2. National Lifeline Inventory

2.1 Introduction

Development of the ATC-25 inventory, for all major lifelines in the United States, was a major task. The project scope required that lifelines be inventoried in sufficient detail for conducting lifeline seismic vulnerability assessments and impact of disruption at the national level. This in turn required that the inventory be compiled electronically in digital form and dictated that inclusion of lifelines at the transmission level, as defined below, was of primary importance. At the same time, the level of effort that could be devoted to this task was constrained by the budget available.

Initially, a number of government, utility, trade and professional organizations, and individuals were contacted in an effort to identify nationwide databases, especially electronic databases. In most cases, these organizations or individuals referred the project back to FEMA, since they had either previously furnished the information to FEMA, or knew that the data had been furnished to FEMA by others. As a result, FEMA's database (FEMA, 1987) became a major source of data for several of the lifelines. A significant portion of these data consist of digitized U.S. Geological Survey (USGS) topographical maps and/or the National Atlas (Gerlach, no date), performed by the U.S. Geological Survey in support of national census requirements. With the exception of oil and gas pipeline data provided by the National Petroleum Council, the inventory data generally date from about 1966, unless later updated by FEMA. A number of other sources were employed in various ways, which are further discussed below.

The network inventory contained in the database is generally at the higher transmission levels, as opposed to lower distribution levels. That is, inventories were generally only compiled for networks at the bulk and/or regional level, as opposed to lifelines at the user-level (i.e., distribution level) *within* an area. To use an analogy, the inventory contains only the national *arterial* level, and neglects the distribution or *capillary* system. For example, all federal and state highways are inventoried, but county and local roads are not. The major reason for focusing on the transmission level is that at lower levels the systems only support local facilities. Thus, a disruption of a local activity could not be used to identify the overall regional importance of the lifeline. However, disruptions at the transmission level impact large regions and are therefore important for understanding the seismic vulnerability and importance of lifelines to the United States. For some lifelines, such as highways and railroads, an additional reason for focusing on the transmission level is the increasing redundancy that contributes to system reliability as one descends in the lifeline hierarchy. Lastly, even at the transmission level, the inventory effort alone is considerable.

The inventory data have been compiled into an electronic database, which generally consists of (i) digitized location and type of facility for single-site lifeline facilities, and (ii) digitized right-of-way, and very limited information on facility attributes for network lifelines. The inventory is only a partial inventory, in that important information on a number of facility attributes (e.g., number or length of spans for highway bridges) was unavailable from FEMA.

2.2 National Lifeline Inventory Data--Overview

The inventory data include information for the conterminous United States only. Lifeline data for Alaska, Hawaii, and U. S. territories, such as Puerto Rico, have been excluded because lifelines in these regions would not be affected by the scenario earthquakes (see Chapter 4) considered in this study.

The specific lifelines that have been inventoried for the conterminous United States are:

Transportation
- Highways
- Railroads
- Airports
- Ports and Harbors

Energy
- Electric Power Transmission
- Gas and Liquid Fuel Transmission Pipelines

Emergency Service Facilities
- Emergency Broadcast Facilities
- Hospitals

Water Aqueducts and Supply

An important lifeline, telecommunication systems, which would be severely impact by earthquake-induced ground shaking, was excluded because of the unavailability of data, as are certain regional distribution network facility types (e.g., railway terminals, bridges, and tunnels; certain aqueducts; major freeway/highway bridges; fossil-fuel power plants; and aqueduct pumping stations). In addition, data on nuclear reactors and dams are excluded because it was believed that such facilities should be the subject of special studies, particularly because of the existing regulations relating to seismic safety in many regions and the expected complexity of the performance and impact of these facility types. As a result, the losses provided by this study will be underestimated to the extent that these facility types are not included.

Also excluded from the inventory, but included in the analysis, are distribution systems at the local level (water, highway, and electrical systems) and police and fire stations. For these facility types, the number of facilities in each 25-km by 25-km grid cell, which is the grid size for the seismic hazard analysis (see Chapter 4), is estimated on the basis of proxy by population.

Each of the above-specified lifelines has been inventoried in terms of its nodes and/or links. Nodes are points on the lifeline, connected by links. Examples of nodes are highway intersections and electric substations. Links would be sections of highway, sections of pipeline, or electric transmission lines. Intermediate points between links have been introduced in some lifelines to provide better location information on the path of a lifeline (i.e., to capture path curvature between nodes).

The data were compiled and reduced on a graphical interactive lifelines seismic risk analysis/database management computer program named *LLEQE** (*LifeLine EarthQuake Engineering*). Two operations were required: (1) reduction in the number of links by a factor of about ten to reduce the size of the database to a manageable size for analysis (i.e., minor curvatures at the local level have been eliminated), and (2) continuity corrections so that transmission lines between separately digitized sections (e.g., across state boundaries) would be continuous. The reduction effort was substantial and utilized a significant portion of the financial resources allocated to the inventory task.

The inventory was generally compiled in terms of nodes, links, and descriptive attributes, if available. These attributes are:

1. Measures of lifeline inventory, appropriate to the lifeline. These are, for example:
   - Miles of oil pipeline, by diameter;
   - Number of electric substations;
   - Miles of water pipeline; and
   - Number of emergency facilities, such as hospitals, fire stations.
2. Additionally, where available, measures of function and redundancy have been compiled on this database. For transmission line links, these include:
   - The capacity of the lifeline and/or the population served;
   - The end points of the nodes; and
   - Whether the nodes are served by other links.

Each of the inventoried lifelines, as well as those estimated by proxy, are discussed below.

2.3 Transportation Data

State and Federal Highway System. A comprehensive national digitized data set on the highway system was obtained from FEMA, as shown in Figure 2-1. The system includes state and federal highways, but excludes county and local roads. It consists of 27,761 links (about 489,892 km of highways). Right-of-way

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alignment is indicated, but capacity (i.e., number of lanes) is not.

Local Highway Distribution. Detailed highway networks at the local level were not readily available in an electronic format. Based on statistics provided by the California Department of Transportation, we have determined that there is approximately 1 mile of local roadway for every 300 persons. This would correspond to approximately 15 feet of local roadway per person.

Federal and State Highway Bridges. Figure 2-2 shows 144,785 bridges, which have been obtained from FEMA's database. Bridges included are those for state and federal highways. Number of spans and structure types were not available.

Railroad System. This system shown in Figure 2-3 consists of about 11,340 links (about 270,611 km). The railroad system was provided by FEMA in digitized form; only right-of-way was indicated.

Airports. Locations of 17,161 civil and general aviation airports were provided by FEMA, as shown in Figure 2-4.

Ports and Harbors. Location information only for about 2,177 ports was provided by FEMA, as shown in Figure 2-5.

2.4 Energy and Fuel Data

Electric Power Generation and Transmission. The electric system provided by FEMA included 230 kV and above and some 115 kV systems (Figure 2-6). The inventory contains 4,551 substations, and 27,372 links, including links used to define path curvature between nodes (about 441,981 km of transmission lines). The number of circuits, and their voltage or capacity, however, are not included in the database. While the lack of capacity information has not been a serious limitation for this study, as discussed elsewhere, we recommend that users of this inventory data seek to add capacity information before using the data to conduct regional or local studies.

Local Electrical System Distribution. Detailed electrical distribution networks at the local level were not readily available in an electronic format. It was assumed, therefore, that the person-to-unit-length ratio for electrical distribution systems was the same as that for highways. In other words, there is approximately 1 mile of electrical distribution line for every 300 persons. This would correspond to approximately 15 feet of electric line per person.

Gas and Liquid Fuel Transmission Pipelines. The National Petroleum Council (NPC, 1989) furnished relatively comprehensive national digitized data on oil and gas pipelines, including size and material of piping. Figures 2-7, 2-8, and 2-9 picture the crude oil, refined oil, and natural-gas pipelines, respectively. The crude oil system includes about 77,109 km of pipelines. The refined oil system consists of about 85,461 km of pipelines and natural gas system has about 67,898 km of pipelines. The database had been developed as part of a major study on the transportation and capacities for this important sector of the economy, and potential catastrophic disruptions (NPC 1989; it is interesting to note that earthquake was not considered as a possible source of disruption in this study).

Refineries. Figure 2-10 shows 19 refineries nationwide having capacities of 80,000 barrels or more per day (the size considered in this study). Locations of these refineries have been digitized from the National Atlas (Gerlach, no date).

2.5 Emergency Service Facility Data

Emergency Broadcast Facilities. The locations of 29,586 stations were obtained from FEMA and are shown in Figure 2-11.

Medical Care Centers. Locations of about 6,973 centers were obtained from FEMA's database and are shown in Figure 2-12. Structural types were not available.

Police and Fire Stations. Detailed information was not available for these facilities. They were estimated as follows:

Fire Stations. Detailed nationwide fire station inventory data were not readily available in an electronic format. Data for the San Francisco and Los Angeles region fire stations were available (AIRAC, 1987) and were correlated with jurisdictional population to determine a relation, which

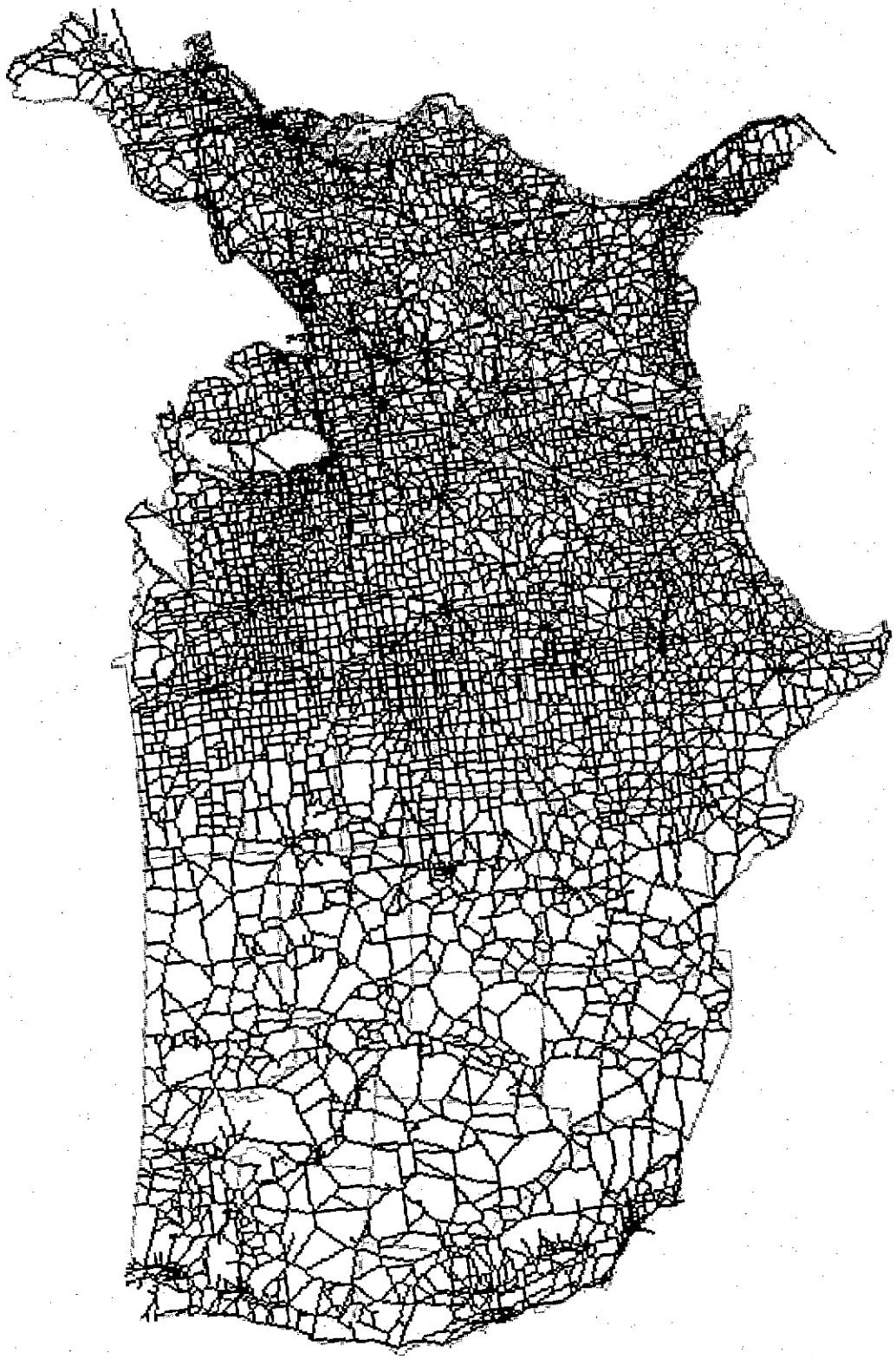

Figure 2-1 *State and federal highways.*

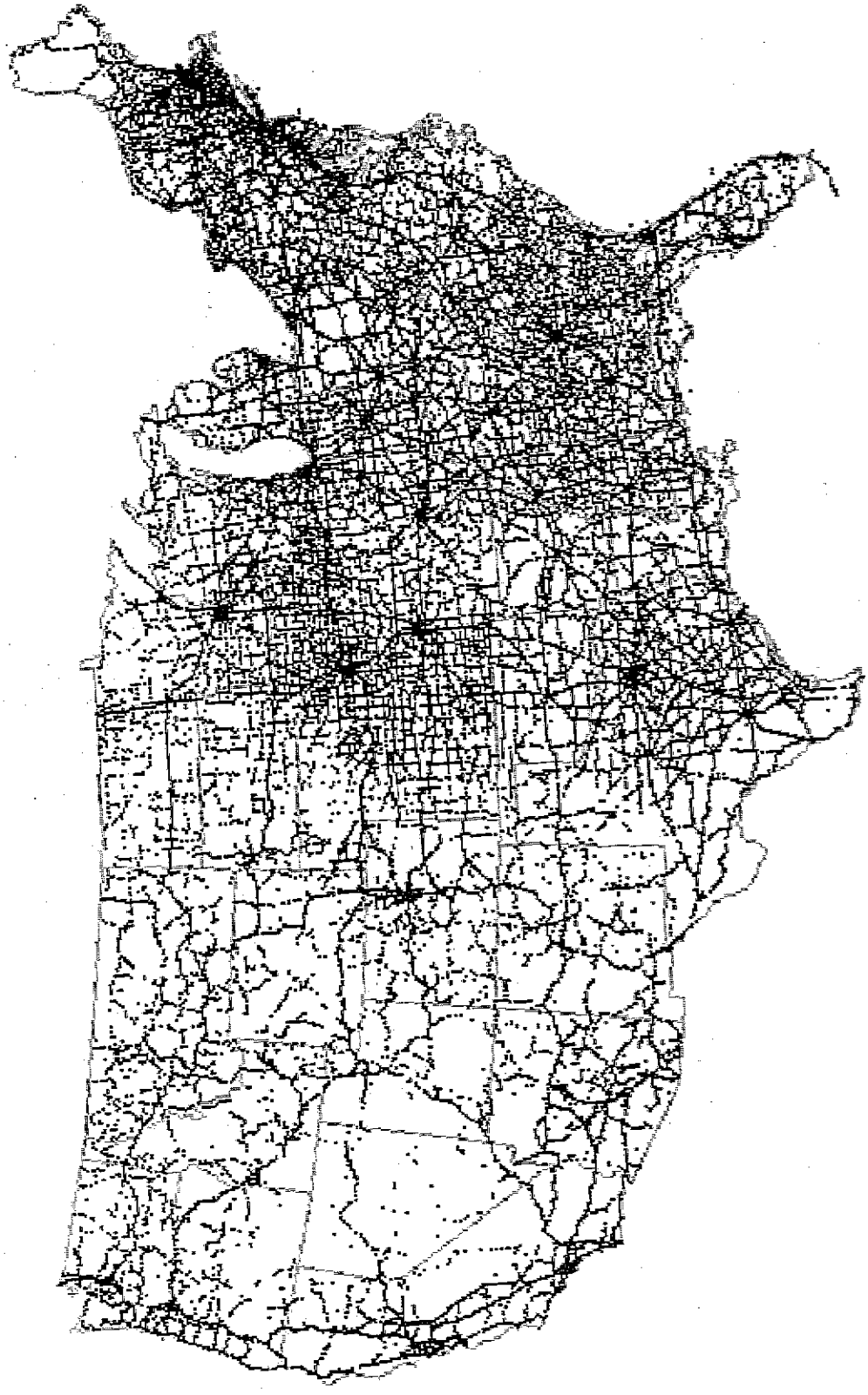

Figure 2-2 *State and federal highway bridges.*

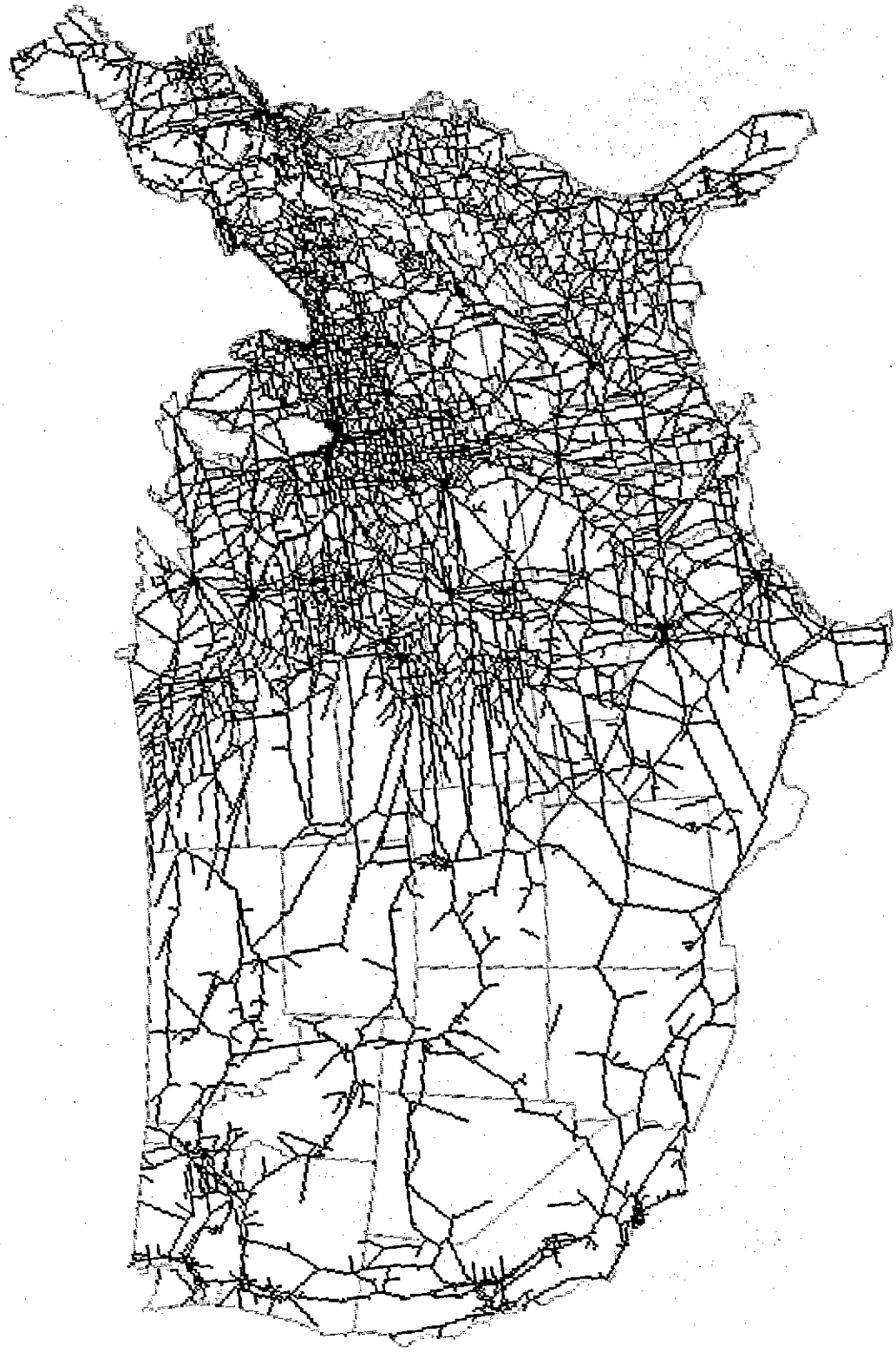

Figure 2-3 *Railroad system.*

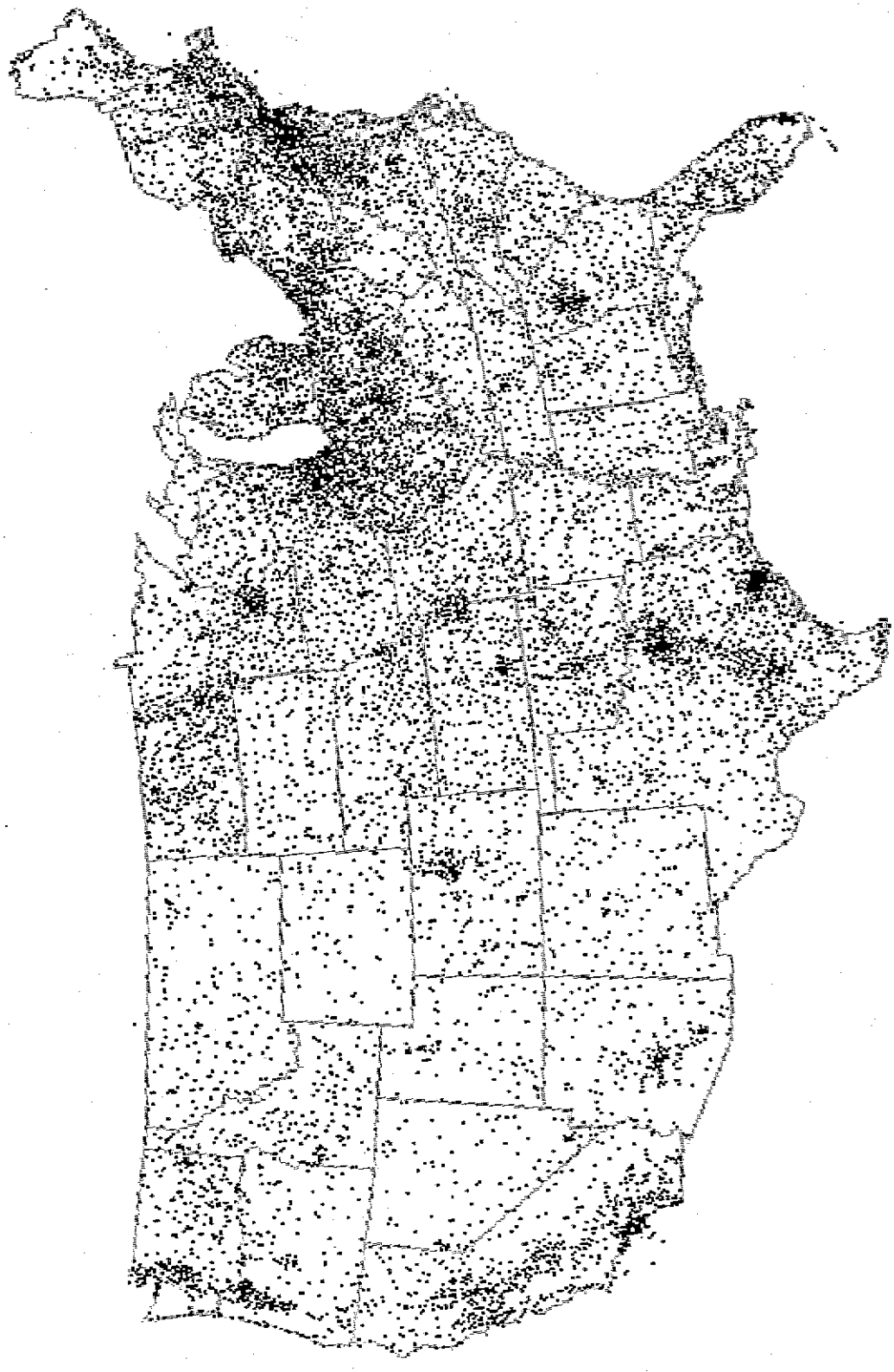

Figure 2-4 Airports.

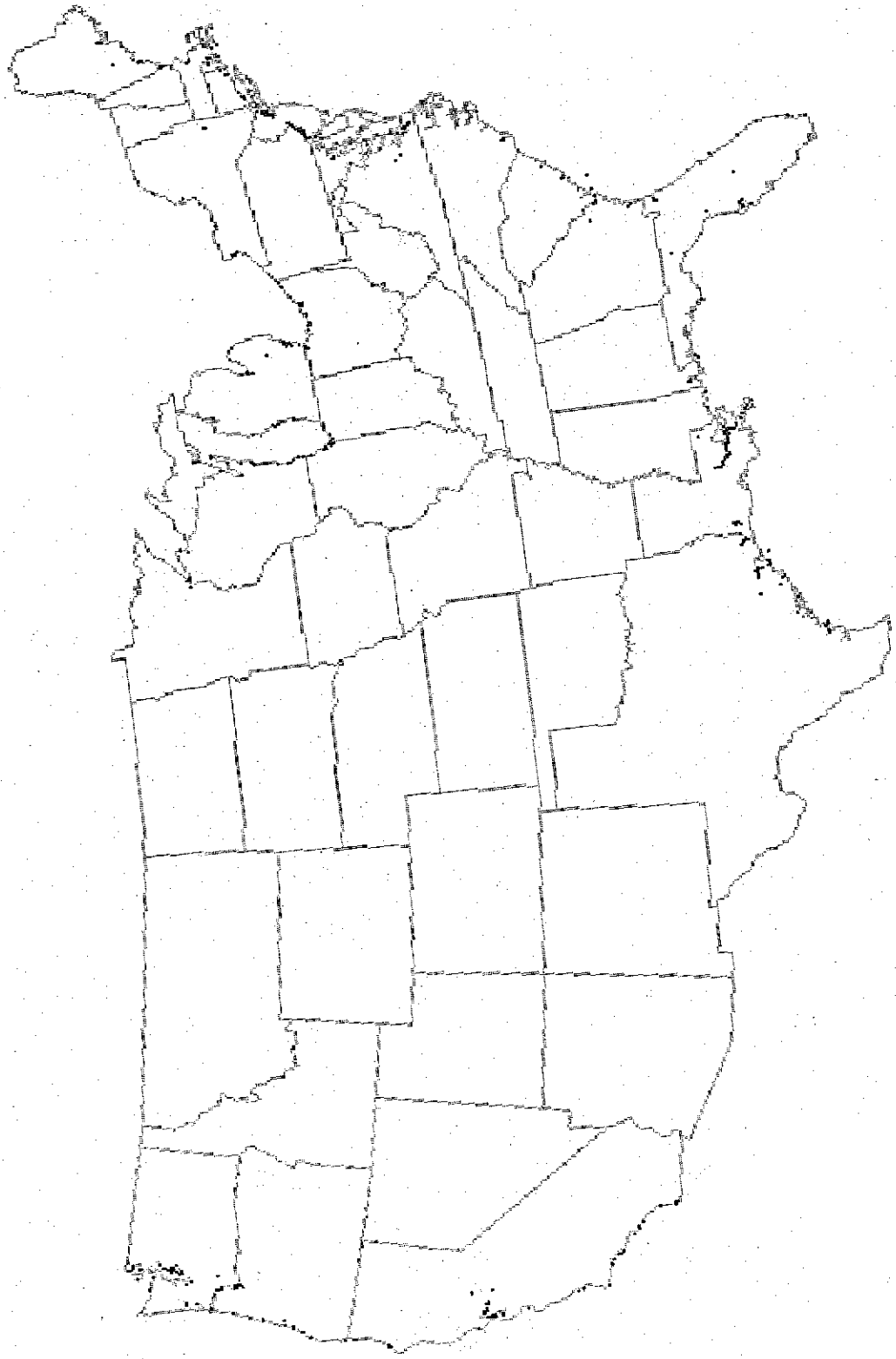

Figure 2-5 *Ports and harbors.*

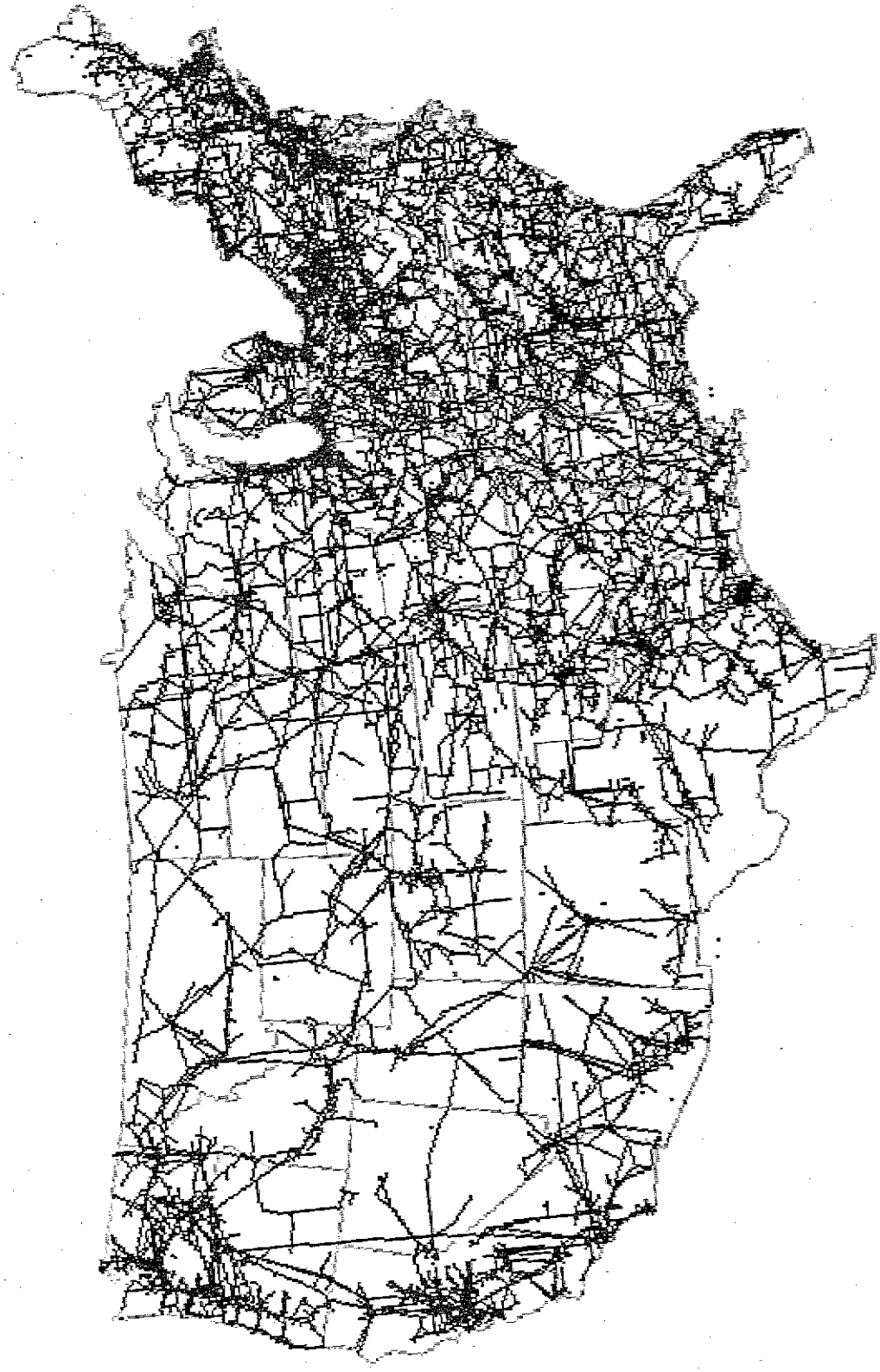

Figure 2-6 *Electric transmission system.*

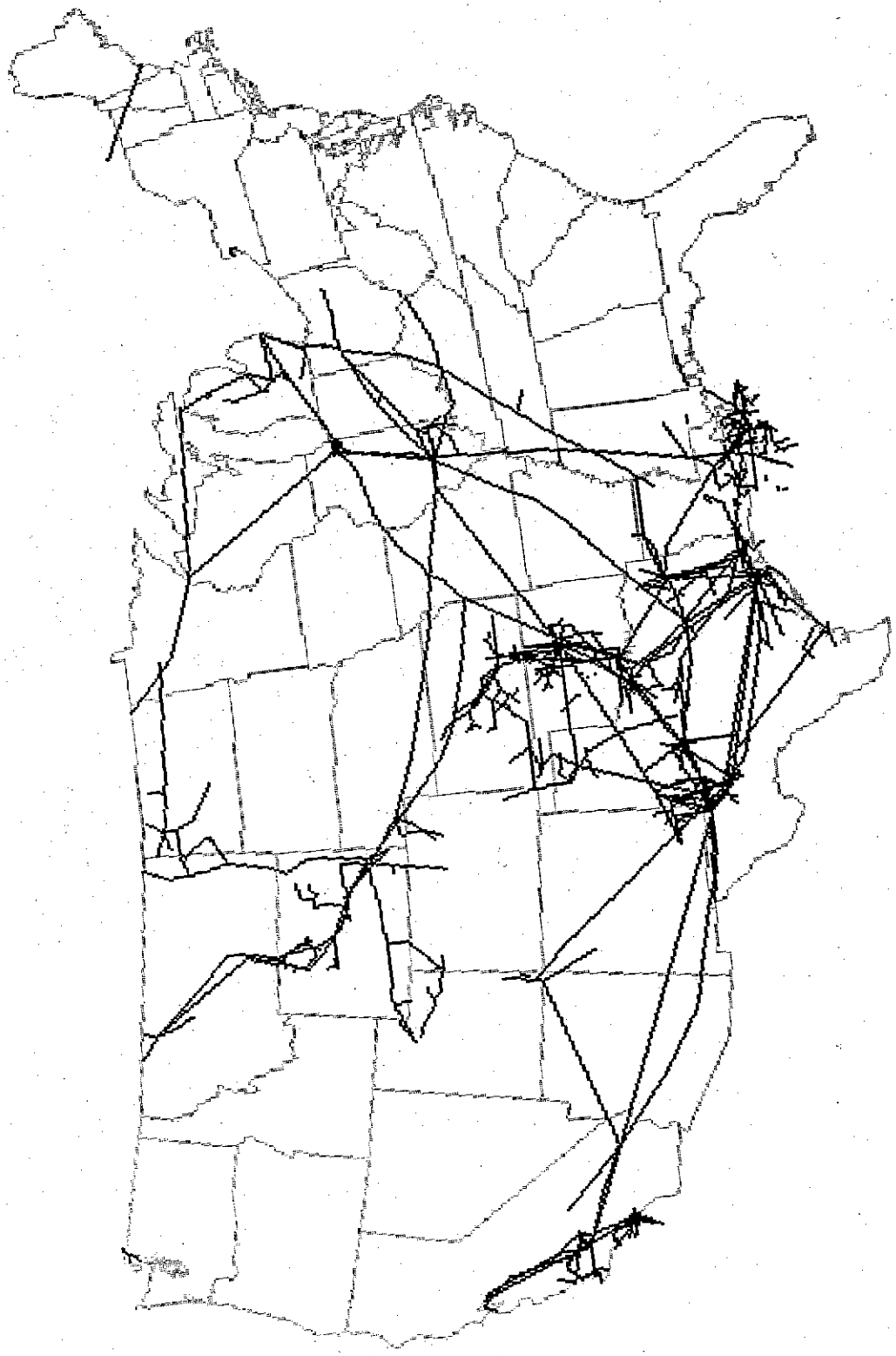

Figure 2-7 *Crude oil pipelines.*

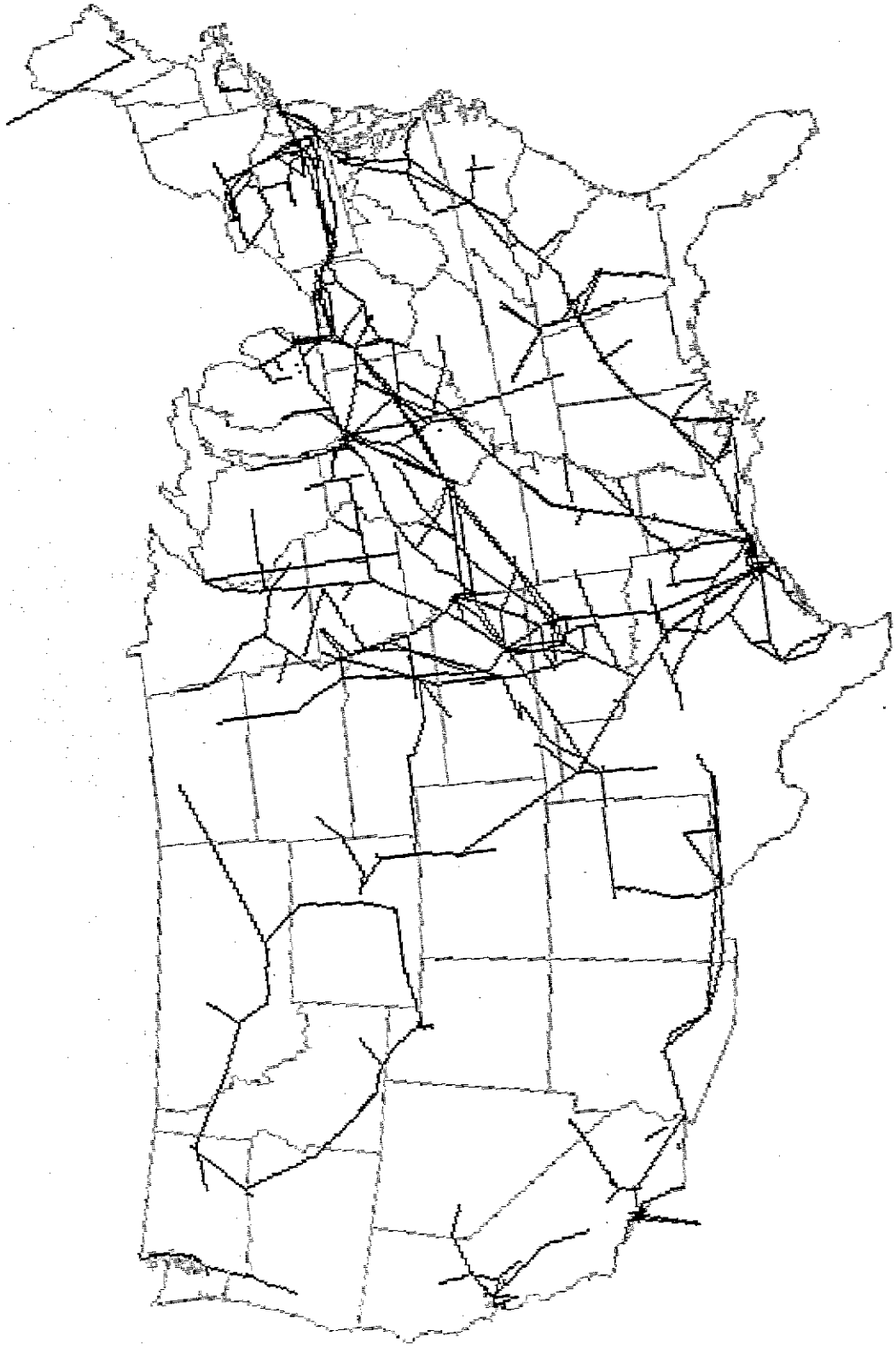

Figure 2-8 *Refined oil pipelines.*

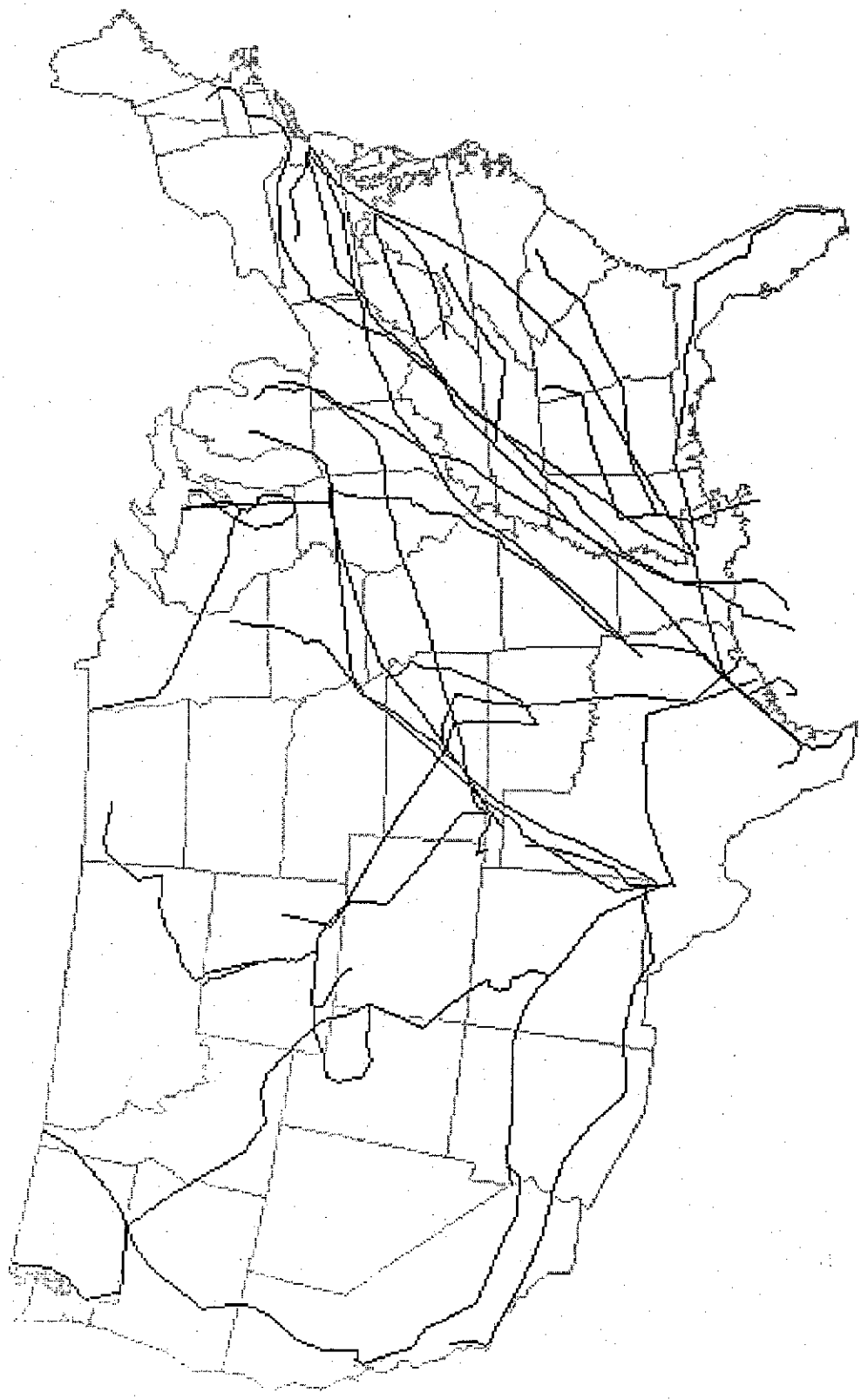

Figure 2-9 *Natural gas pipelines.*

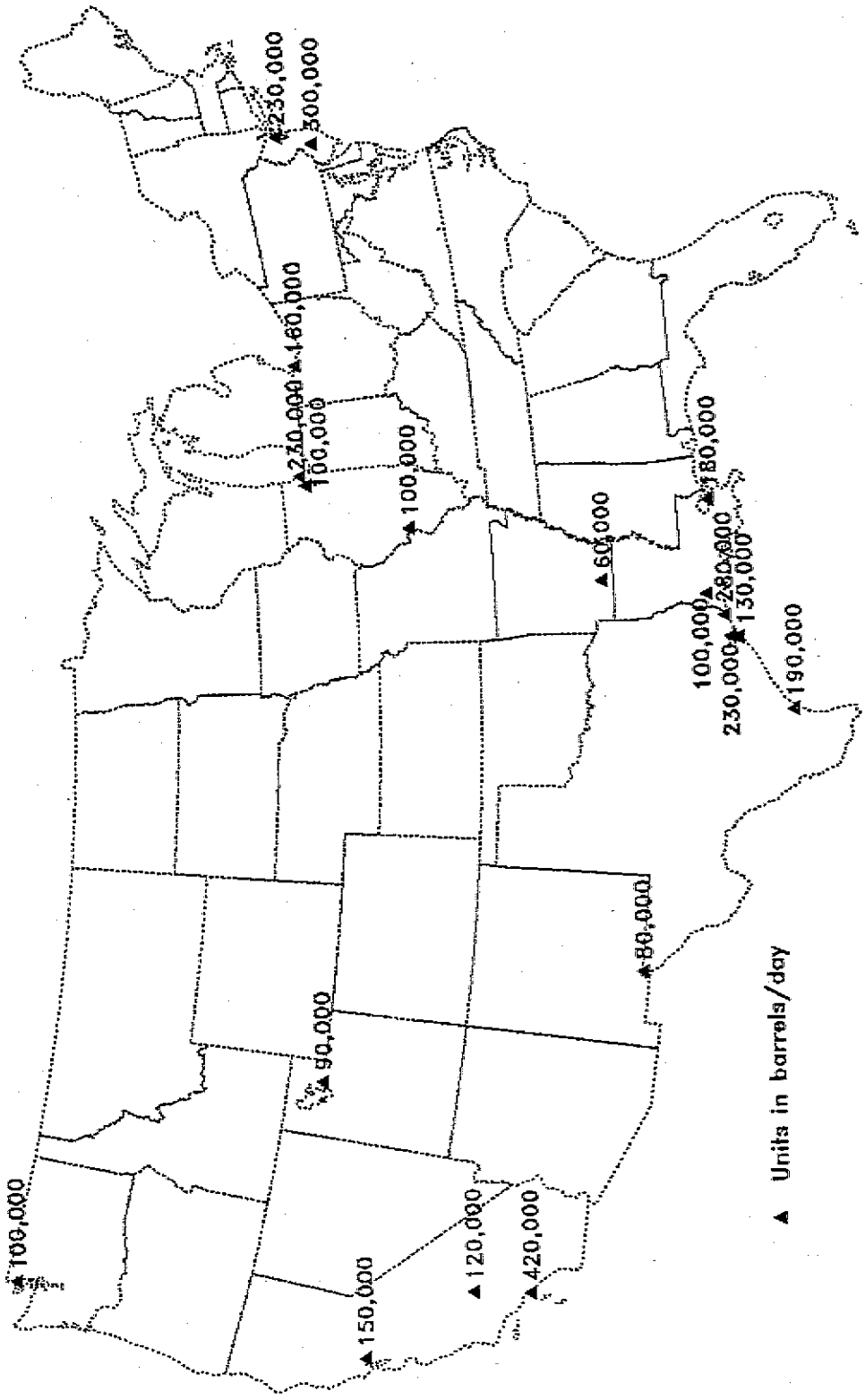

Figure 2-10 Refineries.

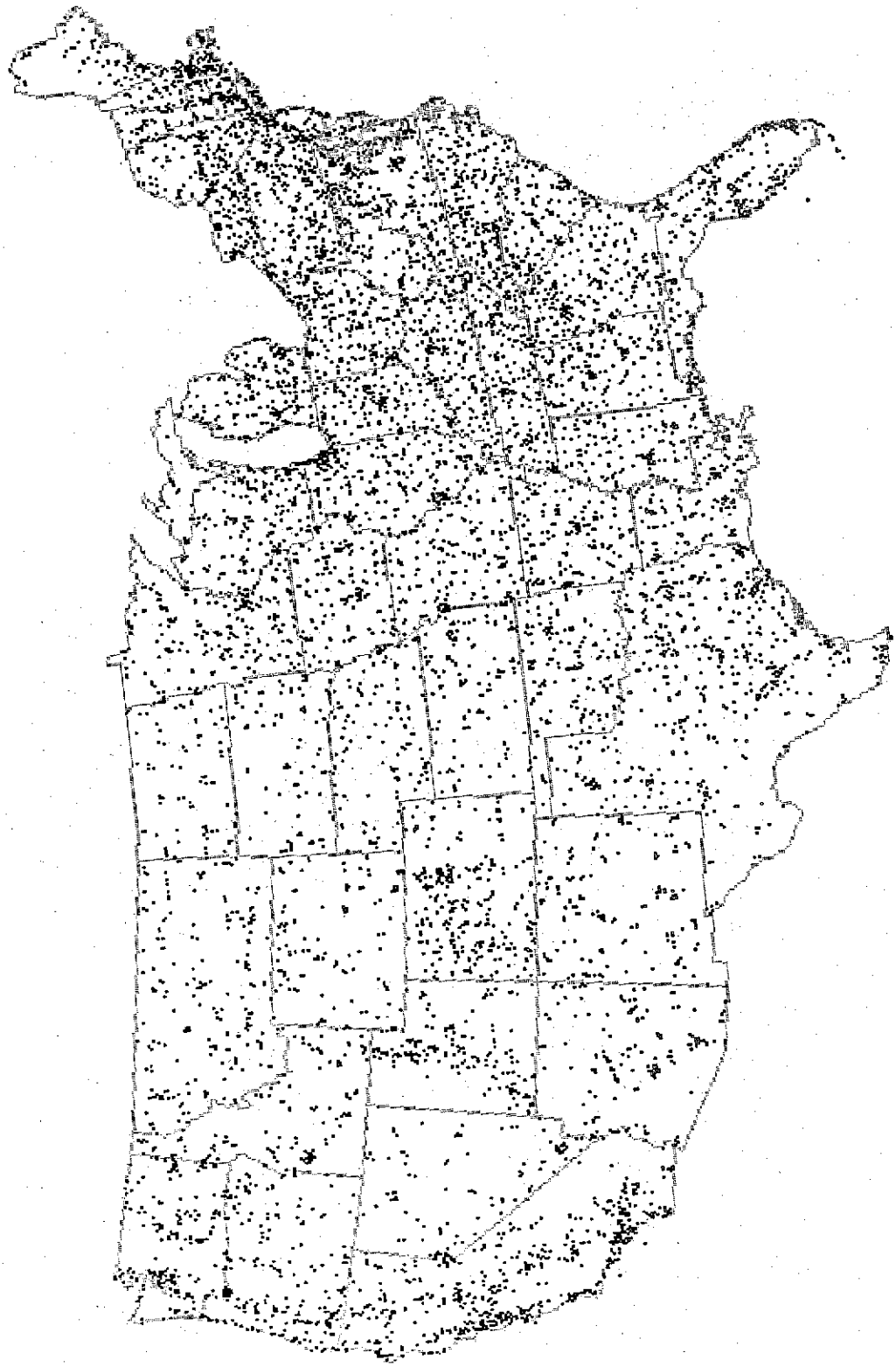

Figure 2-11 Emergency broadcast stations.

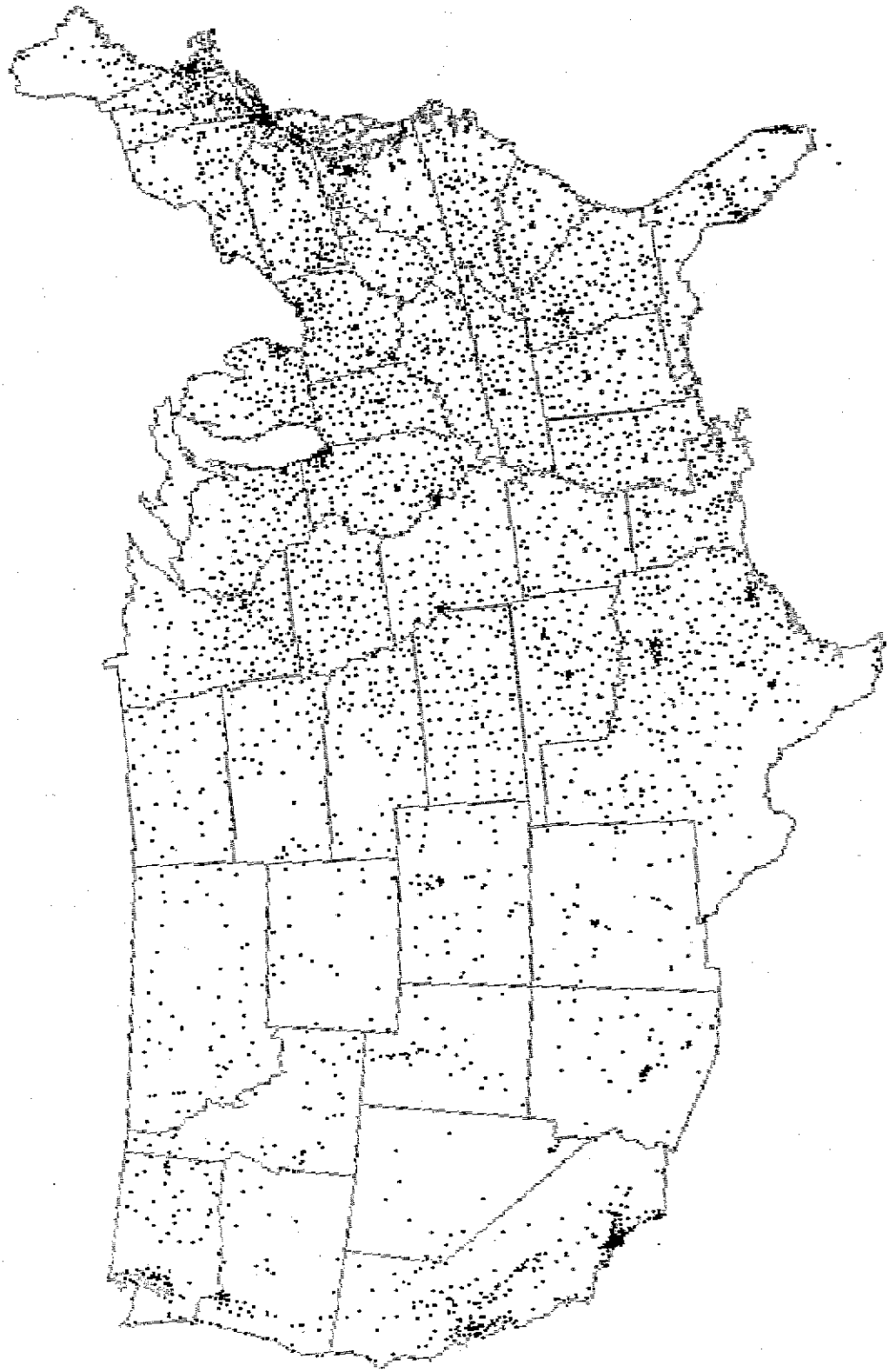

Figure 2-12 Medical care centers.

permits population to be used as the proxy measure of the number of fire stations. The data exhibit a trend that makes population appear to be a good basis for estimating the number of fire stations in an area. Intuition tells us that this would not be a linear function, since at the lower end of the population scale (a very small town), there would be at least one station (perhaps a volunteer unit) in most towns or areas. In rural forest areas, there may be few or no people residing in an area, but it might have several forest fire fighting crews available. A bilinear curve was deemed to be simple enough to be usable in a nationwide inventory, yet more capable of capturing the higher presence of fire stations in the less dense areas. The relationship developed is that there is one fire station per every 13,000 people in a municipality of less than 100,000 people. For municipalities of more than 100,000 people, there are 9 fire stations plus one more for every 36,000 additional people.

Police Stations. Detailed nationwide police station inventory data were not readily available in an electronic format. Data from a limited survey of municipalities with different attendant populations were obtained and correlated with the jurisdictional populations in an attempt to determine a relation, which permits population to be used as a proxy measure of the number of police stations. The data did not exhibit a strong correlation between the number of police stations and the jurisdictional population. There appears to be only one police or law enforcement station per municipality--cities with more than one police station are few, except for the largest cities. More than one police station in a municipality appears to be a relic of older days, with slower travel and communications. The data do make possible a stronger correlation to geography (such as the presence of a municipality) than directly to population, but intuition would say that the existence of law enforcement stations in rural areas, where the station size would be approximately uniform (one or two officers), would follow along population bounds. The relationship developed is that there is approximately one police station per every 60,000 people.

2.6 Water Supply Data

Water Transmission. Detailed information nationwide, on water storage, transmission, and treatment was not readily available. A variety of sources were employed to digitize reservoir locations and long-line transmission lines for large urban areas, of which only a few exceed tens of miles in length, that is, exceed our grid size (e.g., San Francisco, Los Angeles, New York). The inventory includes approximately 3,575 km of aqueduct, as shown in Figure 2-13. Excluded from the inventory are aqueducts in Utah, which were not available for inclusion in this study. It is also possible that other significant water transmission lines are inadvertently omitted from this study, as the project team had neither time nor funding to contact all potential sources of data.

Water Distribution. Detailed water distribution network inventory data were not readily available in an electronic format. Data from a survey of the largest water districts were available (AWWA report no. 20212 "1984 Water Utility Operating Data") and were used to correlate the quantity of piping with population. The data exhibit an apparent relationship between the population served by the water district and the total number of miles of piping in the distribution network. The values vary between different municipalities, apparently according to population density. New York City is one of the most densely populated municipalities in the United States, and the water distribution data reflect this. Overall, the average figure, which reflects the relationship between quantity of piping and populations for almost half the population of the United States, should be a reasonable figure to apply nationwide. The relationship we developed is that there is approximately 1 mile of distribution piping for every 330 persons. This would correspond to approximately 16 feet of distribution piping per person.

2.7 PC-Compatible Electronic Database

The data discussed above, developed as part of this project, form a very significant nationwide database on infrastructure at the regional level. Because the data could also serve as a valuable framework (or starting point) for researchers who wish to investigate lifelines at the regional

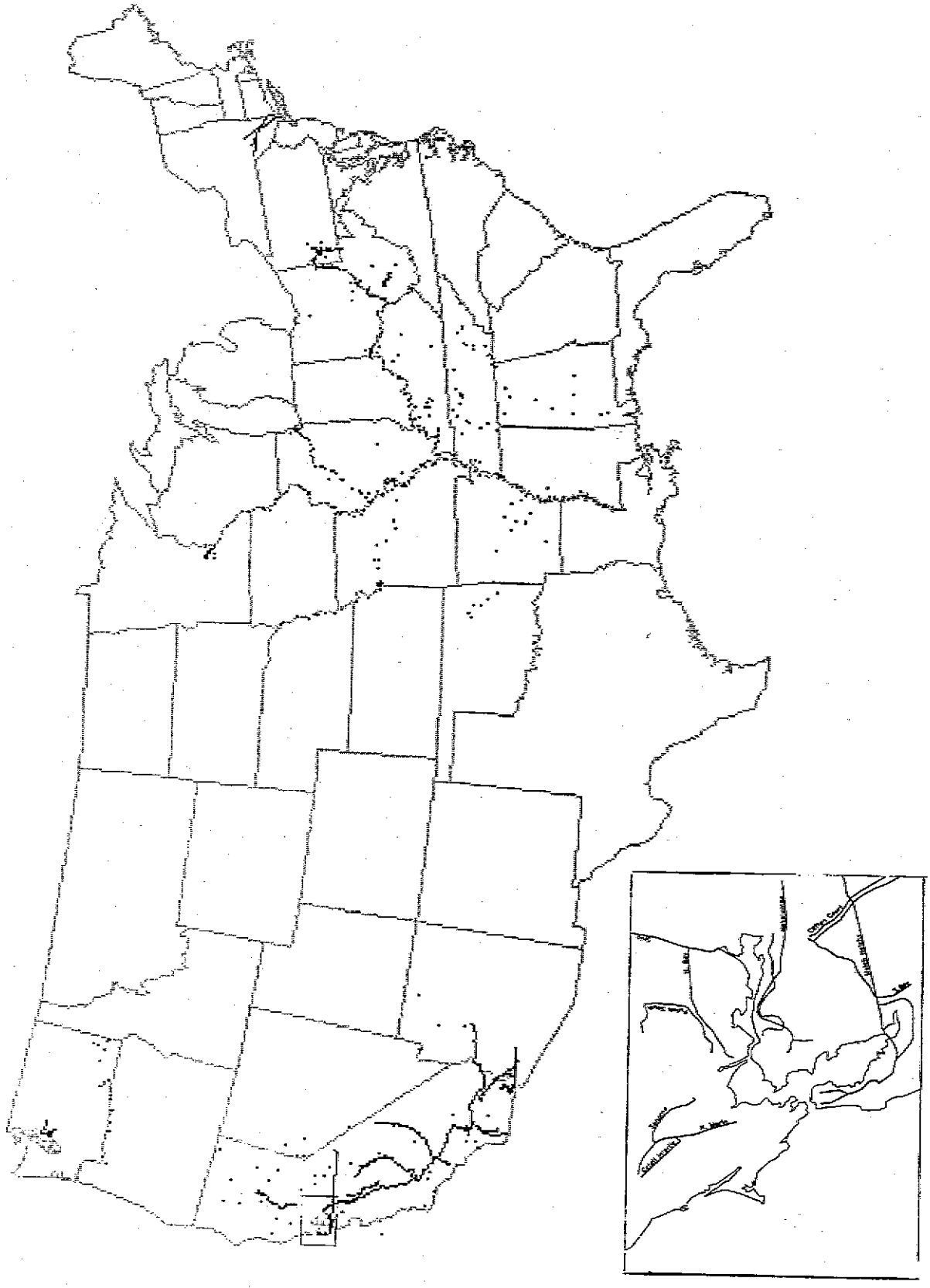

Figure 2-13 Water aqueducts and supplies.

or local level, including applications unrelated to seismic risk, the data have been formatted for use on IBM-PC compatible microcomputers. The data are unrestricted and will be made available by ATC on 18, 1.2-megabyte, floppy diskettes, together with a simple executable computer program for reading and displaying the maps on a computer screen. The disks contain 25 files, as shown in Table 2-1. For many of the networks, two files are presented, a .DAT file representing an ASCII file of latitude and longitude coordinates, and a .DEM file representing an x/y coordinate file for screen plotting purposes, in binary.

Table 2-1 National Lifeline Inventory Electronic Database

File No.	*File Name*	*Contents*
1.	**DEMO.EXE**	
2.	**HW.DEM**	(the highway network in x/y coordinates)
3.	**HW.DAT**	(the highway network in longitude/latitude coordinates)
4.	**RAILR.DEM**	(the railroad network in x/y coordinates)
5.	**RAILR.DAT**	(the railroad network in longitude/latitude coordinates)
6.	**ELECTRIC.DEM**	(the electric network in x/y coordinates)
7.	**ELECTRIC.DAT**	(the electric network in longitude/latitude coordinates)
8.	**CRUDE.DEM**	(the crude oil network in x/y coordinates)
9.	**CRUDE.DAT**	(the crude oil network in longitude/latitude coordinates)
10.	**REFINED.DEM**	(the refined oil network in x/y coordinates)
11.	**REFINED.DAT**	(the refined oil network in longitude/latitude coordinates)
12.	**NGAS.DEM**	(the natural gas network in x/y coordinates)
13.	**NGAS.DAT**	(the natural gas network in longitude/latitude coordinates)
14.	**BRIDGES.DEM**	(the bridges in x/y coordinates)
15.	**BRIDGES.DAT**	(the bridges in longitude/latitude coordinates)
16.	**AIRPORTS.DEM**	(the airports in x/y coordinates)
17.	**AIRPORTS.DAT**	(the airports in longitude/latitude coordinates)
18.	**PORTS.DEM**	(the ports in x/y coordinates)
19.	**PORTS.DAT**	(the ports in longitude/latitude coordinates)
20.	**BRDSTNS.DEM**	(the broadcast sta. in x/y coordinates)
21.	**BRDSTNS.DAT**	(the broadcast sta. in longitude/latitude coordinates)
22.	**MEDCARE.DEM**	(the hospitals in x/y coordinates)
23.	**MEDCARE.DAT**	(the hospitals in longitude/latitude coordinates)
24.	**WATER.DEM**	(the water system in x/y coordinates)
25.	**WATER.DAT**	(the water system in longitude/latitude coordinates)