apparent that injected slurry in dry mine voids traveled more readily downdip, subsequent injection boreholes in dry areas were placed at higher seam altitudes to take advantage of the downdip flow tendency. Data on the behavior of slurry deposition in a dipping bed in both flooded and dry mine cavities are described in more detail in the appendix.

Only two significant operational design problems were encountered during the demonstration. One was the detection of slurry through the water supply wells. This indicated that the mine water was in fact returning to the mine pool as planned, and that recirculation of the mine water was occurring. Because excessive slurry recirculation through the water supply wells could cause damage to well pumps, it was concluded that in future demonstration projects the water supply wells should be located in a more remote area so as to prevent any recirculation of slurry.

On one occasion some entrained air forced slurry to the surface through a plastic-cased monitoring borehole. No property damage was reported; however, slurry was discharged into the street and required a cleanup. It was concluded that henceforth all monitoring boreholes would be cased with steel pipe to a point 4 feet into the top of rock and that accessible steel caps would be welded on to provide for a pressure-tight covering.

The cost of the hydraulic backfill demonstration project, in which 152,467 tons of sandfill material was injected, was $729,000. Reductions in the unit cost of the pumped-slurry technique were anticipated as additional experience was gained in applying the method. Total cost of the project, including exploratory drilling and sonar surveys, was $772,543.67--a unit cost of $5.07 per ton.

The demobilization of the operation, including cleanup and restoration of all project work areas, was conducted in accordance with the contract specifications. Restoration of the borrow pit was completed in accordance with the stipulations set forth by the Bureau of Land Management and included seeding of the borrow area in fall 1974 and a verification inspection of the satisfactory growth after one complete growing season in spring 1976.

PROJECT 2

In fiscal year 1974 Congress provided $700,000 for the Bureau of Mines to continue utilizing the pumped-slurry backfilling technique in areas of Rock Springs where subsidence control would be beneficial to the city.

The demonstration project site was selected in an area of potential subsidence due to extensive mining in No. 1 Seam of the abandoned No. 1 Mine, Union Pacific Coal Co. This would be the first time that the pumped-slurry method of backfilling mine voids would be demonstrated in a central downtown-business area of a city. The objective of the project was to fill both flooded and dry coal mine voids with solids that would support overburden and pillars so as to minimize possible future damage to surface structures, streets, and public facilities. The voids to be backfilled by this project consisted of critical area 14 and about one-half of critical area 11. These areas are shown in figure 16.

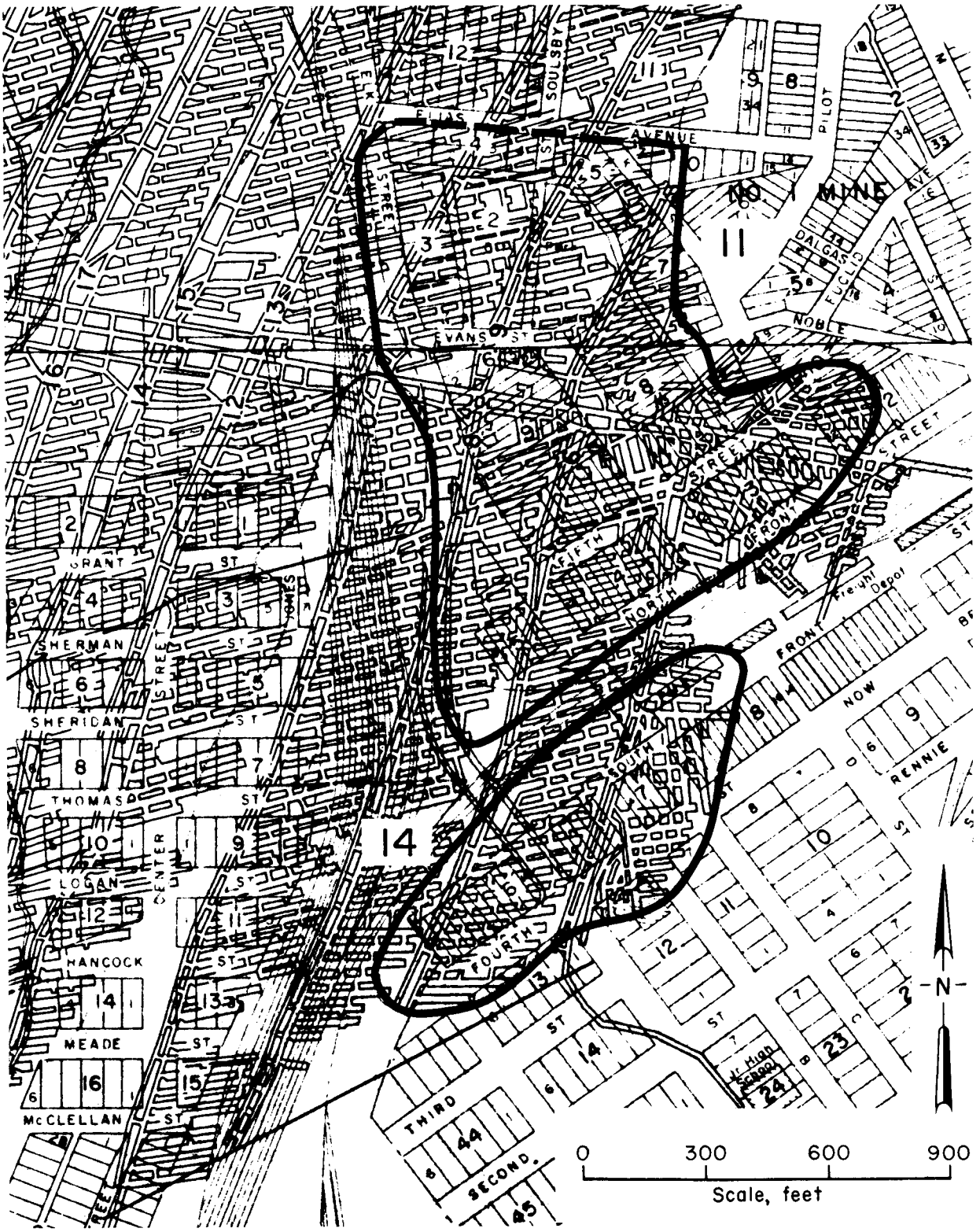

FIGURE 16. - Map of a portion of Rock Springs showing location of critical area 14 and a part of critical area 11 in relation to underground mine workings in the No. 1 Seam.

To accomplish this objective, it was proposed to demonstrate that at least 150,000 tons of screened sand could be introduced into the flooded and/or otherwise inaccessible mine voids beneath the areas described above, a total planned area of about 28 acres. The project work was conducted in two phases: Phase I--Exploratory Borehole Drilling; Phase II--Hydraulic Backfilling. Execution of Phase II was contingent to a degree upon a successful Bureau evaluation of the results of the work conducted under Phase I.

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 proposed drill holes would help to establish the position of mine workings with relation to the surface.

Through Federal Government competitive contracting and bidding procedures, the contract to conduct both phases of the proposed work was awarded April 4, 1974, to the WHAN Engineering and Construction, Inc., Bismarck, N. Dak., the lowest bidder, in the amount of $666,667.00. Provisions were included in the contract to create a minimum of disturbance to the boom-town environment existing in downtown Rock Springs.

Phase I involved the drilling of exploratory boreholes throughout the proposed project area. Twenty-eight holes encountered mine openings, and although some caving had been noted, it was not believed to be sufficient to block effective movement of slurry. Depths to the mine voids ranged from about 30 to 160 feet, and alluvium depths ranged between 15 and 60 feet. Some of the holes intersected the mine-water pool, which helped to determine the location and depth of the pool in the project area. This information, in conjunction with a study of the mine map, gave direction on the best probable locations for water-supply wells, injection boreholes, and monitor holes. It was apparent also from the drilling that the remaining pillars in the project area were somewhat smaller than had been expected. The void space to be filled, therefore, was recalculated adding 15,000 tons of fill material to the previously estimated quantity for a new total of 165,000 tons. To accommodate handling the increased quantity, the contract was modified June 28, 1974, to increase the total contract amount to $680,167.00. An attempt to substantiate exploratory drilling findings of mine conditions by sonar surveys as in Project No. 1 was not deemed necessary in Project No. 2.

Under Phase II, two of the exploratory boreholes completed under Phase I were reamed to a larger size and converted to water-supply wells for the backfilling process. Twenty boreholes were cased with 4-inch-ID steel casing pipe and capped with removable pressure-tight covers to be used as monitoring boreholes.

Phase II also involved the installation of deep-well pumps, 1,300 feet of water-supply pipeline, the slurry injection plant, and some of the slurry distribution pipelines at sites designated by the Bureau of Mines on the right of way of the Union Pacific Railroad. At the request of the Bureau, the railroad company granted permission of the use of its property for water-supply wells

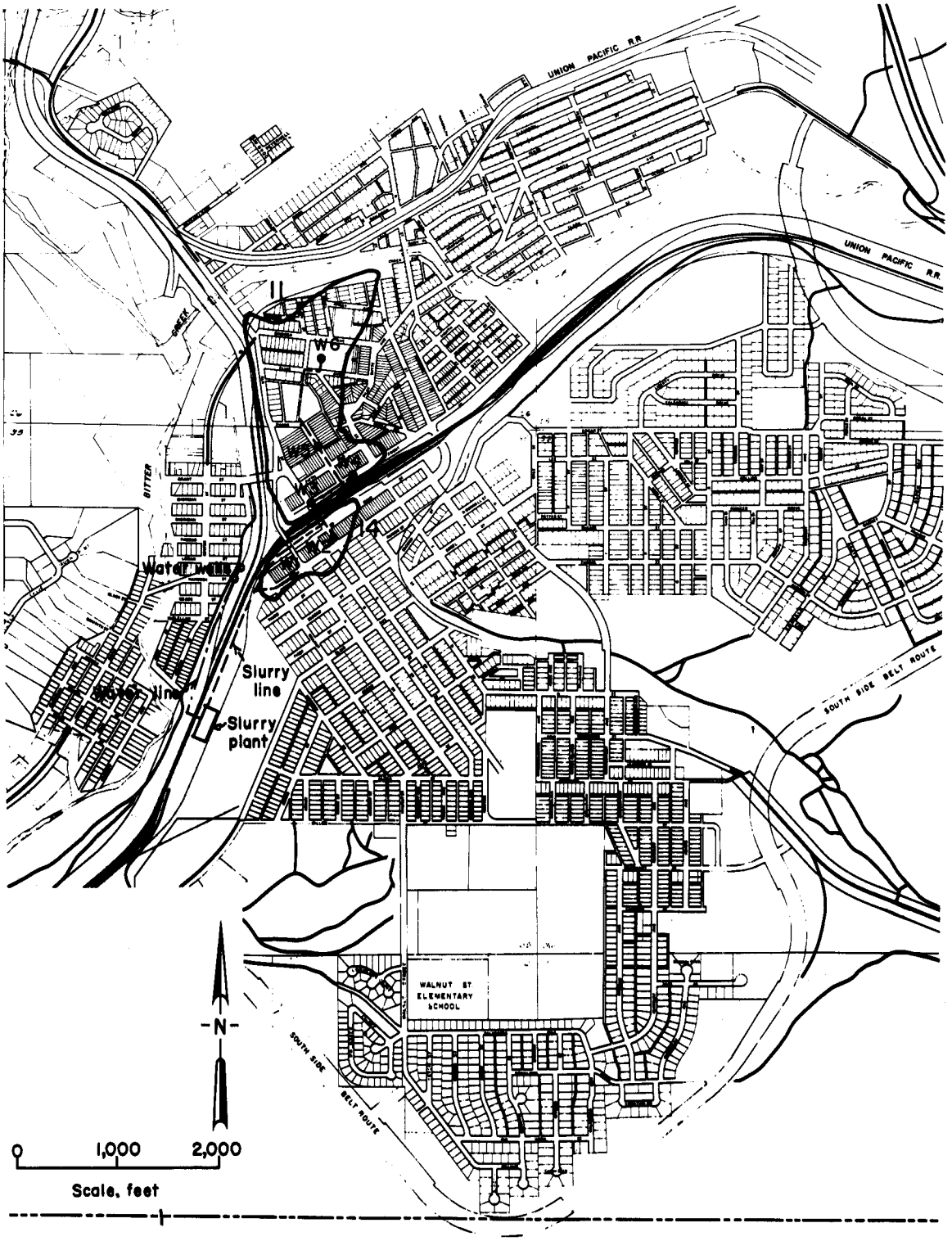

FIGURE 17. - Map of the project area showing location of the slurry plant in relation to water-supply wells and pipeline, slurry pipelines, and injection boreholes.

and much of the installation of the hydraulic backfilling facilities. The right of way was conveniently located to the project areas and provided adequate space for the operations, including room for a sand stockpile, such that the environmental impact upon the community was minimal. Use of the property for these purposes was formally arranged between the contractor and the Union Pacific Railroad. Slurrying and injections of solids into the mine voids began August 7, 1974. The location of the plant, pipelines, and injection boreholes are shown in figure 17.

Two deep-well pumps lifted the water from the mine at a minimum rate of 4,000 gpm and impelled it through about 1,300 feet of 14-inch-ID welded steel pipe to the site of the mixing plant. Two deep-well turbine pumps were used, one in each well, at points located 95 feet below the surface and 35 feet below the average mine-water pool level. The pumps were rated 4,000 gpm each at a dynamic head of 150 feet and driven by 200-hp electric motors. A part of the 1,300 feet of pipeline from the deep-well pumps to the mixing plant included crossing under the mainline of the Union Pacific Railroad. A 120-foot, 18-inch-diameter bore was used for this purpose with the permission of the railroad company.

Sand was obtained from a borrow pit on property of the Upland Industries Corp., Rock Springs, Wyo., and paid for by the Bureau at a rate of $0.10 per ton. Figure 18 is a view of equipment being operated at the borrow pit. The sand was screened to remove rock particles and other debris in excess of 5/8-inch size and loaded into 30-ton bottom-dump trucks, which hauled the sand 2.5 miles to the site of the mixing plant. The change to a larger size screen from that used in the first large-scale project reflected greater confidence in the pumped-slurry process and a saving in handling cost at the borrow pit.

The stockpiled sand was bulldozed into a hopper and fed onto a conveyor where it was weighed as it was being delivered to a mixing tank constructed of concrete. Water from the deep-well pumps entered the tank through a series of jets that created the agitation necessary to maintain the solids in suspension. During most of the time water for slurrying was used at the rate of 5,000 to 6,000 gpm. The sand, in slurry form, was taken from the tank through a suction line at the rates varying from 200 to 350 tons per hour by a horizontal centrifugal pump, capacity 8,000 gpm. The slurry, 10 to 20 percent solids by volume, was impelled by a 650-hp diesel engine through 14-inch-ID pipelines to the various injection boreholes. The engine supplied sufficient energy to overcome the friction in up to 4,000 feet of pipe and deliver the slurry to the top of the borehole at a pressure to 50 psi when required. Figures 19 and 20 are two views of the pumped-slurry mixing plant.

Pressures at the head of each injection borehole were usually in the vacuum range (less than atmospheric), a characteristic of the pumped-slurry process, because of the drop to the mine level. These pressures would sometimes rise momentarily above atmospheric pressure when the slurry pump was started at the beginning of a shift or when an occasional blockage occurred. Care was taken to stop the operation immediately when pressure increased during injection in a relatively shallow hole.

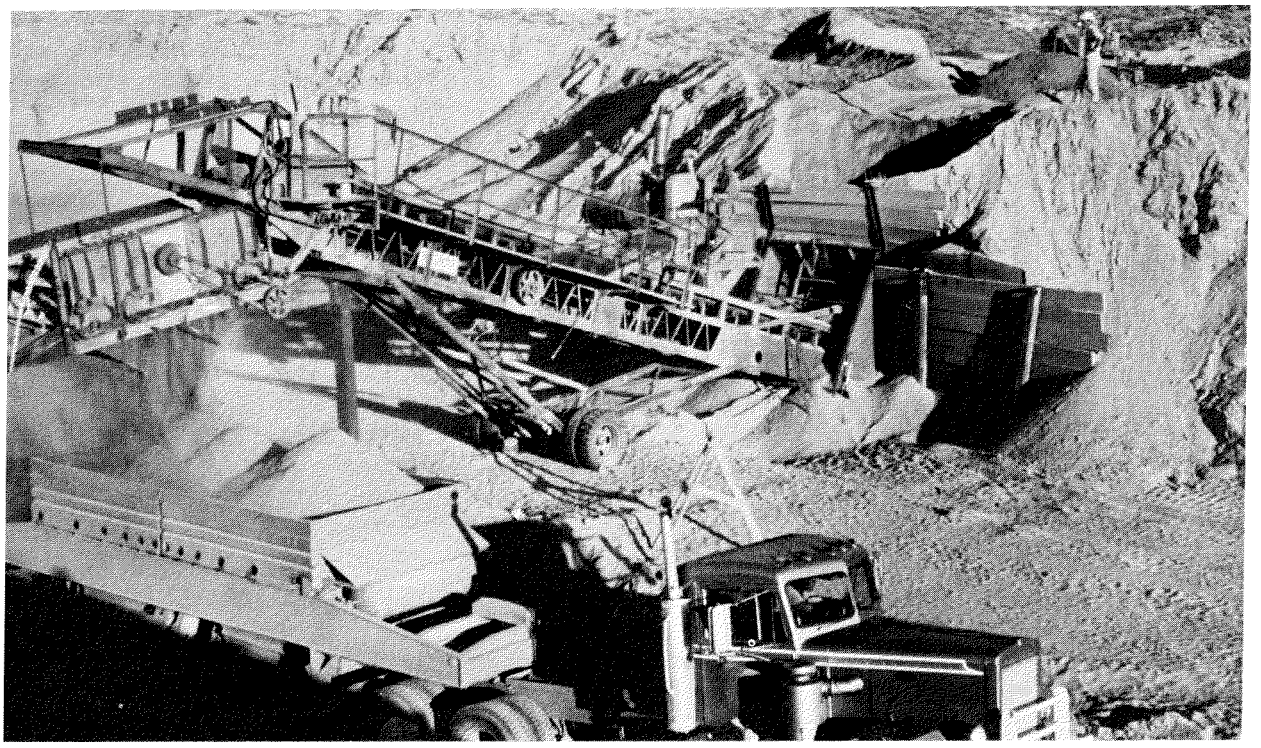

FIGURE 18. - View of earth-moving and screening equipment operations in the borrow pit.

FIGURE 19. - View of end of hopper, conveyor, slurry pump, diesel engine, pipelines and control building at mixing plant.

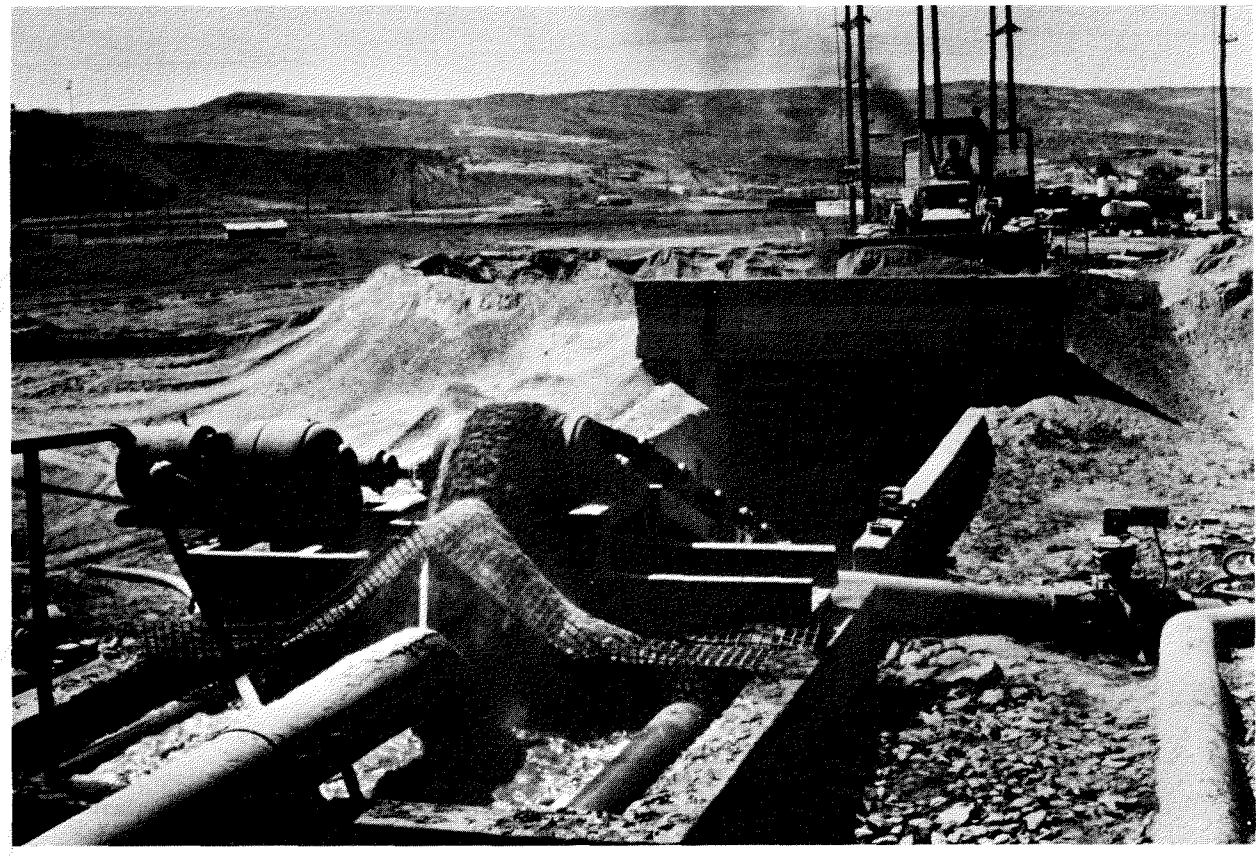

FIGURE 20. - View of mixing tank, suction line, sand being delivered to mixing tank, and bulldozer in the background pushing sand into hopper.

Of necessity, the slurry distribution pipelines were buried beneath the busier downtown streets; this included all intersections. On the less-traveled side streets the pipelines were laid along the curb or the side of the road where arrangements were made with property owners to permit the construction of ramps over the pipelines at entrances to driveways. To facilitate conveying slurry to injection boreholes in the downtown business district, it became necessary to lay the slurry pipeline under a spur of the Union Pacific Railroad at one point and under the mainline tracks at another. With permission of the railroad company, a 90-foot, 18-inch-diameter bore was provided for this purpose under the spur track. The crossing under the mainline tracks was accomplished by installing the slurry pipeline through the existing pedestrian underpass. (See fig. 21.)

In fiscal year 1975 and during Phase II, Congress appropriated an additional $500,000 for the Bureau of Mines to conduct further backfilling operations in Rock Springs, Wyo. This increase in funds provided an excellent opportunity for the Bureau to continue the backfilling of voids under and adjacent to critical area 11. It became apparent during Phase II that the voids under the southern and middle portions of critical area 11 were accepting far more sand than the calculations indicated. The excess was undoubtedly moving into old workings west of area 11 where surface support was also needed.

FIGURE 21. - View of the installed slurry pipeline in the pedestrian underpass beneath the mainline tracks of the Union Pacific Railroad.

The additional funds, however, were not sufficient to warrant contracting for a new backfilling project because at least $300,000 would be required to purchase and make operable the equipment comprising a new injection plant. It became expedient, therefore, to renegotiate the existing contract with WHAN Engineering and Construction, Inc., and utilize the newly available funds almost exclusively for backfilling mine voids.

On November 7, 1974, the contract was modified in the amount of $470,000.00, making the following negotiated changes and additions to the contract:

1. The contractor shall continue to pump slurry into the coal mine voids at the contract unit price of $0.90 per ton until the quantity of material placed amounts to 175,000 tons (original contract).

2. After the contractor accomplishes the work described in item 1 above, he shall then pump an additional estimated amount of 156,666 tons of slurry into the coal mine voids at a new unit price of $3.00 per ton.

3. At the conclusion of the contract, as modified, the entire pipeline system, including all piping, both surface and underground, two bypass valves,

two squeeze valves, and the connector into the tub, which would have reverted to WHAN Engineering and Construction, Inc., under the original contract shall become the property of the Bureau of Mines and all rights, title and interest in and to said pipeline shall vest in the Bureau of Mines free of all encumbrances and liens.

Acquisition of the pipeline system compensated the Bureau to some extent for the increased unit cost per ton of injected material. Moreover, it was anticipated that the newly acquired pipeline system would be used by the Bureau in implementing a future backfilling contract at Rock Springs.

This second contract modification increased the total contract amount from $680,167.00 to a new total of $1,150,167.00; increased the estimated injected fill material quantity from 165,000 tons to 331,666 tons; and increased the estimated project area from 28 acres to 54 acres to include most of area 11 (see fig. 16). On May 29, 1975, the contract was modified a third time in the amount of $50,000 to make a new contract total amount of $1,200,167.00; whereby the estimated quantity of fill material injected was increased by an additional 16,667 tons to make a new estimated total of 348,333 tons.

When the project was completed June 26, 1975, an actual total of 348,427 tons of solids had been injected into two project areas of the No. 1 Seam mined coalbed. The total surface area overlying the backfilled portion of the coalbed was estimated to be approximately 55.2 acres. Six injection boreholes were used in the backfilling. Injection boreholes W-3, W-5, and W-6 were located in inundated mine areas and boreholes W-1, W-2, and W-4 in dry areas. A total of 110,111 tons of sand was injected into dry voids.

During the backfilling operation coincidental pothole-type subsidences occurred under and near the mainline tracks of the Union Pacific Railroad. These mine areas were not included in the original project because they were thought to have been isolated by rock-wall barricades constructed underground and effectively filled earlier by the mining company. Bureau engineers designed and coordinated a backfilling subproject between the Bureau contractor and the railroad company, whereby a 6-inch spur pipeline was constructed off the main 14-inch-diameter slurry line to fill the isolated mine voids. Approximately 5,300 tons of sand was successfully injected through a 1,200-foot plastic pipeline into nine 6-inch-diameter injection boreholes, filling the isolated mine voids to refusal with the water draining away through the old barricades. The progress of backfilling is summarized in table 3.

TABLE 3. - Injection data on the second large-scale demonstration project, 1974-75

Project area and acreage	Injection borehole	Approximate injection periods	Total injections, tons
14, 8.20 acres.....	W-1.....	Aug. 7, 15-18, 21, and Sept. 17, 1974.	13,175
	W-2.....	Aug. 7-15, 18-19, 21, and Sept. 18-20, 1974.	24,802
11, 46.00 acres.....	W-3.....	Aug. 22-Sept. 14 and Sept. 21-22, 1974.	62,023
	W-4.....	Oct. 3-9, 13-26, and Nov. 15-16, 18-21, 1974.	66,834
	W-5.....	Sept. 28-Oct. 2, Oct. 26-Nov. 3, and Nov. 7-13, 1974.	97,866
	W-6.....	June 3-26, 1975.....	78,427
Union Pacific Railroad, 1 acre.	9 holes..	Oct. 13-25 and Nov. 8-9, 12, and 15-16, 1974.	5,300

Backfill material was distributed in the mine workings throughout an area of approximately 55.2 acres, according to observations from the monitoring boreholes. As in the previous project the presence of fill material in monitor holes at levels higher than the roof indicated that filling of the mine workings within the 55.2-acre area was essentially complete from floor to roof. The only place within the confines of the planned project area that the existence of fill is questionable was in dry mine voids along the north side of the railroad tracks between injection boreholes W-3 and W-4, where some suspected dead-ended updip mine rooms exist and/or mine workings are located updip from the injection boreholes in such a position that the gravity flow of the material prevented filling in the area. In addition the previously mentioned underground barricades referred to during the backfilling under the Union Pacific Railroad tracks may also have prevented filling in this small area (about 2 acres). Except for this, the estimated extent of the backfilled area is consistent with the estimated volume of void space in the mined bed and with the quantity of fill material that was injected.

The cost of the hydraulic backfill demonstration project contract, in which 348,427 tons of sandfill material was injected, was $1,200,164.07. In addition, $34,842.70 ($0.10/ton) was paid to Upland Industries Corp. for the acquisition of the sandfill material. The total cost of the project was $1,235,006.77 or $3.54 per ton. This can be compared with the $5.07 per ton cost of the previous large-scale demonstration project.

The demobilization of the operation, including cleanup and restoration of all project work areas, was conducted in accordance with the contract specifications. Although it was situated on private land, restoration of the borrow pit was completed in accordance with the stipulations set forth by the Bureau of Land Management and included seeding of the borrow area in fall 1975 and a

verification inspection of the satisfactory growth after one complete growing season in fall 1976.

PROJECT 3, WITH A MANAGEMENT SUPPORT CONTRACT

In fiscal year 1976 Congress appropriated $1,500,000 for the Bureau of Mines to continue utilizing the pumped-slurry backfilling process in areas of Rock Springs, Wyo., where surface support would be beneficial to the city.

The sites selected for this, the third large-scale subsidence control project in the city, included critical areas 2, 9, 10, 12, 13, and 15 and the remaining portion of area 11. The objective of the project was to fill flooded and dry abandoned coal mine voids in the No. 1 and No. 7 Seams with solid material to support mine overburden and alleviate potential damage to surface structures, streets, and utilities. To accomplish this objective, it was estimated that approximately 350,000 tons of sand would be needed to fill the flooded and/or otherwise inaccessible mine voids beneath the critical areas enumerated above, a total area of about 90 acres. Figure 22 is a map of a portion of Rock Springs showing the location of the critical areas included in the project.

In planning for the project, the Bureau decided that extensive drilling operations to provide monitoring could be dispensed with because the nature of the pumped-slurry filling process had been made apparent in earlier projects and was predictable in similar circumstances. Information as to the position and attitude of the coal seams was determined from the drilling of numerous boreholes. Depths to the mine voids ranged from 64 to 293 feet, with depths of alluvium ranging from 15 to 60 feet. Only seven boreholes encountered mine voids, and these were used for both injection and monitoring. The money saved in this manner was diverted to filling more of the mine voids. Appreciable savings would also accrue to the project because two water wells, two injection boreholes, and some of the pipelines, which had reverted to the Bureau of Mines from the previous project (WHAN), would be made available to the contractor for the third large-scale project. Moreover, because some of these facilities remained on property of the Union Pacific Railroad and in strategic position with respect to the project areas, the Bureau indicated in the contract specifications that the slurry injection plant, sand stockpile, and some of the slurry distribution pipelines be established in the same general area as in the previous project. In due course, the project contractor made satisfactory arrangements with the railroad company in order to comply with the specifications.

Procurement of a contractor to do the specified work was again carried out under Federal Government competitive contracting procedures. On May 28, 1976, a contract to do the work was awarded to M. J. Bober Co., Littleton, Colo., in the amount of $1,043,650.00. This was increased by $1,353.00 to pay for the lease of the plant site on railroad property. Work on the contract was started June 4, 1976. Mobilization included preparation of a borrow pit, drilling to establish injection boreholes, and repair and modification of an existing water supply system, and pipelines. A mixing plant, slurry pumps, and recording equipment were also furnished and installed by the contractor.