The Bureau of Mines report included a recommendation that the mine voids in the 15 critical areas, most of which were flooded, should be filled with sand to support remaining pillars, reduce rock strata breakage in the overburden, and minimize possible damage at the surface. To backfill the entire undermined area of the city, about 900 acres, would be difficult and quite expensive because most of the voids, exclusive of the critical areas, are situated at depths in excess of 300 feet below the surface. Based on local observation and experience gained in subsidence control in the Anthracite region, it was assumed that strata breakage originating at depths below 300 feet would not be significant at the surface.

## HYDRAULIC BACKFILLING METHODS

Before 1970, two methods of hydraulic placement of backfill material in underground mined-out spaces had been used in the Anthracite region. They are known as controlled flushing and blind flushing. In both methods, granular solid material is sluiced down from the surface through boreholes with water by the force of gravity.

### Controlled Flushing

Controlled flushing is possible in mines in which men can safely enter and gain access to key areas for the filling operations. Bulkheads are built in mine passages around the periphery for containment of the fill. Drain boxes may be incorporated in these structures to facilitate rapid removal of water. The injection boreholes, generally about one borehole for 4 acres, are cased from the surface to the mine opening. At the base of each hole, long-radius 90° pipe elbows are placed through which slurry is diverted to horizontal pipes and distributed into the mine workings. Horizontal dispersal ranges from 300 to 1,000 feet, depending on the vertical distance from the ground surface to the mine opening and the solids concentration of the slurry. Controlled flushing provides the best support and is used where conditions permit.

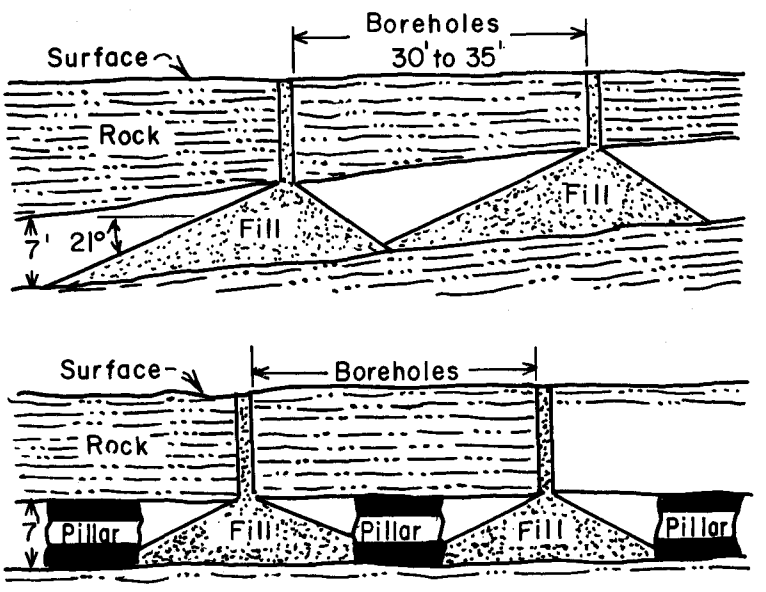


FIGURE 4. - Typical sections showing boreholes and configuration of fill material placed in mine voids by the gravity blind flushing method.

### Blind Flushing

Many abandoned mine openings are inaccessible because of flooding or extensive caving. Such openings were flushed blindly in the past. The gravity-feed method simply builds a conical pile beneath the underground opening of the flushing hole. When the apex of the cone builds up to the mine roof, no more fill will enter the mine opening. Further injection must use other boreholes, as shown in figure 4.

Depending on conditions underground, such as the dip of the bed, its height, and the proximity of pillars or occasional caved roof strata, the volume of material that can be injected in the this manner from each borehole ranges from 20 to 1,000 cubic yards. In a 6-foot bed that is relatively flat, for example, in which about 45 percent of the bed remains in pillars, only about 100 cubic yards can be injected from a single hole. Therefore, injection holes must be closely spaced, but at best only about a third of the underground open space is filled by this blind flushing technique. Most blind flushing projects have required hundreds of flushing holes. In built-up areas, it may not be possible to drill boreholes in critical areas where buildings or other structures interfere or where easements cannot be obtained from property owners. Therefore, most of the backfilling under built-up areas is done through boreholes drilled in streets and alleys, and the support given is of only indirect benefit to adjoining buildings (fig. 5).

## Pumped-Slurry Injection

A new technique for the blind flushing of inaccessible mine workings, termed "the pumped-slurry injection process," was first demonstrated in 1970 at Rock Springs, Wyo., in a test site adjacent to the Connecticut Avenue-D Street area where severe subsidence problems had developed. This technique differs from the open gravity-feed methods previously described in that pumping energy is used to achieve a dynamic suspension of solid particles in water and the system is completely closed from the point of slurry mixing to the bottom of the injection borehole.

In this process, granular material is blended with water, and the suspension (slurry) is pumped to the point of deposition. Water from an inundated mine may be used and recirculated, or water from an external source may be used without being recirculated. During mixing, each solid particle becomes enclosed by fluid so that friction during transit is reduced. The slurry is pumped continuously from the mixing tank through a pipeline on the surface and thence down through a borehole to the mine opening. The energy provided by the pump and the static head in the borehole give the velocity required to keep the solid particles in suspension and to transport them.

The completeness of filling in the open spaces is responsive to changes in the velocity of flow, which changes with the growth of the mound of deposited solids. As the slurry first enters the open space from the injection hole, its velocity drops rapidly, and solid particles settle out near the borehole, forming a doughnut-shaped mound on the mine floor. As the height of the mound approaches the mine roof, the velocity of the slurry increases through the narrowing channel, and solid particles are transported to the outer limit of the mound. Here the velocity decreases abruptly and solids are deposited. This type of deposition continues and the mound of deposited fill builds outward. Stages in the filling of a mine void are shown diagrammatically in figure 6.

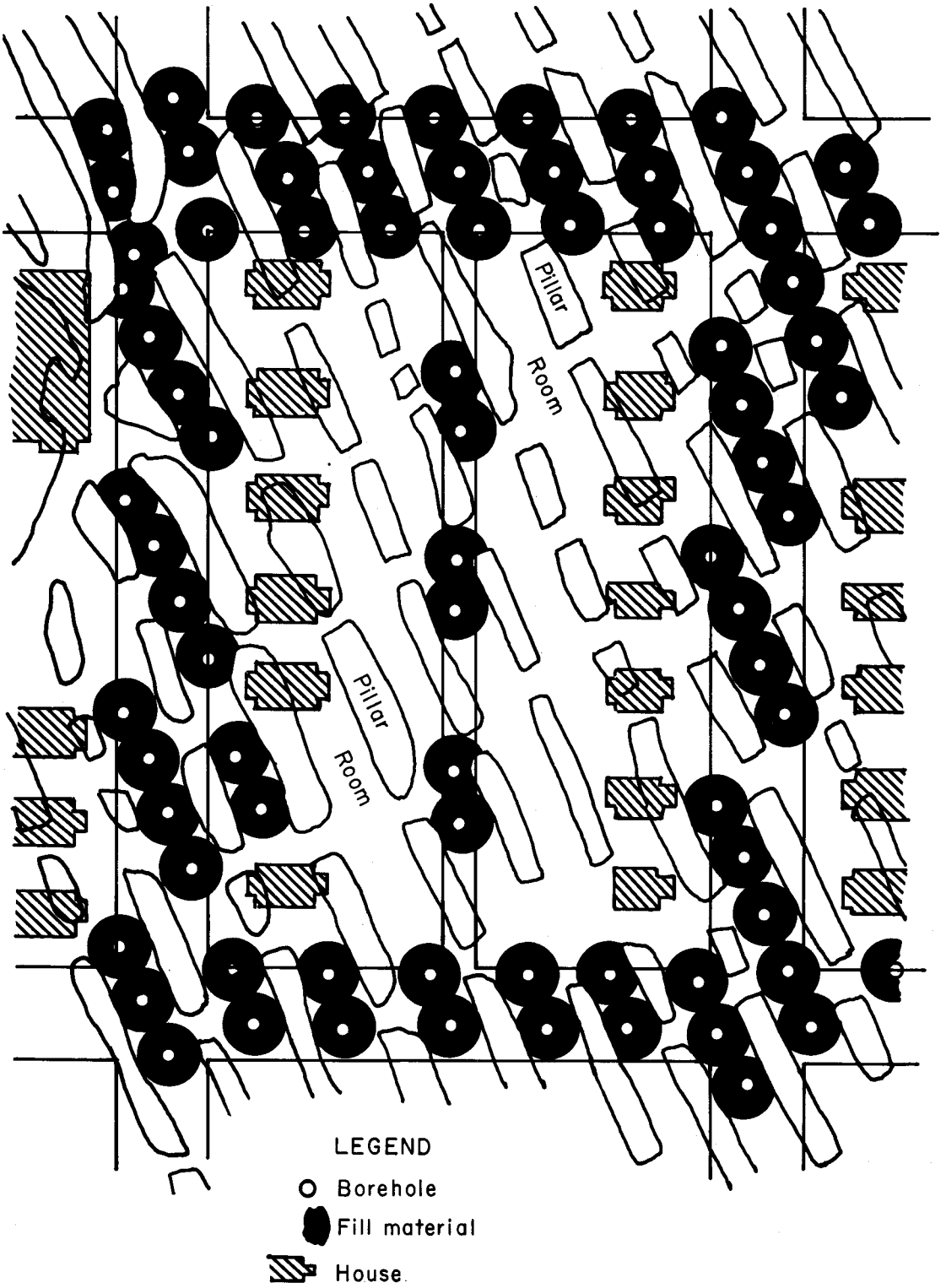


FIGURE 5. - Typical residential block showing the pattern of boreholes in streets, alleys, and vacant lots proposed for blind flushing. Circular areas around boreholes represent backfill material to be placed in the mine voids.

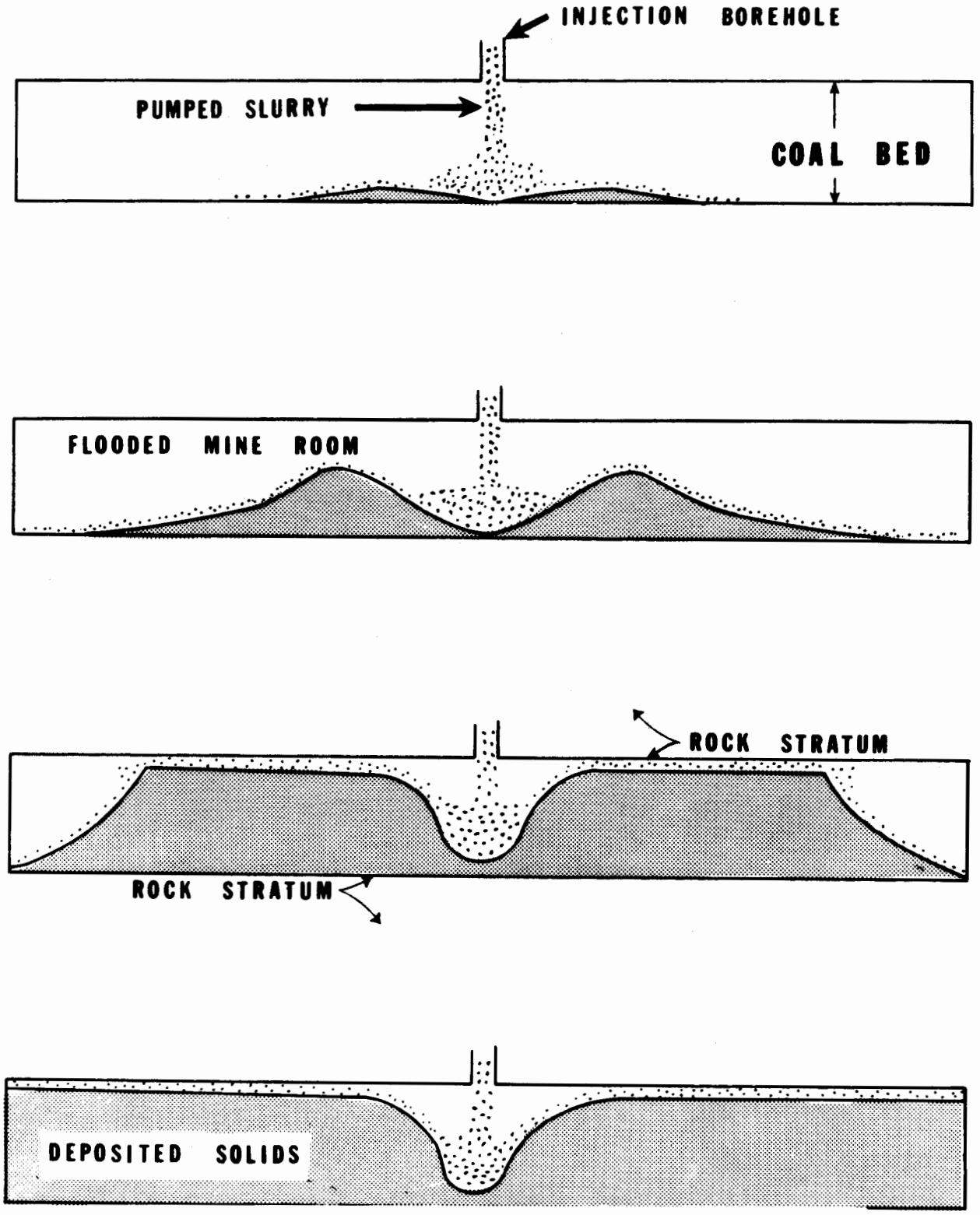


FIGURE 6. - Sectional views through a flooded mine room at the point of slurry injection showing movement of particles and growth of deposit.

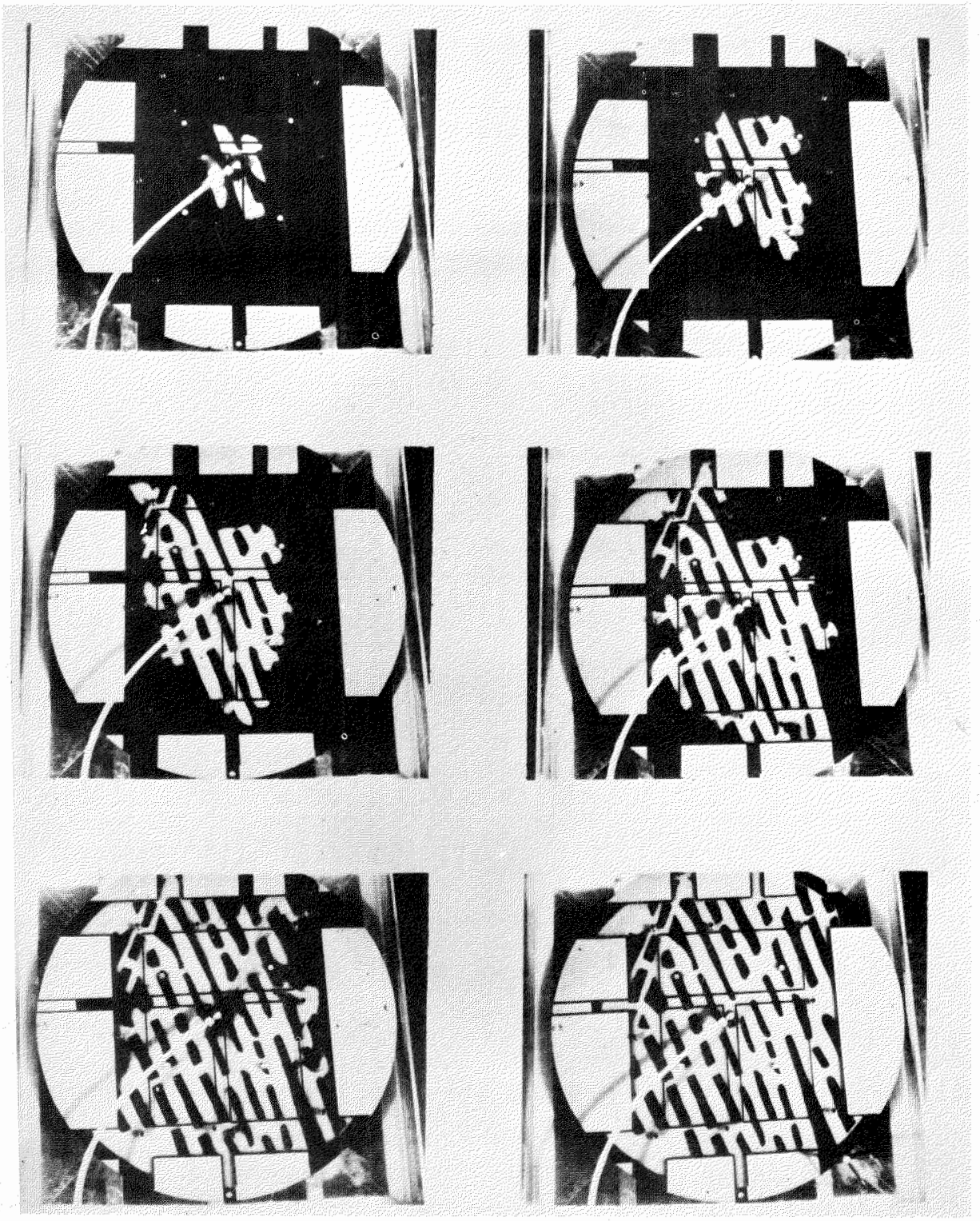

FIGURE 7. - Top view of mine model with transparent roof, showing stages of radial distribution of fill material by the pumped-slurry process.
*(Courtesy of the Dowell Division of the Dow Chemical Co.)*

In a table-size mine model simulating the arrangement of rooms and pillars, deposition of fill material is shown in figure 7. As resistance to flow of the slurry develops in one direction, a new channel is formed in another direction along a line of less resistance. Eventually, nearly all mine openings are filled. The lateral extent of the fill is determined largely by the available energy in the system. As the mound of fill material builds outward in the mine, the flow channels between the mound and the mine roof become longer and resistance to flow increases. When this resistance, combined with resistance in the pipe, becomes great enough to reduce the velocity of the slurry below that required to transport the solid particles, transportation of the particles ceases. The particles then settle out, and the passage becomes filled.

The pumped-slurry method of blind flushing has the following advantages over the open gravity-feed method previously used:

1. Great reduction in the number of injection boreholes. A single injection hole serves the purpose of many injection holes in the gravity-feed method.

2. More complete vertical filling of mine openings.

3. More complete areal coverage. Areas inaccessible because of surface improvements can be filled.

4. Less disruption of the community in the form of noise, dust, and traffic interference by drilling operations and trucking of fill material.

Disadvantages to the use of the pumped-slurry method would be apparent under the following conditions:

1. Where it is safe for men to enter the mine and control the backfilling operation.

2. Where the mine voids to be filled are close to the surface with little or no rock strata cover, in which case the slurry water could invade surface areas.

3. Where the amount of mine void to be filled is too small to warrant the cost of acquiring and installing slurry pumping equipment.

## PUMPED-SLURRY TEST AT ROCK SPRINGS

The test at Rock Springs in 1970 was carried out in cooperation with the city of Rock Springs, the Department of Housing and Urban Development, and the Bureau of Mines. The Bureau's financial participation in the project to the extent of $55,000 was covered by a contribution contract with the city. The city of Rock Springs entered into a contract with Dowell Division of the Dow Chemical Co. of Tulsa, Okla., to perform the injection operation. The total contract cost of the demonstration was $173,140.