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Mine Subsidence—Extent and Cost of Control in a Selected Area

By William Cochran

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MINE SUBSIDENCE–EXTENT AND COST OF CONTROL IN A SELECTED AREA

by

William Cochran[1]

ABSTRACT

The Bureau of Mines investigated mine subsidence caused by recent underground mining, estimated the extent of damages, and formulated a procedure for evaluating subsidence costs. On the basis of the quantity of material removed from beneath the surface, bituminous coal mining currently causes more extensive subsidence problems than mining of other minerals; costs are highest in areas such as western Pennsylvania where urban and suburban development and related types of land use conflict with mineral recovery.

The Bureau of Mines estimated subsidence costs, including surface damages and control costs, for a 12-county area in western Pennsylvania for 1968. Total surface damages attributable to the underground production of bituminous coal in the 1-year period were $295,000; in addition, 12.4 million tons of coal, valued at $4.3 million, was left in place to minimize potential surface damage. Of the total subsidence cost ($4.6 million), $2.7 million was classified as external or social costs, not reflected in the market value of bituminous coal; this averaged $0.05 per ton of production, or slightly less than 1 percent of the market value.

INTRODUCTION

The removal of a substantial quantity of underground materials creates a void which, under certain conditions, may result in subsidence at the surface. Subsidence begins as soon as sufficient material has been removed. The roof or overlying material falls into the mine void, and cracking and caving may then progress upward, at times reaching the surface. Subsidence at the surface may result in excessive damages in highly developed urban areas; other types of land use are usually less severly affected.

Subsidence losses are sometimes completely absorbed by the mineral industry as a production cost. However, in some instances costs are shifted to other parties or deferred for subsequent payment by the general public; an example is the anthracite region of Pennsylvania, where surface owners have absorbed much of the surface damages, and where the State and Federal

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Governments have assumed huge control costs in backfilling abandoned mines. Thus areas or persons not directly affected by physical damage may be affected by increased cost of minerals and goods, or through increased taxes. Therefore, it is important to evaluate the effects of surface subsidence and control procedures so that these costs may be considered in determining the real cost of a mineral commodity, and ultimately its availability.

The Bureau of Mines has long been concerned with subsurface subsidence as it is related to mine roof control and safety practices in underground mining. The Bureau has also conducted field studies on the rate and degree of surface subsidence caused by various types of mineral extraction. Recent work has included a wide range of research projects in rock mechanics and ground control technology. The Bureau has also become increasingly concerned with the environmental effects of mining and their ultimate effect on the Nation's natural resources.

This study had two objectives: The first was to appraise the extent and magnitude of the potential surface subsidence problem; the second was to present a preliminary procedure for evaluating major subsidence costs based on a study of a specific area and commodity. The report is basically concerned with the cost of mine subsidence; emphasis is placed on external or social costs, such as surface damages and control costs not included in the market value of the commodity.

ACKNOWLEDGMENTS

Although relatively few are cited in the text, numerous publications were reviewed to obtain background information on the surface effects of mine subsidence. Particularly noteworthy is an extensive series of bulletins published by the National Coal Board of England. The assistance of the Pennsylvania Bureau of Mine Subsidence and other government agencies is appreciated and hereby acknowledged. Helpful information was also supplied by individuals dealing in real estate and minerals, and by engineers with public utilities, the mining industry, and the construction industry.

CAUSE AND EFFECT OF SURFACE SUBSIDENCE

Underground mining of solid minerals such as coal, potash, metal ores, and other mineral commodities may under certain conditions cause surface subsidence; it may also be caused by the extraction of water and petroleum, and by solution mining of sulfur and salt.

Earth movements at the surface may result in many different types of damage. Building foundations and walls may be cracked and displaced. Railroad tracks may be pushed out of alinement. Highways may crack and deteriorate, or they may subside unevenly to create a roller coaster effect. Bridges may not properly meet the adjoining roadway. Water and gas lines may be ruptured. The flow of sewage lines may be reversed. Smoke stacks may be tilted, and other industrial equipment or plants sensitive to slope may be affected. Natural drainage may be obstructed or altered to form swamps. Structural failure may be induced in dams. Water channels such as canals may be rendered useless, and ground water supplies may be lost through subsidence-induced fracturing of the overburden. However, the presence of such damage does not always indicate mine subsidence; poor construction practices and natural subsidence often have similar effects on surface features.

Factors Contributing to Subsidence

There is an abundance of literature concerning the technology of mine subsidence. A large part of this is concerned with subsidence caused by coal production; however, much of the basic research that has been reported is applicable to minerals other than coal, as well as to different extraction procedures. In some cases, the production of water or petroleum may cause subsidence damage similar to that resulting from mining solid minerals.

Methods have been advanced for estimating the amount of surface subsidence that will occur under various conditions. Basic factors are concerned with the physical aspects of the void created by mining. These include the following:

1. Vertical dimension, or height of void.

2. Lateral dimensions, or length and width of void.

3. Depth below the surface.

Other factors which affect the amount and manner of surface subsidence include the following:

1. Characteristics of the overburden, including faults, joints, and lithology.

2. Size, character, and distribution of support pillars.

3. Amount and method of backfill.

4. Surface topography.

5. Effect of ground water on subsurface rock movement.

Research by the National Coal Board in England, the Bureau of Mines, the Pennsylvania Bureau of Mine Subsidence, and numerous other agencies and individuals has indicated that all of the aforementioned factors contribute to the amount or manner of surface subsidence. The effects of depth and dimensions of a void as well as the effect of backfilling have been established, but difficulty has been encountered in determining a quantitative relationship for other factors.

Factors Determining Degree of Surface Damage

Surface damage is not synonymous with surface subsidence. Although subsidence may be the underlying cause, other factors determine the amount of resulting surface damage. The severity of surface damage is largely dependent on the nature of the surface improvements as well as on the magnitude of subsidence forces affecting the property.

A uniform vertical lowering of the land surface may be accomplished with a minimum of damage in the central part of a large area of subsidence. This is possible even where surface structures are present, although problems may arise with reverse sewage flow and surface drainage. When the surface is lowered with a sideways movement, which is a common effect near the periphery of a subsidence basin, lateral tensile and compressive forces develop. These forces may be large enough to cause severe damage to surface improvements; or they may be small enough, or applied for such a brief period, that no damage results. In general, lateral stresses result in more severe damage than vertical movement, and they are most intense at the periphery of a subsidence area. Structures attached firmly to the ground are likely to be most affected. Large structures are more susceptible to damage than small structures; masonry structures are also more susceptible to damage than wood or metal structures.

In many cases, underground mineral extraction in urban areas has resulted in significant subsidence damages, whereas a similar operation in a rural area has had only minor effects on surface values. Under a simple land classification, less than 10 percent of the Nation's land surface is urban.[2] This affords some perspective to the potential extent of the subsidence problem and suggests a simple but often impractical solution--prohibit mining in or near urban areas. However, it is necessary to consider that much of the Nation's mineral resources is concentrated in certain areas, that production is limited to these source areas, and that in many instances mineral occurrence has been the prime factor in the development of population centers. Actually, it may be in the best interest of some areas as well as the Nation to restrict surface development where past or prospective mining development is expected to result in surface subsidence.

OPPORTUNITIES TO CONTROL THE EFFECTS OF SUBSIDENCE

Although there is no simple or universal solution to all of the problems caused by mine subsidence, various means are available to control surface damages and minimize costs where mining is being considered. The optimum control for a specific situation involves two levels of decision. The first consideration is essentially dependent on mineral demand and leads to a choice among the following alternatives (fig. 1):

1. Sterilized resource--This is a commonly used term in British coalfields which refers to the part of a seam which, for various reasons, is not mined. The term has been used in this report to refer to all minerals which are left for surface support rather than recovered for their mineral value. Sterilization of the total resource is obviously the most effective form of subsidence damage control--when no mining occurs, there can be no "mine subsidence."

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[2] Barlowe, Raleigh. Land Resource Economics, The Political Economy of Rural and Urban Land Use. Prentice-Hall, Inc., New York, 1958, 585 pp.

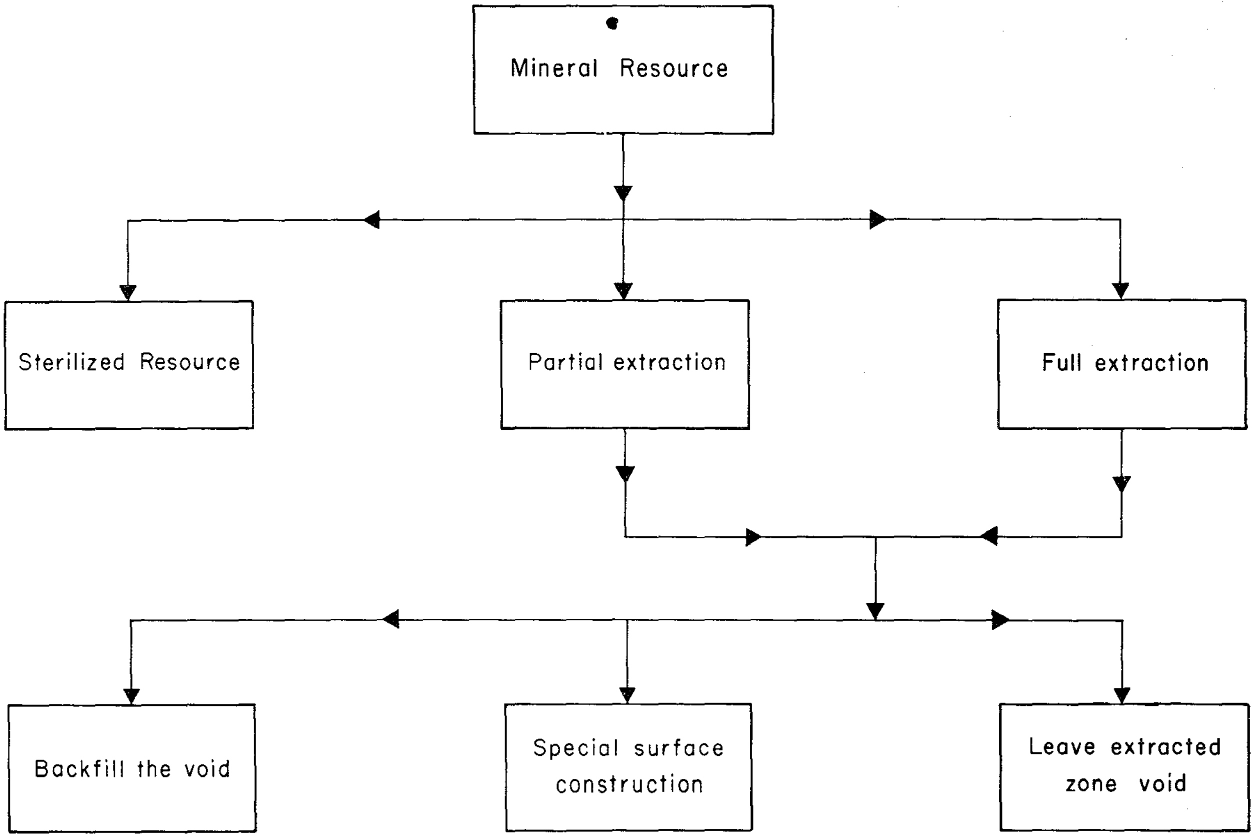

FIGURE 1. - Schematic Diagram of Alternatives to Control Effects of Mine Subsidence.

2. Full extraction--This is the opposite of sterilization as far as mineral production and surface control are concerned. In full extraction, attempts are made to achieve maximum mineral recovery, and without other controls maximum surface damage usually results.

3. Partial extraction--Part of the mineral resource is left underground so as to control subsidence and limit surface damage.

A secondary level of decision is concerned with other means of controlling surface damage which may result from subsidence if the mineral is extracted. These include the following:

1. Backfill the void--A void created by the extraction of minerals may be filled with mine waste or other materials to limit subsequent surface damage. Such procedures may reduce surface subsidence up to 50 percent, but usually at a high cost.[3]

[3] Orchard, R. J. Surface Subsidence Resulting From Alternative Treatments of Colliery Goaf. Colliery Engineering, v. 41, October 1964, p. 429.

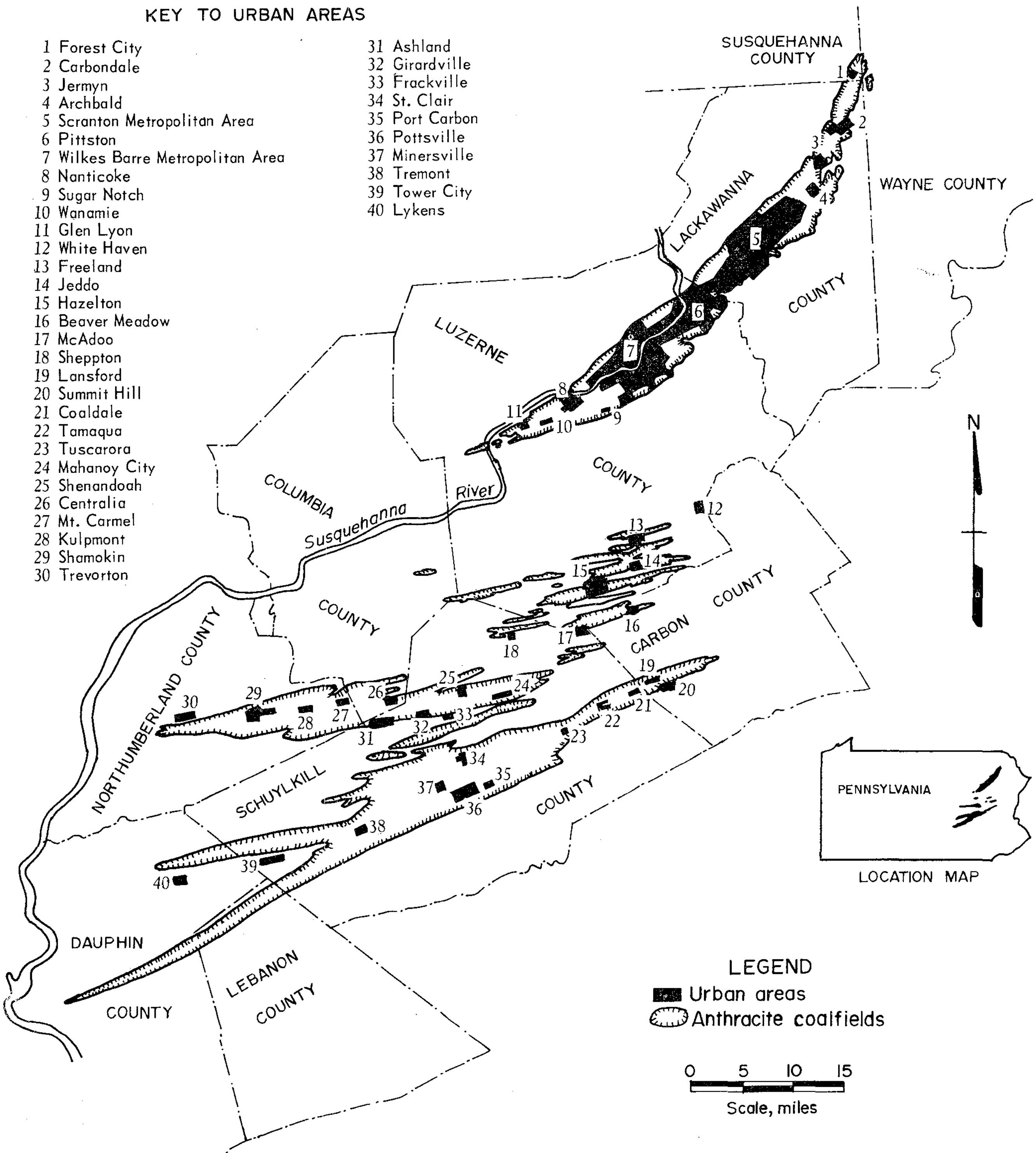

FIGURE 2. - Anthracite Coalfields and Urban Development.

2. Special surface construction--Various construction techniques may be implemented to minimize subsidence damage to surface structures. These include simple design criteria, such as small structures or flexible large ones, reinforced foundations, and leveling devices.

3. Leave the extracted zone void--No control measures are used within the productive zone other than possibly limiting recovery. The void and possible subsidence are left to natural reactions.

It is obvious that these alternatives are applicable in considering production of solid minerals, but they may also be applied to the extraction of liquids from subsurface reservoirs and to solution mining.

EXTENT OF POTENTIAL SUBSIDENCE

Potential surface subsidence exists to some degree in all areas where minerals have been or are capable of being mined. These areas undelie a large portion of the Nation, but most of the reported damage has been in areas producing anthracite and bituminous coal, zinc, iron, copper, and petroleum. Even so, the problems related to past mining in these areas are not always indicative of the amount of damage expected from present or future mining. Production methods and policies have changed. In some areas, restrictions controlling subsidence have been imposed on mine operators. Furthermore, some mineral deposits have been depleted or production has become uneconomical. Such a situation exists in the anthracite coalfields.

Subsidence in the anthracite-producing region of eastern Pennsylvania has been a costly aftermath of 150 years of mining. Over 5 billion tons of anthracite have been mined, primarily by underground methods. Large undermined segments of the coalfields coincide with urban development (fig. 2). Subsidence damages resulting from past mining in these areas and the cost of future subsidence control are extreme. Eleven recent backfilling projects in abandoned mines have cost over $7 million, and this type of control will apparently be continued for many years. Nevertheless, subsidence costs from present and future anthracite operations will probably not reach the proportions caused by past mining. Underground production has declined from a peak of 90 million tons in 1917, to 23 million tons in 1950, and to 2.5 million tons in 1968 (fig. 3). While reduction in underground production alone would tend to minimize future problems, the State has imposed industry controls to further limit surface damages. Legislation enacted in 1961 regulates the mining of anthracite under dwellings, public buildings, and certain other facilities.

Determination of the effect of subsidence on the Nation's supply of a particular mineral commodity would require an evaluation of all factors currently controlling subsidence and surface damage for each mining region and mineral deposit. Such an appraisal is beyond the scope of this report, but relevant data have been assembled in tables 1 and 2 which provide means for making a preliminary appraisal of the problem.

Although no single criterion is available to measure potential subsidence damage, a basic factor is the quantity of material removed by underground mining. When this is considered along with knowledge of surface development and land use in the major producing areas, the extent and characteristics of mineral deposits, and the Nation's reliance on underground sources, it is possible to make some judgments concerning the magnitude of subsidence costs. Tables 1 and 2 show the commodities and sections of the Nation most likely to be affected by underground mining and subsidence problems.

TABLE 1. - Underground mining, by commodity, 1968[1] (thousand tons)

Principal commodity	Total material removed[2]	Coal or crude ore		States with major underground production (in order of total material removed)
		Quantity	Percent of total production[3]	
Coal:				
Bituminous.....	[4]441,200	[5]344,142	63	W. Va., Ky., Pa., Ill.
Anthracite.....	[4]3,100	[5]2,450	21	Pa.
Stone............	38,978	38,712	4	Mo., Ky., Pa., Ohio.
Salt.............	35,978	35,752	87	La., Tex., N.Y., Ohio, Mich.
Copper...........	22,439	21,976	13	Ariz., Mich., Tenn.
Potassium salts..	17,044	16,899	100	N. Mex., Utah.
Iron.............	16,808	14,300	7	Mich., Pa., Mo., Ala., N.Y.
Molybdenum.......	16,515	16,454	78	Colo.
Zinc.............	12,719	10,968	99	Tenn., Va., Colo., Wis., N.Y., Pa.
Lead.............	8,393	7,799	100	Mo., Idaho, Utah.
Sulfur...........	8,353	8,353	100	La., Tex.
Uranium..........	5,011	3,729	63	Colo., N. Mex., Wyo.
Sodium carbonate (natural).	3,213	3,197	100	Wyo.
Gypsum...........	2,483	2,403	23	Ind., N.Y., Kans., Mich., Ohio.
Gold.............	2,370	2,203	19	S. Dak.
Clay.............	1,255	1,235	2	Pa., Ohio, W. Va.
Phosphate rock...	1,243	1,236	1	Mont., Utah.
Silver...........	969	756	95	Idaho, Colo., Mont.
Fluorspar........	708	701	94	Ill., Colo., Ky.
Tungsten.........	544	504	94	Calif.
Talc, soapstone, pyrophyllite.	531	507	51	Vt., N.Y., Calif.
Asbestos.........	429	39	2	Ariz.
Barite...........	129	127	2	Ark.
Others[6].........	403	343	2	-

[1] Excludes production of petroleum.
[2] Includes underground mine waste.
[3] Total production includes crude ore from surface mining.
[4] Estimated, based on 22-percent waste at preparation plants.
[5] Cleaned marketable coal.
[6] Includes mercury, wollastonite, tripoli, mica, feldspar, pumice, and perlite.

Source: Bureau of Mines, Minerals Yearbook, 1968.

TABLE 2. - Underground mining, by State, 1968[1] (thousand tons)

State	Population per square mile[2]	Total material removed[3]	Major commodities produced (in order of output)
West Virginia...	75	167,488	Coal, stone, clay.
Kentucky........	80	85,993	Coal, stone, zinc, fluorspar.
Pennsylvania....	258	82,715	Coal, iron, stone, zinc, clay.
Virginia........	114	43,295	Coal, stone, zinc, gypsum.
Illinois........	195	36,758	Coal, stone, fluorspar, zinc, clay.
Ohio............	255	29,254	Coal, salt, stone, clay, gypsum.
Colorado........	19	24,104	Coal, molybdenum, uranium, zinc, silver.
New Mexico......	8	19,596	Coal, potash salt, uranium, copper, zinc.
Missouri........	67	18,746	Stone, lead, iron.
Michigan........	151	17,330	Copper, iron, salt, gypsum.
Louisiana.......	81	15,345	Salt, sulfur.
Tennessee.......	94	14,390	Zinc, coal, copper, stone.
Alabama.........	70	14,325	Coal, iron, salt.
Arizona.........	14	12,936	Copper, asbestos, zinc.
Texas...........	41	12,098	Salt, sulfur, stone.
Utah............	12	9,057	Coal, potash salt, phosphate rock, lead, uranium, zinc, gold.
New York........	383	7,656	Salt, iron, zinc, gypsum, talc, wollastonite.
Wyoming.........	3	4,860	Sodium carbonate, iron, uranium, stone, coal.
Indiana.........	138	3,952	Coal, gypsum, stone.
Kansas..........	28	2,997	Stone, salt, gypsum, zinc.
Iowa............	49	2,322	Stone, coal, gypsum.
South Dakota....	9	2,141	Gold.
California......	122	1,969	Stone, tungsten, talc.
Idaho...........	9	1,938	Silver, lead, zinc.
Oklahoma........	36	1,623	Stone, zinc, copper.
Georgia.........	78	1,094	Stone.
Wisconsin.......	77	968	Zinc.
Arkansas........	38	929	Stone, zinc, barite.
Montana.........	5	921	Phosphate rock.
Washington......	46	704	Zinc, lead.
Maryland........	372	658	Coal, stone.
Vermont.........	45	247	Talc.
Nebraska........	19	194	Stone.
Nevada..........	4	179	Copper.
New Jersey......	930	162	Zinc.
Oregon..........	21	40	Mercury.
North Carolina..	103	10	Talc.
Minnesota.......	45	7	Iron.

[1]Excludes petroleum.
[2]Bureau of Census, Current Population Reports, 1967.
[3]Bureau of Mines, Minerals Yearbook, 1968. Includes coal production and estimated volume of preparation plant waste.

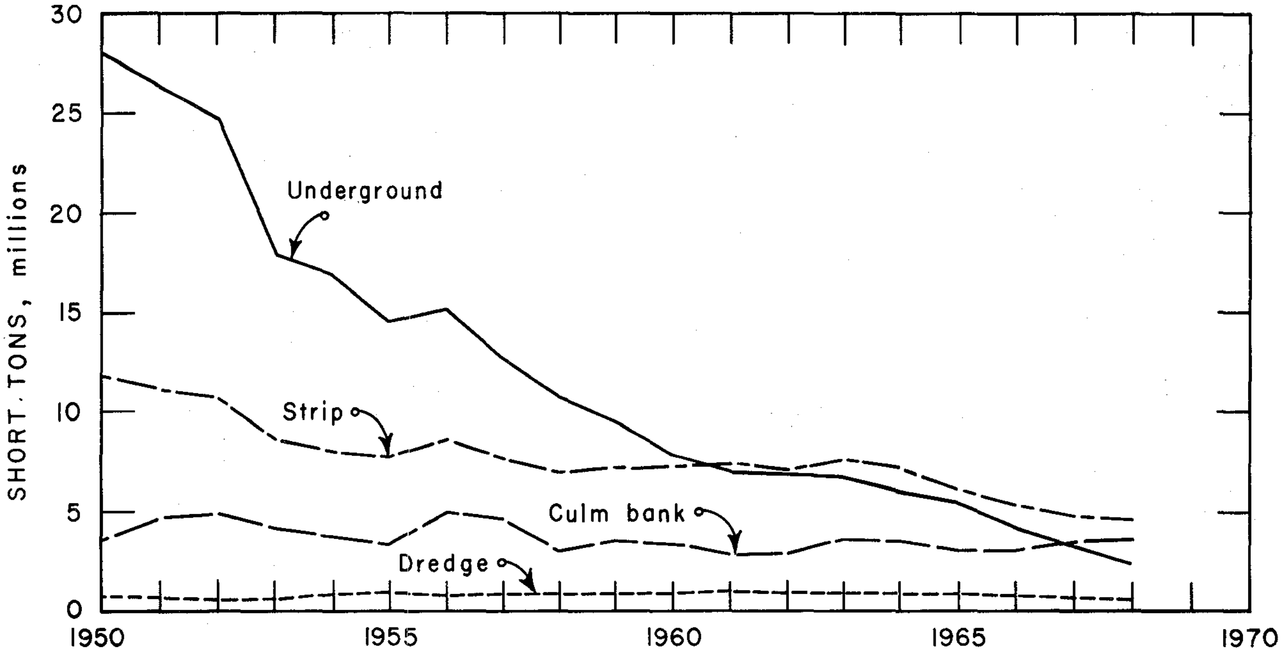

FIGURE 3. - Production of Pennsylvania Anthracite, by Mining Method, 1950-68.

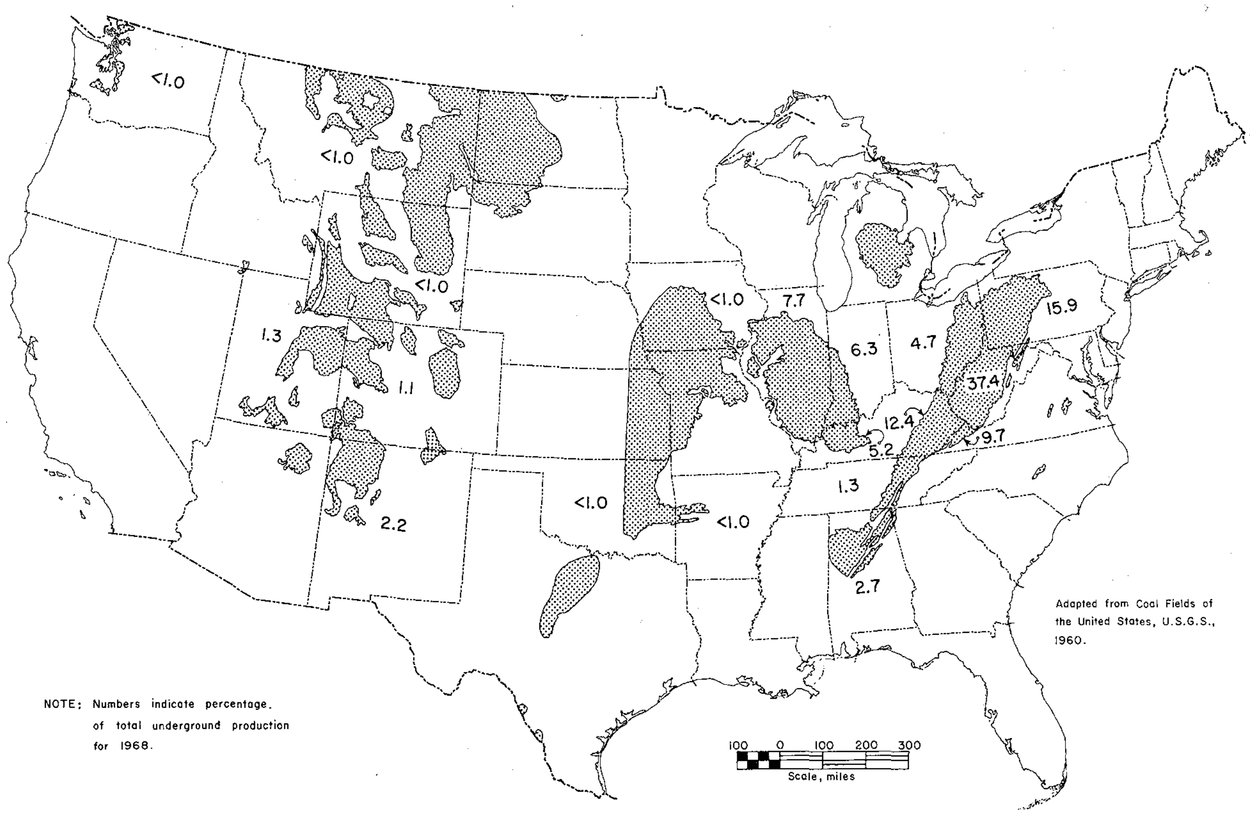

FIGURE 4. - Major Occurrences of Bituminous Coal and Lignite.

Bituminous coal is the most obvious example of a commodity with potential subsidence problems. It accounted for more than two-thirds of the total quantity of material removed by underground mining in 1968. In addition, underground mining accounted for nearly two-thirds of the Nation's total bituminous coal supply. Part of the underground supply involved widespread mining in moderately populated areas where subsidence damages and control costs could ultimately affect the availability of coal (fig. 4). Such subsidence costs for a specific area are examined in more detail in the following sections.

EVALUATION OF MINE SUBSIDENCE COSTS IN WESTERN PENNSYLVANIA

This section of the report examines the major costs of mine subsidence in a specific area. It contains estimates of subsidence costs for 1968 which may be used to evaluate the potential effect of subsidence on mineral supply. Such information will be helpful in determining the real cost of production so that it may be compared on a common basis with that of production from other areas or even with that of substitute minerals.

Surface damages and damage control costs were estimated for alternatives considered technically feasible under specific conditions in a major bituminous coal producing area. This information was used to evaluate alternatives and estimate the major subsidence-related social costs of mining within a particular area for the year 1968.

The area selected for study is a 12-county bituminous coal-producing region in western Pennsylvania, as indicated in figure 5. It includes most of the State's bituminous coal resources, which exceed 57 billion tons[4] and are sufficient to sustain production at the current rate for nearly 400 years. Coal from this area has been and continues to be an important segment of the local and the national economies. In 1968, 248 underground mines in the study area produced 54 million tons of coal. This was 99 percent of the State's and 15 percent of the Nation's underground bituminous coal production. The western Pennsylvania region contains many highly urbanized areas and has a history of subsidence incidents resulting from the mining of bituminous coal. It is therefore an ideal area in which to examine the possible effects of mine subsidence on coal supply.

Limitations of Data and Study Method

Subsidence damages and control costs are dependent on numerous factors, such as local geologic conditions, land surface utilization, and mining procedures, all of which vary from one area to another. The method employed in this study was to collect or estimate major subsidence costs for possible alternatives under various conditions within the study area; these costs were then used to approximate the total cost of subsidence in the entire area for 1968. Since many assumptions were necessary and since much of the data was generalized, discretion should be used in applying the data or conclusions to other areas, or to isolated segments of the study area.

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[4]Averitt, Paul. Coal Resources of the United States, January 1967. Geological Survey Bulletin 1275, 1969, p. 9.

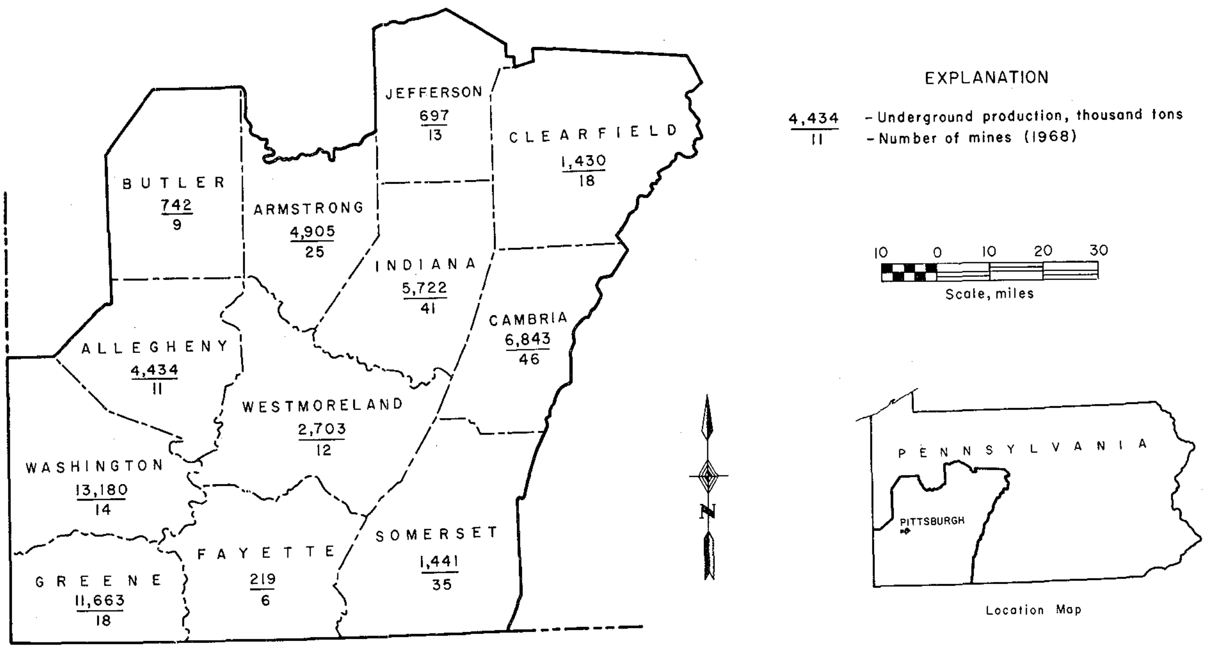

FIGURE 5. - Study Area.

Subsidence Damage and Control Costs

For the most part detailed information on subsidence damage and control costs is not available. Comprehensive records have not been kept on the degree or the frequency of damage. Until recent years, no public record of mine information which could be coordinated with information on land use was maintained. Some control procedures for which data are available have not been applied under conditions similar to those in the study area. Furthermore, the ultimate effectiveness of control procedures is questionable, except where blocks of coal are sterilized. Therefore, it has been necessary to rely on limited data and estimates to generate information necessary to evaluate the effects of subsidence. Derivation of major cost items is discussed in the following sections.

Surface Damage

The most prevalent problems resulting from mine subsidence in the study area are damages to houses and farmland. Except for occasional incidents, damage to other surface facilities has been minor. It has been limited through regulation in the case of public property, or through the purchase of sufficient support coal (solid blocks or pillars of coal to support the overburden and surface improvements) in the case of most commercial and industrial property.

The Pennsylvania Bureau of Mine Subsidence and Land Conservation has maintained records on house damage since 1966. Data through 1968 indicate that 5,500 houses were involved with mining and possible subsidence damage.[5]

[5]Cortis, Samuel E. Coal Mining and Protection of Surface Structures are Compatible. Secretary's Report, Pennsylvania Dept. of Mines and Mineral Industries, July 1969, p. 7.

Virtually all of these houses were protected by a 1966 State subsidence law which in effect limited coal operations to a plan of 50-percent extraction under protected dwellings. Of the total number of houses undermined through 1968, 60 were damaged--an incidence of slightly more than 1 percent. Because of the relatively short period in which damages were recorded, some additional damage might be expected. During 1957-66, a major coal producer in western Pennsylvania provided similar underground protection against surface damage. This operator recorded a damage incidence of approximately 2 percent.[6]

For each of the 60 houses damaged during 1966-68, the amount of damage ranged from $250 to $15,000. Total market value of 47 of these homes prior to being undermined was $774,000 (including estimated land value of $4,000 per house). The total damage to these properties was $121,000. If the damage rate of 15.6 percent is combined with a 2-percent incidence, the result is a damage factor of 0.3 percent of surface property value for 50-percent extraction under houses.

Data are inadequate to determine the potential amount and incidence of house damage over areas of complete extraction, because full recovery methods generally have not been used under residential areas. A few isolated incidents for which damage information is available indicates that the average amount of damage to a house is similar to that in partially extracted areas, but that the expected frequency of damage is higher. Experienced mining people have indicated that the rate of incidence could be as high as 90 to 100 percent of the structures undermined, based on current conditions and procedures in the study area. Thus, a damage factor for complete extraction under residential areas conceivably could be 15.6 percent of the surface value.

Potential subsidence damage for urban-nonresidential areas (industrial-commercial property) is even more difficult to estimate. Mining is usually not conducted in these areas, and little or no subsidence data are available. However, even with a crude value for expected damage (based on the same damage factor used in residential areas), the principle of not mining can be weighed against other alternatives.

Since much current underground mining occurs outside urban areas, it is necessary to consider the effect of mine subsidence on farms and other rural acreage. This land may be classified according to use as cropland, with highest value; grazing land, with a lesser value; and forest and unused land, with least value. In the study area, forest land has not been adversely affected by mine subsidence. Damage to cropland has generally been limited to local depressions or cracks in the surface which can be either accommodated or corrected at nominal cost. However, land which has been undermined may incur a loss of ground water supply. Although this has little effect on forest land or cropland, it does have an impact on land used for grazing. Livestock farms may suddenly lose their supply of water from wells, springs, and ponds. Depending on many factors, the loss may be permanent or the supply may return over an indefinite period. The loss of ground water presents two alternatives.

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[6]Vandale, August E. Subsidence--A Real or Imaginary Problem. Min Eng., v. 19, September 1967, pp. 86-88.

One is to acquire another source--drill deeper wells, build reservoirs to store surface runoff, or transport water from another area. The other alternative is to let the land revert to a lower form of development--forest or unused land--with a resultant loss in value. In 1968, average grazing land in western Pennsylvania was valued at about $140 per acre and unused land at about $70 per acre. Thus, grazing land reverting to unused land involved a subsidence loss of $70 per acre.

Mineral Value

Coal left in the ground for the specific purpose of preventing or controlling surface damage is a subsidence cost. The cost, or loss, is sometimes imposed on the mineral owner through prohibition or restriction of mining in a particular area; the party absorbing the loss could be either a mine operator or simply a property owner of subsurface minerals. Under other circumstances the loss may be transferred by contractual arrangement from the mineral owner to the surface owner, either private or public. This occurs when coal is purchased by the surface owner to be left in the ground for support of a building, highway, or other facility. The cost of such subsidence control depends on the in-ground value of coal. The following is concerned primarily with establishing a basis for determining this cost.

An undeveloped seam of coal has occasionally been purchased for as little as $10 per acre when acquired for mining in the distant future. On the other hand, payments of $1,500 per acre are not uncommon for small blocks of coal which are essential for a continuous and orderly mining operation. Most coal is purchased at a price between these extremes. Based on an average seam (5.3 feet thick in Pennsylvania),[7] with 9,540 tons of coal in place per acre, in-place values range from $0.001 to $0.157 per ton, but these figures do not generally reflect the value at the time decisions are made regarding subsidence control.

Another in-ground value of coal has been established by mine operators transferring all or part of a block of minable coal to the landowner for surface support. The value at this point reflects not only acquisition costs but a portion of mine development costs which will not be utilized. Much of the coal acquired for surface support is obtained at this stage--just prior to actual mining in an area. Such exchanges have generally been made at the rate of $0.35 per ton of coal left in place under residential areas. However, owners of commercial properties negotiate under different circumstances and may pay considerably more for support coal than do homeowners.

In-place coal is purchased by the Pennsylvania Department of Highways where it is deemed necessary to prevent future damage to newly constructed roadways. In 1968 about 450,000 tons of coal were purchased in the study area; costs ranged $0.09 to $0.50 per ton, with an average cost of about $0.35.

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[7] Young, W. H. Thickness of Bituminous Coal and Lignite Seams Mined in 1965. BuMines Inf. Circ. 8345, 1967, p. 5.

It is apparent that in-place coal has a broad range of values which are related to the state of resource development. Subsidence control costs might be reduced through long-range planning of surface development and early acquisition of coal necessary to support the surface.

Additional Costs of Backfilling

Backfilling of mine voids as a phase of active mining to control surface subsidence is not commonly practiced in the bituminous coal areas of the Nation. It is a common procedure in some foreign countries with more limited coal resources. In a typical operation in England during 1963, backfill costs for solid stowing were 11.5 percent of the cost of production. The cost of hydraulic stowing in Poland in 1958 was about 5 percent of the cost of production.[8]

Hydraulic backfilling is conducted in some underground metal mines in the Western States. Although it may result in subsidence control, it is used primarily as an aid in mining--to control rock bursts, to permit recovery of pillars, and to aid in stoping. Hydraulic backfilling has also been used to control surface subsidence in areas with inadequate pillar support in the anthracite region of eastern Pennsylvania. Most of the backfilling in the abandoned anthracite mines has been done since mining was terminated. Costs were therefore higher than they would have been if backfilling had been done concurrently with mining.

Costs were estimated by the Bureau of Mines for backfilling a typical 1-million-ton-per-year bituminous coal mine in western Pennsylvania (appendix A). A hydraulic system was selected because other methods of backfilling are generally more costly and less effective in terms of surface control. Using readily available refuse from a coal preparation plant and returning it to a mine by hydraulic means would cost an estimated $0.59 per ton of material placed, but this cost includes waste disposal as well as subsidence control. The portion attributable to subsidence control depends on the difference between the cost of backfilling and the cost of customary surface disposal of waste material. Surface disposal costs were estimated at about $0.27 per ton for coal mines in the southern Appalachian region.[9] Assuming these costs to be applicable to Pennsylvania mines, the implementation of hydraulic backfilling for subsidence control would result in an additional operating expense of $0.32 ($0.59 less $0.27) per ton of preparation plant waste.

The Bureau of Mines estimates that the volume of preparation plant refuse is sufficient to backfill only 25 percent of a mine void in the study area. It is possible that fill could be limited to selected areas within a mine where surface support is essential. If the remaining 75 percent of the void were filled, it would be necessary to acquire additional material. Under some circumstances, material acquisition costs may be prohibitive, but it is possible that industrial or municipal solid waste may be available at no cost or

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[8] Page 431 of work cited in footnote 3.

[9] Danielson, V. A., and D. H. White, Jr. Waste Disposal Costs at Two Coal Mines in Kentucky and Alabama. BuMines Inf. Circ. 8406, 1969, p. 26.

perhaps as a credit to the backfilling operation, provided backfilling could be coordinated with a waste disposal problem. On this basis, the weighted average additional cost of backfilling the entire mine is estimated at $0.52 per ton, which should be adjusted by the cost (or credit) of acquiring necessary fill material.

Additional Costs of Surface Construction

Special materials and methods of construction, such as rigid foundations or flexible structures, are not generally used in western Pennsylvania as a means of controlling future subsidence damage. Therefore, the cost and effectiveness of such procedures under conditions occurring in western Pennsylvania are not known. However, basic designs have been tested in coal mining areas of England, as well as in areas of poor foundation soils in the United States. They have been found technically feasible, although not always economically acceptable.

The additional construction costs for medium- and large-size structures, such as warehouses, schools, and office buildings, are not easily established since structural precautions can involve major revisions in design which may or may not have a great impact on the cost of the structure. Additional construction costs for small buildings or houses are easier to estimate and have broader application. These costs usually involve reinforcing the foundation. The additional cost will vary with the type, size, and configuration of the foundation.

One procedure used in England is to build a house on a raft of reinforced concrete. The slab acts as a foundation as well as the ground floor. A typical slab would consist of 6 inches of reinforced concrete overlying a 6-inch bed of friable material, such as sand, with a layer of waterproof paper separating the concrete and the sand. This type of construction would eliminate the effects of subsidence caused by horizontal stresses, but would not eliminate all damage from differential vertical movement. The cost of this type of construction would add an estimated 4 percent to the purchase price of the average new house constructed in western Pennsylvania.

A more complex type of foundation is the ribbed raft--a reinforced slab with reinforced ribs or beams in opposite directions for complete rigidity. This type of foundation has been used effectively in mining areas of England as well as in areas of poor foundation soils in the United States. Such construction would cost significantly more than a simple reinforced slab but could eliminate essentially all subsidence damage to the structure. For the most common type of home constructed in the study area (a two-story, brick colonial valued at $25,000), the additional construction cost would increase the purchase price an estimated 7 percent (appendix B). One disadvantage in this type of foundation is that to be effective it should not be located within the ground, but as near the surface as possible. In many instances this would require some adjustment of current construction practices.

Additional Costs of Transportation

Coal resources lost through partial mining or complete sterilization are replaced in the market by coal from other sources. This can result in an increased transportation cost which is dependent on the distance between the lost resource and the next nearest source. National average cost of rail transportation for bituminous coal is about $0.01 per ton-mile with the average length of haul nearly 300 miles.[10] Small units of sterilized coal probably would have no appreciable effect on transportation costs, but the additional cost would become significant if large areas of coal resources were sterilized, requiring several additional miles of transport to acquire an alternate supply.

Other Subsidence Costs

Public utilities are occasionally affected by mine subsidence. Gas transmission lines have accounted for most of the reported damage. Gas utilities in the western Pennsylvania region estimate an average of 10 incidents each year; the average cost of repair in each case in 1968 was about $2,000. This involved repairing breaks in lines, burying lines exposed by surface subsidence, and reducing stress on surface equipment.

Subsidence costs related to highways include surface damages and cost of support coal. Under existing State regulations the mine operator is generally responsible for damages to existing highways. However, if mining occurred many years prior to the surface damage and if liability cannot be established, the State absorbs the cost of repair. Repair costs were estimated by highway department officials at about $10,000 for 1968 in western Pennsylvania. In areas of new construction where mining is anticipated within 6 years, the State Highway Department determines potential subsidence damage and decides on that basis whether to purchase support coal from the mineral owner or to permit mining without restriction; in either case, the State assumes responsibility for subsidence costs.

Evaluation of Alternatives

Based on the foregoing discussion, subsidence costs were estimated for seven alternatives applicable to minable coal under each of four major land-use classes. Costs were limited to those directly affecting a particular alternative; they do not include damages or costs of preventive measures which may result from a postmining change in land use, such as future urbanization of previously mined-out rural areas. In addition, it was necessary to employ the following limits in estimating direct costs of subsidence:

1. Mining was limited to a single seam at an average depth of 300 to 400 feet.

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[10]National Coal Association. Bituminous Coal Facts. Washington, D.C., 1968, p. 96.

2. Partial extraction was limited to a mining plan which leaves 50 percent of the coal in place as pillar support for the surface.

3. Surface damage could be reduced at the same rate as surface subsidence (about 50 percent) by hydraulic backfilling.[11]

4. Surface damage could be reduced nearly 100 percent with adequate construction procedures.

Benefits used in the evaluation are dependent on estimated subsidence damages and control costs. For example, increased coal recovery or a reduction in surface damages as a result of a particular control measure is a benefit for that alternative.

Tables 3-6 show the estimated subsidence damages, control costs, and resulting benefits for each alternative. The tables indicate, through a benefit-to-cost relationship, the optimum alternative for utilizing coal resources under different conditions of surface use in western Pennsylvania. The indicated optimum alternatives are currently in general practice throughout the study area. These include partial extraction under residential areas, sterilization of coal under urban-nonresidential areas, and complete extraction where operationally feasible in rural areas. Estimated average costs for these situations were as follows:

Land use	Subsidence cost per acre
Industrial-commercial..........	$3,340.00
Residential....................	1,860.00
Grazing........................	70.00
Other rural....................	-

Total Subsidence Cost in Western Pennsylvania

On the basis of volume of coal produced, an estimated 9,900 acres of land were undermined during 1968. In order to estimate subsidence costs in the area, it is necessary to know under what surface conditions the coal was produced. Such information is not readily available. Therefore, an estimate of total subsidence costs was made on the basis of the following assumptions:

1. Without subsidence controls (legislative, self-imposed by industry, or privately negotiated), coal mining in the study area would have progressed on a random basis with no regard for surface land use.

2. All coal was produced by single seam mining with the following limitations:

Industrial-commercial areas--no mining.
Residential areas--50-percent extraction with planned pillar support.
Grazing and other rural land--complete extraction.

[11] Page 429 of work cited in footnote 3.

TABLE 3. - Effects of alternative methods of subsidence control--industrial-commercial area

(Bituminous coal mining--western Pennsylvania)

Alternative	Estimated benefits per acre		Estimated costs per acre				Benefit-cost ratio
	Mineral mined[1]	Surface damage avoided[2]	Mineral loss[1]	Surface damage[2]	Backfill[3]	Surface construction[4]	
Sterilized resource.........	-	$46,800	$3,340	-	-	-	14.0
Full extraction, surface construction..............	$3,340	46,800	-	-	-	$21,000	2.4
Full extraction, backfill...	3,340	[5]23,400	-	[6]$23,400	$4,500	-	1.0
Full extraction, leave mine void......................	3,340	-	-	46,800	-	-	.07

[1]Maximum value ($3,340) based on 5.3-foot seam with in-ground value of $0.35 per ton.
[2]Maximum value ($46,800) based on full extraction with $300,000 assumed surface value and 15.6-percent damage factor.
[3]Based on 7,600 tons of fill at $0.59 per ton.
[4]Additional cost of reinforced foundations, estimated at 7 percent of surface value.
[5]Based on maximum potential surface damage less the amount expected from this alternative.
[6]Assumes backfill 50 percent effective in eliminating surface damage.

NOTE.--Factors used in estimating damages and construction cost were derived for a residential area; they were used because data for industrial-commercial areas were unavailable.

TABLE 4. - Effects of alternative methods of subsidence control--residential area

(Bituminous coal mining--western Pennsylvania)

Alternative	Estimated benefits per acre		Estimated costs per acre				Benefit-cost ratio
	Mineral mined[1]	Surface damage avoided[2]	Mineral loss[1]	Surface damage[2]	Backfill[3]	Surface construction[4]	
Partial extraction, leave mine void.................	$1,670	[5]$7,620	$1,670	[6]$190	-	-	5.0
Full extraction, surface construction...............	3,340	7,810	-	-	-	$4,250	2.7
Sterilized resource.........	-	7,810	3,340	-	-	-	2.3
Partial extraction, backfill	1,670	[5]7,710	1,670	[7]100	$2,700	-	2.1
Partial extraction, surface construction...............	1,670	7,810	1,670	-	-	4,250	1.6
Full extraction, backfill...	3,340	[5]3,910	-	[7]3,910	4,500	-	0.9
Full extraction, leave mine void......................	3,340	-	-	7,810	-	-	0.4

[1]Maximum value ($3,340) based on 5.3-foot seam with in-ground value of $0.35 per ton; value for partial extraction ($1,670) based on a plan of 50-percent extraction.

[2]Maximum value ($7,810) based on full extraction with $62,500 estimated surface value, and 15.6-percent damage factor.

[3]Based on 4,600 and 7,600 tons of fill required for partially and fully extracted areas, respectively, at $0.59 per ton.

[4]Additional cost of reinforced foundations, estimated at 7 percent of surface value.

[5]Based on maximum potential surface damage less the amount expected from this alternative.

[6]Based on surface value of $62,500 and 0.3-percent damage factor.

[7]Assumes backfilling 50 percent effective in eliminating surface damage.

A land inventory of Pennsylvania indicated the following surface use in the study area:[12]

Land use	Percent of area
Industrial-commercial	7.4
Residential	9.8
Grazing	8.7
Other rural	74.1
Total	100.0

Assuming random progression of mining in the study area without subsidence controls, 7.4 percent of the total undermined area would have been industrial-commercial (about 730 acres). Accepted practice and legislative controls generally precluded mining under large segments of this class of land, although 50-percent mining was practiced under some areas of light industry and moderately valued industrial-commercial property. The amount of area involved with partial mining was not determined because of the scarcity of information, but it was believed to be relatively small and therefore insignificant in the subsequent calculations. For the purpose of estimating subsidence costs, it was assumed that the coal that could have been mined under the entire industrial-commercial land class was left in the ground for surface support, and a substitute supply was obtained from beneath other land classes. The area undermined in 1968 has therefore been redistributed as follows:

Land use	Undermined area	
	Percent of total	Acres
Residential	10.6	1,050
Grazing	9.4	930
Other rural	80.0	7,920
Total	100.0	9,900

By applying damage and control costs to the area undermined or sterilized, the total subsidence cost for western Pennsylvania in 1968 was estimated at \$4.6 million (table 7); this included \$295,000 for surface damages, and \$4,350,000 for mineral losses (about 12.4 million tons of coal resource) as a result of controls to minimize surface damage. Of the total subsidence cost, \$2.7 million were external costs borne directly by the public. It was similarly estimated that without subsidence controls, 9,200 acres would have been undermined (based on full extraction, at random), with resulting surface damages or external costs of about \$39 million.

[12] Pennsylvania Association of Soil Conservation Directors. Pennsylvania Soil and Water Conservation Needs Inventory. Harrisburg, Pa., 1960, 89 pp.

TABLE 5. - Effects of alternative methods of subsidence control--grazing land

(Bituminous coal mining--western Pennsylvania)

Alternative	Estimated benefits per acre		Estimated costs per acre			Benefit-cost ratio
	Mineral mined[1]	Surface damage avoided[2]	Mineral loss[1]	Surface damage[2]	Backfill[3]	
Full extraction, leave mine void......	$3,340	-	-	$70	-	47.7
Full extraction, backfill.............	3,340	$70	-	-	$2,700	1.3
Partial extraction, leave mine void...	1,670	70	$1,670	-	-	1.0
Partial extraction, backfill..........	1,670	70	1,670	-	4,500	0.3
Sterilized resource...................	-	70	3,340	-	-	0.02

[1] Maximum value ($3,340) based on 5.3-foot seam with in-ground value of $0.35 per ton; value for partial extraction ($1,670) based on a plan of 50-percent extraction.

[2] Based on reduction of value due to loss of ground water.

[3] Cost based on 4,600 and 7,600 tons of fill required for partially and fully extracted areas, respectively, at $0.59 per ton.

TABLE 6. - Effects of alternative methods of subsidence control--forest and cropland

(Bituminous coal mining--western Pennsylvania)

Alternative	Estimated benefits per acre		Estimated costs per acre			Benefit-cost ratio
	Mineral mined[1]	Surface damage avoided[2]	Mineral loss[1]	Surface damage[2]	Backfill	
Full extraction, leave mine void......	$3,340	-	-	-	-	-
Partial extraction, leave mine void...	1,670	-	$1,670	-	-	1.0
Sterilized resource...................	-	-	3,340	-	-	-

[1] Maximum value ($3,340) based on 5.3-foot seam with in-ground value of $0.35 per ton; value for partial extraction ($1,670) based on a plan of 50-percent extraction.

[2] Surface damages assumed nil.

TABLE 7. - Major subsidence costs for western Pennsylvania study area, 1968

(Bituminous coal mining)

Land use	Area affected, acres[1]	Surface damage		Subsidence control (mineral losses)		Total subsidence cost
		Per acre[1]	Total	Per acre[1]	Total	
Industrial-commercial.....	730	-	-	$3,340	$2,438,000	[2] $2,438,000
Residential.....	1,050	$190	$200,000	1,670	1,754,000	1,954,000
Grazing.........	930	70	65,000	-	-	65,000
Other rural.....	7,920	-	-	-	-	-
Highway.........	-	-	10,000	-	158,000	[2] 168,000
Pipeline (gas)..	-	-	20,000	-	-	[2] 20,000
Total......	-	-	295,000	-	4,350,000	4,645,000

[1] Data derived from foregoing tables and material in text.
[2] External cost of subsidence--not reflected in the market value of coal (total $2,691,000).

SUMMARY AND CONCLUSIONS

Surface damage from mine subsidence is a form of environmental pollution related to conflicting land use. The Nation's expanding population contributes to the problem by causing more intensive use of the surface while demanding increased mineral production. In some areas, urbanization and other forms of surface development continually expand over underground sources of minerals and mining operations. This may result in significant subsidence damages or control costs.

Potential subsidence damage from future mining exists in varying degrees in many parts of the Nation; the amount of damage will depend on the type and characteristics of the mineral deposit, the amount and method of production, and the type and extent of surface development. Subsidence damage involves basic commodities such as coal, petroleum, iron, zinc, lead, sulfur, and salt. However, of all the commodities, bituminous coal mining results in the most extensive problems, because of the high volume of production, the large areas affected by underground mining, and surface development in the producing areas.

Major costs of surface damage and subsidence control attributable to mining in 1968 were estimated for the bituminous coal region of western Pennsylvania. Not included in the appraisal are subsidence damages or control costs which might result from a postmining change in land use--such as urban development over partially extracted areas which were rural when mined. Subsequent subsidence costs for such a situation are difficult to anticipate and relate to production; however, they may be minimized through long-range regional planning.

Subsidence costs per acre were used to evaluate various alternatives for utilizing coal under different types of surface development in the western Pennsylvania study area. It was determined that under present conditions existing controls and practices were generally optimal. These include the following:

1. Partial extraction or limited mining in urban areas, with a 50-percent mining plan in residential areas, and generally no recovery under highly valued commercial areas and heavy industry.

2. Full extraction under rural acreage consisting of grazing, crop, forest, and unused land.

Secondary controls such as mine backfilling and modified surface construction appear impractical at present because of excessive cost. However, these alternatives were evaluated on the basis of single seam mining; consideration of mining more than one seam, new mining practices, or other factors would result in different costs, and could possibly change the optimum alternatives.

In 1968, underground mining in the study area produced 54 million tons of coal valued at $323 million, resulting in direct subsidence costs estimated at $4.6 million, or an average of about $0.09 per ton. Subsidence costs included $295,000 for surface damages. The remainder, $4,350,000, was the value of 12.4 million tons of coal left in place to support surface property; it also represented the cost of existing subsidence controls which reduced surface damages in 1968 from a potential $39 million to $295,000.

Although the total cost of subsidence was estimated at $4.6 million, under Pennsylvania law the coal industry was required to assume a large part of the cost--it was liable for nearly all damage to residential property, and it was required to absorb the cost of nearly all mineral losses in residential areas. The external cost of subsidence--that imposed on parties other than the producer and not reflected in the 1968 market value--totaled $2.7 million, or an average of $0.05 per ton of coal produced by underground methods; this included both the value of support coal and unreimbursed surface damages. It amounted to slightly less than 1 percent of market value.

The 12.4 million tons of coal left in place for surface support during 1968 represents a mineral loss which may seem relatively minor compared to the 57 billion tons of remaining resource in the area. However, this loss could have a significant impact on local areas or individual producers; it also hastens the time when industry must turn to energy sources outside the study area, which will result in an increased cost of supply.

Major subsidence costs in western Pennsylvania were relatively low in 1968. If maintained at the same level, they may have no significant effect on the short-term availability (price and amount) of coal in the area. The long-term effects of subsidence will depend largely on the extent of future urban expansion over the bituminous coalfields; it will also depend on the effort applied to minimize subsidence costs through coordinated planning of land use and mineral recovery.

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APPENDIX A.--ESTIMATED COST OF HYDRAULICALLY BACKFILLING AN UNDERGROUND MINE

The following estimate of backfilling costs was based on a hypothetical operation at an underground mine in southwestern Pennsylvania. It was assumed that the mine operates 240 days per year and produces 1,333,000 tons of raw coal. A preparation plant located near a mine portal processes the raw coal, resulting in 1,000,000 tons of marketable coal and 333,000 tons of waste material.

The backfilling operation is concurrent with mining. Waste material from the coal preparation plant is reduced in size and pumped in slurry form into the mine. It is used to fill limited areas of the mine void, thereby supporting the roof and minimizing overlying surface subsidence.

The estimated capital investment and operating costs of this portion of a mining operation are as follows:

	Annual	Per ton
Operating cost................	$168,700	$0.51
Capital investment cost.......	27,700	.08
Total backfilling cost...	196,400	0.59

Figure A-1 shows the flowsheet of a backfill preparation plant.

Estimated Capital Requirements

Equipment and construction capital..................................	$457,300
Interest during construction..	4,600
Working capital...	20,000
Total...	481,900

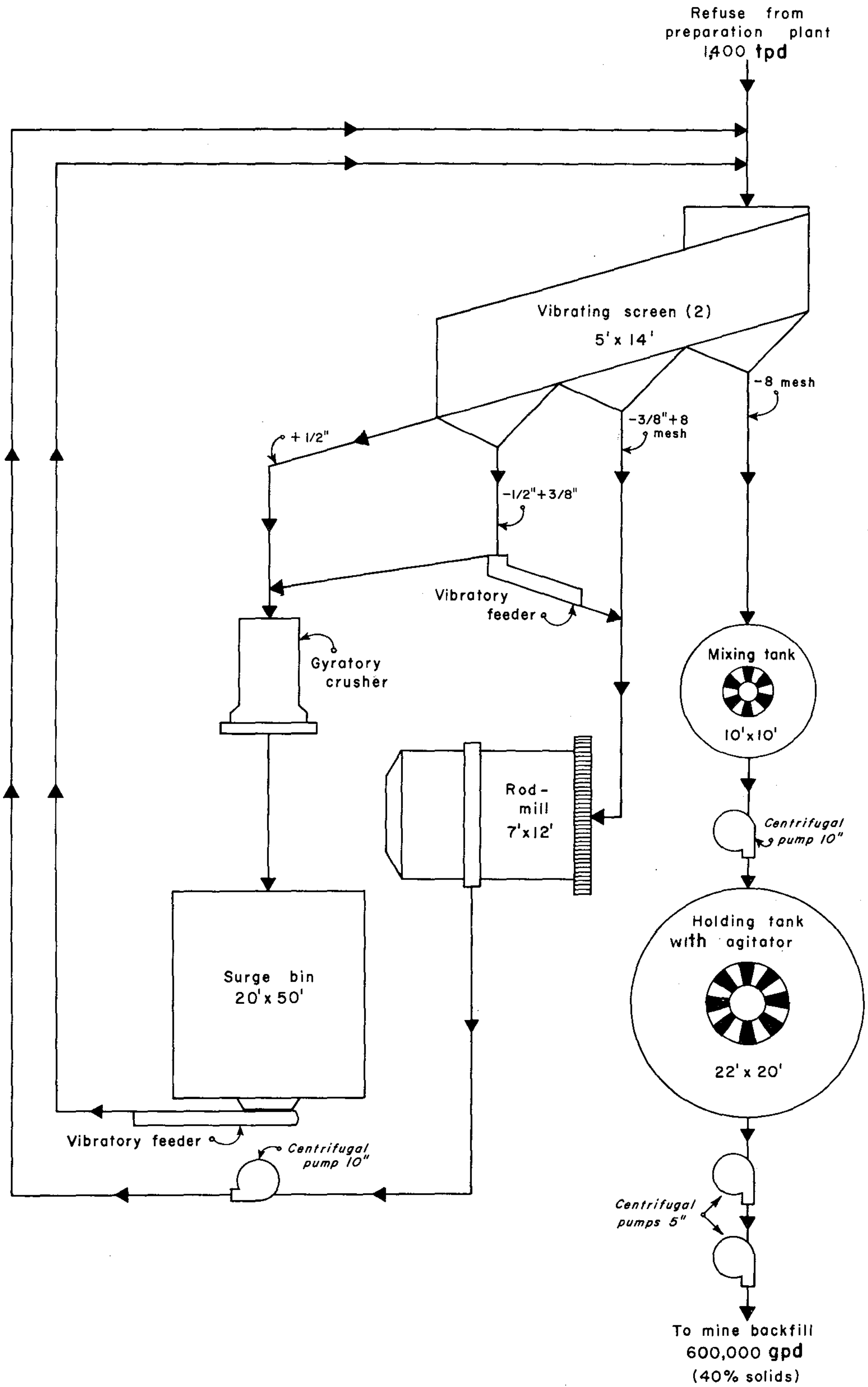

FIGURE A-1. - Flowsheet of a Backfill Preparation Plant.

Equipment and Construction Cost Summary

Item	Quantity	Cost		Total cost
		Material	Labor	
Vibrating screen	2	6,600	400	$14,000
Vibratory feeder	2	1,400	200	3,200
Gyratory crusher	1	30,000	3,400	33,400
Electric motor (100 hp)	1	1,900	1,800	3,700
Surge bin	1	7,500	6,300	13,800
Vibratory feeder	1	1,800	200	2,000
Rodmill	1	92,400	8,400	100,800
Electric motor (300 hp)	1	4,800	4,200	9,000
Conveyors	4	2,300	400	10,800
Mixing tank (10 by 10 ft)	1	4,300	500	4,800
Mixer	1	3,600	600	4,200
Centrifugal pump (10 inch)	2	1,400	200	3,200
Electric motor	2	900	800	3,400
Holding tank	1	12,600	1,400	14,000
Mixer	1	7,900	1,600	9,500
Centrifugal pump	2	1,200	200	2,800
Electric motor	2	1,000	900	3,800
Pipeline (slurry)	15,000 ft	-	-	48,800
Pipeline (water return)	15,000 ft	-	-	30,000
Centrifugal pump (water return)	1	1,800	200	2,000
Electric motor	1	900	900	1,800
Instrumentation and control	-	-	-	4,600
Building	1	-	-	22,800
Total direct	-	-	-	346,400
Field indirect	-	-	-	34,600
Total construction	-	-	-	381,000
Engineering	-	-	-	19,100
Overhead and administration	-	-	-	19,100
Contingency	-	-	-	38,100
Total	-	-	-	457,300

Depreciation Schedule

Item	Straight line depreciation--years	Yearly charge
Vibrating screens	20	$700
Vibratory feeders	10	500
Gyratory crusher	20	1,680
Rodmill	20	5,040
Mixing and holding tanks	20	940
Mixers	10	1,380
Centrifugal pumps	5	1,600
Electric motors	20	1,100
Surge bin	20	690
Conveyors	20	540
Building	20	1,140
Pipeline	5	15,760
Instrumentation	20	230
Total	-	31,300
Indirect cost, engineering, overhead and administration, and contingency	-	5,500
Total depreciation	-	36,800

Manning Schedule

Two men per shift. Two shifts per day.
Rate = \$30/day X 4 men X 240 day/yr = \$28,800.

Maintenance (Annual)

Item	Material	Labor	Total
Centrifugal pumps.......	\$500	\$700	\$1,200
Other equipment.........	6,800	10,200	17,000
Total.............	7,300	10,900	18,200

Operating Supplies

Rods for rodmill (82,000 lb X \$0.10/lb)............................	\$8,200
Flexible hose..	800
Lumber...	500
Brattice cloth...	200
Miscellaneous..	500
Total..	10,200

Estimated Annual Operating Cost

Direct labor...	\$28,800
Direct labor supervision (15 pct of labor).....................	4,300
Maintenance labor..	10,900
Maintenance labor supervision..................................	1,600
Maintenance material...	7,300
Payroll overhead (25 pct of labor and supervision).............	11,400
Operating supplies...	10,200
Electric power (25,700 kw X \$0.009)...........................	23,100
Total direct...	97,600
Administration and general overhead (40 pct of labor, maintenance, and general supplies)...	25,200
Taxes and insurance (2 pct of plant cost)......................	9,100
Depreciation...	36,800
Total..	168,700

Estimated Working Capital

(2 months)

Direct labor...	\$5,500
Maintenance..	3,300
Electric power...	3,800
Supplies...	1,700
Total direct...	14,300
Administration and general overhead............................	4,200
Taxes and insurance..	1,500
Total..	20,000

Capital Investment Cost

Annual cash flow (from alternate investment)[1]	$64,500
Less annual depreciation of backfill plant	36,800
Net potential income on capital investment (capital investment cost)	27,700

[1] Capital requirement for backfill plant is compared to an alternate investment for 20 years with an annual return of 12 percent.

Equipment List

Vibrating screen, 5 by 14 ft, triple deck, 10-hp motor
Vibratory feeder, 65 tph max., 5-hp motor
Gyratory crusher, 100-hp motor
Rodmill, 7 by 12 ft, 300 hp, 8,200-lb rod charge
Mixing tank, 10 by 10 ft, 24-inch fixed propeller mixer, 15 hp
Holding tank, 22 by 20 ft, steel, 84-inch fixed propeller mixer, 60-hp motor
Centrifugal pump, 10 inch, 50 hp
Surge bin, 20 by 50 ft, reinforced concrete
Vibratory feeder, 200 tph max.
Conveyors, 24-inch belt
Pipe, 5 inch, schedule 160 (for slurry line)
Pipe, 4 inch, extra strong (for water return)
Centrifugal pump, 5 inch, 60 hp
Centrifugal pump, 4 inch, 60 hp
Instrumentation and remote control of slurry pumping equipment
Building to house crusher, rodmill, pumps, and control equipment. 30 by 40 ft, steel frame and corrugated steel walls, reinforced concrete floor

APPENDIX B.--MISCELLANEOUS CALCULATIONS

Average Recovery of Marketable Coal

Coal in place	tons/acre-foot..	[1] 1,800
Seam thickness mined (avg)	feet..	[2] 5.3
Coal resource	tons/acre..	9,540
Recoverable marketable coal, rate and amount:		
Full or unrestricted mining	percent..	[3] 61.3
Do	tons/acre..	5,848
Areas with 50-percent mining plan	percent..	[4] 37.5
Do	tons/acre..	3,578

[1] Based on bulk density of 82.6 pounds per cubic foot.
[2] Young, W. H. Thickness of Bituminous Coal and Lignite Seams Mined in 1965. BuMines Inf. Circ. 8345, 1967, p. 5.
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[4] Assumes 50-percent recovery, minus cleaning loss.

Volume of Underground Void

(Per ton of marketable bituminous coal)

Refuse produced	percent of raw coal..	25
Quantity of refuse	lb..	667
Bulk density of coal in place	lb/cu ft..	82.6
Bulk density of refuse in place	lb/cu ft..	[1] 140.6
Void caused by removing coal $\left(\frac{2,000 \text{ lb}}{82.6 \text{ lb/cu ft}}\right)$	cu ft/ton..	24.2
Void caused by removing refuse $\left(\frac{667 \text{ lb}}{140.6 \text{ lb/cu ft}}\right)$	cu ft/ton..	4.7
Total void	cu ft/ton..	28.9

[1] Based on specific gravity of 2.25.

Refuse To Fill Underground Void

Bulk density of preparation plant refuse	lb/cu ft..	[1] 90
Refuse requirements per ton of marketable coal (90 lb/cu ft X 28.9 cu ft = 2,601 lb)	tons..	1.3

[1] Average bulk density recorded by Bureau of Mines, Coal Research Center, Pittsburgh, Pa.

Estimated Foundation Costs

Description of structure:
Two-story house, brick veneer, foundation just below ground level
Size - 40 by 24 ft
Estimated load (total) - 200,000 lb
Value with standard foundation - $25,000

Standard foundation:			
Footers (10 by 16 in by 128 ft)	cu ft..	142	
Floor (40 by 24 ft by 4 in)	cu ft..	320	
Total concrete	cu ft..	462	= 17 cu yd
Cost at $40/cu yd			$680
Raft (reinforced slab):			
Floor (40 by 24 ft by 6 in)	cu ft..	480	
Total concrete	cu ft..	480	= 18 cu yd
Cost at $100/cu yd			$1,800
Ribbed raft or waffle foundation (reinforced):[1]			
Number of beams parallel to long direction		3	
Dimension of beam	in..	24 by 10	
Number of beams parallel to short direction		4	
Dimension of beam	in..	24 by 8	
Floor thickness	in..	4	
Beams:			
24 by 10 in by 40 ft × 3	cu ft..	200	
24 by 8 in by 24 ft × 4	cu ft..	128	
Floor: 40 by 24 ft by 4 in	cu ft..	320	
Total concrete	cu ft..	648	= 24 cu yd
Cost at $100/cu yd			$2,400

[1] Source of specification: Criteria for Selection and Design of Residential Slabs-on-Ground. National Academy of Sciences, Pub. 1571, 1968, 288 pp.

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