centers in the Anthracite region of northeastern Pennsylvania have had a history of subsidence problems as a result of multiple-bed mining over a period of 150 years. Scranton is the largest of the cities in the Anthracite region. As many as 11 different coalbeds have been mined under Scranton, and most of the central part of the city overlies 6 mined beds. The demonstration project site is in an area of potential subsidence due to past mining in five abandoned coalbeds. Subsidence had not yet become apparent at the ground surface in this area, and caving below ground was not believed to be sufficient to block effective movement of slurry.

A 30-acre residential area was stabilized by injecting about 450,000 cubic yards of crushed mine refuse into two coalbeds through five injection boreholes. Nearly 200,000 cubic yards was injected through one borehole from which the material moved into the mine workings on all sides; the injected material reached a maximum lateral distance of 640 feet and filled mine openings from floor to roof. The new method, designed for inundated mines, proved successful also in mine workings above mine-water pool level (22).

HYDRAULIC MODEL STUDIES FOR BACKFILLING MINE CAVITIES

In October 1973, the Bureau of Mines arranged for model studies of the pumped-slurry method of backfilling mine cavities to be conducted by the U.S. Bureau of Reclamation at their hydraulic laboratory in Denver, Colo. The purpose of the studies was to obtain qualitative and quantitative data on the deposit pattern of fine sand, such as that at the Rock Springs projects, when used for backfill material and injected into cavities of a simulated coal mine. The results of the first series of 18 tests are given in a report entitled, "Hydraulic Model Studies for Backfilling Mine Cavities," by E. J. Carlson of the U.S. Bureau of Reclamation, which is included as an appendix in Bureau of Mines Information Circular 8667 (22).

A second series of model studies of the pumped-slurry method using the same fill material and simulating conditions not covered in the first series was made by the Bureau of Reclamation for the Bureau of Mines in 1974. That report was also by E. J. Carlson, U.S. Bureau of Reclamation; dated March 1975, it is included as an appendix to this report.

THREE LARGE-SCALE PROJECTS AT ROCK SPRINGS

The success achieved with the pumped-slurry technique at Rock Springs and at Scranton, where for the first time extensive mine voids in two beds under about 30 acres were filled from only five injection boreholes, prompted the Bureau to initiate several more large-scale subsidence control demonstration projects in both the Anthracite region and Rock Springs. Experiments were needed to determine the various types and sizes of material as well as the optimum range of conditions under which the pumped-slurry method could be used more effectively in minimizing adverse environmental problems associated with underground coal mining. In addition to the original 20,000-cubic-yard test, this report covers the three large-scale demonstration projects that were conducted in Rock Springs during the period 1973-76.

It became apparent, however, that the Bureau's proposed subsidence control efforts at Rock Springs would proceed in an atmosphere of unprecedented industrial expansion. Areas near the city saw the construction of a $500 million coal-fired steam-electric powerplant; development and expansion of trona operations by four chemical companies; oil and gas exploration; and stepped-up activities relating to the extraction of coal and uranium. The population of Rock Springs rose from a more or less stable 12,000 in 1970 to 26,000 in January 1974. In addition to subsidence problems, therefore, the city was obliged to cope with crowded schools, traffic jams, lack of housing, rising crime rates, overloaded public facilities, and insufficient tax revenues.

Under the authority of the Organic Act, the Bureau of Mines entered into a cooperative agreement with the city of Rock Springs to conduct large-scale demonstrations of the pumped-slurry method that would also provide surface support for the subsidence-prone critical areas of the city. The agreement provided that the Bureau design, direct, and supply the funds to accomplish the work by contracts obtained through Federal rules and regulations governing competitive procurements. The Bureau, through its contractors, was required to conduct all phases of the work with a minimum of inconvenience to residents and with as little adverse effect upon the environment as possible. The city was required to grant the Bureau, its officials, contractors, or employees, the right to enter streets, roads, and any other land owned or controlled by the city overlying or adjacent to the project areas for the purpose of conducting the injection operations. The city also furnished without charge all licenses, permits, or other authorizations required in the conduct of project work, which included detours for local traffic and police surveillance of Bureau property. City engineers and utility personnel also provided accurate information regarding locations of utility pipelines, wires, cables, and sewer lines together with maps showing ownership of property within and adjacent to the project areas.

Drilling Operations

All drilling and reaming of boreholes that were used for water wells, slurry injection, exploration, and monitoring was done with rotary drills equipped with efficient dust control mechanisms. While drilling was done with air, insofar as possible, water (mist) injection was also used to reduce the amount of dust discharged into the atmosphere. After drilling through unconsolidated overburden, all boreholes that were used for water supply and injection were cased and cemented to a point 4 feet into the rock stratum. From here drilling was continued at sufficient diameter to accommodate the required casing to the mine opening. Such boreholes were collared, sealed to the standpipe, and fitted with removable pressure-tight caps at the surface. For the monitoring boreholes, casing was not installed below the point 4 feet into the rock stratum. Logs of all the boreholes, and particularly the depth at which the bit broke through to the mine opening as well as the height of the mine opening, were furnished to the Bureau of Mines. Figures 11 and 12 are typical cross sections of the various boreholes used in the projects.

Boreholes that penetrated into solid coal and therefore not usable were filled with drill cuttings to within 3 feet of the top of solid rock, then

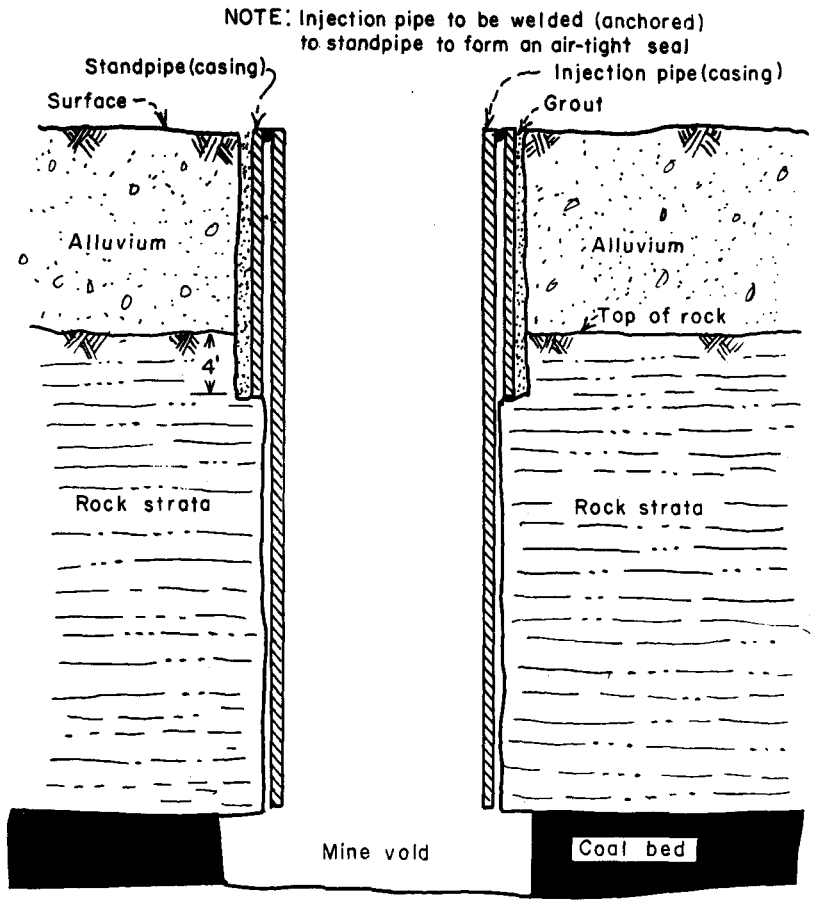

FIGURE 11. - Typical sections of water supply and injection boreholes.

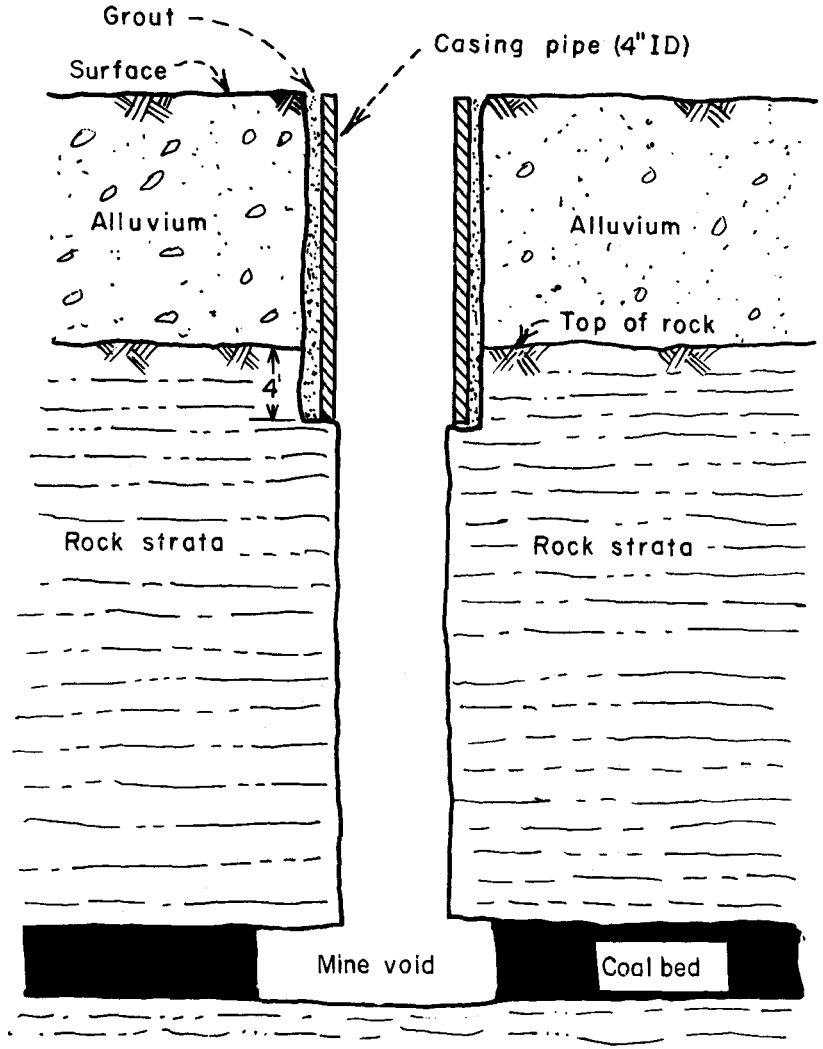

FIGURE 12. - Typical section of a monitoring borehole.

with 3 feet of concrete. From this point the hole was filled with cuttings or soil within 1 foot of the surface. The remaining 12 inches was filled with dirt, asphalt, or concrete depending upon the kind of material originally present. After the injection and monitoring boreholes served their purpose, they were filled with sand to within 4 feet of the top of rock, then with 4 feet of concrete to the top of rock. From this level the hole was filled with sand to the surface, except in those instances where the boreholes are in roadway surfaces, in which case they were filled with concrete or the type of roadway material present for at least the top 12 inches. Where not used to backfill boreholes, the mud and drill cuttings produced during drilling were removed from the various sites. Wherever possible, casings were removed after the work was completed.

In addition to providing usable boreholes, the purpose of the exploratory borehole drilling was to outline and define, to the extent necessary, the size, location, and condition of the abandoned coal mines underlying the proposed project areas. Because of apparent errors in maps of the coal workings and the inaccessibility of the mines for inspection or resurveying, the purpose of the proposed drill holes was also to help establish the position of mine workings with relation to the surface. In a few parts of the project areas the locations of mine voids were represented accurately; however, in most of the project areas, after the drill holes encountered pillars, it became necessary to reposition the mine maps with respect to surface features until the drill holes penetrated voids on a more frequent basis. A device of this kind may be applied successfully in other mining areas where similar inaccuracies exist.

Slurry Components

Fine sand from various deposits of wind-blown origin in the vicinity of Rock Springs was used as fill material in all of the demonstration projects at Rock Springs. Except for screening out rocks and other debris, little else was done in preparing the sand for injection into mine voids. The grain-size gradation of a typical sample of sand used in the various projects and in the model studies is shown graphically in appendix figure 3. Data on settlement tests, in-place density, and bearing capacity of the fine, uniform, blow sand (median size, ~ 0.14 mm) from the Rock Springs area are also given in the appendix.

Specifications regarding the use and reclamation of borrow areas where sand was obtained were established in accordance with requirements of the Bureau of Land Management, U.S. Department of the Interior, and incorporated in the contracts for the three large-scale demonstration projects. Sandfill for Project 1 (Dow Chemical Co.) and for Project 3 (M. J. Bober Co.) was taken from deposits controlled by the Bureau of Land Management. Sand for Project 2 (WHAN Engineering and Construction, Inc.) was obtained from a deposit on privately owned land of the Upland Industries Corp., Rock Springs, Wyo. In all instances, the following stipulations regarding the use of borrow pits applied:

1. Topsoil, if present, will be removed and stockpiled.

2. At such time when materials (blow sand) has been removed and rehabilitation is underway, the floor of the pit shall be leveled to coincide with the existing watershed slope. If no other use is made of the screening rejects they will be scattered over the pit floor. Topsoil will be replaced. Pit slopes will be 3:1 ratio. Haulage roads will be leveled and berms smoothed. Haulage roads and materials pit will be seeded with crested wheat at 5 lb per acre and thickspike wheatgrass at 3 lb per acre. Seeding will be accomplished by using a grass seed or grain drill with grass seed attachment. Seeding shall be at 1/2-inch depth and will continue until a satisfactory stand is established and approved by the Bureau's representative.

3. Seeding will be done in the fall after September 15 and before freeze-up.

4. Leveling, grading, and seeding shall be completed within 1 year after the completion or termination of any operation hereunder.

5. Road crossings shall not impede drainage; either culverts should be installed or approaches cut down to drainage bottom level.

6. In the event an archeological site is unearthed, the Bureau of Mines shall be notified immediately.

7. Signs shall be properly posted to warn the public of the extraction area.

8. Proper precaution will be taken at all times to prevent and suppress fires. The contractor will be held responsible for suppression costs for the fires caused through negligence of his employees or subcontractors.

9. Should the material be slurried at the site, water shall be controlled.

10. Upon termination of the pit, the contractor shall submit a final accounting of the total material removed.

The source of water, which is needed in large quantities for the pumped-slurry injection technique, was the local mine-water pool beneath the test site and beneath the three large-scale projects. Advantages of using mine water include its availability, low cost, and the probability that withdrawal and injection of large quantities of water from, and into, the same body of water would create minimum disturbance of the subsurface equilibrium. The mine water contained about 13,500 parts per million (ppm) dissolved solids but had no disagreeable odor and was not highly corrosive (9).

Probe boreholes that intersected the mine-water pool at required pump drawdown depths at or near the various project sites were enlarged to accommodate large casings in which deep-well or submersible pumps were installed. Specifications for the first and second large-scale projects required delivery

of a minimum of 4,000 gallons per minute (gpm) to the mixing tank. This was increased to a minimum of 5,000 gpm for the third large-scale project to allow for an increased volume of slurry injection. Data on solids, water, and slurry covering the range of quantities utilized at the various projects are given in table 1.

TABLE 1. - Data on solids, water, and slurry

Slurry water to solids ratios	Water pumped				
	4,000 gpm (16.66 tons/min)	5,000 gpm (20.82 tons/min)	6,000 gpm (24.99 tons/min)	7,000 gpm (29.15 tons/min)	8,000 gpm (33.32 tons/min)
SOLIDS INJECTED: 200 TONS/HR, 3.33 TONS/MIN, 307 GPM					
Weight.....	5.0	6.3	7.5	8.7	10.0
Volume.....	13.0	16.3	19.5	22.8	26.0
SOLIDS INJECTED: 350 TONS/HR, 5.83 TONS/MIN, 538 GPM					
Weight.....	2.9	3.6	4.3	5.0	5.7
Volume.....	7.4	9.3	11.2	13.0	14.9
SOLIDS INJECTED: 450 TONS/HR, 7.50 TONS/MIN, 692 GPM					
Weight.....	2.2	2.8	3.3	3.9	4.4
Volume.....	5.8	7.2	8.7	10.1	11.6

Sand:
Bulk density 100 pcf (loose) 38.3 pct voids; 61.7 pct solids
2.6 (specific gravity) × 62.4 lb = 162.2 pcf (solid)
162.2 ÷ 7.48 gal/ft^3 = 21.68 lb/gal (solid)

Water:
4,000 gpm × 8.33 lb/gal = 33,320 lb/min = 16.66 tons/min
5,000 gpm × 8.33 lb/gal = 41,650 lb/min = 20.82 tons/min
6,000 gpm × 8.33 lb/gal = 49,980 lb/min = 24.99 tons/min
7,000 gpm × 8.33 lb/gal = 58,310 lb/min = 29.15 tons/min
8,000 gpm × 8.33 lb/gal = 66,640 lb/min = 33.32 tons/min

Injection rate of solids:
200 tons/hr = 3.33 tons/min = 307 gal/min
350 tons/hr = 5.83 tons/min = 538 gal/min
450 tons/hr = 7.50 tons/min = 692 gal/min

Injection rate of slurry by volume (two examples):

Water	+	Solids	=	Slurry
5,000 gpm		3.33 tons/min		5,307 gpm
7,000 gpm		5.83 tons/min		7,538 gpm

Mixing Plants and Slurry Pumps

Equipment at a typical mixing plant site at Rock Springs included a hopper, variable-rate feeder, belt weighing scale, mixing tank, diesel-powered slurry pump, piping and valves, and other auxiliary apparatus necessary to operate, control, maintain, and monitor the backfilling operation. Each

mixing tank was constructed and arranged in such a manner that it was capable of receiving measured and weighed sand at a rate of at least 1,600 tons per shift and mine water ranging from 3,000 to 6,000 gpm from electric-powered deep-well pumps. Mixing tanks were fitted with manifolds connecting the incoming water supply with a series of nozzles, producing sufficient turbulence to maintain the solids in suspension. In each tank the suction line was fitted with a snorepiece that picked up the suspended material (slurry) and conveyed it to the impellers in the slurry pumps. From here the slurry was pumped through distribution lines to the various injection boreholes.

In each case all operations involved in the mixing, pumping, and injection processes were controlled from a conveniently located instrument panel. This included the rate of waterflow, the rate at which sand was introduced, the amount of slurry discharged, cumulative weight of solids injected, and the pressure both at the slurry pump and injection borehole.

Because of the experimental nature of the work and varying conditions to be encountered at the three projects, the specifications allowed a certain amount of flexibility in conducting the work. Each contractor and/or his engineer was encouraged to select and operate the equipment so as to discover the optimum range of such variables as volume, velocity, and density of slurry flow in relation to changes in pump head, pressure at the injection borehole, length of discharge line, and depth to mine voids.

PROJECT 1

Subsequent to the completion of the first successful large-scale application of the pumped-slurry mine backfilling process at Scranton, Pa., Congress in fiscal year 1973 appropriated $700,000 for the Bureau to conduct a similar large-scale demonstration at Rock Springs, Wyo.

In designing the project, the Bureau selected critical areas 1, 7, and 8 because the estimated cost of the work and material to fill the mine voids would approximate available funds. Moreover, it was hoped that providing support in the mine workings under area 1 might arrest the continuing subsidence occurrences in and near the Connecticut Avenue-D Street section. The three critical areas were located in the southeast portion of Rock Springs above both flooded and dry mine voids in the No. 7 seam of the abandoned No. 2 Mine, Central Coal and Coke Co. The old mine workings were believed to be under less than 300 feet of overburden, and this was to be the first time that sand fill would be used in the pumped-slurry process to fill both inundated and dry coal mine voids. It was proposed to demonstrate that approximately 150,000 cubic yards (200,000 tons) of screened sand could be introduced into the designated mine voids under critical areas 1, 7, and 8, a total area of about 33 acres (see fig. 13).

Prior to preparing specifications for the backfilling project, exploratory drilling was conducted in the three critical areas. It was necessary to know the nature and depth of overburden; condition of the mine workings; and whether or not the available maps of the mine workings show a true relationship with overlying surface features. The Bureau, therefore, through Federal