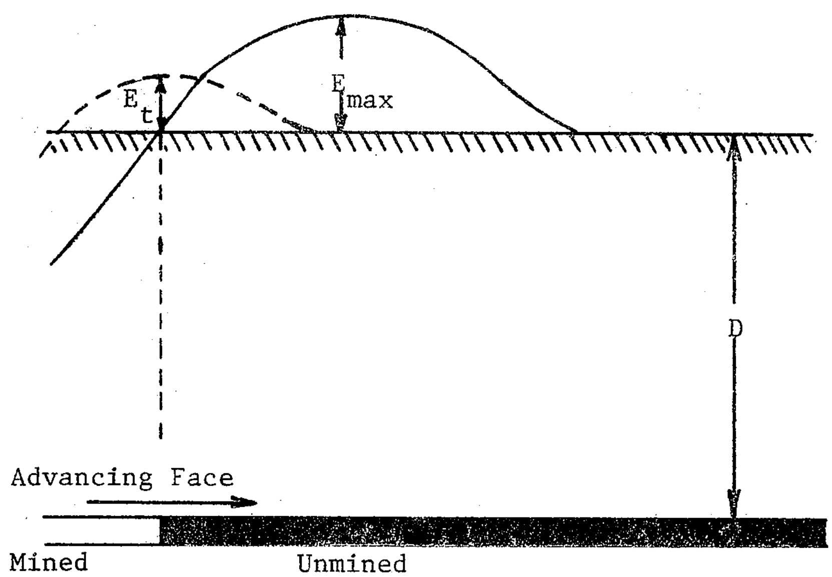


Figure 19- Traveling and Final Surface Strain
(after Brauner, 1973)

The Pittsburgh seam has been mined for over 100 years in Pennsylvania. Most of the mining was conducted at shallow cover by the room and pillar method. Percentage of extraction varied very widely, as reflected in the size of pillars and width of rooms. Over the years, several instances of sinkhole type collapses took place. Most of them went unnoticed except when they caused damage to surface structures. Recently, public opinion has grown stronger, and demands for compensation for damages due to mining subsidences resulted in several studies of the phenomena being undertaken. Consequently, a large number of sinkholes in Pennsylvania have been documented along with their size, depth, the method of mining, including percentages of extraction, and the thickness of cover wherever this information was available.

3.8.1 Sinkhole Geometry

In partial extraction systems, the strata overlying the mine roadways are supported by the pillars and temporary supports erected at the time of mining. With the passage of time, the bedded and jointed strata forming the roof collapses into the workings due to creep and weathering action. Depending on the nature of strata, this process continues unless arrested by the presence of a competent rock bed. In the absence of a competent rock bed, the deterioration process continues till the void is filled with broken rock. Further collapse is arrested at this stage as the broken rock starts providing support to the overlying strata. The phenomena is illustrated in Figure 20.

For a given width of the mine opening (s), the height of the collapse is a function of the original height of the mine opening and the bulking factor of the overlying strata for different geometric shapes of the collapse.

Mining experience suggests that the maximum height of collapse may reach up to ten times the height of the original roadway, but much more frequently, it is limited to 3 to 5 times the roadway height. Of course, there are several notable exceptions. Field measurements for the bulking factor for typical coal measure rocks range from 30% to 50%. Thus, for the different geometrical forms of collapse, the maximum height could be as follows:

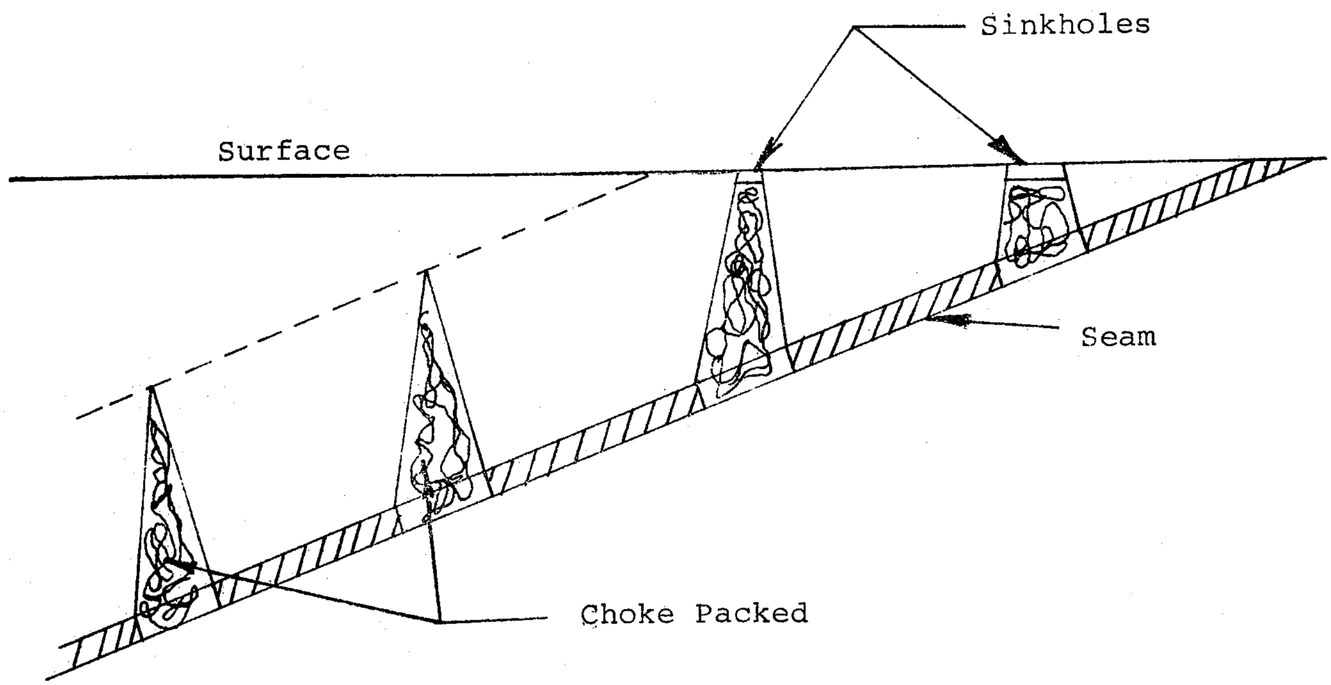


Figure 20 - Sinkhole Phenomena

Conical-type collapse	6t to 10t
Wedge-type collapse	4t to 6.7t
Rectangular-type collapse	2t to 3.3t

These are illustrated in Figure 21.

3.8.2 Overburden Thickness Relationship

It will be seen from the histograms presented in (Figures 22 and 23) that nearly 81% of the documented cases of sinkholes in Pennsylvania took place at a cover of less than 100 ft. The maximum depth of cover at the site of a sinkhole recorded in Illinois is on the order of 160 ft. Crane (1927) observed that sinkholes did not occur beyond a depth of about 140 ft when mining a 20 ft thick bedded iron ore foundation in Alabama, for a height of collapse of 7t.

3.8.3 Dimensions of Sinkholes

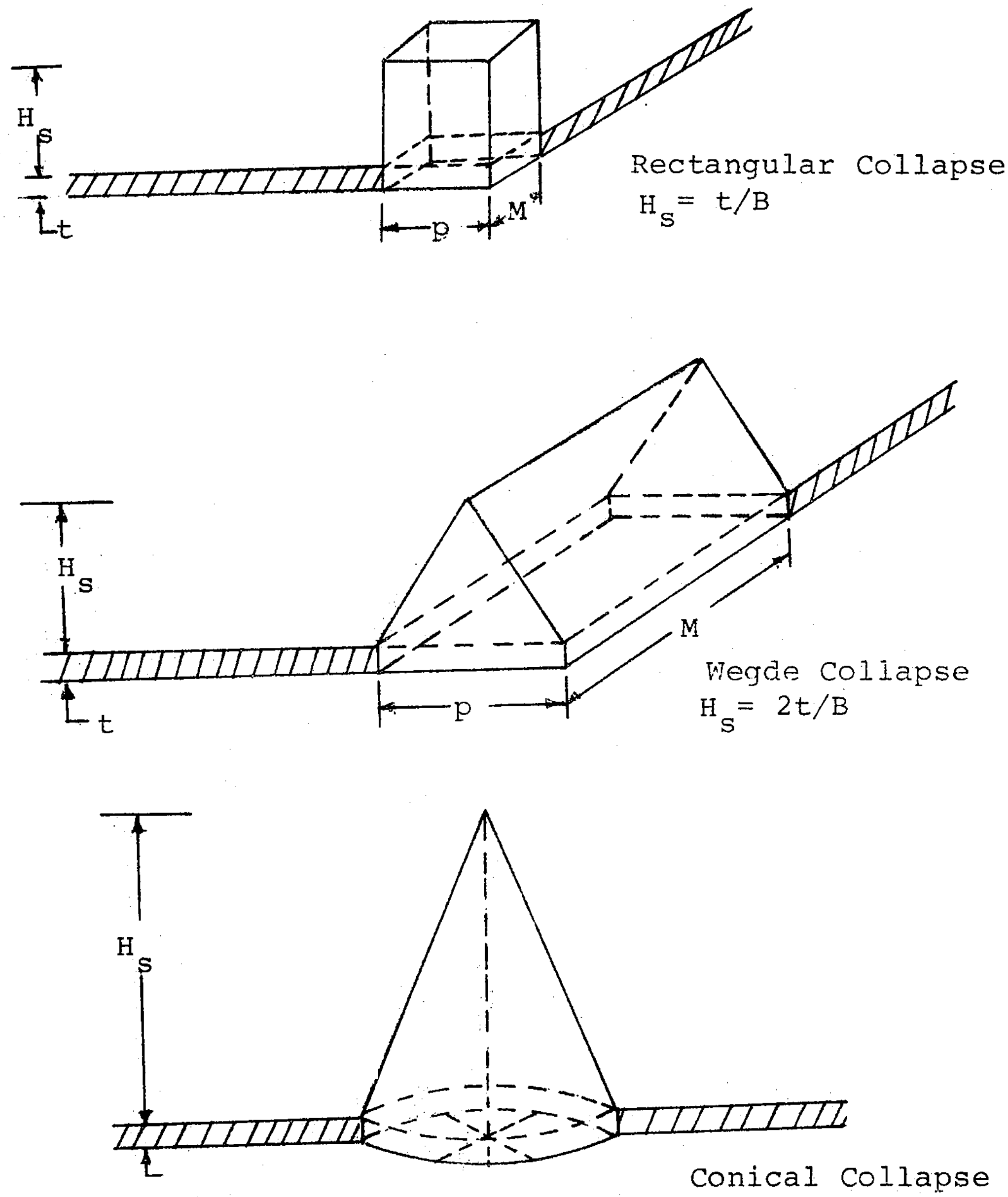
Over 84% of the sinkholes recorded in Pennsylvania are less than 15 ft in diameter. Their diameter varies from a few feet to up to 45 ft. Appoximately 89% of the recorded cases have less than 25 ft depth.

3.8.4 Time and Frequency

More than 50% of the incidents noted in Pennsylvania occurred 50 or more years after the completion of the mining operations. A few of the incidents took place even after 100 years and others happened soon after the mining operations.

3.8.5 Nature of Strata

The time factor, and also whether a sinkhole will occur or not, depends largely on the nature of the overlying strata. The sinkhole phenomena is generally associated with partially extracted seams by the room and pillar method. In the absence of a competent bed of sufficient thickness which will bridge over the rooms and resist deterioration, the roof strata will lose its strength and collapse into the workings. The process continues until either the void is filled or a more competent bed is exposed. In the latter event, the deterioration process is slowed down and it may take years before this bed finally collapses. It explains the reasons for extremely variable time periods taken by different incidents. Several strata sections above the



$B = (U_c - U_o)/U_o$

where

U_c = Total volume of the void
U_o = Insitu volume of the collapsed roof
B = Bulking Factor

Figure 21 - Maximum Collapse Height for Different Geometrical Forms

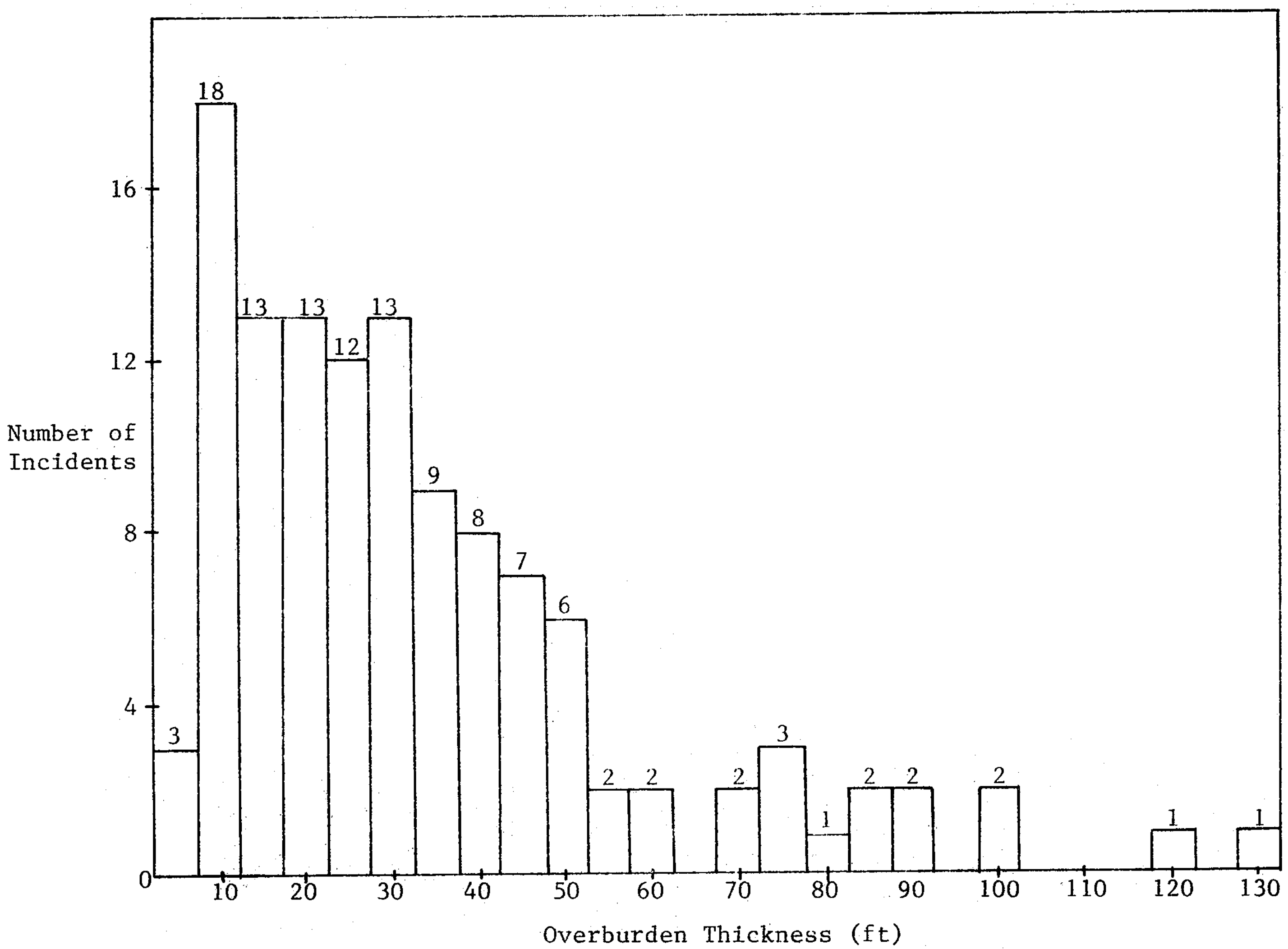


Figure 22- Histogram Showing Incidents of Sinkholes in Relation to Depth of Cover (after GAI, 1977)

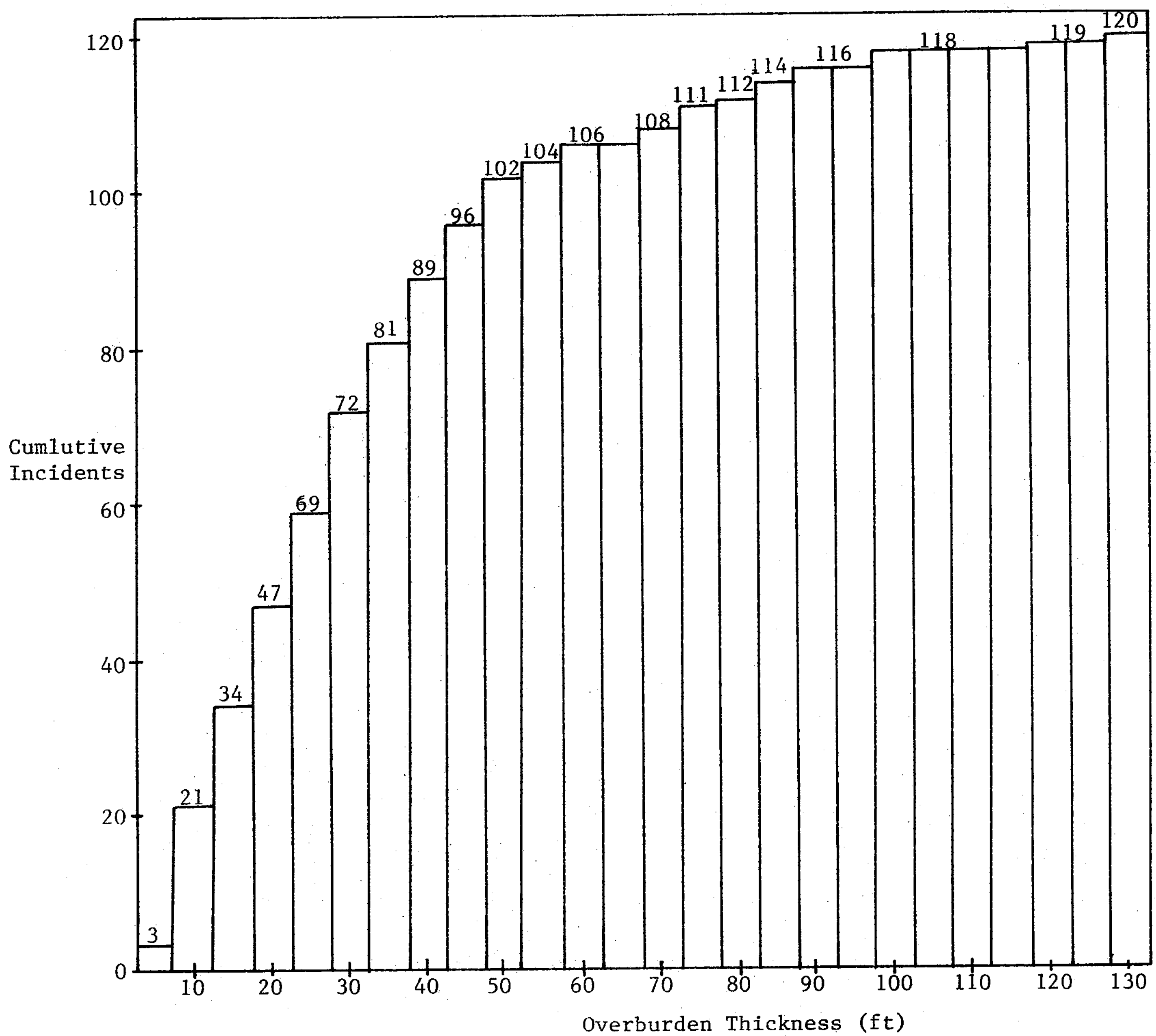


Figure 23- Histogram Showing Cumulative Incidents of Sinkholes in Relation to Depth of Cover

Pittsburgh seam taken in Allegheny County, Pennsylvania, are shown in Figure 24. They show absence of sufficient thickness of hard sandstone beds competent enough to resist weathering for a long period. However, limestone beds are present which can resist weathering for a long period. The presence of these beds of different thicknesses explains why it takes sometimes over 100 years before a sinkhole shows up on the surface.

3.8.6 Relevance of the Phenomena of Sinkholes

A sinkhole is a circular or eliptical type surface subsidence which is usually associated with partial extraction of seams by room and pillar method at shallow cover. It gives rise to a circular crack which may be several inches wide. It is obvious that a sinkhole developing under the surface body of water could provide a direct pathway for the water. Moreover, even if the pillars are relatively stable, the surface can be affected by sinkholes at shallow depth. Therefore, it is essential to take proper precautions such as limiting the width of the entries while working by room and pillar method below bodies of surface water especially when the depth of cover is less than 100 ft. It may be noted that these precautions are necessary if a sufficiently thick competent bed like hard sandstone is absent in the superincumbent strata.

Sinkholes resulting from the collapse of immediately overlying strata in coal mining are similar to the chimneys created by the underground detonation of nuclear devices. Since nuclear devices have primarily been detonated in rocks that are not coal measures, any similarity would indicate the wide application of the phenomena. Figure 25 illustrates nuclear explosion produced chimney geometry. It has been found that height of collapse varies from 2.2 times the cavity diameter in granite, to 2.7 times in tuff, to more than 5 times in alluvium (Boardman, Rabb and McArthur, 1964), indicating that less competent materials that flow rather than bulk form taller chimneys or sinkholes. These figures agree well with the maximum sinkhole heights computed earlier, realizing that the coal mine openings are low and wide.

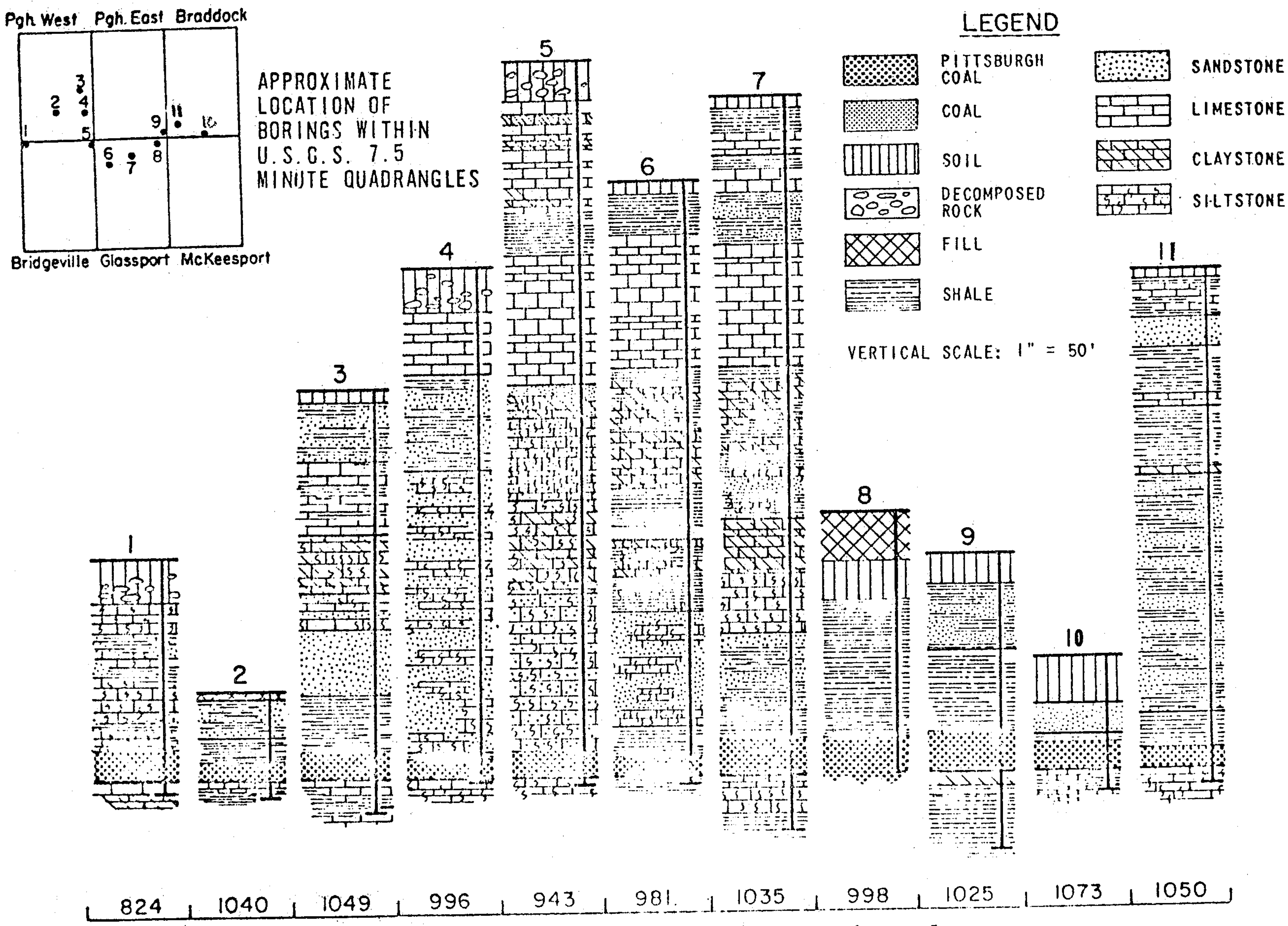


Figure 24 - Selected Geologic Logs, Allegheny Co., Pa. (after GAI, 1977)

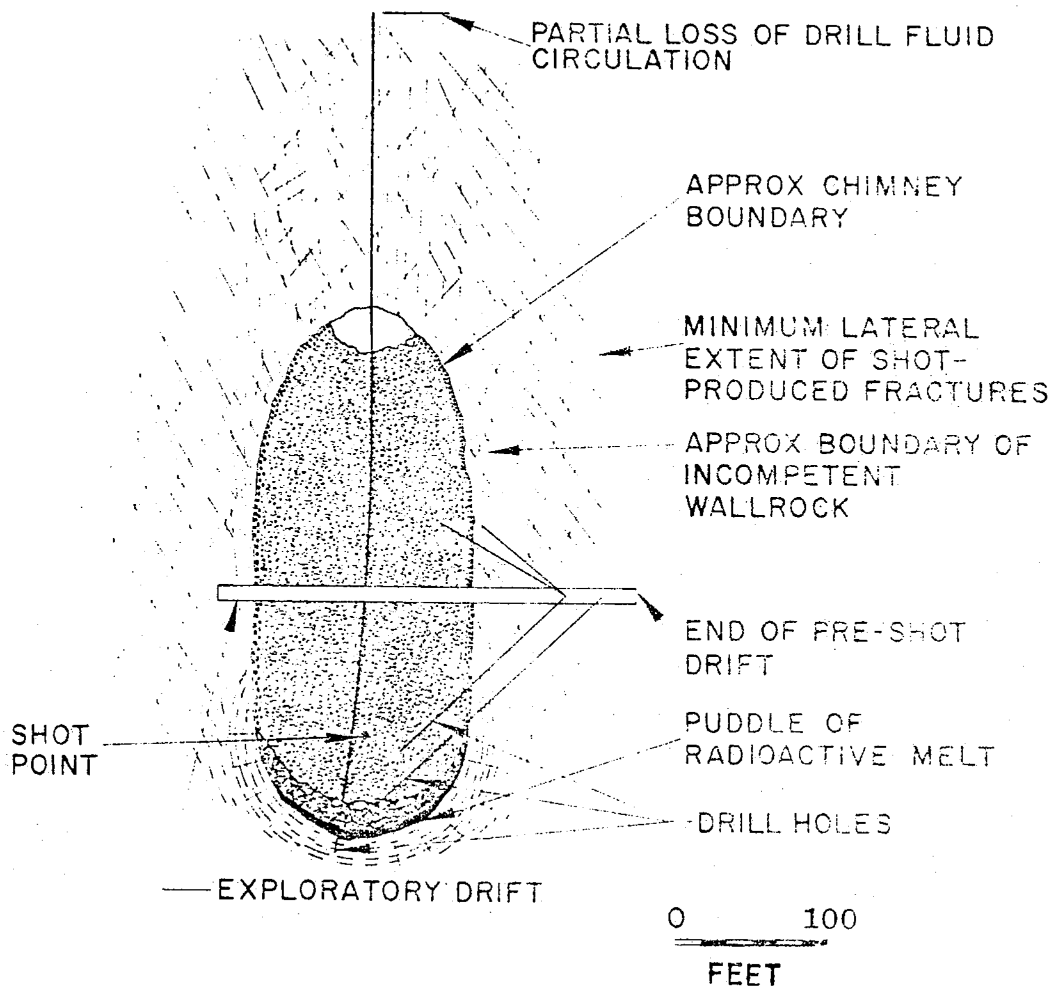


Figure 25 - Typical Chimney Produced by an Underground Nuclear Detonation. (after Boardman, Rabb and McArthur, 1964)

4.0 JOINTS AND CRACKS IN COAL MEASURE STRATA

Coal measure strata, besides being bedded, have joints whose spacing and orientation vary depending on the type of rock, thickness of individual beds, geological age, depth and various geological stresses to which they have been subjected during deposition and subsequently. Joints can be defined as surfaces across which rock has lost cohesion without displacement. Jointing systems are mainly characteristic of the brittle or nearly brittle rocks. They are generally not associated with ductile or plastic materials. Joints are universally present and have a highly variable geometry and spatial distribution. Few new cracks are formed by mining disturbances in coal mining and most subsidence is accomplished by movements along pre-existing joints and cracks.

4.1 Types of Joints

Sedimentary rocks have generally 2 or 3 sets of joints which may be classified into the following four categories:

1. Systematic Joints - which intersect other joints and bedding surfaces.

2. Non-systematic Joints - which terminate at other joints and bedding surfaces, and may be strongly curved in plan.

3. Cross Joints - which are a special type of non-systematic joints in plan.

4. Bedding Joints - which are parallel to the bedding surfaces and may be continuous or discontinuous.

Some of the common characteristics of joints in sedimentary rocks are as follows:

- spacing often depends on lithology and the thickness of the bed. Denser rocks have wider spacing. Spacing also increases with depth of the bed and ranges from a few inches to several hundred feet. However, 1 to 10 ft spacing is common in coal measures strata

- in alternating sandstone - shale sequences, joints are generally better developed in the sandstone and may be confined to it

- in limestones, joints are generally widely spaced

- joints in shales are inconspicuous unless composition make them rigid. However, shales may develop closely spaced joints near the surface

- a minimum 35-micron opening is needed to transmit water

- joints may be smooth, rough, filled, "healed", or open. Openings tend to close with great depth due to weight of the superincumbent strata, or high horizontal stresses

- joint openings may have rough, interlocking, or polished (slickensided) surfaces or they may be coated with thin films of clay

As a result of total extraction of coal either by the room and pillar method or the longwall method, the immediate strata above the extracted area caves into the void. This induces disturbance in the strata within the zone of influence of the extracted area. The disturbance on the surface manifests itself as mining subsidence and surface cracks depending on the depth to seam thickness ratio besides other factors. As regards subsurface disturbance, it is known that the strata constituting the immediate roof layers caves into the void and the layers above the caved zone are subjected to compressive and tensile stresses. The tensile strain in the vertical direction generally gives rise to bed separation, whereas, in the horizontal direction it tends to open up joints in the rock formations. An understanding of these phenomena can be a great help in planning mine layouts for working under bodies of water or aquifers. However, the available information regarding the following factors is insufficient at the present and needs to be investigated further:

- the manner in which the strain tends to distribute itself over the entire length of the strata which is under tensile stress, that is whether the strain distributes over the entire length or it tends to concentrate at a few points

- in what manner the constraining depth effects the distribution of the horizontal strain among different joints in different strata beds

- in what manner the spatial distribution of joints and their geometry influence development of cracks wide enough to provide water pathways

- whether the thickness of individual beds affect the development of cracks cutting across the bedding planes or not

- whether alternating multiple beds of shale, sandstone, and limestone are more effective as regards development of cracks which will provide a water pathway, or individual bed thickness such as that of shale bed, are more important

4.2 Possible Closure of Cracks

An attempt has been made to find out the factors which tend to close the cracks soon after they are induced as a result of mining operations. For working under bodies of surface water, the closure of cracks in the constrained strata above the caved zone is of particular interest.

4.2.1 Induced Lateral Strain

Several continuum mechanics theories, such as elastic (Berry, 1963; Hacket, 1959; Salamon, 1963), viscoelastic (Iman, 1965), and plastic-elasto-plastic (Dahl and Choi, 1973), have been developed for different rock behavior. These theories mainly deal with the mode of strata deformation. It may be sufficient to assume for closure of cracks, that the constrained typical coal measure strata, above the caved zone and below some depth form the surface, behaves more or less elastically. Then perhaps any fractures induced by mining tend to close up due to lateral expansion of the rock beds as a consequence of vertical load of the overlying strata. The Poisson's ratio for clays and shales is more than sandstone and limestone beds, and as such, their lateral expansion if more than sandstone and limestone. In order to illustrate the effects of this factor, a hypothetical example is solved here as given in Figure 26:

Assume:

Seam thickness	= t = 5 ft (1.5m)
Depth of cover	= D = 250 ft (76m)
Modulus of elasticity for shale	= 2.5×10^6 psi
Poisson's ratio	= 0.25
Average sp. gravity for coal measure rocks	= 150 lb/cu ft
Vertical strata load for every 1 ft depth	= 1 psi (approximately)
Average stress on the shale bed	= 200 psi
Unit compressive, strain on the bed, $E_{comp} = 200/E$	= $(200/2.5) \times 10^6 = 60\ \mu\varepsilon$
Unit lateral strain	= $0.25 \times 80 \times 10^{-6} = 20\ \mu\varepsilon$

Total lateral expansion of the shale bed in left half $= (50\tan35° + 0.7D) \times 20 \times 10^{-6}$ ft
$= 0.05$ inches (1.3mm)

It is seen that the closure of cracks on account of vertical strata load in this case is 0.05 inches at an average depth of 200 ft. This is not a significant amount but may be an important factor at greater depths.

DeGraff (1979) has reported that surface tension cracks above a Utah coal mine at a depth of 800 ft to 1000 ft ultimately closed over an average of 56% of their length at an average rate of 1/16 inch per week. The likely mechanism is not hypothesized, but would include simple mass movement (creep) with time and the progression of the compression zone of the subsidence profile into the measurement area.

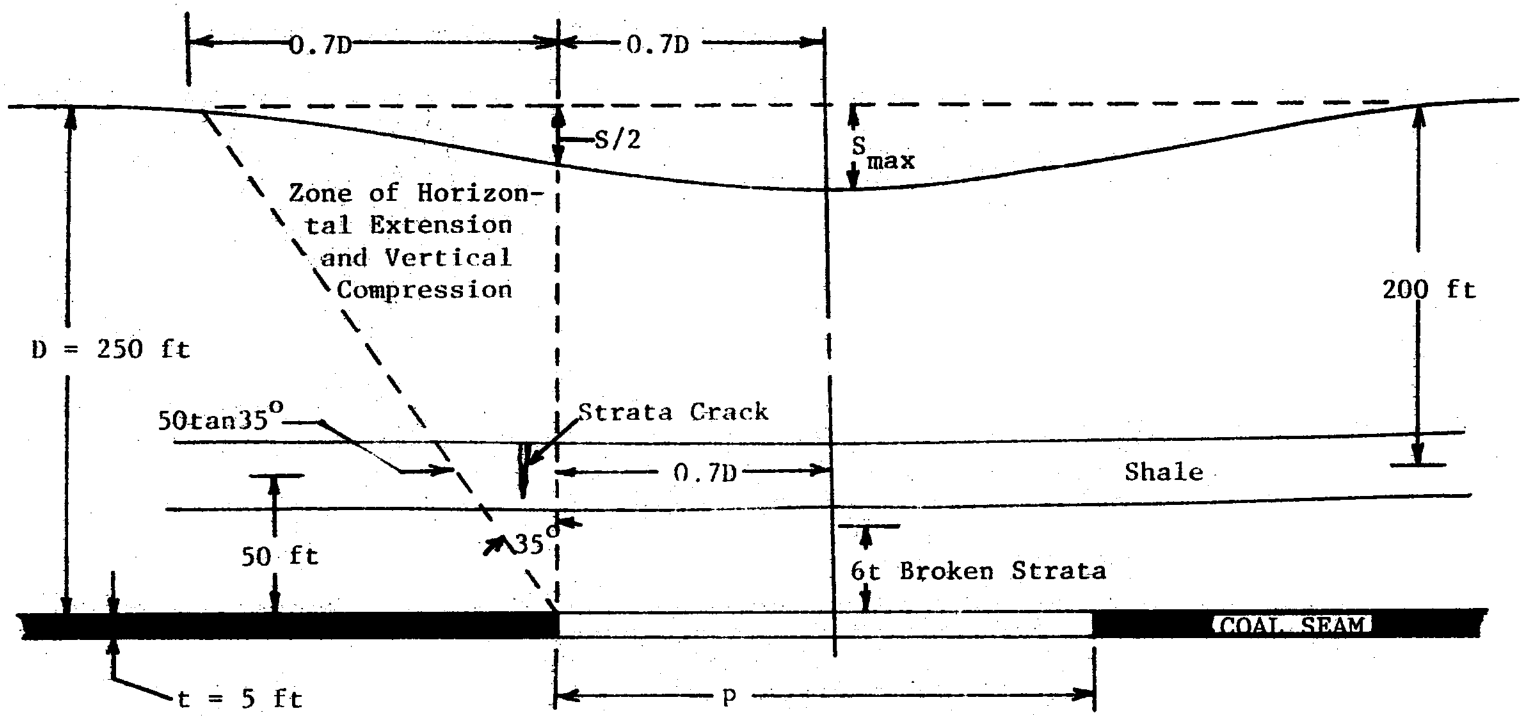


Figure 26- Effect of Strata Load on Closure of Crack

4.2.2 Natural Horizontal Stress Field

High horizontal stress fields have been detected in some area such as parts of southern Pennsylvania and West Virginia. Whenever high horizontal stresses are encountered, they help in reclosing cracks that may be induced in the strata on account of mining activity, and need to be investigated further. Excessively high horizontal stresses may aid in the disturbance of rock above caving areas by promoting breakage and deformation of stressed blocks of rock.

4.2.3 Effect of Creep

Creep pertains to time-dependent behavior of rock. It may be defined as an inelastic deformation of rock at some constant load below the yield point or fracture strength, considered as a function of time. The creep curve for most rocks can be expressed by a relationship of the form (Obert and Duvall, 1967):

$$E = A_C + B_C T + C_C E\,(T) \text{ tertiary creep}$$

where

A_C is the elastic strain at $T = 0$.

$B_C T$ is the steady-state creep.

$C_C E\,(T)$ is the transient or primary creep.

T = time

Tertiary creep: Once it is initiated, failure cannot be arrested. Hence, generally its duration is short.

The in-situ rocks exhibit varying degrees of transient, steady-state and tertiary creep. Experiments on rock samples have revealed that at any time, the creep may be expressed as:

$$\text{Strain rate: } E_r = \delta\,\sigma^n$$

or

$$\text{Strain at time T: } E = \delta T \sigma^n$$

where

δ = deviation of a value from the average

σ = normal stress

E = strain

n = exponent

The dependence of the creep rate on stress is rather complex and the above expression may not be valid for all ranges of strain or for the creep occurring in the steady-state phase. It has been reported that the creep deformation for a shale specimen is of the order of 20 $\mu\varepsilon$ at a load of nearly 1200 psi (Phillips, 1948). It shows that at shallow depths, creep will not be of much significance in closure of fractures in common coal measures rocks.

4.2.4 Filling of Cracks

The freshly exposed fractured surfaces are subjected to weathering and cracks may fill up with weathered material. The cracks also can get filled up with sand, clay, or calcite in due course of time. When working below surface bodies of water, it is important that the cracks get filled up soon after they are formed. It is presumed that materials such as ocean ooze and estuarine silt act as effective filling materials for cracks. It is, however, not desirable to depend solely on such materials to provide the safety for working below surface water bodies, owing to their low strength and consequent lack of resistance to higher water pressures.

Crane (1927) has reported that silt-charged streams deposited their silt in mining-induced cracks and thereby minimized water infiltration in the bedded iron ore mines in Alabama.

5.0 COVER DETERMINATION

5.1 Trough Subsidence and Surface Fissures

When a void created by mining becomes sufficiently large, the immediate roof breaks and falls into the cavity. The broken rock is generally in the form of blocks and thus increases in bulk. This process goes on until a height of some 3 to 6 times the seam thickness above the seam, at which the caving ceases since the entire void is filled up with the bulked out broken rock. The broken rock offers support to the overlying beds of rock. Thus the strata at higher levels sag rather than break into blocks. Sagging of these beds extends up to the surface provided a sufficiently large area is extracted. This gives rise to a fairly regular trough-shaped depression on the surface which may or may not be accompanied by surface cracks.

The general deformation and development of accompanying trough subsidence is illustrated in Figure 27 and the state of stress after mining is given in Figure 28.

As may be seen from these figures, the strain is maximum in the roof almost vertically above the rib sides bending into the void and diminishes above the coal seam. Practically, there is a level above which the lateral strain is not sufficient to open any more pre-existing joints, and thus further fracturing of the strata above that point ceases. The thickness of cover at which the fracturing ceases depends primarily on the height of extraction, width of the panel under extraction, the method of mining, the percentage of extraction, the nature of strata, and the restraint. However, the cracks which may appear on the surface or in the strata to depth of about 50 ft or so may not necessarily be the extension of the continuous strata fracturing commencing from the gob.

Homogeneous and sufficiently strong rocks will fail under tensile strains as low as 1,000 $\mu\varepsilon$ in laboratory testing. It is difficult to prepare samples from weaker rocks for testing in the laboratory, and therefore it is difficult to determine at what tensile strain they fail. It will be seen in Table 14 that quite wide fissures can occur with strains as low as 2,000 $\mu\varepsilon$ whereas on the contrary, mining under the sea bed has been carried out which produced calculated strains up to 12,000 $\mu\varepsilon$ without any adverse results.

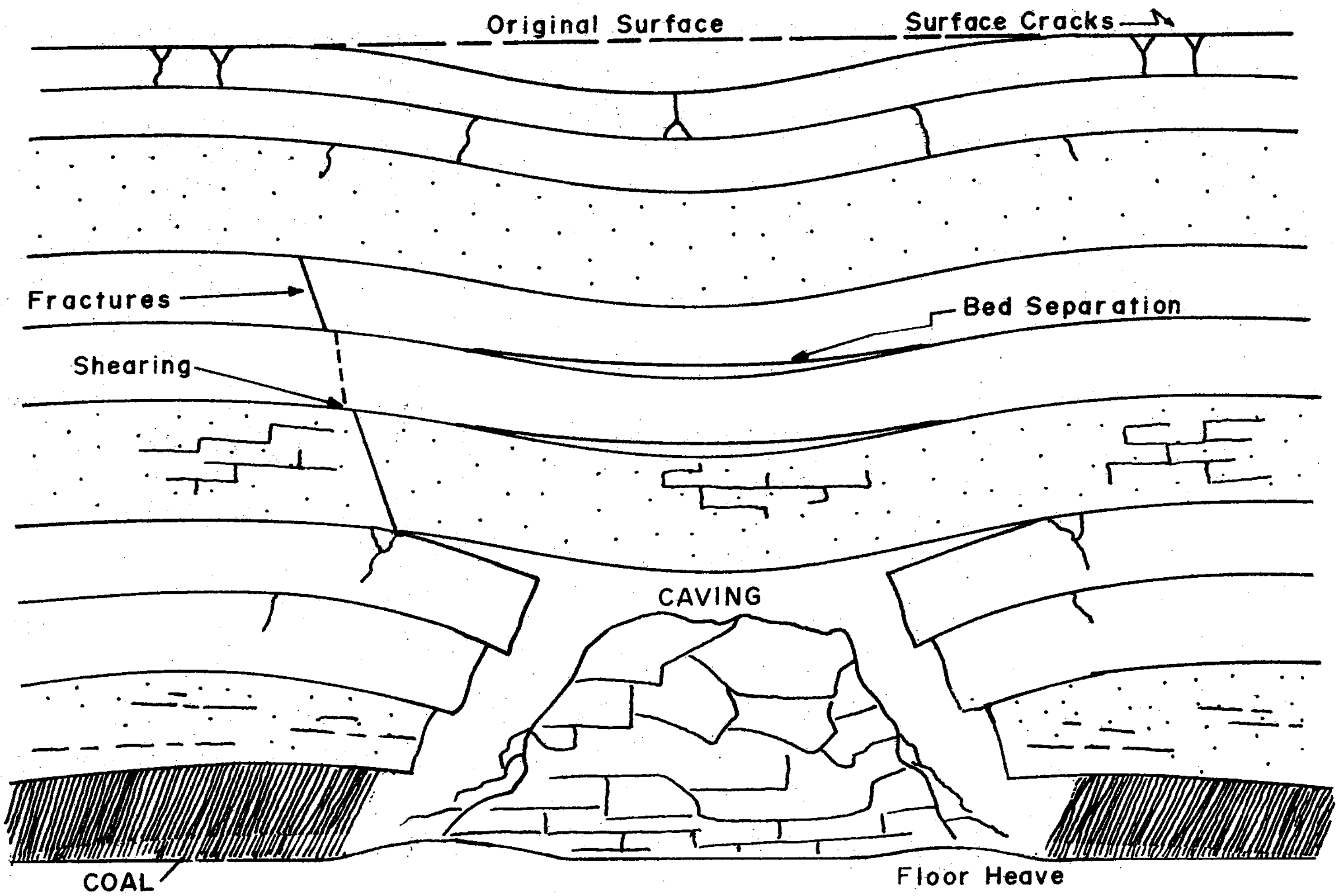


Figure 27- Strata Deformation and Development
Subsidence Trough from Underground Mining
(after Shadbolt, 1977)

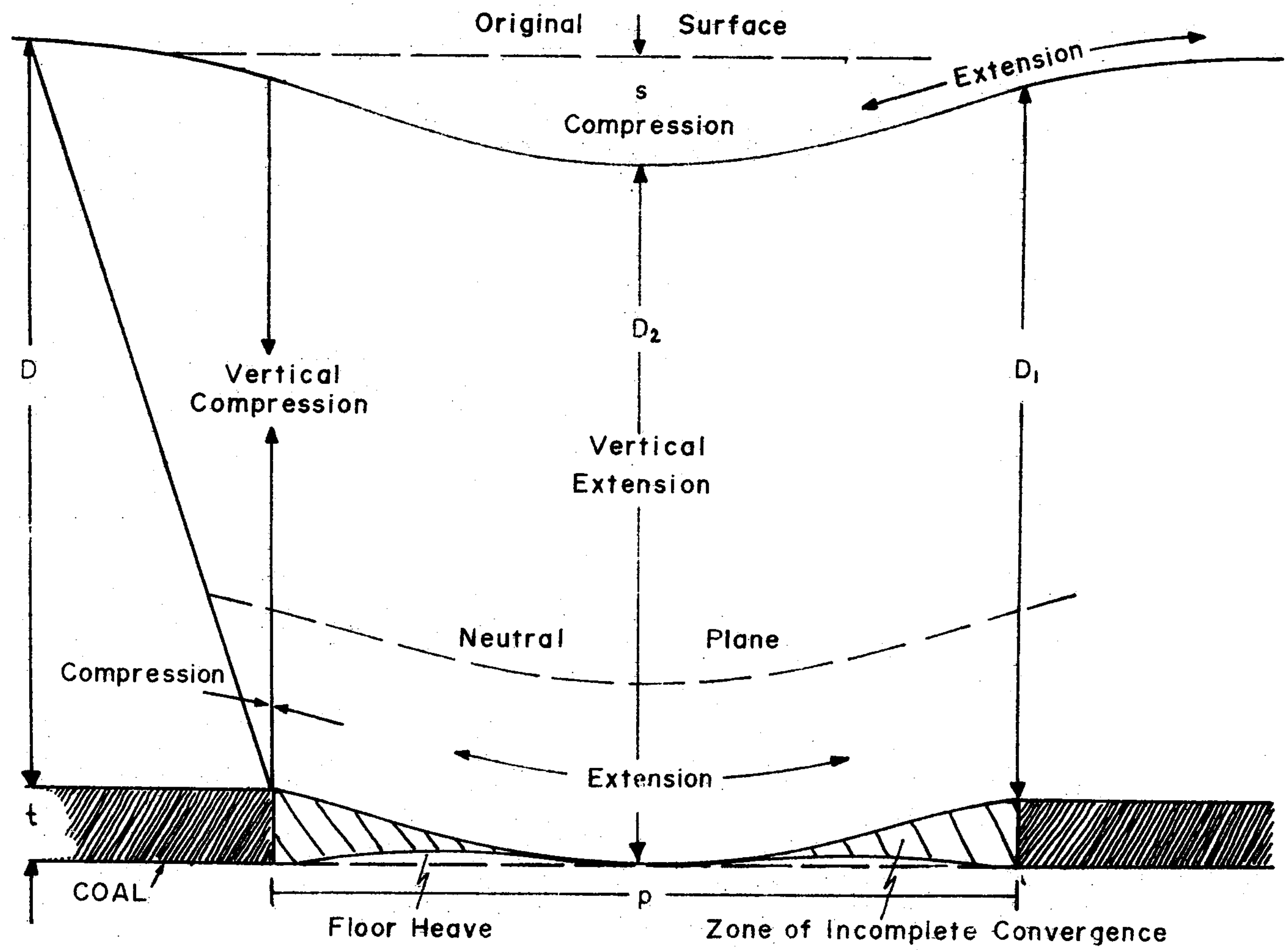


Figure 28 - State of Stress After Mining
(after Shadbolt, 1977)

Table 14 - Surface Fissures and Tensional Strain (after Orchard, 1969). Used with permission of the Institution of Mining Engineers, London. Reference: Orchard, R.J., The Control of Ground Movement in Undersea Workings. The Min. Eng. Vol. 128, No. 101, Feb. 1969, p. 259-273.

Colliery	Seam	Depth (ft)	Other seams worked (+ above) (- below)	Tensional strain in microstrains Estimated or Measured	Surface Geology	Location of fissure or fracture, etc.	Nature of fissure
Thoresby	Top Hard	2,040	None	4,000 measured	Bunter sandstone 450 ft thick	Parallel to ribside 540 ft outside	1 in wide vertical fracture
Ormonde	Blackshale	375	None	5,500 estimated	Made ground over Coal Measures	Parallel to and over the face	3/8 in wide fractures
Newstead	High Main	1,059	Top Hard - 217 ft	2,200 measured	Bunter pebble beds	Over face following subsidence contour	1 in crack in ground surface
Wollaton	Piper	726	Deep Soft + 81 ft Deep Hard + 51 ft	4,800 measured	Lower mottled sandstone 57 ft thick	Parallel to and over coincident ribside of three seams	2 in fracture in surface
Grassmoor	2nd Piper	450	1st Piper + 24 ft Tupton - 48 ft Three-quarters - 100 ft	4,900 estimated	Middle Coal Measures	Parallel to approximate coincident ribs of four seams 150 ft outside rib	2 in to 12 in wide; fractures 15 ft deep minimum
Parkhouse	Deep Hard	360	Tupton - 300 ft Three-quarters Blackshale	10,800 estimated	Middle Coal Measures	Associated with 150 ft barrier of unworked coal in four seams. Fissures at 30° to and crossing barrier	6 in wide fissures up to 750 ft in length
Ireland	Deep Hard	510	Deep Soft + 100 ft	4,100 estimated	Middle Coal Measures	Over edge of unworked coal in Deep Soft. Parallel to and 150 ft outside Deep Hard ribside	720 ft long 18 in wide
Newstead	High Main	1,080	Top Hard - 648 ft	2,000 estimated	Bunter pebble beds	Parallel to and 30 ft outside High Main seam rib	Wide fissure
Shirebrook	Top Hard	1,590	None	8,000	Magnesian Limestone	Generally parallel to face. Line 300 ft in front of face	300 ft long up to 1 in wide

Numerous practical examples of this nature have led to the conclusion that not only the induced fractures are self sealing to some extent on account of weathering, being filled up by clay and silt, and so on, but it also appears that the fracturing is confined to the free surfaces such as the surface and the roof. It appears that for a significant part of the intermediate overburden, natural constraints prevent fracturing; or in other words, the induced stress is absorbed or resisted without any fracturing taking place.

It follows then that the observable surface fractures may extend only down to a depth of 50 ft or so, and similarly the known fractures in the roof may extend up perhaps an additional 50 ft. If the overburden is 150 ft thick then it is quite likely that the middle 50 ft thickness of the strata is free from induced fractures with no increase in its prior permeability (Figure 29).

5.2 Rationale for the Cover

Based on the foregoing considerations, the behavior of strata above a panel under total extraction by either room and pillar or the longwall method can be generalized as depicted in Figure 30.

The caving of the strata above the extracted area continues generally up to a height of 3t to 6t (where t is the height of seam extraction) above the coal seam depending on the bulking factor and caving characteristics of the roof strata. The beds above the caved zone are now provided with some kind of support by the caved rock and they sag giving rise to bed separation and a gentle, contoured trough shaped surface subsidence. It appears that the beds above the caved zone are subjected to fracturing due to bending and also by the stresses induced by mining for a further height of about 24t to 54t. The beds lying above this height and about 50 ft below the surface are sufficiently constrained to prevent development of any fractures. Thus, the constrained layers of the strata tend to absorb most of the strain energy without fracturing.

The strata layers close to the surface are again not sufficiently constrained and are more or less free to move in any direction. Thus, even a small amount of horizontal tensional strain can produce cracks of measurable widths in the surface layers. It is estimated that the depth of these surface cracks is generally confined to 50 ft.

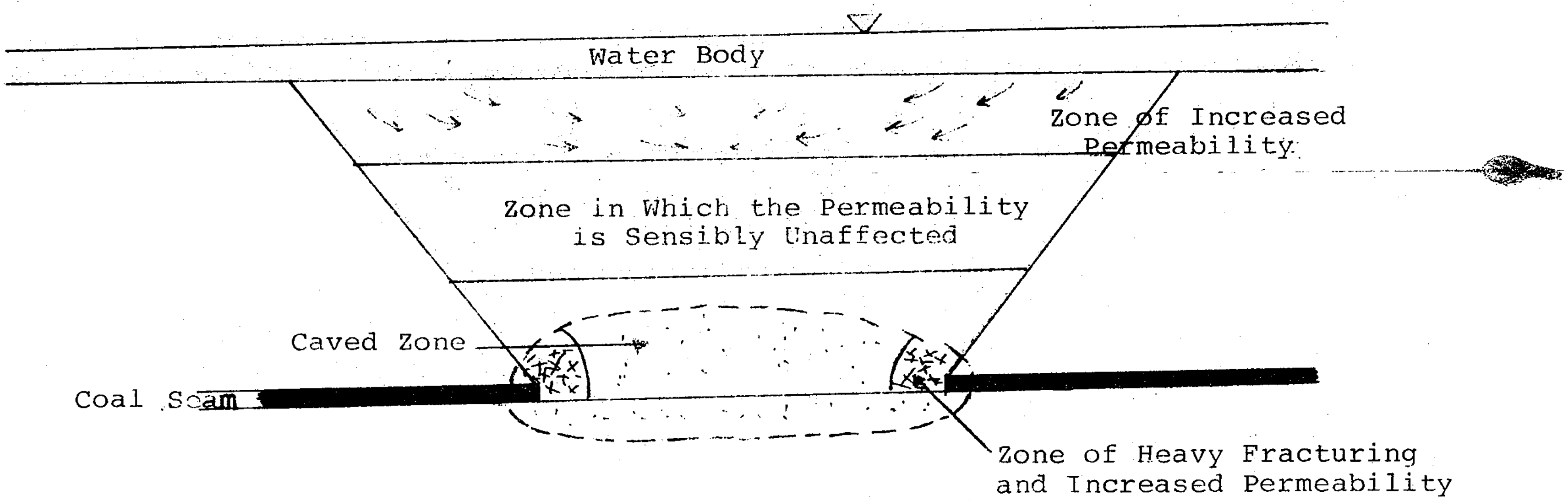


Figure 29- Probable Effect of Strata Constraint (after Orchard, 1969)

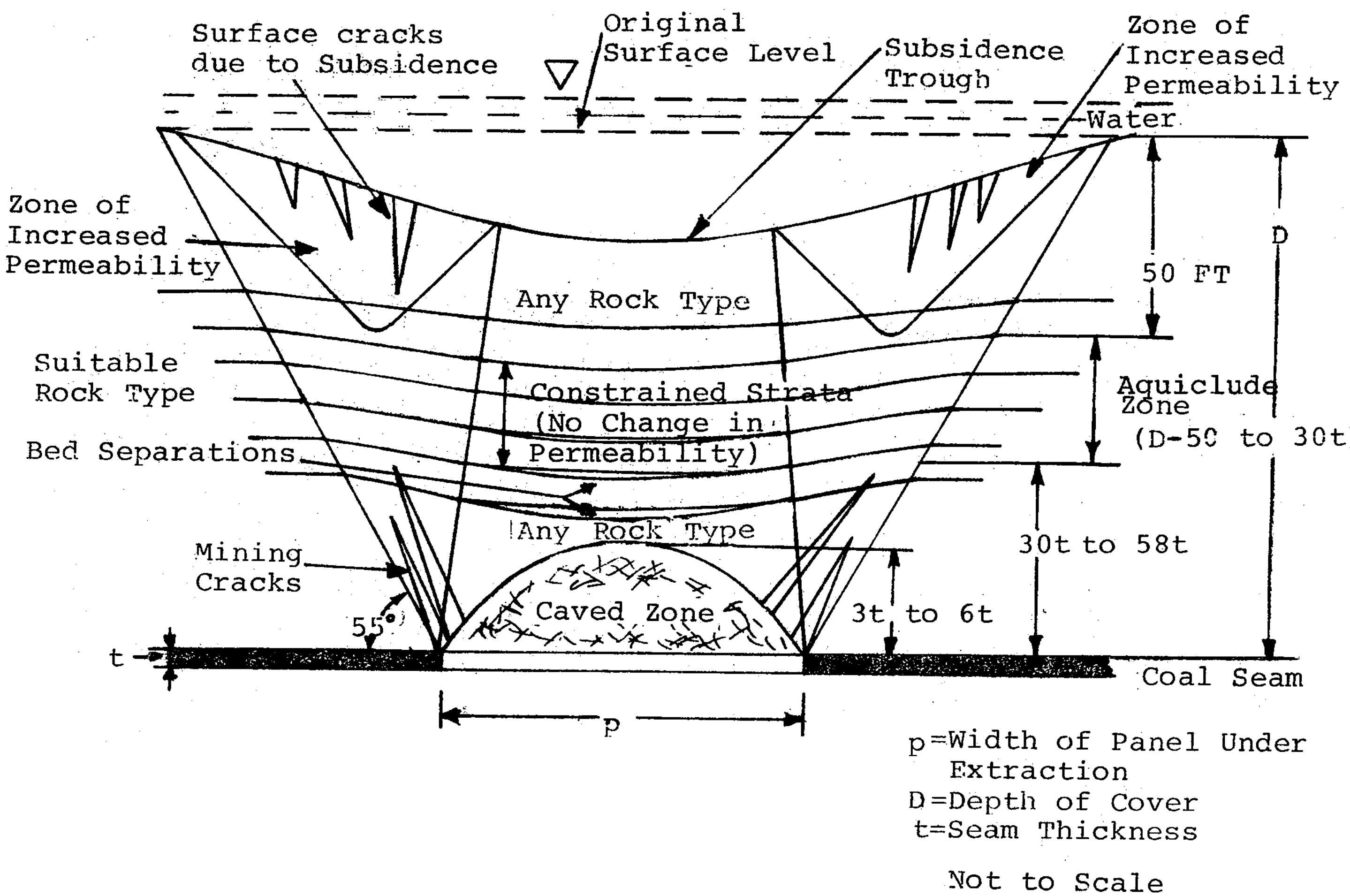


Figure 30 - Generalized Strata Behavior Above a Panel Under Total Extraction

It is surmised from these considerations that the main safety against any inflow of water from the bodies of surface water is afforded by the constrained strata herein termed the aquiclude zone, which is a hydrogeological term meaning a leaky barrier to vertical movement of water. It also follows that the nature of the rocks and the thickness of individual beds constituting the aquiclude zone are particularly important factors.

Mudstones and clays can absorb a large strain energy before they fracture. As such, a small thickness of clay or mudstone in the aquiclude zone can provide an adequate barrier against any inflow from the surface water body. Similarly, shales absorb sufficient strain energy before fracturing particularly when they are ductile, but to a lesser extent as compared to clay beds or mudstones. Thus, somewhat greater thickness of the aquiclude zone containing fairly high percentages of shale beds will be needed to afford adequate safety for working below the water bodies. If the strata in this zone have no mudstone or clay beds or sufficiently thick shale beds then a much higher thickness of the zone having a relatively low overall permeability will be needed to afford necessary protection from the surface water body. In actual practice a situation may exist when the aquiclude zone consists of only an aquifer or highly permeable rocks. In that case, the zone may provide water flow paths from the surface water body to the workings below which will result in continuous draining of the water body. Therefore, it is important that at least one bed in the aquiclude zone has a low permeability.

It can be concluded for the above considerations that a cover for undermining surface water bodies should contain an adequate thickness of the aquiclude zone which is generally free from opened cracks and fissures, and has one bed having a low permeability. It should also provide for commonly occurring geological anomolies like small faults, slips, and fissures, et cetera.

Wardell and Partners (1976) concluded that a safe cover for total extraction below water bodies should be 60t. These conclusions were based primarily on direct and indirect observations that the caving and fracturing of the strata was limited up to a height of 30t above the extracted area and a limiting tensile strain of 8,750 $\mu\varepsilon$. In the absence of sufficient practical examples of total extraction at a depth of less than 60t, it would appear to be a fairly conservative figure for a combined thickness of extraction of a single or multiple seams more than 7.5 ft. For lesser heights of extraction, a higher margin of safety is required in view of the results of on-site determinations of the height of water-conducting fissure zones in the Soviet Union and elsewhere. In addition to the height of the water-conducting fissure zone, the depth of about 50 ft or so of surface cracks is also required to be taken into consideration. For ensuring a reasonable margin of safety, the safe cover should provide for a sufficient thickness of aquiclude zone free from opened fissures or cracks. In view of these factors Table 15 has been developed which gives the cover for working below water bodies of catastrophic potential.

The margin of safety has to be substantial in the absence of sufficient experience as is the case with total extraction workings below surface water bodies at a depth of less than 60t.

However, for working below those bodies of water which are small as compared to the available mine storage volume, this figure is restrictive and can be suitably revised. Revision of this figure can be achieved by incorporating in the mine plan suitable layouts and sequence of extraction of different panels which will prepare the mine for accepting an inflow from the water body.

Table 16 has been accordingly prepared which gives the minimum cover required for total extraction below surface water bodies of major potential size.

Data concerning the height of disturbed strata above full extraction obtained from Gvircman, et al. (1977), was incorportated into Table 16 by plotting the seam thickness, t, versus the height of disturbed strata, h, for the presented data. Using curve fitting techniques, an equation was developed to represent the data. The data distribution was forced to a parabolic shape since it was reasoned that t = 0 corresponds to h = 0, while rising quickly and stabilizing at larger values of t. The equation thus derived is $h = 56\sqrt{t}$, and the range of validity is t = 0 through t = 3.5, in meters.

Table 15 - Minimum Cover Required for Total Extraction Below Water Bodies of Catastrophic Potential Size

Thickness of Seam ft	Minimum Total Thickness of Cover	
t	t	ft
3	117t	351
4	95t	380
5	80t	400
6	71t	426
7	63t	441
7.5	60t	450
> 7.5	60t	-

Table 16 - Minimum Cover Required for Total Extraction Below Surface Water Bodies of Major Potential Size

Seam Thickness in ft t	Height of Disturbed Strata Above Seam		Aquiclude Zone Thickness I Minimum 20 ft clay		II Minimum 75% shale		III Shaley and Silty Sandstones		IV 100% Limestones and Sandstones		Depth of Surface Cracks		Minimum Total Thickness of Cover I		II		III		IV	
	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t
3	174	58	30	10	50	17	90	30	Special Investigations Required	Special Investigations Required	50	17	254	85	274	92	314	105	Special Investigations Required	Special Investigations Required
4	203	51	30	8	50	13	90	23			50	13	283	72	303	77	343	87		
5	226	45	30	6	50	10	90	18			50	10	316	61	326	65	366	73		
6	249	42	30	5	50	8	90	15			50	8	329	55	349	59	389	65		
7	269	38	30	4	50	7	90	13			50	7	349	49	369	52	409	58		
8	285	36	30	4	50	6	90	11			50	6	365	46	385	49	425	53		
9	305	34	30	3	50	6	90	10			50	6	385	43	405	45	445	50		
10	321	32	30	3	50	5	90	9			50	5	401	40	421	42	461	46		
11	352	32	30	3	50	5	90	8			50	5	432	39	452	41	492	45		
12	360	30	30	3	50	4	90	8			50	4	440	37	460	38	500	42		

In Table 16, minimum thicknesses of the various categories of aquiclude zones were computed based upon an acceptable infiltration rate of 10,000 gpm over an area 600 ft by 600 ft, with a hydraulic head of about 100 ft. Darcy's Law was used, and permeabilities of various strata were obtained from Davis and DeWiest (1966). Overlying strata consisting solely of jointed limestones and sandstones without shales and related rocks, Class IV in Table 16, are not known to occur with coal and other stratified mineral deposits and since they are quite permeable, special individual investigations would be required.

The figure of 30t to 58t depending on the height of extraction represents the maximum height of the strata above the coal seam which may be broken or fractured, and the depth of surface cracks has been assumed to be 50 ft (based primarily on the British experience). It may well be, that at smaller extracted seam heights, and consequent reduced overall subsidence, this figure may be reduced, but no data presently exists to justify such a change. The minimum cover required given in Table 16, along with the precautions incorporated in the mine plan (to be covered in subsequent sections), are expected to provide the same margin of safety while working below water bodies of major potential as 60t for extraction below water bodies of catastrophic potential (where t is the thickness of seam extraction).

The strata contained within the designation "Height of Disturbed Strata above Seam" in Table 16 must be rock and not unconsolidated strata. Unconsolidated materials are more likely to pipe and chimney and extend to great heights.

The strata contained within the "Aquiclude Zone Thickness" must all be firm strata, not necessarily rock, that have no tendency to flow when water-charged.

The material in the "Depth of Surface Cracks" designation must be essentially permanent geological materials, not river, estuarine, lake, or other deposits subject to reworking or removal by natural processes, and not placed fill. Also these materials must have no tendency to flow when water-charged.

These recommendations of cover are presently limited for working below bodies of water of major potential size provided adequate emergency sump capability is maintained in the mine as described in later sections. After sufficient experience is gained, these recommendations may be suitably modified and extended for working below catastrophic potential sized water bodies as well.

5.3 Substantiating Related Phenomena

In order to determine the importance of different types of strata in the development of possible pathways for water inflow from a body of surface water into the mine workings, the strata deformation associated with block caving in copper ores was examined.

Block caving is generally practiced where the ore body and the surrounding strata have good caving capability consisting of ubiquitous fractures. It involves extraction of a horizontal slice from under the ore body and allowing the ore to cave into the void. The caved ore is gradually drawn out through multiple chutes or slusherways from under the slice. The ore is drawn until the overburden and the barren surrounding rock reach the under cut level. This block is then abandoned and the mining proceeds to the next block.

After a certain percentage of the ore is drawn, a breakthrough occurs at the surface. This has been studied carefully at some of the mines (McNicholas, Rogers and Walker, 1945; Thomas, 1971). For instance, at the San Manuel Mine of Magma Copper Company in Arizona, it was found that the first crack on the surface appeared only after 8.5 to 15% of the total vertical column height was drawn from a block at a depth of nearly 1,120 ft. It shows that the strata was able to absorb a tensile strain of sufficient magnitude before a fracture could develop at the surface. The particulars of the occurrence of first breakthrough to the surface are given in Table 17. It will be noted that the ore body and the surrounding strata were fractured, thus, they caved easily. As extraction progressed, and the total height was fixed, it is reasonable that surface expressions of drawing or caving could extend to much higher ratios than were available.

In coal measure strata, surface cracks due to caving appear generally at a much higher h/t ratio, where h are the thickness of the strata above the seam or slice and thickness of extraction up to the time of breakthrough, respectively. For these phenomena h equals D. It does illustrate that this difference in h/t ratio depends to a large extent on the caving or bulking characteristic and the nature of the strata besides other factors.

Table 17 - Particulars of First Breakthroughs at the Surface Due to Block Caving (after Thomas, 1971)

Mine	Draw at Time of Break-through (ft) (t)	Total Height of Original Rock Column (ft) (D)	Block Area (A) (ft^2)	D/t	Time Under Draw Before Breakthrough (days)	Type of Fracture at Surface	Note
Magma Copper San Manuel, AZ Panel 7-1	89.6	1120	52,000	12.5	174	Vertical 35 ft outside vertical limits	Initial block caving, block under fault zone
Panel 34-1	108	1256	15,000	11.6	150 ±	Ellipitical hole 100 ft by 150 ft	Thin layer of conglomerate (25 ft - 50 ft)
Panel 9-1	134.4	1120	52,000	8.3	305	Concentric cracks	Thick layer of conglomerate (300 ft - 350 ft)
Panel 3-2	159	1120	36,750	6.7	N/A	Vertical	Thick layer of conglomerate (300 ft - 350 ft)

Only a few case histories are available where total extraction was carried out under surface water at a D/t ratio of less than 60 with apparently complete success. The particulars of these cases are given in Table 18. It may be noted at the same time that there are no known instances of water rushing into a mine from a surface source on account of total extraction being carried out at a depth exceeding 30t. The particulars of Wongawilli and Kemira collieries in Sydney, Australia, where increase in strata permeability was measured as a result of undermining (Williamson, 1978) are also included in this table. These studies also indicate that there is no increase in permeability beyond a height of 33.7t above the extracted area. The strata in these two mines consisted of predominantly sandstone and shale beds.

Similar studies were also carried out in the Soviet Union where increased permeability was observed up to an average height of 30t to 58t depending on the thickness of extraction (Gvircman, et al., 1977).

Indirect evidence from mines where methane drainage has been practiced above the extracted gobs also indicated that the increase in permeability is generally confined to a height of 100 to 150 ft above the seam. This height is again not expected to exceed 30t. All of this direct and indirect evidence indicates that the figures of 30t to 58t for caved and fractured strata used in Table 16 are reasonable.

It is recognized that differences will exist between various coal fields that could significantly alter the generalizations presented in Table 16. It is considered that such a format could best be applied with more detailed knowledge of local conditions, which is beyond the scope of this present work.

5.4 Existing Subsidence Control Requirements

Although the published information on mining subsidence in the United States is not extensive, most of the major coal producing companies have collected considerable subsidence data of their own in the recent years. Moreover, the U. S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, on 13 March 1979, issued a

Table 18 .- Case Histories of Total Extraction Under Surface Water at Less Than 60t Cover and Measurement of the Increase in Permeability Above Gobs

	Mine	Location	Date	Source and Quantity of Water	Geologic Conditions	Seam Thickness (ft) (t)	Depth (ft) (D)	D/t	Mining Method, Percentage Extraction, and Remark
1	Thrackley Isabela Colliery	U. K.	1925	River Tyne	100 ft to 130 ft alluvium and silt (supposedly water bearing)	4	190	47.5	Room and pillar followed by total extracting of the pillars over 400 ft to 900 ft area. (Orchard,1975)
2	Broad Oak Colliery	S. Wales	1877	Lougher R. Estuary	Esturine silt constituted considerable thickness of the strata	4	110	27.5	Full extraction . (Orchard, 1975)
3	Broad Oak Colliery	S. Wales	1907	Lougher R. Estuary	Esturine silt constituted considerable thickness of the strata	+5	110 + 320 = 430	47.7	Swansea 5 ft seam was extracted under Swansea 4 ft seam gob. (Orchard, 1975)
4	Wongawilli Colliery	Sydney, Aust.	1972	Stored water of 5 ft dams	Over 60% Sandstones of low permeability (Max. surface subsidence = 7 ft)	6 +10 = 16	923	57.7	Bulli and Wongawilli seams were extracted by longwall caving over super-criticalarea. Boreholes drilled in the extraction areas indicated that the strata disruptions (increased permeability) extended for 460 ft above Bulli seam i.e. upto h/t ratio of 29. Tension fractures at the surface were present which did not extend either directly or indirectly down into the working. (Williamson, 1978)
5	Kemira Colliery	Sydney, Aust.	1976	Stored water of 5 ft dams	Over 60% sandstones of low permeability (Max. surface subsidence = 7 ft)	6 + 10 = 16	923	57.7	Panel width 1/3 of depth = 375 ft (subcritical). Pressure and permeability data collected from boreholes over the panel indicated that only 320 ft thickness of the strata above Bulli seam was affected . This gives h/t ratio of 21.3. (Williamson, 1978)

permanent regulatory program covering surface coal mining and reclamation operations. This program contains specific rules and regulations regarding surface subsidence control plans as a part of the general underground mining permit applications. According to the rules, if subsidence occurred and if it "could cause material damage or diminution of reasonably foreseeable use of structures or renewable resouce lands" a subsidence control plan is required to be prepared and filed. This plan is required to contain a detailed description of the mining method and other measures that might affect subsidence. The purpose of these measures is to prevent subsidence from causing material damage or lessening the value of reasonably foreseeable use of the surface, to mitigate the effects of any material damage or diminution of value or foreseeable use of land, and to determine the degree of material damage or diminution of value of foreseeable use of the surface (Department of the Interior, 1979).

These stipulations more or less require mine operators to carry out subsidence measurements. Thus, it is expected that within a short period sufficient subsidence information will be available which will make it possible to determine average values for subsidence factor and coefficient k for each geological locale. The stipulation of a criterion for working below water bodies in terms of maximum calculated tensile strain is more realistic as it allows account to be taken of coal thickness extracted, maximum subsidence, and locally observed values of coefficient k, which depend on the nature of the strata.

If this criterion is adopted, it will be possible to avoid dangerous superpositions of subsidence and strain profiles as mentioned earlier and illustrated in Figure 9. According to 60t safe cover criterion, both panels A and B can be extracted under the water body but the value of the maximum superimposed strain may exceed 16,900 $\mu\varepsilon$ which is nearly twice the suggested value of 8,750 $\mu\varepsilon$. The maximum tensile strain criterion will also facilitate proper planning of the multiple seam extraction and adoption of new layouts which will ensure adequate recovery with due regard to safety. In this regard, the superimposed strain profile of multiple seam extraction by panel and pillar method is also illustrated in Figures 31 and 32. It will be seen from

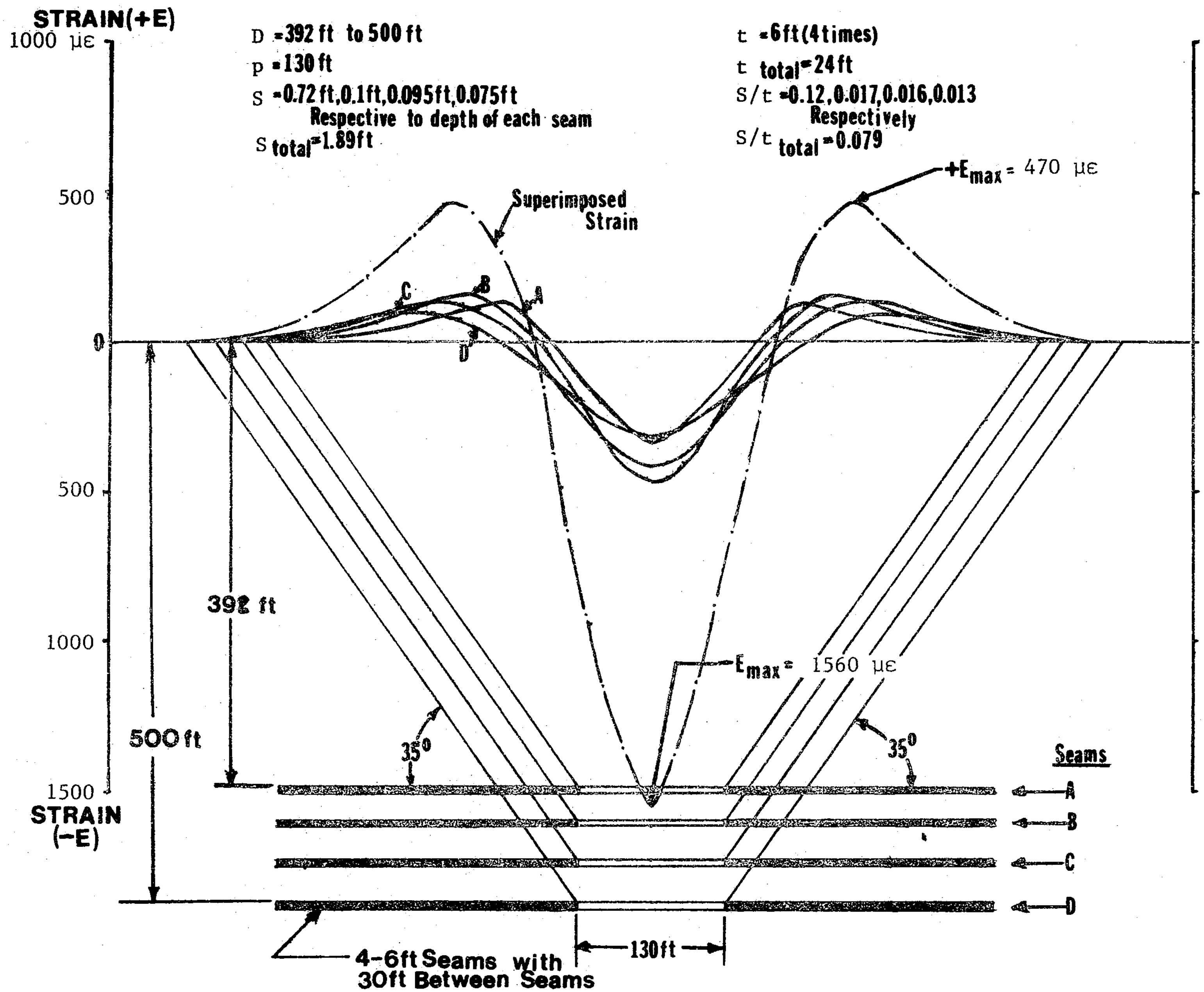


Figure 31 - Superimposed Strain Profile for Multiple Seam Extraction

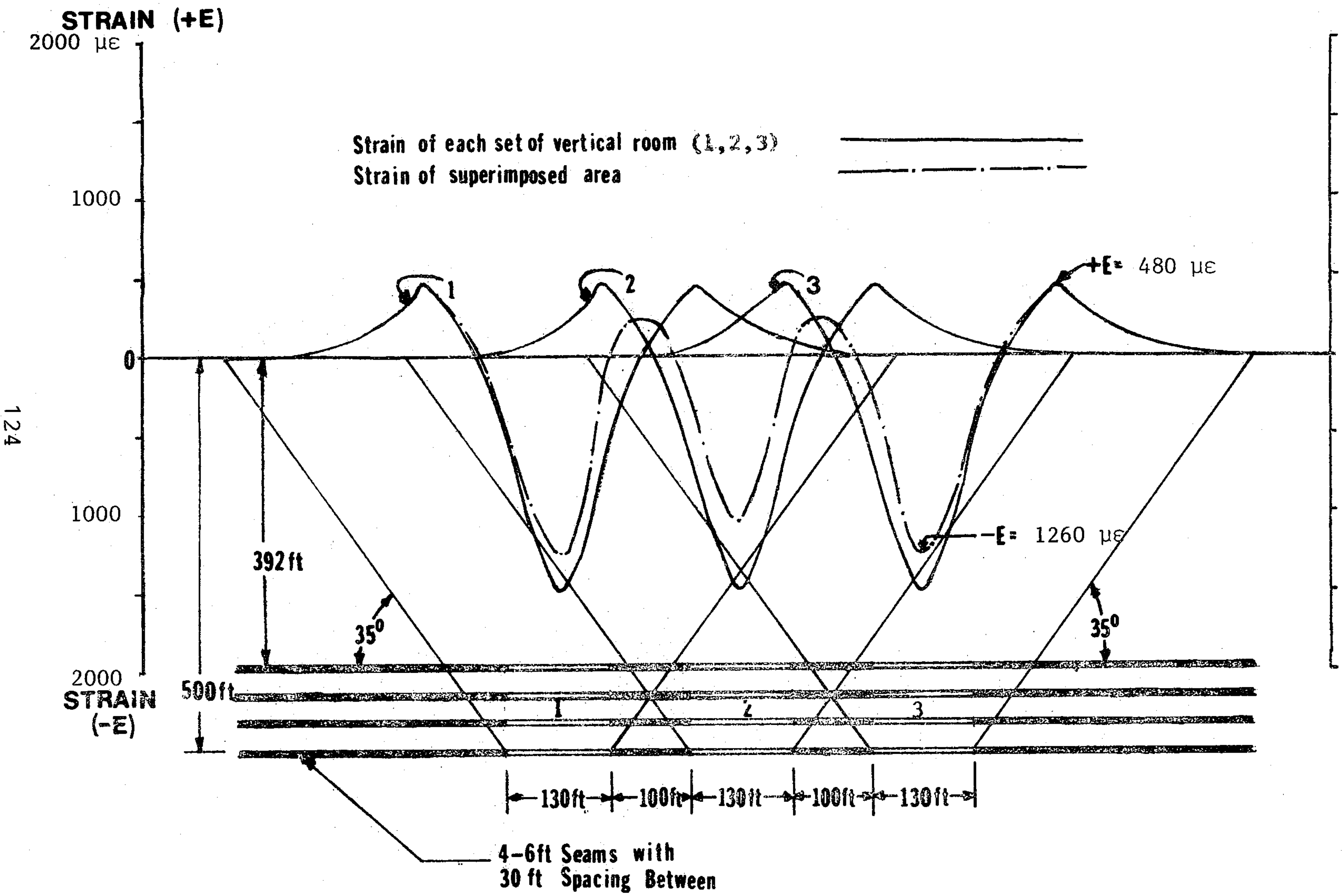


Figure 32 - Superimposed Strain Profile of Multiple Seam Extraction by Panel and Pillar Method

the latter figure that though the strain profile tends to flatten out in the middle portion, it increases at the extreme rib sides. Theoretically, it is possible for the strain to exceed the suggested limit of 8,750 $\mu\varepsilon$ at the extreme rib sides if a large number of closely spaced multiple seams are extracted. Therefore, in order to make sure that the total accumulated strain does not exceed a predetermined and established safe value, it is suggested to adopt the criterion of the maximum tensile strain in addition to the cover criterion.

The subsidence factor, N, for different coal districts of the United States is generally less than the 0.9 figure commonly used by the NCB. The value of coefficient k is generally taken as 750,000. The value of 60t suggested for cover is also partly based on the maximum acceptable tensile strain of about 10,000 $\mu\varepsilon$. Thus, where established data for subsidence factor and for the value of k are not available, the above mentioned values may be used which will essentially amount to erring on the safe side. It is suggested that the value of 10,000 $\mu\varepsilon$ for the maximum acceptable tensile strain is more reasonable as it corresponds more closely to the 60t cover concept and the same should be incorporated in the guidelines.

6.0 POSSIBLE INFLOW RATES

It cannot be stated in absolute terms that a minimum cover or a maximum limiting horizontal strain of 10,000 $\mu\varepsilon$ will provide total safety against any inflow of water while working below a body of surface water. These criteria provide for at best statistical safety and all that can be said about them is that they are based on engineering judgement and limited field data. Therefore, in order to provide additional safety, it is appropriate to assess the likely inflow rates in the event of the failure of the aquiclude zone to provide protection against inflow of water, mud, sediments, or other flowing material into the mine.

Accurate forecasts of water inflows to be expected in the event of failure of the aquiclude zone are extremely difficult to achieve because of the large number of variable factors involved. The best basis for prediction is often past experience combined with knowledge of the local geology. Alternatively, a two dimensional model can be developed if the change in permeability and the specific yield of the rock mass can be characterized. Then it may be possible to perform an analysis based on idealized assumptions.

6.1 Calculations of Inflow Rates

As already mentioned, there are no recorded case histories of sudden inrush of water on account of systematic total extraction below a surface water body at a cover exceeding 30t where t is the extraction thickness. As such, there is practically nothing to learn from past experience in this respect. However, studies of the changes in rock permeability associated with strata movement have been carried out in Sydney, Australia, and the Soviet Union, which can be analyzed to forecast the inflow rates to some extent.

Areas of coal were extracted under large surface reservoirs of water in Sydney, Australia, at a depth of cover of about 923 ft (Williamson, 1978). Extraction of two seams with a combined thickness of about 16 ft produced surface subsidence of up to 7 ft depth. Although a number of surface cracks around the periphery of the subsidence basin were induced, there was no inflow of water into the workings indicating that the cracks did not connect directly to the workings. The information collected from boreholes located in the subsidence zone indicated that the permeability of the strata increased consistently, but the limit at which the vertical drainage could readily occur was reached at a depth of about 29 times the combined thickness of extraction above the upper coal seam. In one of the field experiments, boreholes were drilled at two sites, one over a worked area where width of the panel extracted was about one third of the depth, and the other over an unworked area. Permeability of the tested horizons in the unworked area were consistently low. They ranged from 8.5 x 10^{-3} down to 1.2 x 10^{-4} gpd/ft^2. Over the work area, the permeabilities of the corresponding horizons were consistently higher, ranging from 8.5 x 10^{0} down to 1.4 x 10^{-3} gpd/ft^2, and fractures were also more pronounced. The pressure and permeability data indicated that vertical drainage into the workings could readily occur from a height of nearly 320 ft above the workings, that is, about 21.3 times the combined thickness of extraction (Williamson, 1978).

A number of similar studies in a geological "type locale" can be made and then suitable empirical relationship to fix a more precise value for the safe cover or maximum limiting tensile strain can be determined. However, in the absence of analogous studies, the values for safe cover and limiting tensile strain have to be conservative. Assuming that the length of the panel under extraction is large as compared to its width, suitable two dimensional models can be developed based on these studies to determine the rates of inflow of water from the water body to the workings below ground for different depths of cover.

The minimum cover presented in Table 16 assumes that the water may enter the mine, therefore the water inflow rate and pathway need to be studied. The area where vertical drainage into the workings can take place readily, will be just under the water body where the aquiclude zone is of zero thickness and the disturbed strata immediately above the seam reaches the surface cracks. This will result in the water body draining into the mine workings. The rate of inflow at this stage will depend on the lateral extent of the water body, the area of extraction, and the hydraulic gradient (Figure 33). Using Darcy's formula:

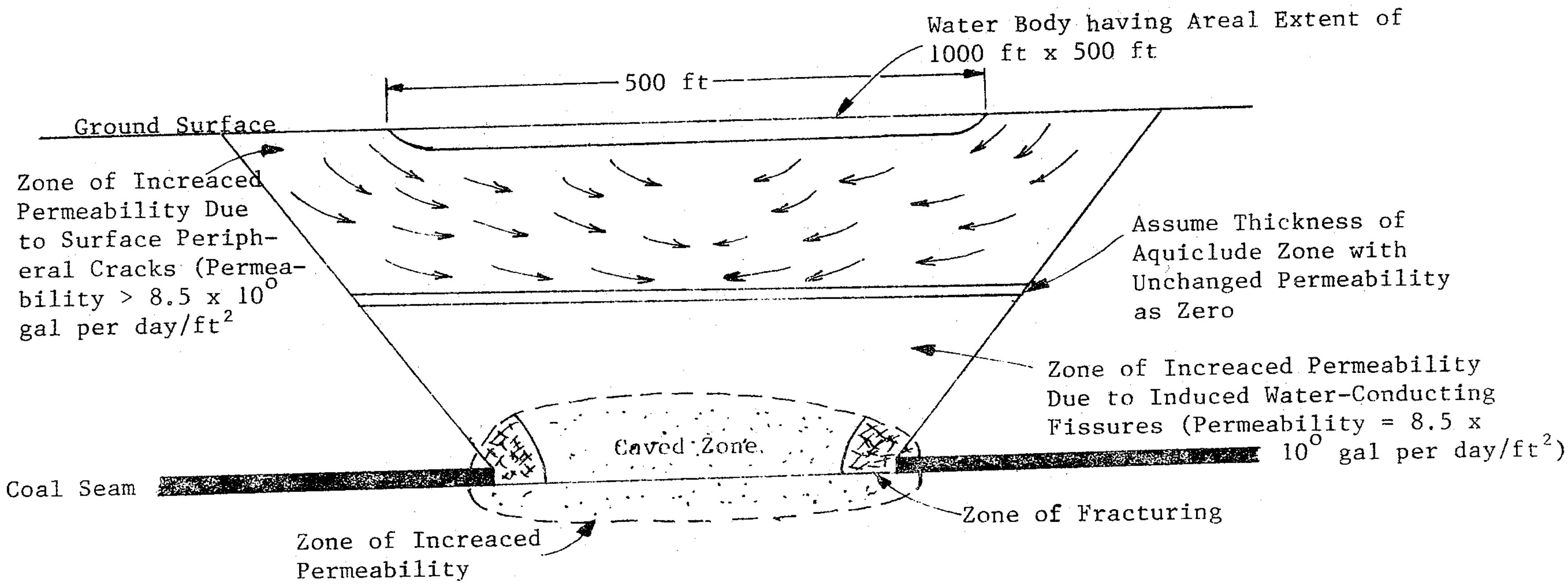


Figure 33- Determination of Likely Inflow Rates Assuming Thickness of Aquiclude Zone as Zero

$$Q = K A\frac{h}{L}$$

where Q is the inflow rate

A is the area of intersection of the subsidence basin and the water body

h is the height of water

L is the length of the water pathway

K is coefficient of permeability
$= 8.5 \times \text{gpd/ft}^2$
$= 1.3 \times 10^{-5}$ ft/sec

Assuming the extent of the water body to be 1,000 ft by 500 ft which is totally within the subsidence basin of the panel under extraction, and h = L, the inflow rate will be $1.3 \times 10^{-5} \times 1000 \times 500 \times 1 = 6.5$ cubic ft/sec = 2925 gallons per minute.

An inflow rate of this magnitude from bodies of surface water of major potential size can generally be dealt with by incorporating certain precautions in the mine plan.

Goodman et al. (1964), worked out an approach to predict ground water inflows into tunnels being driven through pervious, crushed, or faulted zones. In order to describe the inflow patterns, mathematical approaches were combined with the results of computer studies and results of experiments with physical models. Reliance on this approach mainly depends to what degree of accuracy the permeability and specific yield of the rock mass under study can be characterized. In order to determine the steady discharge through a tunnel penetrating a water bearing zone or a crushed zone near a fault under a water body having sufficient water supply such that drawdown cannot occur, use of the following approximate expression is suggested which has been rearranged from the original presented by Goodman et al. (1964):

$$Q = \frac{K(D+d)\ q \times 1.39 \times 10^{-3}}{\log\ (D/s)}$$

where Q is the discharge in gpm

D is the distance of the tunnel to the top of the ground

d is the depth of the water body from the surface

s is the diameter of the tunnel (entry)

K is coefficient of permeability of the penetrated zone in gpd/ft^2

and q is the tunnel (entry) length in feet penetrating the fissured zone.

The induced permeability above the caved zone in case of total extraction of a coal seam varies from one strata layer to the next and depends on a large number of variables, as such it cannot be characterized accurately without field investigations, but it may be possible to do so in case of crushed zones around a fault. Therefore, the above expression can be used to estimate the steady discharge for mine entries which may be driven through crushed or fissured zones underlying surface water bodies.

6.2 Inflow Rates from Mining Case Histories

Underground lignite mining in Hungary and Yugoslavia has been carried out for several years. The lignite beds are overlain with clays, aquifers or sand beds containing water. Thick sections of lignite in multiple slices have been totally extracted in these mines. These mines experienced large number of mud inrushes generally of small magnitude (Kesserü, 1978). These inrushes were investigated with care and have been properly logged. The inflow rates varied widely between a few and 33,600 gallons per minute. The highest recorded inflow during a period of 24 hours was on the order of 8.4 million gallons corresponding to an average inflow rate of 5,833 gallons per minute. A few of these inflows resulted in injury or death, but these injuries were not necessarily associated with the highest inflow rates of the highest total inflows. The injury in these cases generally resulted from the suddenness of inflow, accompanying roof or rib fall, the density of the mud or other material carried by water, and cut-off of the escape routes.

With this base of information, the Hungarian researchers have developed stochastic prediction methods for the probabilities of the maximum yields of single water inundations (Schmieder, et al., 1979). In this technique, the maximum inflow for a given area A is Q_{max}, and may be found by the following method. A rough approximation of the yield of any <u>single</u> inflow is

$$\tilde{Q} = \tilde{c}\,\tilde{w}^{3/4}\,\tilde{h}^{1/2}$$

where $\tilde{c}$ is the loss coefficient near the inflow

$\tilde{w}$ is the fissure width

and $\tilde{h}$ is the head of water.

It should be noted that this is not considered to be a satisfactory method of calculating $\tilde{Q}$, but can be used to show that Q is a transformed distribution of $\tilde{w}$, and the Q can be reasoned to follow a log normal distribution. The number of inflows $\tilde{N}$ over an area A is assumed to be found by the following probability function

$$P_{\tilde{N}}(n) = \frac{(\lambda A)^n e^{-\lambda A}}{n!} \qquad n = 0,1,2,...$$

where P is the probability,

and λ is the average number of inflows per unit which can be shown to be a function of the average fracture condition.

If N is fixed, then the distribution function of $\tilde{Q}_{max}$ is

$\left[F_{\tilde{Q}}(X)\right]^N$ where $F_{\tilde{Q}}(X)$ is the distribution function of $\tilde{Q}$.

When N is not fixed, the distribution function of $\tilde{Q}_{max}$ for a random number of $\tilde{N}$ is

$$P(\tilde{Q}_{max} \leq X) = f\,\tilde{Q}_{max}(X) = \exp\left[-\lambda A\,(1-F_{\tilde{Q}}(X)\right].$$

Such an approach is possible where the distributions of the various variates can be found based upon experience. The technique has been applied in Hungary and extended to the design of mine water control systems (Bogardi, et al., 1979), water entering mines from underlying karstic formations (Kesserü, 1976), and tunnel dewatering (Kapolyi, Schmeider and Kesserü, 1978).

In Velenje, Yugoslavia (Kesserü, 1978), 166 ft to 366 ft thick lignite beds are mined at 830 ft to 1,000 ft depth. The beds are mined by extracting 10 to 30 ft thick slices by the caving method from top to bottom. The water bearing sand in the roof strata is separated from the lignite bed by clay beds of varying thickness. As a result of successive extraction of the slices, water accumulates in the subsidence trough forming ponds containing several million gallons of water. The undermining of the lower slices was continued with certain precautions such as reducing the pressure of water in the sand beds to a range between 43.5 to 7.25 psi by draining the water table through underground wells. Here the main reliance is placed on impervious clay beds which provide the necessary protection. It will be seen that the D/t ratio was only 3 to 4, but there is one significant difference that the strata here consists primarily of soft rocks without fractures.

These mines also experienced several inrushes of water and mud. An analysis of these inrushes and several other analogous case histories enabled proper precautions to be taken to guard against further inrushes. Keeping in view the importance of analyzing past case histories, major inundation accidents from surface water in the United States and foreign countries have been summarized. Their available particulars are given in Tables 19 and 20 respectively.

In most of these cases, the inflow rates were not recorded. However, examination of a few cases where some data is available reveals some useful information. For instance, in the 24 July 1912 inundation at Superba and Lemont Mines in Pennsylvania, water from flooded streams entered into the mines through roof collapse at shallow cover and also flowed into the mine openings. It is estimated that over 20 million gallons of water flowed into the mine in less than one hour which would give an average rate of inflow of

Table 19- Summaries of Major Inundation Accidents in the United State
(from Bureau of Mines Bulletin 616, 1963)

	Location	Source & Quantity of Water	Geologic Conditions	Seam Thick-ness (t)	Depth (D)	D/t	Method and % Extraction	Remarks
1	Diamond Mine, Illinois Feb. 16, 1883	Flooded overlying fields due to general thaw breakthrough (Crevasse)	Marshy land with poor drainage	About 3 ft	68 to 84 Av. 75 ft	22 to 30	L.W.	Even though there was 3 ft. deep water over the gob of L.W. faces, there was no more than normal percolation. (Accident mainly due to too shallow cover - 50 ft. or less.)
2	No. 1 Slope, Nanticoke, Pennsylvania Dec. 18, 1885	Punched into glacial pothole of inverted cone shape containing loose sand and mud. (300 ft. dia. and 242 ft. height)	Mine workings traversed anticlinal and synclinal folds. Average dip around the slope was 18° for the first 2000 ft.	Ross Vein	242 ft	NA	R&P	The workings were systematic and the cover was apparently adequate. It was difficult to foresee such a geological anomaly.
3	Superba and Lemont Mines, Pennsylvania July 24, 1912	Flooded streams through roof collapse at shallow cover and also overflowing into mine openings.	Sewickly seam having a general 7% dip was worked too close to the outcrop.	5 ft	Only a few feet of cover	NA	R&P	The workings within the flood zone of the streams should have had a minimum safe cover and the mine openings should have been at least 1.5m above the H.F.L. of the streams. It is estimated that over 20 million gallons of water flowed into the mine in less than one hour which would give an approximate rate of inflow of 330,000 gpm.
4	Wilkeson Mine, Washington Dec. 17, 1917	Subsurface water and clay, probably trapped under pressure in a glacial pothole or channel. Quantity not known.	The seam dips from 35 to 42° which has roof composed of sandy shale that caves easily and needs to be supported elsewhere.	No. 3 Bed 10.5 to 12 ft	NA	NA	Breast and pillar for steeply pitching seams.	The strata 70 feet above and surface were unaffected by this inrush and other factors also indicate that the inrush was not as a result of collapse of pillars.

	Location	Source & Quantity of Water	Geologic Conditions	Seam Thick-ness (t)	Depth (D)	D/t	Method and % Extraction	Remarks
5	Carbondado Mine, Washington April 8, 1927	Gravel, clay, earth, and mud forming the over-burden rushed into the mine while pillars were under extraction.	North Morgan seam dips at 60 to 80° overlain with 200 ft. glacial material.	North Morgan 15 to 20'ft. hav-ing 60 to 80° pitch.	200 ft	10 to 13	Breast and pillar with pillar rob-bing on retreat.	The hanging wall was very strong which did not cave easily. The glacial material which was drawn down on account of pillar extrac-tion, did not make proper contact with the highwall resulting in voids getting filled in with water and clay which ultimately caved suddenly leaving a hole about 100 ft. long by 50 ft. wide and about 50 ft. deep.
6	River Slope Mine, Port Griffith, Pennsylvania Jan. 22, 1959.	Susquehanna River in state of high flood.	Cover of consoli-dated rock was only 19 inches thick (sandstone) above Pittson vein separating mine workings from river.	Pittson vein and Marey: 12 ft. and 4.5 ft. thick resp. Flat to 45°	1.5 ft	0-15	Multiseam breast and pillar con-ventional method.	The parting of the workings in Pittson vein below swollen Susquehanna River was only 19 inches thick which failed result-ing in sudden inrush of water. The workings generally stood well where the cover of hard strata was adequate with respect to pillar and entry dimensions.
7	American Tunnel Mine, Silverton, Colorado June 4, 1978	Lake Emma, 500,000 gal. entered the mine due to parting collapse.	The mine produced base metals. After the inundation it was found that only 20 ft. of cover existed between the lake and the point of entry.	NA	20 ft	NA	Shrinkage slope was the method of extrac-tion.	Lake Emma was thought to be a shallow, flatbottomed body of water; however, the resulting cavity remaining after the lake drained is about 80 ft. deep (After Gardner, 1978).

Table 20 - Summaries of Major Inundation Accidents in Foreign Countries

	Location	Source & Quantity of Water	Max. Rate of Inflow	Geologic Conditions	Seam Thick-ness (t)	Depth (D)	D/t	Mining Method	Remarks
1	Isabella Pit, Workington U.K. July 27, 1837	Irish Sea	NA	Out of the total 90 feet to 150 feet cover only 24 feet was reported to be hard rock.	Main Band 10 ft	120 ft (total average)	12	R&P with pillar extraction. Pillars 45 ft X 30 ft Headings: 12 ft to 15 ft wide.	The pillars were robbed at places thereby increasing the width of rooms. Moreover, the thickness of competent rock was reported to be only 24 feet which was not adequate to bridge the wide rooms. (Orchard, 1969)
2	Point of Ayr Colliery North Wales 19th Century	Sea (Dee Estuary)	4000+ gpm	The boundary fault had brought down aquiferious red measures to the working horizon.	NA	NA	NA	R&P	An exploratory heading was driven too close to the boundary fault which resulted in 4000 gpm of water entering the heading. This was dealt with by constructing an underground dam. (Orchard, 1969)
3	Mostyn Colliery U.K. 1883	Sea (Dee Estuary)	NA	NA	9 ft to 15 ft	72 to 96 ft	8 to 11	R&P with pillar extraction.	It appears that the size of pillars of coal was not adequate to support the workings. (Orchard, 1969)
4	Levant Tin U.K. 1930 to 1959	Atlantic Ocean	NA	Ore bodies containing copper, tin and arsenic minerals extend out to sea at depths ranging from 50 ft to 2000 ft.	NA	50 ft to 2000 ft	NA	Stopes at various levels.	According to the available reports mining was conducted so close to the sea floor that stones could be heard rolling at the ocean floor. It shows that the parting was not adequate. (Skelly and Loy, 1975)
5	Beattie Mine, Quebec, Canada June, 1943	Glory hole containing over 1 million cubic yards of wet clay	NA	Brecciated, silicified and mineralized volcanic ore body containing silver and gold is about 100 ft wide and 2000 ft long extending down vertically 900 ft to the sixth level.	NA	NA	NA	Glory hole and stopes at various levels.	Western section mine by glory hole measuring 900 ft by 150 ft at the surface down to fifth level 750 ft below. Main pillars supporting the glory hole failed soon after the caving of the eastern and central sections resulting in over 1 million cubic yards of clay, sand boulders, and debris to run into the mine filling shaft and mine workings up to 450 ft level. (Skelly and Loy, 1975)
6	Josephine Mine, Ontario, Canada Oct. 9, 1946	Parks Lake containing 80,000 cubic yards of water, peat and inorganic sediments	NA	Hematite ore bodies beneath the lake.	42 ft	600 ft	14	By undercutting benching and slashing from stopes.	In the absence of consolidated strata the lake bottom subsided over a 3 1/2 acre area by an average depth of 14 ft and a hole 60 ft across and 20 ft deep revealed an absence of any bed rock. (Skelly and Loy, 1975)

Table 20- Continue

	Location	Source & Quantity of Water	Max. Rate of Inflow	Geologic Conditions	Seam Thickness (t)	Depth (D)	D/t	Mining Method	Remarks
7	Sunro Copper Vancouver Island, Canada Dec. 5, 1963	Jordan River. Quantity of water and boulders undetermined.	NA	Irregular steep copper ore deposits at the intersection of three steep fracture systems.	330 ft	390 ft	1	Stopes	Stope started 390 ft below the bed of the river and continued upwards till the final void was 77 to 96 ft wide, 185 ft long and at the highest point of the dome back only 55 ft below the river. This parting failed and an undetermined quantity of water along with boulders rushed into the mine. (Skelly and Loy, 1975)
8	Mufulira Copper Mine Zambia, Africa Sept. 25, 1970	Tailings dumped in caved area which amounted to 16 million cubic feet of mud.	NA	No information.	NA	NA	NA	Sub-level caving	Tailings were slowly admitted to the underground workings by caving and draw off of the ore down-dip. In due course of time, hydraulic conditions developed which caused the sudden inrush of the tailings-water slime. (Eng. and Min. J., 1971)
9	San Antonio Mine Chihuahua, Mexico Nov. 10 1945	Solution cavities in limestone beds released 16 million gallons of water into the mine.	100,000 gpm	Zinc, silver, tin, lead and vanadium ore bodies overlain with altered and unaltered limestone beds occur near thick steep rhyolite dikes.	NA	NA	NA	NA	While advancing the south drift, it holed into a solution cavity connected to an extensive water table with numerous solution cavities. The water discharged into the drift through a 2 by 4 ft opening at the rate of 100,000 gpm. (Skelly and Loy, 1975)
10	Philen Mine Philippines June 28, 1967	Unspecified quantity of water collected in an open pit by torrential rains and sediments.	NA	Chalcopyrite ore extending up to the surface.	NA	638 ft	NA	Continuous panel block caving.	Ore was open pit mined first. This open pit was fed by a large watershed. A 400 ft. high block having 24,000 square feet undercut was under extraction under an already extracted block of 238 ft height. Due to torrential rain totalling 10 inches in one day caused high infiltration and mixing of water with sediment which eventually rushed into the mine through high pressure. (Skelly and Loy, 1975)

Table 20- Continue

	Location	Source & Quantity of Water	Max. Rate of Inflow	Geologic Conditions	Seam Thick-ness (t)	Depth (D)	D/t	Mining Method	Remarks
11	West Driefontein Mine Transvaal, South Africa Oct. 26, 1968	Solution cavities and fault zones.	57,000 gpm which probably passed through ¼ in X 50 ft opening in the fault plane at 3000' depth.	Gold is usually found in reef systems which vary from 1 in to 8 ft in depth and dip 20 to 30 degrées having extensive lateral persistence. Dolomites overlying the gold reefs have solution cavities.	NA	NA	NA	Stopes. Workings extend up to 9000ft depth which is almost the bottom of the deposit.	Normally about 32 million gallons of water was being pumped out per day. A fault zone previously thought to be tight, opened and released a large quantity of water with the peak quantity measuring up to 82 million gallons per day. This inflow was controlled with emergency plugs, bulkhead doors and successful grouting of the opening in the fault plane at 1000 psi pressure. The total pumping capacity of the mine at the time of inrush of water was 63 million gallons per day. (Wolmarans, 1978)
12	Coppice Pit U.K. 1908	Porous gravel bed	14,500 gpm tapered to 900 gpm after 12 days.	Roof strata consisted of unconformable conglomerates, unconsolidated sandstones, and a layer of marl which broke, letting in water from the gravel bed.	Shallow coal	NA	NA	R&P	This inrush did result in loss of of life. It was perhaps the suddenness rather than the quantity. (Wardell and Partners, 1976)
13	Folschwiller Mine France 1933	NA	22,000 gpm	NA	NA	1000 ft	NA	NA	The inrush brought in about 1000 tons of sand and resulted in loss of one life. (Orchard, 1969)
14	Knockshinnock Castle Colliery U.K. Sept., 1950	Peat swamps	NA	Coal measures strata overlain with boulder sand about 38 ft thick.	NA	38 ft	NA	R&P	The boulder sand was exposed in a heading which collapsed resulting in an inrush of water, peat, and sand. (Wardell and Partners, 1976)
15	Cardowan Colliery U.K. March 10, 1952	Coal Measures sandstone beds and a fault plane. 4000 gallons.	NA	Faulted coal measures	NA	NA	NA	L.W.	A roof fall probably caused by subsidence exposed a fault plane from which only 4000 gallons of water burst out resulting in death of two and injuries to one person. (Orchard 1975)

Table 20- Continue

	Location	Source & Quantity of Water	Max. Rate of Inflow	Geologic Conditions	Seam Thick- ness (t)	Depth (D)	D/t	Mining Method	Remarks
16	Port Hood Nova Scotia, Canada 1912	Sea	3000 gpm	The overlying strata consisted of mostly shaley sequence with some sandstone beds. No major faults existed.	6 ft to 7 ft	942 ft	135	R&P with some pillar extraction	According to the commission of enquiry, the mine was flooded by the water of the ocean through a near vertical fissure. Subsequent researchers tend to treat the Commission's findings with considerable reservations. (Rept.of Inspector of Mines and Appraisers, 1913)
17	Higashimi-some Mine Japan April 12, 1915	Sea 79 million gallons	661,500 gpm	Predominently arenaceous rock in the stratigraphic sequence and a fault zone.	Not known. Two beds.	155 ft sandstone & 83 ft sand & clay	NA	R&P with some extraction.	Two coal seams were worked. Levels in lower bed were driven up to the fault and a heading in the upper bed was driven to the fault on August 14, 1914 in which a 2 cubic feet per minute water inflow rate was encountered. The management tried to check this by timber and clay, and series of brick dams but the water pressure forced a 4 foot square hole and burst out in the workings. The entire mine was filled up with about 79 million gallons of water in two hours killing 237 workers employed in the lower bed. (The Colliery Eng., 1975)
18	Diana Mine Sundsgruvorna, Sweden 1948	NA	2600 gpm	NA	NA	762 ft	NA	Pilot Tunnel	Abandoned after inflow steadily increased. (Hagerman, 1969)
19	Bodaas Mine Gaestrikland, Sweden 1950	Ester	1319 gpm	NA	NA	915 ft	NA	Ore Mine	Grouting was done to stop seepage. (Hagerman, 1969)

330,000 gallons per minute. Although several workers lost their lives, quite a few escaped by wading through water which must have been flowing at a rate of over 100,000 gallons per minute through 20 ft wide entries. Moreover, many of the workers who could not escape were knocked down by the timber, tree branches and other materials floating in the water. It does illustrate that persons can escape to safety by wading through water flowing at high rates in mine entries provided certain precautions are taken. However, it is indicated that most inundations resulted from roof collapses at shallow depth, therefore, no actual information is available regarding the likely inflow rates in situations of total extraction below water bodies with a cover of upwards of 30t.

In West Driefontein gold mine located in Transvaal, South Africa, an inflow at the rate of 57,000 gallons per minute was encountered on 26 October 1968. The water issued from a 1/4 inch by 50 ft long opening in a fault plane at 3000 ft depth connected to solution cavities. This inflow was controlled with emergency plugs, bulkhead doors and grouting of the opening in the fault plane. Precautions such as precementation, shaft cementation, establishment of water pillars along the lines of intersection between major water fissures, drivage of development headings with cover holes, grouting of the canopy of the stopes in highly fissured areas are now taken. In order to cope with any unexpected inflow, water doors are provided at strategic places, emergency plugs are provided for damming off sections of mines, and a sufficient stand-by pumping capacity is provided. It illustrates that by taking suitable precautions very high quantities and unexpected inflows of water can be dealt with (Wolmarans, and Guise-Brown, 1978).

Another approach to estimate the likely inflow rates involved Equivalent Material Mine Modeling (Singh and Singh, 1978; Goodman, et al, 1965). Extraction of a coal seam at Mahakali mine in Chanda-Wardha coalfield is planned by caving method under a highly aquiferous Kamptee formation. "Equivalent Material Modeling" was used to estimate the magnitude and rates of inflows. The equivalent mine model was constructed in a frame 9 ft by 1 ft to accommodate two modeled panels of 330 ft width each on a scale of 1:100. The physical and mechanical properties of the different rock layers were determined.

Corresponding to these properties, the model was constructed to simulate different aquifers, aquifuges, and aquicludes as determined from borehole sections. The model extraction was done to simulate extraction of one longwall panel by the caving method. As the caving progressed, the factors such as fracture patterns, influence of water head, drainage and pumping problems, sudden release of water, peripheral inflow, transverse flow, the effects of recharging and flow rates, recharge under influence of mining subsidence, sump, and pumping capacity were evaluated.

Indications were that the first major fall of the gob will result in about 78,000 cubic yards of rock caving in. This is likely to contain 1,680,000 gallons of water out of which 168,000 is expected to be released soon after caving. In the first 30 minutes after the cave-in, about 84,000 gallons of water will be released which will give an average rate of inflow of 2,800 gallons per minute plus peripheral and transverse flow from the aquifer. With the advance of the caving face, the inflow rate will successively increase and is expected to fluctuate between 3,000 and 9,600 gallons per minute. Thus, a pumping capacity of nearly 12,000 to 14,000 gallons per minute is envisaged. It illustrates that mines can be planned to have large sumps and pumping capacity. However, additional precautions such as suitable escape routes, warning systems, and so on, will also be necessary.

Analytical approaches based on mechanical or hydraulic models and computer simulation (mainly the finite element method) have also been used to solve specific problems. However, in the absence of sufficient field data, much reliance cannot be placed on these approaches.

6.3 Inflow Rates from Tunneling Case Histories

Case histories of tunnel inundations were also examined. Particulars of some of them are given in Table 21. For instance, in driving the Tanna Tunnel in Japan in 1925, inflows at rates over 53,800 gallons per minute had to be dealt with. Moreover, the water from these inflows had a temperature of up to 97° F (Crocker, 1955). While driving the Mahr Tunnel, a steady inflow of water at a rate of 20,000 gallons per minute was encountered which had a peak rate of 50,000

Table 21- Some Case Histories of Tunnel Inundation

Location	Rock Type	Depth (ft)	Type	Size (ft X ft)	Water Source	Water Path	Peak Flow (gpm)	Steady Flow (gpm)	Total Water
Tanna Tunnel Atami, Japan 1918-1934 (Szechy, 1966)	Volcanic Debris	378	Rail	27 1/2 X 17 1/4	NA	Fault	53,800	NA	1.0 X 10^6 g
Mahr (King Mill) Tunnel Morococha, Peru 1933 (Eng. and Min. J., 1934)	NA	1700	Drainage & prospect & haulage	12 X 9	Morococha Lake	Fissure	50,000	26,000	NA
San Jacinto Tunnel Banning, California, 1930's (Thompson, 1978)	Granite	815	Aqueduct	18 ft. horseshoe bore	Water trapped in cavities fractures	Fault	40,000 including 16,000 from one single point	NA	NA
Eklutna Alaska, 1951 (Goodman et al, 1964)	Graywacke & Argillite	NA	NA	NA	NA	Fault	18,000	NA	NA
Casacalpa Tunnel Casacalpa, Peru (McKinstry, 1948)	Porphyritic, Andesite Silicited Shale	NA	Drainage	NA	NA	Joints & Faults	15,000	10,000	Steady
Boyati Tunnel Athens, Greece 1928 (Keays, 1931)	Creviced and cavernous limestone and Chlorite schist	Shallow to 600.	Aqueduct	horseshoe 7.54 X 7.87	Ground water	Fault	5,550	Varied	NA
Great Apennine Tunnel Prato, Italy 1920-1931 (Szecky, 1966)	Sandy, Clayey, Shale, Marl	1,420	Rail	31 X 27 1/4	NA	Bedding	5,500	NA	NA
Tvaerforsend Power Plant Haelsinoland, Sweden (Hagerman, 1969)	NA	NA	NA	NA	NA	Crushed Rock	3,900	3,900	NA
Stockholm Subway Stockholm, Sweden 1958 (Morfeldt, 1970)	Granite	NA	Subway	NA	ESKER	Fault	2,600	2,100	NA
Moffat Tunnel Northern Colorado 1925 (Keays, 1927)	Biotite, Granite, Gneiss	NA	Rail	NA	Crater lakes	Fault	1,800	NA	NA

gallons per minute (Goodman, et al, 1964). In driving the Eklutna Tunnel in Alaska in 1951, water inflow at a rate of 18,000 gallons per minute was dealt with while crossing a faulted zone (Goodman, et al, 1964). There are several other examples where inflow rates upwards of 4,000 gallons per minute were encountered and dealt with while driving tunnles. As may be seen from Table 21 most of these inflows were associated with fault zones or crushed zones.

6.4 Summary of Inflow Data

From the above considerations it may be concluded that

- inflow rate as a result of total extraction below a water body at a cover exceeding 30t is not likely to be more than a few thousand gallons per minute.

- inflow rates of several thousand gallons per minute can be coped with by taking suitable precautions.

- mines can be developed under water in fissured and faulted areas by taking suitable precautions.

- persons can escape by wading through water flowing at a rate of over 100,000 gallons per minute in a typical mine entry.

7.0 WATER FLOWING IN A MINE

7.1 Flow Rates

Water from strata percolation or any other discharge after entering the mine follows open channel flow principles in flowing from the high point to the low points along the mine entries. The flowing water must overcome boundary induced resistance because water is a viscous fluid, which implies that the flowing water gradually loses its energy along its path. To estimate water discharge for practical engineering purposes, it is generally assumed that the energy grade line is parallel with the bottom slope of the channel. In this simplified state the energy is lost through friction. Since it is assumed that there is no acceleration or deceleration along the flow, the depth as well as the kinetic energy, $V^2/2g$, remain constant. This flow is called normal flow and is generally computed by the Chezy formula which states that:

$$V = Q/A = c\sqrt{Rh_1} \qquad (1)$$

where c = Chezy roughness coefficient

V = mean velocity of flow

Q = discharge flow

A = area of flow

h_1 = slope of energy grade line or loss of head due to friction per linear ft of channel

R = A/P_w = hydraulic radius, ft

P_w = wetted perimeter, ft.

Manning proposed

$$c = \frac{1.486\ R^{1/6}}{n} \qquad (2)$$

where n is the coefficient of roughness in the Ganguillet-Kutter formula. Combining relations 1 and 2, the following relation is obtained which is generally referred to as Manning's formula

$$V = \frac{1.486\ R^{2/3} h_1^{1/2}}{n} \qquad (3)$$

or

$$Q = \frac{1.486\ A\ R^{2/3} h_1^{1/2}}{n} \qquad (4)$$

Values of the roughness coefficient n have been determined for a wide range of artificial and natural rock channels. The average value for n for smooth and uniform channels is generally taken as 0.035. This value can be used for mine entries as well. Manning's equation has generally been found to give fairly accurate estimates of water discharge in open channel flows. It is simple to use and is preferred for estimating water discharge in mine entries as well.

Appendix C provides graphical solutions for water flowing in typical mine entries.

7.2 Flow Paths

As mentioned in the earlier sections, it is important to incorporate suitable precautions in the mine plan as a defense against any unexpected inflow while working below a surface water body besides providing for adequate cover. If an inflow does take place due to unforeseeable geological anomalies or other reasons, it will be necessary to know the effects of such an inflow so that suitable precautions may be taken in advance. A better understanding of these effects can be had by studying a practical example. The Water Hazard Map of a coal mine is shown in Figure 34. It shows the layout of the workings indicating the mine entries, gobs, zone of influence, and the panel under extraction beneath a body of surface water. The zone of influence around the water body should be determined and marked on the map. Essentially, it is the same as the safety zone given in Figure 1. However, the presence of a major fault which may intersect the water body and the mine workings will have to be taken into consideration even if the workings are outside the safety zone. Any mining operations to be conducted within the zone of influence should be carried out according to the specified guidelines.

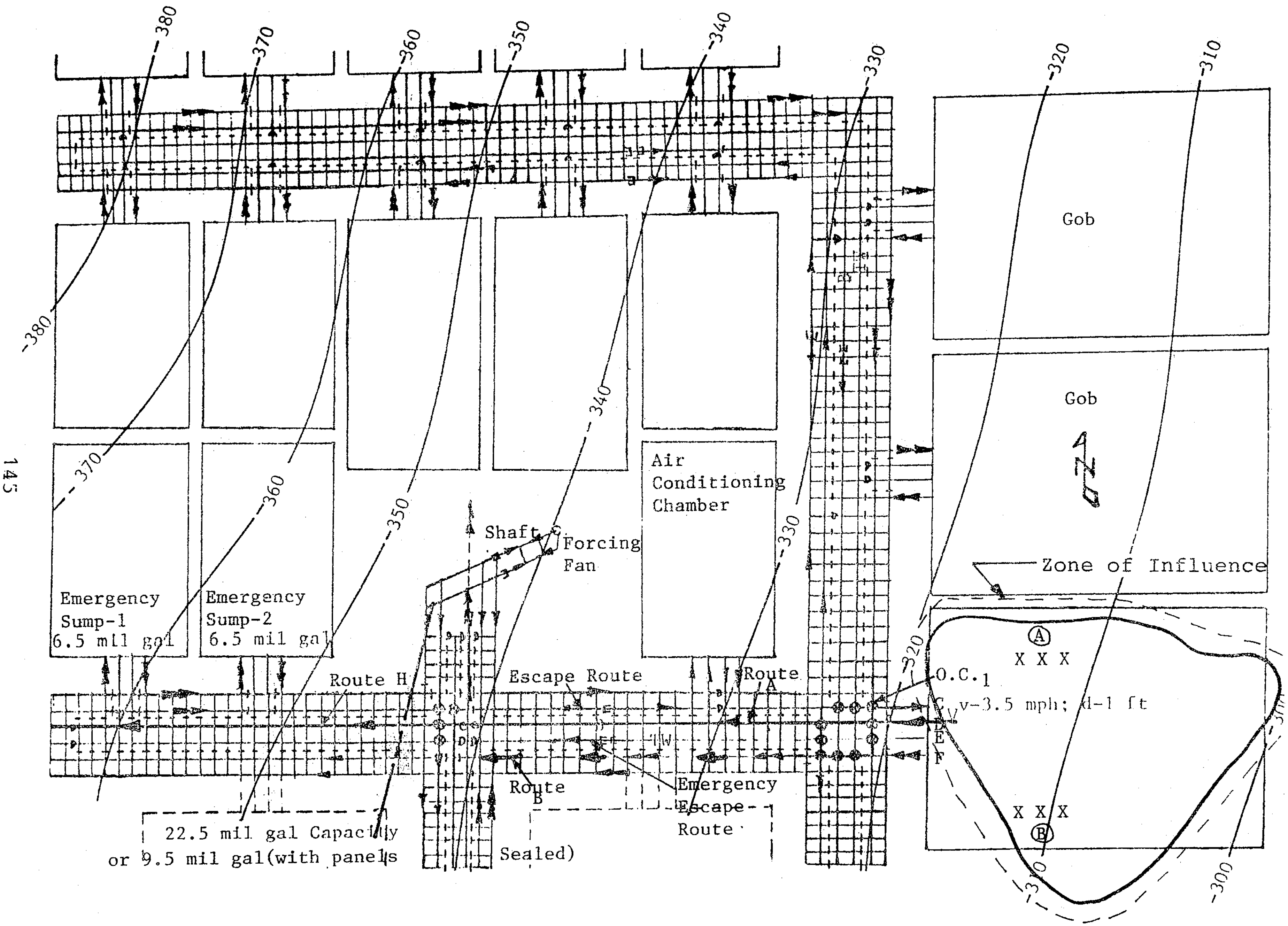


Figure 34 - Water Hazard Map

Assume that the thickness of the cover below the water body is as given in Table 16 and that the total extraction gives rise to an inflow resulting in the water body draining into the workings. Depending on the place of this inflow marked A or B on the map (Figures 35 and 36), the water will start flowing out of the panel either through the intake entries C, D, or the return entries E, F. Whichever route it takes, the water will flow from a higher point to the lower point. The flow will, however, be channeled by physical barriers like overcasts, stoppings, retaining walls, and muck piles.

An important implication at this stage which will need special consideration is the competency of these physical barriers. To what an extent these will have to be relied upon for channeling water flow for safety of persons and the mine is another important factor. For instance, in this case the water from area A may initially try to flow out through entry C but will be channeled through belt entry D after it encounters overcast S_1. Should the flow break the walls of this and other succeeding overcasts, then it will follow a different route. The water thus channeled through entry D will keep flowing downhill until it reaches mine bottom, where depending on the location of stoppings or doors it will again get channeled before going down into the emergengy sump. It shows that the following main factors will affect the safety of the workers, equipment, and the mine:

- the probable rate of inflow
- the gradient of the workings
- escape considerations for workers
- channelization of flow
- availability of escape routes
- water storage capacity
- size of the water body
- pumping capacity
- economic considerations.

As discussed in Section 6, inflow from a surface water body resulting from total extraction at a cover specified in Table 16 can occur if the permeability of the successively higher layers keeps on increasing right up to the ground below the water body. This increase in permeability affects each successive higher layer as the area of extraction increases, thus at the start of the inflow, there would be relatively a small area of increased permeability next to the

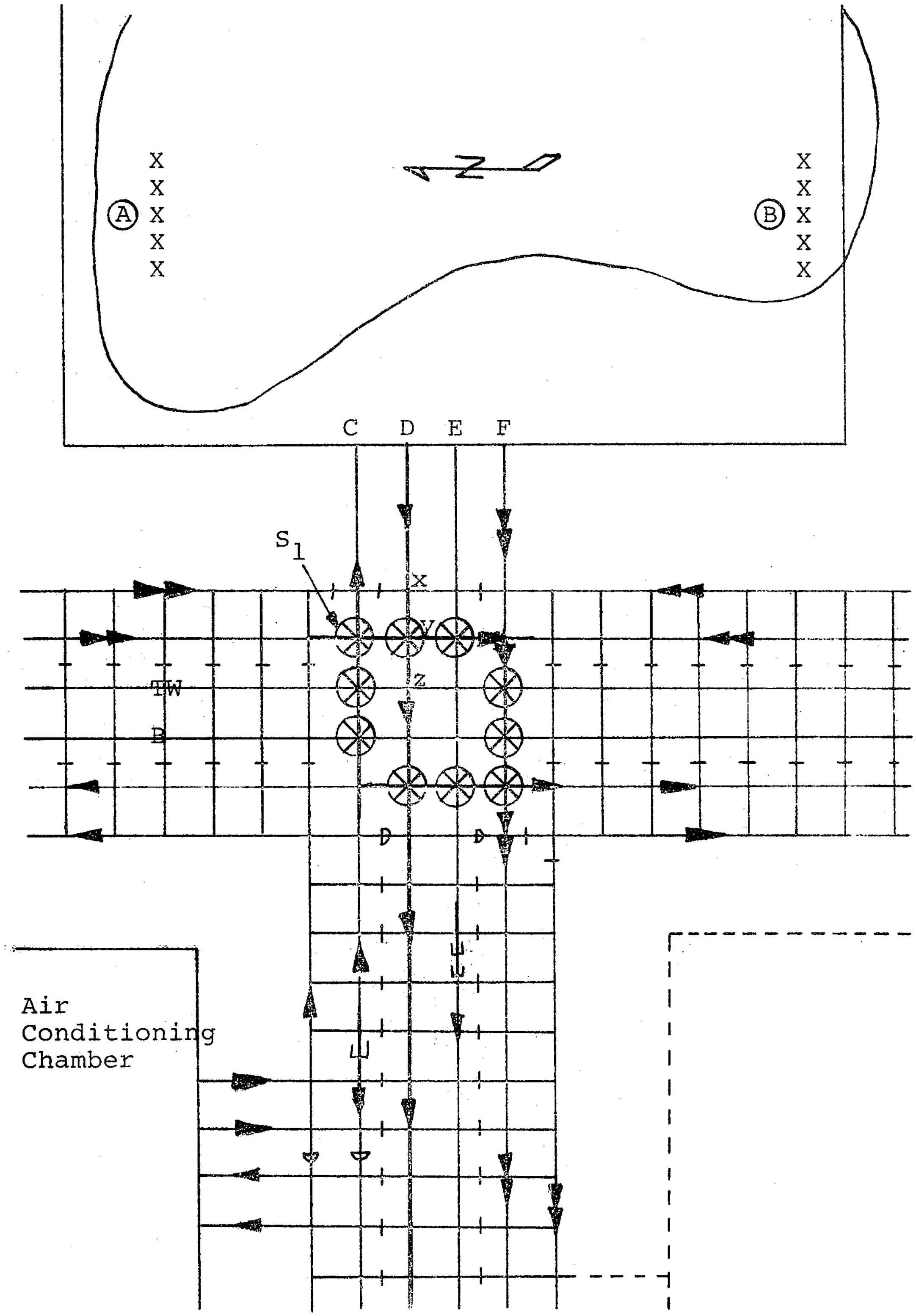


Figure 35- Enlarged View of the Panel Under Extraction Beneath the Water Body

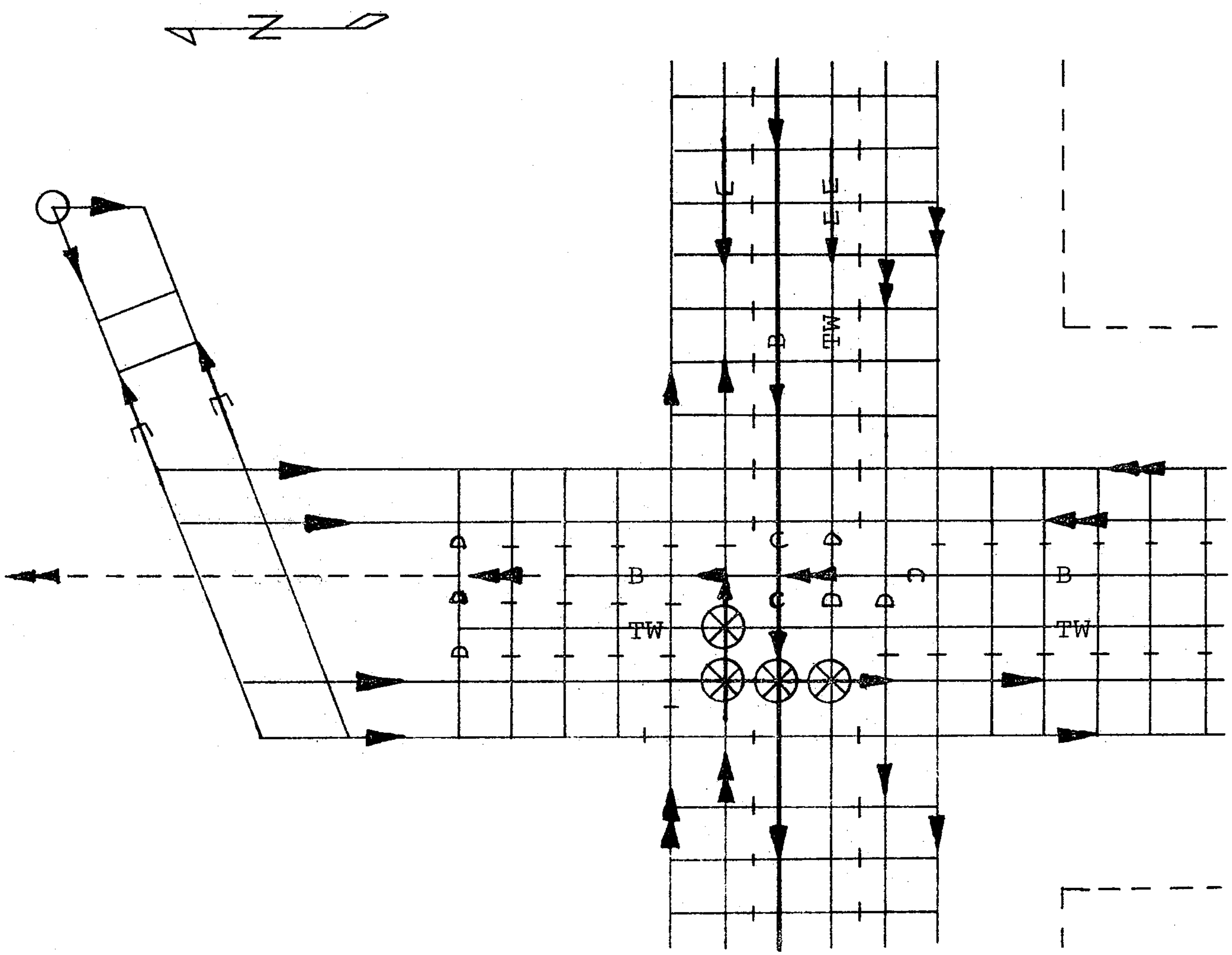


Figure 36- Enlarged View of Shaft Area

water body. Therefore, the initial rate of inflow can likely be coped with. However, in order to take unforeseeable geological anamolies into account, precautions could be taken for sufficiently higher rates of inflow.

Both the direction and the amount of gradient of the mine entries are important. The layout of the workings will have to be suitably planned in order to provide for adequate emergency sump capacity on the down dip side of the water body. In case of steep gradients, flowing water tends to accelerate. This coupled with increased velocity will exert a higher force on a person caught in the flow or who is required to wade through it in order to escape. The gradient also determines the depth of water flow, the height and length of water back-up behind stoppings, overcasts, and other structures. In case of steep gradients, the flowing water may carry or roll appreciable quantities of debris and other materials.

7.3 Wading Through Water

The safety of the workers is of parmount importance. To ensure this, it will be necessary to have escape routes clear of the likely flow routes. This can be achieved by providing an additional emergency escape route or by channelizing the likely water flow route. In either case, it may be necessary for persons to wade through flowing water for some distance in order to get to the proper escape route. Thus, it will be desirable to know the magnitude of the force that will act on a clothed person wading through flowing water. This force is given by the relation

$$F = C_D \rho_W A \ V^2/2$$

Where F = force acting on the person by the flowing water

C_D = drag coefficient

ρ_W = mass density of water

A = area

V = velocity

C_D, the drag coefficient for a person wearing clothes was determined experimentally withing a range of Reynolds Number for 2×10^4 to 5×10^4 and was found to be 2 (University of Kentucky, n.d.).

Area, A, is measured by placing a light parallel to the flow and a screen perpendicular to the light. The area of the shadow cast by the person is measured. The area required is the area of the person submerged in water. It will be noticed that if a person in flowing water turns sideways and side steps, the force on him will be greatly reduced.

With the help of Manning's formula and the above relation, the force acting on a person moving in flowing water with respect to gradient of the roadways, depth of flow, and the rate of flow has been determined for 20, 18, and 16 ft wide mine entries. These forces are given in Tables 22, 23, and 24 and are graphically represented in Figures 37 to 42.

In order to determine the limiting force which will not knock down a person wading through flowing water, several offices were contacted with the hope that one might have carried out a formal study to determine the safe force. The following offices were contacted:

- Office of Naval Research, Chicago, IL
- Naval Research Station, Washington, DC
- Naval Personnel Research and Development Center, San Diego, CA
- Naval Safety Medical Center, Norfolk, VA
- Occupational Safety Center, Norfolk, VA
- Marine and Bridge Laboratory, USAEC, Ft. Belvoir, VA

In addition to the above, several other offices such as the Coast Guard, and the Fish and Wildlife Service were also contacted. All informed that they were not aware of any formal study that might have been carried out to estimate the safe force which a person can overcome to wade through flowing water. However, the Chief of Marine and Bridge Laboratory indicated that a flow of 2 ft depth having a velocity of about 5 ft/sec should be about the safe limit. He indicated that at this intensity of flow, the floating elements of temporary bridges are not stable and they start knocking and rolling. Furthermore, the Army takes 3 ft/sec

Table 22- Force Acting on a Clothed Man for Different Rates of Flow in 20 Feet Wide Entry

Slope	Depth of Flow ft	Velocity miles/hr	Rate of Flow gpm	Submerged Area ft^2	Force lb_f
0.01	0.5	1.8	11,655	0.5	6.7
0.01	1.0	2.7	35,865	1.0	30.3
0.01	1.5	3.5	68,400	1.5	76.5
0.01	2.0	4.1	107,550	2.14	149.7
0.01	2.5	4.6	151,650	3.10	273.0
0.02	0.5	2.5	16,550	0.5	13.0
0.02	1.0	3.9	50,850	1.0	63.3
0.02	1.5	4.9	97,200	1.5	149.9
0.02	2.0	6.0	152,550	2.14	320.7
0.02	2.5	6.5	215,100	3.10	545.2
0.04	0.5	3.5	23,400	0.5	25.5
0.04	1.0	5.4	71,730	1.0	121.4
0.04	1.5	6.9	136,800	1.5	297.3
0.04	2.0	8.1	215,100	2.14	584.4
0.04	2.5	11.5	303,300	3.10	1076.5
0.10	0.5	5.6	36,900	0.5	65.3
0.10	1.0	8.6	113,400	1.0	307.9
0.10	1.5	10.9	216,450	1.5	741.8
0.10	2.0	12.9	339,750	2.14	1482.3
0.10	2.5	14.5	479,250	3.10	2712.9

Table 23- Force Acting on a Clothed Man for Different Rates of Flow in 18 Feet Wide Entry

Slope	Depth of Flow ft	Velocity miles/hr	Rate of Flow gpm	Submerged Area ft^2	Force lb_f
0.01	0.5	1.76	10,450	0.5	6.4
0.01	1.0	2.70	32,060	1.0	30.3
0.01	1.5	3.42	60,995	1.5	72.6
0.01	2.0	4.02	95,510	2.14	144.1
0.01	2.5	4.53	134,495	3.10	264.5
0.02	0.5	2.49	14,780	0.5	12.9
0.02	1.0	3.80	45,200	1.0	60.2
0.02	1.5	4.82	82,395	1.5	144.7
0.02	2.0	5.67	134,800	2.14	286.6
0.02	2.5	6.37	189,110	3.10	523.28
0.04	0.5	3.52	20,910	0.5	25.8
0.04	1.0	5.40	64,100	1.0	121.1
0.04	1.5	7.47	133,090	1.5	348.0
0.04	2.0	8.05	191,210	2.14	576.6
0.04	2.5	9.03	268,244	3.10	1053.1
0.10	0.5	5.57	33,060	0.5	64.4
0.10	1.0	8.53	101,285	1.0	302.3
0.10	1.5	11.80	210,285	1.5	869.7
0.10	2.0	12.72	302,110	2.14	1440.3
0.10	2.5	14.27	423,825	3.10	2627.7

Table 24- Force Acting on a Clothed Man for Different Rates of Flow in 16 Feet Wide Entry

Slope	Depth of Flow ft	Velocity miles/hr	Rate of Flow gpm	Submerged Area ft^2	Force lb_f
0.01	0.5	1.75	9,250	0.5	6.39
0.01	1.0	2.67	28,245	1.0	29.73
0.01	1.5	3.38	53,605	1.5	71.41
0.01	2.0	3.96	83,640	2.14	139.78
0.01	2.5	4.45	117,460	3.10	255.78
0.02	0.5	2.47	13,040	0.5	12.68
0.02	1.0	3.77	39,830	1.0	59.17
0.02	1.5	4.77	75,580	1.5	142.22
0.02	2.0	5.58	117,930	2.14	277.76
0.02	2.5	6.27	165,620	3.10	507.71
0.04	0.5	3.50	18,490	0.5	25.56
0.04	1.0	5.35	56,490	1.0	119.24
0.04	1.5	6.77	107,205	1.5	286.20
0.04	2.0	7.92	167,275	2.14	559.12
0.04	2.5	8.90	234,925	3.10	1021.56
0.10	0.5	5.53	29,220	0.5	63.79
0.10	1.0	8.45	89,260	1.0	297.53
0.10	1.5	10.69	169,385	1.5	713.62
0.10	2.0	12.51	264,295	2.14	1394.33
0.10	2.5	14.06	371,180	3.10	2550.47

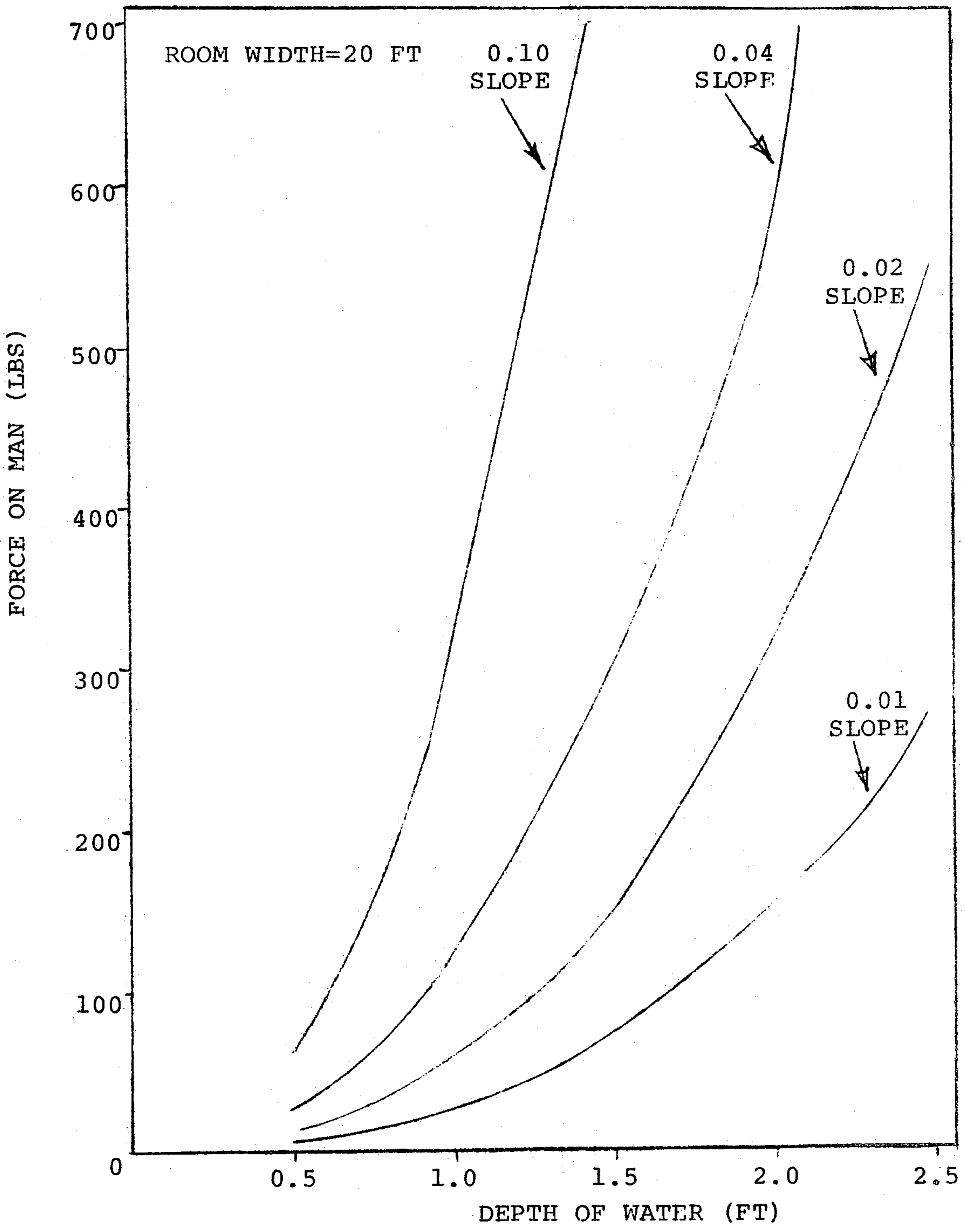


Figure 37 - Force Acting on a Clothed Man at Various Depths of Flow

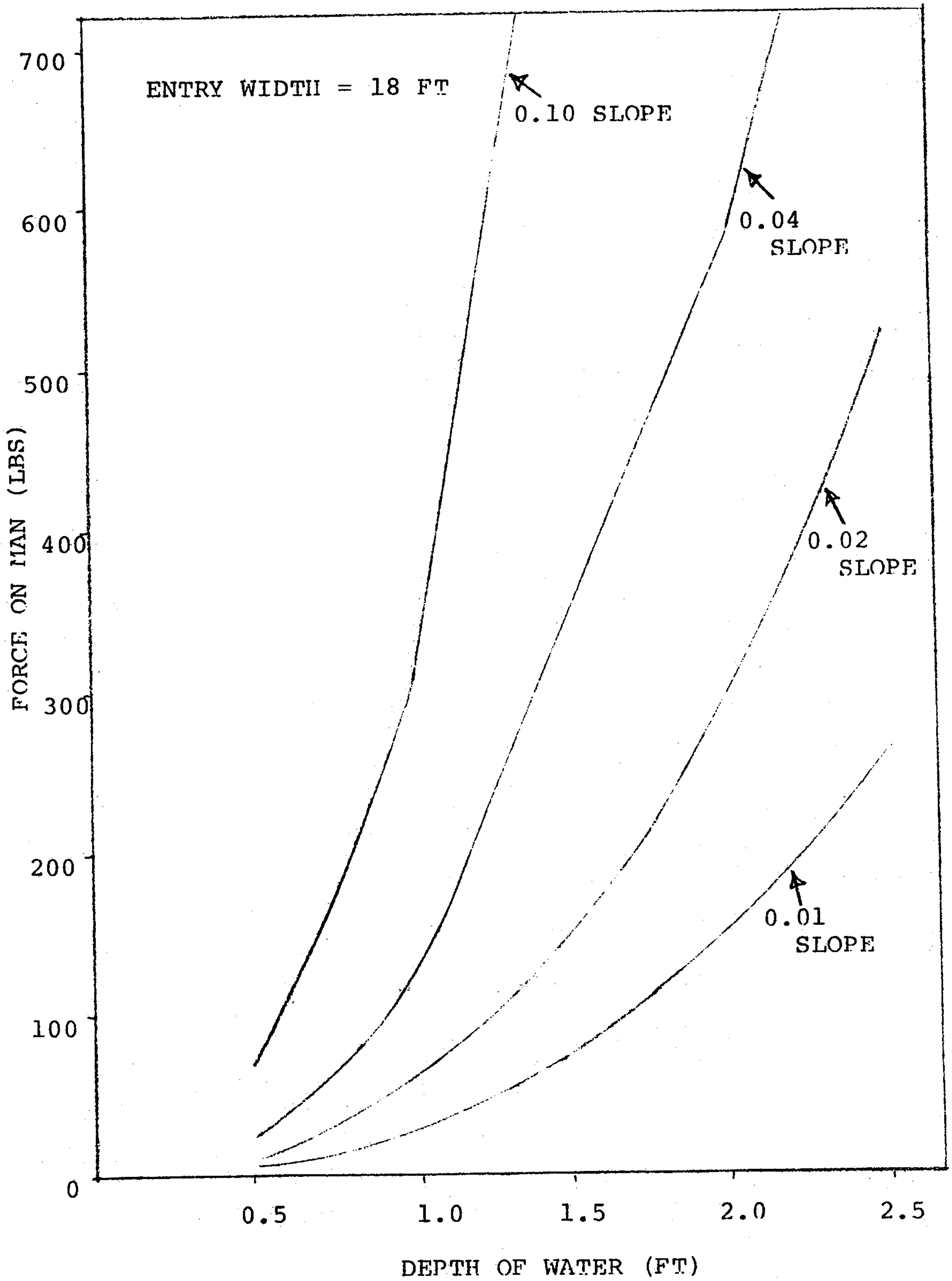


Figure 38 - Force Acting on a Clothed Man at Various Depths of Flow

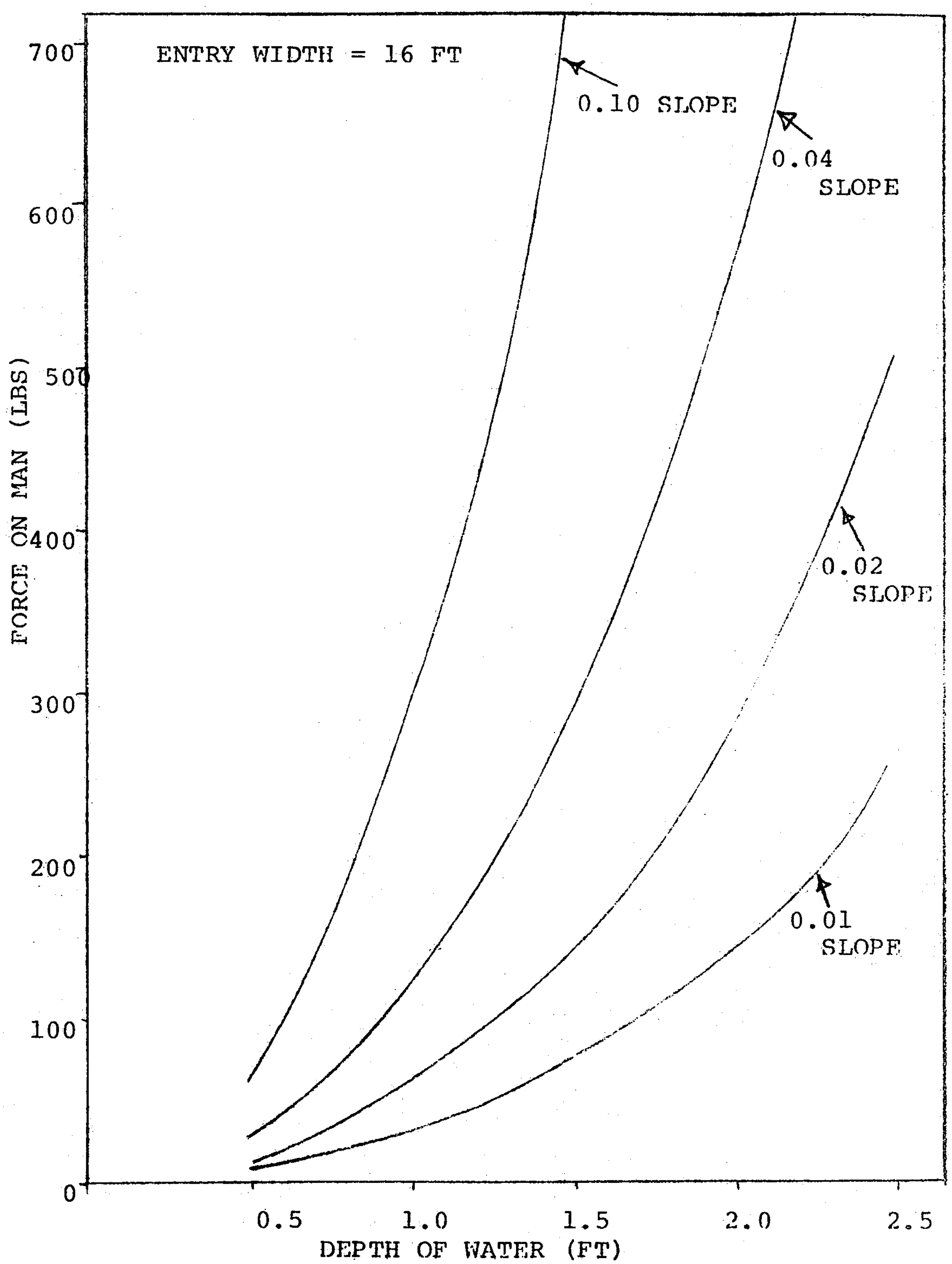


Figure 39- Force Acting on a Clothed Man at Various Depths of Flow

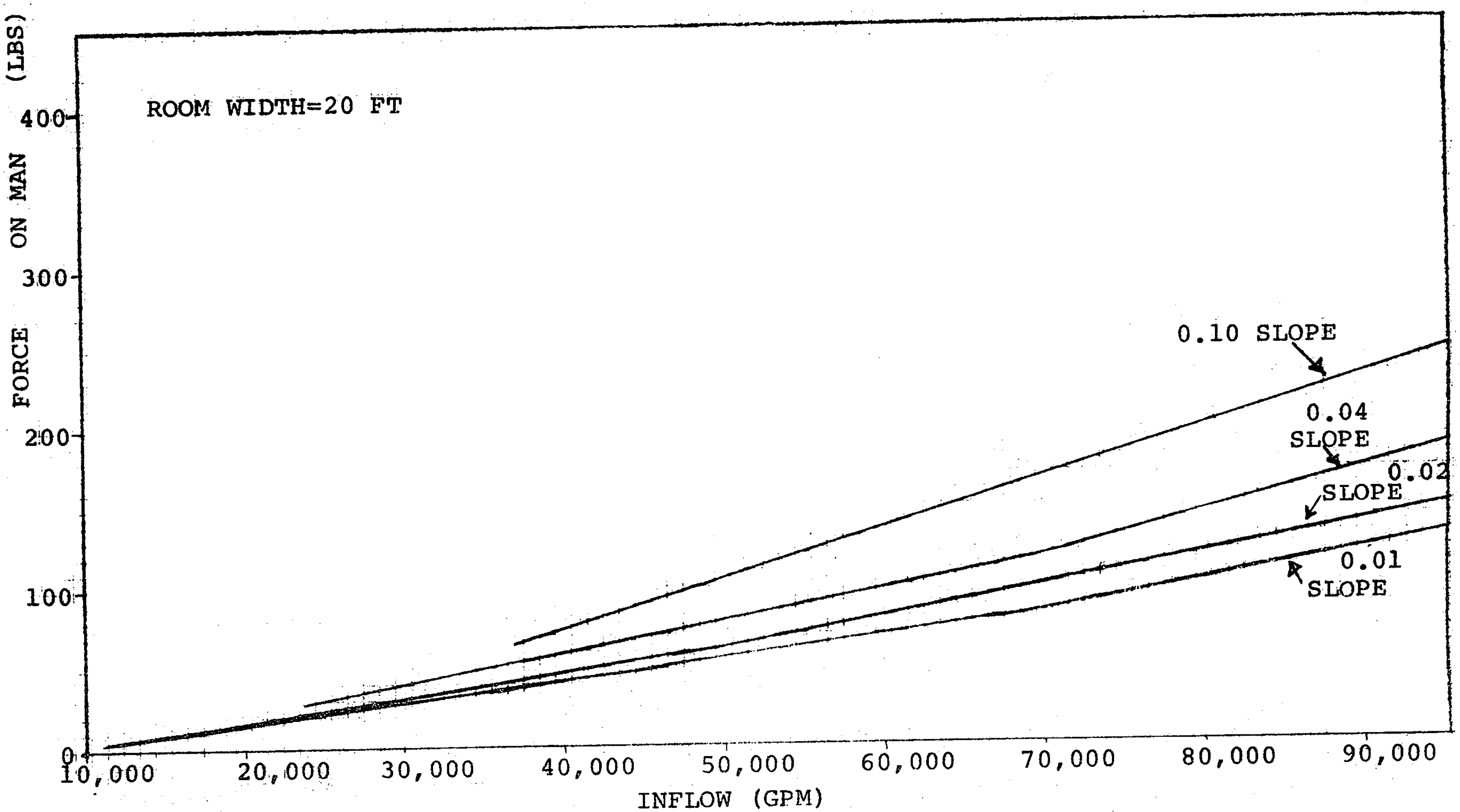


Figure 40- Force Acting on a Clothed Man at Various Rates of Flow

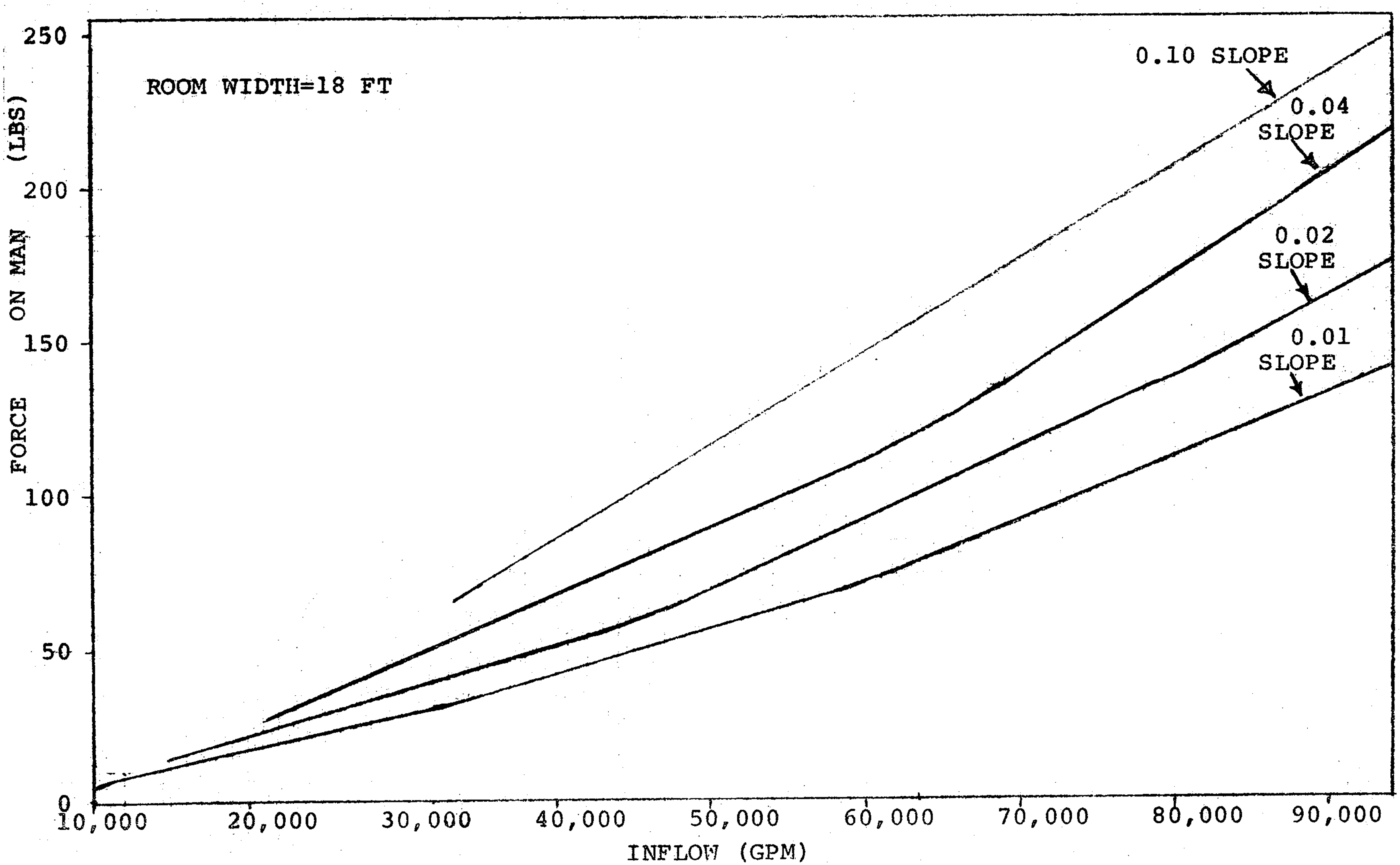


Figure 41 - Force Acting on a Clothed Man at Various Rates of Flow

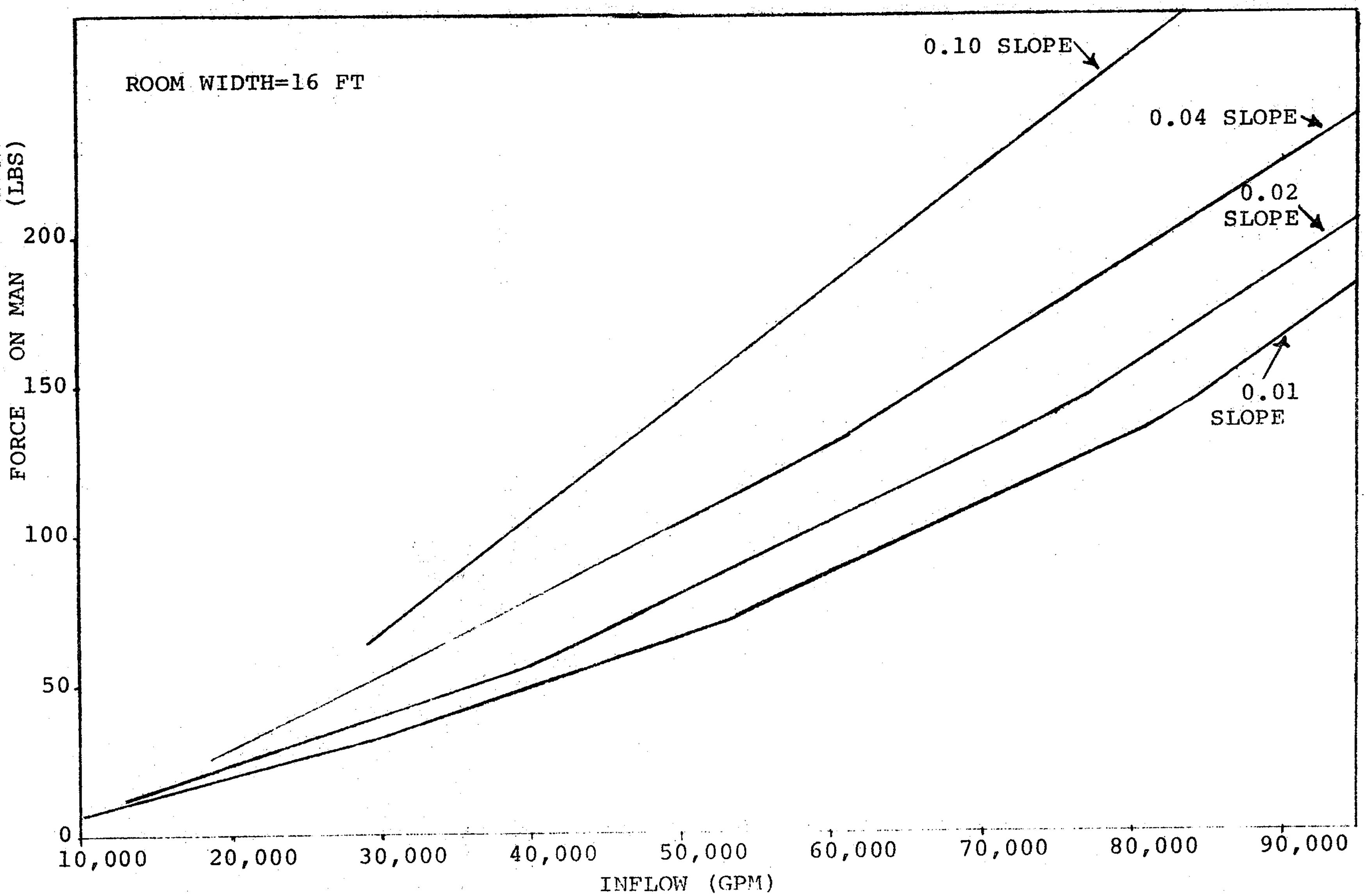


Figure 42 - Force Acting on a Clothed Man at Various Rates of Flow

as the maximum flow that a soldier in combat gear can wade, which is similar to a miner with lamp, self-rescuer, tools, and so on. Corresponding to this estimate a force of 100 pounds can be assumed as the safe force. Table 25 shows the rates of flow corresponding to 100 pounds acting on a person for different entry widths and gradients. It will be seen from Table 25 that the miners can escape to safety by wading through flow rates from 38,500 gpm to 82,000 gpm depending on the width and gradient of the entry. This is a substantial rate of flow and is much more than the likely inflow rate should an inflow occur while undermining a surface water body.

These safe flow rates are for clear water. Should the flow consist of mud or sand or other silty material, the safe flow rates will be much smaller. Also, a discount needs to be kept for floating materials in the flow. For this reason, it will be desirable to keep all routes which the water may take free from loose floatable materials

7.4 Mine Planning for Water Flow

Water will flow from a point at higher elevation to points at lower elevation. Referring to Figure 35, it will be seen that the water flowing down entry D will try to divide at junctions such as x, y, and z. The entries dip toward West and North in this case. Therefore, at junction x the water will have a tendency to divide toward North and West in a proportion depending on the gradients in the two directions. In this case, the water flowing toward North will hit the ventilation stopping. If the stopping is not ruptured, the water will back-up and keep flowing down the belt entry D toward the West. At junction y, the walls of the overcast will keep the water flowing down dip toward the West. However, at junction z, the water will divide itself and a part of it will flow toward the North. As the gradient toward the North is less than that toward the West, and the energy required for water to change direction of flow being appreciable, the quantity that may flow toward North will be small in comparison with the quantity of flow in the straight direction toward the West. Thus, the main flow of water will continue down grade as shown in Figure 34. However, if the walls of the overcasts and stoppings are not strong enough to withstand the head of water that may build up against them, they will rupture and the flow will then take a different route.

Table 25 - Rates of Flow Corresponding to $100\ lb_f$ Acting on an Average Man

Seam Gradient	Safe Depth of Flow (ft)	Rate of Flow (gpm)		
		Entry Width		
		20 Feet	18 Feet	16 Feet
0.10	0.62	55,000	45,000	38,500
0.04	0.90	63,000	55,000	48,750
0.02	1.25	73,000	63,000	58,250
0.01	1.90	82,000	74,500	65,500

Note:

1. The entry height shall not be less than the depth of flow plus 1.5 feet Air space.
2. The entries should be free from depressions.

7.4.1 Strength of Stoppings

In order to take suitable precautions for the safety of workers, material, and the mine, it is essential to know the likely route of flow. As this may depend on the strength of the stoppings or the walls of the overcasts, a detailed analysis was carried out of the strength in flexure of the walls commonly used in mines for construction of stoppings and overcasts. The basis and details of analysis are given in Appendix D. Based on this analysis, the heads of water which concrete block walls of different thicknesses can withstand have been computed and are given in Tables 26 and 27 and depend on the type of mortar, the width of the entry, and whether they are keyed into floor and ribs with top free or they are keyed into floor only with the remaining three sides free. Thus, in order to channelize the flow through suitable routes to the emergency sump, the stoppings and walls should be properly constructed according to these Tables and other applicable specifications for an assumed rate of inflow depending on the size of the water body and the thickness of cover. The stoppings can also be designed in such a manner that they will rupture with a small head of water, if it is so required to channelize the flow.

In the event of an inflow, the safety of persons will primarily depend on the availability of suitable escape routes. Thus, in addition to the one escape route which is generally provided, an additional emergency escape route should also be provided as indicated in Figure 34. The escape routes should be free from low spots so that even if water is flowing through them, they will provide sufficient air space above the water level to enable persons to breathe while escaping.

7.4.2 Capacity of Emergency Sumps

The safety of the workers and the equipment will largely depend on the emergency sump capacity. This capacity will be planned depending on the size of the surface water body. The available storage capacity of the emergency sumps should not be less than that of the mine-life flood volume of the water body. In the case referred to in Figure 34, if the volume of the water body is more than 22.5 million gallons and should an inflow take place and all the water flows down the steepest gradient toward the emergency sumps, the water level will rise above the shaft entries and may totally cut off the outlets

Table 26 - Safe Heads of Water in Inches of Concrete Block Walls of Different Thicknesses Keyed into Floor and Ribs.

3 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT (w)	25	29	30	35	36	40	41	46
	18 FT (w)	25	29	30	35	36	40	41	46
	20 FT (w)	25	29	30	35	36	40	41	46

5 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT	25.5	28.5	30	35	36	41.5	41.5	47.5
	18 FT	24	27	29	33.5	35	41	40	46
	20 FT	23	25	29.5	32.5	34	40.5	39.5	45

8 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT	20	30	32	36	36	41.5	40	47.5
	18 FT	19.5	28	31.75	35	36	40.5	39.75	46
	20 FT	18	24	31.5	34	36.5	39.5	39.5	45

Note:

1. Based on the assumption that the wall is keyed into the floor and both ribs and has its top free.
2. N, M and S represent types of mortar.
3. The walls should comply with the specifications of the National Concrete Masonry Association.

Table 27 - Safe Heads of Water in Inches for Concrete Block Walls of Different Thicknesses Keyed into the Floor Only.

3 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT (w)	25	29	30	35	36	40	41	46
	18 FT (w)	25	29	30	35	36	40	41	46
	20 FT (w)	25	29	30	35	36	40	41	46

5 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT	25	28.2	31+	35	35.75	41	41+	46
	18 FT	25	28.1	31-	34.5	35.5	40.5	41-	45.5
	20 FT	24.5	28	30.5	34	35	40	40	45

8 FT High Wall

		6 inches (z)		8 inches (z)		10 inches (z)		1 FT (z)	
		N	M or S	N	M or S	N	M or S	N	M or S
Wall Width	16 FT	21	28	31.5	37	36	42	40	46.5
	18 FT	20.5	27	31	36	35.5	41	39.5	45.5
	20 FT	20	26	30.5	35	35	40	39	44.5

Note:

1. N, M and S represent types of Mortar.
2. The walls should comply with the specifications of the National Concrete Masonry Association.

and the air supply. This can lead to disastrous consequences, such as cut-off of escape routes from the mine making the rescue and recovery operations extremely difficult, the loss of production, and the damage to the equipment that may be submerged under water. Obviously, in this example, the available water storage capacity of the emergency sumps 1 and 2 along with a part of the main dip entries is about 22 million gallons which represents the critical volume of the surface water body. Of course, the sump capacity can be increased by working additional panels on the west or south sides which then becomes the critical volume.

The emergency sumps consist of in-seam panels developed by the room and pillar method and left standing on pillars. The pillars could be extracted later after completing the extraction below the water body. Alternatively, it may consist of panels which have been totally extracted and the gobs are maintained free of water accumulation. The water capacity coefficients of gobs depending whether the panel was extracted by longwall or room and pillar method and whether the gob was hydraulically or otherwise packed have been determined by a regression analysis of several Polish mining situations, and are given in Table 28 (Rogoz, 1978). The available water storage capacity of each panel then can be determined by multiplying the total volume of the panel by the suitable coefficients from this Table.

The emergency sumps must be located on the dip side of the water body to take advantage of the gravity drainage. Unlike the case given in Figure 34, the sumps should be located away from the mine bottom if practicable, in order to keep the main outlets and the escape routes free from water flows.

In most mines, 50 to 100% stand-by pumping capacity is provided. There are only a few coal mines which pump out water in excess of 2000 gallons per minute in the United States at present. Most mines have much smaller pumping rates. On the other hand, there are mines like West Driefontein in Transvaal, South Africa, where nearly 32 million gallons of water are pumped out daily, and the available pumping capacity is on the order of 63 million gallons per day. In this case, an inflow from a small volume surface water body may

Table 28 - Gob Water Storage Coefficients
(after Rogoz, 1978)

Depth ft	Rock Pressure psi	Longwall Caving	Hydraulic Filling	Packing
500	550	0.26	0.35	0.15
1000	1100	0.25	0.24	0.12
1500	1650	0.23	0.19	0.091
2000	2200	0.22	0.14	0.073

Coefficients (in the metric system of MN/m^2 and m) are calculated from regression equations:

Longwall caving: $0.275e^{-0.0147(\text{rock pressure})}$

Hydraulic filling: $0.485e^{-0.00205(\text{depth})}$

Packing: $0.4-0.19(\text{rock pressure})^{0.2}$

not pose any problem to the mine, the entire inflowing water being taken care of by the stand-by pumping capacity. Whereas, mines which have a small installed pumping capacity may find it more economical to provide emergency sumps rather than install substantial stand-by pumping capacity at considerable expense and which may never be used. Moreover, even if a mine may decide to intall additional pumping capacity, it will be hard to know its value because the rate of inflow can not be predicted. Thus, it appears that the provision of an emergency sump capacity will be a better choice in many cases in the event of an inflow from a major potential sized water body. Subsequently, the sump could be drained gradually by the available stand-by pumping capacity with very little additional expense.

7.4.3 Overall Planning Considerations

The decision to go ahead with total extraction below a surface water body at a cover thickness of less than the stipulated minimum which will require additional precautions to be incorporated in the mine plan, will primarily depend on the cost of these precautions and the economic gain which will accrue as a result of higher percentage recovery. Therefore it is pertinent that the cost of these precautions is assessed carefully. The cost of providing emergency sumps is minimal as they will be in-seam in most cases. The additional cost may involve construction of stoppings, retaining walls, or water seals.

The channelization of the inflow into the emergency sumps may also involve construction of a few additional walls and strengthening or weakening of some of the existing stoppings or walls of the overcasts. The provision of an emergency escapeway will also involve some additional cost of cleaning and supporting it.

Loss of production may be minimized by proper location of the emergency sump, so that it is limited to the period of inflow only. Damage to equipment and plant can also be avoided by providing for channelization of any unexpected inflow. The other factors which will need to be considered are:

- compensation which may be required to be paid in the event of the water body draining into the mine.

- the likely additional cost involved in pumping out the water.

- the probable cost of repair of the roadways, belt conveyors, track, stoppings, overcasts, and of cleaning the roadways and resupporting them where necessary.

Besides conservation, the economic gain of increased recovery can be substantial. For example, the coal reserves locked up in a 4 ft thick seam below a surface body of water having a mine-life flood areal extent of 750,000 square ft (1000 ft x 750 ft) are nearly 150,000 tons. The recovery by total and partial extraction methods will be approximately 120,000 and 75,000 tons respectively. Thus, an additional recovery of nearly 45,000 tons of coal can be expected by resorting to total extraction which can mean a substantial economic gain.

8.0 HAZARD DETERMINATION METHODS

IT SHOULD BE NOTED THAT A SUGGESTED STEP-BY-STEP PROCEDURE FOR HAZARD DETERMINATION HAS BEEN SUMMARIZED AS APPENDIX E OF THIS REPORT AND INCLUDES A SUGGESTED APPLICATION FORMAT TOGETHER WITH SUGGESTED GUIDELINES FOR MINING.

8.1 Hazard Recognition

The main hazards of undermining a surface water body can arise if it drains into the mine workings. The draining may be sudden or gradual depending on the manner by which the inflow is initiated. A sudden inrush can be precipitated due to induced fractures or the presence of fissures, cracks, and faults which may provide direct "pipelines." Gradual drainage will depend on the absence of impermeable strata in the aquiclude zone. The degree of hazard will also depend on the size and shape of the water body, whether it is of catastrophic or major potential size and whether it is of the finite or replenishing type.

Other direct and indirect hazards are associated with mine flows which will include pumping cost, electrical hazards, damage to equipment, cleaning of roadways after the inflow, loss of production, reduced efficiency of equipment and crews, increased maintenance of equipment, chances of injury or loss of life, morale, and reduced stability of ribs and the roof (Loofbourow and Brittain, 1964; Greeslade, 1979).

The following factors will have to be considered in order to make an assessment of the degree of hazard:

- catastrophic or major potential size of the water body
- finite or replenishing
- depth
- presence of water barriers in the "aquiclude zone"
- mine-life water body flood stage
- capacity of storage area
- pumping capacity
- water hazard mine map
- other hazard acceptability factors like safety of personnel, permanent loss of resource, and undue financial risk.

From the foregoing, a potential inundation hazard may be recognized by the following steps:

1. If a water body is flowing, full extraction mining may not be carried out within a designated distance of the water body bottom, unless inflow is channeled to sumps and inflow is less than pumping capacity, and other depth and strata criteria are met.

2. If a water body is non-flowing, and if mining by total extraction within a designated distance of the bottom of the water body, water inflow must be channeled into emergency sumps with a volume larger than the water volume, and other depth and strata criteria are met.

3. If a water body is non-flowing, and small enough in volume so that the determined inflow rate and volume allow time for a person to wade through the water a distance equal to the longest blocked, dead-end, or blind entry to safety and ponded depth is everywhere 1.5 ft less than mined height, and not more than 4.5 ft deep mining may proceed by total extraction at any depth.

Several methods are available for determining the water body size and flow rate for identifying the limited potential size water body. Visual estimates by persons not specifically trained in hydrology can be extremely misleading and are almost universally severe underestimates of volume or flow. Barnes (1967) has provided a useful aid to such field estimetes in that color photographs of numerous streams in varying locales and environments are given followed by measured peak discharges indicative of mine life flood stages. Apparently small "quiet" streams such as Clear Creek near Golden, CO, and Salt Creek near Roca, NE, have measured peak discharges of 618,000 gpm and 833,000 gpm!

Darcy's Law may be used to determine possible flows by conservatively using a permeability of about K = 100,000 gpd/ft^2 as for a good aquifer (Davis and DeWiest, 1966) so that for a 20 ft wide x 6 ft high entry at 200 ft depth in water-charged strata below a 10 ft deep water body with a direct crack or fissure connection to a rubble filled collapsed area 36 ft high (6t):

$$Q = KA\frac{h_1}{L}$$

where $K = 100{,}000\ \text{gpd/ft}^2$

$A = 20 \times 6 = 120\ \text{ft}^2$

$h_1 = 200\ \text{ft}$

$L = 36\ \text{ft}$

and $Q = 46{,}000\ \text{gpm}$

Alternatively, the method of Goodman, et al. (1964) may be used where

$$Q = \frac{K(D+d)q \times 1.39 \times 10^{-3}}{\log\ (D/s)}$$

where $K = 100{,}000\ \text{gpd/ft}^2$

$q = 60\ \text{ft}$

$D = 200\ \text{ft}$

$d = 10\ \text{ft}$

$s = 20\ \text{ft}$

and $Q = 92{,}000\ \text{gpm}$ if the water enters through an area 1 ft wide the full width of the entry.

The first method, Darcy's Law, assumes laminar steady flow, and the second method assumes no drawdown of the water, so neither are totally satifactory. However, no case histories of inflows exceed 100,000 gpm, so the results are reasonable. Since one may arrive at almost any desired inflow rate by properly adjusting permeabilities and geometries, the case history data may be more instructive.

It is recognized that the inflow rate at the point of the break-in will be considerably reduced as the flow spreads out downstream. However, for this work it is assumed that the break-in occurs quite close to the area of interest so that the initial flow rate is the in-mine flow rate.

8.2 Determination of Limited Potential Water Body

If a flow of 100,000 gpm is assumed, Tables 22, 23, and 24 give water velocities and forces on persons in the water. It is suggested here that the rate of progress for a person walking in flowing water be taken as 50 ft/min, but further work should be carried out to refine this number for various situations. Also, a "confusion time" of 2 minutes is suggested to allow time for a person to realize that a problem exists and to get out of equipment he may be in.

Since a person can apparently walk through flowing waters of this magnitude, he can reach safety if he is at the face and the slope is away from the face. However, the water will begin to pond downdip somewhere.

Accordingly, the limited potential size of a non-flowing water body may be computed by considering first the time for a person to walk out of a blind entry before it is filled to a depth of not more than 4.5 ft or not less than 1.5 ft breathing space.

The length of an entry being filled may be found by

$$L = \frac{4.5}{h_1} \text{ for extraction height more than 6 ft, and}$$

$$L = \frac{t-1.5}{h_1} \text{ for extraction height less than 6 ft,}$$

where L = length of entry

h_1 = slope of entry

t = extracted seam height.

Table 29 presents this information for various extraction heights and slopes of entries.

The rate of filling of a single entry may be found by computing the volume for extraction heights more than 6 ft high by:

Table 29- Safe Length of Water Filled Entries in Feet

Slope Of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	300	500	700	900	900	900	900	900	900	900
0.01	150	250	350	450	450	450	450	450	450	450
0.02	75	125	175	225	225	225	225	225	225	225
0.04	37.5	62.5	87.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
0.06	25	42	58	75	75	75	75	75	75	75
0.08	19	31	44	56	56	56	56	56	56	56
0.10	15	25	35	45	45	45	45	45	45	45

$$m = \frac{1}{2} \times \frac{4.5^2}{h_1} \times s \times 7.5$$

where m = volume of water in gallons

h_1 = slope of entry

s = width of entry

and for a single entry with extraction height less than 6 ft high by

$$m = \frac{1}{2} \times \frac{(t-1.5)^2}{h_1} \times s \times 7.5$$

where t = extracted height of seam.

Tables 30, 31, 32, and 33 give the safe volume in gallons for entries of various heights and slopes. Divide the volume m by the inflow rate Q (100,000 gpm) to obtain the filling rate in minutes. If several entries are parallel, one will fill preferentially because none are exactly equal in level.

To determine the maximum size of a limited potential water body

1. Assume an inflow rate of 100,000 gpm
2. Assume a walking rate of 50 ft/min plus a lead "confusion time" of 2 minutes
3. Knowing extracted height and slope of entry find safe length of water filled entry in Table 29
4. If maximum length of blind entry is less than safe length of water filled entry from step 3, use in further steps instead, otherwise use length obtained in step 3
5. Compute escape time by dividing length of entry in ft obtained in either step 3 or 4 by 50 ft/min and then adding 2 minutes confusion time from step 2

Table 30- Volume of Water in 20 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	33,750	93,750	183,750	303,750	303,750	303,750	303,750	303,750	303,750	303,750
0.01	16,875	46,875	91,875	151,875	151,875	151,875	151,875	151,875	151,875	151,875
0.02	8,438	23,438	45,938	75,938	75,938	75,938	75,938	75,938	75,938	75,938
0.04	4,219	11,719	22,969	37,969	37,969	37,969	37,969	37,969	37,969	37,969
0.06	2,813	7,813	15,313	25,313	25,313	25,313	25,313	25,313	25,313	25,313
0.08	2,110	5,860	11,484	18,984	18,984	18,984	18,984	18,984	18,984	18,984
0.10	1,688	4,688	9,188	15,188	15,188	15,188	15,188	15,188	15,188	15,188

Table 31- Volume of Water in 18 ft Wide Entry in Gallons

Slope of Entry, hl, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	30,375	84,375	165,375	273,375	273,375	273,375	273,375	273,375	273,375	273,375
0.01	15,188	42,188	82,688	136,688	136,688	136,688	136,688	136,688	136,688	136,688
0.02	7,594	21,094	41,344	68,344	68,344	68,344	68,344	68,344	68,344	68,344
0.04	3,797	10,547	20,672	34,172	34,172	34,172	34,172	34,172	34,172	34,172
0.06	2,531	7,031	13,781	22,781	22,781	22,781	22,781	22,781	22,781	22,781
0.08	1,898	5,273	10,336	17,086	17,086	17,086	17,086	17,086	17,086	17,086
0.10	1,519	4,219	8,269	13,669	13,669	13,669	13,669	13,669	13,669	13,669

Table 32- Volume of Water in 16 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	27,000	75,000	147,000	243,000	243,000	243,000	243,000	243,000	243,000	243,000
0.01	13,500	37,500	73,500	121,500	121,500	121,500	121,500	121,500	121,500	121,500
0.02	6,750	18,750	36,750	60,750	60,750	60,750	60,750	60,750	60,750	60,750
0.04	3,375	9,375	18,375	30,375	30,375	30,375	30,375	30,375	30,375	30,375
0.06	2,250	6,250	12,250	20,250	20,250	20,250	20,250	20,250	20,250	20,250
0.08	1,688	4,688	9,188	15,188	15,188	15,188	15,188	15,188	15,188	15,188
0.10	1,350	3,750	7,350	12,150	12,150	12,150	12,150	12,150	12,150	12,150

Table 33- Volume of Water in 14 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	23,625	65,625	128,625	212,625	212,625	212,625	212,625	212,625	212,625	212,625
0.01	11,813	32,813	64,313	106,313	106,313	106,313	106,313	106,313	106,313	106,313
0.02	5,906	16,406	32,156	53,156	53,156	53,156	53,156	53,156	53,156	53,156
0.04	2,953	8,203	16,087	26,578	26,578	26,578	26,578	26,578	26,578	26,578
0.06	1,969	5,469	10,719	17,719	17,719	17,719	17,719	17,719	17,719	17,719
0.08	1,477	4,102	8,039	13,289	13,289	13,289	13,289	13,289	13,289	13,289
0.10	1,181	3,281	6,431	10,631	10,631	10,631	10,631	10,631	10,631	10,631

6. Determine volume of water in a single entry by knowing entry width and using Tables 30, 31, 32, or 33

7. Divide volume obtained in step 6 by 100,000 gpm assumed in step 1 to obtain filling rate in minutes

8. Compare times in minutes obtained from step 5 and step 7, and note which is shortest

9. Compute maximum volume of limited potential water body by multiplying time obtained in step 8 by 100,000 gpm to obtain volume in gallons.

For an example, assume a mine with 20 ft wide entries, 7 ft high, with a slope of 0.005, and maximum length of downdip blind entries of 80 feet. From step 3, Table 29, safe entry length is 900 ft, but maximum blind entry length is 80 ft. Escape time is 80/50 = 1.6 min, + 2 min = 3.6 min. From Table 30, entry volume is 303,750 gallons for a filling rate of 3.04 minutes. Therefore, maximum size of this limited potential water body is 304,000 gallons.

Another example has a mine with 16 ft wide entries, 4 ft high, with a slope of 0.06, and a maximum blind drift length of 200 ft. From step 3, Table 29, safe entry length is 42 ft. Escape time is 42/50 = 0.84 min, + 2 min = 2.84 min. From Table 31, entry volume is 6,250 gallons for a filling rate of 0.06 min. Therefore, maximum size of this limited potential water body is 6,250 gallons.

For flowing streams, the streams flow must all be assumed to enter the mine and not exceed 100,000 gpm and the velocity and depth as determined from Tables 22, 23, and 24, and Figures 40, 41, and 42, should not result in a force greater than 100 lb on a person in the water, and the mine must have pumping capacity in the downdip mine portion to handle the water without allowing it to pond.

For example, for a mine with an entry width of 18 ft and entry slope of 0.02, from Figure 41, a flow of approximately 63,500 gpm is the maximum and available pumping capacity must be equivalent and properly located.

8.3 Required Cover

Thickness of cover for total extraction for water bodies of catastrophic potential size is recommended to be as given in Table 15. Cover for bodies of major potential size will vary from 37t to 105t as suggested in Table 16 depending on the nature of strata in the aquiclude zone. The cover should consist of firm strata as previously explained.

According to the 1978 Code of Federal Regulation, Title 30, Section 75.1716, administered by MSHA, shown in Appendix B, determination of the minimum cover thickness shall be based on test holes drilled by the operator. However, if a shaft or slope exists in the vicinity of the water body, the strata section obtained from it could be regarded as in lieu of a test bore hole. However, it may be noted that several core test holes may be required which will depend on the size of the water body, availability of historic data, availability of information from neighboring mines, and the nature and magnitude of known or expected geological disturbances.

Mining-induced cracks in certain cases may extend to the surface below water bodies, or they may connect the pre-existing fissures and faults, or mining may cause differential movement across fault planes which may provide direct "pipeline" connections to the water body on the surface. Mining-induced cracks, as borne out by the existing evidence, are not likely to extend beyond a height of 30t to 58t above the coal seam under total extraction depending on its height of extraction. Also, tensional cracks on the surface, which may be limited to an average depth of 50 ft, may be induced irrespective of the ratio of depth to seam extraction height.

Inundation of the Port Hood mine in Nova Scotia, Canada, in 1912 is of particular relevance in this case. In this mine a 6 to 7 ft thick seam was worked by the room and pillar method. The pillars were extracted in some areas. The workings were under the sea at a depth of cover of 942 ft which gave a D/t ratio of 135. The mine inflow of 3000 gallons per minute which according to the commission of enquiry was sea water traveling through a nearly vertical fissure. Although subsequent investigators tend to treat the Commission's findings with considerable reservations, such anomalies may exist irrespective of the depth of cover which was considered to be more than adequate in this case. Geologic anomalies are difficult to locate and the detailed investigations to cover such isolated cases may give rise to diminished return on the investment.

8.4 Water Body Size

Mine-life water flood stage for a storm should be determined with respect to each water body on the surface and this should be marked on the water hazard map. The volume of the water contained in each finite body on the surface should be calculated at this flood stage. The depth of water shall be determined by an accepted method. While measuring the depth, the thickness of mud, sand, silt, or other similar materials should also be assessed. It will be noted that an inflow of mud, silt, or sand is much more dangerous than that of water. The combined volume of water, mud, sand, or silt, should be used for designing underground emergency sump capacity. Similarly, the peak discharge of streams should be determined using the mine-life flood stage. The mining method and the stand-by pumping capacity for working below streams should be planned according to these values. The elevation of points at regular intervals along creeks or streams should be determined and recorded on the map.

8.5 Hazard Determination

The suggested method of hazard determination for mining beneath surface waters is summarized in Appendix E in a step-by-step fashion. Also included in Appendix E is a suggested application for mining beneath surface waters. This hazard determination method allows a person with little or no technical background, armed with the appropriate required data, to make a rapid determination of the presence of either Limited Potential or Catastrophic Potential water bodies; and further, if the mine desires to mine with special plans under Major Potential water bodies, (which would otherwise be considered Catastrophic Potential) a suggested application form and planning procedure is given to aid the mine or MSHA in proceeding with such planning, approval, and mining.

9.0 MINE PLANNING FOR AN INFLOW

For undermining major potential surface water bodies the mine plan should incorporate certain precautions, such as provision of in-mine emergency sump capacity, channelization of water, provision of additional emergency escape routes, and adequate stand-by pumping capacity. These precautions are desirable for all sizes of water bodies at all depths of cover but must be taken when the thickness of cover is less than that given in Table 15.

It has been suggested in the earlier sections that only major potential size bodies of water should be undermined with a cover of less than that given in Table 15 for the present. Therefore, it will be necessary to determine whether the size of the body of surface water is of major potential or not. Essentially, it will depend on the available water storage capacity of the emergency sumps specially provided and the available stand-by pumping capacity.

9.1 Pumping

As mentioned earlier, the available stand-by pumping capacity in most existing coal mines seldom exceeds a few hundred gallons per minute, moreover, that will not be generally available at the emergency sump, and can be ignored for all practical purposes. Thus, catastrophic potential surface water bodies can be defined as ones that will exceed the available in-mine water storage capacity of the emergency sump.

The reference to emergency sump is significant in the sense that it is that part of the mine that can be flooded and not unduly interrupt the overall production of the mine. As the water storage capacity of the emergency sump is finite, the water body of major potential size also has to be finite, that is, not flowing.

As oceans, large lakes, large rivers, and streams, have essentially a much larger volume of water than that which can be provided for in the emergency sump, they all have catastrophic potential size. However, those surface creeks which have sufficiently small flow can be undermined by total extraction methods at any depth provided the economics are favorable. The economics can be assessed by following the procedure explained in the example given below:

1. Work out the cost of pumping. For this example it can be assumed to be \$0.20 per 1,000,000 ft-gallons (including cost of water treatment before discharge)

2. Work out the quantity of additional reserves that can be recovered from beneath the creek by adopting a total extraction method. Let it be 5000 tons

3. Let the profit per ton of coal = \$2

4. Total additional profit P_r = 5000 x 2 = \$10,000

5. Let the remaining life of the mine = x = 10 years

6. Let the rate of interest = i = 8%

7. Let Y = sum of money which can be spent every year for additional pumping effort without causing any loss to the mine. It can be worked out by using the capital recovery formula

$$Y = P_r \frac{i(1 + i)^x}{(1 + i)^x - 1}$$

$$= 10,000 \times \frac{0.08(1 + 0.08)^{10}}{(1 + 0.08)^{10} - 1}$$

$$= \$881$$

8. The cut-off rate of flow for this case:

$$= \frac{881}{0.2} \times 1,000,000 \text{ ft-gallons per annum}$$

$$= 8380 \text{ ft-gallons per minute}$$

9. If the workings of the mine are 200 ft deep, the average cut-off rate of flow of the creek will be approximately 42 gpm.

It will be seen from the above example that the cut-off rate depends to a great extent on the remaining life of the mine. If the remaining life of the mine is only 1 year, it may be possible to undermine a creek having an average discharge of over 500 gallons per minute. However, care will have to be taken that the maximum discharge at any time does not exceed that which can be tackled by pumping and available sump capacity. Certain other gains, such as improved recovery, may be considered to outweigh the above economic consideration and the operations in such cases may be carried out under creeks having somewhat higher discharge rates.

9.2 Emergency Sumps

The available water storage capacity of the emergency sump should be larger than the volume of the major potential water body. Care will have to be taken to make sure that all water, in the event of an inflow, no matter where it initiates, is channeled into the sump. The position of stoppings, doors, overcasts, retaining walls, debris heaps, and other structures which may interfere with water flow routes should be carefully logged and their effect on diversion, ponding, and division of water flow will have to be assessed. The specifications of construction of stoppings or other walls located at strategic positions will have to be determined. Based on these specifications, it will be determined whether they will need further strengthening. Flexural strength analyses of walls of different thickness, width, and height are given in Appendix D and may be used. It will also be necessary to make sure that when full, the emergency sump will not interfere with the production from other sections of the mine and it does not cut-off escape routes from other panels.

In view of the many variables involved, it is difficult to estimate the rate of inflow. Therefore, it is not advisable to solely depend on the stand-by pumping capacity. However, if there is no room to provide an emergency sump of adequate size, a smaller sized emergency sump, with adequate stand-by pumping capacity able to deal with the entire inflow within some specified period, may also be considered as an alternative. This stand-by pumping capacity including pipelines should be available at the proper site.

9.3 Water Hazard Map

A separate water hazard map showing the location of bodies of water and their relation to all working places shall be prepared. The map should include the following pertinent information:

- location and mine life flood extent, depth, and volume of surface water bodies
- coal seam contours which are important to determine the likely flow routes, the velocity, and the depth of flows
- locations of entries and aircourses with direction of airflow indicated by arrows
- the likely flow routes in the event of an inrush from the water body
- location of all escapeways including emergency escapeways
- the emergency sump with water storage capacity contours. If caved or filled gobs which are maintained dry are proposed to be used for emergency water storage, their capacity should be worked out by using recommended coefficients given in Table 28
- the construction specifications of the stoppings and the walls of the overcasts or any other structure which may be necessary for channelizing the water current in the event of an inrush

- location and elevation of any body of water dammed or held back in any portion of the mine

- location and extent of adjacent active or abandoned underground workings above, below, or in the same seam. If abandoned workings are known to exist in an area, but exact extent is not known, it should be so indicated. Also, if it is proposed to use any of the old abandoned workings for emergency water storage, they should be indicated.

9.4 Strata Characteristics

In addition to the water hazard map, a profile showing the type of strata and the distance in elevation between the coal seam and the water body involved should be prepared. This should be prepared on the basis of information collected from core test drill holes, shaft or slope sections and measurements of total depth of the water body at regular intervals. The test core drill holes may be drilled from the surface or in the roof from underground workings. It is difficult and expensive to obtain geological information ahead of the workings under large lakes or an ocean, since drilling of core boreholes from a floating platform is very expensive, and seismic surveys by themselves do not give dependable information under all conditions (Watson, 1979). Therefore, reliance may have to be placed on the precautionary advanced boreholes drilled in the roof and ahead of the advancing workings.

9.5 Escape Routes

Another important requirement should show the profiles of the escape routes (Figure 43) including emergency escape routes in order to make sure that there are no depressions or other obstructions which, if filled with water, would cut off the escape of persons.

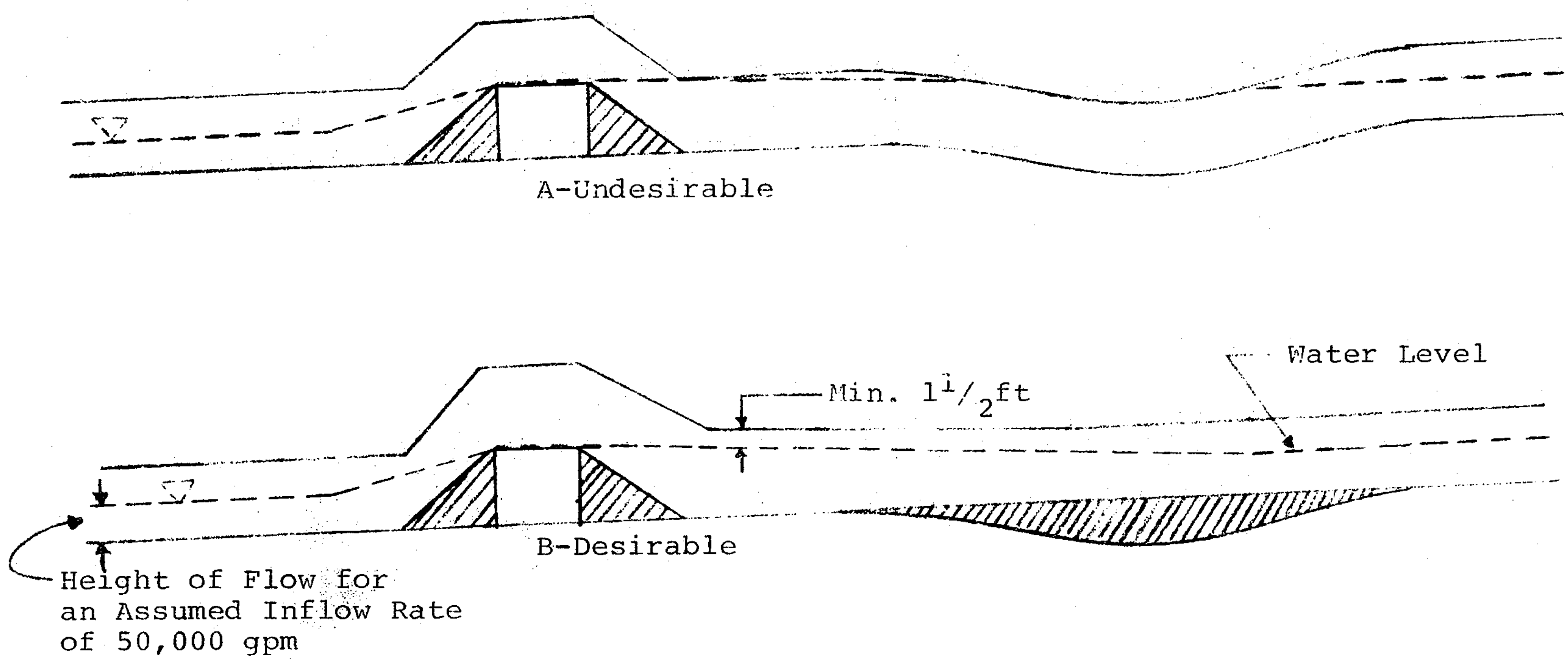


Figure 43 - Profiles Along Escape Routes

9.6 Example Mine Plans

Figures 44 to 51 show several alternative methods of designing emergency sump capacity and channelization of flow routes depending on the location of the water body in relation to the mine workings and the expected area of inflow. Table 34 gives the analyses of these cases including the additional coal reserves that may be recovered on account of total extraction beneath the water body as compared to partial extraction for a seam thickness of 5 ft. The slope of the seam is 0.01. Maximum depth of flow and the maximum velocity of flow that will be encountered for assumed rates of inflow of 50,000 and 100,000 gallons per minute are also indicated. In most of these cases the force on a man wading through the flow is less than 100 pounds, which implies that if the height of the entries is sufficient and the water is free from large quantities of mud or sand, the miners could make their escape to safety. The analyses also show that fairly large sized emergency sumps depending on the availability of area on dip side can be designed.

The safety of the personnel is not likely to be endangered unduly if the inflow can be channelized into the emergency sump specially provided for working below major potential sized water bodies except, perhaps, when it is accompanied with inflow of sand, mud, or other various materials which may inhibit escape. Moreover, if persons are working in the panel in which a heavy inflow occurs and their escape is inhibited by the water flow routes, they may only have to wait until the water body is drained out as the emergency sump has a larger capacity than the water body. Workers employed in extraction of panels below such water bodies may be trained accordingly.

9.7 Preventive Measure

In the Durham and Northumberland Coalfield of the United Kingdom, overhead boring techniques and cement grouting have been used successfully for several years to control inflow of water from the pervious Permian formations for longwall extraction below the sea. Several grout materials by themselves or in combination, such as sulfacrete, silicate of soda and calcium chloride, vermicalite, bentonite, cement, and so on have been tried successfully depending on individual conditions. However, the purpose of grouting was

Figure 44

Legend for Figure 45 to Figure 52

Surface Extent of Water Body	
Perimeter of Panels	
Perimeter of Future Panels	
Entries (centerlines)	
Shaft	
Escape Routes (Emergency Escape Routes)	E EE
Intake Air (fresh air)	
Exhaust Air	
Overcast	
Seam Floor Contours	350
Conveyor Belt Line	B
Track and/or Trolley Wire	TW
Flow Pattern Path (Main)	
Water Line in Panels (locates possible air pockets)	
Sump Fill Rate Line	
Stopping	
Door	D
Entry Seal	
Curtains	C
Maximum Inflow Depth	d-1 ft
Maximum Inflow Rate	∇v- 3.5 mph

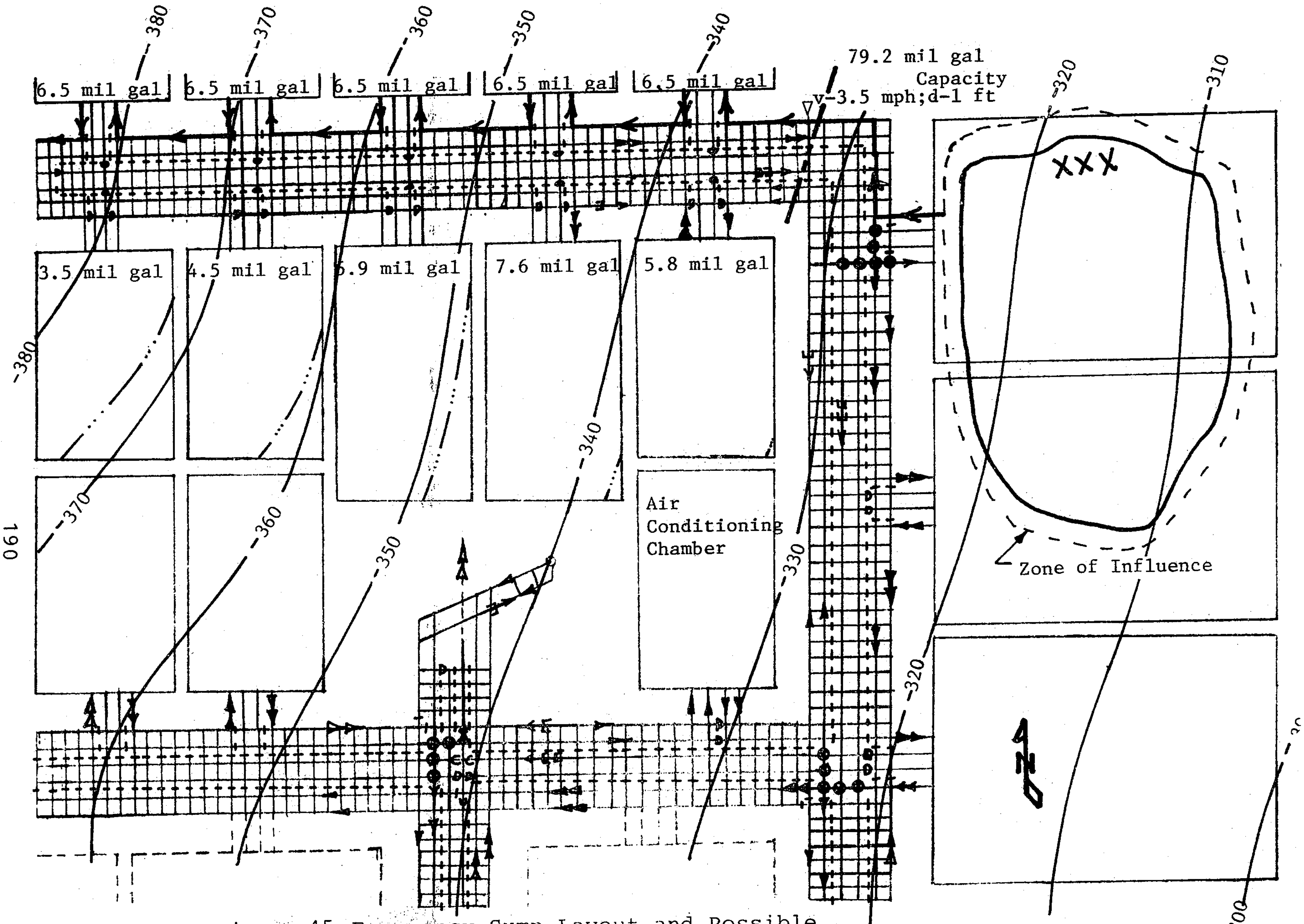


Figure 45.-Emergency Sump Layout and Possible
Flow Routes
Case 1: Sump Panels Standing on Pillars
Case 2: Sump Panels Gobbed but Maintained Dry.

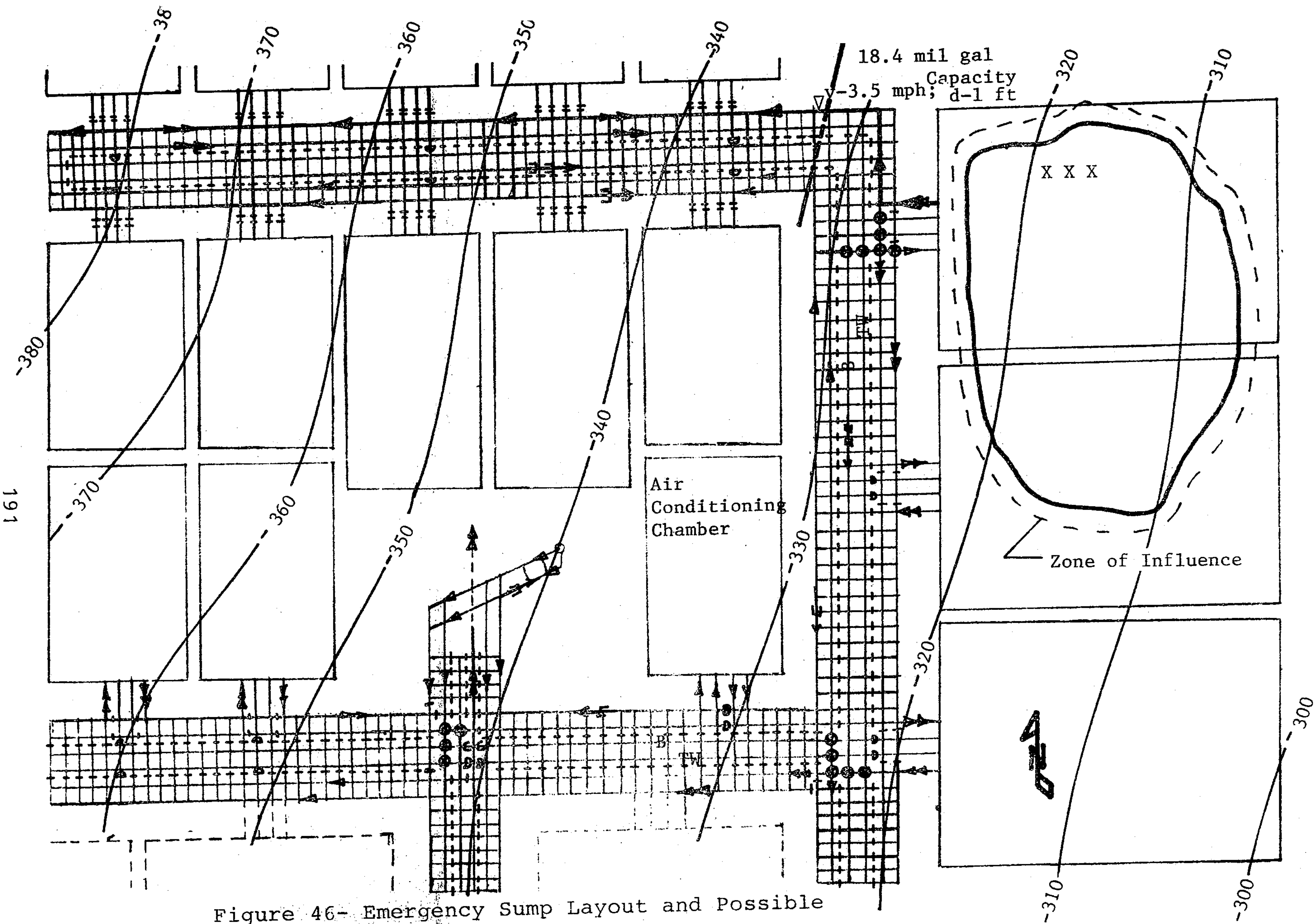


Figure 46- Emergency Sump Layout and Possible Flow Routes
Case 3: Sump Panels Sealed

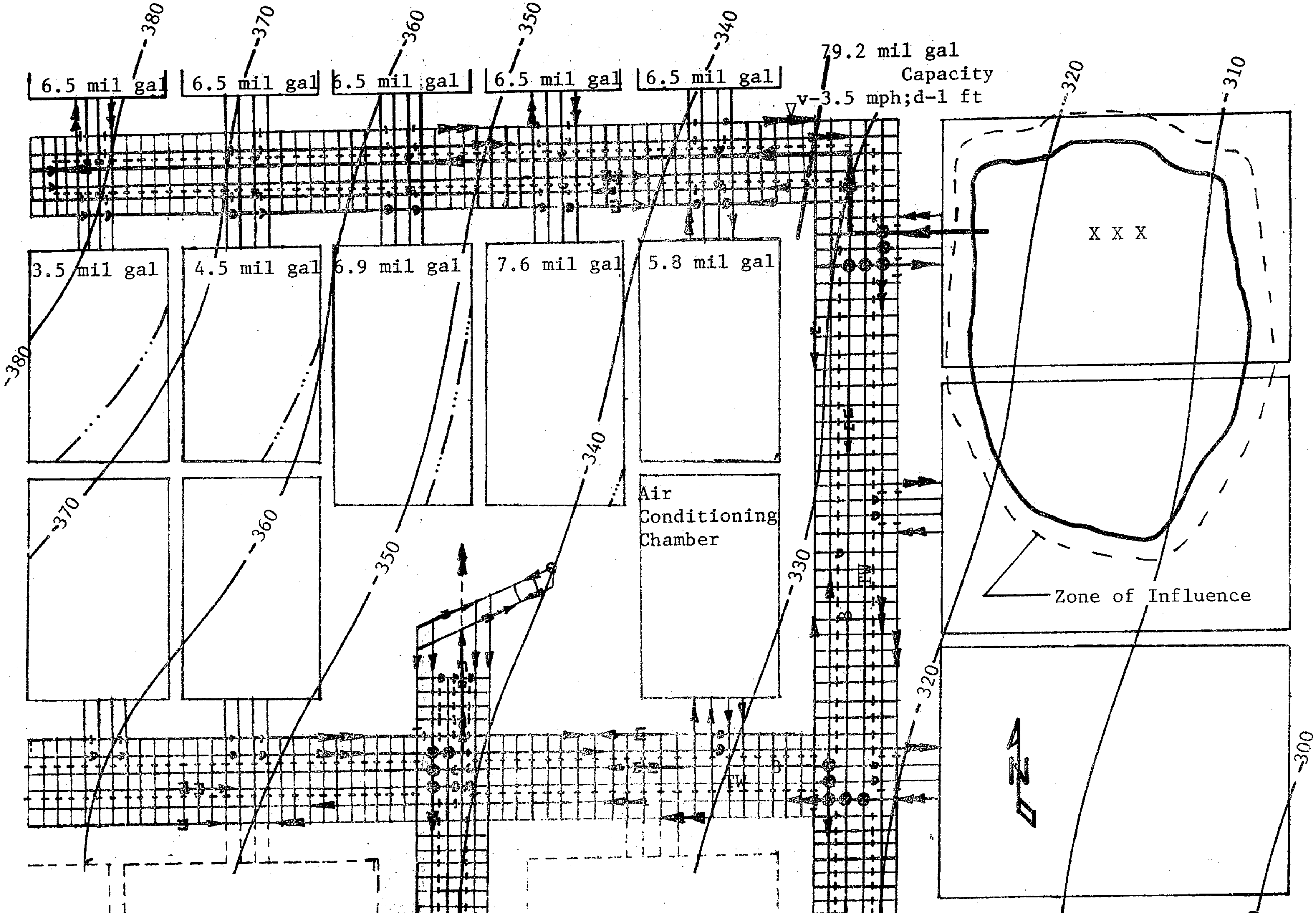


Figure 47 - Emergency Sump Layout and Possible Flow Routes
Case 4: Sump Panels Standing on Pillars
Case 5: Sump Panels Gobbed but Maintained Dry

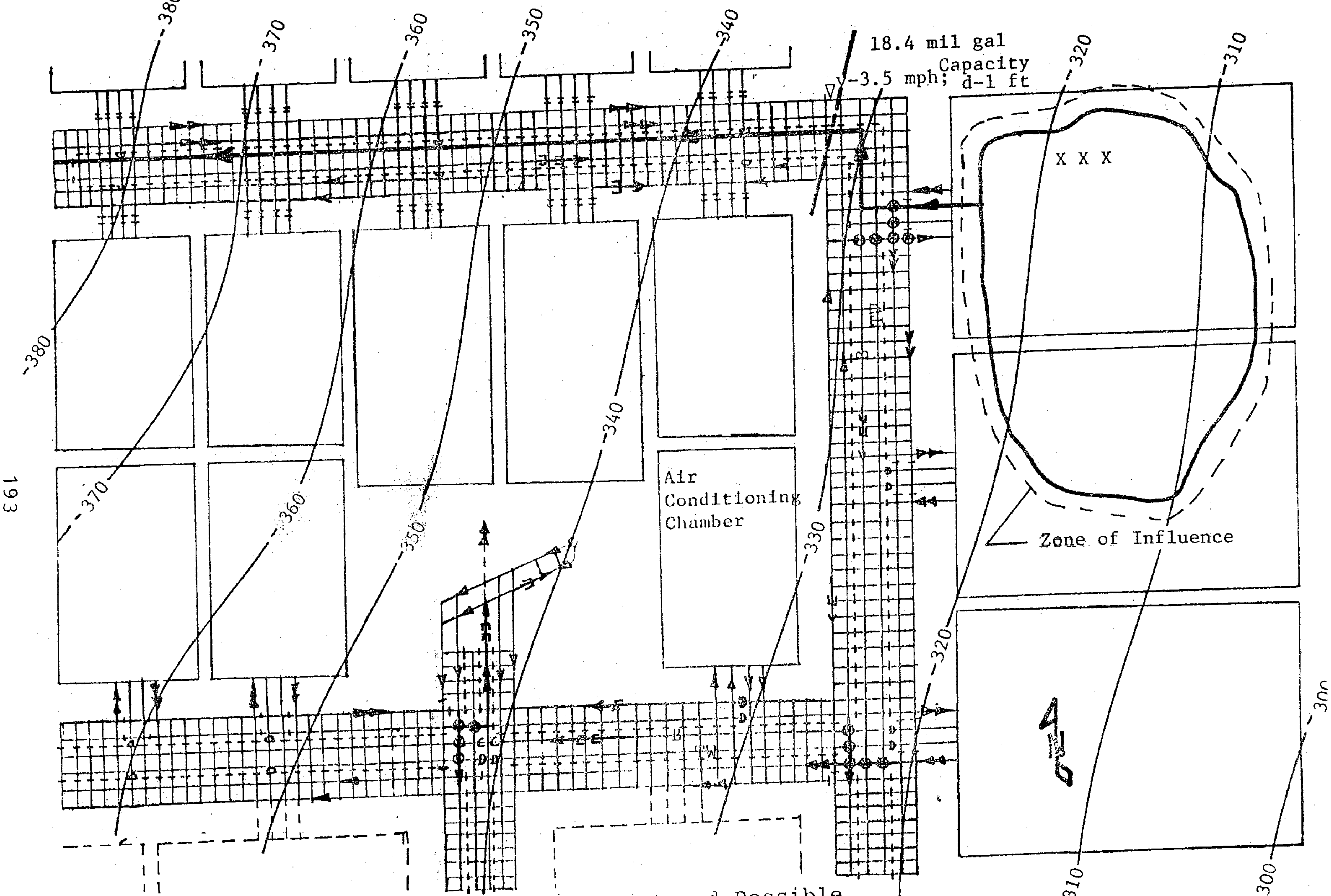


Figure 48 - Emergency Sump Layout and Possible
Flow Routes
Case 6: Sump Panels Sealed

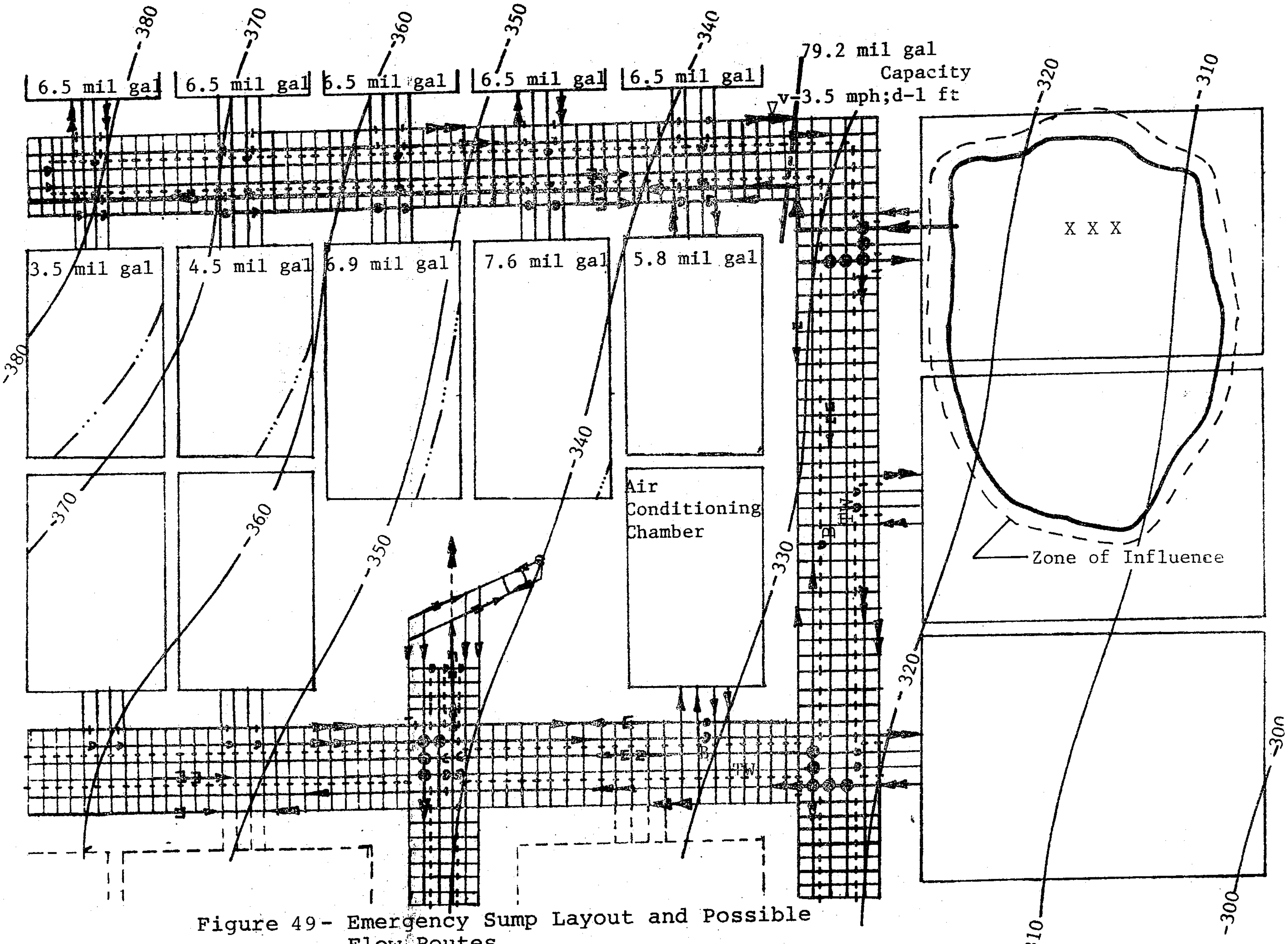


Figure 49 - Emergency Sump Layout and Possible Flow Routes
Case 7: Sump Panels Standing on Pillars
Case 8: Sump Panels Gobbed but Maintained Dry

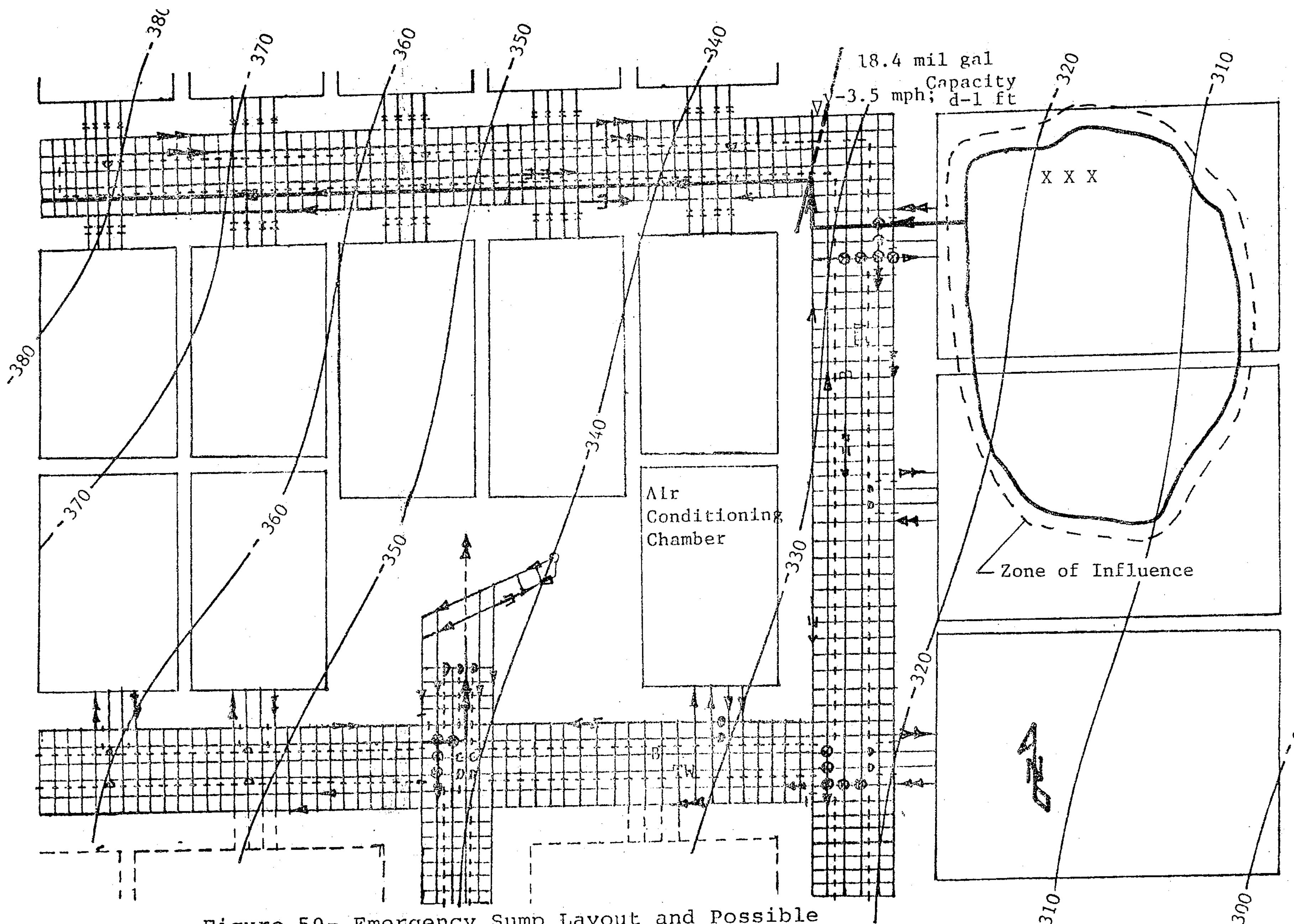


Figure 50- Emergency Sump Layout and Possible Flow Routes
Case 9 : Sump Panels Sealed

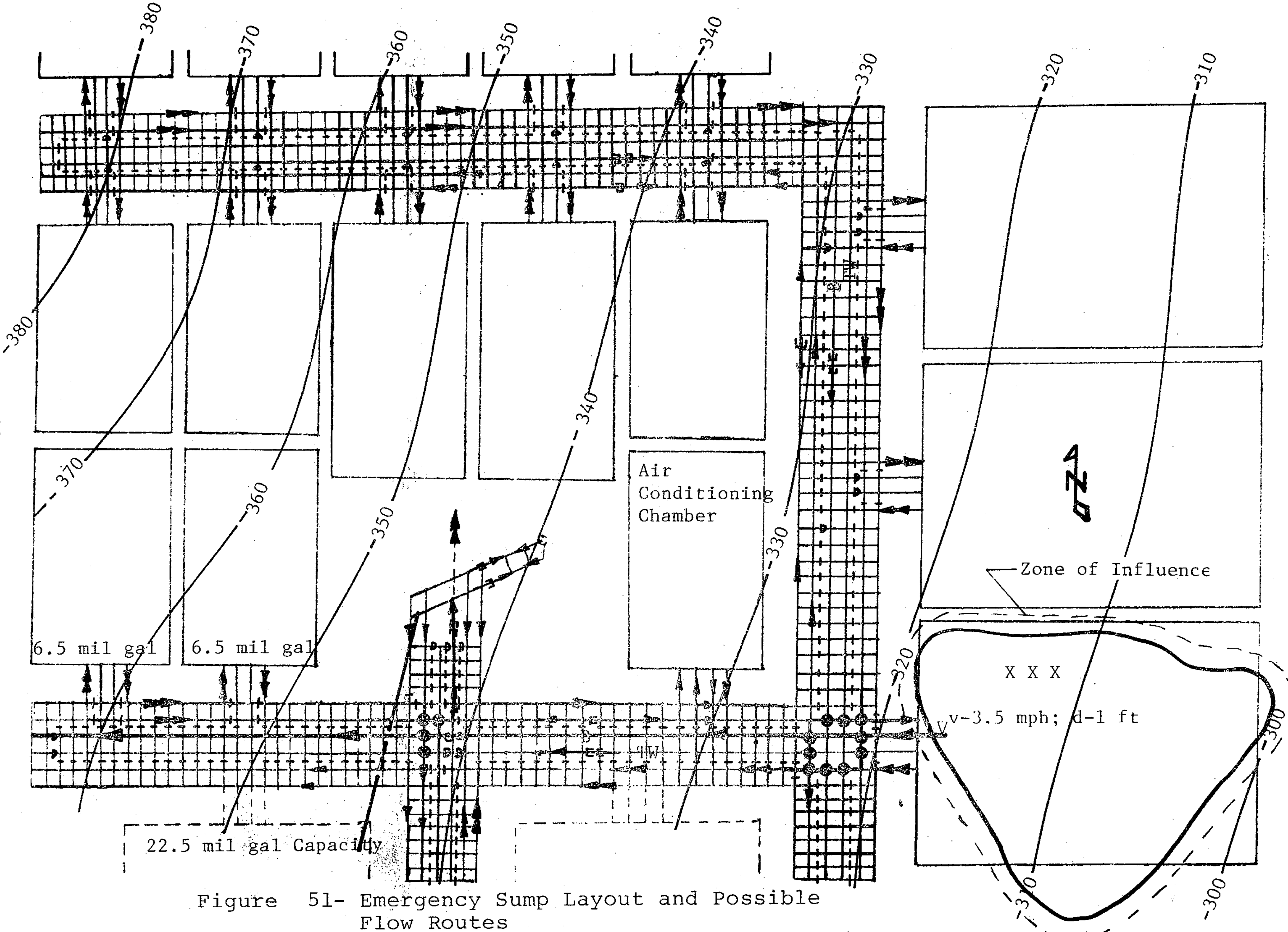


Figure 51- Emergency Sump Layout and Possible Flow Routes
Case 10: Sump Panels Standing on Pillars
Case 11: Sump Panels Gobbed but Maintained Dry

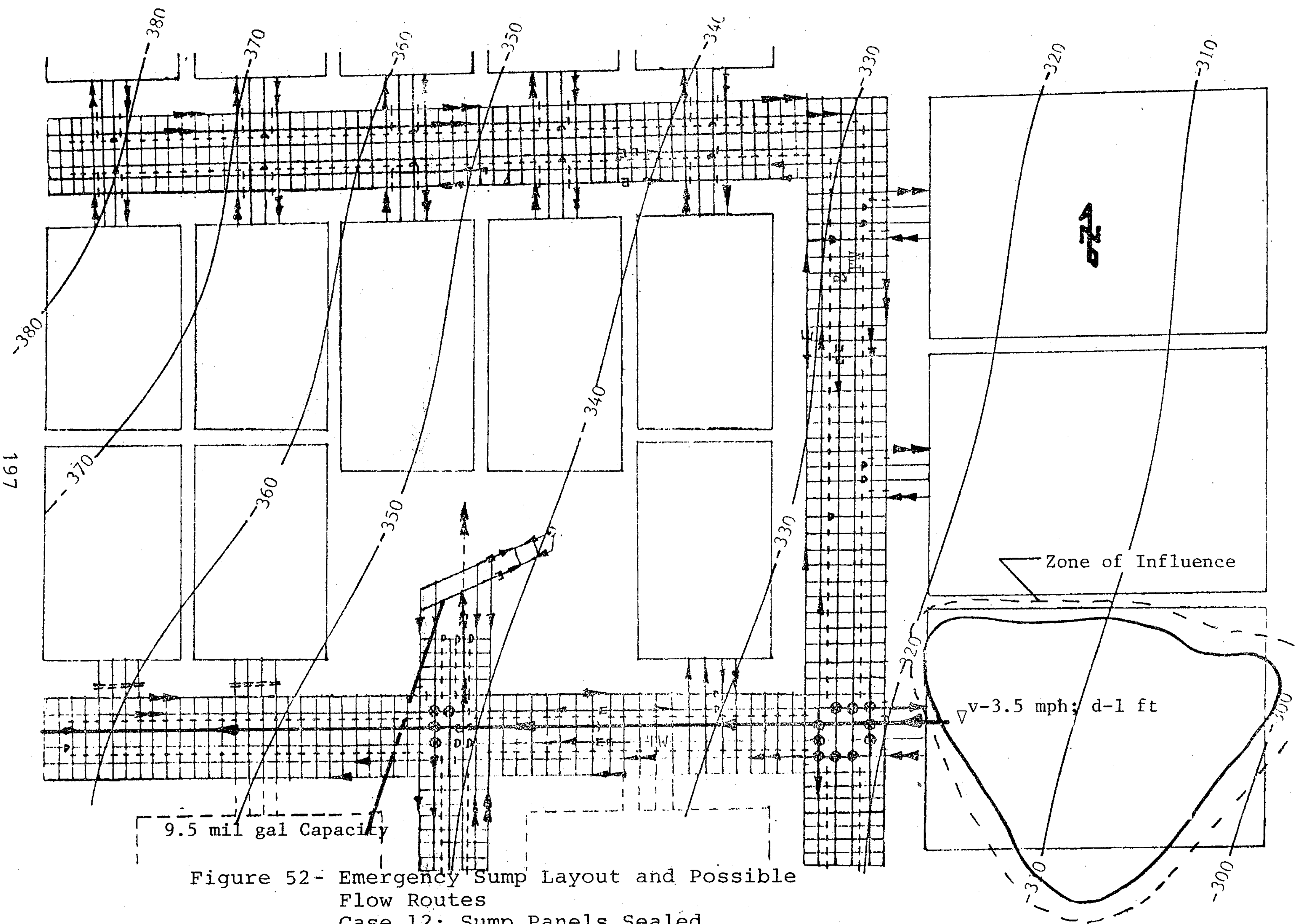


Figure 52 - Emergency Sump Layout and Possible Flow Routes
Case 12: Sump Panels Sealed

Table 34- Analysis of Some Possible Emergency Sump Layouts with Respect to Major Potential Sized Water Bodies

Case No.	Mine-life Flood Capacity of Water Body (gal.)	Gross Coal Res. Below Safety Zone (tons)	Coal Res. Recoverable by Part. Extr. (tons)	Coal Res. Recoverable by Full Extr. (tons)	Assumed Rate of Inflow (gpm)	Max. Depth of Inflow (ft)*	Max. Vel. of Inflow (mph)*	Total Head=Velocity Head + Water Depth (ft)	Emergency Sump Cap. Available (gal.)	Availability of Escape Routes	Likely Loss of Prod.	Likely Danger to Equipment
	1	2	3	4	5	6	7	8	9	10	11	12
1	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	good	none	small
2	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	good	none	small
3	18.4 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	18.4 mil.	good	none	small
4	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	½ of the routes carry water	none	small
5	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	½ of the routes carry water	none	small
6	18.4 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	18.4 mil.	½ of the routes carry water	none	small
7	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	Poss. of all routes carrying some water	none	small
8	79.2 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	79.2 mil.	Poss. of all rtes. carrying some water	none	small
9	18.4 mil.	225,000	112,500	180,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	18.4 mil.	Some water	none	small

*Based on 20 feet width of mine entries.

Table 34- Analysis of Some Possible Emergency Sump Layouts with Respect to Major Potential Sized Water Bodies

Case No.	Mine-life Flood Capacity of Water Body (gal.)	Gross Coal Res. Below Safety Zone (tons)	Coal Res. Recoverable by Part. Extr. (tons)	Coal Res. Recoverable by Full Extr. (tons)	Assumed Rate of of Inflow (gpm)	Max. Depth of Inflow (ft)*	Max. Vel. of Inflow (mph)*	Total Head=Velocity Head + Water Depth (ft)	Emergency Sump Cap. Available (gal.)	Availability of Escape Routes	Likely Loss of Prod.	Likely Danger to Equipment
	1	2	3	4	5	6	7	8	9	10	11	12
10	22.5 mil.	112,500	56,250	90,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	22.5 mil.	½ of the routes carry water	all	med
11	22.5 mil.	112,500	56,250	90,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	22.5 mil.	½ of the routes carry water	all	med
12	9.5 mil.	112,500	56,250	90,000	50,000 100,000	1.50 2.35	4.0 4.8	2.0 3.1	9.5 mil.	½ of the routes carry water	all	med

to seal the voids and fissures in the aquiclude zone so that they do not connect into the cracks induced by caving of the roof. Grouting has been used in a large number of non-coal mines but, there also, the intention was never to seal the cracks or bed separations induce by caving. Moreover, if the thickness of cover is inadequate, pregrouting may not necessarily prevent extension of cracks induced by caving up to the surface.

10.0 SUGGESTED GUIDELINES FOR MINING BENEATH SURFACE BODIES OF WATER

According to the Code of Federal Regulations Title 30, Section 75.1716, administered by MSHA, which are given in Appendix B, an operator of coal mines intending to conduct mining operations under any river, stream, lake, or other body of water is required to give notice to the Coal Mine Safety District Manager in which the mine is located prior to the commencement mining operations. If in the judgement of the Coal Mine Safety District Manager, the proposed mining operations may constitute a hazard, the operator is notified that a permit is required. The application for such a permit should contain, besides a map and other general information, a profile showing the type of strata and the cover thickness between the river, stream, lake or other body of water and the coal bed to be mined. The type of strata is required to be determined by core test drill holes or as may be prescribed by the Coal Mine Safety District Manager. If the Coal Mine Safety District Manager determines that the proposed mining operations under water can be safely conducted a permit is issued for conducting such operations subject to the conditions which he may deem necessary.

As may be seen from these stipulations, there are no prescribed regulations to help the mine operators plan mining operations below water bodies with a view to achieve reasonable resource recovery without sacrificing the safety of the miners. Likewise, there are no prescribed regulations to aid the Coal Mine Safety District Managers to ensure uniformity of action while issuing the permits. Keeping these factors in view, and in the light of discussion in the preceeding sections, consolidated guidelines have been developed for working below bodies of surface water which may be used by the industry and the Mine Safety and Health Administration. These guidelines are given below.

10.1 Surface Water Bodies

Surface water bodies have been divided into three sizes as follows:

1. Catastrophic Potential: These water bodies include an ocean, and large inland lakes or reservoirs that can completely flood the mine workings, and rivers and streams whose mine-life flood stage is beyond the pumping capacity of the mine or whose flow in the mine would create a hazard.

2. Major Potential: These are finite size water bodies like small lakes, farm ponds or sediment ponds, the mine-life flood volume of which is less than the available in-mine water storage capacity of the specially provided emergency sump.

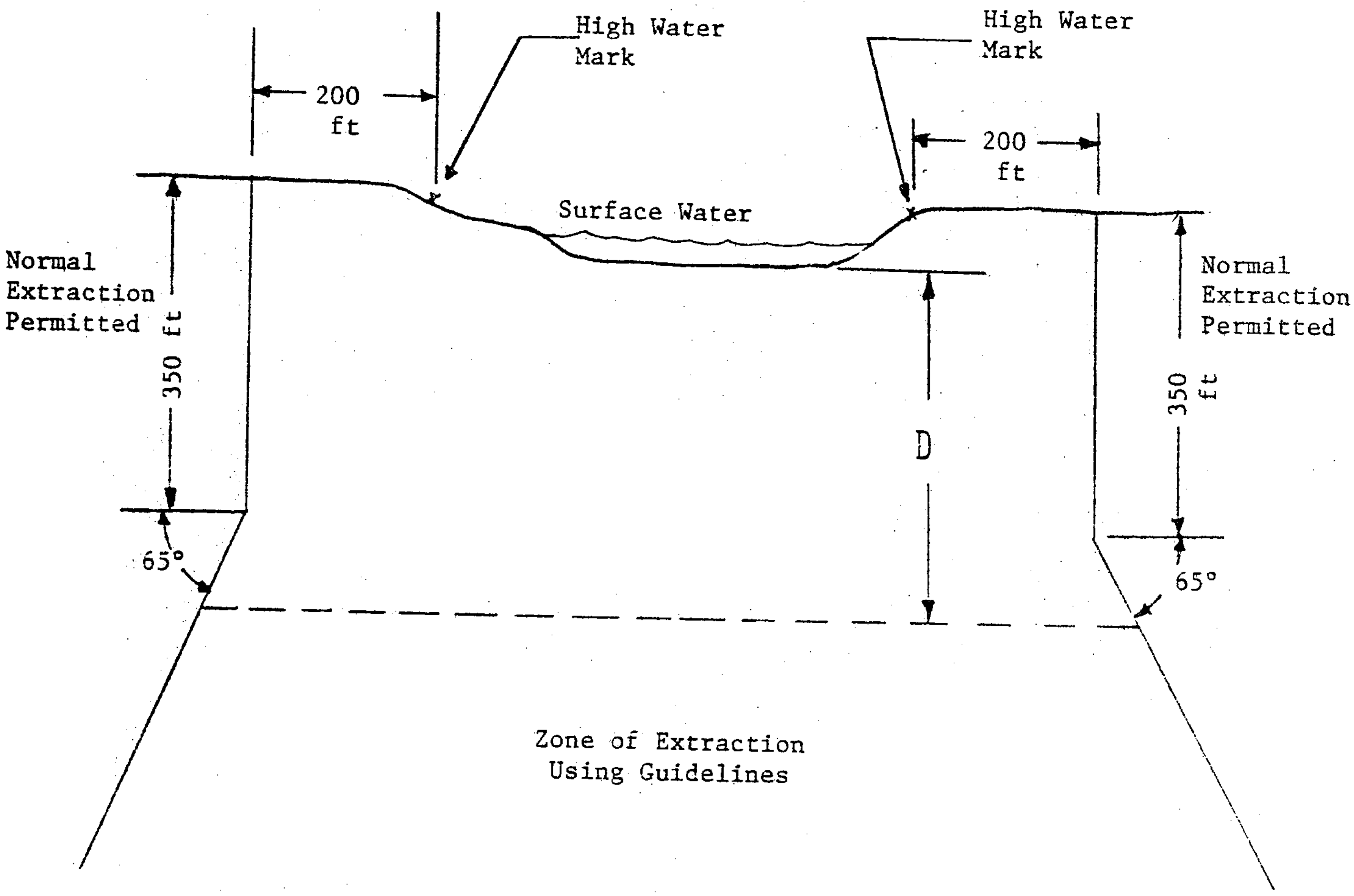
3. Limited Potential: Those streams of water whose discharge is within the specifically provided stand-by pumping capacity in the mine and whose flow in the mine, does not create a hazard; or those non-flowing water bodies that would not create a hazard by allowing time for escape from the immediate area of inundation and nowhere resulting in an excessive depth of impoundment.

10.2 Safety Zones

1. Where any body of surface water is present above the potential mine working, a safety zone around the body of surface water should extend 200 ft horizontally from the high-water mark all along the perimeter of the water body, and vertically downward from the perimeter to a depth of 350 ft, then outward at an angle of dip of 65° as shown in Figure 53.

2. If mining is considered within the safety zone, it should be carried out in accordance with the guidelines for mining beneath surface water bodies.

3. The width of such a safety zone may be increased or decreased if lcoal observations and experience so justify.



D is determined from the following table:

	D*
Room and Pillar	5s or 10t
Panel and Pillar	3p or 270 ft
Total Extraction	60t

*Whichever value of D is larger.

Figure 53-Safety Zone Beneath Body of Surface Water (after Babcock and Hooker, 1977)

10.3 Catastrophic Potential Water Bodies

10.3.1 Total Extraction Mining

Total extraction coal mining involves excavating a sufficiently large width of a seam, as in longwall mining or extraction of pillars in a room and pillar mining system, with essentially concurrent caving of the roof behind the face supports or the line of extraction. The method of extraction, whether by longwall, continuous, or conventional mining, the extraction thickness, shortwall, and whether the gob is packed or not is not relevant. Also, the shortwall or longwall faces flanked with wide barrier pillars which may constitute the panel and pillar system of partial extraction, are not included in this definition.

The following guidelines are recommended for total extraction below catastrophic potential sized water bodies. These guidelines require the establishment by drilling or otherwise of the nature of the strata above the proposed total extraction workings. Where the word "coal" or "seam" is used, it also applies to any bedded mineral deposit.

1. Any single seam beneath or in the vicinity of any body of surface water may be totally extracted, whether by longwall mining or by pillar robbing, provided that a minimum thickness of strata cover as given in Table 35 exists between the proposed workings and the bottom of the body of surface water.

2. Where more than one seam exists, all may be worked by total extraction provided that for all seams to be extracted, a minimum of the aggregate mineral and rock thickness of strata cover as given in Table 35 exists between the proposed workings in the uppermost seam and the bottom of the body of surface water.

3. The maximum cumulative, calculated tensile strain beneath a body of surface water shall nowhere exceed 10,000 $\mu\varepsilon$, and shall be calculated by an approved method. The layouts of panels in the same seam or in different seams, in case of multiple seam mining, shall be planned accordingly.

Table 35 - Minimum Cover Required for Total Extraction Below Water Bodies of Catastrophic Potential Size

Thickness of Seam ft	Minimum Total Thickness of Cover	
t	t	ft
3	117t	351
4	95t	380
5	80t	400
6	71t	426
7	63t	441
7.5	60t	450
> 7.5	60t	-

4. Where a single seam has already been mined by total extraction in accordance with the provision that for each 1-foot thickness of mineral and rock extracted a minimum strata of cover as given in Table 35 should exist, no other underlying seam may be mined by total extraction. The lower seam may be mined by partial extraction in accordance with the subsequent stipulated guidelines considering as though the upper seam constituted the bottom of a body of surface water, however, the pillars shall be designed to support the entire strata up to the surface including the water body.

5. Where unconsolidated natural or artificial deposits exist between bedrock and the bottom of a body of surface water, which may be highly permeable or which when wet may flow, these should be excluded from the thickness of overlying strata, except where it has been demonstated that such deposits would not be likely to flow when wet and could be considered as impermeable.

6. Where a fault which might connect mine workings with a body of surface water, and which has a vertical displacement greater than 10 ft, or an intrusive dike having a width greater than 10 ft, is known to exist or is met with during development, no seam should be totally extracted within 50 ft horizontally on either side of such fault or dike.

7. Where the gob is stowed by some method, the requirement of minimum strata cover may be reduced using a suitable approved subsidence factor which will be determined depending on the compressibility of the stowing material and the manner of stowing.

10.3.2 Partial Extraction Mining

A partial extraction system is one in which pillars are deliberately left unworked for the purpose of giving more or less permanent support to the land surface. Two such systems are the room and pillar first working and the panel and pillar system which also includes the shortwall method.

10.3.2.1 Room and Pillar Method

In this system two sets of parallel entries usually at right angles to each other are driven in a seam leaving rectangular pillars to support the roof strata. The pillars may be extracted as in "secondary working" or they may be left behind permanently to support the strata after "first working."

10.3.2.1.1 Minimum Depth of Cover

A minimum thickness of strata cover should be left above the seam while working below water bodies. Both the height and the width of the entries and the characteristics of the roof beds are significant parameters to ensure stability and support of the intervening strata.

Separate provisions with respect to drifts and tunnels are stipulated because the practicability and cost of supporting and maintaining them would be generally acceptable. In room and pillar entries, however, the cost of permanent supports would be exceptionally high and their maintenance would be generally impracticable.

The following guidelines are recommended for determining a minimum depth of strata for room and pillar workings.

1. No entry should be driven in any seam lying beneath or in the vicinity of any body of surface water where the total thickness of strata cover above the seam is less than 5 times the maximum entry width (5s) or 10 times the maximum entry height (10t), whichever is the greater. Where at least one competent bed of sandstone or similar material is present within the strata and has a thickness at least 1.75 times the maximum entry width, mining at a lesser cover than 5s or 10t may be considered.

2. For drifts or tunnels beneath or in the vicinity of a body of surface water driven through the strata for the purpose of gaining access to a seam, the provision of 10t or 5s should also apply unless the drifts or tunnels are permanently supported and are so maintained. In the latter event, however, there should be a minimum rock cover of 1.75 times the maximum drift or tunnel width.

10.3.2.1.2 Pillar Dimensions for First Workings

Pillars must be adequately designed in order to provide permanent support for the strata. The design will primarily depend on the depth of the seam, height of extraction, width of the entries, and the nature of overlying strata. The phenomena of sinkholes is generally associated with shallow cover and some particular types of strata. Thus, depending on the nature of strata, pillar design methods may be modified to prevent the formation of sinkholes. It is suggested that for the present, the empirical relation (Wardell, 1976) be used

$$[(W+s)/W]^2 \; 1.5D=1000/ \; t+20(W+t)^2$$

where W = pillar width

s = room width

t = seam thickness

D = depth from surface

until such time that other methods are generally accepted and validated.

Accordingly, the following guidelines are proposed for pillar dimensions for room and pillar first workings:

1. Where room and pillar first working is to be carried out beneath or in the vicinity of any body of surface water at cover depth greater than the stipulated minimum, the minimum width of pillar should be determined in accordance with Tables 36 through 42. If the minimum width of pillar is required for seam thicknesses other than those given in these tables, the width may be calculated using the above relationship. However, an exception can be made where specific local data (including relevant and comparable mining experience) exist which demonstrate that a lesser width could be used with safety.

2. Where an upper seam has been mined by room and pillar first working in accordance with these guidelines, underlying seams should not be mined by either total or partial extraction except by considering the upper seam as though it were the bottom of the surface body of water.

3. Where pillar widths are determined in accordance with these provisions, the calculated pillar loading should not exceed the determined load bearing capacity of either the immediate roof or floor beds.

4. Where the strata does not contain any competent rock bed, such as a sufficient thickness of hard sandstone, additional precautions shall be taken to prevent formation of sinkholes.

10.3.2.2 <u>Panel and Pillar Method</u>

The panel and pillar system is defined total extraction of a coal seam from panels of such width in relation to their depth that the main strata can span any one of them with little deflection. Individual extraction panels are separated by abutment pillars which are designed to be much wider than the minimum required for stability so that no additional

Table 36 - Minimum Pillar Widths for Pillar Heights of 3 Feet, Feet

Depth, feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	12	13	14	-	-
150	15	16	16	17	18
200	17	18	19	20	20
250	19	20	21	22	22
300	20	21	22	23	24
350	22	23	24	25	26
400	23	24	25	26	27
450	25	26	27	28	29
500	26	27	28	28	30
550	27	28	29	30	31
600	28	28	30	31	32

Table 37 - Minimum Pillar Widths for Pillar Heights of 4 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	14	15	16	-	-
150	17	18	19	20	21
200	20	21	22	23	24
250	23	24	25	26	27
300	25	26	27	28	29
350	27	28	29	30	31
400	29	30	31	32	33
450	30	31	33	34	35
500	32	33	34	35	36
550	33	34	36	37	38
600	35	36	37	38	39

Table 38 - Minimum Pillar Widths for Pillar Heights of 6 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	17	19	20	-	-
150	22	24	25	26	27
200	26	28	29	30	32
250	30	31	33	34	35
300	33	35	36	37	38
350	36	37	39	40	41
400	39	40	41	43	44
450	41	42	44	45	46
500	43	45	46	47	48
550	45	47	48	49	51
600	47	49	50	51	53

Table 39 - Minimum Pillar Widths for Pillar Heights of 8 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	21	22	24	-	-
150	27	29	30	32	33
200	33	34	36	37	38
250	37	39	40	42	43
300	41	43	44	46	47
350	45	47	48	49	51
400	48	50	51	53	54
450	51	53	55	56	57
500	54	56	57	59	60
550	57	59	60	62	63
600	60	61	63	64	66

Table 40 - Minimum Pillar Widths for Pillar Heights of 10 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	24	26	27	-	-
150	32	34	35	37	38
200	39	40	42	43	45
250	44	46	48	49	51
300	49	51	53	54	56
350	54	56	57	59	60
400	58	60	61	63	64
450	62	64	65	67	68
500	66	67	69	70	72
550	69	71	72	74	75
600	72	74	76	77	79

Table 41 - Minimum Pillar Widths for Pillar Heights of 12 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	37	39	40	42	44
200	45	46	48	50	51
250	51	53	55	57	58
300	57	59	61	63	64
350	63	65	66	68	70
400	68	70	71	73	75
450	73	74	76	78	79
500	77	79	80	82	84
550	81	83	84	86	88
600	85	87	88	90	91
650	88	90	92	94	95
700	92	94	95	97	99
720	93	95	97	98	100

Table 42 - Minimum Pillar Widths for Pillar Heights of 14 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	41	43	45	47	48
200	51	53	54	56	58
250	58	60	62	64	66
300	66	67	69	71	73
350	72	74	76	77	79
400	78	80	81	83	85
450	83	85	87	88	90
500	88	90	92	93	95
550	93	95	96	98	100
600	97	99	101	103	104
650	102	103	105	107	108
700	106	107	109	111	113
750	109	111	113	115	116
800	113	115	116	119	120
840	116	118	120	121	123

subsidence for pillar failure needs to be allowed. The panels may be extracted by longwall or shortwall mining, or they may be first developed by the room and pillar method and the pillars may be subsequently totally extracted.

The following guidelines are recommended for panel and pillar mining beneath and in the vicinity of bodies of surface water:

1. Where mining by the panel and pillar method is to be carried out beneath or in the vicinity of any body of surface water, there should be a minimum strata cover thickness of 270 ft or 3p, where p is the width of the panel, whichever is greater.

2. The widths of extraction panels should not exceed one-third the depth of mining, and the widths of pillars between extraction panels should be 15 times their height or one-fifth the depth of mining, whichever is greater.

3. Where more than one seam is to be mined by this system, the panels and pillars in all seams should be superimposed in the vertical direction with the panel widths being determined from the depth to the uppermost seam and the pillar widths being determined by reference to either the thickest or the deepest seam, whichever would give the greater dimension.

4. Where the panel and pillar system of mining has been employed in an upper seam, mining a lower seam by total extraction may be carried out only by considering the upper seam the base of a body of surface water.

10.4 Major Potential Water Bodies

10.4.1 Total Extraction Mining

The following guidelines are recommended for total extraction below major potential sized water bodies:

1. Any single seam of coal beneath or in in the vicinity of any body of surface water of major potential size may be totally extracted, whether by longwall mining or by pillar robbing provided that a minimum strata cover of a suitable nature exists between the proposed workings and the bottom of the body of surface water as given in Table 43.

2. Where more than one seam exists all may be worked by total extraction provided that for the aggregate mineral and rock thickness of all seams to be extracted, a minimum thickness of cover as given in Table 43 exists between the proposed workings in the uppermost seam and the bottom of the body of surface water of major potential size.

3. An in-mine emergency sump shall be provided to receive the body of surface water of major potential size. The available water storage capacity of this sump shall not be less than the mine-life flood volume of the water body.

4. The maximum cumulative, calculated tensile strain beneath a body of surface water of major potential size shall nowhere exceed 15,000 $\mu\varepsilon$ as calculated by an approved method. The layouts of panels in the same seam or in different seams in case of multiple seam mining shall be planned accordingly. Strains shall be cumulated for each mining activity affecting an area, regardless of the intervening time.

Table 43 - Minimum Cover Required for Total Extraction Below Surface Water Bodies of Major Potential Size

Seam Thickness in ft t	Height of Disturbed Strata Above Seam		Aquiclude Zone Thickness								Depth of Surface Cracks		Minimum Total Thickness of Cover							
			I Minimum 20 ft clay		II Minimum 75% shale		III Shaley and Silty Sand-stones		IV 100% Lime-stones and Sandstones				I		II		III		IV	
	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t
3	174	58	30	10	50	17	90	30	Special Investigations Required	Special Investigations Required	50	17	254	85	274	92	314	105	Special Investigations Required	Special Investigations Required
4	203	51	30	8	50	13	90	23			50	13	283	72	303	77	343	87		
5	226	45	30	6	50	10	90	18			50	10	316	61	326	65	366	73		
6	249	42	30	5	50	8	90	15			50	8	329	55	349	59	389	65		
7	269	38	30	4	50	7	90	13			50	7	349	49	369	52	409	58		
8	285	36	30	4	50	6	90	11			50	6	365	46	385	49	425	53		
9	305	34	30	3	50	6	90	10			50	6	385	43	405	45	445	50		
10	321	32	30	3	50	5	90	9			50	5	401	40	421	42	461	46		
11	352	32	30	3	50	5	90	8			50	5	432	39	452	41	492	45		
12	360	30	30	3	50	4	90	8			50	4	440	37	460	38	500	42		

5. Where a single seam has already been mined by total extraction in accordance with the minimum strata cover stipulations as given in Table 43, no other underlying seam may be mined by total extraction. The lower seam may be mined by partial extraction in accordance with the guidelines stipulated for partial extraction considering the upper seam as the bottom of a body of surface water but, the pillars shall be designed to support the entire strata upto the surface including the water body.

6. Where unconsolidated natural or artificial deposits, which may be highly permeable or which when wet may flow, exist between the seam to be extracted and the bottom of a body of surface water, these should be excluded from the thickness of overlying strata except where it has been demonstrated that such deposits would not be likely to flow when wet and could be considered as impermeable.

7. Where a fault which might connect mine workings with a body of surface water and which has a vertical displacement greater than 10 ft, or an intrusive dike having a width greater than 10 ft, is known to exist or is met with during development, no seam should be totally extracted within 50 ft horizontally on either side of such fault or dike.

8. Where the gob is stowed by some method, the requirement of minimum strata cover may be reduced using a suitable approved subsidence factor which will be determined depending on the compressibility of the stowing material and the manner of stowing.

9. An operator shall be required to obtain a permit from the Coal Mine Safety District Manager for working beneath or in the vicinity of a body of surface water of major potential size where the minimum strata cover is provided in accordance with Table 43.

10. An application for such a permit shall be submitted in the prescribed form as given in Appendix E and shall include a water hazard map besides other general information, maps and sections as required under Section 75.1716 of the Code of Federal Regulations, Chapter 1 Title 30 (see Appendix B). The water hazard map shall specifically show the position and capacity of the emergency sump in relation to the water body, the likely water flow routes in the event of an inflow, the specifications of structures like stoppings or overcasts which may be involved in channeling of the water flow or flows, a provision for the location of an emergency escape route if the likely water flow route interferes with regular escape routes, and profile sections of the escape and emergency escape routes in order to make sure that they are free from depressions likely to be filled.

10.4.2 Partial Extraction Mining

The same guidelines as for surface water bodies of catastrophic potential size shall be used for water bodies of major potential size.

10.5 <u>Limited Potential Water Bodies</u>

10.5.1 Total Extraction Mining

1. Where sufficient in-mine pumping capacity equivalent to the mine life flood discharge of all small surface streams affected is available, any number of seams may be totally extracted at any thickness of cover between the uppermost seam and the bottom of the surface water and at any thickness of parting between the seams.

2. Small non-flowing bodies of water may be under mined at any depth provided that the determined inflow rate and volume allow time for a person to wade through the water a

distance equal to the longest blocked, dead-end, or blind entry to safety (whether in an entry in which the breakthrough occurs or in an entry in which the flow ponds) and ponded depth is everywhere 1.5 ft less than the mined height and not more than 4.5 ft total depth.

10.6 Structures Retaining Water

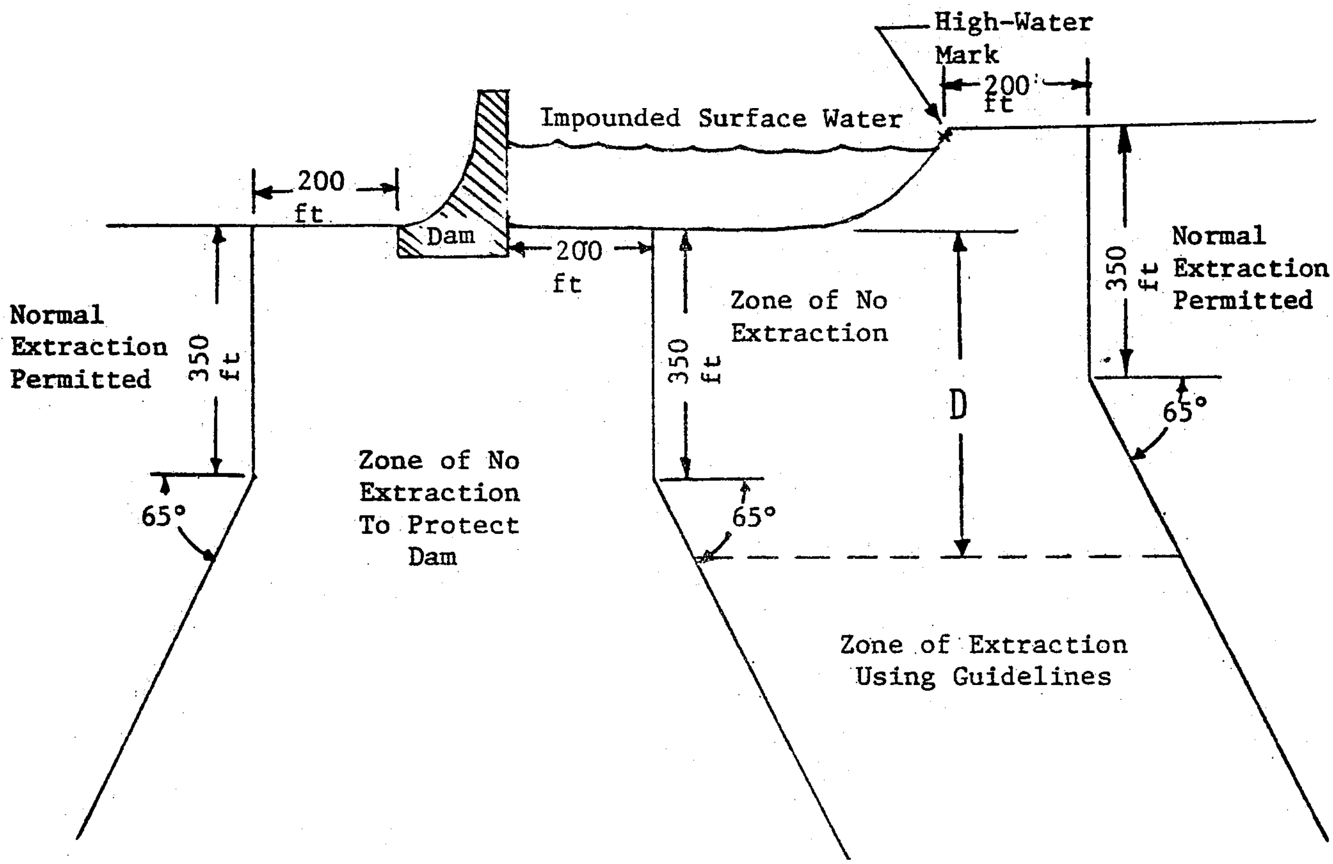
10.6.1 Structures Important to the Public Safety

The following guidelines are recommended for safety zones around and beneath structures, the survival of which is important to the public welfare:

1. Where any surface structure is impounding a body of surface water and damage to that structure by mine subsidence could lead to a risk of structural failure and prejudice to public safety, no mining should be premitted within the safety zone of such a structure.

2. The perimeter of the structure requiring protection should be established by those responsible for its maintenance and safety. The safety zone around the perimeter of protection should extend outward 200 ft in all directions, then downward for 350 ft, and then outward at a dip of 65° from the horizontal as shown in Figure 54. This safety zone is designated as a zone of no extraction. Figure 54 also shows the restriction on mining beneath the impounded water.

3. A greater or lesser distance than that specified in paragraph 2 may be used where local observations or experience so indicate.



D is Determined From the Following Table:

	D*
Room & Pillar	5s or 10t
Panel & Pillar	3p or 270 ft.
Total Extraction	60t

* Whichever Value is Larger

Figure 54- Safety Zone Beneath Surface Structure Impounding Large Body of Surface Water (after Babcock and Hooker, 1977)

10.6.2 Small Structures or Embankments Impounding Water

A structure may be classified as small when:

- failure of the structure would not result in loss of life; in damage to homes; commercial or industrial buildings; main highways or railroads; in interruption of the use of service of public utilities; or damage other existing water impoundments; and
- the contributing drainage area does not exceed 200 acres; and
- the maximum vertical height of the dam or embankment as measured along the centerline of the embankment to the crest of the spillway does not exceed 15 ft; and
- the area of impounded water at the spillway level does not exceed 10 surface acres; and
- the structure conforms to all applicable laws and regulations pertaining to the storage of water.

The following guideline is recommended for working beneath and in the vicinity of small structures or embankments impounding water.

1. The mining of single or multiple seams by total or partial extraction methods may be undertaken beneath or in the vicinity of small structures or embankments impounding water in accordance with the guidelines recommended for other equivalent volume and flow surface water bodies.

11.0 CLOSURE

11.1 Conclusions

Criteria to define the critical size of a body of surface water in relation to the mining system have been developed and presented in this report.

Above an area which has been totally extracted there exists a zone of strata which usually extends from a height of 30 to 58 times the thickness of extraction up to about 50 ft depth from the ground surface. This zone, termed the aquiclude zone, provides the main protection against inflows of water while working beneath and in the vicinity of bodies of surface water. The degree of protection depends on the thickness and the nature of the strata.

Accordingly, a concept has been developed to determine the cover for working beneath and in the vicinity of bodies of surface water. It has been possible to reduce the requirement of cover thickness for working below major potential size surface water bodies by incorporating certain precautions in the mine plan. By adopting this arrangement, it is expected that the overall safety will not be affected adversely.

Also, methods of determining limited potential sized water bodies which pose little threat to the mine and personnel have been presented. These are based upon the volume or rate of flow and their likely affect on the mine.

The reserves of coal locked up below surface water bodies such as small lakes, farm ponds, sediment ponds and so on can be considerable though no formal assessment has been made. It is expected that the recovery percentage of these reserves will increase significantly by reducing the thickness of cover required for total extraction as suggested in this report.

11.2 Recommendations for Future Studies

The following recommendations are made for future studies:

- The guidelines for working below bodies of surface water presented in this report are of a general nature as they are intended to encompass all possible situations, such as different nature of strata, single seam mining or multiple seam mining situations, different methods of mining, and so on. Although these guidelines are of a practical nature, they can be made more "locale" specific so that they are not overly restrictive for conditions in specific geological locales. For example, if a coalfield has thick clay or mudstone beds overlying coal seams, it may be possible to carry out total extraction below bodies of surface water at much lower depth to height of extraction ratio than that proposed in the guidelines. Similarly, there exists a possibility of further reducing the requirement of cover in case of extraction of thick seams in successive slices or multiple seams as indicated by the studies carried out in the Soviet Union, Hungary, and Yugoslavia. Also, the cover requirement for seams thinner than 3 ft may need to be defined more specifically. Therefore, in the interest of conservation and safety, it is recommended that the guidelines be made more locally specific.

- The height to which the water conducting fissures extend above the mined area can be determined by known hydrogeological methods. These determinations give results which are locally specific. If the results of such determinations are consistent, then it may be possible to revise the requirement of minimum thickness of cover for working below bodies of surface water. Therefore, it is recommended that hydrogeological investigations be carried out at different "type locales."

- It is of particular relevance to determine whether a single thick bed of shale is more effective or whether multiple thin alternate beds of shale and sandstone or limestone are more effective in arresting extension of water conducting fissures over the mined area. It is recommended that this be determined by carrying out hydrogeological or other suitable subsurface investigations.

- Surface water bodies have been divided into 3 categories which are catastrophic potential, major potential, and limited potential. In order to find out the impact of the presented guidelines, it is recommended that a study be undertaken to determine the estimated minable coal reserves under the 3 categories of water bodies which come within the purview of the guidelines.

- Model, theoretical, or field studies of the hydraulic phenomena of the in-mine flow of water resulting from an inflow should be carried out to define further the assumed phenomena for mine planning purposes.

- The water flows which miners can safely walk in to reach safety need to be determined for a variety of conditions such as low seam, mud flows, debris-filled flows, various bottom conditions, and so on.

It is considered that this report has presented conservative methods for determining when a surface water body constitutes a hazard to mining and has outlined mining methods and mine planning procedures to minimize any adverse impacts. Also, mining guidelines have been presented that are generally applicable but could be made more regionally specific.

12.0 REFERENCES

Abel, J. F., Jr. and D. W. Gentry. A Longwall Subsidence Prediction Model. Am. Soc. Civil Eng., Conv. and Exhibit, Preprint no. 3293, 1978, p. 56-57.

Auchmuty, R.L. Subsidence and Ground Movement in a Limestone Mine Caused by Longwall Mining in a Coal Bed Below. Proc. Ann. Meeting, AIME, NY, Feb. 1931, p. 27-50.

Babcock, C.O. and V.E. Hooker. Result of Research to Develop Guidelines for Mining Near Surface and Underground Bodies of Water. Bureau of Mines Information Circular 8741, 1977, 17 p.

Barnes, H.H. Jr. Roughness Characteristics of Natural Channels. Geol. Survey Water - Supply Paper no. 1849, 1967, 209 p.

Barton, R.B. et al. Anthracite in the Narragansett Basin of Rhode Island and Massachusetts. Bureau of Mines Information Circular 8760, 1977, 15 p.

Berry, D.S. Ground Movement Considered as an Elastic Phenomenon. Trans., AIME, v. 123, no. 37 Oct. 1963, p. 29-39.

Boardman, C.R., D.D. Rabb, and R.D. McArthur. Contained Nuclear Detonations in Four Media - Geological Factors in Cavity and Chimney Formation. Proc. of 3rd Plowshare Symp. University of California, Davis, California, April, 1964, p. 109-126.

Bogardi, I. et al. Reliability of Underground Flood Control Systems. Proc. of the Min. Development Inst., Budapest, Hungary, May 1979, p. 67-83.

Brauner, G. Subsidence Due to Underground Min. - Part 1 and Part 2. Bureau of Mines Information Circular 8571 and 8572 1973, 109 p.

Bureau of Mines. Major Coal Mine Disasters in the United States. Bulletin no. 616, 1963, p. 66-78.

Choi, D.S. and D.L. McCain. Design of Longwall Systems. Mini Symp. Series, SME/AIME, no. 79-07, 1979, p. 15-26.

Colliery Eng. Drowning of Higashimisome Colliery. Aug., 1915.

Conroy, P.J. Subsidence Above a Longwall Panel in the Illinois no. 6 Coal. Am. Soc. Civil Eng. Conv. and Exhibit, Preprint, 1978, p. 79-92.

Crane, W.R., 1927, Subsidence and its Relation to Drainage in the Red Iron Mines of the Birmingham District, Alabama. Trans. AIME, v.75, 1927, p. 837-869

Crocker, E.R. Hottest, Wettest Tunnel Holed Through. Civil Eng. v. 25, 1955 p. 142-146.

Curth, E.A. Safety Aspects of Longwall Min. in the Illinois Coal Basin. Bureau of Mines Information Circular 8776, 1978, p. 1-37.

Curth, E.A. and M.D. Cavinder. Longwall Mining the Herrin no. 6 Coalbed in Southern Illinois. Proc. of the Illinois Min. Inst., 1977, p. 49-60.

Dahl, H.D. and D.S. Choi. Measurement and Prediction of Mine Subsidence Over Room and Pillar Working in Three Dimensions. Continental Oil Co., Res. and Development Dep., Min. and Minerals Division, Min. Res. Section, Oct. 1974, 9 p.

Dahl, H.D. and D.S. Choi. Some Case Studies of Mine Subsidence and its Mathematical Modeling, Fifteenth Symp. on Rock Mechanics, 1973, p. 1-21.

Dahl, H.D. and H.A. von Schonfeldt. Rock Mechanics Elements of Coal Mine Design. Monograph on Rock Mechanics Applications in Min., W.S. Brown, S.J. Green and W.A. Hustrulid, eds., SME/AIME, NY, 1977, p. 31-39.

Davis, S.N. and R.J.M. DeWiest. Hydrogeology. John Wiley & Sons, Inc., NY, 1966, 442 p.

DeGraff, J.V., Subsidence Tension Cracks: Initial Assessment of "Self-Healing" Rates and Magnitude (abstract only). Geol. Soc. America Abstracts with Programs 1979 Annual Mtg. v. 11, No. 7, 1979, p. 411.

Dept. of the Interior, Office of Surface Min., Reclamation, and Enforcement, Regulations Federal Register, v. 44, no. 50, March 1979, Section 784.20, 817.121 to 817.126.

Eng. and Min. J. Mahr Tunnel Completed. v. 135, no. 5, May 1934, p. 217.

Eng. and Min. J. Mufulira Disaster Prompts Strict Regulations in Zambia. v. 172, no. 12, Dec. 1971, p. 40 and 102.

Fawcett, D.H., Notes on Statutory Provisions, etc., in Respect of Mining Below the Sea and Bodies of Water in Japan. Unpublished, 1973, 12 p.

GAI Consultants, Inc. Study and Analysis of Surface Subsidence Over the Mined Pittsburgh Coalbed. Final Report for Bureau of Mines Contract no. J0366047, July 1977, 134 p.

Gentry, D.W. and J.F. Abel, Jr. Rock Mass Response to Mining Longwall Panel 4N, York Canyon Mine. SME, Preprint no. 77-AM-2, 1977, 33 p.

Goodman, R.E. et al. Groundwater Inflow During Tunnel Driving. Ann. Meeting of the Assoc. of Eng. Geol., 1965, 28 p.

Greenslade, W.M. Depressurization for Shaft Sinking. First Intern. Mine Drainage Symp., Denver, Colorado, 1979, 20 p.

Grond, G.J.A. Ground Movements Due to Mining. Coll. Eng., v. 34, no. 399, May 1957, p. 197-205.

Gvircman, B.Y. et al. Undermining Water Reservoirs Without Risk (in Russian), Nedra, Moscow, 1977, 174 p.

Hacket, P. An Elastic Analysis of Rock Movement Caused by Min. Trans., AIME, v. 118, no. 7, April, 1959, p. 421-433.

Hagerman, T. H. Ground Water Problems in Underground Construction. Proc. of the Intern. Symp. on Large Permanent Underground Openings, T. L. Brekke and F. A. Jorstad, eds., Universitetsforlaget, Oslo, Norway, 1970, p. 319-321.

Holland, C.T. The Strength of Coal in Mine Pillars. Proc. 6th Symp. on Rock Mechanics, Rolla, Missouri, 1964, p. 450-466.

Hwang, W.T. Petrology McGraw-Hill Book Co., NY, 1962, p. 323.

Iman, H.I. A Viscoelastic Analysis of Mine Subsidence in Horizontal Laminated Strata. Ph.D. Dissertation, University of Minnesota, 1965.

Kapolyi, L., A. Schmieder and Zs. Kesserü. Forecasting the Hazard of Water Inrush and New Possibilites of Fighting Against Them in Constructing Tunnels. Interna. Tunnel Symp., Tokyo, 1978, p. B-1-5-1 to B-1-5-11.

Keays, R.H. Construction Methods on the Moffat Tunnel. Trans. AIME, Paper no. 1657, March 1927, p. 63-69.

Keays, R.H. Inflows Block Construction of Aqueduct Tunnel for Athens, Greece. Eng. News - Records, June 11, 1931, p. 978-981.

Kesserü, Zs. Methodology and Application of Analysing Rock-Water Interaction Endangering Mines. in Water in Min. and Underground Works, Asociacion Nacional de Ingenieros de Minas, Granada - Espana, 1978, p. 637-655.

Kesserü, Zs. Recent Investigations and Some New Observations on Protecting Layers. Publication of the Hungarian Min. Res. Inst., Budapest, 1977, 6 p.

King, H.J., B.N. Whittaker and A.S. Batchelor. The Effects of Interaction in Mine Layouts. Fifth Internat. Strata Control Conf., London, N.C.B., Paper no. 17, n.d., 11 p.

Lehmann, K. Systematic Extraction. Glückauf, 1938 (in German), p. 321-329.

Littlejohn, G.S. Observations of Brick Walls Subjected to Mining Subsidence. Symp. on Settlement of Structures, Pentech Press, London, 1974, p. 384-393.

Loofbourow, R.L. and R.L. Brittain. Dewatering Through Wells Before Mine Development. Min. Cong. J., July 1964, 8 p.

Maize, E.R. and H.P. Greenwald. Studies of Roof Movement in Coal Mines - Part 2. Crucible Mine of the Crucible Fuel Co. Bureau of Mines Rept. of Investigation 3452, June 1939, 16 p.

Maize, E.R., E. Thomas and H.P. Greenwald. Studies of Room Movement in Coal Mines - Part 3. Gibson Mine of the Hillman Coal and Coke Co. Bureau of Mines Rept. of Investigation 3506, April 1940, 9 p.

Maize, E.R., E. Thomas and H.P. Greenwald. Studies of Roof Movement in Coal Mines - Part 4. Study of Subsidence of a Highway Caused by Mining Coal Beneath. Bureau of Mines Rept. of Investigation 3562, March 1941, 9 p.

McKinstry, H.E. Mining Geology. Prentice-Hall, Inc, Englewood Cliffs, New Jersey, 1948, p. 518-544.

McNicholas, F.S., V.C. Rogers and M.S. Walker. An Experimental Study of Caving and Drawing Large Ore Bodies. Trans., AIME, 163, 1945, p. 1-42.

Morfeldt, C. Significance of Groundwater at Rock Constructions of Different Types. Proc. Intern. Symp. on Large Permanent Underground Openings, T. L. Brekke and F. A. Jorstad, eds., Universitetsforlaget, Oslo, Norway, 1970, p. 305-317.

National Coal Board. Subsidence Engineers Handbook, (Revised) Min. Dept., London, 1966, 109 p.

Obert, L. and W.I. Duvall. Rock Mechanics and the Design of Structures in Rock. John Wiley & Sons, Inc, NY, 1967, 295 p.

Orchard, R.J. The Control of Ground Movements in Undersea Working. The Min. Eng. v. 128, no. 101, Feb. 1969, p. 259-273.

Orchard, R.J. Working Under Bodies of Water. The Min. Eng. v. 130, no. 170, March 1975, p. 261-270.

Orchard, R.J. and W.S. Allen. Longwall Partial Extraction Systems. The Min. Eng., June 1970, p. 523-534.

Panek, L.A. Methods and Equipment for Measuring Subsidence. Third Symp. on Salt, J.L. Rau and L.F. Dellwig, eds., The Northern Ohio Geol. Soc., Inc., Cleveland, Ohio, 1966, p. 321-338.

Phillips, D.W. Tectonics of Mining Part II. Coll. Eng., August, 1948.

Randall, F.A. and W.C. Panarese. Concrete Masonry Handbook for Architects, Eng., Builders. Portland Cement Assoc., no. 75-44908, 1976, p. 27-55.

Rept. of Inspector of Mines and Appraisers. Port Hood Mine. Kings Printer, Halifax, Nova Scotia, 1913.

Reynolds, R.G. Coal Mining Under Stored Water: Report of the Commissioner, The Hon. Mr. Justice R.G. Reynolds, Judge of Appeal, Supreme Court of New South Wales on an Inquiry into Coal Mining Under or in the Vicinity of the Stored Waters of the Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs, New South Wales, Australia. Dept. of Mineral Resources and Development, N.S.W. Govt., Sydney, Australia, 1976, 124 p.

Roark, R.J. and W.C. Young. Formulas for Stress and Strain. McGraw-Hill Book Co., 5th Edition, 1975, p. 386-401.

Rogoz, M. Water Capacity of Abandoned Workings in Underground Coal Mines. In Water in Min. and Underground Works, Asociacion Nacional de Ingenieros de Minas, Granada - Espana, 1978, p. 1291-1301.

Salamon, M.D.G. Elastic Analysis of Displacements and Stresses Induced by Mining of Seam or Reef Deposits, J. South African Inst. Min. Met., Nov. 1963, p. 128-149.

Salamon, M.D.G. and A.H. Munro. A Study of the Strength of Coal Pillars. J. of South African Inst. of Min. and Met., Sept. 1967. 12 p.

Schmieder, A. et al. Stochastic Forecasting of Mine Water Inrushes. Proc. of the Min. Development Inst., Budapest, Hungary, May 1979, p. 2-26.

Shadbolt, C.H. Min. Subsidence - Historical Review and State of the Art. Proc. at Conf. on Large Ground Movement and Structures, Univ. of Wales, Inst. of Sci. and Tech., London, 1977, p. 705-748.

Singh, T.N. and B. Singh. Caving of a Coal Seam Under Kamptec Aquifers of India. in Water in Min. and Underground Works, Asociacion Nacional de Ingenieros de Minas, Granada, Espana, 1978, p. 657-673.

Skelly and Loy. Guidelines for Mining Near Surface Water Bodies: Phase I - Interim Rept. for Bureau of Mines Contract no. H0252083, Aug. 23, 1975, 113 p.

Skelly and Loy. Guidelines for Mining Near Surface Waters: Phase II - Interim Rept. for Bureau of Mines Contract no. H0252083, Jan. 16, 1976, 106 p.

Skelly and Loy. Guidelines for Mining Near Water Bodies: Phase III - Final Rept. for Bureau of Mines Contract no. H0252083, April 1976, 101 p.

Szechy, K. The Art of Tunnelling. Akademiai Kiado, Budapest, 1966, p. 40-45 and 79-84 and 99-106.

Thomas, L.A. Subsidence and Related Caving Phenomena at the San Manuel Mine. Unpublished Paper, Magma Copper Co., San Manuel Division, San Manuel, Arizona, 1971, 83 p.

Thompson, T.F. San Jacinto Tunnel. in Lest We Forget - Case History Lessons, K.S. Lane, ed., Underground Space, v. 3, no. 2, 1978, p. 91-94.

Toennies, H. Nonreinforced Concrete Masonry Design Tables. Nat. Concrete Masonry Assoc., 1971, p. 1-32, 47-49, 79-81, 111-113 and 143-145.

University of Kentucky. Calculation of Force Acting on a Clothed Man in a Flowing Stream. Unpublished Notes, Dept. of Civil Engineering, n.d., 1 p.

von Schonfeldt, H., F.D. Wright and K.F. Unrug. Subsidence and its Effects on Longwall Mine Design. Ann. Am. Min. Cong. Coal Conv., St.Louis, May 1979, 12 p.

Wade, L.V. and P.J. Conroy. Rock Mechanics Study of Old Ben Longwall Panel no. 1. Proc. of the Illinois Min. Inst., Springfield, Illinois, Oct. 1977, p. 61-79.

Wardell, K. Ground Subsidence and Control. Min. Cong. J., Jan. 1969, p. 36-42.

Wardell, K. and Partners. Guidelines for Mining Near Surface Water: Phase I - Rept. for Bureau of Mines Contract No. H0252021, Nov. 1975, 29 p.

Wardell, K. and Partners. Guidelines for Mining near Surface Waters: Phase II - Rept. for Bureau of Mines Contract no. H0252021, Feb. 1976, 37 p.

Wardell, K. and Partners. Guidelines for Mining near Surface Waters: Phase III - Rept. for Bureau of Mines Contract no. H0252021, May 1976, 50 p.

West Virginia Department of Natural Resources. Drainage. Handbook for Surface Mining. 1975, p. 9-10.

Whittaker, B.N. and J.H. Pye. Design and Layout of Longwall Methods of Coal Mining Design Methods in Rock Mechanics Proc. 16th Symp. on Rock Mechanics, C. Fairhurst and S.L. Crouch, eds., Am. Soc. Civil Eng., NY, 1977, p. 303-314.

Williamson, W.H. Hydrogeological Aspects of Coal Mining Under Stored Water Near Sydney, Australia. in Water in Min. and Underground Works, Asociacion Nacional de Ingenieros de Minas, Granada, Espana, 1978, p. 309-328.

Wilson, A.H. and D.P. Ashwin. Research into Determination of Pillar Size. Trans. of the Inst. of Min. Eng. v. 131, June 1972, p. 409-430.

Wolmarans, J.F. and F.H. Guise-Brown. The Water Hazard in Deep Gold Mining of the Far West Witwatersrand - South Africa. in Water in Min. and Underground Works, Asociacion Nacional de Ingenieros de Minas, Granada, Espana, 1978, p. 329-346.

13.0 APPENDICES

APPENDIX A

BUREAU OF MINES INFORMATION CIRCULAR 8741

Information Circular 8741

Results of Research To Develop Guidelines for Mining Near Surface and Underground Bodies of Water

By Clarence O. Babcock and Verne E. Hooker

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

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SPECIAL NOTE

The section on mine maps (pages 11-13) is synopsized from existing Federal regulations (30 CFR 75.1200). This section is included to emphasize the importance of mine maps in relation to mining under or near bodies of water and is not intended as an additional mapping requirement or as a proposed amendment to current regulations.

Panel and pillar mining, being used in the United Kingdom, is not yet extensively used in the United States. This system which works well in deep coal, has much less application here, particularly in the eastern part of the country where the biggest tonnage is relatively shallow. The panel width used has been so wide that only deep coal can qualify for mining by this method. However, if this method is imported, as the longwall method was in the past, some guidelines for its use will be available. The method should find use where the coal is at the necessary depth, because higher recovery is possible than with room-and-pillar methods.

RESULTS OF RESEARCH TO DEVELOP GUIDELINES FOR MINING NEAR SURFACE AND UNDERGROUND BODIES OF WATER

by

Clarence O. Babcock[1] and Verne E. Hooker[2]

ABSTRACT

This Bureau of Mines publication presents guidelines for mining near surface and underground bodies of water. The guidelines were based on information developed under contract in three phases of study, as follows: (1) Collection and documentation of data from worldwide sources; (2) application of existing guidelines, foreign, Federal, and State, to case histories of previous inundations; and (3) development of recommended guidelines for underground coal mining near bodies of water aimed at maximum efficient utilization of underground coal resources consistent with minimizing inundation hazards. While the contract guidelines were for the mining of coal seams, they may also be used for mining any tabular sedimentary mineral deposit. Tables are given for the determination of the size of coal pillars needed; for other bedded deposits, similar tables could be determined based on their strength properties.

INTRODUCTION

The need for practical safety guidelines when mining near bodies of water is growing because of increasing mineral demands and an increasing number of water impoundments near mineral resources. Accordingly, the Bureau of Mines generated a program for the development of potential recommended guidelines for mining in close proximity to bodies of water. The objective was maximum efficient utilization of underground coal resources consistent with minimizing inundation hazards.

It should be emphasized that an empirical approach to data collection was used in developing these recommendations. The basic engineering concepts are sound; however, when there is sufficient engineering data or mining experience available, these conservative recommendations should be modified. Further research is under consideration to refine the engineering conditions on which the recommendations are based.

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Two contracts on the subject were initiated in May 1975 and completed in September 1976.[3] Results of the contracts were evaluated and compiled by the authors into a single comprehensive set of recommended technical guidelines relative to surface waters, surface structures, and abandoned workings.

These recommended guidelines cover total extraction by longwall or retreat pillar robbing, partial extraction by room and pillar, partial extraction by panel mining, and a combination of these methods. Some of the important variables involved are the solid rock cover above the coal seam(s), allowable tensile strain at the bottom of the water body, the number of seams that may be mined or restricted, and the allowable proximity of faults, old workings, etc.

SURFACE WATERS

Total Extraction Mining

A total extraction mining system is defined as the extraction of the whole minable thickness of a coal seam or other bedded mineral deposit over a large enough area so that the lateral dimensions in any direction are equal to or greater than the depth of mining. The method of extraction, whether by longwall, continuous, or conventional mining, is not relevant to this definition.

The following guidelines are recommended with respect to total extraction mining. These guidelines require the establishment--by drilling or otherwise--of the thickness of solid rock cover above the proposed total extraction workings. If it is desired to have overlying material(s) other than solid rock cover included in the minimum depth stipulation, it is necessary to demonstrate the nature and permeability of such materials. Where the word "coal" or "seam" is used, it also applies to any bedded mineral deposit.

1. Any single seam of coal beneath or in the vicinity of any body of surface water may be totally extracted, whether by longwall mining or by pillar robbing, provided that for each 1-foot thickness of coal seam to be extracted, a minimum of 60 feet of solid strata cover exists between the proposed workings and the bed of the body of surface water.

2. Where more than one seam of coal exists, all may be worked by total extraction provided that for each 1 foot of the aggregate coal and rock thickness of all seams to be extracted, a minimum thickness of 60 feet of solid strata cover exists between the proposed workings in the uppermost seam and the bed of the body of

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[3] Skelly and Loy (Harrisburg, Pa.). Guidelines for Mining Near Surface Waters (Contract H0252083). BuMines Open File Rept. 29-77, 1977, 190 pp.; available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh., Pa., Spokane, Wash., and Carbondale, Ill.; at the Central Library, U.S. Department of the Interior, Washington, D.C.; at the libraries of the Morgantown Energy Research Center--ERDA, Morgantown, W. Va., and the Training Facility--MESA, Beckley, W. Va.; and from the National Technical Information Service, Springfield, Va., PB 264 728/AS.

K. Wardell and Partners (Newcastle, United Kingdom). Guidelines for Mining Near Surface Waters (Contract H0252021). BuMines Open File Rept. 30-77, 1977, 59 pp.; available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh, Pa., Spokane, Wash., and Carbondale, Ill.; at the Central Library, U.S. Department of the Interior, Washington, D.C.; at the libraries of the Morgantown Energy Research Center--ERDA, Morgantown, W. Va., and the Training Facility--MESA, Beckley, W. Va.; and from the National Technical Information Service, Springfield, Va., PB 264 729/AS.

surface water. When subsidence observations have been carried out and satisfactory calculations of surface tensile strain can be made, any number of seams may be mined by total extraction provided that the maximum cumulative, calculated[4] tensile strain beneath a body for surface water will nowhere exceed 8.75 mm/m (0.875 percent).

3. Where a single seam has already been mined by total extraction in accordance with the provision that for each 1-foot thickness of mineral and rock extracted, a minimum of 60 feet of solid strata cover should exist, no other underlying seam should be mined by total extraction. Where the cover between the two seams is 60 times (or greater) the extractable thickness of the lower seam, such a lower seam should be mined by partial extraction--in accordance with the subsequent guidelines here stipulated--as though the upper seam represented a body of surface water.

4. Where wash or other natural or artificial deposits, which may be highly permeable or which when wet may flow, exist between bedrock and the bed of a body of surface water, these should be excluded from the thickness of solid strata mentioned, except where it has been demonstrated that such wash or other deposits would not be likely to flow when wet and could be considered as impermeable.

5. Where a fault which might connect mine workings with a body of surface water and which has a vertical displacement greater than 10 feet, or an intrusive dike having a width greater than 10 feet, is known to exist or is met with during development, no seam should be totally extracted within 50 feet horizontally on either side of such fault or dike.

Partial Extraction Mining

A partial extraction system is one in which designated pillars are deliberately left unworked for the purpose of giving more or less permanent support to the overlying strata and the land surface. Two such systems are the room-and-pillar first working and the panel-and-pillar system.

Room and Pillar

In the room-and-pillar system of mining about 50 percent of the coal is recovered by two intersecting sets of parallel entries, usually nearly perpendicular to one another. The result is a checkerboardlike array of pillars which systematically support the roof rock. In the following discussion the term "first working" means that the coal is mined by driving the entries, as opposed to "secondary workings" in which the coal left in the pillars is mined to increase recovery.

Minimum Depth of Cover

A minimum thickness of solid strata cover should be left above the coal seam. Both the height and width of the entries and the characteristics of

[4]Calculation procedure is given in the appendix.

the roof beds are significant parameters with respect to expected roof collapse height.

The separate provisions with respect to drifts and tunnels are stipulated because the practicability and cost of supporting and maintaining them would be generally acceptable. In room-and-pillar entries, however, the cost of permanent supports would be exceptionally high and their maintenance would be generally impracticable.

The following guidelines are recommended with respect to a minimum depth of solid strata for room-and-pillar workings.

1. No entry should be driven in any coal seam lying beneath or in the vicinity of any body of surface water where the total thickness of solid strata cover above the seam is less than 5 times the maximum entry width (5s) or 10 times the maximum entry height (10t), whichever is the greater. Where at least one competent bed of sandstone or similar material is present within the solid strata and has a thickness at least 1.75 times the maximum entry width, mining at a lesser cover than 5s or 10t may be considered.

2. In the case of drifts or tunnels beneath or in the vicinity of the body of surface water driven through the strata for the purpose of gaining access to a coal seam, the provision of 10t or 5s should also apply unless drifts or tunnels are permanently supported and are so maintained. In the latter event, however, there should be a minimum solid rock cover of 1.75 times the maximum drift or tunnel width.

Pillar Dimensions for First Workings

The results of observing the behavior of mine pillars underground with respect to stability, of laboratory testing of coal samples, and of theoretical considerations were combined to establish the size of coal pillars needed for safety as functions of coal thickness, depth below surface of the coal seam, and the room width used. In accordance with the results, the following guidelines are proposed with respect to pillar dimensions for room-and-pillar first workings.

1. Where room-and-pillar first working is to be carried out beneath or in the vicinity of any body of surface water and at cover depth greater than the stipulated minimum, the minimum width of pillar should be determined in accordance with tables 1 through 7.[5] An exception is made where specific local data (including relevant and comparable mining experience) exist which demonstrate that a lesser width could be used with safety.

[5]Tables include seams thicknesses of 3, 4, 6, 8, 10, 12, and 14 feet. If other seam thickness data are required, the tabulated value, W, can be obtained by trial and error or numerical methods from the equation $((W+R)/W)^2 1.5D = 1000/\sqrt{H} + 20\ (W/H)^2$, where W, R, H, and D are pillar width, room width, seam thickness, and depth from surface, respectively.

2. Where an upper seam has been mined by room-and-pillar first working in accordance with these guidelines, underlying seams should not be mined--whether by total or partial extraction--except by considering the upper seam as though it were the base of the surface body of water.

3. Where pillar widths are determined in accordance with these provisions, the calculated pillar loading should not exceed the allowable load-bearing capacity of the immediate roof and/or floor beds.

TABLE 1. - Minimum pillar widths for pillar heights of 3 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	12	13	14	-	-
150	15	16	16	17	18
200	17	18	19	20	20
250	19	20	21	22	22
300	20	21	22	23	24
350	22	23	24	25	26
400	23	24	25	26	27
450	25	26	27	28	29
500	26	27	28	28	30
550	27	28	29	30	31
600	28	28	30	31	32

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 2. - Minimum pillar widths for pillar heights of 4 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	14	15	16	-	-
150	17	18	19	20	21
200	20	21	22	23	24
250	23	24	25	26	27
300	25	26	27	28	29
350	27	28	29	30	31
400	29	30	31	32	33
450	30	31	33	34	35
500	32	33	34	35	36
550	33	34	36	37	38
600	35	36	37	38	39

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 3. - Minimum pillar widths for pillar heights of 6 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	17	19	20	-	-
150	22	24	25	26	27
200	26	28	29	30	32
250	30	31	33	34	35
300	33	35	36	37	38
350	36	37	39	40	41
400	39	40	41	43	44
450	41	42	44	45	46
500	43	45	46	47	48
550	45	47	48	49	51
600	47	49	50	51	53

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 4. - Minimum pillar widths for pillar heights of 8 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	21	22	24	-	-
150	27	29	30	32	33
200	33	34	36	37	38
250	37	39	40	42	43
300	41	43	44	46	47
350	45	47	48	49	51
400	48	50	51	53	54
450	51	53	55	56	57
500	54	56	57	59	60
550	57	59	60	62	63
600	60	61	63	64	66

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 5. - Minimum pillar widths for pillar heights of 10 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	24	26	27	-	-
150	32	34	35	37	38
200	39	40	42	43	45
250	44	46	48	49	51
300	49	51	53	54	56
350	54	56	57	59	60
400	58	60	61	63	64
450	62	64	65	67	68
500	66	67	69	70	72
550	69	71	72	74	75
600	72	74	76	77	79

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 6. - Minimum pillar widths for pillar heights of 12 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	37	39	40	42	44
200	45	46	48	50	51
250	51	53	55	57	58
300	57	59	61	63	64
350	63	65	66	68	70
400	68	70	71	73	75
450	73	74	76	78	79
500	77	79	80	82	84
550	81	83	84	86	88
600	85	87	88	90	91
650	88	90	92	94	95
700	92	94	95	97	99
720	93	95	97	98	100

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 7. - Minimum pillar widths for pillar heights of 14 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	41	43	45	47	48
200	51	53	54	56	58
250	58	60	62	64	66
300	66	67	69	71	73
350	72	74	76	77	79
400	78	80	81	83	85
450	83	85	87	88	90
500	88	90	92	93	95
550	93	95	96	98	100
600	97	99	101	103	104
650	102	103	105	107	108
700	106	107	109	111	113
750	109	111	113	115	116
800	113	115	116	119	120
840	116	118	120	121	123

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

Panel and Pillar

The panel-and-pillar system is defined to be one in which a bedded deposit is totally extracted from panels which are of such width in relation to their depth that the main strata can span any one of them with little deflection. Individual extraction panels are separated by abutment pillars designed to sustain the load of the main strata overlying a group of such panels and pillars. The minerals from the panels may be extracted by long-wall mining, or the panels may first be mined by room and pillar and the pillars may subsequently be taken by either continuous or conventional mining methods.

The following guidelines are recommended with respect to panel-and-pillar mining beneath and in the vicinity of bodies of surface water.

1. Where the panel-and-pillar system is to be carried out beneath or in the vicinity of any body of surface water, there should be a minimum solid strata cover thickness of 270 feet or 3p, where p is the width of the panel, whichever is greater.

2. The widths of extraction panels should not exceed one-third the depth of mining, and the widths of pillars between extraction panels should be 15 times their height or one-fifth the depth of mining, whichever is greater.

3. Where more than one seam is to be mined by this system, the panels and pillars in all seams should be superimposed in the vertical direction with the panel widths being determined from the depth to the uppermost seam and the pillar widths being determined by reference to the thickest and/or deepest seam, whichever would give the greater dimension.

4. Where the panel-and-pillar system of mining has been employed in an upper seam, it should not be permissible to mine by total extraction in any underlying seam except by considering the upper one as though it were the base of the surface body of water.

Safety Zones

From observed behavior of rock strata and soil above mined-out regions, a zone is known to exist that will most likely fail if mined, causing flooding of the workings and damage to the surface and to surface structures. From rock mechanics considerations the approximate shape and extent of this zone can be identified. If no risk can be taken, obviously no mining is possible. For many conditions of mining, no damage is likely to occur and mining should be permitted.

Surface Waters

The following guidelines are recommended with respect to safety zones around and beneath bodies of surface water.

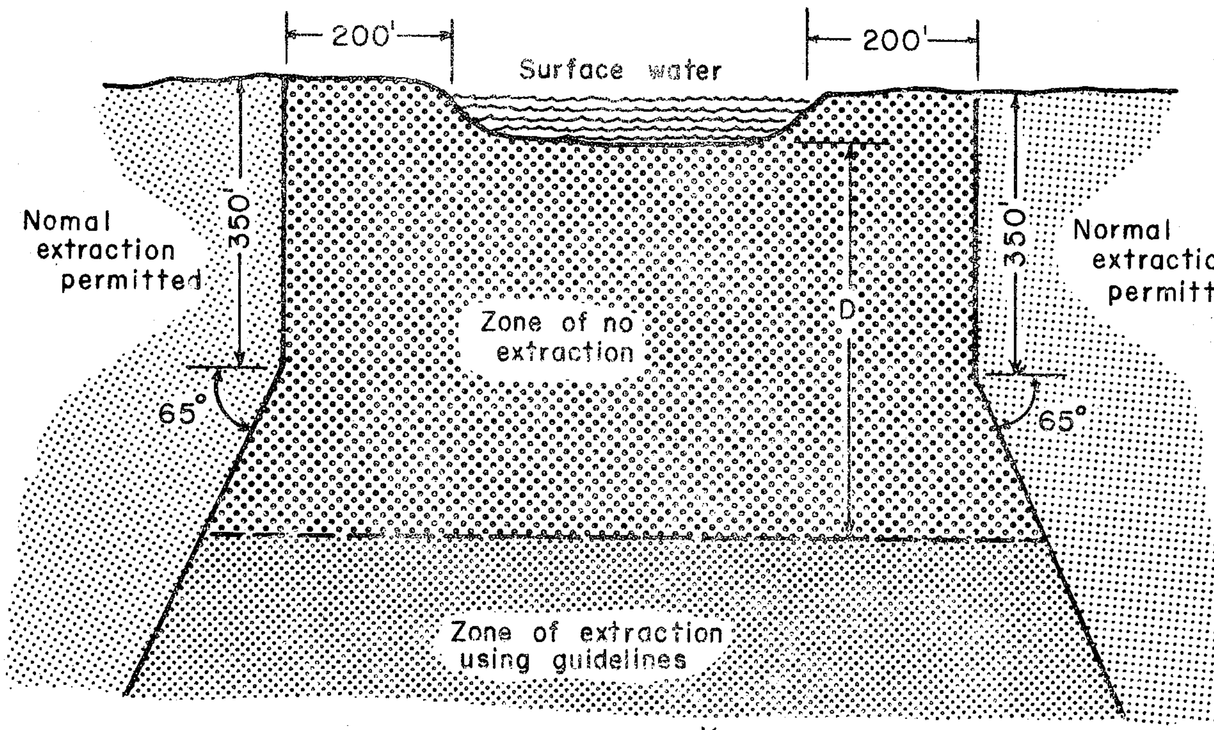
1. Where any body of surface water is present above the potential mine workings, a safety zone around such body of surface water should extend 200 feet horizontally from the high-water mark, or perimeter of the water body, and vertically downward from this point to a depth of 350 feet, then outward at an angle of dip of 65° as shown in figure 1.

2. If mining is considered within such a safety zone, it should be in accordance with the guidelines for mining beneath surface waters.

3. The width of such a safety zone may be increased or decreased if local observations and/or experience justify.

Structures Retaining Water

Since there is always some risk that damage will occur to surface structures by mining, no mining should be done in a safety zone beneath and around



	D*
Room and pillar	5s or 10t
Panel	3p or 270 ft
Total extraction	60t

*-Whichever is larger

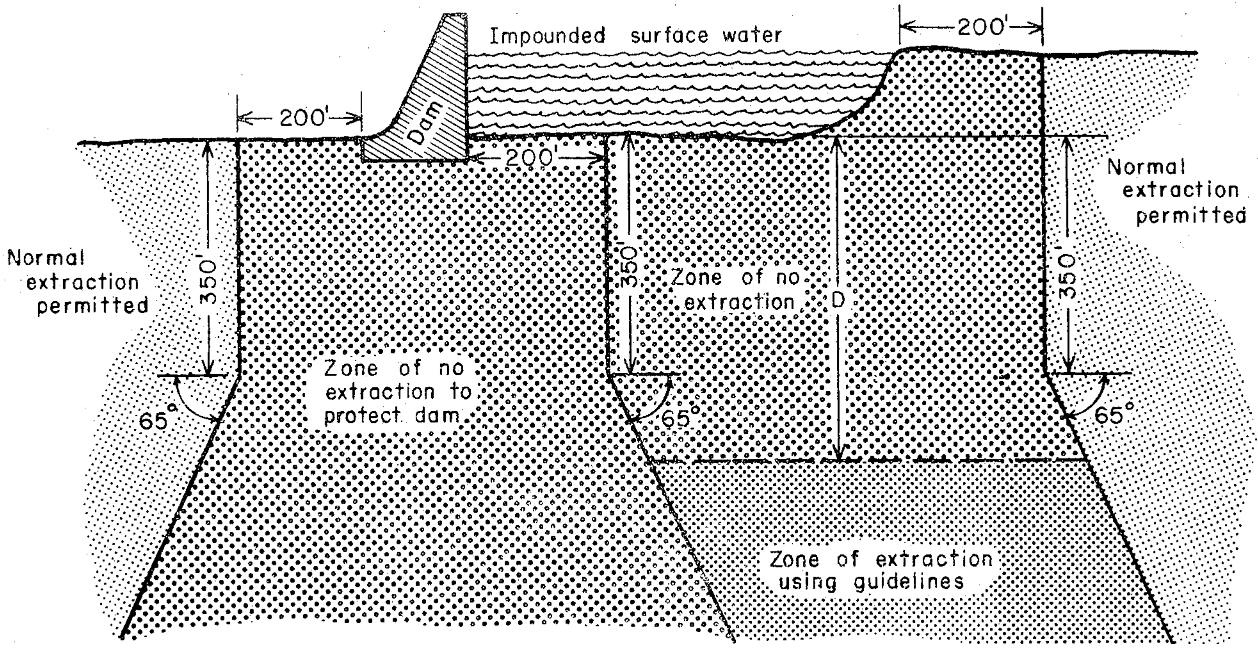
FIGURE 1. - Safety zone beneath body of surface water.

a structure where its failure would cause loss of life, property damage, or damage to water supplies needed for the public welfare. If the consequences of structural failure are not severe, mining may be undertaken.

The following guidelines are recommended with respect to safety zones around and beneath structures the survival of which is important to the public welfare.

1. Where any surface structure is impounding a substantial body of surface water and damage to that structure by mine subsidence effects could lead to a risk of structural failure and prejudice to public safety, no mining should be permitted within the safety zone of such a structure.

2. The perimeter of the structure requiring protection should be established by those responsible for its maintenance and safety. The safety zone around the perimeter of protection should extend outward 200 feet in all directions, then downward for 350 feet, and then outward at a dip of 65° from the horizontal as shown in figure 2. This safety zone is designated as a zone of no extraction. Figure 2 also shows the restriction on mining beneath the impounded water.



	D*
Room and pillar	5s or 10t
Panel	3s or 270 ft
Total extraction	60t

*Whichever is larger

FIGURE 2. - Safety zone beneath dam and impounded body of surface water.

3. A greater or lesser distance than that specified in paragraph 2 may be used where local observations and/or experience so indicate.

UNDERGROUND WATERS

Mine Maps

The operator of a coal mine should have in a fireproof repository (located in an area on the surface of the mine chosen by the mine operator to minimize the danger of destruction by fire or other hazard) accurate, up-to-date maps of the mine drawn to scale.

Surface Features

Surface features may be shown directly on the mine map, or on a transparent or translucent sheet, which, when overlain on a map of underground workings, shows true and exact relations of surface features to mine workings and excavations. Surface features to be shown include--

1. Name and address of the mine.
2. Scale and orientation of the map.
3. Boundary lines and names of all surface property owners.

4. Boundary lines of the coal rights pertaining to each mine.
5. All outcrop lines.
6. Topographic features such as hills, ravines, intermittent and permanent streams, bodies of standing waters (with elevations and estimated depths).
7. Location and identification of municipal subdivisions (State, county, townships).
8. Location of all railroads and sidings, highways, and other roads.
9. Location and identification of mine buildings and facilities.
10. Location of all utilities and pipelines.
11. Location and depth of holes drilled for oil, gas, water, or geologic information that penetrate a workable seam.
12. Location of all surface fans.
13. Location of mine openings.
14. The location and description of at least two permanent baseline points coordinated with the underground and surface mine traverses, and the location and description of at least two permanent elevation bench marks used in connection with establishing or referencing mine elevation surveys. Location and description of a permanent bench mark or monument near the main mine opening.

Underground Features

Whether or not combined on the same sheet with surface features, at least one set of maps showing underground features should be composed on the same scale. Pertinent information to be recorded on the mine map should include--

1. Name and address of the mine.
2. Scale and orientation of the map.
3. Boundary lines of coal rights and owner identification.
4. Structure contours and dip of the coalbed being mined at not greater than 10-foot elevation intervals.
5. Location of all drill holes that penetrate the mined bed.
6. All shaft, slope, drift, and tunnel openings and auger- and strip-mined areas of the bed being mined.
7. Location of all ventilation fans.
8. Location and exact extent of adjacent active or abandoned underground workings above, below, or in the same seam. If abandoned workings are known to exist in an area, but exact extent is not known, it should be so indicated.
9. Up-to-date locations of active work areas, worked-out areas, and abandoned areas.
10. Locations of entries and aircourses with direction of airflow indicated by arrow.
11. Location of all escapeways.
12. Location and exact extent of all water pools, water-bearing strata, or fluidlike materials which tend to flow when wet (quicksands, peat, etc.).
13. Location and elevation of any body of water dammed or held back in any portion of the mine.

14. The elevation of tops and bottoms of shafts and slopes, and the floor at the entrance to drift and tunnel openings.
15. The elevation of the floors at intervals of not more than 200 feet in--

    a. At least one entry of each working section and main and cross entries.
    b. The last line of open crosscuts of each working section, and of main and cross entries, before such sections and main and cross entries are abandoned.
    c. Rooms advancing toward or adjacent to property or boundary lines or adjacent mines.

16. The owner, agent, or manager of a mine should take all reasonable steps to determine whether there is any material below the surface which could affect active, or soon to be active, areas in a mine so as to cause danger to miners working in that mine. All facts pertaining to such conditions should be presented to the manager.

Property Boundary Barrier Pillars

To insure that the mining of the coal seam by one company up to the property line does not favor that company over another company that mines later, the following guidelines are recommended.

1. A boundary pillar of unmined coal should be left to the property line; it should be of a width calculated by the equation Pb = 10 + 2T + 5D. Pb is the pillar width in feet, 10 is a constant safety factor, T is the thickness of the bed in feet rounded to the next highest integer, and D is the depth of the seam at the property line in 100-foot increments rounded to the next highest integer. This pillar width should be required on both sides of the property line. When mining on one side of the property line has approached closer than would be permitted by this guideline, the advancing working should increase its property boundary barrier pillar requirement so that the cumulative pillar size is equal to 2 Pb. Where faults are known to occur, which could result in a connection between the abandoned and active workings or which could seriously weaken pillar stability and strength, additional pillar widths should be used. This additional width should be based on the experience and judgment of the mine engineer and mine inspector.

2. Boundary barrier pillars should not be altered for increased mineral recovery unless the mining proposal insures inspection and certification that all of the affected workings are free from hazardous accumulations of water, and the proposal has--

a. Been agreed to by the interested mining companies and superintendents.
b. Been approved by the mine inspector.
c. Received approval from the responsible government regulatory agency.
d. Considered eventual interconnection of the mining operations by either accident or development plan.
e. Considered the development plans from all affected mining companies.

Abandoned Workings, Abandoned Areas, and Adjacent Mines

Water-filled mine openings, the presence of which is unknown or if known the extent of which is poorly defined, are of major concern to mine operators. The following guidelines are recommended with respect to these problems.

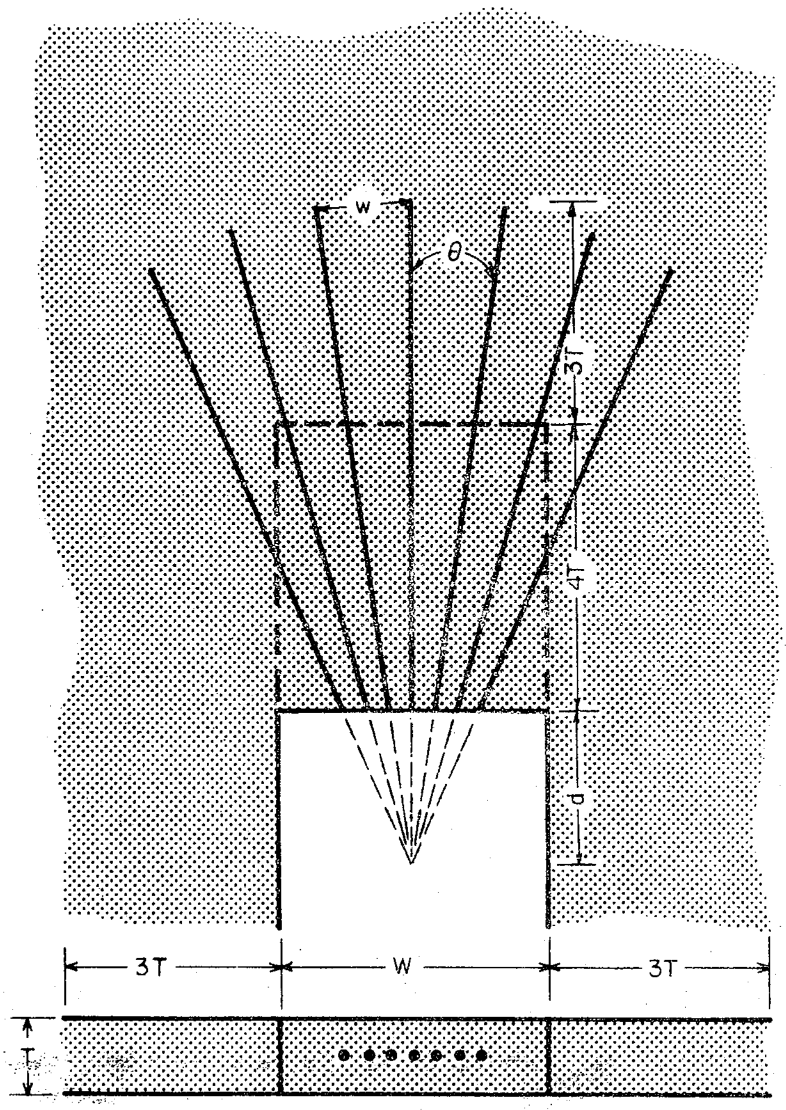
1. No mining should be permitted within 200 feet of any known or suspected abandoned workings (that are part of the present mine and/or other prior mine) which cannot be inspected and certified free of dangerous accumulations of water. When these abandoned workings can be inspected and certified as safe, mining can proceed to within the distance permitted by the Property Boundary Barrier Pillar guidelines, or to within the distance corresponding to a pillar width-to-thickness ratio of 10 to 1, whichever is larger. Where faults are known to occur that could impair the effectiveness of the pillar as a water barrier, additional pillar width may be used as determined by the mine engineer and mine inspector.

2. Locator boreholes should be drilled from the advancing face nearest to the abandoned mine through the 200-foot barrier pillar to determine the location of abandoned workings. The equipment and materials necessary to plug the borehole upon breakthrough must be available to the drill crew. The water head pressure or atmospheric conditions in the abandoned workings should be determined.

3. Unless downhole instrumentation definitely established that no water exists in the abandoned workings, even though pressure or gravity flow does not occur at breakthrough, the workings should be assumed to be flooded. If it is subsequently determined that the abandoned workings are dry, mining may proceed up to the limits of boundary barrier pillar (when approaching the property line) as defined by $Pb = 10 + 2T + .5D$; or normal mining operations should be permitted when the property limits are not a factor to be considered in this development.

4. Water may be drained from abandoned workings through a drift or auger entry, if possible, or from boreholes drilled from the surface. Water also may be drained through the 200-foot barrier pillar to the active workings and pumped to the surface. This latter method is potentially hazardous, however, and should only be used under the direction of knowledgeable and experienced personnel. If permits are necessary to discharge the water on the surface, they will need to be procured.

5. If the abandoned workings are not initially dry or drained of water, an effective safety barrier pillar should be sized by utilizing modeling techniques and unconfined compressive strength tests. For modeling, a factor of safety of 4 should be used in pillar design. Whenever the pressure head is equal to or greater than 5 atmospheres, consideration should be given to draining these workings. The permeability of the unmined barrier pillar should also be determined for consideration of its effect on waterflow and further pillar development. Two proving headings (for ventilation purposes), kept as narrow as possible and protected by boreholes, would be a safe mining plan to utilize for developing the barrier pillar up to the limits determined



Coal thickness = T

Number of holes required = $\frac{W+6T}{w}$ (next whole number)

Hole length = 7 T

Safe advance = 4T

Safety pillar = 3T

Angle θ = ATAN w/(7T+d)

w = width of old headings, if known; if w is unknown, use w = T

FIGURE 3. - Drill pattern for safe advance through coal with unknown inundation hazards.

by this recommended testing procedure. These headings should be limited to 15 feet in width. The mining crew should be alert for signs of pillar instability, excessive water leakage, strong sulfur smell, or other indicators of water, and mining halted or reevaluated as necessary. The permeability of the pillar can be reduced and its strength increased by introduction of grout or other cementing agents.

6. Whenever any working place approaches (1) within 10t or Pb, whichever is greatest, of abandoned areas in the mine as shown by surveys made and certified by a registered engineer or surveyor and the area cannot be inspected, or (2) within 200 feet of any other known abandoned areas of the mine that cannot be inspected and that may contain dangerous accumulations of water or gas, or (3) within 200 feet of known workings of an adjacent mine, a borehole configuration such as that shown in figure 3 should be drilled in advance of the working face of such working place and should be continually maintained in advance of the working face. (NOTE.--In figure 3, w is the width of the smallest old openings, if known. If not known, w is the value of the seam thickness, T).

Oil and Gas Well Pillars

Mining should not come closer to active oil and gas wells than 150 feet in any direction). When these wells are abandoned, however, they can be sealed and the barrier pillar mined through, provided that the seals are tested for leakage prior to mining.

Shaft and Vertical Opening Barrier Pillars

When these abandoned openings can be inspected and certified free of hazardous accumulations of water, they can be mined through as in normal pillar recovery operations.

When mining in the area of any abandoned shafts, raises, or other openings that cannot be inspected and certified free of dangerous accumulations of water, a barrier pillar 300 feet in diameter should be left around the opening, provided that a minimum of 100 feet of solid coal is left around the abandoned opening. Where these openings can be inspected and certified safe, a pillar of width-to-thickness ratio of 10 to 1 should be left around each opening. When mining in the area of abandoned slopes and like openings, the guidelines for mining near abandoned workings should be followed.

Mining Under Abandoned Flooded Workings

Mining under flooded abandoned workings should conform to the 60t and maximum tensile strain rules for total extraction, to the 5s or 10t rules for room-and-pillar extraction, and to the 3p or 270-foot rules for panel-and-pillar extraction.

APPENDIX

In the United Kingdom, numerous examples of total extraction beneath the sea have been examined in which no seawater passed into the mines. The maximum seabed tensile strain for each of these cases was calculated, and the results ranged from 5.0 to 15.0 millimeters per meter (mm/m). On the basis of this analysis, the National Coal Board has adopted a criterion of 10.0 mm/m of calculated maximum tensile strain as governing the minimum depth for total extraction. The expression used in the United Kingdom for calculating maximum tensile strain E_m , is

$$E_m = \frac{K\ S_{max}}{D}.$$

The value of S_{max} with longwall caving is normally taken as 0.90t, and the average value for K as 0.75 in the United Kingdom. Thus, the minimum depth of cover required for safety, D_{min} is

$$D_{min} = 67.5t,$$

where t is the thickness of the coal seam mined. For a limiting tensile strain of 5.0 mm/m, the limiting depth for total extraction would be 135t; for a limiting tensile strain of 15.0 mm/m, the limiting depth would be 45t.

If experience in the United States results in recommended strain values other than those used in the United Kingdom, these values may be used.

APPENDIX B

CODE OF FEDERAL REGULATIONS, TITLE 30
CHAPTER I - MINE SAFETY AND HEALTH ADMINISTRATION
SECTION 75.1716, 1978

§ 75.1716 Operations under water.

(STATUTORY PROVISIONS)

Whenever an operator mines coal from a coal mine opened after March 30, 1970, or from any new working section of a mine opened prior to such date, in a manner that requires the construction, operation, and maintenance of tunnels under any river, stream, lake, or other body of water that is, in the judgment of the Secretary, sufficiently large to constitute a hazard to miners such operator shall obtain a permit from the Secretary which shall include such terms and conditions as he deems appropriate to protect the safety of miners working or passing through such tunnels from cave-ins and other hazards. Such permits shall require, in accordance with a plan to be approved by the Secretary, that a safety zone be established beneath and adjacent to such body of water. No plan shall be approved unless there is a minimum of cover to be determined by the Secretary, based on test holes drilled by the operator in a manner to be prescribed by the Secretary. No such permit shall be required in the case of any new working section of a mine which is located under any water resource reservoir being constructed by a Federal agency on December 30, 1969, the operator of which is required by such agency to operate in a manner that protects the safety of miners working in such section from cave-ins and other hazards.

§ 75.1716-1 Operations under water; notifications by operator.

An operator planning to mine coal from coal mines opened after March 30, 1970, or from working sections in mines opened prior to such date, and in such manner that mining operations will be conducted, or tunnels constructed, under any river, stream, lake or other body of water, shall give notice to the Coal Mine Safety District Manager in the district in which the mine is located prior to the commencement of such mining operations.

§ 75.1716-2 Permit required.

If in the judgment of the Coal Mine Safety District Manager the proposed mining operations referred to in §75.1716-1 constitute a hazard to miners, he shall promptly so notify the operator that a permit is required.

§ 75.1716-3 Applications for permits.

An application for a permit required under this section shall be filed with the Coal Mine Safety District Manager and shall contain the following general information:

(a) Name and address of the company.
(b) Name and address of the mine.
(c) Projected mining and ground support plans.
(d) A mine map showing the locations of the river, stream, lake or other body of water and its relation to the location of all working places.
(e) A profile map showing the type of strata and the distance in elevation between the coal bed and the river, stream, lake or other body of water involved. The type of strata shall be determined by core test drill holes as prescribed by the Coal Mine Safety District Manager.

§ 75.1716-4 Issuance of permits.

If the Coal Mine Safety District Manager determines that the proposed mining operations under water can be safely conducted, he shall issue a permit for the conduct of such operations under such conditions as he deems necessary to protect the safety of miners engaged in those operations.

APPENDIX C

DEPTH AND VELOCITY OF FLOW FOR DIFFERENT RATES OF DISCHARGE

Depth and velocity of flow for different rates of discharge through mine entries of different widths and gradients were determined using Manning's Formula. They are graphically represented in Figures C-1 to C-12.

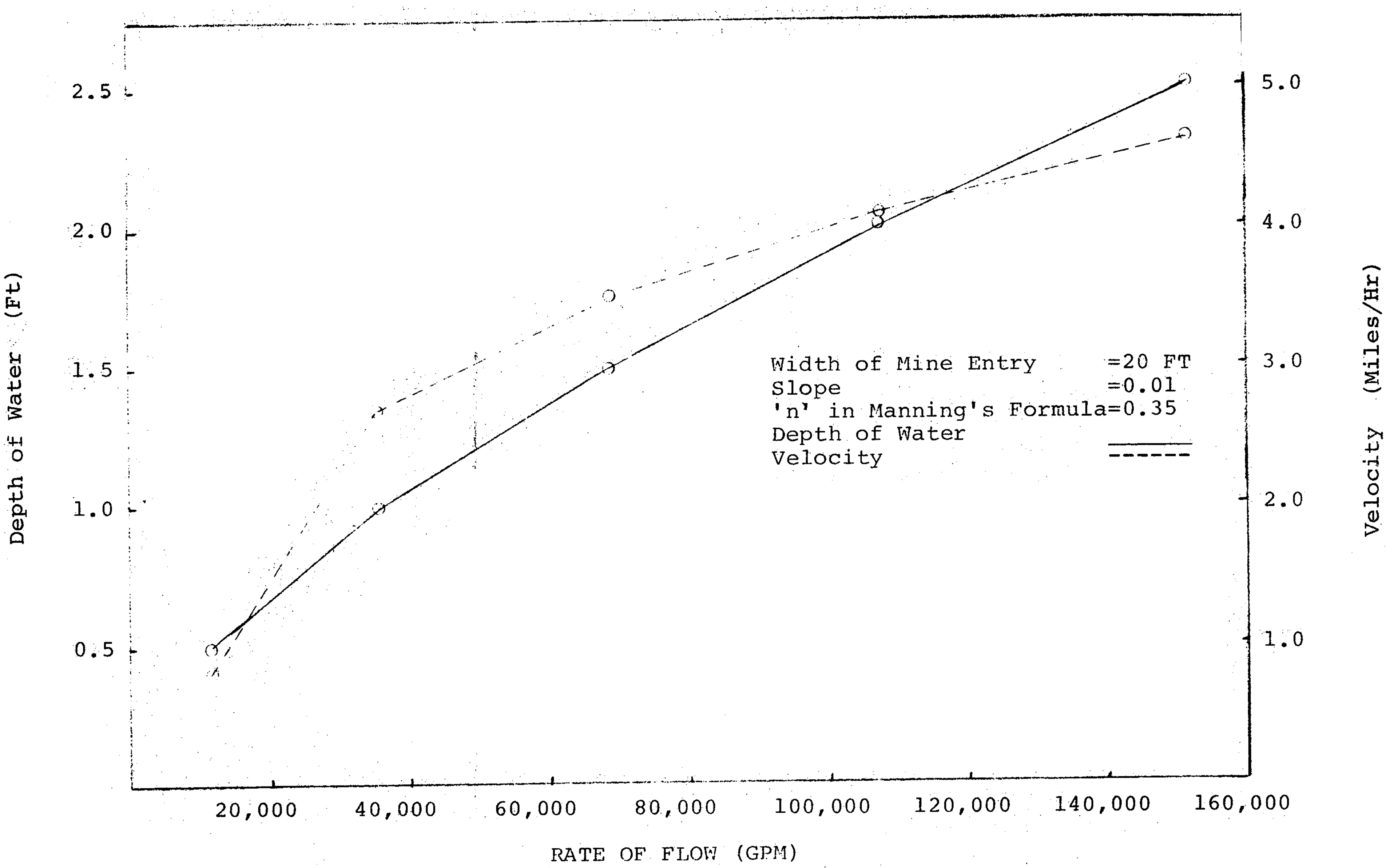


Figure C-1 Depth and Velocity of Flow for Different Rates of Discharge

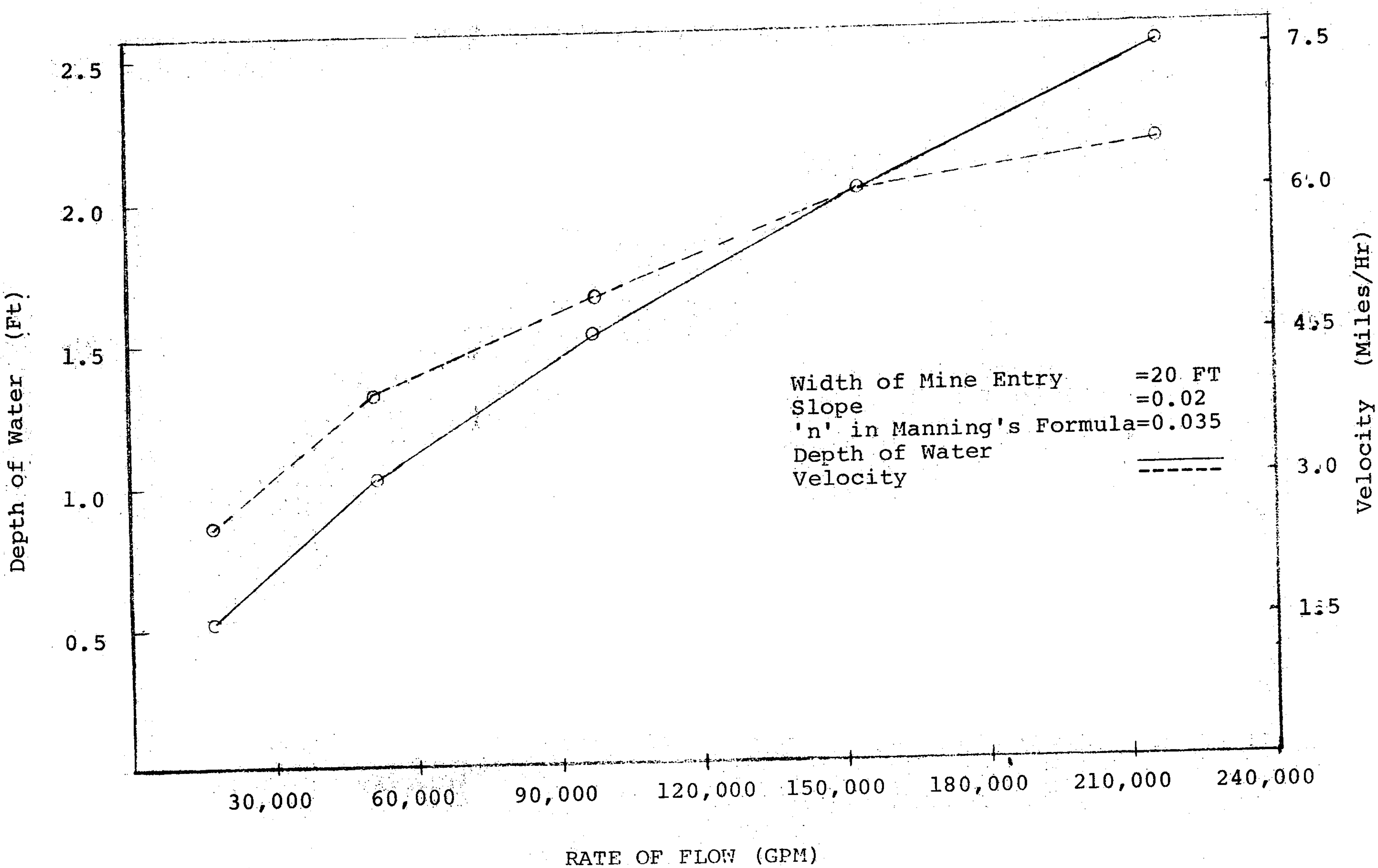


Figure C-2 Depth and Velocity of Flow for Different Rates of Discharge

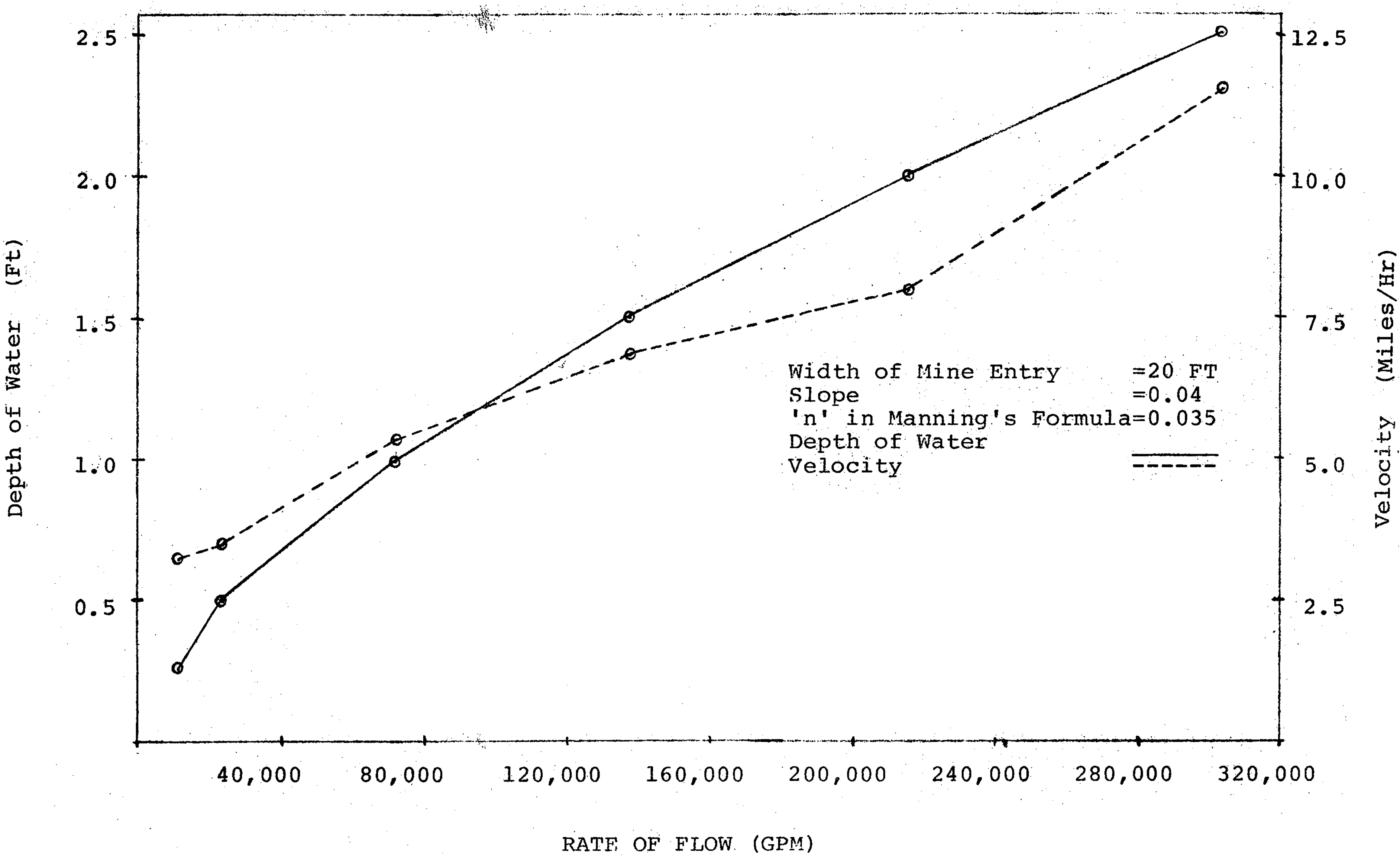


Figure C-3 Depth and Velocity of Flow for Different Rates of Discharge

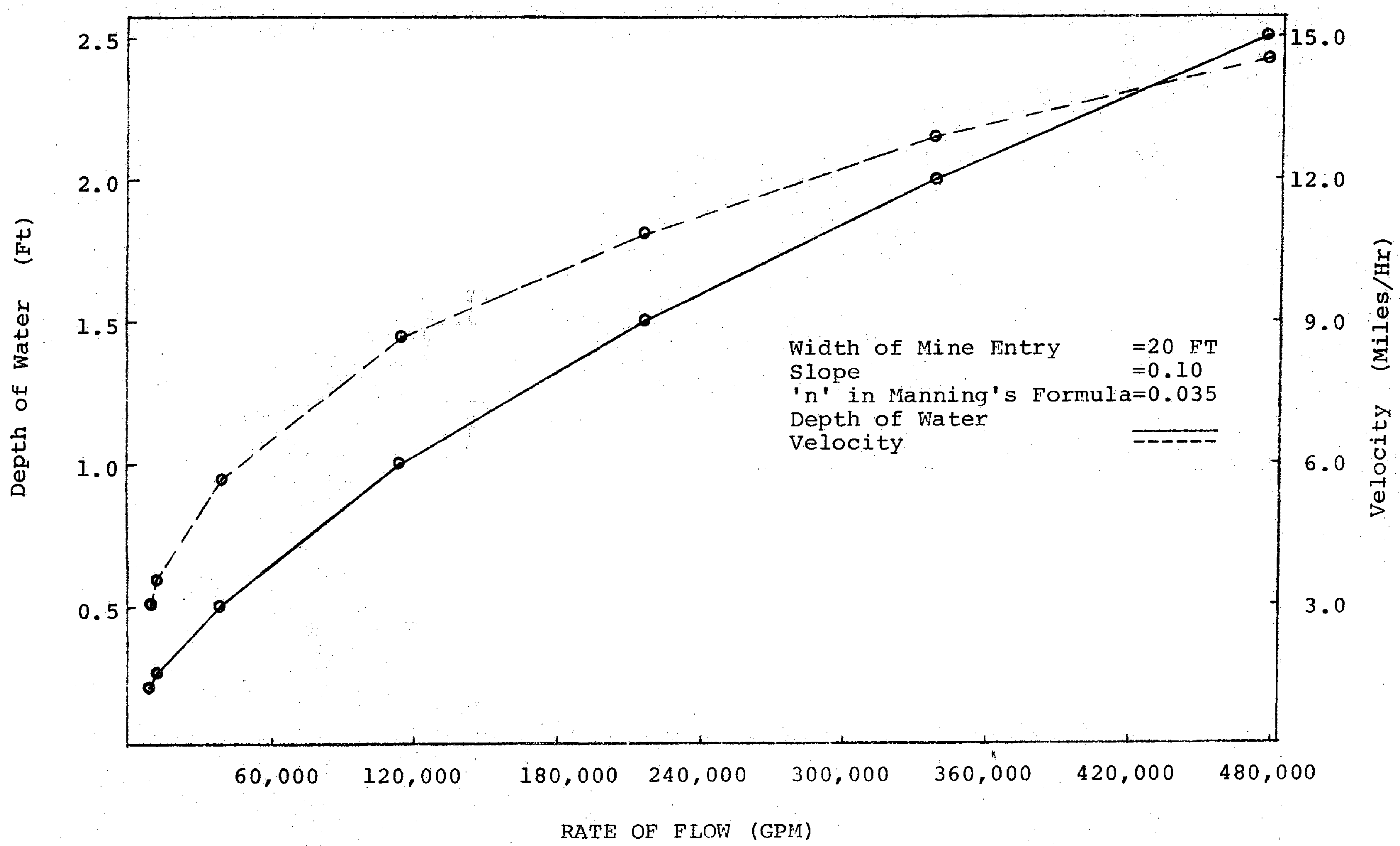


Figure C-4 Depth and Velocity of Flow for Different Rates of Discharge

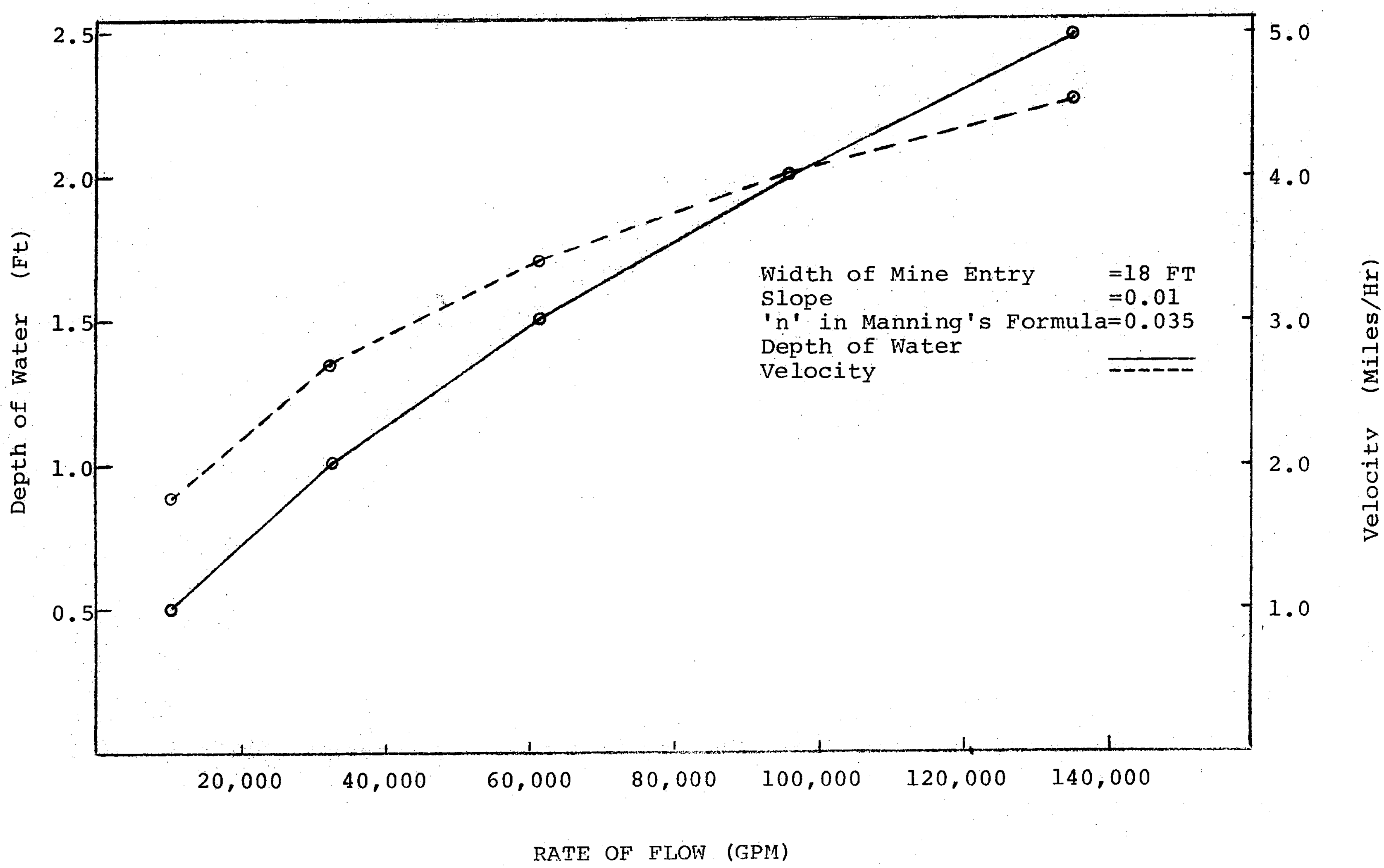


Figure C-5 Depth and Velocity of Flow for Different Rates of Discharge

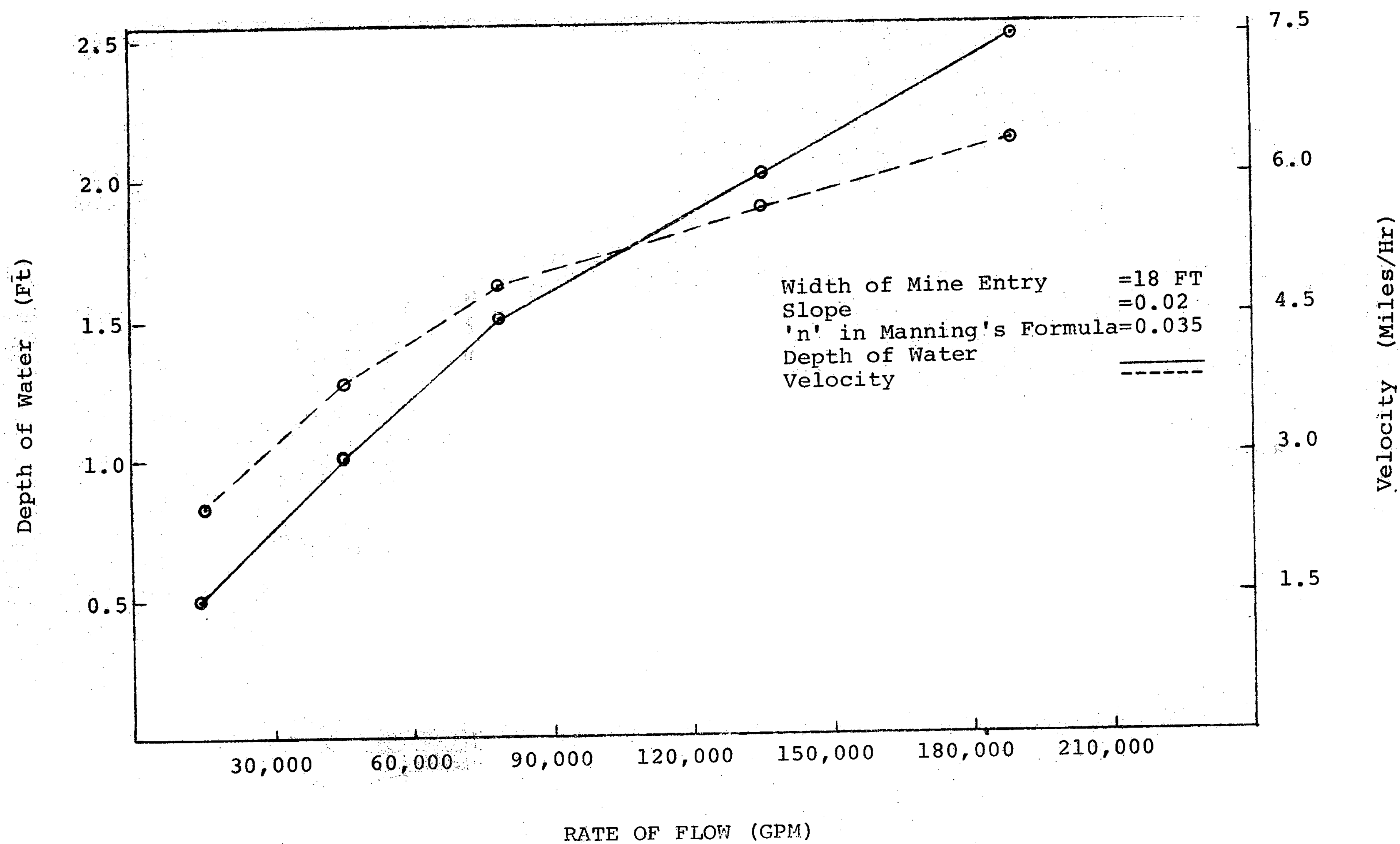


Figure C-6 Depth and Velocity of Flow for Different Rates of Discharge

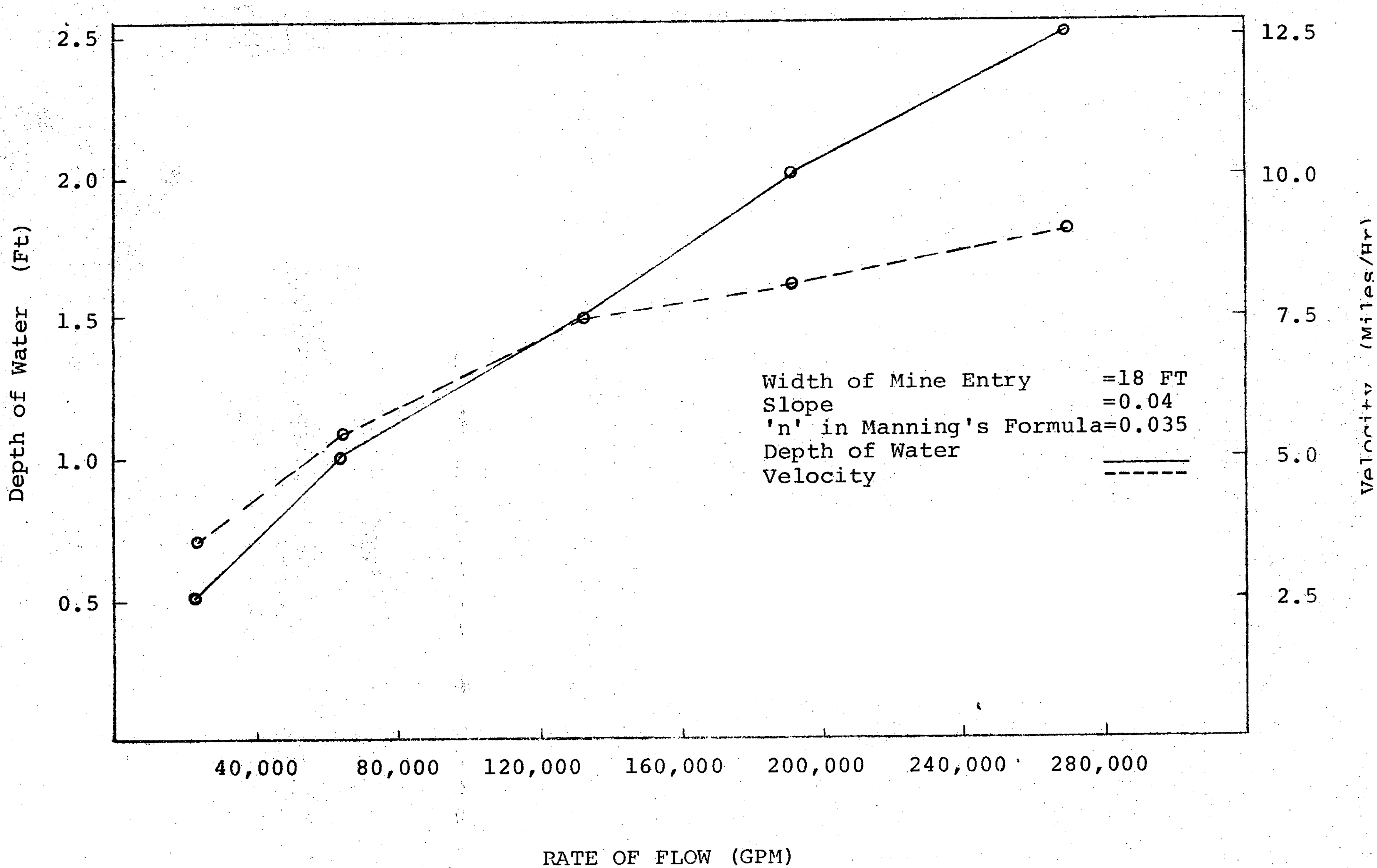


Figure C-7 Depth and Velocity of Flow for Different Rates of Discharge

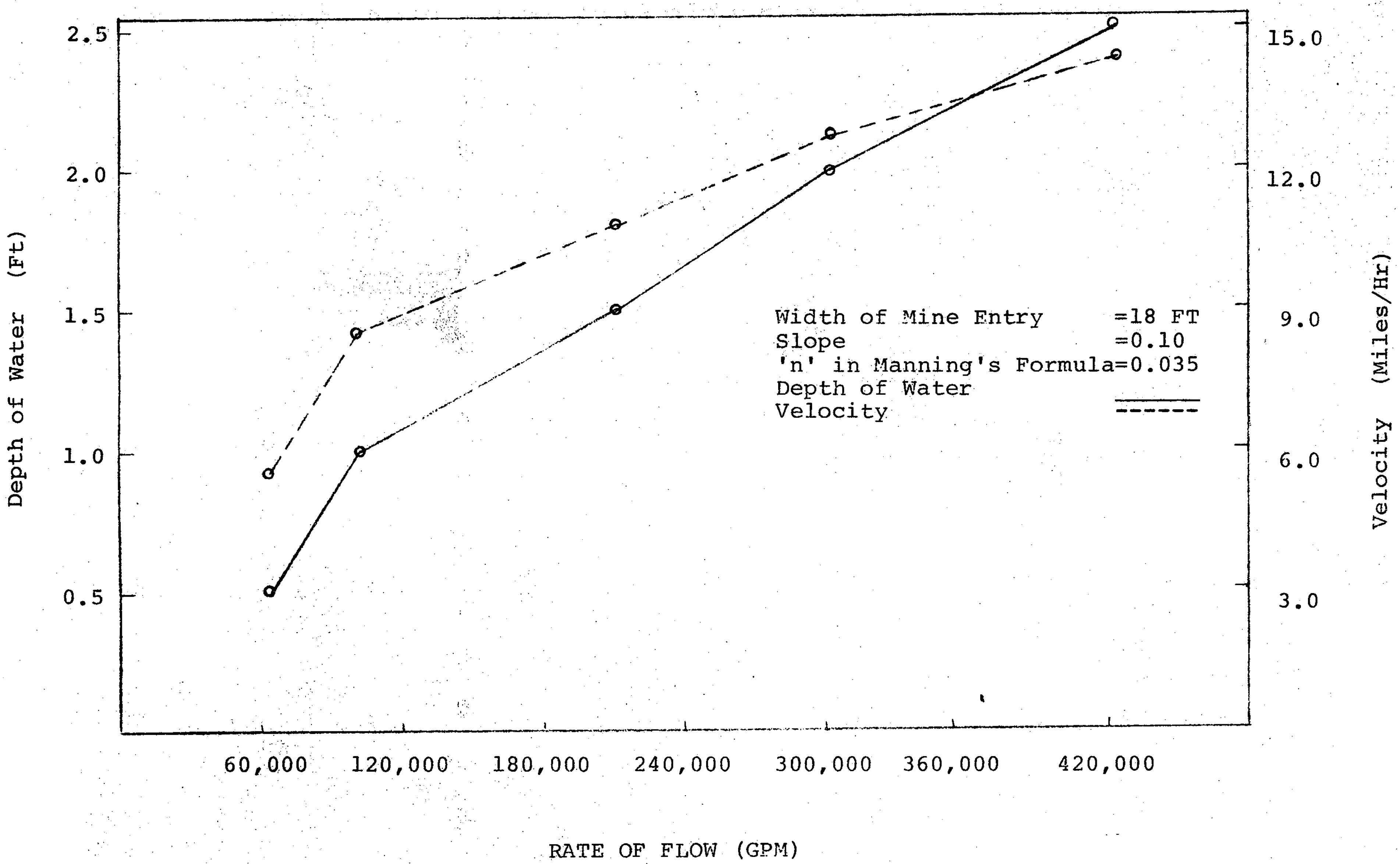


Figure C-8 Depth and Velocity of Flow for Different Rates of Discharge

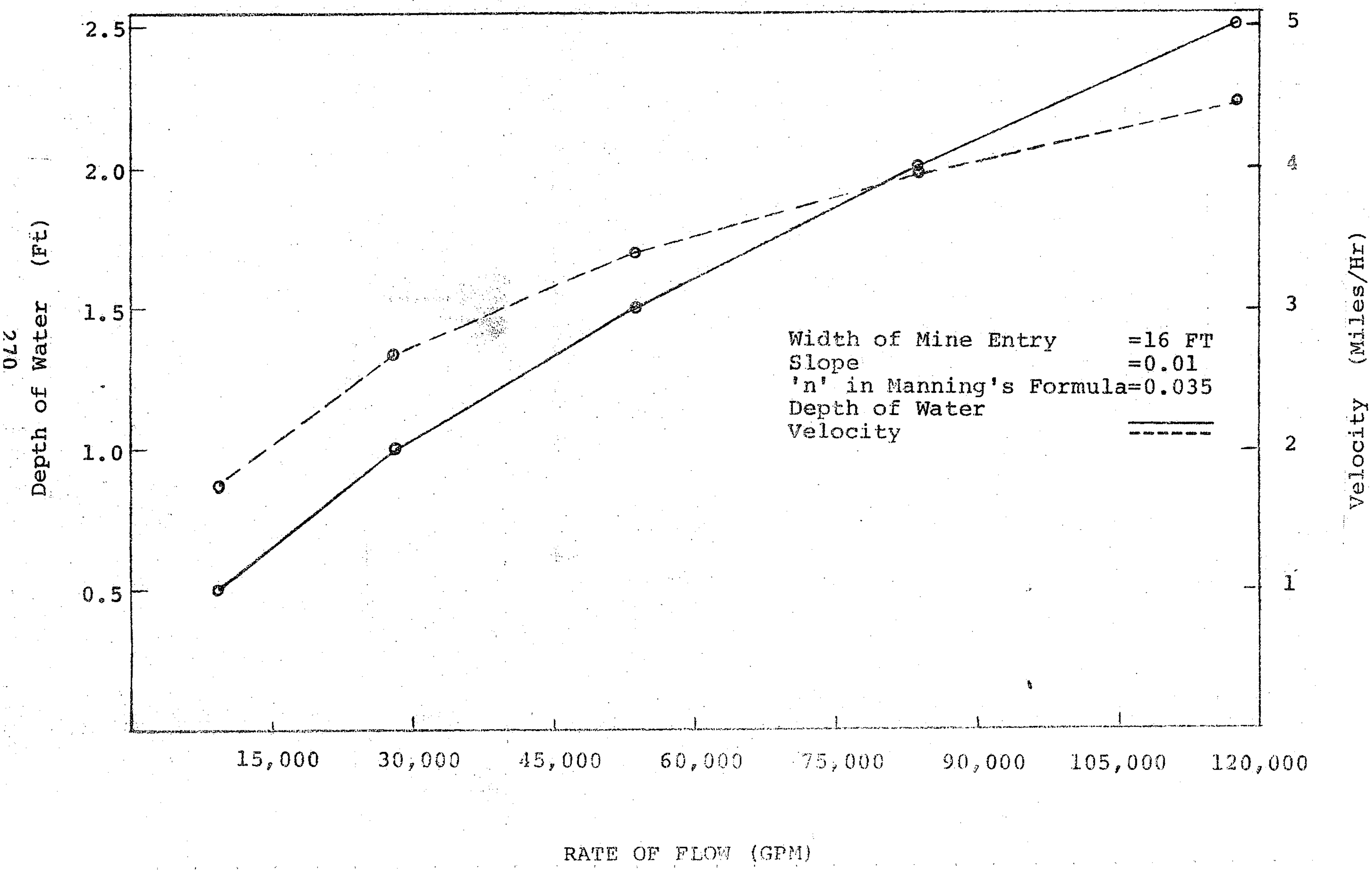


Figure C-9 Depth and Velocity of Flow for Different Rates of Discharge

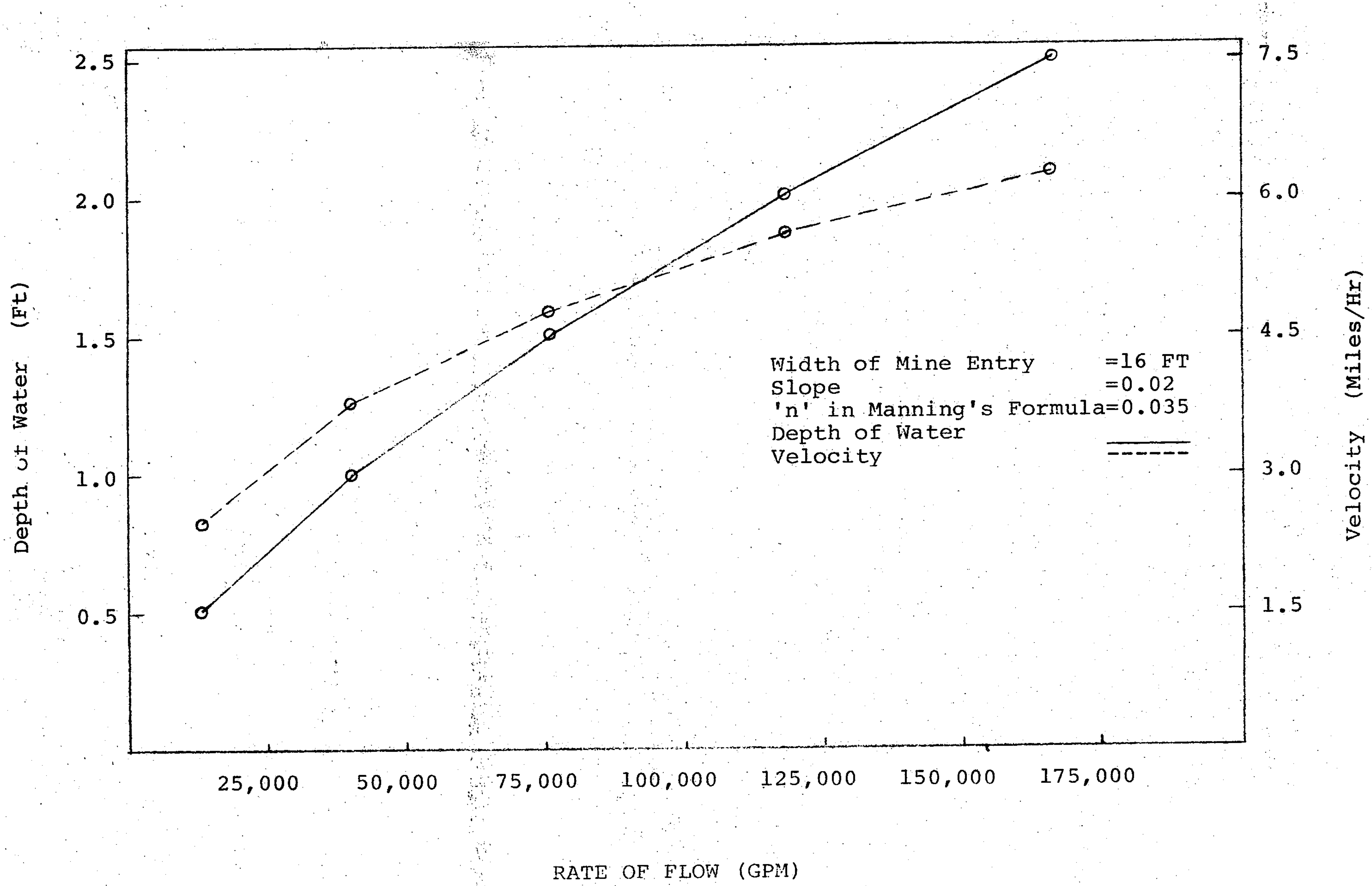


Figure C-10 Depth and Velocity of Flow for Different Rates of Discharge

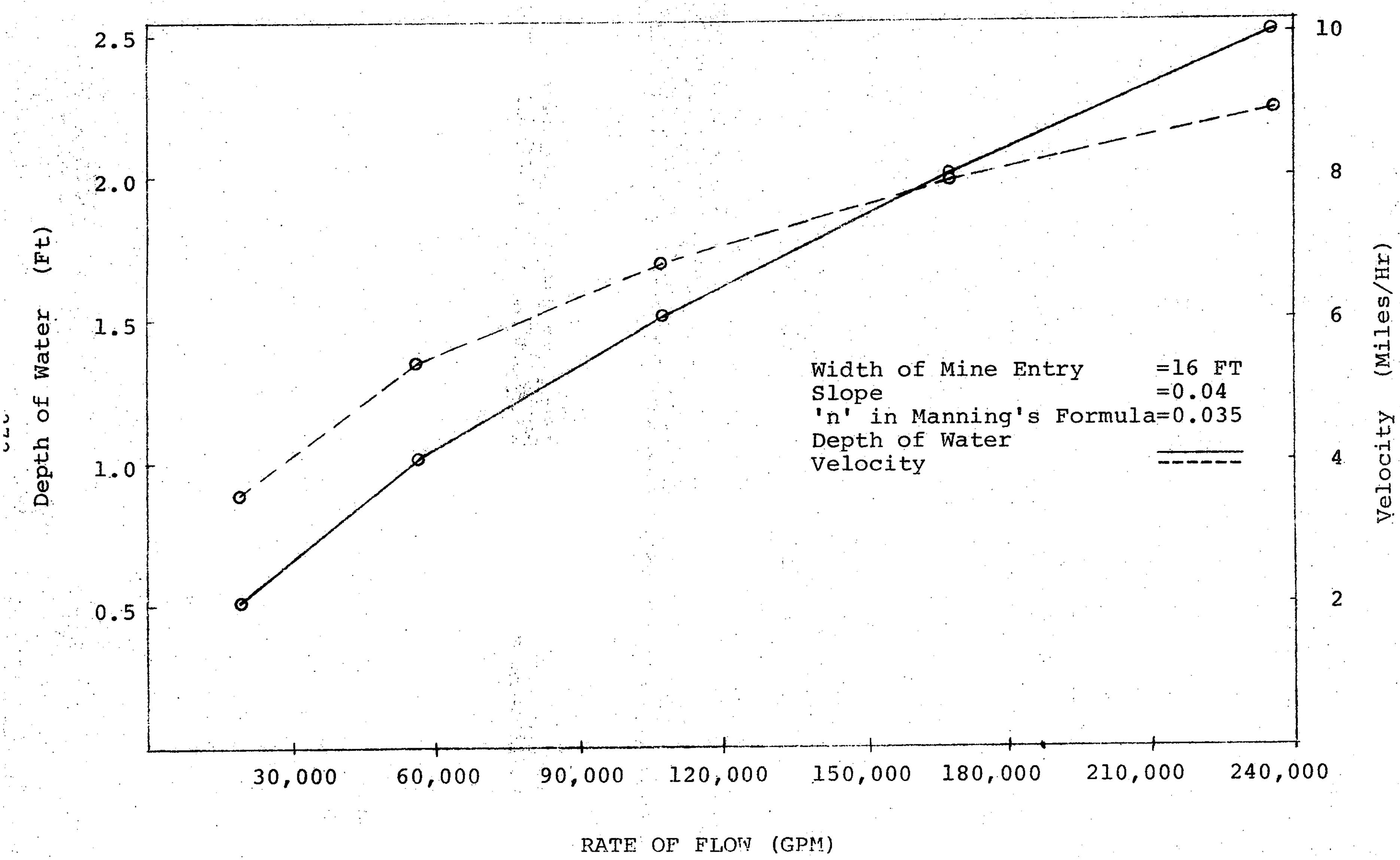


Figure C-11 Depth and Velocity of Flow for Different Rates of Discharge

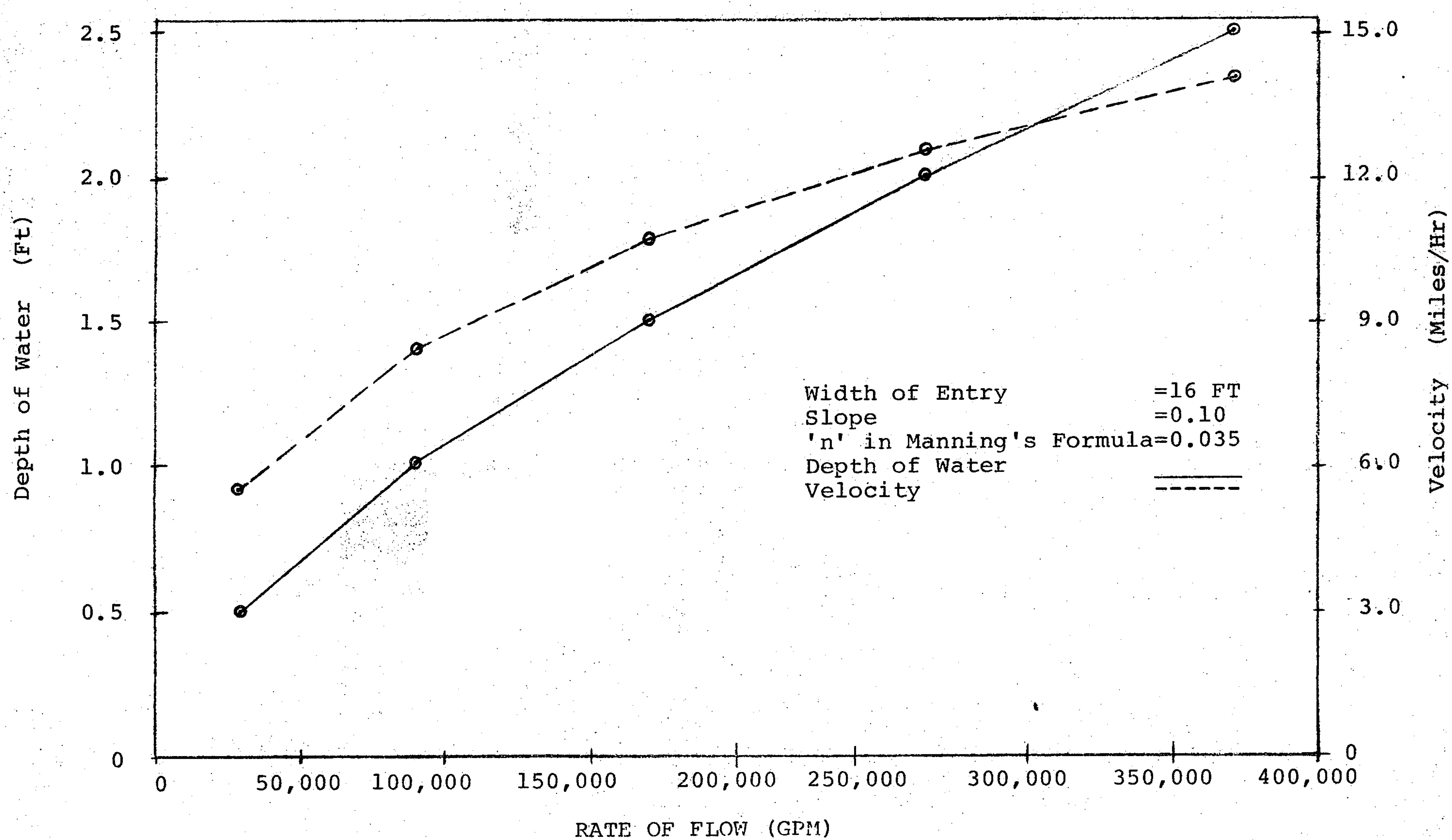


Figure C-12 Depth and Velocity of Flow for Different Rates of Discharge

APPENDIX D

STRENGTH ANALYSIS OF MINE STOPPINGS AND WALLS OF OVERCASTS

Mine stoppings or walls of overcasts are generally made of solid or hollow concrete blocks. The walls of overcasts are always mortared, whereas the stoppings may be dry-stacked occasionally. Dry-stacked stoppings are much weaker and thus will fail at much smaller heads than that the mortared stoppings can withstand. Therefore, strength analysis has been carried out for mortared walls only.

Ventilation stoppings are generally not keyed into the floor, roof or ribs, whereas walls of overcasts are generally fixed. The fixing of the stoppings to the floor, ribs and roof with mortar only will depend on the care with which the site is prepared, and the quality of construction. Properly constructed stoppings which are fixed on at least three sides when subjected to a rising head of water are most likely to fail in flexure, whereas the stoppings with no fixed side or only one fixed side are likely to fail by toppling or by toppling and shear. Accordingly, the strength analysis of the walls has been carried out by flexure, by toppling alone and by toppling and shear combined.

Flexure Analysis

The stress on a wall is given by the following equation (Roark and Young, 1975)

$$\sigma f = \beta f b^2/z^2$$

where σf is the stress
β is a correction factor
f is the maximum force on the wall
b is the wall height
and z is the wall thickness.

Given f, b, z and the loading condition on the wall, σ can be determined. β is a variable factor and is required to be determined separately for the given conditions. The flexural strength of the wall constructed with concrete blocks depends on the flexural strength of the mortar besides its dimensions. Thus, depending on the standard type of mortar and the dimensions of the wall it can be determined as to what head of water will cause failure. Figure D-1 gives the correction factor β for different a/b ratios and water heads. Figures D-2 to D-7 give the minimum safe thickness of walls for different heads of water depending on the type of mortar and the dimensions of the walls. These analyses are based on the assumption that the three sides of the wall are fixed and the top is free. The assumption is justified as in actual practice it is generally difficult to obtain a proper uniform contact between the top of the stopping and the roof. Also, Figures D-8 to D-14 have been developed which give the stresses induced in the walls at different heads of water.

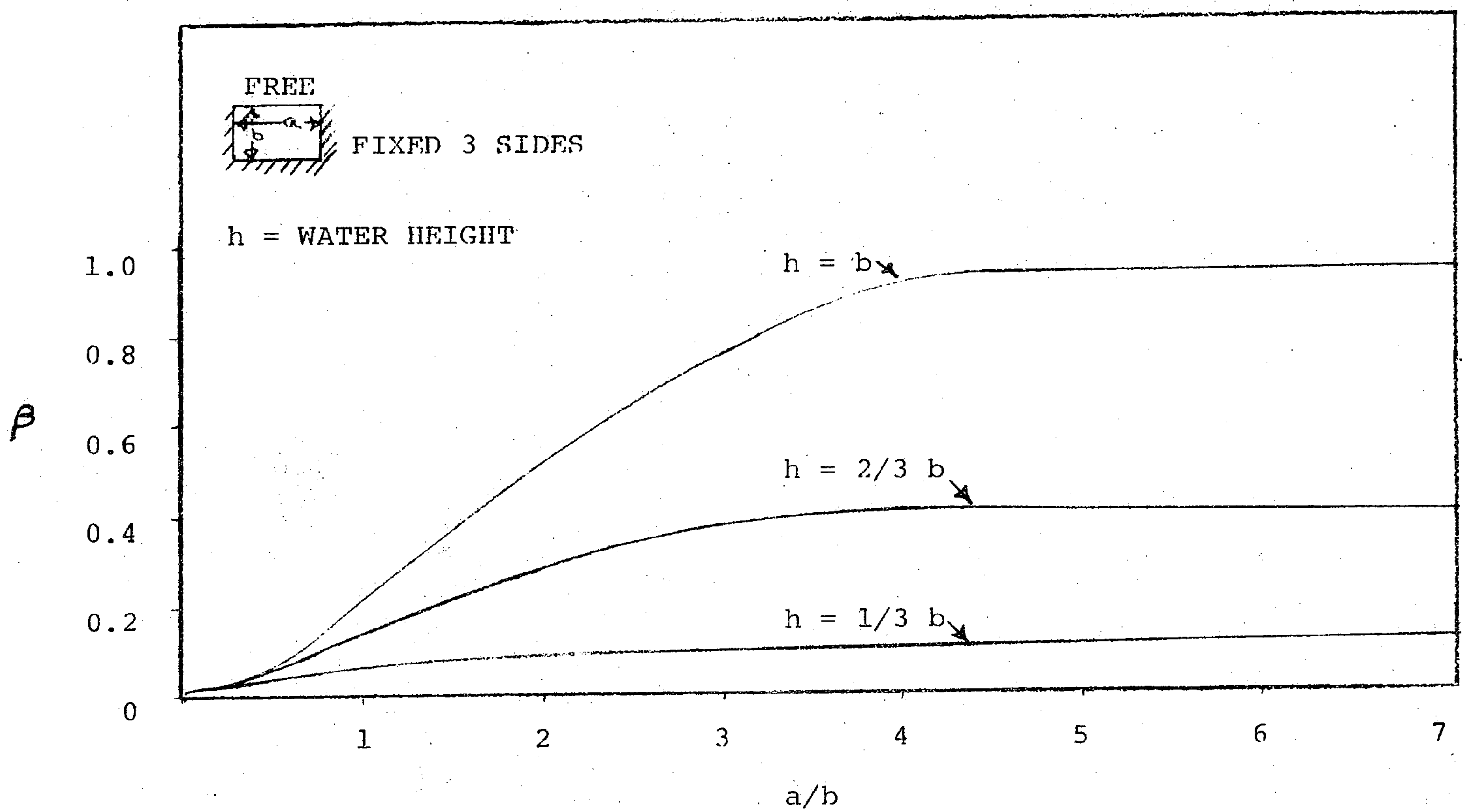


Figure D-1 Correction Factor for a/b Ratio at Given Conditions

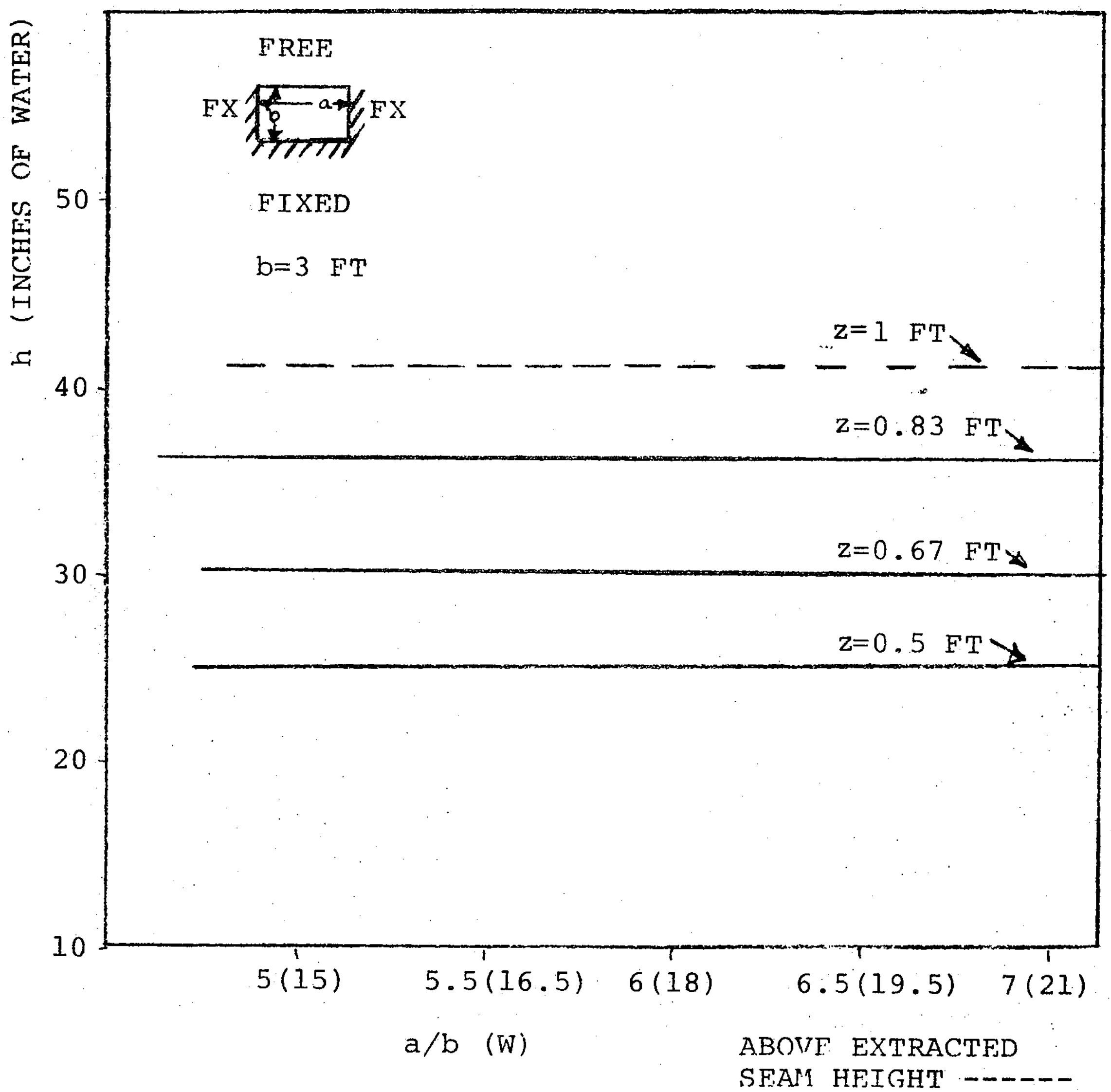


Figure D-2 Minimum Allowable Thickness of Wall for Type N Mortar at 3 FT Height of Wall

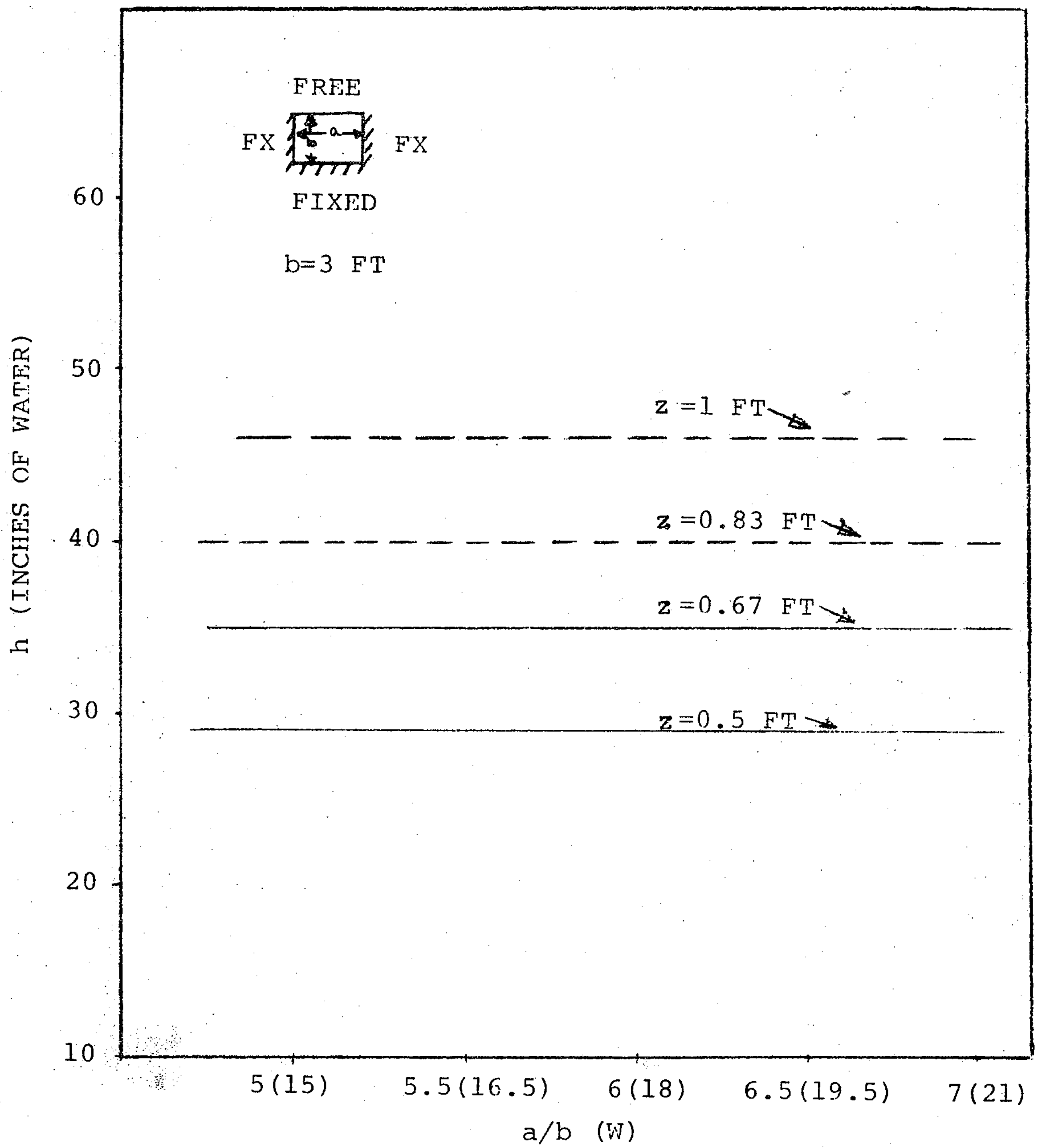


Figure D-3 Minimum Allowable Thickness of Wall for Type M or S Mortar at 3 FT Height of Wall

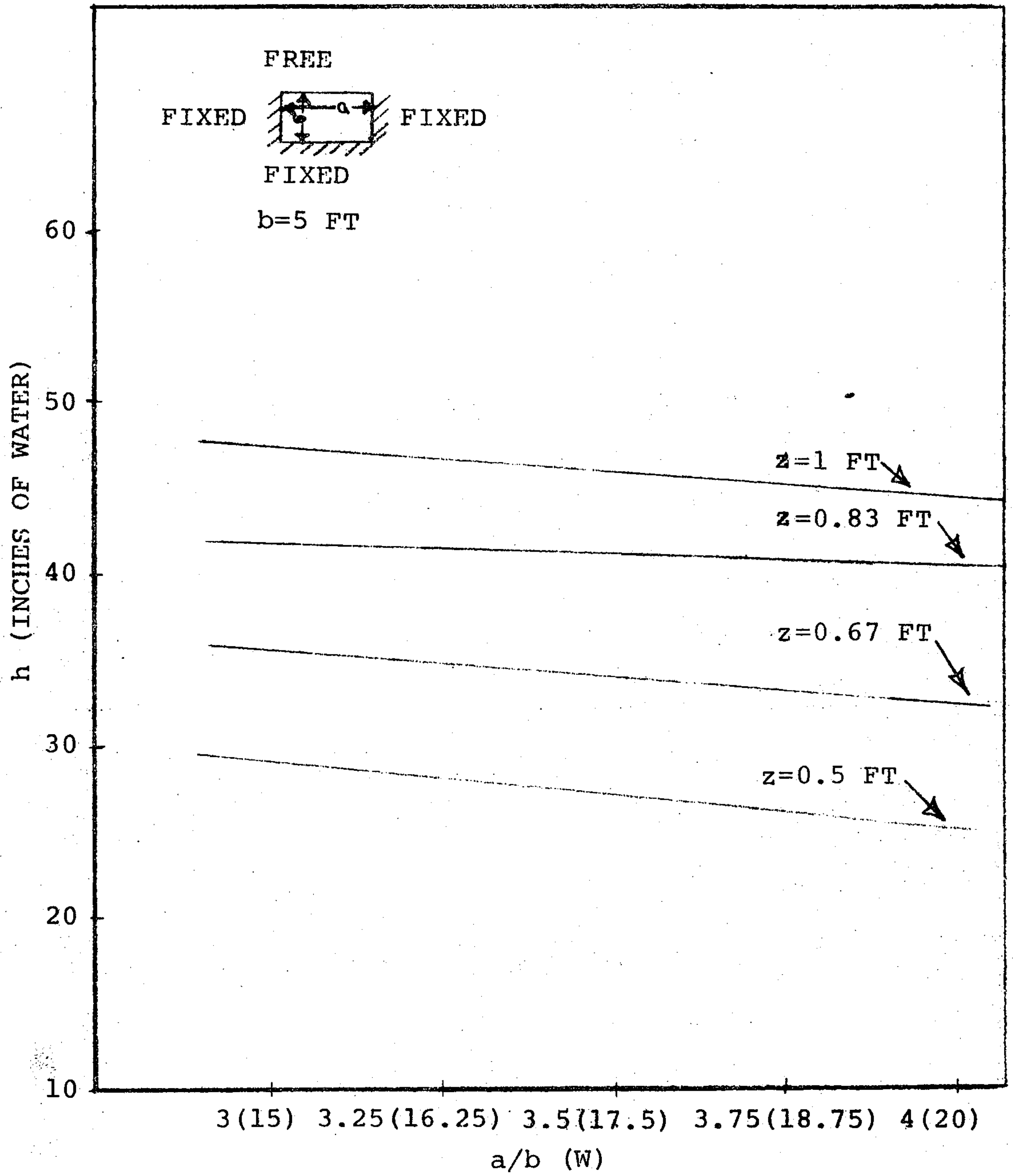


Figure D-4 Minimum Allowable Thickness of Wall for Type M or S Mortar at 5 FT Height of Wall

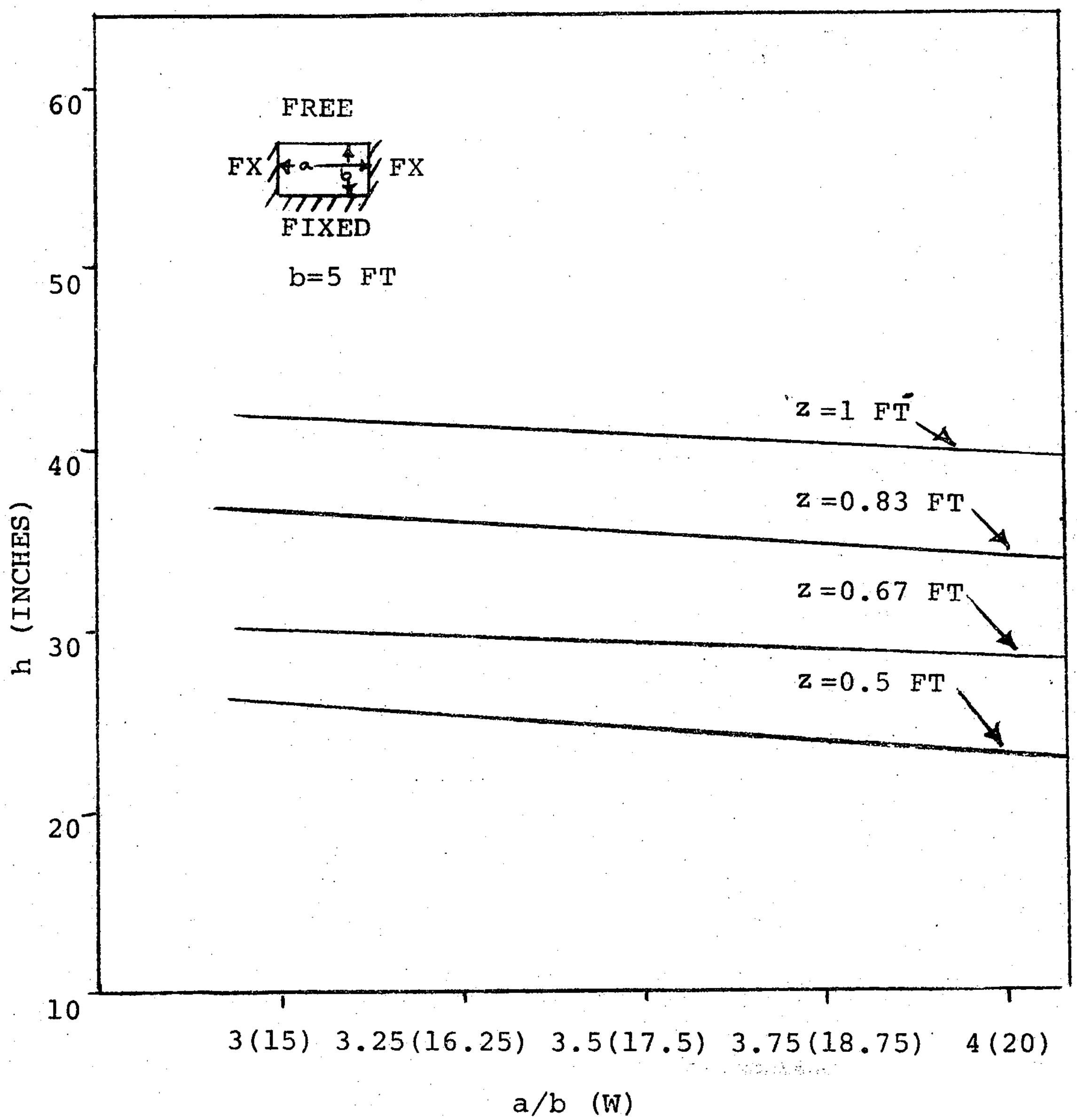


Figure D-5 Minimum Allowable Thickness of Wall for Type N Mortar at 5 FT Height of Wall

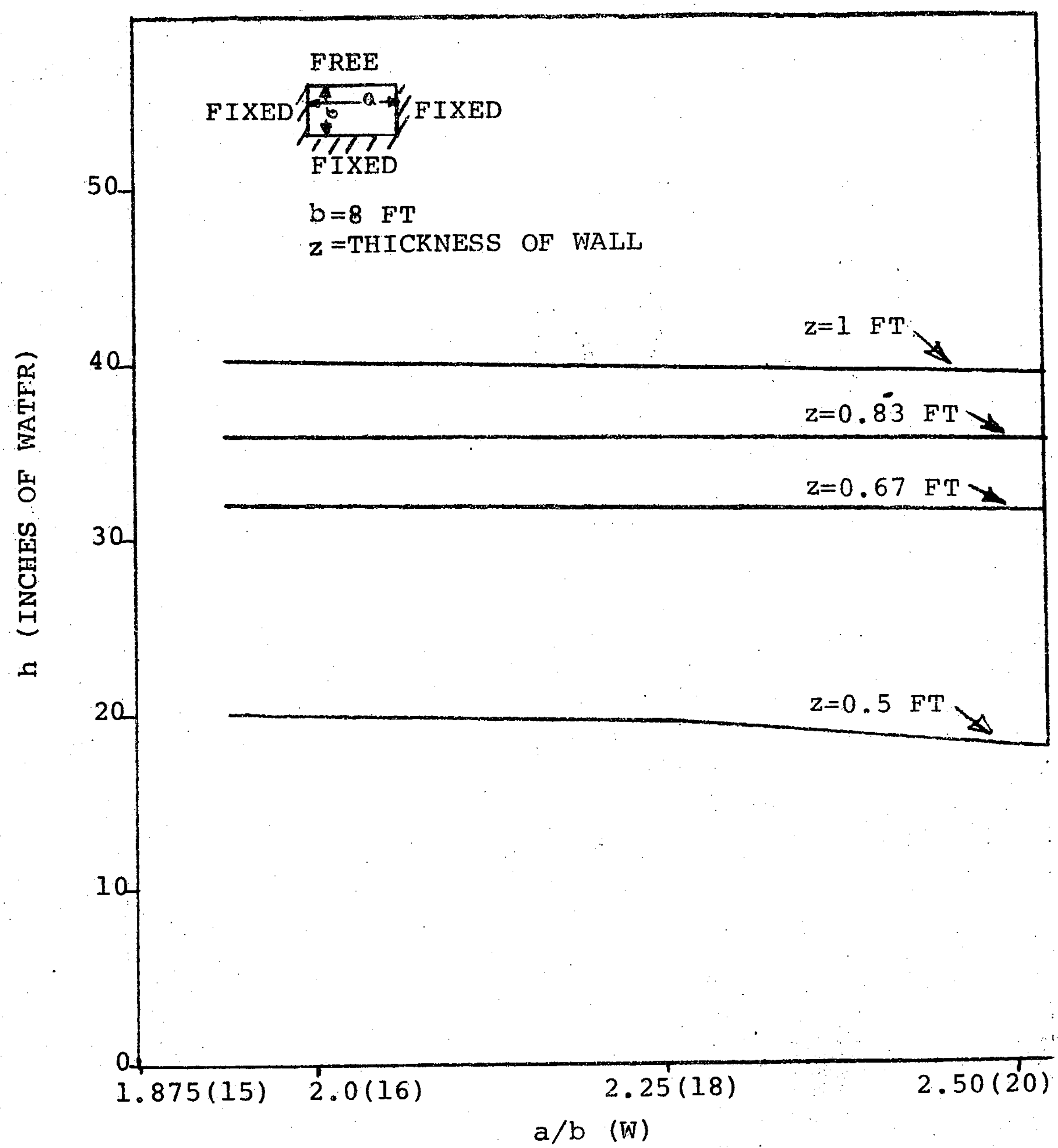


Figure D-6 Minimum Allowable Thickness of Wall for Type N Mortar at 8 FT Height of Wall

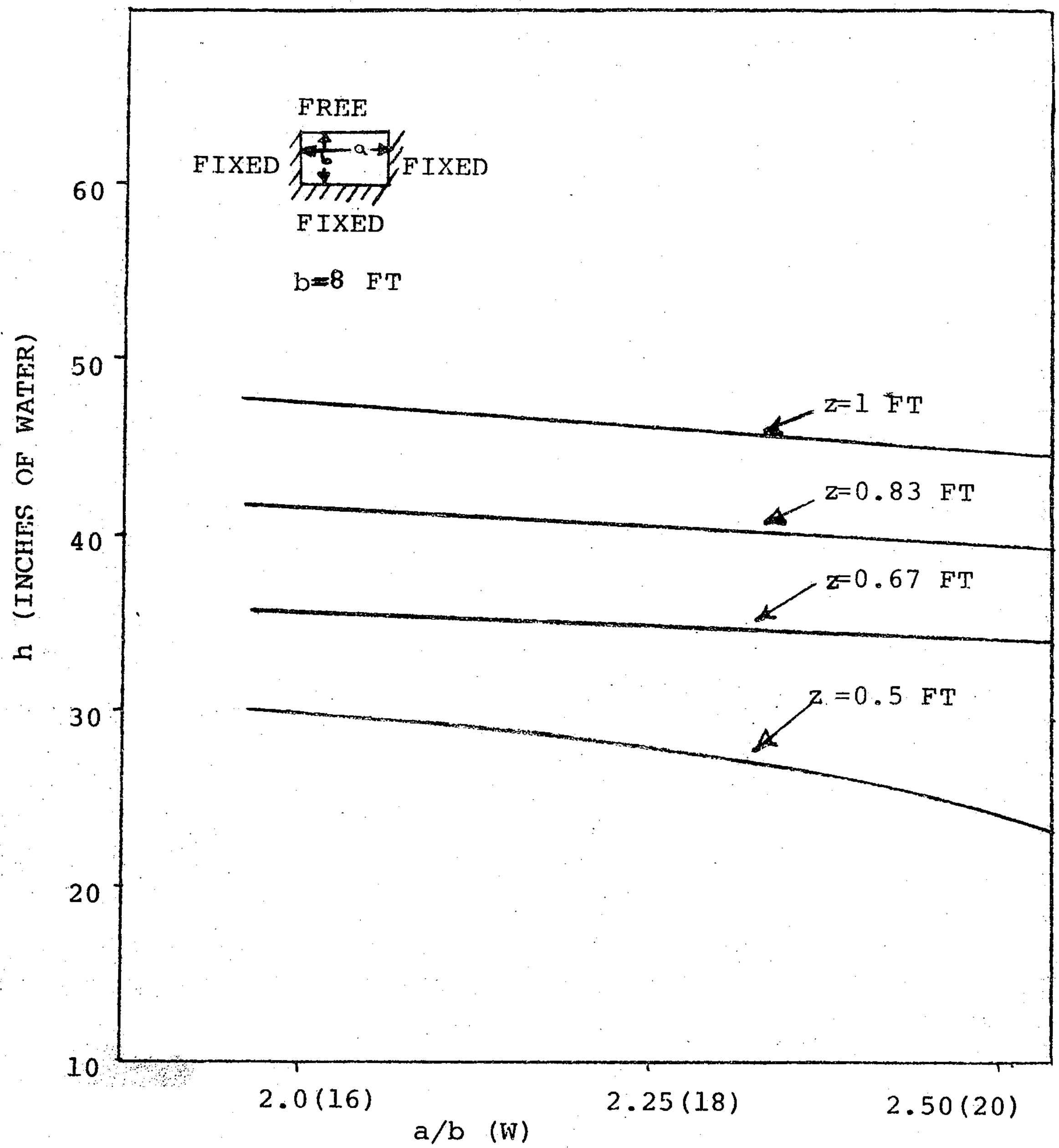


Figure D-7 Minimum Allowable Thickness of Wall for Type M or S Mortar at 8 FT Height of Wall

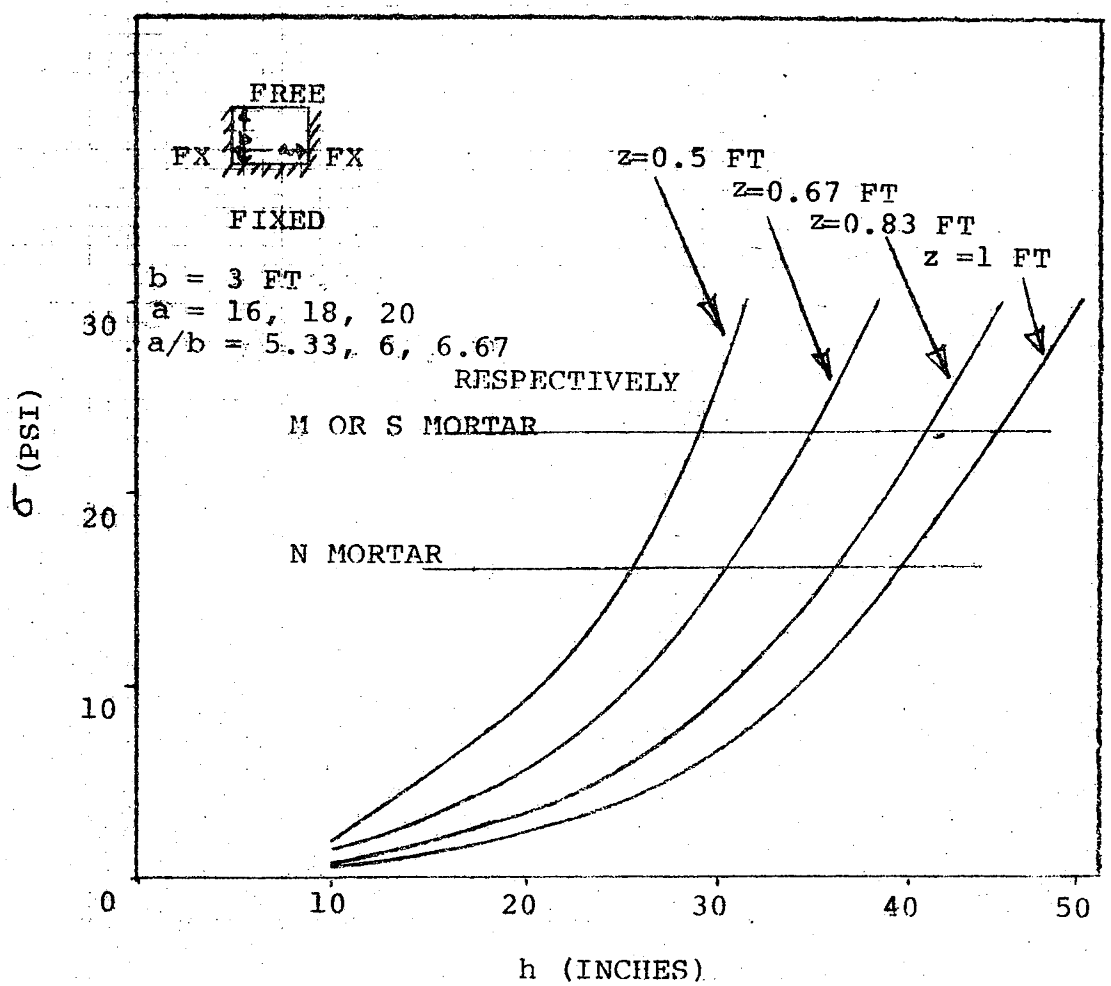


Figure D-8 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

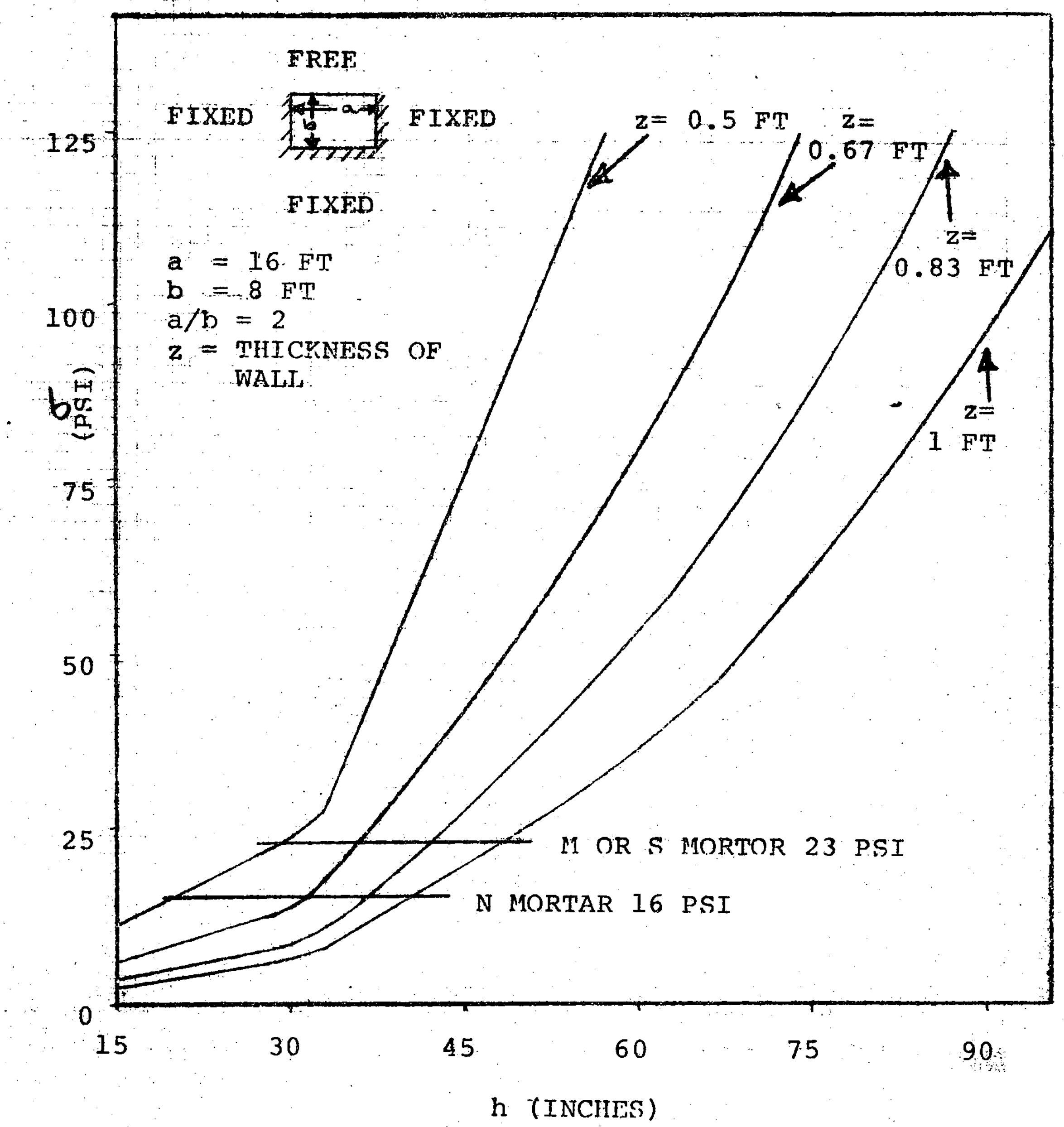


Figure D-9 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

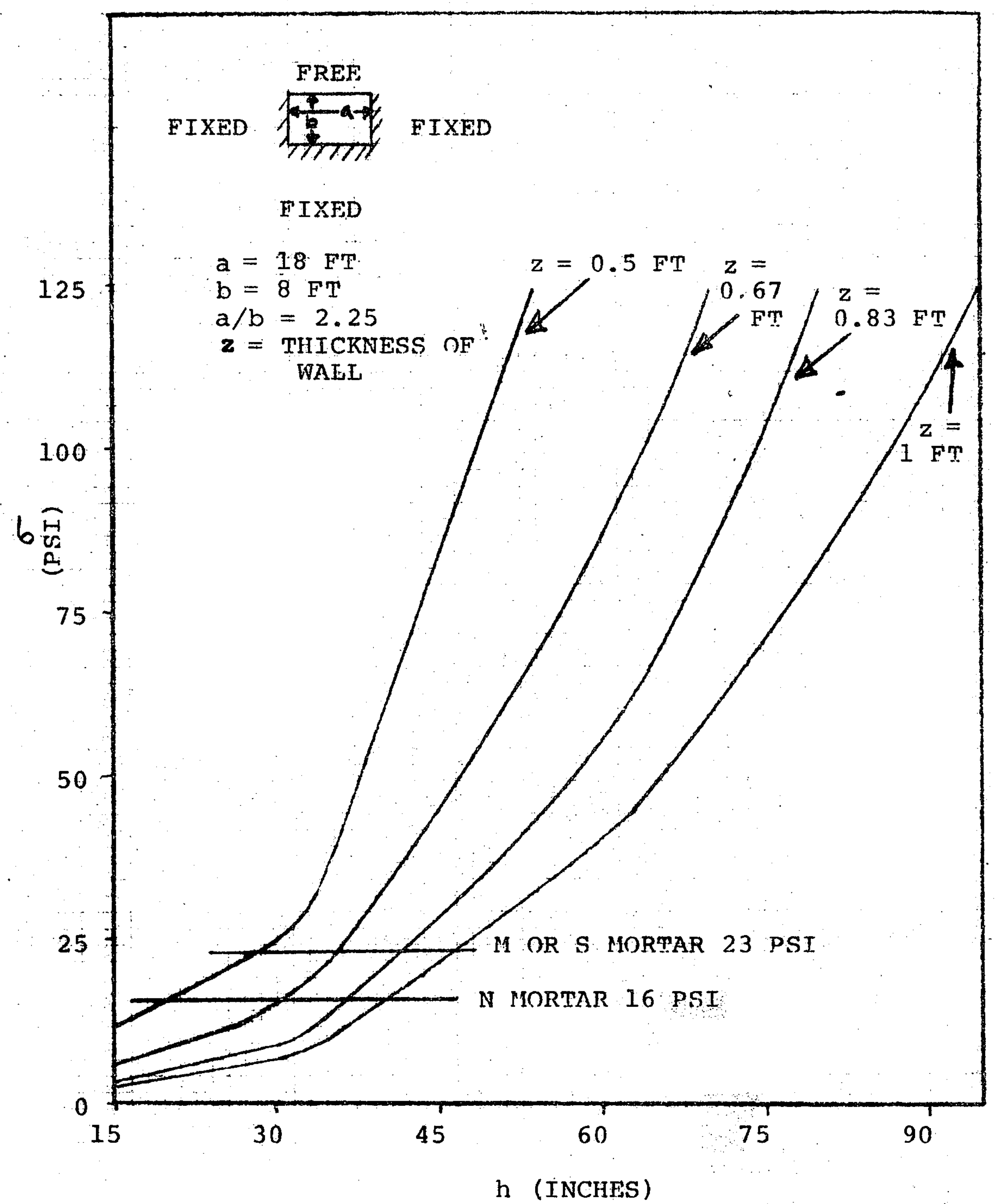


Figure D-10 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

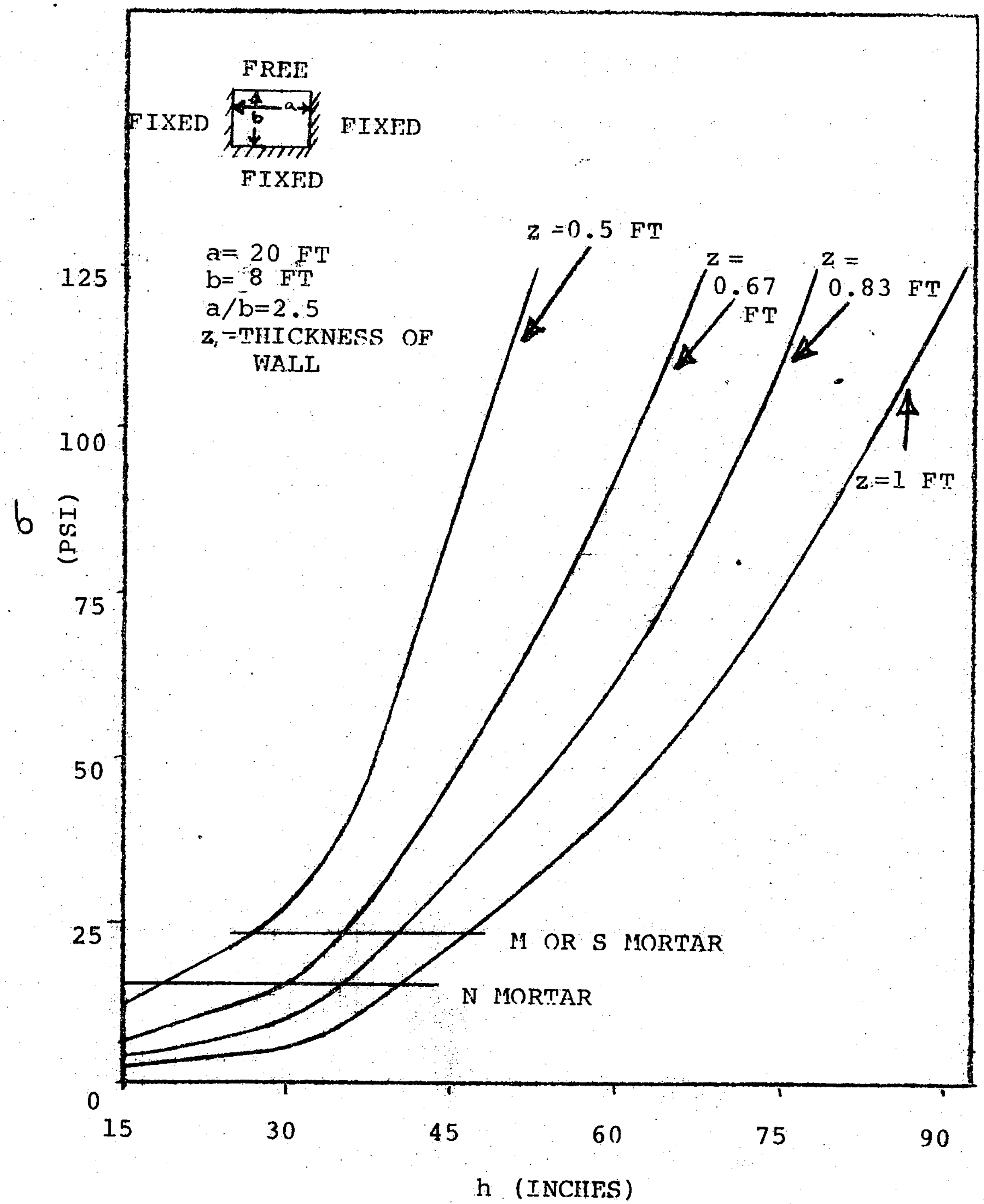


Figure D-11 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

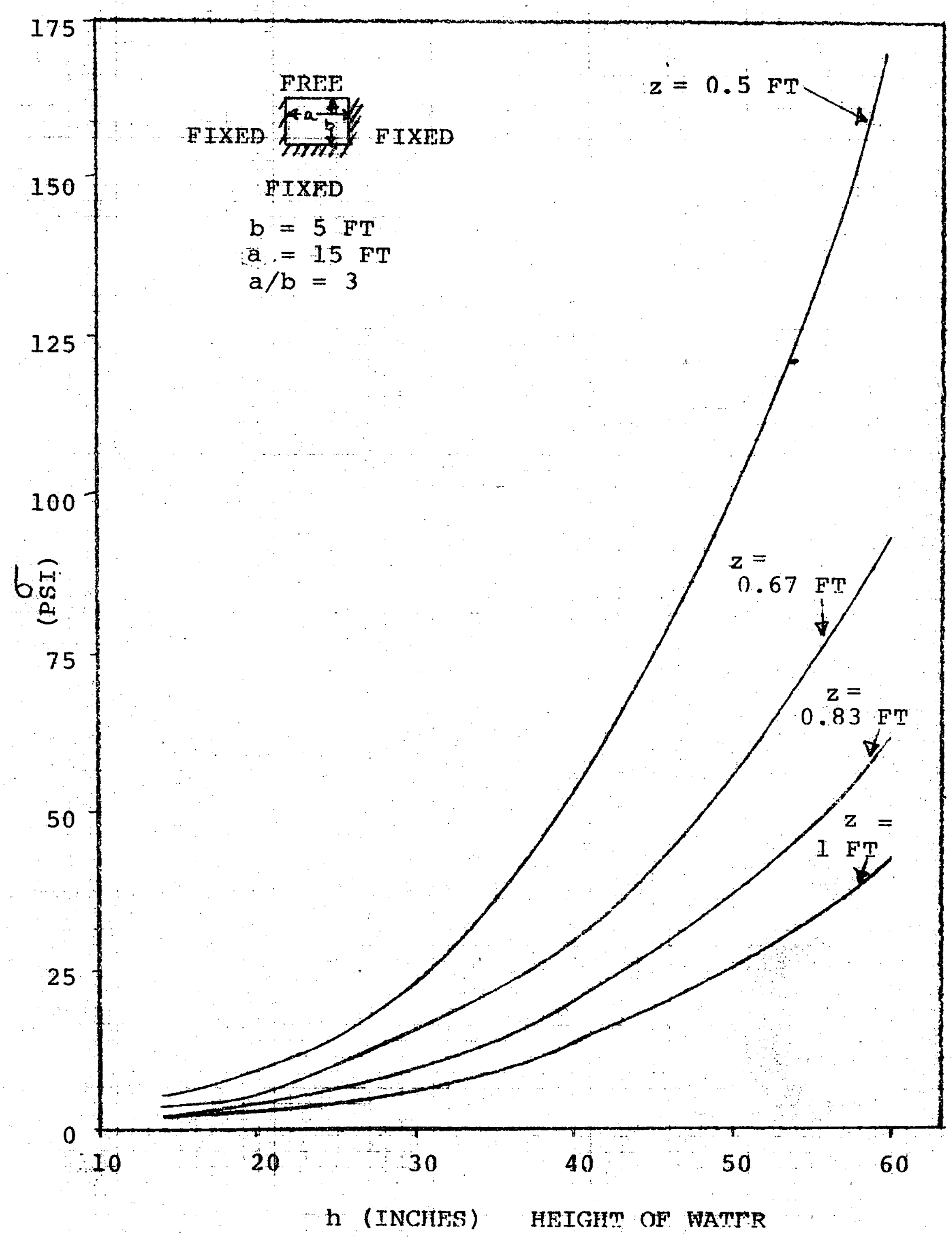


Figure D-12 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

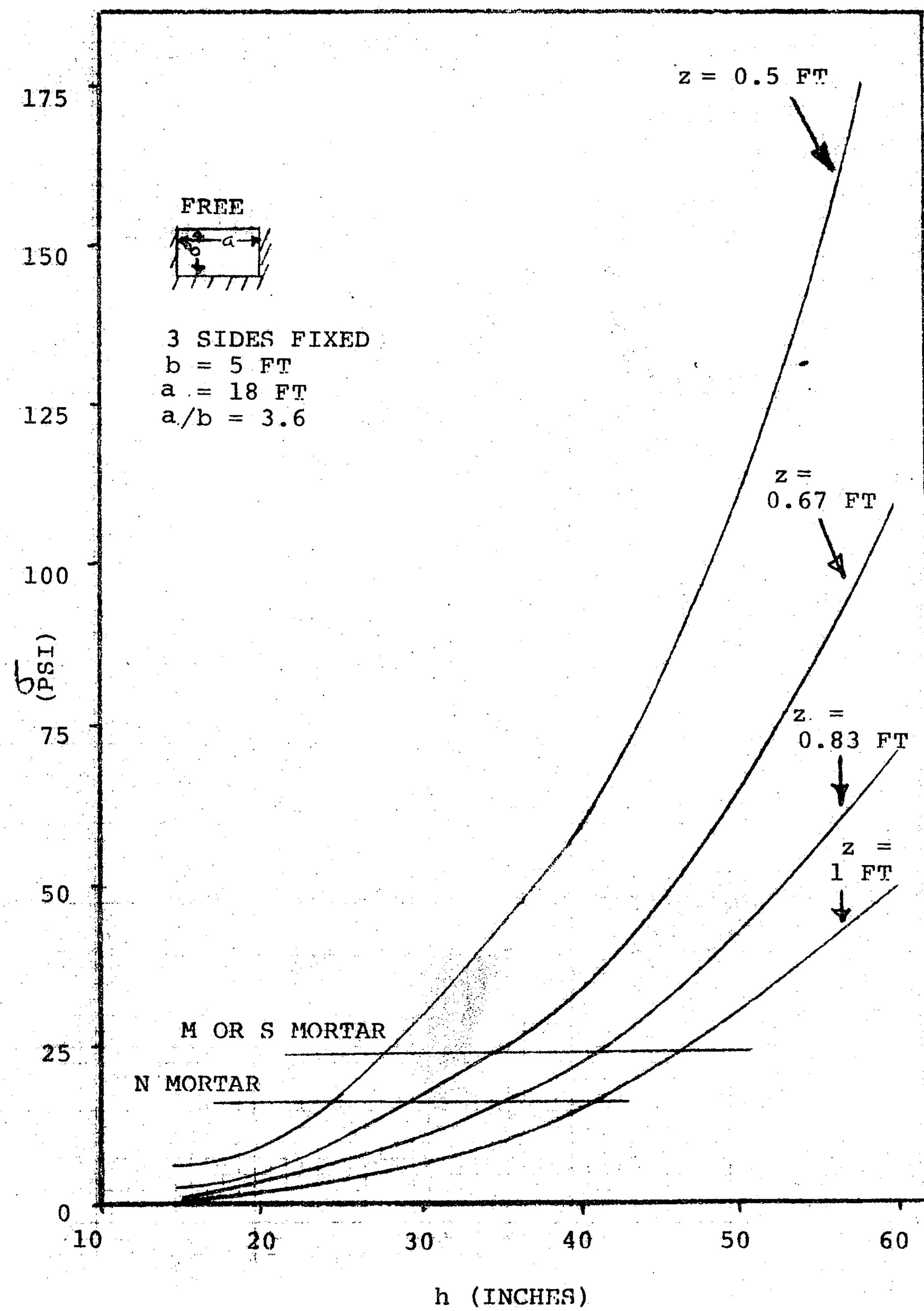


Figure D-13 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

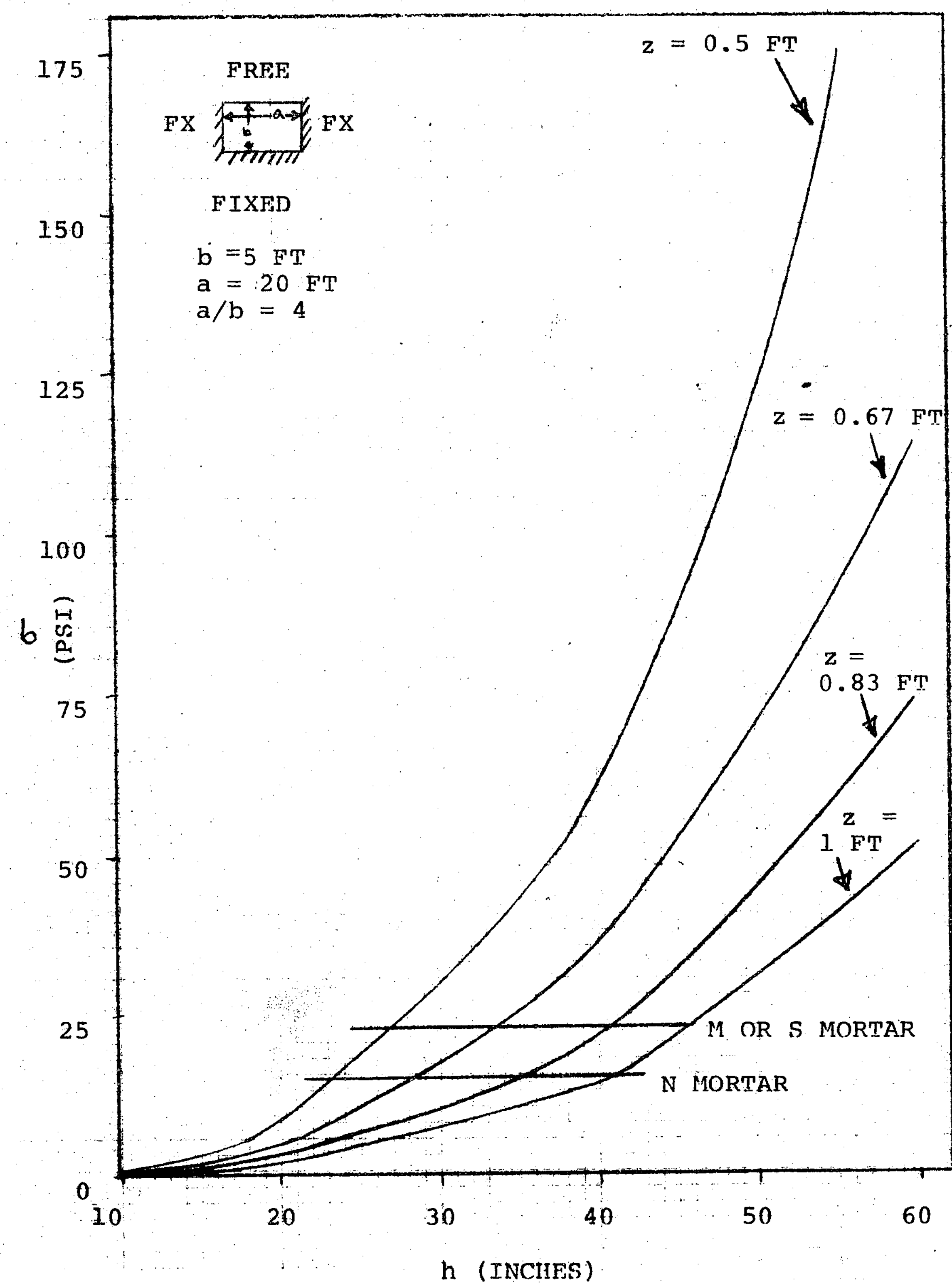


Figure D-14 Wall Stresses Induced at a Given Water Height and a Given Wall Condition

Toppling Alone Analysis

Depending on the site condition and the quality of construction, sometimes the stoppings in the mine may not develop a proper bond with the floor, roof, and ribs. Such stoppings when subjected to water buildup are most likely to fail by toppling. Table D-1 gives the wall weight for one square foot area (Toennies, 1971). If γ_w is specific weight of water, h is height of water built up against the wall, z is the thickness of the wall, b is the height, and m_w is the weight of wall per square foot of surface, the Moment Equation will be

$$\Sigma M@A = \gamma_w h(h/2) - z/2(m_w/b) = 0.$$

This can be simplified to

$$h = \sqrt[3]{3zm_w b/\gamma_w}$$

Figure D-15 has been drawn based on this equation which gives the maximum head which an unbonded wall can withstand without toppling.

$$h = \sqrt[3]{\frac{(3) z m_w b}{\gamma_w}}$$

(INDEPENDENT OF WALL LENGTH)

h=HEIGHT OF WATER
z=THICKNESS OF WALL
b=HEIGHT OF WALL
m_w=WEIGHT OF WALL LB/FT^2
γ_w=62.4 LB/FT^3

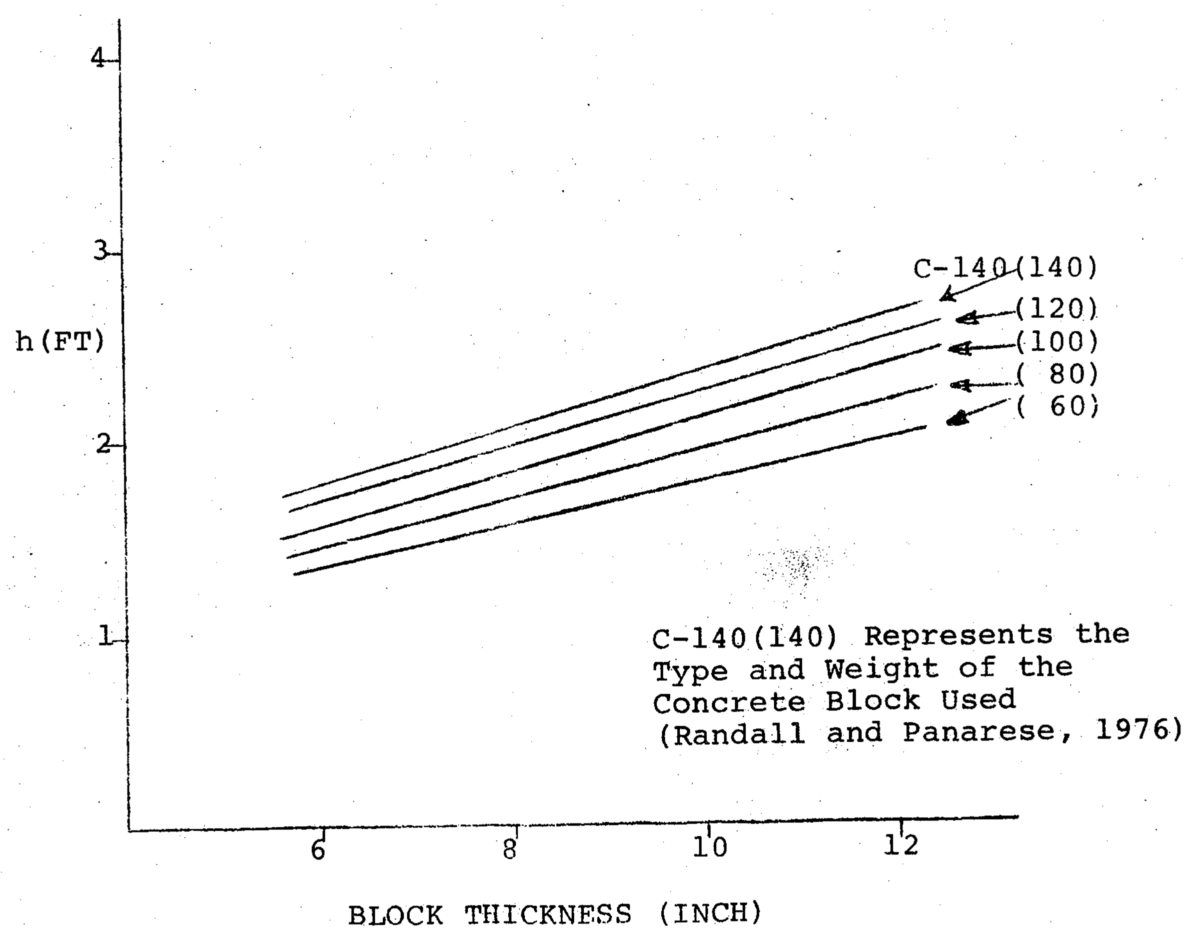


Figure D-15 Maximum Height of Water Allowable with Toppling Analysis Only

Table D-1 Wall Weight in Pounds per Sq. Ft. (Toennies, 1971)

THICKNESS	Unit Weight, LB/CF (ASTM C-140) 60	80	100	120	140
6 in.	20	26	30	40	46
8 in.	24	32	40	47	55
10 in.	28	37	47	56	65
12 in.	34	45	55	67	78

Toppling and Shear Analysis

In case only one of the sides of a stopping is bonded to the floor, roof or ribs, then the likely mode of failure will be by a combination of shear and toppling. The moment equation for the combined mode is

$$\Sigma M@A = \gamma_w h(h/2)\ (h/3)\ s - z/2(smb) - b/2\{z(2b+2s)f_s\}=0$$

or

$$h = \sqrt[3]{(3zsm_w b + 6b^2 zf_s + 6bszf_s)\ /s\gamma_w}$$

where f_s is the shear strength of the mortar and s is the width of the wall. Table D-2 gives the allowable stresses in shear and tension in flexure of different mortars for nonreinforced concrete masonry. Figure D-6 is derived from the above equation and it indicates the allowable height of water for walls of different block thicknesses.

However, it may be noted that a wall having dimensions generally obtained in the mines will fail in flexure at a much smaller head of water.

Table D-2 Allowable Stresses in Shear and Tension in Flexure for Nonreinforced Concrete Masonry (a)

Allowable Stresses	Masonry Construction of: Hollow Units, Type M or S Mortar	Hollow Units, Type N Mortar	Grouted or Solid Units, Types M or S Mortar	Grouted or Solid Units, Type N Mortar
Shear, psi	34(d)	23(d)	34	23
Tension in Flexure: (e)				
Normal to bed joints (b)	23(d)	16(d)	39	27
Parallel to bed joints (c)	46(d)	32(d)	78	54

(a) Toennies, 1971
(b) Direction of stress is normal to bed joints; vertically in normal masonry construction.
(c) Direction of stress is parallel to bed joints; horizontally in normal masonry construction. If masonry is laid in stack bond, tensile stresses in the horizontal direction shall not be permitted in the masonry.
(d) Net mortar bedded area.
(e) For computing flexural resistance, the section modulus of a cavity wall shall be assumed to be equal to the sum of the section moduli of each wythe.

$$h = \sqrt[3]{\frac{3zm_w b + 6b^2 z f_s + 6bszf_s}{\gamma_w s}}$$

s=WIDTH OF WALL=20 FT
h=HEIGHT OF WATER
z=THICKNESS OF WALL
b=HEIGHT OF WALL
m_w=WEIGHT OF WALL LB/FT^2
γw=62.4 LB/FT^3
f_s=SHEAR STRENGTH psf

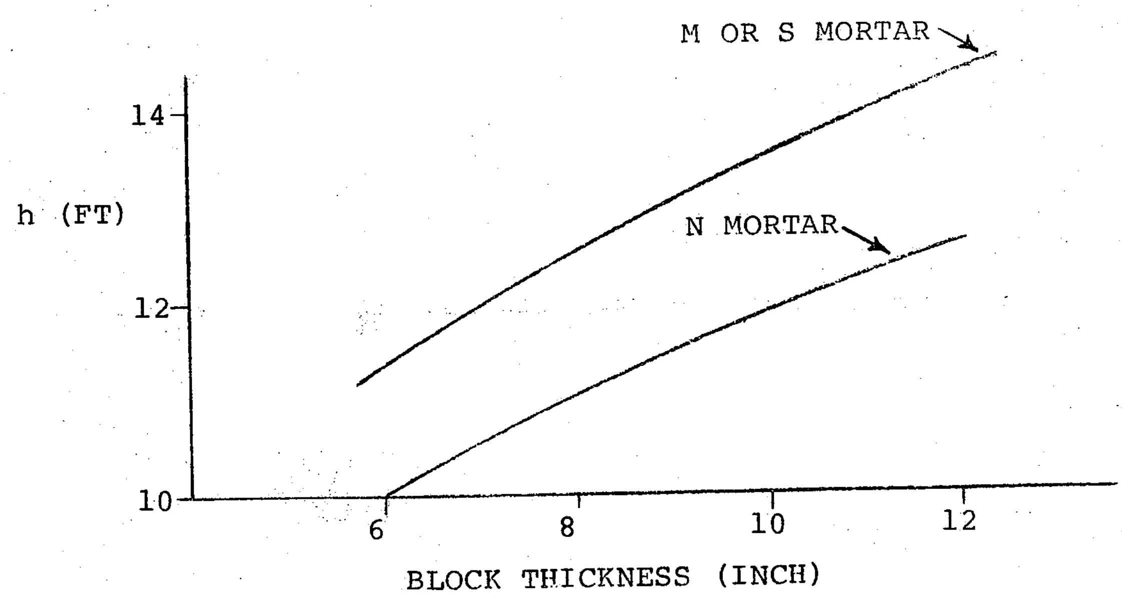


Figure D-16 Maximum Height of Water Allowable with Toppling and Shear Analysis Only

APPENDIX E

SUGGESTED HAZARD DETERMINATION METHOD, GUIDELINES, AND APPLICATION FOR MINING BENEATH SURFACE WATERS

SECTION A. GENERAL INFORMATION

Step A1. Obtain mine map of planned developments showing slopes of all workings, heights of extraction, width of entries, length of longest dead-end or blocked entry and all pumping capacities. Go to Step A2.

Step A2. Obtain map of overlying surface showing all water bodies whether natural or impounded, flowing or non-flowing. Water bodies which are connected must be treated as the same water body. Go to Step A3.

NOTE: The following steps must be carried out for each water body in turn.

Step A3. Determine expected working lifetime of mine or part of mine effected by water body. Go to Step A4.

Step A4. Determine for water body: flood stage areal extent, and either flood stage flow rate or volume corresponding to expected lifetime of mine or part of mine from Step A2. Go to Step A5.

Step A5. Determine in-mine area of influence of each water body by horizontally extending flood stage extent of water body 200 ft, and then vertically downward to a depth of 350 ft, then by using cross-sections, outward at an angle of 65° measured from the horizontal. Plot in appropriate position on mine map. Local observations and experience may modify this determination, but must be justified. Go to Step A6.

Step A6. For flowing water bodies, use as inflow rate the smaller of flood stage flow rate or 100,000 gpm, and go to Section B. For non-flowing water bodies, use as inflow rate 100,000 gpm, and go to Section C. For any water bodies retained by structures, go to Section D.

SECTION B. FLOWING WATER BODIES

Step B1. Determine pumping capacity in likely area of ponding in lowest area downhill from zone of influence (which may be within zone of influence). Go to Step B2.

Step B2. Compare pumping capacity from Step B1 with inflow rate from Step A6. If inflow rate is larger than pumping capacity, water body is of Catastrophic Potential. Go to Section G for guidelines to be applied, and then go back to Step A3 if another water body is present. If inflow rate is less than pumping capacity, go to Step B3.

Step B3. Using graphs 1 through 12 in Section E, and information obtained in Step A1, determine if flow depth anywhere equals or exceeds 4.5 feet depth or the extracted height minus 1.5 feet. If flow depth equals or exceeds this depth, water body is of Catastrophic Potential. Go to Section G of guidelines to be applied, and then go back to Step A3 if another water body is present. If flow depth is less, go to Step B4.

Step B4. Using graphs 1 through 12 in Section E, and information obtained in Step A1, determine highest flow depth. Go to Step B5.

Step B5. Using graphs 13 through 15, determine force on clothed man. If force is 100 lbs or more, water body is of Catastrophic Potential. Go to Section G for guidelines to be applied, and then go back to Step A3 if another water body is present. If force is less than 100 lbs, go to Step B6.

Step B6. Water body is of Limited Potential. Go to Section I for guidelines to be applied, and then go back to Step A3 if another water body is present.

SECTION C. NON-FLOWING WATER BODIES

Step C1. Using graphs 1 through 12 in Section E, and information obtained in Step A1, determine if flow depth anywhere exceeds 4.5 feet depth or the extracted height minus 1.5 feet. If flow depth is greater than this depth, water body is of Catastrophic Potential. Go to Section G for guidelines to be applied, and then go back to Step A3 if another water body is present. If flow depth is less, go to Step C2.

Step C2. Using graphs 1 through 12 in Section E, and information obtained in Step A1, determine highest flow depth. Go to Step C3.

Step C3. Using graphs 13 through 15 in Section E, determine force on clothed man. If force is 100 lbs or more, water body is of Catastrophic Potential. Go to Section G for guidelines to be applied, and then go back to Step A3 if another water body is present. If force is less than 100 lbs, go to Step C4.

Step C4. Using information from Step A1, obtain safe length of downhill water filled entry where water is likely to pond from Table 7 from Section E. Go to Step C5.

Step C5. Using length in feet of longest dead-end or blocked entry obtained in Step A1, divide this length by 50 and then add 2 to obtain required escape time in minutes. Go to Step C6.

Step C6. Determine maximum allowable volume of water ponded in downhill entry from information obtained in Section A, Step 1, and Tables 2 through 5 in Section E. Go to Step C7.

Step C7. If volume of water body obtained in Step A4 is greater than maximum allowable volume obtained in Step C6, go to Step C12. If volume of water body obtained in Step A4 is less than maximum allowable volume obtained in Step C6, go to Step C8.

Step C8. Divide volume obtained in Step C6 by 100,000 to obtain filling time in minutes. Go to Step C9.

Step C9. Compare escape time from Step C5 to filling time from Step C8. If escape time is smaller than filling time, go to Step C12. If filling time is smaller than escape time, go to Step C10.

Step C10. Multiply escape time obtained in Step C5 by 100,000 to obtain intermediate volume. Go to Step C11.

Step C11. If intermediate volume from Step C10 is greater than maximum allowable volume obtained in Step C6, go to Step C12. If intermediate volume from Step C10 is less than maximum volume obtained in Step C6, water body is of Limited Potential. Go to Section I for guidelines to be applied, and then go back to Step A3 if another water body is present.

Step C12. The volume of the water body is such that the mine or part of mine must be planned to accept an inflow. Major Potential guidelines must be applied, (go to Section H for guidelines) with proper application to and permission from MSHA (Go to Section F for application). If no such inflow plan is desired, the water body is of Catastrophic Potential. Go to Section G for guidelines to be applied, and then go back to Step A3 if another water body is present.

SECTION D. WATER BODIES RETAINED BY STRUCTURES

Step D1. From information obtained in Section A, and from other sources as necessary, determine if

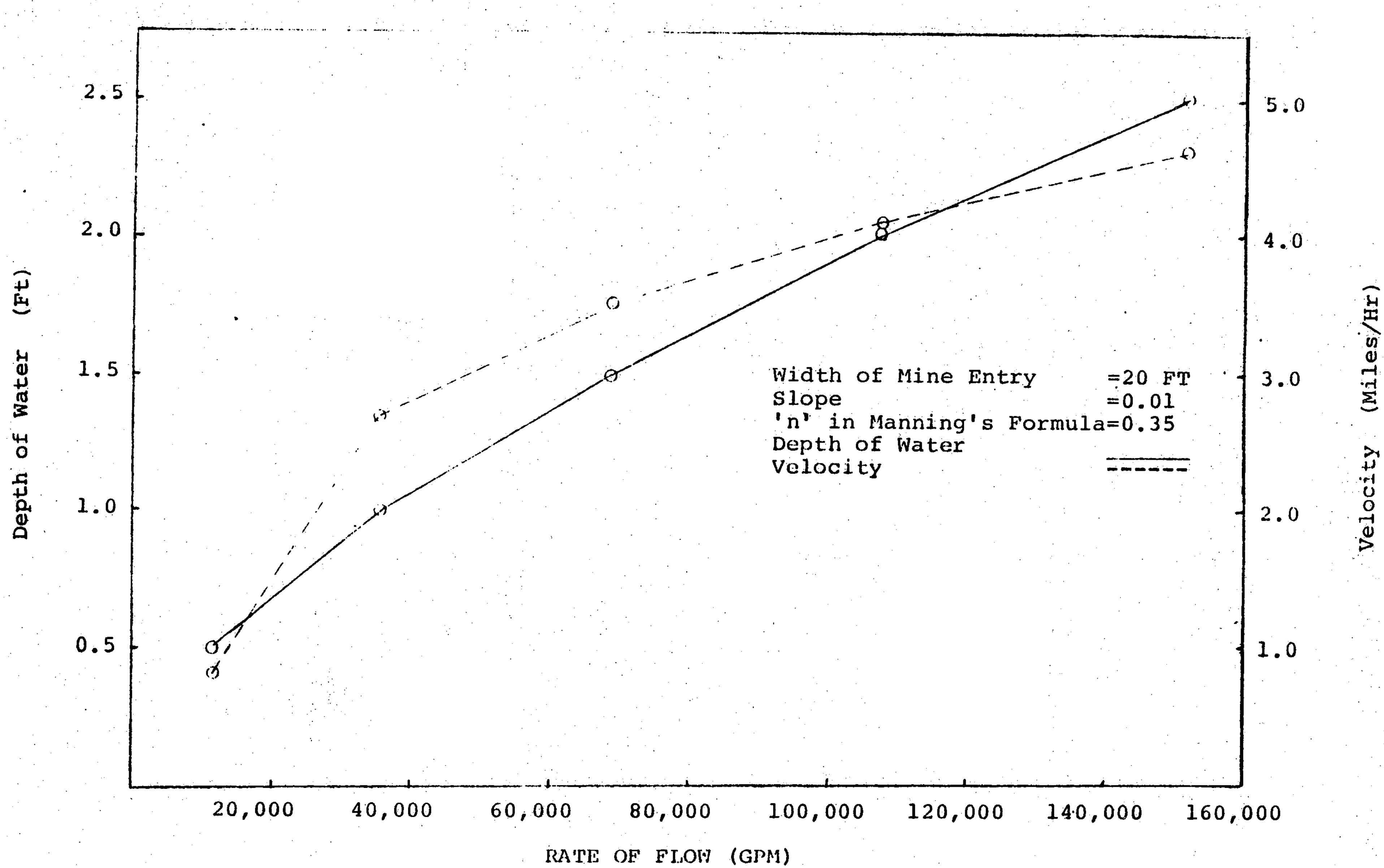
- failure of the structure would not result in loss of life; in damage to homes; commercial or industrial buildings; main highways or railroads; in interruption of the use of service of public utilities; or damage other existing water impoundments; and
- the contributing drainage area does not exceed 200 acres; and
- the maximum vertical height of the dam or embankment as measured along the centerline of the embankment to the crest of the spillway does not exceed 15 ft; and
- the area of impounded water at the spillway level does not exceed 10 surface acres; and
- the structure conforms to all applicable laws and regulations pertaining to the storage of water.

Go to Step D2.

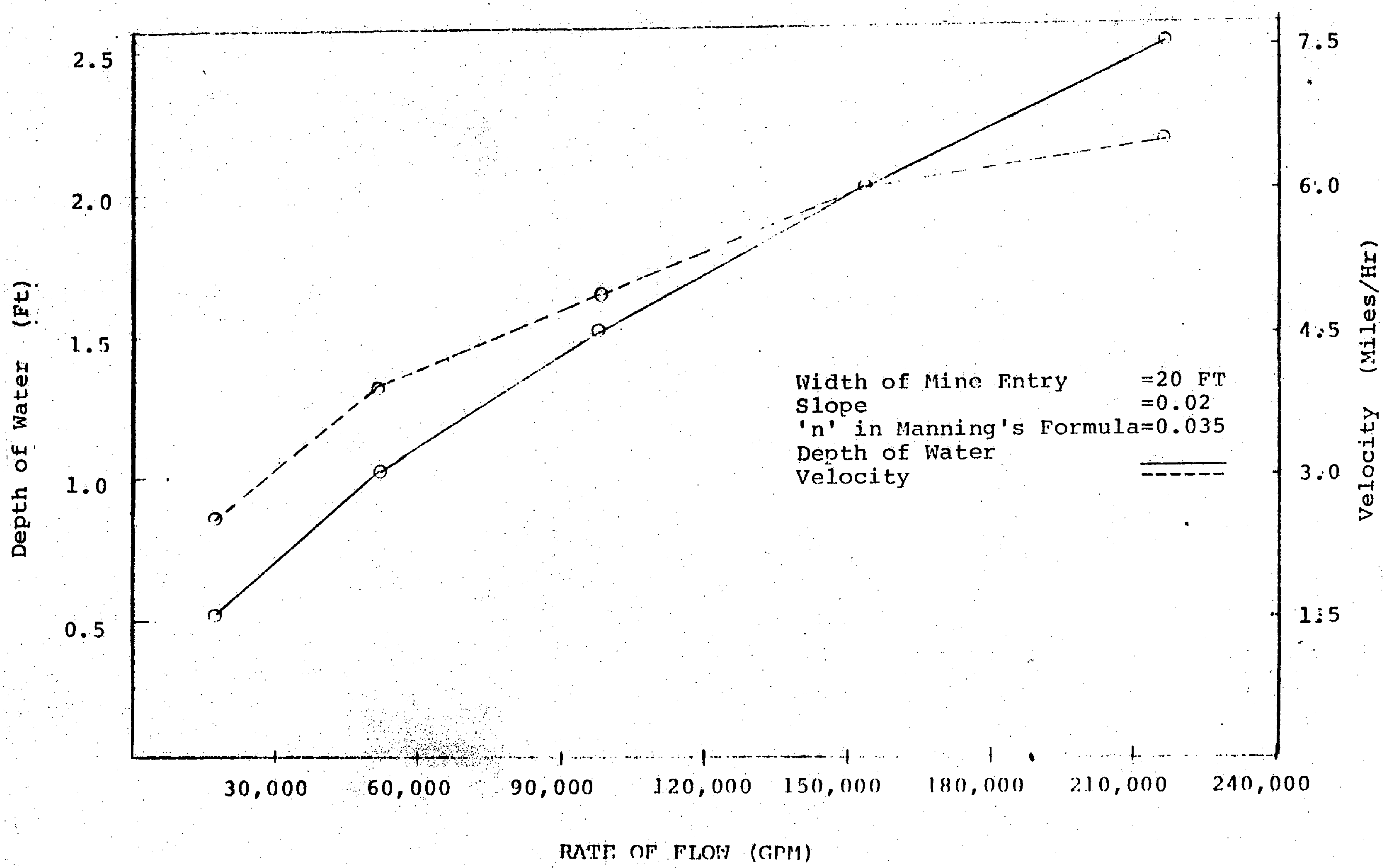
Step D2. If _all_ of the criteria in Step D1 have been met, and water body is flowing, go to Section B. If _all_ of the criteria in Step D1 have been met, and water body is non-flowing, go to Section C. If _all_ of the criteria in Step D1 have not been met, the guidelines for Structures Retaining Water must be applied. Go to Section J for guidelines and then go back to Step A3 if another water body is present.

SECTION E

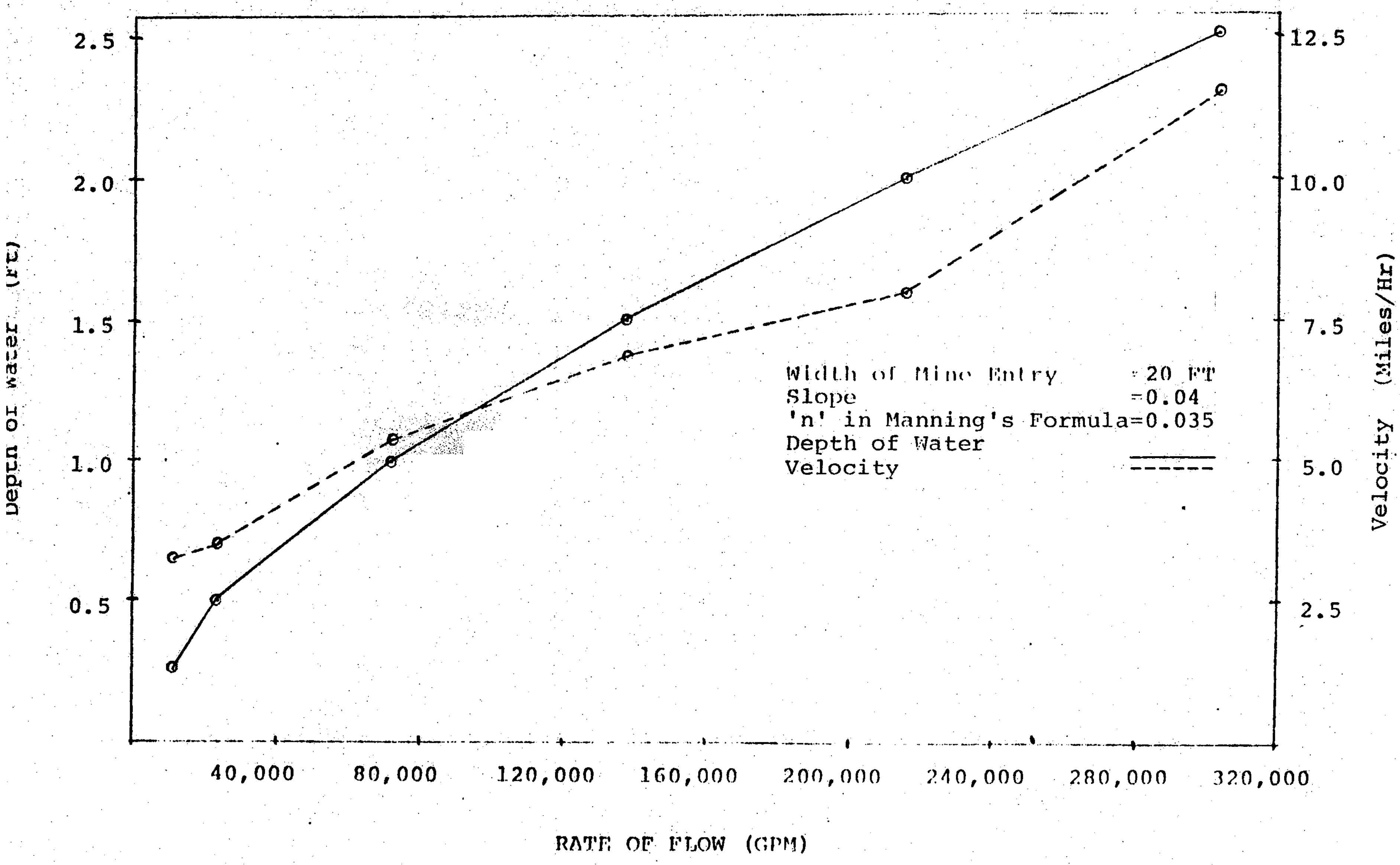
GRAPHS AND TABLES



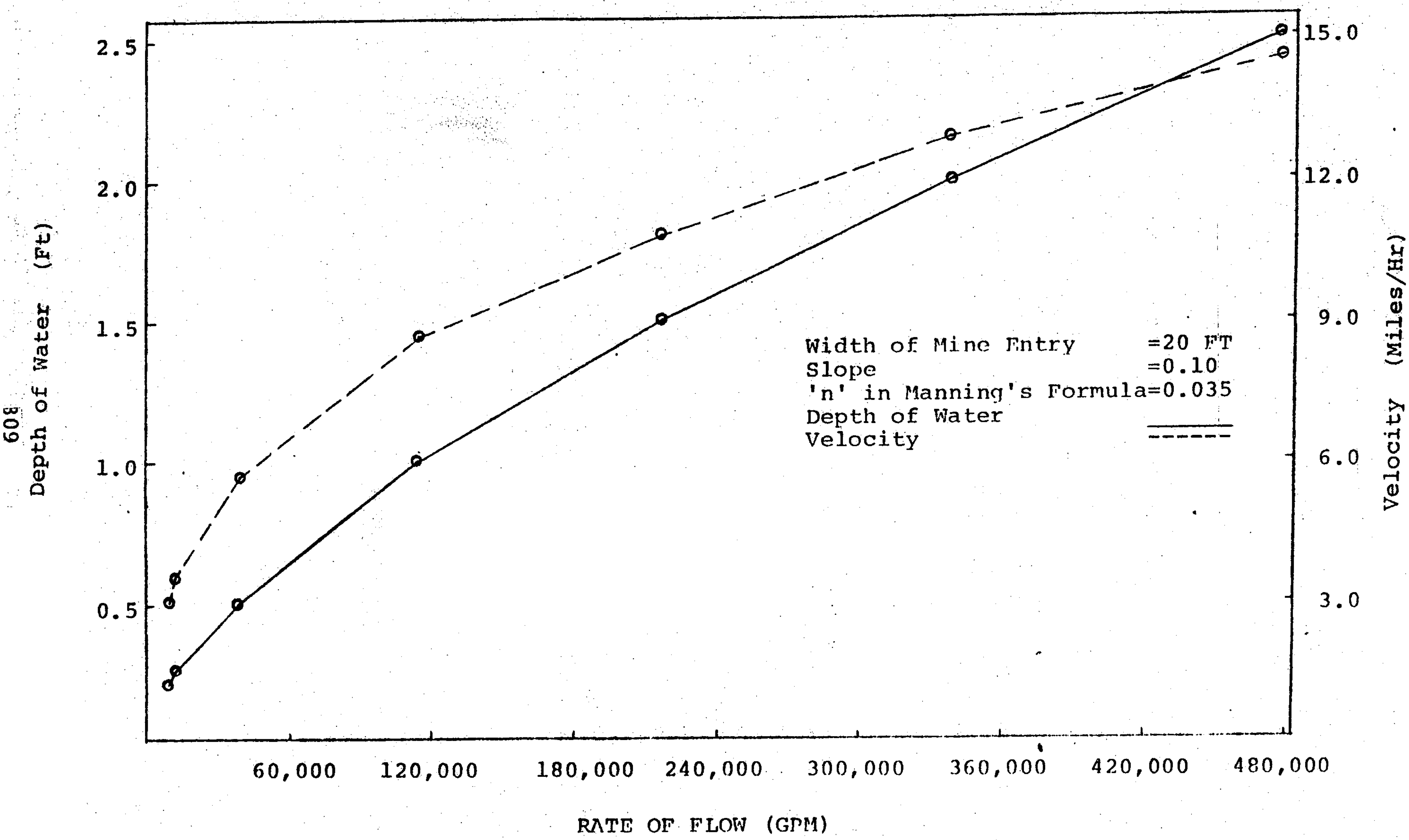
Graph 1 Depth and Velocity of Flow for Different Rates of Discharge



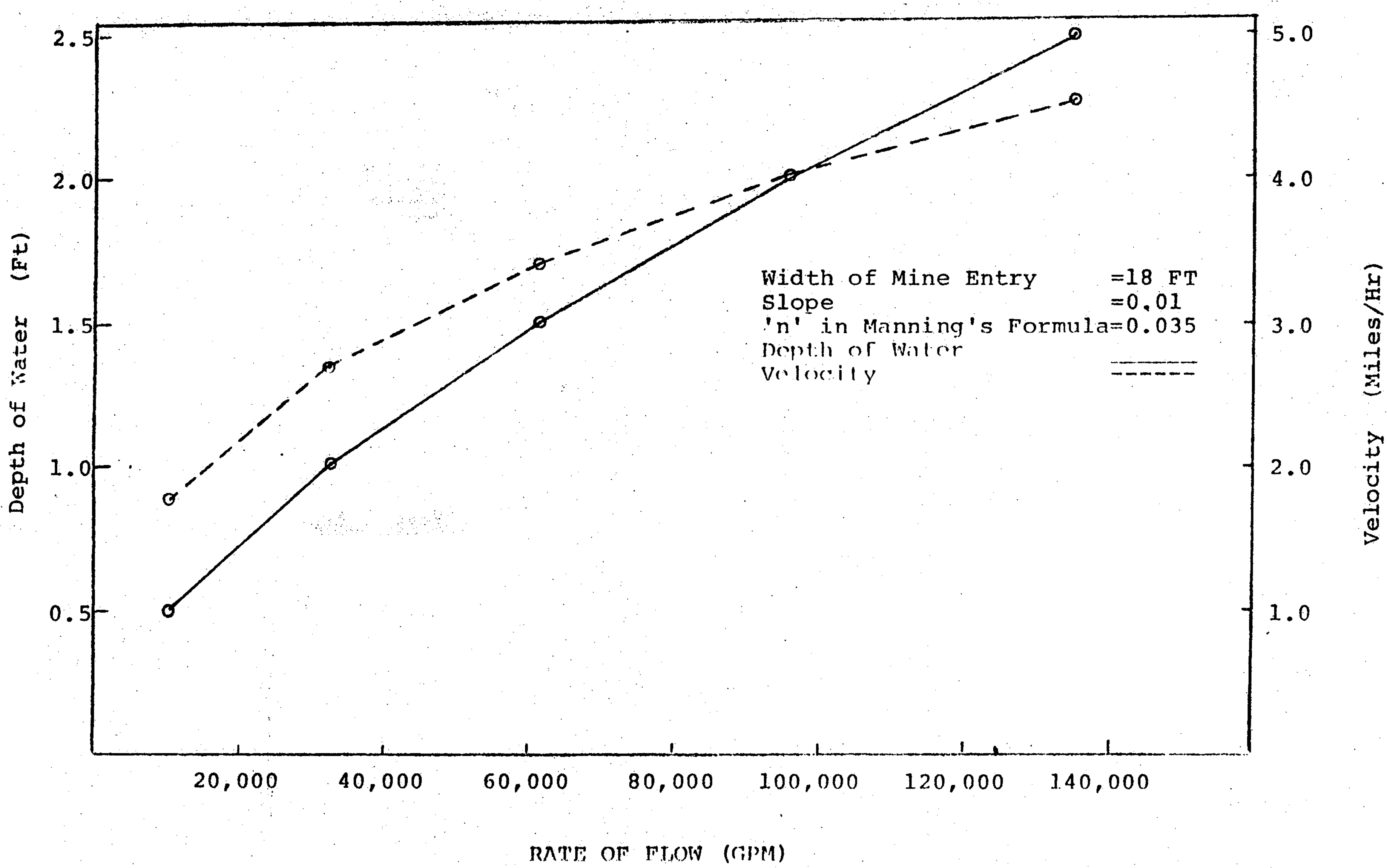
Graph 2 Depth and Velocity of Flow for Different Rates of Discharge



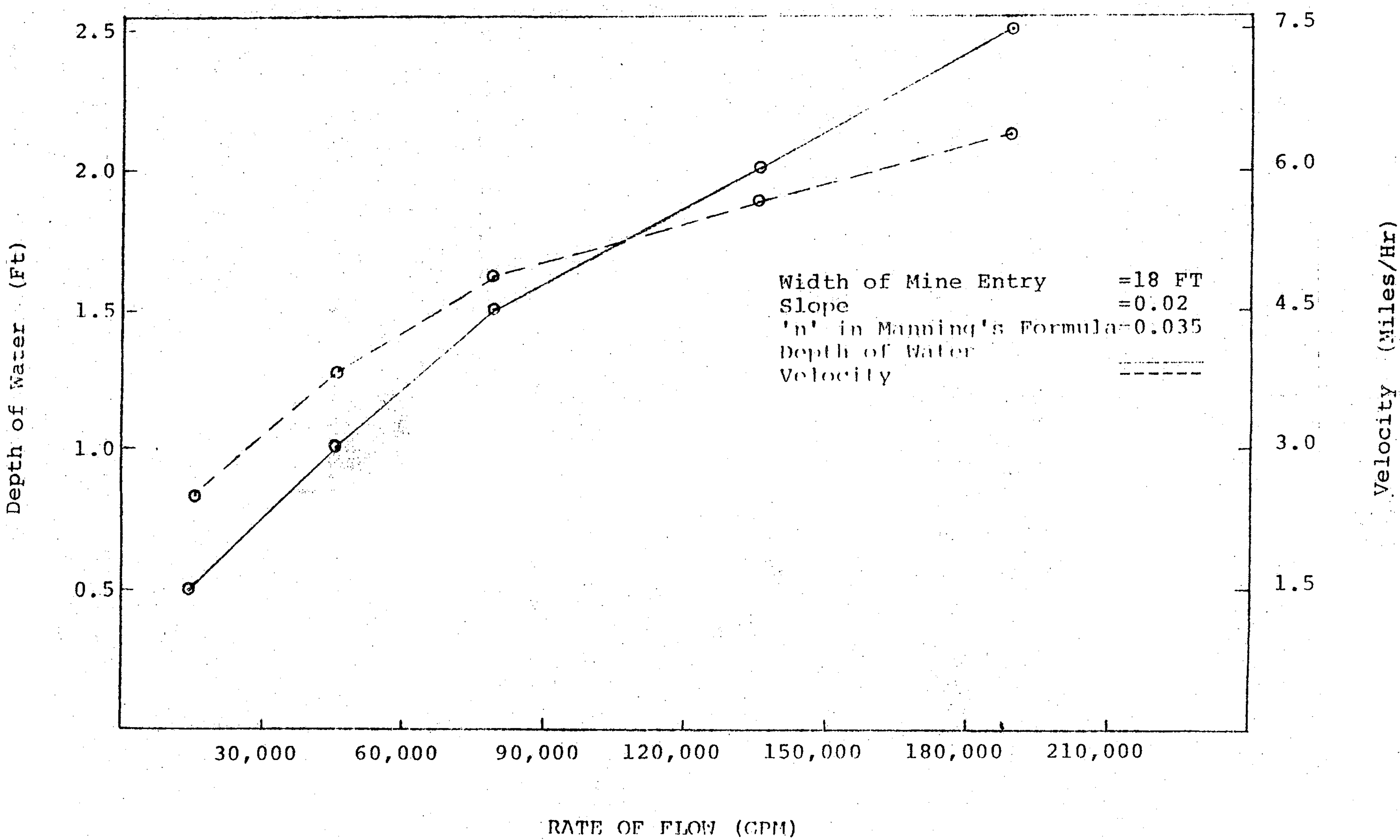
Graph 3 Depth and Velocity of Flow for Different Rates of Discharge



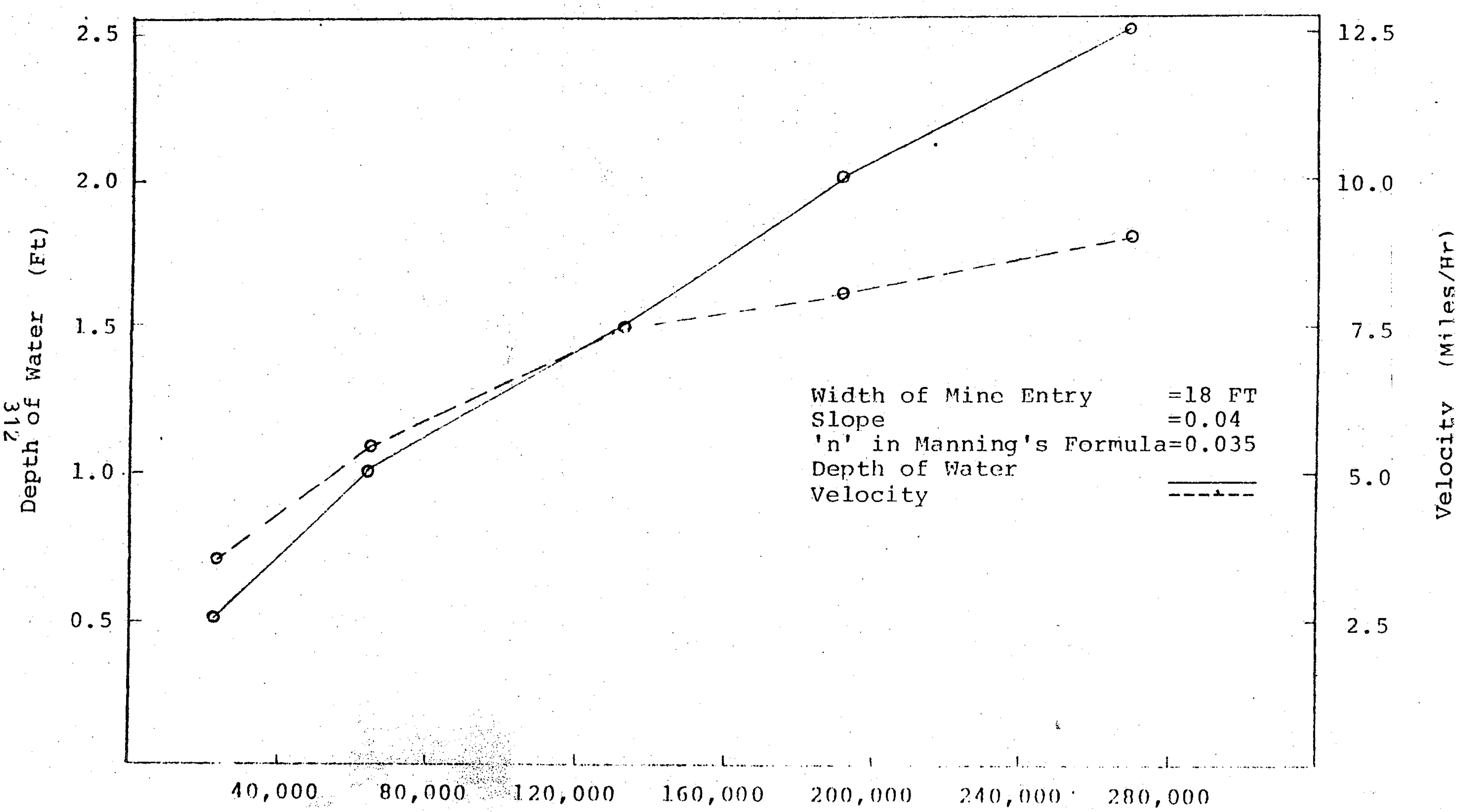
Graph 4 Depth and Velocity of Flow for Different Rates of Discharge

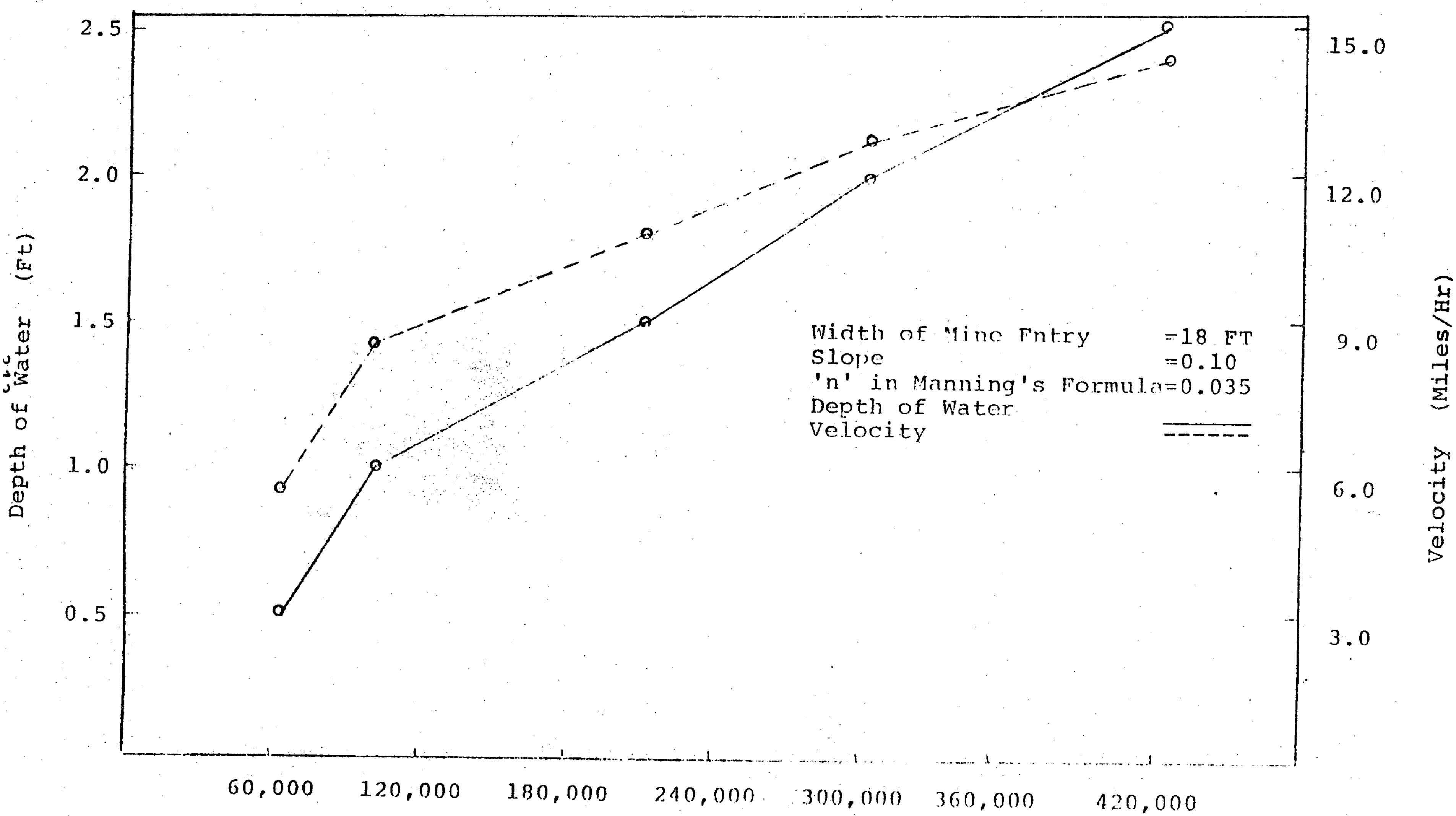


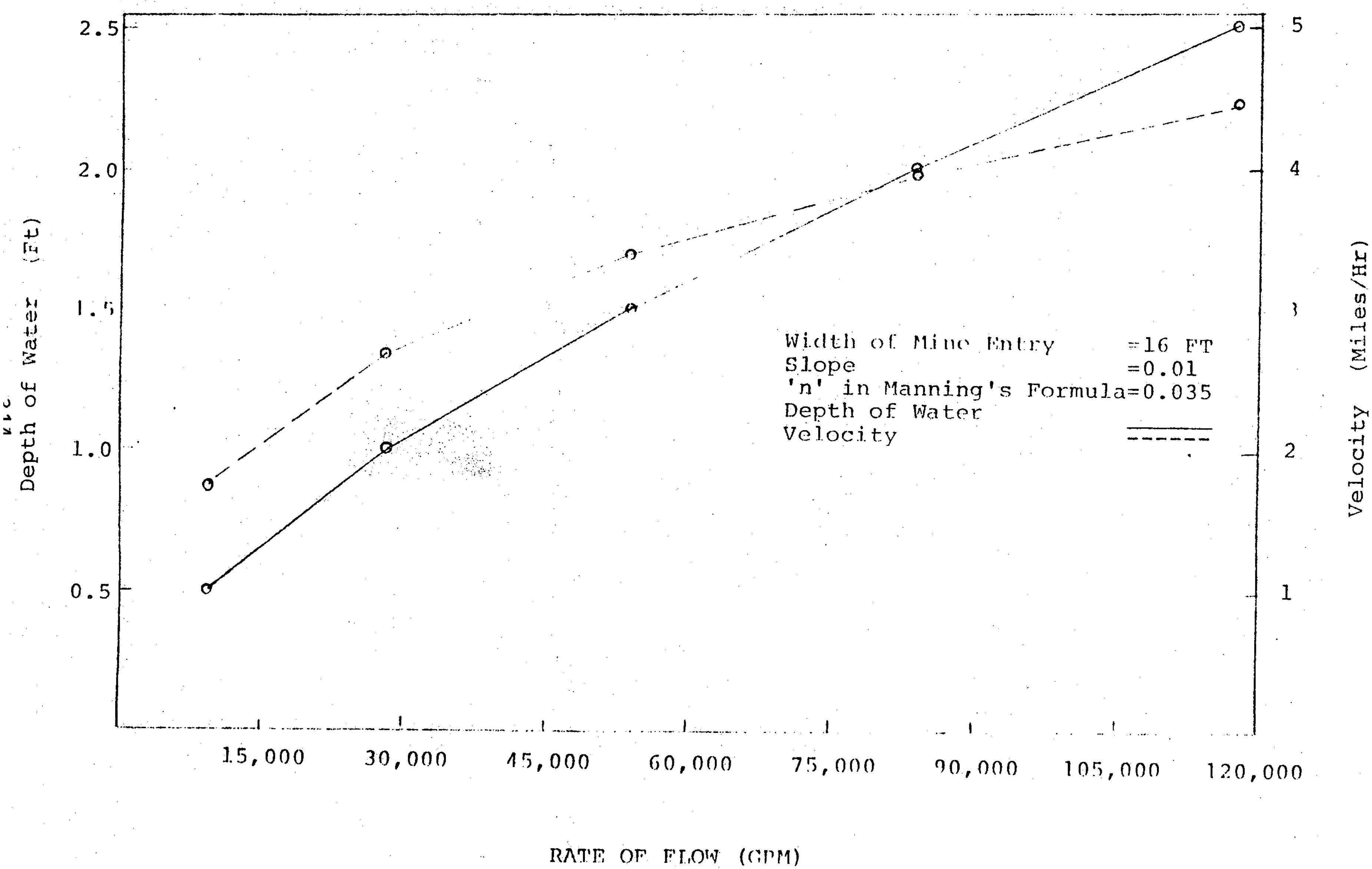
Graph 5 Depth and Velocity of Flow for Different Rates of Discharge



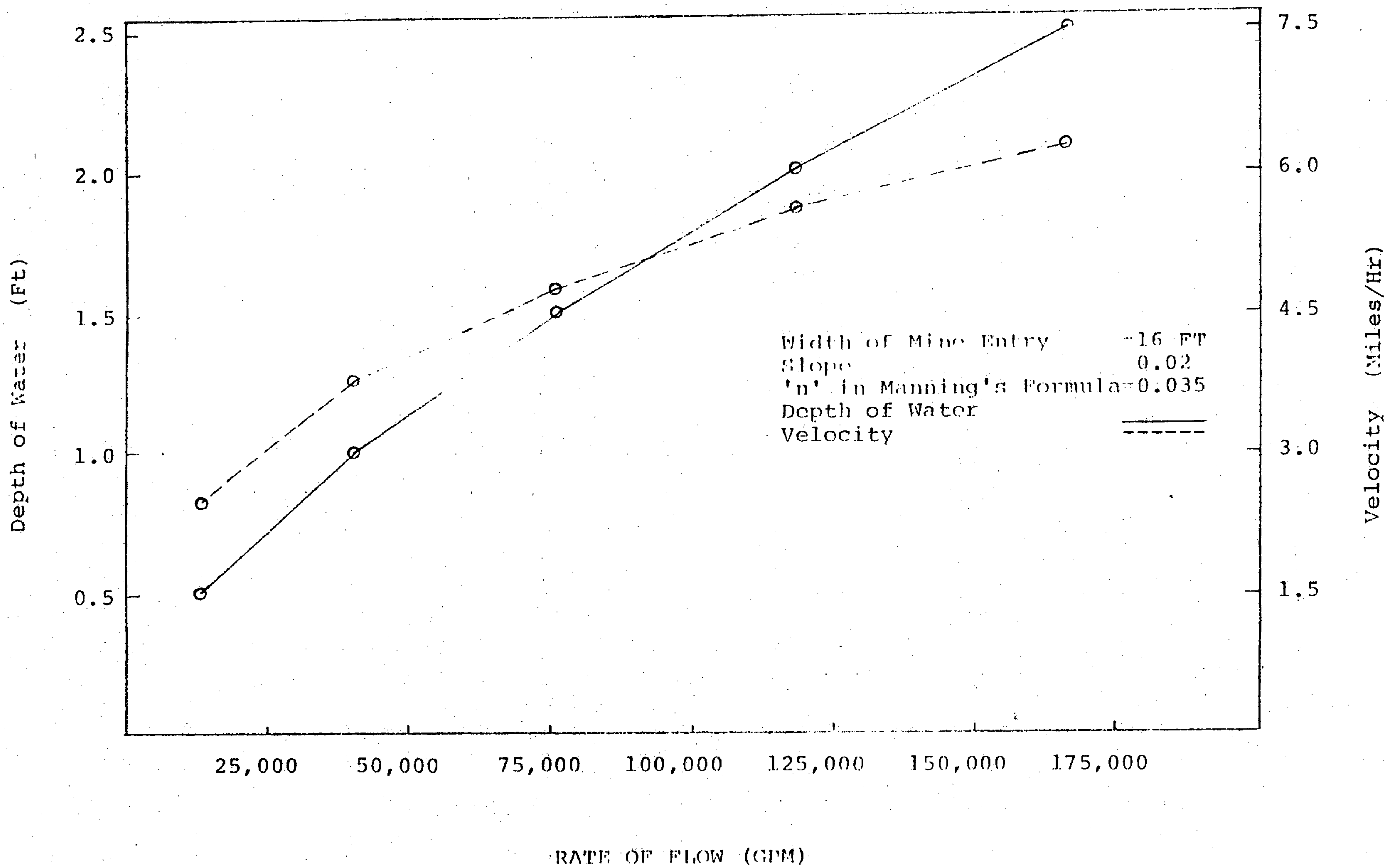
Graph 6 Depth and Velocity of Flow for Different Rates of Discharge


Depth of Water (Ft)
2.5
2.0
1.5
1.0
0.5
Velocity (Miles/Hr)
12.5
10.0
7.5
5.0
2.5
40,000
80,000
120,000
160,000
200,000
240,000
280,000
Width of Mine Entry =18 FT
Slope =0.04
'n' in Manning's Formula=0.035
Depth of Water
Velocity

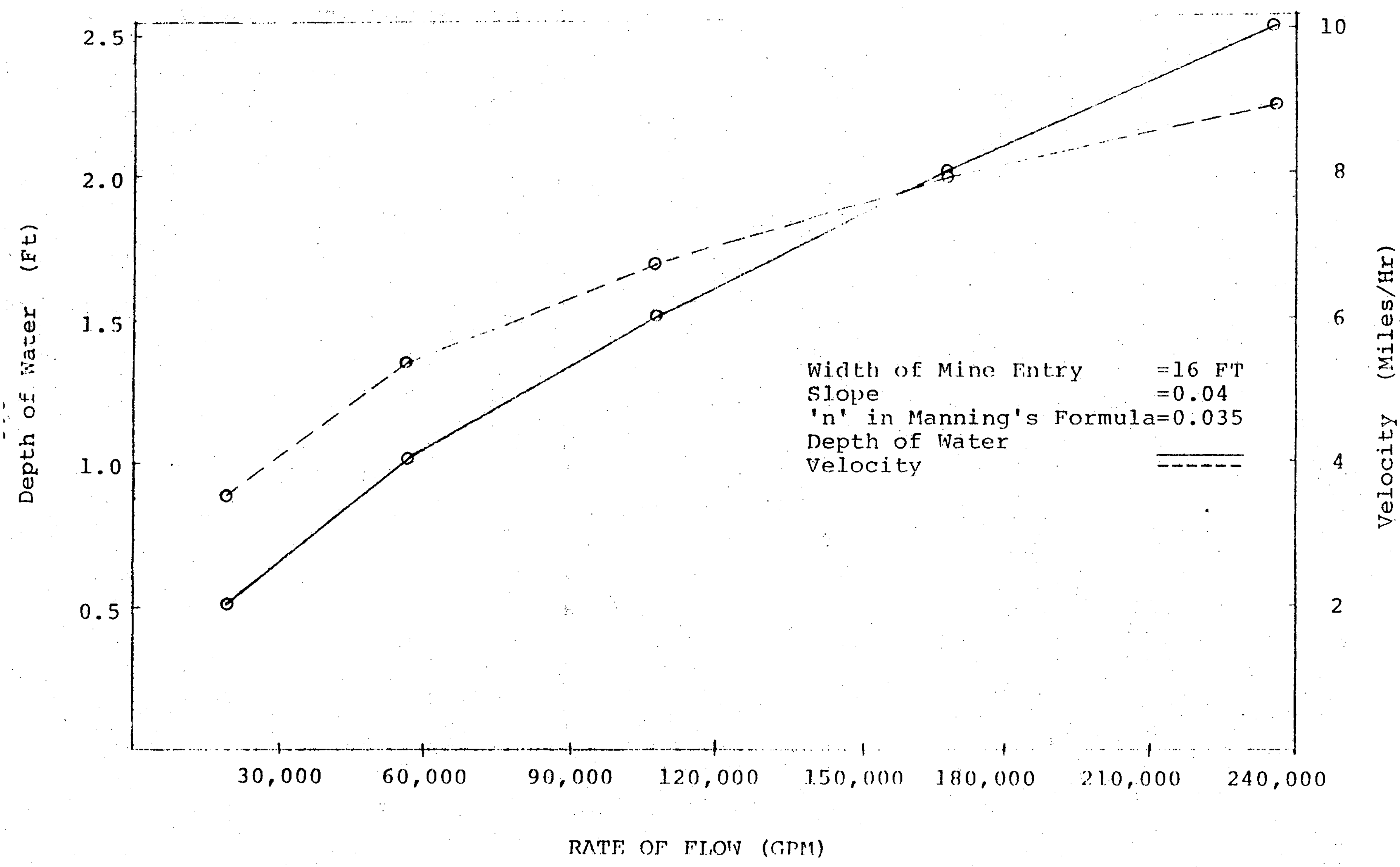

Depth of Water (Ft)
2.5
2.0
1.5
1.0
0.5
Velocity (Miles/Hr)
15.0
12.0
9.0
6.0
3.0
60,000
120,000
180,000
240,000
300,000
360,000
420,000
Width of Mine Entry =18 FT
Slope =0.10
'n' in Manning's Formula=0.035
Depth of Water
Velocity



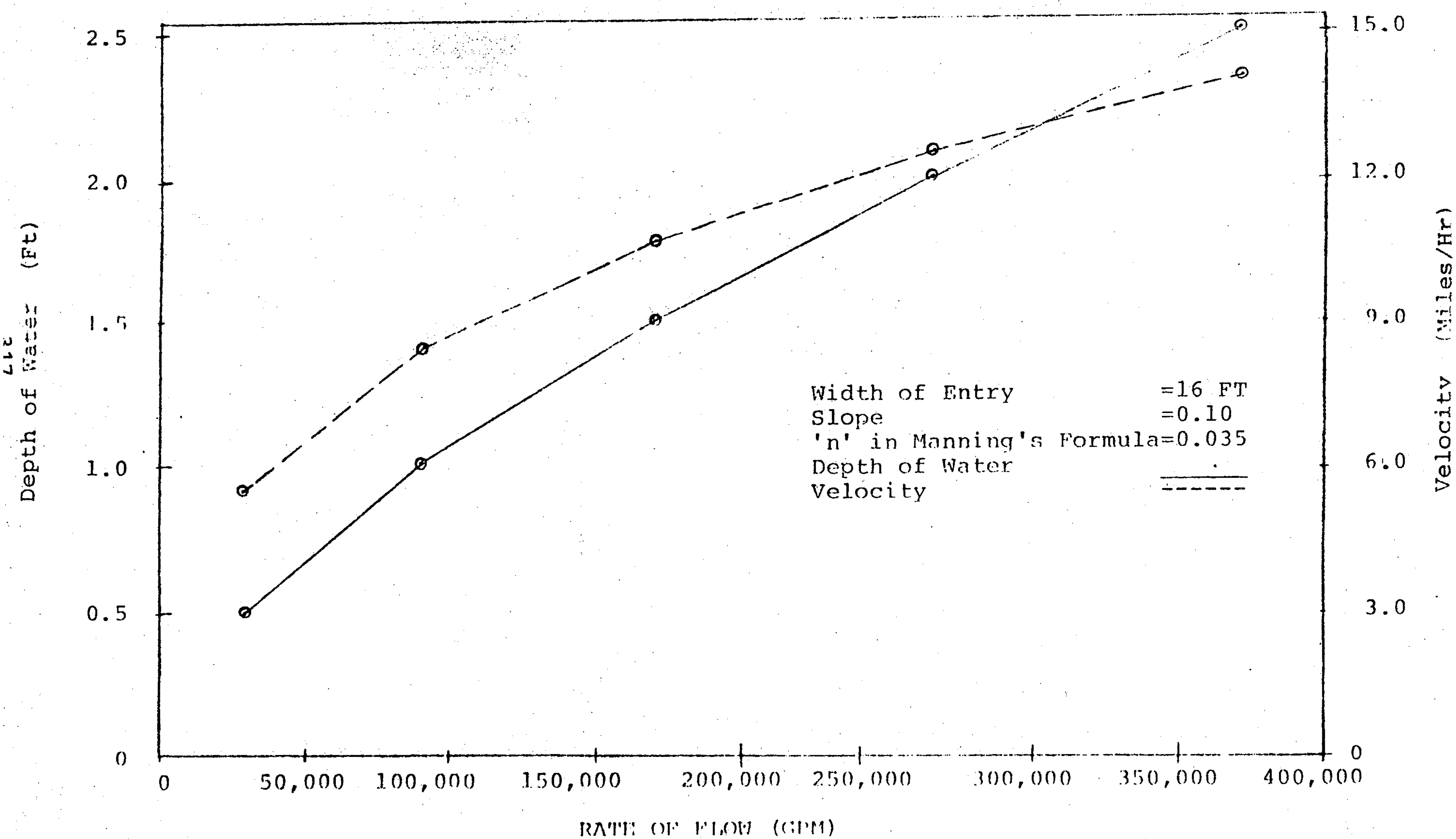
Graph Depth and Velocity of Flow for different Rates of Discharge



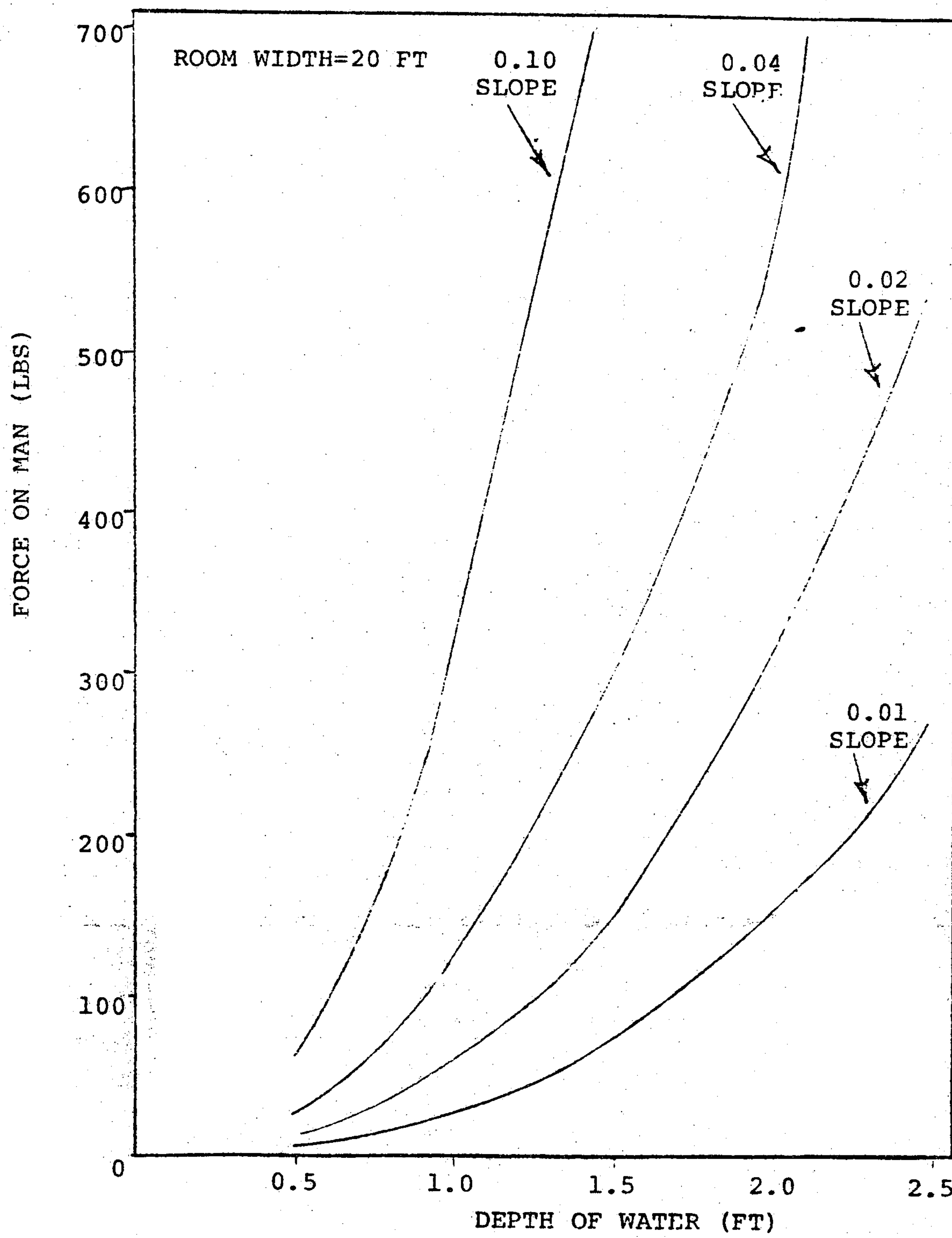
Graph 10 Depth and Velocity of Flow for Different Rates of Discharge



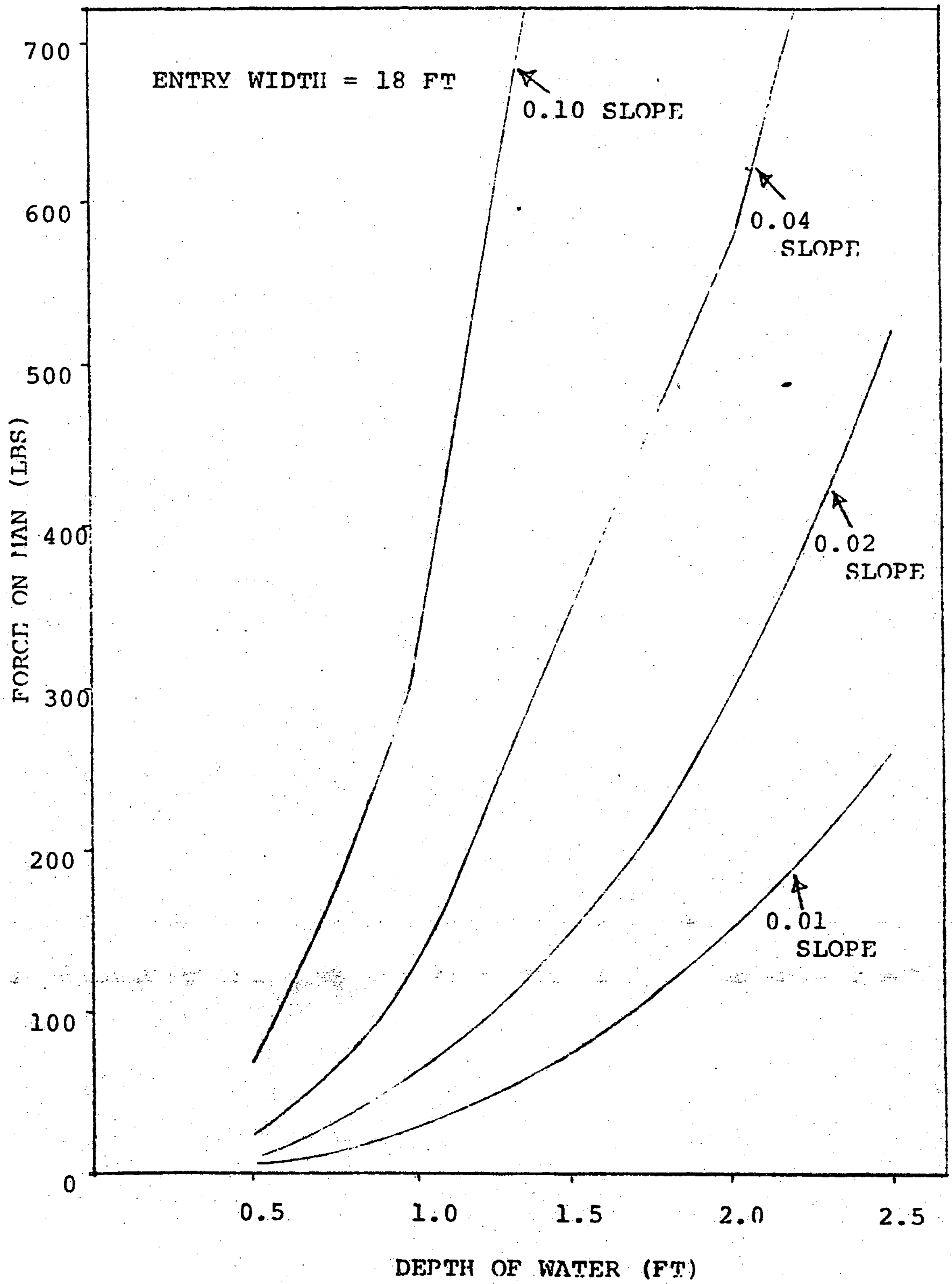
Graph 11 Depth and Velocity of Flow for Different Rates of Discharge



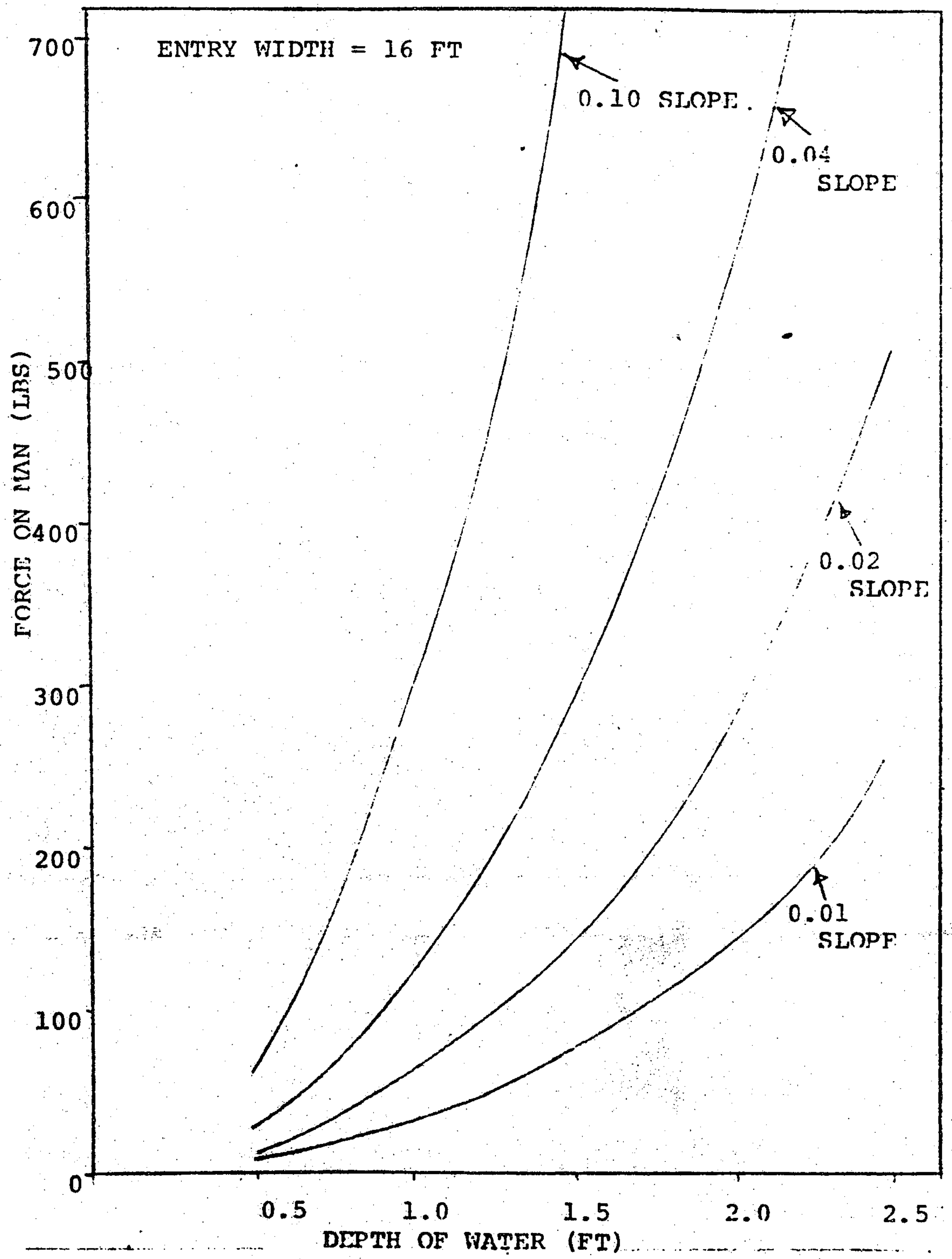
Graph 12 Depth and Velocity of Flow for Different Rates of Discharge



Graph 13 - Force Acting on a Clothed Man at Various Depths of Flow



Graph 14 - Force Acting on a Clothed Man at Various Depths of Flow



Graph 15 - Force Acting on a Clothed Man at Various Depths of Flow

Table 1 - Safe Length of Water Filled Entries in Feet

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	300	500	700	900	900	900	900	900	900	900
0.01	150	250	350	450	450	450	450	450	450	450
0.02	75	125	175	225	225	225	225	225	225	225
0.04	37.5	62.5	87.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
0.06	25	42	58	75	75	75	75	75	75	75
0.08	19	31	44	56	56	56	56	56	56	56
0.10	15	25	35	45	45	45	45	45	45	45

Table 2 - Volume of Water in 20 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	33,750	93,750	183,750	303,750	303,750	303,750	303,750	303,750	303,750	303,750
0.01	16,875	46,875	91,875	151,875	151,875	151,875	151,875	151,875	151,875	151,875
0.02	8,438	23,438	45,938	75,938	75,938	75,938	75,938	75,938	75,938	75,938
0.04	4,219	11,719	22,969	37,969	37,969	37,969	37,969	37,969	37,969	37,969
0.06	2,813	7,813	15,313	25,313	25,313	25,313	25,313	25,313	25;313	25,313
0.08	2,110	5,860	11,484	18,984	18,984	18,984	18,984	18,984	18,984	18,984
0.10	1,688	4,688	9,188	15,188	15,188	15,188	15,188	15,188	15,188	15,188

Table 3 - Volume of Water in 18 ft Wide Entry in Gallons

Slope of Entry, hl, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	30,375	84,375	165,375	273,375	273,375	273,375	273,375	273,375	273,375	273,375
0.01	15,188	42,188	82,688	136,688	136,688	136,688	136,688	136,688	136,688	136,688
0.02	7,594	21,094	41,344	68,344	68,344	68,344	68,344	68,344	68,344	68,344
0.04	3,797	10,547	20,672	34,172	34,172	34,172	34,172	34,172	34,172	34,172
0.06	2,531	7,031	13,781	22,781	22,781	22,781	22,781	22,781	22,781	22,781
0.08	1,898	5,273	10,336	17,086	17,086	17,086	17,086	17,086	17,086	17,086
0.10	1,519	4,219	8,269	13,669	13,669	13,669	13,669	13,669	13,669	13,669

Table 4 - Volume of Water in 16 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	27,000	75,000	147,000	243,000	243,000	243,000	243,000	243,000	243,000	243,000
0.01	13,500	37,500	73,500	121,500	121,500	121,500	121,500	121,500	121,500	121,500
0.02	6,750	18,750	36,750	60,750	60,750	60,750	60,750	60,750	60,750	60,750
0.04	3,375	9,375	18,375	30,375	30,375	30,375	30,375	30,375	30,375	30,375
0.06	2,250	6,250	12,250	20,250	20,250	20,250	20,250	20,250	20,250	20,250
0.08	1,688	4,688	9,188	15,188	15,188	15,188	15,188	15,188	15,188	15,188
0.10	1,350	3,750	7,350	12,150	12,150	12,150	12,150	12,150	12,150	12,150

Table 5 - Volume of Water in 14 ft Wide Entry in Gallons

Slope of Entry, h_1, ft/ft	Extracted Seam Height, t, ft: 3	4	5	6	7	8	9	10	11	12
0.005	23,625	65,625	128,625	212,625	212,625	212,625	212,625	212,625	212,625	212,625
0.01	11,813	32,813	64,313	106,313	106,313	106,313	106,313	106,313	106,313	106,313
0.02	5,906	16,406	32,156	53,156	53,156	53,156	53,156	53,156	53,156	53,156
0.04	2,953	8,203	16,087	26,578	26,578	26,578	26,578	26,578	26,578	26,578
0.06	1,969	5,469	10,719	17,719	17,719	17,719	17,719	17,719	17,719	17,719
0.08	1,477	4,102	8,039	13,289	13,289	13,289	13,289	13,289	13,289	13,289
0.10	1,181	3,281	6,431	10,631	10,631	10,631	10,631	10,631	10,631	10,631

SECTION F. SUGGESTED APPLICATION FOR PERMIT TO MINE BENEATH BODIES OF SURFACE WATER

The information requested herein will allow a determination by the Coal Mine Health and Safety District Manager of the nature, if any, of the hazard posed by mining beneath bodies of surface water. If approved, mining must proceed by particular methods and plans as required by the published "Guidelines for Mining Beneath Bodies of Surface Water.*" All technical determinations and procedures required in this application shall be in accordance with the published "Manual for Hazard Determination for Mining Beneath Bodies of Surface Water.*"

General Information

1. Name of company

   Form of ownership

2. Address

   Permanent Mailing

3. Name and title of person representing company

4. Address

5. Location of operation

   County Nearest Post Office

6. Other designation: Subdivision, tract, coordinates

*Note: These titles are hypothetical, only for the purpose of this report, and are not intended to suggest actual or proposed documents.

7. Mineral to be mined

8. Geological title and correlation of seams

9. Owner(s) of surface land

10. Owner(s) of minerals to be mined

11. Owners of affected water rights

12. Attach copies of agreement with or notification of the above owners by registered or certified mail, whichever is required by other state and federal provisions.

13. Date of proposed first development in affected area.

<u>Particulars of Coal Seams, Geology and Method of Work</u>

1. Name and thickness of seams proposed to be worked:

Seam	Thickness	Thickness of Working Section

2. Thickness of cover below the water body: Enclose a profile map showing the type of strata and the distance between the seam and the surface water body. The strata section should preferably be determined from core test drill hole data; however, the strata sections obtained from nearby shafts, slopes, surface mines, or other sources, may be considered in lieu of core test drill holes.

3. Faults and dikes: Show all known or inferred faults and dikes on a plan map of the proposed mining area.

4. Other important geological disturbances: Show all such disturbances on the plan map.

5. Nearby mining: Show all known or suspected mines, above or occuring in the same seam, their extent, nature, water condition, current or last known owner, and any other available information.

6. Method of Mining:

Room & Pillar:	Room width	Pillar width	Cover present
Panel & Pillar:	Panel width	Barrier pillar	Cover present

Total Extraction:

Longwall or room and Pillar	Panel Width or face length	Panel length	Cover Present

Water Hazard Map

An application for a permit for working beneath and in the vicinity of surface water bodies to be filed with the Coal Mine Health and Safety District Manager shall be accompanied by a Water Hazard Map showing the location of the water body and its relation to the location of all working places. It shall be an accurate, up-to-date map of the mine drawn to a scale of 1 inch = 500 feet. Information required on the map must include the following:

Surface Features

Surface features may be drawn directly on the Water Hazard Map, or on a transparent or translucent sheet, which, when overlain on a map of underground workings, shows true and exact relations of surface features to mine workings and excavations. Surface features to be shown shall include:

1. Name and address of the mine.
2. Scale and orientation of the map.
3. Boundary lines and names of all surface property owners.
4. Boundary lines of the mineral rights pertaining to each mine.
5. All outcrop lines.
6. Topographic features.
7. Location and identification of municipal subdivisions (State, county, townships).
8. Location of all railroads and sidings, highways, and other roads.
9. Location and identification of mine buildings and facilities.
10. Location of all utilities and pipelines.
11. Location and depth of all holes drilled for oil, gas, water, or geologic information in the property.
12. Location of all surface fans.

13. Location of mine openings.

14. Surface topographic countour lines.

15. The location and description of at least two permanent baseline points coordinated with the underground and surface mine traverses, and the location and description of at least two permanent elevation bench marks used in connection with establishing or referencing mine elevation surveys. Location and description of a permanent bench mark or monument near the main mine opening.

16. The location and mine-life flood extent, including flow, volume, and area, of all bodies of surface water, whether natural or artificial including depth contours at mine-life flood stage.

17. The owner of the surface water rights.

Underground Features

Whether or not combined on the same sheet with surface features, the Water Hazard Map showing underground features should be composed on the same scale. Information to be recorded on the mine map must include:

1. Name and address of the mine.

2. Scale and orientation of the map.

3. Boundary lines of mineral rights and owner identification.

4. Structure contours and dip of the seam being mined at not greater than 5-ft elevation intervals.

5. All shaft, slope, drift, and tunnel openings and auger and strip-mined areas of the seam being mined.

6. Location and depth of all drill holes.

7. Location of all ventilation fans.

8. Location and extent of adjacent active or abandoned underground workings above, below, or in the same seam. If abandoned workings are known to exist in an area, but exact extent is not known, it should be so indicated. Also, indicate if it is proposed to use any of the old abandoned workings for emergency water storage.

9. Up-to-date locations of active work areas, worked-out areas, and abandoned areas.

10. Locations of entries and aircourses with direction of airflow indicated by arrow.

11. Location of all escapeways.

12. Location and exact extent of all water pools, water-bearing strata, or fluidlike materials which tend to flow when wet.

13. Location and elevation of any body of water dammed or held back in any portion of the mine.

14. Subsurface projection of limits of body of surface water at mine-life flood stage, including any required safety zones.

15. The likely flow routes in the event of an inrush from the water body.

16. In-mine water storage capacity contours. They should be worked out by subtracting the volume of the ponded water and other fluids from the total capacity of the voids (using recommended coefficients for caved and filled gobs) under completely dry conditions.

17. The construction specifications of the stoppings and the walls of the overcasts or any other structure which may be necessary for coursing the water current in the event of an inrush.

18. The elevation of tops and bottoms of shafts and slopes, and the floor at the entrance to drift and tunnel openings.

19. The elevation of the floors at intervals of not more than 2 ft in:

    a. At least one entry of each working section and main and cross entries.

    b. The last line of open crosscuts of each working section, and of main and cross entries, before such sections and main and cross entries are abandoned.

c. Rooms advancing toward or adjacent to property or boundary lines or adjacent mines.

20. The owner, agent or manager of a mine should take all reasonable steps to determine whether there is any material below the surface which could affect active, or soon to be active, areas in a mine so as to cause danger to miners working in that mine. All facts pertaining to such conditions should be presented on the map.

Size of Water Body and Capacity of the Designed Emergency Sump

1. Particulars of Water Body:

Show water body on plan map, indicating:

a. General mine-life flood area.

b. Mine-life flood maximum depth.

c. Depth contours.

d. Mine-life flood volume.

e. Mine-life flood flow.

2. Mine Design Parameters:

Show on plan map of mine proposed:

a. Width of entries.

b. Height of entries.

c. Gradients of the entries.

d. Pumping capacity in various areas.

3. Likely Water Flow Routes:

a. Mark the likely water flow routes on the mine plan or hazard map in the event of an inflow.

b. Show whether any structures like stoppings or overcasts are proposed to be used for directing the water current.

c. If so, give their specifications. Such stoppings and overcasts should be constructed in accordance with American Concrete Institute's Standard ACl 67-23 or other acceptable standard.

4. Determination of available in-mine water storage capacity of the emergency sump.

a. Mark on the plan map or water hazard map the position of the emergency sump which may be flooded in the event of an inflow from the surface water body.

b. Determine total water capacity of the emergency sump. In case gobbed panels maintained free of water are proposed to be used for part of the emergency sump, determine their water storage capacity by using the appropriate capacity coefficients.

c. Determine the quantity of water already stored in these workings.

d. Determine the available water storage capacity by subtracting the value obtained in c from the value obtained in b.

5. Escape Routes:

a. Mark the escape routes on the mine plan or water hazard map.

b. Indicate interferences with water flow routes.

c. If interferences occur, a provision of an alternative emergency escape route should be made and shown on the map.

d. Enclose profiles of the escape routes to indicate that there are no depressions which may fill up and block the escape route.

SECTION G. GUIDELINES FOR CATASTROPHIC POTENTIAL WATER BODIES

Total Extraction Mining

Total extraction coal mining involves excavating a sufficiently large width of a seam, as in longwall mining or extraction of pillars in a room and pillar mining system, with essentially concurrent caving of the roof behind the face supports or the line of extraction. The method of extraction, whether by longwall, continuous, or conventional mining, the extraction thickness, and whether the gob is packed or not is not relevant. Also, the shortwall or longwall faces flanked with barrier pillars which may constitute the panel and pillar system of partial extraction, are not included in this definition.

The following guidelines are recommended for total extraction below catastrophic potential sized water bodies. These guidelines require the establishment by drilling or otherwise of the nature of the strata above the proposed total extraction workings. Where the word "coal" or "seam" is used, it also applies to any bedded mineral deposit.

1. Any single seam beneath or in the vicinity of any body of surface water may be totally extracted, whether by longwall mining or by

pillar robbing, provided that a minimum thickness of strata cover as given in Table 1 exists between the proposed workings and the bottom of the body of surface water.

2. Where more than one seam exists, all may be worked by total extraction provided that for the aggregate mineral and rock thickness of strata cover as given in Table 1 exists between the proposed workings in the uppermost seam and the bottom of the body of surface water.

3. The maximum cumulative, calculated tensile strain beneath a body of surface water shall nowhere exceed 10,000 $\mu\varepsilon$, and shall be calculated by an approved method. The layouts of panels in the same seam or in different seams, in case of multiple seam mining, shall be planned accordingly.

4. Where a single seam has already been mined by total extraction in accordance with the provision that for each 1-foot thickness of mineral and rock extracted a minimum strata of cover as given in Table 1 should exist,

Table 1 - Minimum Cover Required for Total Extraction Below Water Bodies of Catastrophic Potential Size

Thickness of Seam ft	Minimum Total Thickness of Cover	
t	t	ft
3	117t	351
4	95t	380
5	80t	400
6	71t	426
7	63t	441
7.5	60t	450
> 7.5	60t	-

no other underlying seam may be mined by total extraction. The lower seam may be mined by partial extraction in accordance with the subsequent stipulated guidelines considering as though the upper seam constituted the bottom of a body of surface water, however, the pillars shall be designed to support the entire strata up to the surface including the water body.

5. Where unconsolidated natural or artificial deposits exist between bedrock and the bottom of a body of surface water, which may be highly permeable or which when wet may flow, these should be excluded from the thickness of overlying strata, except where it has been demonstrated that such deposits would not be likely to flow when wet and could be considered as impermeable.

6. Where a fault which might connect mine workings with a body of surface water, and which has a vertical displacement greater than 10 ft, or an intrusive dike having a width greater than 10 ft, is known to exist or is met with during development, no seam should

be totally extracted within 50 ft horizontally on either side of such fault or dike.

7. Where the gob is stowed by some method, the requirements of minimum strata cover may be reduced using a suitable approved subsidence factor which will be determined depending on the compressibility of the stowing material and the manner of stowing.

Partial Extraction Mining

A partial extraction system is one in which pillars are deliberately left unworked for the purpose of giving more or less permanent support to the land surface. Two such systems are the room and pillar first working and the panel and pillar system which also includes the shortwall method.

Room and Pillar Method

In this system two sets of parallel entries usually at right angles to each other are driven in a seam leaving rectangular pillars to support the roof strata. The pillars may be extracted as in "secondary working" or they may be left behind permanently to support the strata after "first working".

Minimum Depth of Cover

A minimum thickness of strata cover should be left above the seam while working below water bodies. Both the height and the width of the entries and the characteristics of the roof beds are significant parameters to ensure stability and support of the intervening strata.

Separate provisions with respect to drifts and tunnels are stipulated because the practicability and cost of supporting and maintaining them would be generally acceptable. In room and pillar entires, however, the cost of permanent supports would be exceptionally high and their maintenance would be generally impracticable.

The following guidelines are recommended for determining a minimum depth of strata for room and pillar workings.

1. No entry should be driven in any seam lying beneath or in the vicinity of any body of surface water where the total thickness of strata cover above the seam is less than 5 times the maximum entry width (5s) or 10 times the maximum entry height (10t), whichever is the greater. Where at least one competent bed of sandstone or similar

material is present within the strata and has a thickness at least 1.75 times the maximum entry width, mining at a lesser cover than 5s or 10t may be considered.

2. For drifts or tunnels beneath or in the vicinity of a body of surface water driven through the strata for the purpose of gaining access to a seam, the provision of 10t or 5s should also apply unless the drifts or tunnels are permanently supported and are so maintained. In the latter event, however, there should be a minimum rock cover of 1.75 times the maximum drift or tunnel width.

Pillar Dimensions for First Workings

Pillars must be adequately designed in order to provide permanent support for the strata. The design will primarily depend on the depth of the seam, height of extraction, width of the entries, and the nature of overlying strata. The phenomena of sinkholes is generally associated with shallow cover and some particular types of strata. Thus, depending on the nature of strata, pillar design methods may be modified to prevent the formation of sinkholes. It is suggested that for the present, the empirical relation (Wardell, 1976) be used

$$[(W+s)/W]^2\ 1.5D=1000/t+20(W+t)^2$$

where W = pillar width
s = room width
t = seam thickness
D = depth from surface

until such time that other methods are generally accepted and validated.

Accordingly, the following guidelines are proposed for pillar dimensions for room and pillar first workings:

1. Where room and pillar first working is to be carried out beneath or in the vicinity of any body of surface water at cover depth greater than the stipulated minimum, the minimum width of pillar should be determined in accordance with Tables 1 through 7. If the minimum width of pillar is required for seam thicknesses other than those given in these tables, the width may be calculated using the above relationship. However, an exception can be made where specific local data (including relevant and comparable mining experience) exist which demonstrate that a lesser width could be used with safety.

Table 1 - Minimum Pillar Widths for Pillar Heights of 3 Feet, Feet

Depth, feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	12	13	14	-	-
150	15	16	16	17	18
200	17	18	19	20	20
250	19	20	21	22	22
300	20	21	22	23	24
350	22	23	24	25	26
400	23	24	25	26	27
450	25	26	27	28	29
500	26	27	28	28	30
550	27	28	29	30	31
600	28	28	30	31	32

Table 2 - Minimum Pillar Widths for Pillar Heights of 4 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	14	15	16	-	-
150	17	18	19	20	21
200	20	21	22	23	24
250	23	24	25	26	27
300	25	26	27	28	29
350	27	28	29	30	31
400	29	30	31	32	33
450	30	31	33	34	35
500	32	33	34	35	36
550	33	34	36	37	38
600	35	36	37	38	39

Table 3 - Minimum Pillar Widths for Pillar Heights of 6 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	17	19	20	-	-
150	22	24	25	26	27
200	26	28	29	30	32
250	30	31	33	34	35
300	33	35	36	37	38
350	36	37	39	40	41
400	39	40	41	43	44
450	41	42	44	45	46
500	43	45	46	47	48
550	45	47	48	49	51
600	47	49	50	51	53

Table 4 - Minimum Pillar Widths for Pillar Heights of 8 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	21	22	24	-	-
150	27	29	30	32	33
200	33	34	36	37	38
250	37	39	40	42	43
300	41	43	44	46	47
350	45	47	48	49	51
400	48	50	51	53	54
450	51	53	55	56	57
500	54	56	57	59	60
550	57	59	60	62	63
600	60	61	63	64	66

Table 5 - Minimum Pillar Widths for Pillar Heights of 10 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	24	26	27	-	-
150	32	34	35	37	38
200	39	40	42	43	45
250	44	46	48	49	51
300	49	51	53	54	56
350	54	56	57	59	60
400	58	60	61	63	64
450	62	64	65	67	68
500	66	67	69	70	72
550	69	71	72	74	75
600	72	74	76	77	79

Table 6 - Minimum Pillar Widths for Pillar Heights of 12 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	37	39	40	42	44
200	45	46	48	50	51
250	51	53	55	57	58
300	57	59	61	63	64
350	63	65	66	68	70
400	68	70	71	73	75
450	73	74	76	78	79
500	77	79	80	82	84
550	81	83	84	86	88
600	85	87	88	90	91
650	88	90	92	94	95
700	92	94	95	97	99
720	93	95	97	98	100

Table 7 - Minimum Pillar Widths for Pillar Heights of 14 Feet, Feet

Depth, Feet	Room Width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	41	43	45	47	48
200	51	53	54	56	58
250	58	60	62	64	66
300	66	67	69	71	73
350	72	74	76	77	79
400	78	80	81	83	85
450	83	85	87	88	90
500	88	90	92	93	95
550	93	95	96	98	100
600	97	99	101	103	104
650	102	103	105	107	108
700	106	107	109	111	113
750	109	111	113	115	116
800	113	115	116	119	120
840	116	118	120	121	123

2. Where an upper seam has been mined by room and pillar first working in accordance with these guidelines, underlying seams should not be mined by either total or partial extraction except by considering the upper seam as though it were the bottom of the surface body of water.

3. Where pillar widths are determined in accordance with these provisions, the calculated pillar loading should not exceed the determined load bearing capacity of either the immediate roof or floor beds.

4. Where the strata does not contain any competent rock bed, such as a sufficient thickness of hard sandstone, additional precautions shall be taken to prevent formation of sinkholes.

Panel and Pillar Method

The panel and pillar system is defined total extraction of a coal seam from panels of such width in relation to their depth that the main strata can span any one of them with little deflection. Individual extraction panels are separated by abutment pillars which are designed to be much wider than the minimum required for stability so that no additional subsidence for pillar failure need to be allowed.

The panels may be extracted by longwall or shortwall mining, or they may be first developed by the room and pillar method and the pillars may be subsequently totally extracted.

The following guidelines are recommended for panel and pillar mining beneath and in the vicinity of bodies of surface water:

1. Where mining by the panel and pillar method is to be carried out beneath or in the vicinity of any body of surface water, there should be a minimum strata cover thickness of 270 ft or 3p, where p is the width of the panel, whichever is greater.

2. The widths of extraction panels should not exceed one-third the depth of mining, and the widths of pillars between extraction panels should be 15 times their height or one-fifth the depth of mining, whichever is greater.

3. Where more than one seam is to be mined by this system, the panels and pillars in all seams should be superimposed in the vertical direction with the panel widths being determined from the depth

to the uppermost seam and the pillar widths being determined by reference to either the thickest or the deepest seam, whichever would give the greater dimensions.

4. Where the panel and pillar system of mining has been employed in an upper seam, mining a lower seam by total extraction may be carried out only by considering the upper seam the base of a body of surface water.

SECTION H. GUIDELINES FOR MAJOR POTENTIAL WATER BODIES

Total Extraction Mining

The following guidelines are recommended for total extraction below major potential sized water bodies:

1. Any single seam of coal beneath or in the vicinity of any body of surface water of major potential size may be totally extracted, whether by longwall mining or by pillar robbing provided that a minimum strata cover of a suitable nature exists between the proposed workings and the bottom of the body of surface water as given in Table 8.
2. Where more than one seam exist, all may be worked by total extraction provided that for the aggregate mineral and rock thickness of all seams to be extracted, a minimum thickness of cover as given in Table 8 exists between the proposed workings in the uppermost seam and the bottom of the body of surface water of major potential size.

Table 8 - Minimum Cover Required for Total Extraction Below Surface Water Bodies of Major Potential Size

Seam Thickness in ft t	Height of Disturbed Strata Above Seam		Aquiclude Zone Thickness I Minimum 20 ft clay		Aquiclude Zone Thickness II Minimum 75% shale		Aquiclude Zone Thickness III Shaley and Silty Sandstones		Aquiclude Zone Thickness IV 100% Limestones and Sandstones		Depth of Surface Cracks		Minimum Total Thickness of Cover I		Minimum Total Thickness of Cover II		Minimum Total Thickness of Cover III		Minimum Total Thickness of Cover IV	
	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t	ft	t
3	174	58	30	10	50	17	90	30	Special Investigations Required	Special Investigations Required	50	17	254	85	274	92	314	105	Special Investigations Required	Special Investigations Required
4	203	51	30	8	50	13	90	23			50	13	283	72	303	77	343	87		
5	226	45	30	6	50	10	90	18			50	10	316	61	326	65	366	73		
6	249	42	30	5	50	8	90	15			50	8	329	55	349	59	389	65		
7	269	38	30	4	50	7	90	13			50	7	349	49	369	52	409	58		
8	285	36	30	4	50	6	90	11			50	6	365	46	385	49	425	53		
9	305	34	30	3	50	6	90	10			50	6	385	43	405	45	445	50		
10	321	32	30	3	50	5	90	9			50	5	401	40	421	42	461	46		
11	352	32	30	3	50	5	90	8			50	5	432	39	452	41	492	45		
12	360	30	30	3	50	4	90	8			50	4	440	37	460	38	500	42		

3. An in-mine emergency sump shall be provided to receive the body of surface water of major potential size. The available water storage capacity of this sump shall not be less than the mine-life flood volume of the water body.

4. The maximum cumulative, calculated tensile strain beneath a body of surface water of major potential size shall nowhere exceed 15,000 $\mu\varepsilon$ as calculated by an approved method. The layouts of panels in the same seam or in different seams in case of multiple seam mining shall be planned accordingly. Strains shall be cumulated for each mining activity affecting an area, regardless of the intervening time.

5. Where a single seam has already been mined by total extraction in accordance with the minimum strata cover stipulations as given in Table 8, no other underlying seam may be mined by total extraction. The lower seam may be mined by partial extraction in accordance with

the guidelines stipulated for partial extraction considering the upper seam as the bottom of a body of surface water but, the pillars shall be designed to support the entire strata upto the surface including the water body.

6. Where unconsolidated natural or artificial deposits, which may be highly permeable or which when wet may flow, exist between the seam to be extracted and the bottom of a body of surface water, these should be excluded from the thickness of overlying strata except where it has been demonstrated that such deposits would not be likely to flow when wet and could be considered as impermeable.

7. Where a fault which might connect mine workings with a body of surface water and which has a vertical displacement greater than 10 ft, or an intrusive dike having a width greater than 10 ft, is known to exist or is met with during development, no seam should be totally extracted within 50 ft horizontally on either side of such fault or dike.

8. Where the gob is stowed by some method, the requirement of minimum strata cover may be reduced using a suitable approved subsidence factor which will be determined depending on the compressibility of the stowing material and the manner of stowing.

9. An operator shall be required to obtain a permit from the Coal Mine Safety District Manager for working beneath or in the vicinity of a body of surface water of major potential size where the minimum strata cover is provided in accordance with Table 8.

10. An application for such a permit shall be submitted in the prescribed form as given in Section F and shall include a water hazard map besides other general information, maps and sections as required under Section 75.1716 of the Code of Federal Regulations, Chaper 1 Title 30 (see Appendix B). The water hazard map shall specifically show the position and capacity of the emergency sump in relation to the water body, the likely water flow routes in the event of an inflow, the

specifications of structures like stoppings or overcasts which may be involved in channeling of the water flow or flows, a provision for the location of an emergency escape route if the likely water flow route interferes with regular escape routes, and profile sections of the escape and emergency escape routes in order to make sure that they are free from depressions likely to be filled.

Partial Extraction Mining

The same guidelines as for surface water bodies of catastrophic potential size shall be used for water bodies of major potential size.

SECTION I. GUIDELINES FOR LIMITED POTENTIAL WATER BODIES

Total Extraction Mining

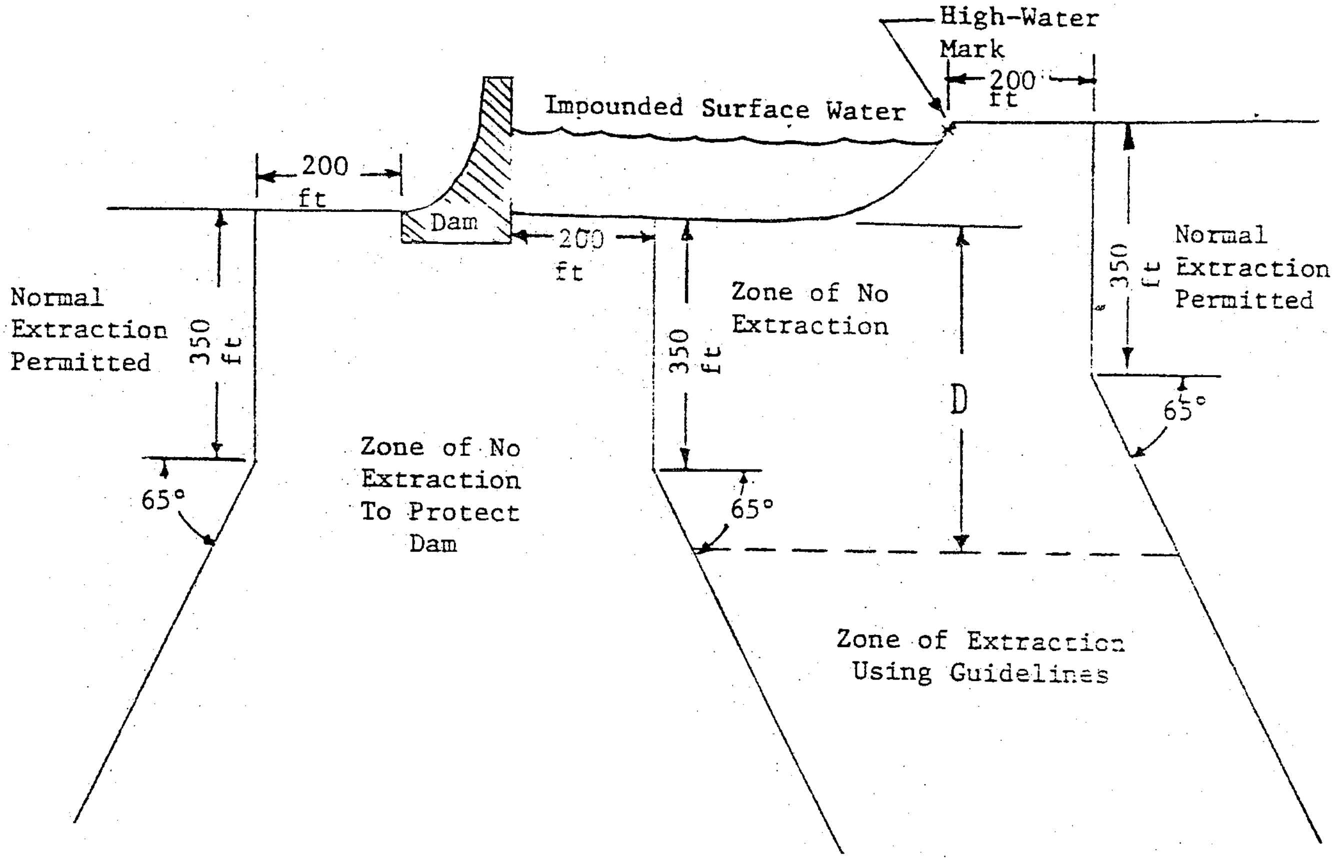
1. Where sufficient in-mine pumping capacity equivalent to the mine life flood discharge of all small surface streams affected is available, any number of seams may be totally extracted at any thickness of cover between the uppermost seam and the bottom of the surface water and at any thickness of parting between the seams.
2. Small non-flowing bodies of water may be undermined at any depth provided that the determined inflow rate and volume allow time of a person to wade through the water a distance equal to the longest blocked, dead-end, or blind entry to safety (whether in an entry in which the break-through occurs or in an entry in which the flow ponds) and ponded depth is everywhere 1.5 ft less than the mined height and not more than 4.5 ft total depth.

SECTION J. GUIDELINES FOR STRUCTURES RETAINING WATER

Structures Important to the Public Safety

The following guidelines are recommended for safety zones around and beneath structures, the survival of which is important to the public welfare:

1. Where any surface structure is impounding a body of surface water and damage to that structure by mine subsidence could lead to a risk of structural failure and prejudice to public safety, no mining should be permitted within the safety zone of such a structure.
2. The perimeter of the structure requiring protection should be established by those responsible for its maintenance and safety The safety zone around the perimeter of protection should extend outward 200 ft in all directions, then downward for 350 ft, and then outward at a dip of 65° from the horizontal as shown in Figure 1. This safety zone is designated as a zone of no extraction. Figure 1 also shows the restriction on mining beneath the impounded water.



D is Determined From the Following Table:

	D*
Room & Pillar	5s or 10t
Panel & Pillar	3p or 270 ft.
Total Extraction	60t

* Whichever Value is Larger

Figure 1 - Safety Zone Beneath Surface Structure Impounding Large Body of Surface Water (after Babcock and Hooker, 1977)

3. A greater or lesser distance than that specified in paragraph 2 may be used where local observations or experience so indicate.

Small Structures or Embankments Impounding Water

A Structure may be classified as small when:

- failure of the structure would not result in loss of life; in damage to homes; commercial or industrial buildings; main highways or railroads; in interruption of the use of service of public utilities; or damage other existing water impoundments; and
- the contributing drainage area does not exceed 200 acres; and
- the maximum vertical height of the dam or embankment as measured along the centerline of the embankment to the crest of the spillway does not exceed 15 ft; and
- the area of impounded water at the spillway level does not exceed 10 surface acres; and
- the structure conforms to all applicable laws and regulations pertaining to the storage of water.

The following guideline is recommended for working beneath and in the vicinity of small structures or embankments impounding water.

1. The mining of single or multiple seams by total or partial extraction methods may be undertaken beneath or in the vicinity of small structures or embankments impounding water in accordance with the guidelines recommended for other equivalent volume and flow surface water bodies.