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

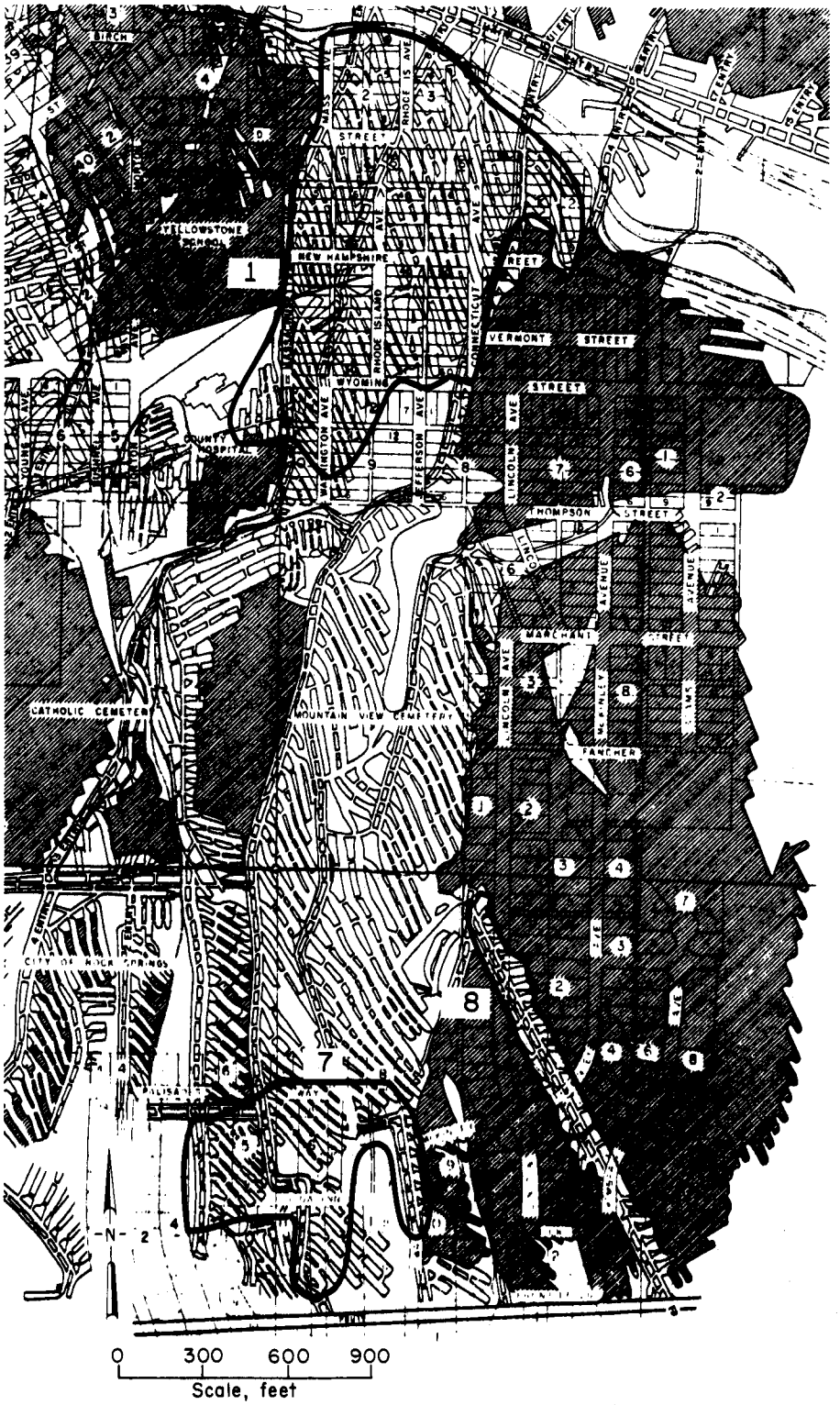

FIGURE 13. - Map of a portion of Rock Springs showing locations of critical areas 1, 7, and 8 in relation to mine workings of the No. 7 Seam.

Government competitive contracting and bidding procedures, awarded a drilling contract on January 26, 1973, to the Delta Drilling and Development Co., Dana, Ind., in the amount of $39,636.00. Forty usable boreholes, large enough to accommodate 4-inch-ID plastic casing, were eventually drilled in the project areas to provide the necessary information. Depths to the mine voids ranged from 85 to 272 feet, and alluvium ranged between 10 and 45 feet. Actual cost of the work was $37,707.02. Under the ensuing backfilling contract, eight of the boreholes were reamed to larger sizes to provide water-supply wells and injection boreholes. The remaining 32 boreholes were used to monitor the backfilling progress.

As in the earlier test project, it was believed that while the exploratory drilling provided approximate vertical depth of the void at each borehole, the lateral extent of the voids was not apparent. The Bureau, therefore, employed the Dowell Division of the Dow Chemical Co. to explore the extent of mine passageways between boreholes with "Sonar Caliper" surveys. Eleven boreholes were probed with the instrument, which confirmed to some extent the continuity of the voids. The cost of the work was $5,135.15.

Through competitive contracting procedures, the Bureau, on June 4, 1973, awarded a pumped-slurry backfilling contract to the Dowell Division of the Dow Chemical Co. in the amount of $721,777.50 to provide surface support under areas 1, 7, and 8. The contract was modified on June 29, 1973, to allow for the drilling, casing, and cementing of a necessary alternate injection borehole, increasing the total contract amount by $7,924.00 to a new total of $729,701.50.

During the mobilization and installation of equipment, the contractor elected to locate the injection plant at the borrow site rather than use trucks to haul the sand about 1-1/2 miles to the Bureau's suggested plant site location. This of course involved pumping the slurry directly from the borrow site through a network of pipelines an average distance of 2.1 miles to the injection boreholes. Other work included under mobilization involved preparation of the borrow pit, installation of the water-supply system, erection of the injection plant facilities, and construction of the 14-inch-ID slurry pipeline. At this time, the injection boreholes were also provided and suitably capped to await being used. The slurry injection was started August 24, 1973.

Two submersible water pumps were installed, one in each of the two water wells just north of critical area 1. The pumps were 137 feet below the surface and about 35 feet below the average mine-water pool level. The pumps were rated at 4,000 gpm each, at a dynamic head of 150 feet, and were driven by 200-hp electric motors. The water was pumped from the pool in the No. 7 Seam and impelled with the aid of a 1,200-hp, diesel-powered booster pump through 1-1/2 miles of 14-inch-ID steel pipeline to the mixing plant at the borrow site. Because of the friction head in the relatively long pipeline, only an average of 3,600 gpm was delivered to the mixing plant.

The sandfill material was obtained from a nearby deposit on Federal land controlled by the Bureau of Land Management (BLM). This designated site was

made available to the contractor through a "Free Use Permit" between the BLM and the Bureau of Mines. Removal of the fill material and subsequent reclamation of the borrow site was conducted in accordance with the stipulations required by the BLM, which were made part of the demonstration project specifications by an amendment. Adequate screening equipment was installed to reject rock particles larger than one-half inch as well as other foreign debris.

At the borrow pit sand was loaded by bulldozers and scrapers into a hopper and fed through a reciprocating plate onto a conveyor, then weighed as it was being delivered to the steel mixing tank. Water from the submersible pumps entered the tank through a manifold and a series of nozzles producing sufficient turbulence to maintain the solids in suspension. The slurry pump, of high-chrome cast iron, was a 1,200-hp, diesel-powered, centrifugal dredge service pump, capable of pumping slurry at a rate of 8,400 gpm at a head of 175 feet. Figure 14 is a view of the slurry injection plant at the site of the borrow pit. Although the slurry was transported slightly down-grade, the friction head that developed in the long pipelines reduced the volume of slurry delivered to the injection holes to an average of about 4,000 gpm.

The slurry distribution pipelines were buried beneath the busier streets and intersections to minimize the impact on traffic. On less-traveled streets they were laid along curbs where arrangements with property owners permitted construction of ramps over pipelines at entrances to driveways. The locations of the water-supply wells, the water-supply pipeline complete with booster pump, the borrow pit, injection plant, housing for recording and control equipment, slurry distribution pipelines, and injection boreholes are shown in figure 15.

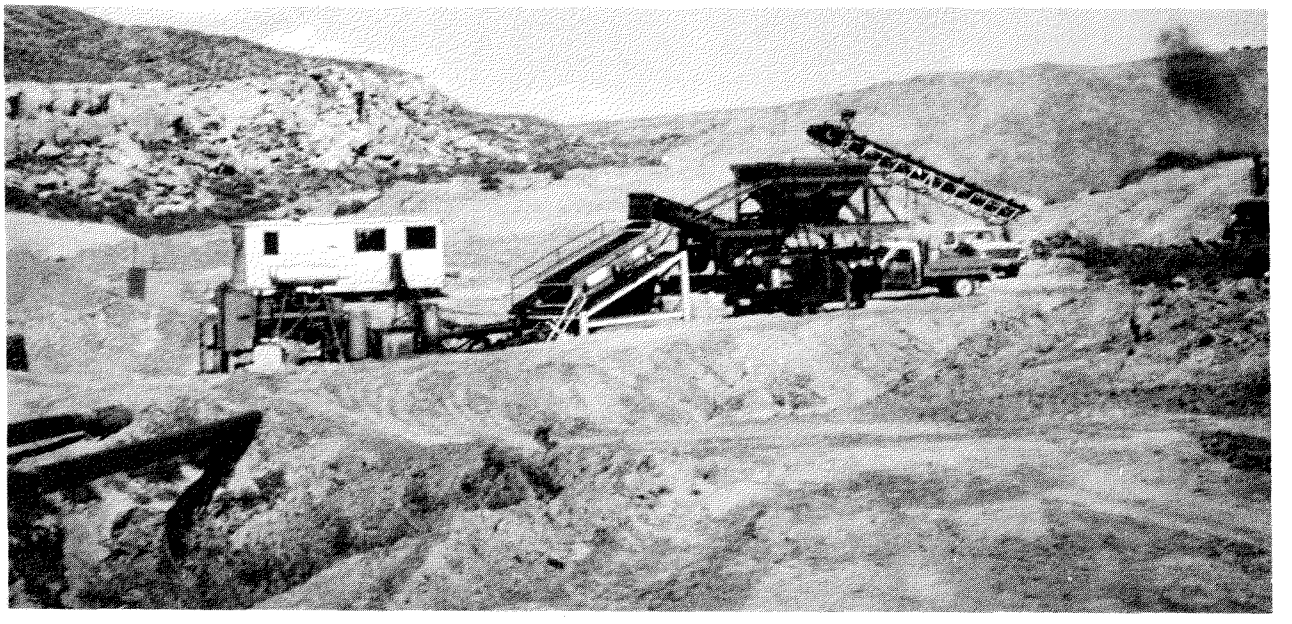

FIGURE 14. - View of the slurry mixing plant installation at the site of the borrow pit about 2 miles from the built-up areas of the city. Note natural rock outcropping in left background off project limits and slurry pipeline in left foreground.

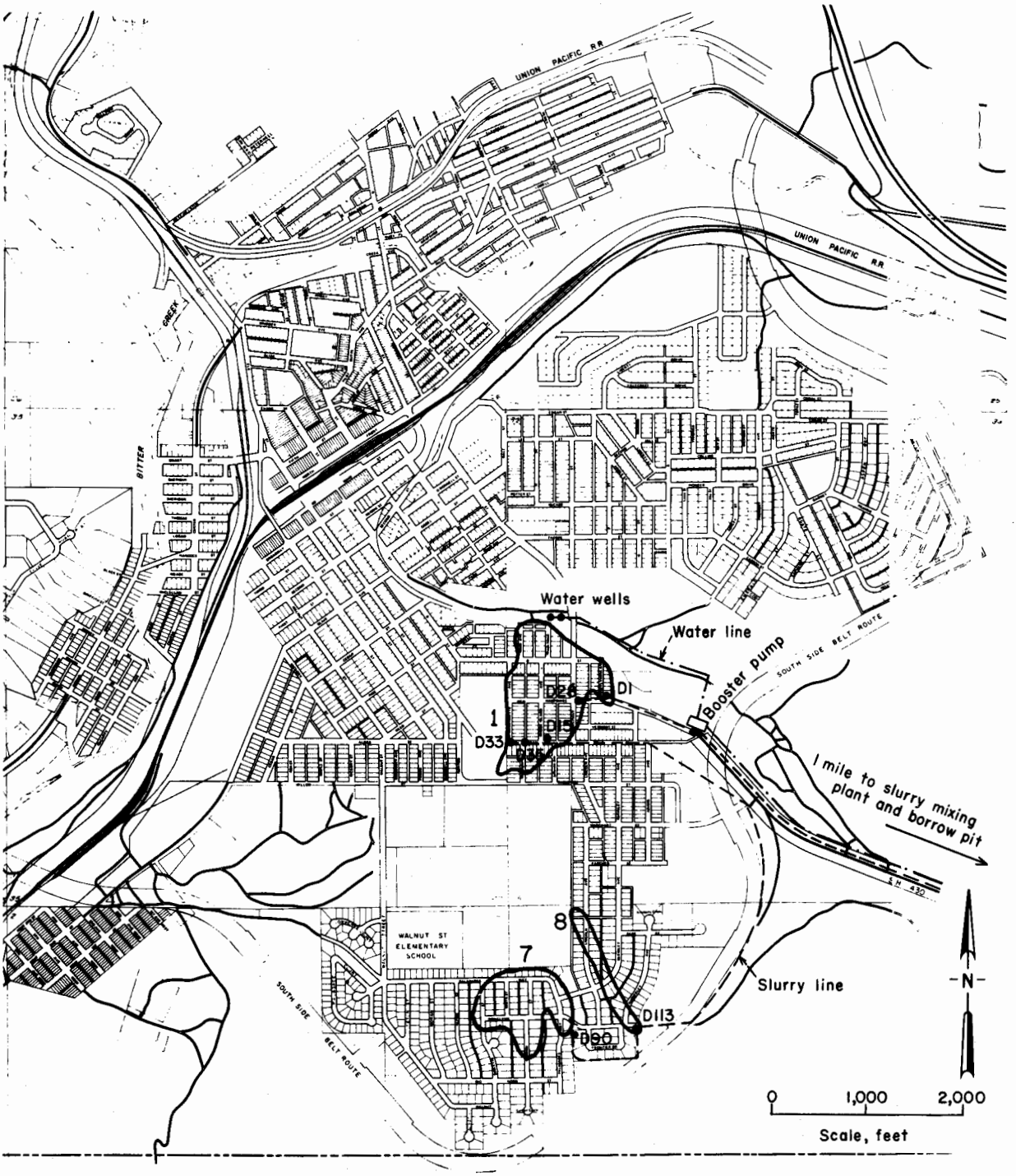

FIGURE 15. - Map showing location of water-supply wells and pipeline, slurry pipelines, and injection boreholes in relation to critical areas 1, 7, and 8. (The distance to the injection plant at borrow pit is indicated.)

A total of 152,467 tons of solids was injected into the three separate areas of the No. 7 mined coalbed. The total surface area overlying the backfilled portions of the coalbed was estimated to be approximately 33.2 acres. Seven injection boreholes were used in the backfilling. Injection boreholes D-33 and D-35 were located in inundated mined areas and boreholes D-15, D-1, D-28, D-90, and D-113 in dry areas. A total of 62,119 tons of fill material was injected into inundated mine voids, and a total of 90,348 tons was injected into dry voids. The progress of backfilling is summarized in table 2.

TABLE 2. - Injection data on the initial large-scale demonstration project, 1973-74

Project area and acreage	Injection borehole	Approximate injection periods	Total injections, tons
1, 21.10 acres	D-33.....	Aug. 24-Sept. 10, Sept. 17-19, 1973...	54,726
	D-15.....	Sept. 10-17, 22-24, 1973.....	15,914
	D-35.....	Sept. 19-22, 25-26, 1973.....	7,393
	D-1.....	Sept. 24-25, 1973.....	1,105
	D-28.....	Sept. 25, 1973.....	1,579
7, 3.90 acres	D-113....	Oct. 3-13 and Nov. 11-12, 1973.....	26,054
8, 8.30 acres	D-90.....	Nov. 12-18, 1973, and Apr. 2-28, 1974.	45,696

The slurry operation began on August 24, 1973, and was completed on April 28, 1974. Two major interruptions in the operation were experienced:

1. Breakdown and subsequent overhaul of the diesel engines operating the water-supply booster pump and slurry pump, resulting in downtime October 14 through November 11, 1973.

2. The shutdown of operations in anticipation of severe winter conditions that would cause the freezing of pipelines, valves, etc., from November 18, 1973, through April 1, 1974.

Backfill material was distributed in the mine workings throughout the three critical areas, comprising about 33.2 acres, as indicated by observations of the 32 monitoring boreholes. The presence of fill material in monitor holes at or above mine-roof levels indicated that filling of the mine voids within the project areas was essentially complete from floor to roof. The estimated extent of the backfilling in the three areas is consistent with the computed volume of void space in the mine workings and with the quantity of fill material that was injected. Undoubtedly some fill material extends beyond the limits of the completely filled voids where it would be expected to conform to the submerged angle of repose of the sand, about 30°.

In the three project areas, the dip of the No. 7 Seam ranged up to 5°. The monitoring results, which were later confirmed by laboratory model studies (see appendix), indicated that in inundated voids the water serves as a flow medium yielding a balanced updip-downdip distribution pattern. When it became

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.