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ENERGY CONSUMPTION IN THE PIPELINE INDUSTRY

by

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**MASTER**

Technical Report - Task 1 (partial)  
Contract EY-76-C-03-1171

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## Energy Consumption in the Pipeline Industry

by  
William F. Banks

## ABSTRACT

Estimates are developed of the energy consumption and energy intensity (EI) of five categories of U. S. pipeline industries: natural gas, crude oil, petroleum products, coal slurry, and water. For comparability with other transportation modes, it is desirable to calculate EI in Btu/Ton-Mile, and this is done, although the necessary unit conversions introduce additional uncertainties. Since water and sewer lines operate by lift and gravity, a comparable EI is not definable.

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## 1.0 OBJECTIVES

### 1.1 Purpose of the Project

The work reported here is a part of a project which is being conducted by the team of Systems, Science and Software (S<sup>3</sup>) of San Diego, and Pipe Line Technologists, Inc. (Pipetech) of Houston, under ERDA Contract E(04-03)-1171, "Energy Study of Pipeline Transportation Systems." The basic purpose of the project is to assess the susceptibility of the oil, gas, and other pipeline industries to energy-conservative technological innovations, and to identify the necessary research, development, and demonstrations (R, D, & D) to exploit those opportunities.

The project final report is being published as S<sup>3</sup> report SSS-R-77-3020, "An Energy Study of Pipeline Transportation Systems." That final report will be a summary, combining the results from the seven task reports listed in Table 1.1-1. As will be noted from the table, this present report is one of those task reports.

### 1.2 Purpose of this Report

Accomplishment of the broad objectives defined above can best be realized if the energy consumption of the pipeline industry is understood. Stated equivalently, it is desired to understand the magnitude of the energy being expended, its pattern, what measures could reduce it, and what R, D, and D program will best enable and/or enhance such reduction. The purpose of this report is to address the first two of these questions, i.e., how much energy is being expended by the industry and what general pattern it follows.

TABLE 1.1-1

## Project Reports

| <u>SSS-R-77-</u> | <u>Title</u>  | <u>Associated Tasks</u> |
|------------------|---|-------------------------|
| 3020             | An Energy Study of Pipeline Transportation Systems - Executive Summary                    | All                     |
| 3021             | An Economic Model of Pipeline Transportation Systems                                      | 1<br>(partial)          |
| 3022             | Energy Consumption in the Pipeline Industry   | 1                       |
| 3023             | Slurry Pipelines - Economic and Political Issues - A Review                               | 2.1                     |
| 3024             | Federal Regulation of the Pipeline Industry   | 2.2                     |
| 3025             | Efficiency Improvements in Pipeline Transportation Systems                                | 3                       |
| 3027             | Prospects for Energy Conservation in the Pipeline Industry                                | 4,5                     |
| 3069             | S <sup>3</sup> Financial Projection Model - Preliminary User's Manual and System Overview | 1<br>(partial)          |

A second purpose is to estimate the unit energy consumption, i.e., the energy consumed per unit of transport accomplished. This index of merit is often called energy intensiveness (EI), but for succinctness it is herein referred to as energy intensity. It is calculated from any of the formulae

$$I_E = \frac{E}{QxD} = \frac{P}{FxD} = \frac{\frac{dE}{dt}}{\frac{dQ}{dt} \cdot xD}$$

where

$I_E \triangleq$  energy intensity

$E \triangleq$  energy consumed

$Q \triangleq$  quantity of commodity transported

$D \triangleq$  distance transported

$P \triangleq$  power

$F \triangleq$  commodity flow.

The second and third formulae yield an instantaneous value for  $I_E$ , while the first yields an average over whatever time period  $E$  and  $Q$  have been integrated. In this study, only annual averages are considered, so the line is considered to be in quasi-steady state operation. It is, of course, recognized that system transients do in fact adversely affect energy consumption, as is discussed in Report 3025 of this series, Section 4.3.6.1.2, in connection with pipeline duty cycles.

The task of developing an accurate and precise estimate of energy intensity reduces in practice to an effort to determine the three quantities  $E$ ,  $Q$ , and  $D$ , or equivalently, the numerator  $E$  and the denominator ( $Q \times D$ ). As will be seen in what follows, in the case of gas pipelines the numerator  $E$  is known rather accurately but the denominator ( $Q \times D$ ) can only be determined accurately by research into the records of each individual pipeline company. The opposite situation obtains with the oil pipelines, where the denominator ( $Q \times D$ ) is reported by each company and published by the ICC, but the numerator  $E$  can only be determined accurately by research into the records of each individual pipeline company.

For purposes of drawing comparisons with other transportation modes, it is highly desirable to convert the  $I_E$  to a common set of units, which in the ancient English system is

$$\frac{\text{Btu}}{\text{Ton-Mile.}}$$

This conversion introduces an inaccuracy, since the standard units of measure for quantity are different in the different types of pipelines. The standard unit in the natural gas industry is the standard cubic foot (Scf). In the petroleum industry it is the Barrel (Bbl or B), which is 42 gallons. In the water industry it is the gallon. And in the slurry industry it is the ton of coal. These and other inaccuracies, and their reduction in the course of future research into the subject, are discussed in the text as they are encountered.

## 2.0 SUMMARY

Table 2.0-1 presents a summary of the energy estimates for the six types of pipelines which were examined.

### 2.1 Gas Pipeline Energy Summary

The total annual energy consumption of the gas pipeline industry, as pipeline fuel, is approximately 0.7 Quad ( $7 \times 10^{14}$  Btu/hr). The 25-year trend may be seen by reference to Table 3.3-1. The peak consumption, which occurred in 1972, was  $766,156 \times 10^6$  cf, or approximately 0.8 Quad. Additionally, a small amount of compression energy, estimated to be less than five percent, is taken from non-gas sources, principally as purchased electricity.

It is estimated that between 85 and 90% of the pipeline fuel is consumed in the transmission function. The production function consumes 4 or 5%, and the collection function consumes between 6 and 8%, while the storage function appears to consume a negligible amount. No reliable data have been found to indicate consumption by the distribution function, but it is believed to be of the same order of magnitude as the collection function, i.e., less than 8%. The approximate breakdown for 1974 can be seen by reference to Table 3.3-3 in Section 3.3, p. 3-29.

The energy intensity (EI) of gas pipelines varies widely, usually between about 1000 and 4000 Btu/Ton-Mile. The average appears to lie near 2000.

The pipeline companies do not calculate their energy intensity since it is not a useful parameter to them in their business, although energy consumption and conservation are matters of primary concern to all levels of their management. However, one large gas pipeline company, as an

Table 2.0-1

## Pipeline Energy Estimates

|                                   | Natural<br>Gas      | Crude<br>Oil       | Petroleum<br>Products | Coal-Water<br>Slurry | Water<br>Supply    | Waste<br>Water | Total |
|-----------------------------------|---------------------|--------------------|-----------------------|----------------------|--------------------|----------------|-------|
| Energy Con-<br>sumption,<br>Quads | 0.710               | 0.070              | 0.068                 | 0.0044               | 0.050              | 0.017          | 0.92  |
| Energy<br>Intensity               | 2000 <sup>(1)</sup> | 300 <sup>(1)</sup> | 400 <sup>(1)</sup>    | 4000 <sup>(1)</sup>  | 220 <sup>(2)</sup> |                |       |

(1) Btu/Ton-Mile

(2) Kw-Min/ $10^5$  Gal-Ft

2-2

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act of cooperation with the ERDA, performed the necessary research to assemble the data and calculate the EI of their entire trunkline system for 1976. The result was just over 1000 Btu/Ton-Mile. In earlier years, when the system throughput was higher, the EI was possibly as much as 50% greater.

The minimum-cost EI appears to occur near the lower end of the 1000-4000 range as may be seen from Table 3.4.2-1, p. 3-41. A further point of interest is the fact that the maximum profit and cash flow appear to occur near the top of the range. It therefore appears that the price of gas must increase by several times above the present interstate regulated value of \$1.48/Mcf before the pipeline owner will be motivated to operate at the most energy-conservation condition. In making this observation, it is of course recognized that there are other practicalities that militate against operating gas pipelines in their most energy-conservative mode.

## 2.2 Crude Oil Pipeline Energy Summary

The 1976 energy consumption of the United States crude oil pipeline industry is estimated to be  $2 \times 10^{10}$  kw-hr (0.07 Quad). Within the inherent accuracy of the method which was employed to derive this figure, it would carry a high confidence level. There are, however, unknowns regarding the input data which render the estimate suspect. Further research would be required to resolve these unknowns and improve the accuracy of both the method and of the specific results.

The estimate for the energy intensity of the crude lines is 286 Btu/Ton-Mile. This estimate is much below others, e.g., those of Hirst (1973) and of Project Independence (1974). However, search of those references has not yet revealed the basis for those higher numbers, so that reconciliation has not yet been completed, although it is planned to continue the reconciliation.

To avoid leaving impressions of non-existent accuracy, it is suggested that the rounded value of 300 Btu/Ton-Mile be used.

### 2.3 Products Pipeline Energy Summary

The estimates for products lines are 0.068 Quad for the energy consumption and 388 Btu/Ton-Mile for the energy intensity. The general comments made earlier regarding the crude oil estimates apply here also. It is suggested that the rounded value of 400 Btu/Ton-Mile be used for the EI.

### 2.4 Coal-Water Slurry Pipeline Energy Summary

This industry presently consists of only one system, the Black Mesa Pipeline, Inc. The estimate for its total energy consumption, when the complete deslurification process is taken into account, is 0.0044 Quad. The components of this figure are shown in Table 2.4-1, which is a replica of Table 6.4-1. The estimate for energy intensity is 3899 Btu/ton-mile, rounded to 4000. Several comments are in order.

First, although the figure of 351,000 Btu/Ton-Mile for the pipeline operation is known to be accurate, since it was supplied as a courtesy by Black Mesa Pipeline, it of course includes whatever inaccuracy is introduced by the postulated efficiency of the electric generation and distribution grid.

TABLE 2.4-1

Energy consumption - Black Mesa Pipeline  
(Btu/ton of coal)

|  |                |
|--|----------------|
| Slurry Water Supply                      | 36,000         |
| Pipeline Operation                       |                |
| Pumping energy                           | 186,000        |
| Slurry preparation<br>& other operations | <u>155,000</u> |
|  | 341,000        |
| Deslurification                          |                |
| Initial separation                       | 205,000        |
| Moisture correction,<br>32 to 10.74%     | <u>483,000</u> |
|  | 688,000        |
| Total                                    | 1,065,000      |

Also, the 341,000 Btu for all pipeline operation may be either overstated or understated, depending upon viewpoint, if the purpose is comparison with other transportation modes. On one hand, most of the energy of slurry preparation is for grinding. Since the coal must be pulverized in any case, it is not fair to charge all of this to transportation. On the other hand, the line falls 2600 feet between its head and its critical elevation. This free gravitational energy compares with less than 8000 feet of head which is added by the pumps. Thus, when a comparison is made for equilevel terminals, taking both of these factors into account, the energy consumed in pipeline operation is slightly less, as may be seen in the first column of Table 2.4-2.

Second, if one accepts the estimate of Zandi [1974] of 544 Btu/ton-mile for the energy intensity of a railroad to move the coal between the same two points, one sees an apparent large advantage for the railroad. When the effects of distance, scale, and current technology are taken into account, an energy intensity of about 600 Btu/ton-mile is anticipated for a 1000-mile, 25 million-ton/year pipeline. The comparison between this estimate and the estimate for the Black Mesa line is presented in Table 2.4-2, which is a replica of Table 6.4-5.

Finally, a major conclusion that was reached earlier in this program regarding the future of coal-slurry pipelines is confirmed. In report R-3025 of this series, the conclusion emerged that the coal slurry pipeline is a cost-effective and energy-effective mode of transport, but not in the coal-water form. The coal-methanol slurry offers promise of eliminating the huge energy penalties in the deslurification process, reducing the total pipeline water requirement by a factor of perhaps three, and at the same time making a premium engine fuel available. It is not suggested that coal can be converted to methanol as easily as coal can be separated from water, but there are many other returns that accrue from the energy invested

TABLE 2.4-2  
(TABLE 6.4-5)  
Comparison of adjusted energy consumption  
(Btu/ton of coal)

|                               | Black Mesa             | ETSI                   |
|-------------------------------|------------------------|------------------------|
|                               | 273 mi                 | 1000 mi                |
|                               | 10.74% moisture        | 26% moisture           |
|                               | $4 \times 10^6$ tons   | $25 \times 10^6$ tons  |
|                               | <u>1967 technology</u> | <u>1977 technology</u> |
| Slurry water supply           | 36,000                 | 25,000                 |
| Pipeline operation            |                        |                        |
| Pumping energy                | 250,000                | 351,000                |
| Other operations              | <u>31,000</u>          | <u>47,000</u>          |
|                               | 281,000                | 398,000                |
| Deslurification               |                        |                        |
| Initial separation            | 205,000                | 65,000                 |
| Moisture correction           | <u>483,000</u>         | <u>136,000</u>         |
|                               | 688,000                | 201,000                |
| Total                         | 1,005,000              | 624,000                |
| Length of pipeline (mi)       | 273                    | 1,000                  |
| Energy intensity (Btu/ton-mi) | 3681                   | 624                    |

in the conversion process and which render the coal-methanol system much to be preferred. Unhilitated enthusiasm for the concept is premature under the present absence of an overall system analysis. Clearly, however, the concept merits such analysis.

## 2.5 Water Systems Energy Summary

The estimate for energy consumption in water supply systems is 0.05 Quad, and for waste water systems, it is 0.017 Quad. Energy intensity cannot be calculated for water systems in the same way as is done for the other pipelines and other transportation modes, because in water distribution systems, unlike petroleum pipelines, the fluid is not pumped through from source to destination. Instead, the water is pumped to a high-level storage tank from which it flows by gravity through the distribution lines to consumers. Since all the energy is input to the system as work to raise the water to the storage reservoirs, the energy intensity for water systems is defined as energy per unit of mass per unit of lift. Thus, an energy intensity that would put these systems on a comparative base with other modes is not definable.

### 3.0 ENERGY CONSUMPTION IN GAS PIPELINES

#### 3.1 Gas Pipeline Industry Profile

##### 3.1.1 Systems Description - Typical Gas Pipeline

Figure 3.1.1-1 displays a schematic of a complete natural gas grid. At the top and bottom are shown gathering and transmission systems which feed into a main loop. Gas is sold off of the loop through sales meters, shown here at several points around the loop. Gas may also be taken off the loop and placed in storage, or of course returned from storage to the loop, processes which consume energy and require compression facilities. Compression facilities, called boosters, are also shown at several points around the loop. In addition to supply from long-distance transmission (trunk) lines, gas may be fed into the loop from manufactured-gas sources, LNG sources or LPG plants. At the upper right is shown an offshoot through a sales meter into a distribution system, of which there are typically several.

The present study is concerned with energy consumption and conservation in transportation, which for a pipeline is the main line, or transmission system. On Figure 3.1.1-1, these are the sections between the treating plants and the purchase meter stations, upper left and lower left corners.

##### 3.1.2 Statistical Characterization of Gas Pipelines

As will be further explained in the next section, the FPC collects data from the 81 Class A and Class B companies (those whose annual revenue exceeds \$1 million). For studying industry trends, the FPC further defines "major" Class A and Class B companies as those which sell 50 billion cubic feet per year.

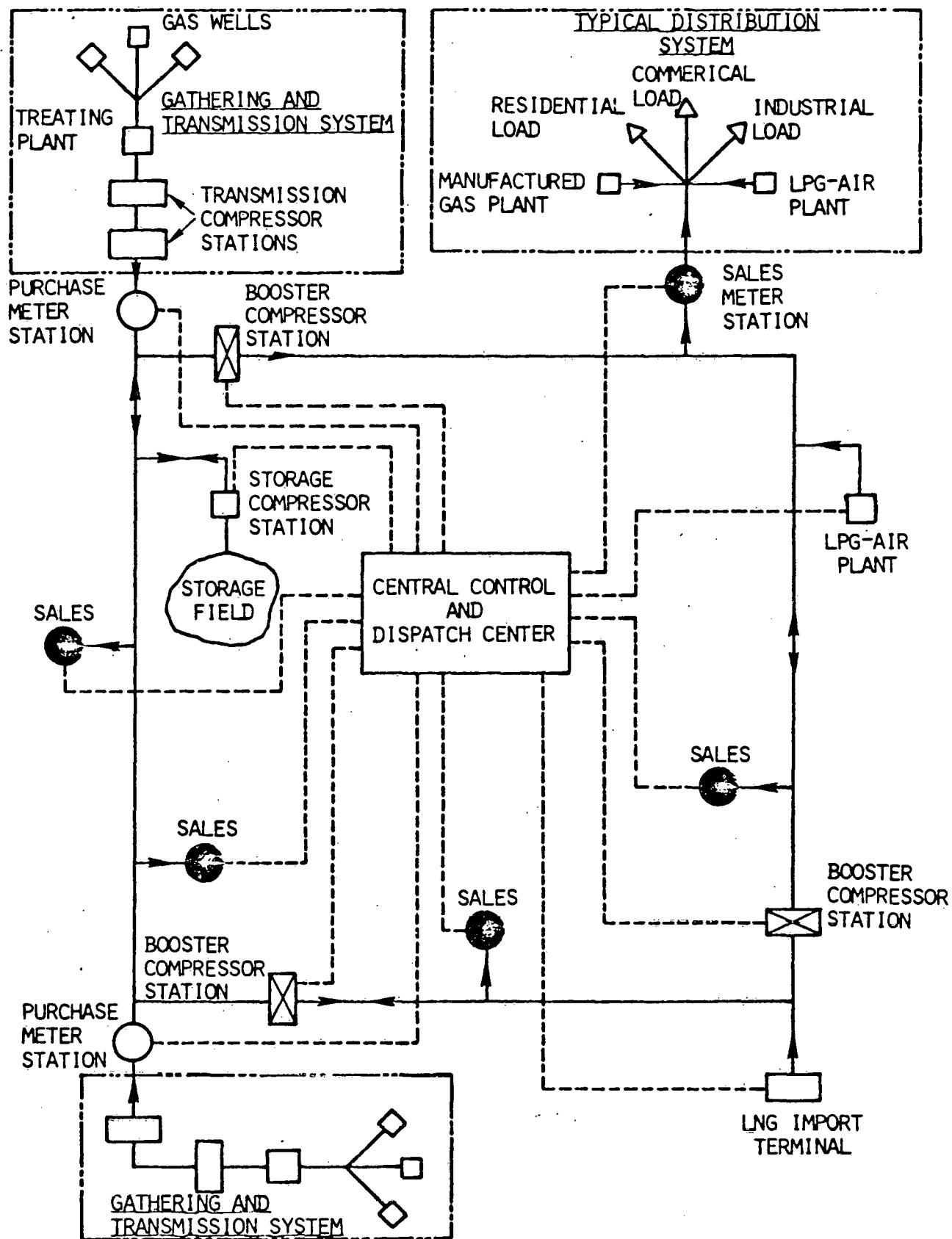


Figure 3.1.1-1. Schematic - Typical Natural Gas System

Figure 3.1.2-1 shows the growth of gas pipeline mileage by type for the years 1950-1975. In Figure 3.1.2-2, the mileage for 1973 and 1974 is disaggregated by pipe size, and Figure 3.1.2-3 shows the size trends during the decade 1964-1974 for the major companies. The Task Force which compiled the National Gas Survey in 1973 developed considerable additional information beyond that contained in the regular FPC statistics, and their breakdown is shown in Figure 3.1.2-4.

Figures 3.1.2-5 and 3.1.2-6 present statistics on total compressor horsepower. Figure 3.1.2-7 shows statistics on both pipe miles and horsepower for a selected subset of the major companies, along with peak sendouts and revenues.

The investments in plant to perform the major functions are shown in Figure 3.1.2-8 for the period 1964-1974, and more detailed breakdown compiled by the National Gas Survey Task Force is shown in Figure 3.1.2-9. Expenses to maintain and operate those plants are shown in Figure 3.1.2-10, and some load factors are shown in Figure 3.1.2-11.

Finally, consumer profiles are shown in Figures 3.1.2-12 and 3.1.2-13.

| Year                 | Total | Field and Gathering | Transmission Pipeline <sup>b</sup> | Distribution Main |
|----------------------|-------|---------------------|------------------------------------|-------------------|
| 1950                 | 387.5 | 32.8                | 113.1                              | 241.6             |
| 1951                 | 406.6 | 34.6                | 119.1                              | 252.9             |
| 1952                 | 425.3 | 38.4                | 123.4                              | 263.5             |
| 1953                 | 446.4 | 41.5                | 130.4                              | 274.5             |
| 1954                 | 470.5 | 43.8                | 139.0                              | 287.7             |
| 1955                 | 496.7 | 45.7                | 145.9                              | 305.1             |
| 1956                 | 525.2 | 47.6                | 153.8                              | 323.8             |
| 1957                 | 548.8 | 50.0                | 160.1                              | 338.7             |
| 1958                 | 571.5 | 52.0                | 165.4                              | 354.1             |
| 1959                 | 599.8 | 54.1                | 174.3                              | 371.4             |
| 1960                 | 630.9 | 55.8                | 183.7                              | 391.4             |
| 1961                 | 659.0 | 56.7                | 191.9                              | 410.4             |
| 1962                 | 683.2 | 58.7                | 196.4                              | 428.1             |
| 1963                 | 709.9 | 60.7                | 200.9                              | 448.3             |
| 1964                 | 736.2 | 61.0                | 205.4                              | 469.8             |
| 1965                 | 767.5 | 61.7                | 211.3                              | 494.5             |
| 1966                 | 799.6 | 63.0                | 217.0                              | 519.6             |
| 1967                 | 828.3 | 63.7                | 225.4                              | 539.2             |
| 1968                 | 861.6 | 64.4                | 234.5                              | 562.7             |
| 1969                 | 891.6 | 64.9                | 248.1                              | 578.6             |
| 1970R                | 913.3 | 66.3                | 252.2                              | 594.8             |
| 1971R                | 931.4 | 66.2                | 254.8                              | 610.4             |
| 1972R                | 948.1 | 66.9                | 258.1                              | 623.1             |
| 1973R                | 962.9 | 65.9                | 263.1                              | 633.8             |
| 1974R                | 974.1 | 66.4                | 262.2                              | 645.6             |
| 1975                 | 980.0 | 68.5                | 262.6                              | 648.9             |
| 1975 Steel           | 879.4 | 68.4                | 260.9                              | 550.1             |
| Plastic <sup>c</sup> | 35.6  | 0.0                 | 0.0                                | 35.6              |
| Other                | 65.0  | 0.1                 | 1.7                                | 63.2              |

a Includes data for Hawaii subsequent to 1959 and for Alaska subsequent to 1960; excludes service pipe. Data not adjusted to common diameter equivalent. Mileage shown as of end of each year.

b Includes 3.6 thousand miles of Underground Storage pipe in 1971, 3.3 thousand miles in 1972, 3.4 thousand miles in 1973, 4.9 thousand miles in 1974, and 5.0 thousand miles in 1975, some of which was formerly included in Field and Gathering pipe.

c Includes fiberglass.

R—Revised.

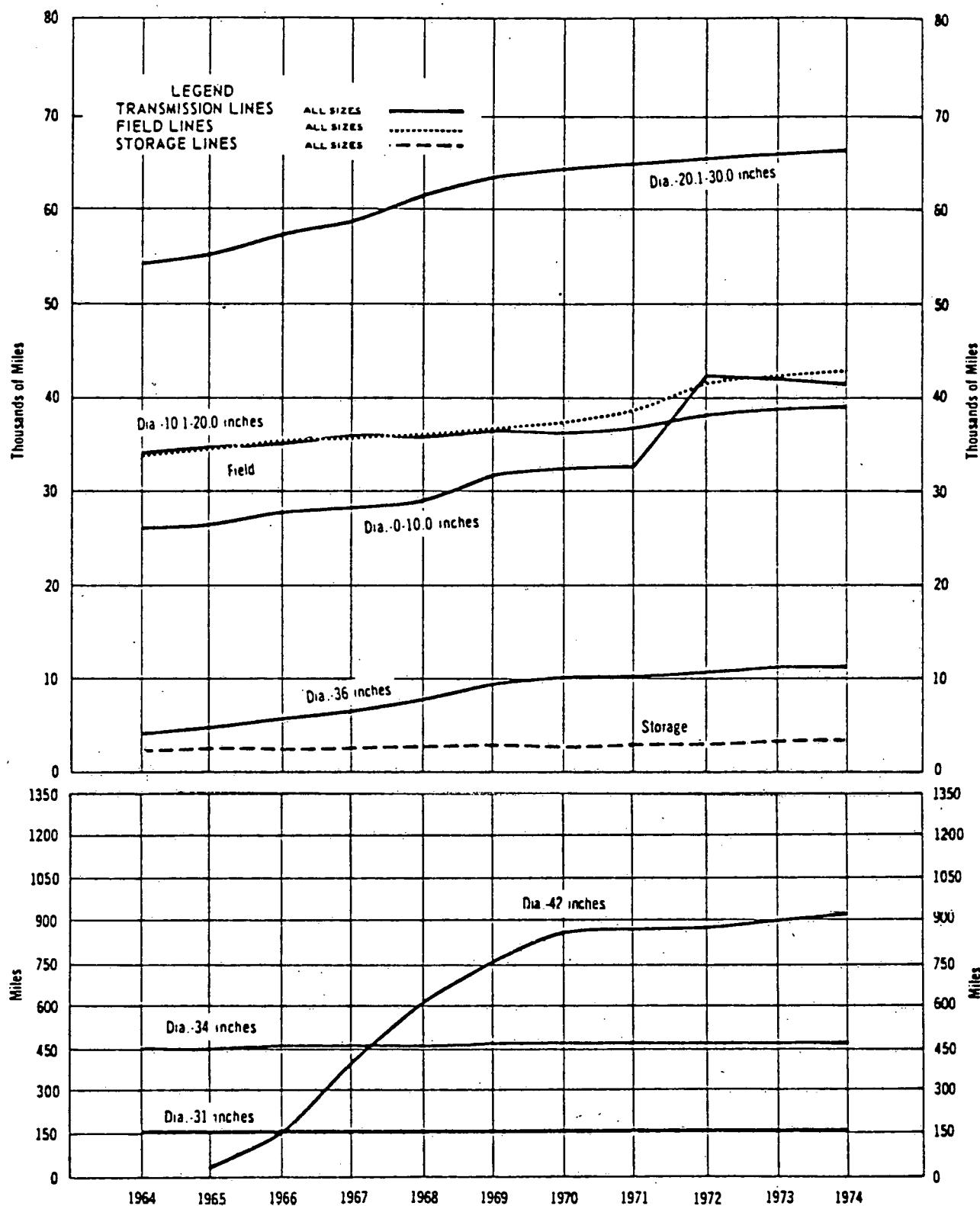
Source - AGA Gas Facts, 1976 Edition, published by  
American Gas Association

Figure 3.1.2-1 - Gas Pipeline Mileage (in thousands)

| Item   | All classes A and B pipelines (amount) |                | Major classes A and B pipelines <sup>a</sup> (amount) |                |
|--|--|----------------|---|----------------|
|  | 1973                                   | 1974           | 1973  | 1974           |
| Field, all sizes combined.....                     | 84,980                                 | 55,268         | 42,311  | 42,856         |
| <b>Transmission:</b>                               |  |                |   |                |
| 0 to 5.0 inches.....                               | 24,338                                 | 23,473         | 19,201  | 18,552         |
| 5.1 to 10.0 inches.....                            | 34,310                                 | 33,339         | 22,828  | 22,849         |
| 10.1 to 15.0 inches.....                           | 17,820                                 | 17,823         | 12,917  | 12,930         |
| 15.1 to 20.0 inches.....                           | 38,852                                 | 31,496         | 26,063  | 22,071         |
| 20.1 to 25.0 inches.....                           | 22,361                                 | 23,646         | 23,873  | 22,727         |
| 26 inches.....                                     | 13,878                                 | 13,892         | 13,878  | 13,892         |
| 28 inches.....                                     | 1                                      | 1              | 1   | 1              |
| 30 inches.....                                     | 30,120                                 | 30,462         | 29,537  | 29,712         |
| 31 inches.....                                     | 154                                    | 152            | 154   | 154            |
| 32½ inches.....                                    | 37                                     | 38             | -----   | -----          |
| 34 inches.....                                     | 472                                    | 471            | 472   | 471            |
| 36 inches.....                                     | 11,163                                 | 11,252         | 11,160  | 11,150         |
| 40 inches.....                                     | 8                                      | 6              | 6   | 6              |
| 42 inches.....                                     | 887                                    | 916            | 887   | 916            |
| 43 inches.....                                     | 9                                      | 9              | -----   | -----          |
| 53 inches.....                                     | 16                                     | 16             | -----   | -----          |
| <b>Total gas transmission pipe-<br/>lines.....</b> | <b>183,855</b>                         | <b>186,927</b> | <b>159,866</b>  | <b>159,462</b> |
| Storage, all sizes com-<br>bined.....              | 3,960                                  | 3,634          | 3,234   | 3,347          |

Source: FPC Statistics

Figure 3.1.2-2 - Gas Pipeline Mileage by Size



Source: FPC Statistics

Figure 3.1.2-3 - Gas Pipeline Mileage by Function

| Pipeline Size<br>Nominal O.D. |     | Miles of Pipeline |              |         |           |
|-------------------------------|-----|-------------------|--------------|---------|-----------|
|                               |     | Gathering         | Transmission | Storage | Total     |
| <b>On Shore</b>               |     |                   |              |         |           |
| Under                         | 10" | 92,657.1          | 99,462.5     | 2,908.9 | 195,028.5 |
|                               | 10" | 5,787.0           | 13,324.8     | 342.1   | 19,453.9  |
|                               | 11" | 161.1             | 867.1        |         | 1,028.2   |
|                               | 12" | 4,301.7           | 20,081.2     | 531.9   | 24,914.8  |
|                               | 13" | 120.2             | 905.0        | 25.9    | 1,051.1   |
|                               | 14" | 928.8             | 5,176.7      | 11.9    | 6,117.4   |
|                               | 15" | 7.3               | 75.8         |         | 83.1      |
|                               | 16" | 3,305.6           | 16,205.4     | 314.8   | 19,825.8  |
|                               | 18" | 516.9             | 5,291.4      | 34.3    | 5,842.6   |
|                               | 20" | 1,930.7           | 18,186.9     | 322.1   | 20,439.7  |
|                               | 21" |                   |              |         |           |
|                               | 22" | 231.2             | 5,323.3      | 5.4     | 5,559.9   |
|                               | 23" |                   | 170.7        |         | 170.7     |
|                               | 24" | 1,193.2           | 19,652.4     | 86.1    | 20,931.7  |
|                               | 26" | 272.0             | 14,123.7     | 33.3    | 14,429.0  |
|                               | 28" | 2                 | 1.1          |         | 1.3       |
|                               | 30" | 627.5             | 34,228.2     | 8.7     | 34,864.4  |
|                               | 31" | 3                 | 154.3        |         | 154.6     |
|                               | 32" |                   | 18.9         |         | 18.9      |
|                               | 34" | 6.8               | 1,717.4      |         | 1,724.2   |
|                               | 36" | 41.7              | 11,444.2     | 40.2    | 11,526.1  |
|                               | 40" |                   | 6.4          |         | 6.4       |
|                               | 42" |                   | 865.2        | 3.3     | 868.5     |
| <b>Off Shore</b>              |     |                   |              |         |           |
| Under                         | 10" | 954.1             | 204.3        |         | 1,158.4   |
|                               | 10" | 109.8             | 193.3        |         | 243.1     |
|                               | 12" | 155.1             | 406.9        |         | 562.0     |
|                               | 14" | 27.8              | 44.2         |         | 72.0      |
|                               | 16" | 65.2              | 402.1        |         | 467.3     |
|                               | 18" | 39.7              | 36.1         |         | 75.8      |

Source: National Gas Survey, FPC, 1973

Figure 3.1.2-4 - Gas Pipeline Mileage in Use, 31 December 1970

| Year  | Total  | Transmission        |
|-------|--------|---------------------|
| 1955  | 5,517  | 4,350               |
| 1956  | 6,011  | 4,838               |
| 1957  | 6,633  | 5,412               |
| 1958  | 6,996  | 5,612               |
| 1959  | 7,504  | 6,046               |
| 1960  | 7,843  | 6,359               |
| 1961  | 8,169  | 6,696               |
| 1962  | 8,609  | 7,064               |
| 1963  | 8,818  | 7,261               |
| 1964  | 9,309  | 7,546               |
| 1965  | 9,708  | 7,736               |
| 1966  | 10,242 | 8,182               |
| 1967  | 10,746 | 8,596               |
| 1968  | 11,438 | 9,146               |
| 1969  | 12,742 | 9,375               |
| 1970  | 13,150 | 9,692               |
| 1971  | 14,142 | 10,763              |
| 1972  | 14,506 | 10,976              |
| 1973  | 14,858 | 11,272              |
| 1974R | 15,181 | 11,883 <sup>a</sup> |
| 1975  | 15,413 | 12,069 <sup>a</sup> |

a. Not comparable to previous years due to reclassification  
 R—Revised.

Source: AGA Gas Facts

Figure 3.1.2-5 - Gas Pipeline Compressor Horsepower (Thousands)

|           | Type of Facility  |           |                   |            |                   |          |                   |            |
|-----------|-------------------|-----------|-------------------|------------|-------------------|----------|-------------------|------------|
|           | Gathering         |           | Transmission      |            | Storage           |          | Total             |            |
|           | No. Driving Units | Total HP  | No. Driving Units | Total HP   | No. Driving Units | Total HP | No. Driving Units | Total HP   |
| On Shore  | 7,777             | 3,860,751 | 6,215             | 11,459,777 | 749               | 941,944  | 14,741            | 16,262,472 |
| Off Shore | 203               | 166,343   | 4                 | 4,400      |                   |          | 207               | 170,743    |
| Total     | 7,980             | 4,027,094 | 6,219             | 11,464,177 | 749               | 941,944  | 14,948            | 16,433,215 |

Source: FPC National Gas Survey, 1973

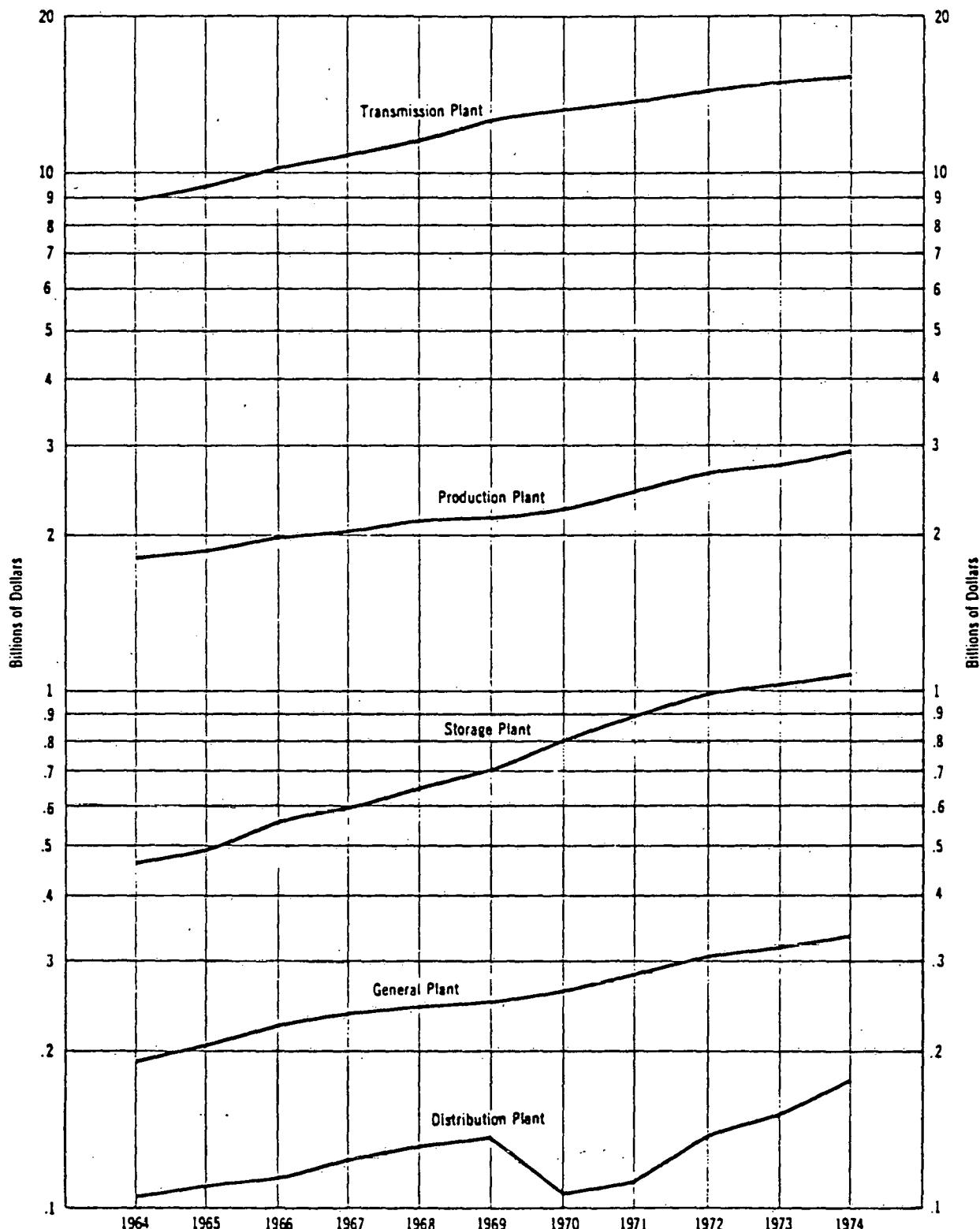
Figure 3.1.2-6 - Gas Pipeline Compressor Horsepower,  
31 December 1970

| Name of Transmission System         | Compressor Stations          |                       | Miles of Transmission Pipeline |                      |                          | 1975                    |                         |                                |
|-------------------------------------|------------------------------|-----------------------|--------------------------------|----------------------|--------------------------|-------------------------|-------------------------|--------------------------------|
|                                     | No. of Transmission Stations | Installed Horse-power | Total                          | 10" & Under Diameter | 10 1/2" - 20 0" Diameter | 20 1/2" & Over Diameter | Peak Day Sendout (MMCF) | Operating Revenues (\$000,000) |
| Algonquin Gas Transmission Co.      | 3                            | 30,900                | 909                            | 281                  | 138                      | 490                     | 704                     | 233 4                          |
| Cities Service Gas Co.              | 35                           | 225,510               | 5,275                          | 1,417                | 2,443                    | 1,415                   | 1,975                   | 244 5                          |
| Colorado Interstate Gas Co.         | 14                           | 125,180               | 2,440                          | 425                  | 1,217                    | 798                     | 1,255                   | 230 1                          |
| Columbia Gas Transmission Co.       | 85                           | 346,577               | 10,325                         | 3,774                | 4,896                    | 1,655                   | 6,562                   | 1,078 6                        |
| Columbia Gulf Transmission Co.      | 18                           | 470,516               | 3,576                          | 130                  | 368                      | 3,078                   | 1,477                   | 134 9                          |
| Consolidated Gas Supply Corp.       | 46                           | 119,367               | 3,672                          | 538                  | 2,454                    | 680                     | 4,423                   | 598 7                          |
| East Tennessee Natural Gas Co.      | 10                           | 25,170                | 1,012                          | 447                  | 383                      | 182                     | 308                     | 46 9                           |
| El Paso Natural Gas Co.             | 53                           | 803,068               | 9,488                          | 1,801                | 2,690                    | 4,997                   | 3,624                   | 1,079 8                        |
| Florida Gas Transmission Co.        | 20                           | 144,070               | 4,267                          | 1,384                | 893                      | 1,990                   | 684                     | 101 5                          |
| Michigan Wisconsin Pipeline Co.     | 39                           | 766,942               | 7,620                          | 1,323                | 700                      | 5,597                   | 4,801                   | 703 1                          |
| Midwestern Gas Transmission Co.     | 14                           | 94,560                | 903                            | 55                   | 0                        | 848                     | 948                     | 278 4                          |
| Mississippi River Transmission Co.  | 18                           | 97,245                | 1,834                          | 203                  | 220                      | 1,411                   | 1,014                   | 191 8                          |
| Natural Gas Pipeline Co. Of America | 50                           | 938,105               | 9,775                          | 917                  | 979                      | 7,879                   | 4,773                   | 710 9                          |
| Northern Natural Gas Co.            | 61                           | 919,508               | 18,806                         | 11,039               | 3,214                    | 4,553                   | 3,140                   | 645 7                          |
| Pacific Gas Transmission Co.        | 12                           | 235,620               | 639                            | 0                    | 0                        | 639                     | 1,282                   | 507 8                          |
| Panhandle Eastern Pipeline Co.      | 57                           | 632,574               | 6,695                          | 729                  | 1,348                    | 4,618                   | 2,090                   | 427 3                          |
| South Georgia Natural Gas Co.       | 2                            | 3,500                 | 769                            | 563                  | 206                      | 0                       | 93                      | 20 0                           |
| Southern Natural Gas Co.            | 36                           | 354,726               | 6,690                          | 968                  | 3,579                    | 2,143                   | 2,171                   | 442 1                          |
| Tenneco, Inc.                       | 60                           | 1,244,113             | 13,071                         | 1,295                | 1,705                    | 10,071                  | 4,303                   | 823 6                          |
| Texas Eastern Transmission Corp.    | 73                           | 1,176,110             | 8,816                          | 882                  | 1,380                    | 6,354                   | 3,060                   | 678 5                          |
| Texas Gas Transmission Corp.        | 19                           | 461,710               | 5,559                          | 1,191                | 1,439                    | 2,929                   | 2,498                   | 386 9                          |
| Transcontinental Gas Pipeline Corp. | 36                           | 951,185               | 8,780                          | 753                  | 1,444                    | 6,583                   | 4,727                   | 601 1                          |
| Transwestern Pipeline Co.           | 134                          | 226,714               | 3,327                          | 1,336                | 438                      | 1,553                   | 880                     | 184 0                          |
| Trunkline Gas Co.                   | 20                           | 332,000               | 3,679                          | 6                    | 544                      | 3,129                   | 1,407                   | 279 3                          |
| United Gas Pipeline Co.             | 30                           | 175,505               | 7,309                          | 2,364                | 3,044                    | 1,901                   | 3,633                   | 602 5                          |

<sup>1</sup> Includes transmission systems with more than 500 miles of transmission pipeline and \$5,000,000 operating revenues.  
 Source: Federal Power Commission.

Source: AGA Gas Facts

Figure 3.1.2-7 - Major Gas Pipeline Companies Operation Statistics, 1975



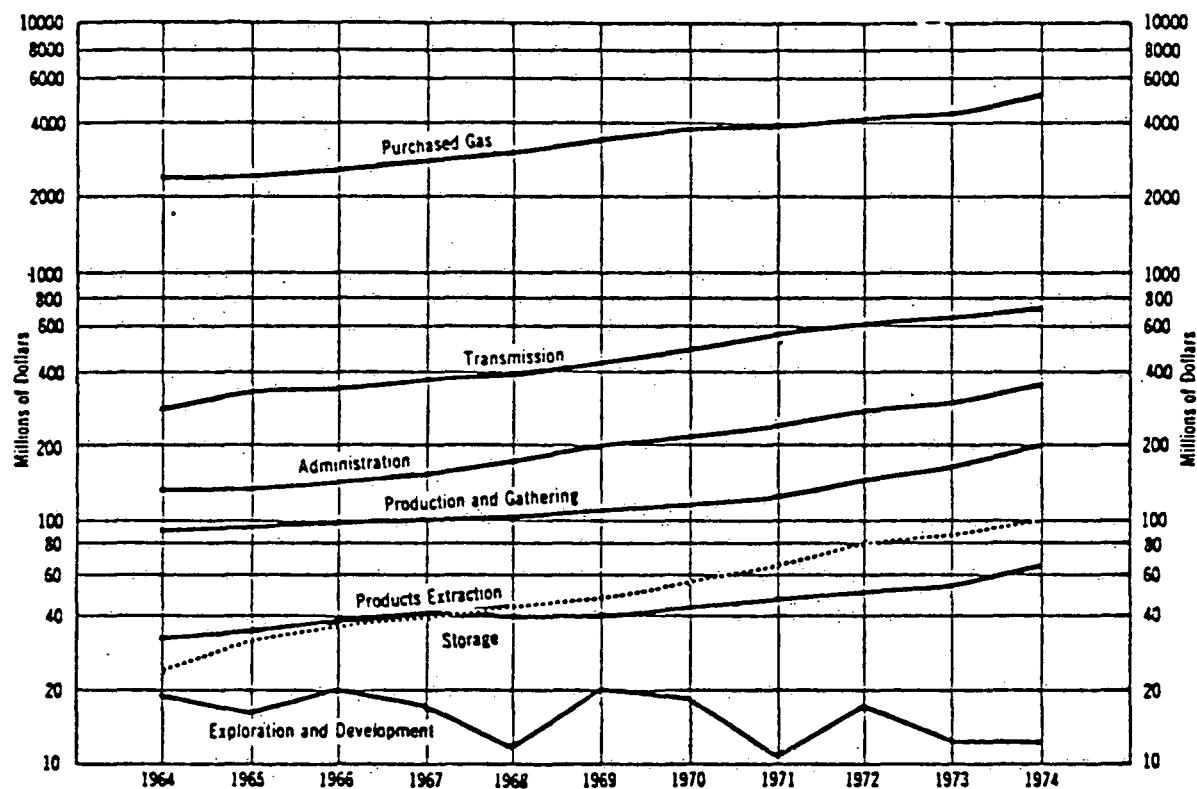
Source: FPC Statistics

Figure 3.1.2-8 - Major Gas Pipelines, Plant in Service

| Gross Plant By Type of Facility                 |                 |                        |                             |                |                 | Accumulated<br>Depreciation<br>Reserves |
|---|-----------------|------------------------|-----------------------------|----------------|-----------------|---|
|   | Pipeline        | Compressor<br>Stations | Process and<br>Conditioning | All<br>Other   | Total           |   |
| <b>Production Plant</b>                         |                 |                        |                             |                |                 |   |
| On Shore  | 1,849.5         | 912.9                  | 826.1                       | 950.0          | 4,538.5         |   |
| Off Shore                                       | 210.7           | 65.2                   | 46.4                        | 15.1           | 337.4           |   |
| <b>Total</b>                                    | <b>2,060.0</b>  | <b>978.1</b>           | <b>872.5</b>                | <b>965.1</b>   | <b>4,875.7</b>  |   |
| <b>Transmission Plant</b>                       |                 |                        |                             |                |                 |   |
| On Shore  | 14,019.7        | 2,961.1                | 70.9                        | 1,038.6        | 18,090.3        |   |
| Off Shore                                       | 505.8           | .4                     | .4                          | 3.1            | 509.3           |   |
| <b>Total</b>                                    | <b>14,525.5</b> | <b>2,961.1</b>         | <b>71.3</b>                 | <b>1,041.7</b> | <b>18,599.6</b> |   |
| <b>Storage Plant</b>                            |                 |                        |                             |                |                 |   |
| On Shore  | 235.5           | 368.0                  | 42.5                        | 1,001.3        | 1,647.3         |   |
| Off Shore                                       |                 |                        |                             |                |                 |   |
| <b>Total</b>                                    | <b>235.5</b>    | <b>368.0</b>           | <b>42.5</b>                 | <b>1,001.3</b> | <b>1,647.3</b>  |   |
| <b>Intangible Plant</b>                         |                 |                        |                             |                |                 |   |
| On Shore  | 6.9             |                        |                             | 132.2          | 139.1           |   |
| Off Shore                                       | .4              |                        |                             | .2             | .6              |   |
| <b>Total</b>                                    | <b>7.3</b>      |                        |                             | <b>132.4</b>   | <b>139.7</b>    |   |
| <b>General Plant</b>                            |                 |                        |                             |                |                 |   |
| On Shore  | 84.3            | .4                     |                             | 547.1          | 631.8           |   |
| Off Shore                                       |                 |                        |                             | .3             | .8              |   |
| <b>Total</b>                                    | <b>84.3</b>     | <b>.4</b>              |                             | <b>547.4</b>   | <b>632.1</b>    |   |
| <b>Other Plant</b>                              |                 |                        |                             |                |                 |   |
| On Shore  | 267.4           | 2.0                    | 27.5                        | 458.8          | 755.7           |   |
| Off Shore                                       | 1.5             |                        |                             |                | 1.5             |   |
| <b>Total</b>                                    | <b>268.9</b>    | <b>2.0</b>             | <b>27.5</b>                 | <b>458.8</b>   | <b>757.2</b>    |   |
| <b>Total Facilities</b>                         |                 |                        |                             |                |                 |   |
| On Shore  | 16,463.1        | 4,244.4                | 967.0                       | 4,128.0        | 25,802.5        |   |
| Off Shore                                       | 718.4           | 65.2                   | 46.8                        | 18.7           | 849.1           |   |
| <b>Total</b>                                    | <b>17,181.5</b> | <b>4,309.6</b>         | <b>1,013.8</b>              | <b>4,146.7</b> | <b>26,651.6</b> |   |
| <b>ACCUMULATED DEPRECIATION, PLANT RESERVES</b> |                 |                        |                             |                |                 |   |
| (For Companies Reporting Depreciation Reserves) |                 |                        |                             |                |                 |   |
| <b>Totals</b>                                   | <b>-</b>        | <b>-</b>               | <b>-</b>                    | <b>-</b>       | <b>24,300.0</b> | <b>8,190.1</b>                          |

Source: FPC National Gas Survey, 1973

Figure 3.1.2-9 - Gas Pipeline Plant Investment,  
31 December 1970



Source: FPC Statistics

Figure 3.1.2-10 - Gas Pipeline Operation and Maintenance Expenses

| Range<br>1-6     | Load Factors<br>Included in Range | 1965      | 1971      |
|------------------|-----------------------------------|-----------|-----------|
| 1                | 70.00-74.99                       | 4         | 1         |
| 2                | 75.00-79.99                       | 1         | 1         |
| 3                | 80.00-84.99                       | 2         | 4         |
| 4                | 85.00-89.99                       | 4         | 2         |
| 5                | 90.00-94.99                       | 3         | 4         |
| 6                | 95.00-99.99                       | 2         | 4         |
| <b>Total</b>     |                                   | <b>16</b> | <b>16</b> |
| Weighted Average |                                   | 82.26     | 87.87     |
| Arith. Average   |                                   | 84.77     | 88.67     |

(1) Source: Form 2.

Source: FPC National Gas Survey, 1973

Figure 3.1.2-11 - Gas Pipeline Load Factors

| Year | Total | Residential | Commercial | Industrial | Other    |
|------|-------|-------------|------------|------------|----------|
| 1950 | 175.4 | 62.5        | 235.9      | 23,188.4   | 7,506.0  |
| 1951 | 193.3 | 70.3        | 255.1      | 25,269.2   | 8,417.4  |
| 1952 | 203.9 | 72.7        | 263.7      | 26,913.2   | 9,749.2  |
| 1953 | 211.4 | 73.2        | 258.6      | 28,385.9   | 12,231.6 |
| 1954 | 223.1 | 78.9        | 271.6      | 29,549.6   | 10,345.7 |
| 1955 | 233.8 | 85.2        | 294.5      | 29,167.5   | 10,250.9 |
| 1956 | 245.6 | 90.5        | 306.4      | 30,752.8   | 8,996.6  |
| 1957 | 252.8 | 92.5        | 316.1      | 30,663.6   | 11,309.1 |
| 1958 | 257.0 | 97.7        | 334.5      | 30,375.6   | 10,770.1 |
| 1959 | 274.2 | 100.7       | 350.1      | 33,478.4   | 11,836.6 |
| 1960 | 281.0 | 104.8       | 374.2      | 33,495.0   | 12,577.5 |
| 1961 | 283.4 | 106.7       | 390.7      | 32,621.7   | 13,468.7 |
| 1962 | 295.1 | 110.9       | 420.7      | 32,713.9   | 13,795.1 |
| 1963 | 302.8 | 112.1       | 430.6      | 33,630.8   | 13,460.2 |
| 1964 | 317.9 | 115.3       | 469.5      | 37,089.1   | 13,234.6 |
| 1965 | 320.9 | 116.5       | 482.1      | 36,982.6   | 12,009.8 |
| 1966 | 336.4 | 118.8       | 510.0      | 38,259.3   | 12,755.1 |
| 1967 | 345.2 | 121.5       | 537.8      | 38,710.3   | 11,397.0 |
| 1968 | 362.4 | 124.1       | 567.6      | 40,378.0   | 13,129.2 |
| 1969 | 376.7 | 128.4       | 611.0      | 42,220.0   | 11,327.2 |
| 1970 | 386.8 | 129.2       | 640.9      | 42,386.7   | 12,232.3 |
| 1971 | 395.0 | 129.9       | 673.8      | 42,235.0   | 17,064.6 |
| 1972 | 397.7 | 130.4       | 697.3      | 41,948.8   | 16,428.8 |
| 1973 | 377.0 | 124.5       | 684.6      | 40,051.7   | 15,129.5 |
| 1974 | 361.1 | 119.6       | 676.1      | 42,066.8   | 12,586.1 |
| 1975 | 333.6 | 121.9       | 708.9      | 37,253.5   | 12,039.8 |

a. Excludes customers purchasing for resale and sales for resale. Customer data is based on yearly averages. Excludes data for Alaska prior to 1959 and Hawaii prior to 1960.

Source: AGA Gas Facts

Figure 3.1.2-12 - National Gas Consumption (10<sup>6</sup> Btu/Customer)

| Year  | Total      | Field Use | Carbon Black Plants <sup>c</sup> | Petroleum Refineries | Portland Cement Plants | Used as Pipeline Fuel | Electric Public Utility Power Plants <sup>b</sup> | Other Industrials <sup>a</sup> |
|-------|------------|-----------|----------------------------------|----------------------|------------------------|-----------------------|---|--------------------------------|
| 1950  | 4,440,197  | 1,187,473 | 410,852                          | 455,096              | 96,986                 | 125,546               | 628,919   | 1,535,325                      |
| 1951  | 5,163,528  | 1,441,870 | 426,423                          | 537,774              | 102,508                | 192,496               | 763,898   | 1,698,559                      |
| 1952  | 5,475,843  | 1,483,754 | 368,399                          | 536,402              | 111,479                | 207,207               | 910,117   | 1,858,485                      |
| 1953  | 5,763,185  | 1,471,085 | 300,942                          | 558,695              | 115,039                | 230,314               | 1,034,072   | 2,052,838                      |
| 1954  | 5,923,647  | 1,456,883 | 251,176                          | 563,315              | 125,257                | 230,615               | 1,165,498   | 2,130,903                      |
| 1955  | 6,317,172  | 1,507,671 | 244,794                          | 625,243              | 131,400                | 245,246               | 1,153,280   | 2,409,538                      |
| 1956  | 6,662,443  | 1,420,550 | 242,598                          | 679,343              | 144,192                | 295,972               | 1,239,311   | 2,640,477                      |
| 1957  | 7,003,590  | 1,479,720 | 233,788                          | 678,810              | 146,000                | 299,235               | 1,338,079   | 2,827,958                      |
| 1958  | 7,174,623  | 1,604,104 | 211,048                          | 681,912              | 164,000                | 312,221               | 1,372,853   | 2,828,485                      |
| 1959  | 7,931,930  | 1,737,402 | 214,612                          | 752,239              | 188,000                | 349,348               | 1,627,097   | 3,063,232                      |
| 1960  | 8,386,038  | 1,779,671 | 197,628                          | 775,154              | 171,000                | 347,075               | 1,724,763   | 3,390,747                      |
| 1961  | 8,756,287  | 1,881,208 | 161,377                          | 772,028              | 180,000                | 377,607               | 1,825,341   | 3,558,726                      |
| 1962  | 9,204,898  | 1,993,128 | 133,302                          | 789,877              | 188,000                | 382,496               | 1,963,590   | 3,752,505                      |
| 1963  | 9,783,676  | 2,081,339 | 117,378                          | 789,951              | 198,000                | 423,783               | 2,142,930   | 4,030,295                      |
| 1964  | 10,327,458 | 2,082,029 | 115,626 <sup>c</sup>             | 820,989              | 202,000                | 433,204               | 2,321,889   | 4,351,721                      |
| 1965  | 10,709,017 | 1,909,697 | 115,374 <sup>c</sup>             | 859,899              | 198,507                | 500,524               | 2,318,253   | 4,806,563                      |
| 1966  | 11,454,494 | 1,772,708 | 114,936 <sup>c</sup>             | 903,398              | 203,805                | 535,353               | 2,608,768   | 5,315,526                      |
| 1967  | 12,167,932 | 1,925,500 | 108,961 <sup>c</sup>             | 936,085              | 195,717                | 575,752               | 2,741,251   | 5,682,666                      |
| 1968  | 13,208,942 | 2,065,008 | 104,973 <sup>c</sup>             | 973,957              | 202,921                | 590,965               | 3,143,858   | 6,127,260                      |
| 1969  | 14,239,996 | 2,212,208 | 98,251 <sup>c</sup>              | 997,886              | 201,295                | 630,962               | 3,486,391   | 6,613,003                      |
| 1970  | 15,151,792 | 2,305,171 | 85,884 <sup>c</sup>              | 1,028,794            | d                      | 722,166               | 3,894,019   | 7,115,758                      |
| 1971  | 15,532,192 | 2,296,777 | 63,699                           | 1,062,938            | d                      | 742,592               | 3,992,983   | 7,373,203                      |
| 1972  | 15,596,902 | 2,363,556 | 53,939                           | 1,070,626            | d                      | 766,156               | 3,978,673   | 7,363,952                      |
| 1973R | 15,833,909 | 2,412,466 | 49,682                           | 1,073,742            | d                      | 728,177               | 3,640,756   | 7,929,086                      |
| 1974  | 15,061,627 | 2,364,876 | 40,130                           | 1,040,057            | d                      | 668,834               | 3,429,230   | 7,518,500                      |

a. Industrial consumption as reported by the Bureau of Mines includes sales by non-utility producers and others, and natural gas mixed with manufactured gas. Hence quantities reported in this table substantially exceed those reported in Section VII, as utility industrial sales.

b. Consumption by "Electric Public Utility Power Plants" includes small quantities of gas other than natural, impossible to segregate. To this extent consumption by other industrials is understated.

c. Data revised to include natural gas to enrich hydrocarbons, as of 1964.

d. Included in "Other Industrial".

Sources: U.S. Bureau of Mines, *Natural Gas Annual*, 1974. (Consumption of "electric public utility power plants" as reported to the Bureau by the Federal Power Commission).

R—Revised

Source: AGA Gas Facts (Data from BoM)

Figure 3.1.2-13 - Industrial Natural Gas Consumption ( $10^6$  Btu)

### 3.2 Gas Pipeline Data Sources

There are two primary sources of gas pipeline data: the FPC Form 2 and the Bureau of Mines (BoM) Form 6-1341-A.

#### 3.2.1 FPC Data

The FPC data is submitted on FPC Form 2 by the 81 Class A and B pipeline companies. These classes, by definition, include all companies with annual gas revenues exceeding one million dollars. In addition, there are 22 Class C and D companies, i.e., those having annual revenues between \$25,000 and \$1,000,000. These latter, who account for less than 1 percent of all interstate sales, file an abbreviated Form 2A.

All of the Form 2 and 2A reports are available for public inspection. The FPC annually publishes a summary of statistics relating only to the 81 Class A and B companies.

For statistical summary purposes, the commission also defines a category called major companies, which includes those whose combined sales for resale and gas transported (interstate) for a fee exceed 50 MMMcf per year. This category included 34 companies for 1975. Only the statistics on these companies are used by the FPC to observe developments in the interstate part of the industry. In 1975, these companies accounted for 84 percent of total gas purchases by FPC regulated pipeline companies from natural gas producers, and 85 percent of the natural gas production of all regulated pipeline companies. These 34 major companies also accounted for 98 percent of city gate sales to intrastate utilities not regulated by the Commission and 68 percent of the industrial sales made by pipeline companies from their main transmission lines.

Almost all of the data reported on the Form 2 consists of dollar amounts, and is, therefore, not of interest for present purposes. Figure 3.2.1-1, Sheets 1, 2, and 3, displays the List of Schedules which comprises the Form 2 submittal. Those schedules which are of present interest are on Sheet 3 and have been overshaded to assist the reader. Examples of the information and its potential use are presented in the sections to follow.

### 3.2.2 BoM Data

The BoM collects data independently of the FPC. Their data are collected on their Form 6-1341-A, which is shown in Figure 3.2.2-1 Sheets 1 and 2. There are two interesting aspects to their operation. First, their coverage is more comprehensive than that of the FPC, in that the BoM tries to include all of the intrastate companies. Second, the submissions are voluntary and therefore proprietary, and cannot be disclosed without consent.

Additionally, it is worth noting that it would be remarkable indeed if full coverage were obtained by means of voluntary submissions, so there must be some omissions. This naturally leads to the thought that if it were decided to further refine the calculations which use these data, it would be desirable to verify the extent of the coverage.

### 3.3 Energy Consumption in Gas Pipelines

The BoM data of present interest are the figures for consumption of compressor fuel. These figures are published in their annual Minerals Yearbook, and are tabulated annually in the AGA publication, Gas Facts. Table 3.3-1 presents these figures for selected years since 1950. The conversion to Quads has been done using three conversion factors -

## LIST OF SCHEDULES (Natural Gas Company)

Designate in column (c) by the terms "none" or "not applicable," as appropriate, in instances where no information or amounts have been reported in certain schedules. Pages may be omitted where the responses are "none" or "not applicable" to the schedules on such pages.

| Title of Schedule<br>(a)  | Schedule<br>Page No.<br>(b) | Date<br>Revised<br>(c) | Remarks<br>(d) |
|---|-----------------------------|------------------------|----------------|
| <b>GENERAL CORPORATE INFORMATION AND SUMMARY FINANCIAL STATEMENTS</b>   |                             |                        |                |
| General Information.....  | 101-101A                    | Dec. 72                |                |
| Control Over Respondent.....  | 102                         | Oct. 1966              |                |
| Corporations Controlled by Respondent.....  | 103                         |                        |                |
| Officers.....   | 104                         | Dec. 73                |                |
| Directors.....  | 105                         |                        |                |
| Security Holders and Voting Power.....  | 106-107                     |                        |                |
| Important Changes During the Year.....  | 108-109                     |                        |                |
| Comparative Balance Sheets—Statement A.....   | 110-112                     | Dec. 74                |                |
| Summary of Utility Plant and Accumulated Provisions for Depreciation, Amortization, and Depreciation—Statement B.....                       | 113                         | Dec. 73                |                |
| Statement of Income for the Year—Statement C.....   | 114-116A                    | Dec. 74                |                |
| Statement of Retained Earnings for the Year—Statement D.....  | 117 - 117A                  | Dec. 74                |                |
| Statement of Changes in Financial Position—Statement E.....   | 118-119                     | Dec. 72                |                |
| <b>BALANCE SHEET SUPPORTING SCHEDULES</b>   |                             |                        |                |
| Nonutility Property.....  | 201                         | Dec. 73                |                |
| Accumulated Provision for Depreciation and Amortization of Nonutility Property.....   | 201                         | Dec. 69                |                |
| Investments.....  | 202                         | Dec. 74                |                |
| Investments in Subsidiary.....  | 203                         |                        |                |
| Notes and Accounts Receivable.....  | 204                         | Dec. 65                |                |
| Accumulated Provisions for Uncollectible Accounts—Cr.....   | 204                         |                        |                |
| Receivables from Associated Companies.....  | 206                         | Dec. 73                |                |
| Materials and Supplies.....   | 207                         | Dec. 73                |                |
| Gas Stored.....   | 207A                        | Dec. 71                |                |
| Production Fuel and Oil Stocks.....   | 209                         | Dec. 73                |                |
| Prepayments.....  | 210                         | Dec. 70                |                |
| Miscellaneous Current and Accrued Assets.....   | 210                         | Oct. 73                |                |
| Extraordinary Property Losses.....  | 210                         | Oct. 73                |                |
| Prepaid Gas Purchases Under Purchase Agreements.....  | 210A                        | Dec. 72                |                |
| Advances for Gas Prior to Initial Deliveries or Commission Certification.....   | 210B                        | Dec. 72                |                |
| Unamortized Debt Disc. and Exp. and Unamort. Premium on Debt.....   | 211                         | Dec. 73                |                |
| Preliminary Survey and Investigation Charges.....   | 212                         |                        |                |
| Miscellaneous Deferred Debits.....  | 214                         | Dec. 74                |                |
| Deferred Losses from Disposition of Utility Plant.....  | 214A                        | Dec. 73                |                |
| Unamortized Loss and Gain on Reacquired Debt.....   | 214B                        |                        |                |
| Accumulated Deferred Income Taxes.....  | 214C-D                      | Dec. 75                |                |
| Capital Stock.....  | 215                         |                        |                |
| Capital Stock Subscribed, Capital Stock Liability for Conversion, Premium on Capital Stock, and Installments Received on Capital Stock..... | 216                         |                        |                |
| Other Paid-In Capital.....  | 217                         |                        |                |

Rev. (12-75)

Figure 3.2.1-1 - Sheets 1-3, List of Schedules, FPC Form 2,  
filed by Class A and B Natural Gas Companies

| LIST OF SCHEDULES (Natural Gas Company) (Continued)  |                             |                        |                |
|--|-----------------------------|------------------------|----------------|
| Title of Schedule<br>(a)   | Schedule<br>Page No.<br>(b) | Date<br>Revised<br>(c) | Remarks<br>(d) |
| <b>BALANCE SHEET SUPPORTING SCHEDULES (Continued)</b>  |                             |                        |                |
| Discount on Capital Stock.....   | 218                         |                        |                |
| Capital Stock Expense.....   | 218                         |                        |                |
| Long-Term Debt.....  | 219                         | Dec. 73                |                |
| Securities Issued or Assumed and Securities Refunded or Retired During the Year.....   | 220                         | Dec. 73                |                |
| Notes Payable.....   | 221                         | Dec. 73                |                |
| Payables to Associated Companies.....  | 221                         | Dec. 73                |                |
| Taxes Accrued, Prepaid and charged During Year.....  | 222-222A                    | Dec. 73                |                |
| Reconciliation of Reported Net Income with Taxable Income for Federal Income Taxes.....  | 223                         | Dec. 73                |                |
| Miscellaneous Current and Accrued Liabilities.....   | 224                         | Dec. 73                |                |
| Customer Advances for Construction.....  | 224                         | Dec. 73                |                |
| Deferred Gains From Disposition of Utility Plant.....  | 224A                        | Dec. 73                |                |
| Other Deferred Credits.....  | 225                         | Dec. 73                |                |
| Undelivered Gas Obligations Under Sales Agreements.....  | 225A                        | Jul. 65                |                |
| Operating Reserves.....  | 226                         | Dec. 73                |                |
| Accumulated Deferred Income Taxes.....   | 227-227E                    | Dec. 74                |                |
| Investment Tax Credits Generated and Utilized.....   | 228                         | Dec. 75                |                |
| Accumulated Deferred Investment Tax Credits.....   | 229                         | Dec. 75                |                |
| <b>INCOME ACCOUNT SUPPORTING SCHEDULES</b>   |                             |                        |                |
| Gain or Loss on Disposition of Property.....   | 300                         | Dec. 73                |                |
| Income from Utility Plant Leased to Others.....  | 301                         | Dec. 73                |                |
| Particulars Concerning Certain Other Income Accounts.....  | 303                         | Dec. 73                |                |
| Particulars Concerning Certain Income Deduction and Interest Charges Accounts.....   | 304                         | Dec. 73                |                |
| Expenditures for Certain Civic, Political and Related Activities.....  | 305                         | Dec. 73                |                |
| Extraordinary Items.....   | 306                         | Dec. 74                |                |
| <b>COMMON SCHEDULES</b>  |                             |                        |                |
| Common Utility Plant and Expenses.....   | 351                         |                        |                |
| Regulatory Commission Expenses.....  | 353                         | Dec. 74                |                |
| Charges for Outside Professional and Other Consultative Services.....  | 354                         | Dec. 70                |                |
| Distribution of Salaries and Wages.....  | 355-356                     | Dec. 74                |                |
| <b>Gas Plant, Sales, Operating and Statistical Data</b>  |                             |                        |                |
| Gas Plant in Service.....  | 501-504                     | Dec. 72                |                |
| Gas Plant Leased to Others.....  | 505                         |                        |                |
| Gas Plant Held for Future Use.....   | 506                         | Dec. 65                |                |
| Production Properties Held for Future Use.....   | 506A                        |                        |                |
| Construction Work in Progress and Completed Construction Not Classified—Gas.....   | 507                         | Dec. 72                |                |
| Accumulated Provision for Depreciation of Gas Utility Plant.....   | 508                         | Dec. 74                |                |
| Accumulated Provision for Amortization and Depletion of Gas Utility Plant—Producing Natural Gas Land and Land Rights.....  | 509                         | Dec. 73                |                |
| Accumulated Provision for Amortization and Depletion of Gas Utility Plant—Underground Storage Land and Land Rights.....  | 510                         | Dec. 73                |                |
| Accumulated Provision for Amortization and Depletion of Gas Utility Plant—Other Gas Plant in Service, Amortization and Depletion of Gas Plant Leased to Others, Amortization of Gas Plant Held for Future Use..... | 511                         | Dec. 73                |                |

Figure 3.2.1-1 - (Continued)

| LIST OF SCHEDULES (Natural Gas Company) (Continued)   |                             |                        |                |
|---|-----------------------------|------------------------|----------------|
| Title of Schedule<br>(a)  | Schedule<br>Page No.<br>(b) | Date<br>Revised<br>(c) | Remarks<br>(d) |
| <b>GAS PLANT, SALES, OPERATING AND STATISTICAL DATA (Continued)</b>   |                             |                        |                |
| Accum. Prov. for Amort. & Depletion of Gas Util. Plant-Aband. of Leases..   | 512                         | Dec. 73                |                |
| Gas Plant Acquisition Adjustment and Accumulated Provision for Amortization of<br>Gas Plant Acquisition Adjustment..... | 513                         | Dec. 74                |                |
| Gas Operating Revenues.....   | 514                         | Dec. 69                |                |
| Unauthorized Overuse Penalties and Waivers of Penalties.....  | 515                         |                        |                |
| Sales of Natural Gas by Communities.....  | 515-517                     | Dec. 1967              |                |
| Residential and Commercial Space Heating Customers.....   | 518                         | Dec. 1966              |                |
| Interruptible, Off Peak, and Firm Sales to Distribution System Industrial Customers.....                                | 518                         | Dec. 1966              |                |
| Piped and Metered Sales of Natural Gas.....   | 519-520                     | Dec. 72                |                |
| Sales for Resale—Natural Gas.....   | 521-522                     | Dec. 73                |                |
| Interdepartmental Sales—Natural Gas.....  | 523                         | Dec. 1966              |                |
| Rent from Gas Property and Interdepartmental Rents.....   | 523                         |                        |                |
| Revenue from Transportation of Gas of Others—Natural Gas.....   | 524                         | Oct. 1966              |                |
| Sales of Products Extracted from Natural Gas.....   | 525                         |                        |                |
| Revenues from Natural Gas Processed by Others.....  | 525                         | Dec. 1966              |                |
| Incidental Gasoline and Oil Sales and Other Gas Revenues.....   | 526                         | Dec. 72                |                |
| <u>Gas Operation and Maintenance Expenses</u> .....   | 527-532                     | Dec. 73                |                |
| Number of Gas Department Employees.....   | 532                         |                        |                |
| Lease Rentals Charged.....  | 533-5330                    | Dec. 72                |                |
| Exploration and Development Expenses.....   | 534                         |                        |                |
| Abandoned Leases.....   | 534                         |                        |                |
| Gas Purchases.....  | 535-538                     | Dec. 72                |                |
| Exchange Gas Transactions.....  | 537                         | Dec. 1966              |                |
| Exchange Gas Accounting.....  | 538                         | Dec. 69                |                |
| Gas Util. Economy Operations—Credits.....   | 539                         | Dec. 1966              |                |
| Other Gas Supply Expenses.....  | 540                         |                        |                |
| Transmission and Compression of Gas by Others.....  | 541                         | Dec. 1966              |                |
| Franchise Requirements.....   | 542                         | Dec. 1966              |                |
| Miscellaneous General Expenses (Gas).....   | 543                         | Dec. 73                |                |
| Construction Overheads—Gas.....   | 543                         |                        |                |
| General Description of Construction Overhead Procedure.....   | 544                         | Dec. 73                |                |
| Depreciation, Depletion, and Amortization of Gas Plant.....   | 545-5463                    | Dec. 71                |                |
| Natural Gas Reserves and Land Acreage (Deleted, see FPC Form No. 40)  | --                          | --                     |                |
| Natural Gas Reserves and Land Acreage (Deleted, see FPC Form No. 40)  | --                          | --                     |                |
| Changes in Estimated Hydrocarbon Reserves and Costs.....  | 549A-549B                   |                        |                |
| Natural Gas Reserves Available from Purchase Agreements.....  | 550-551                     | Dec. 72                |                |
| <u>Natural Gas Production and Gathering Statistics</u> .....  | 552-553B                    | Dec. 73                |                |
| Product Extraction Operations—Natural Gas.....  | 554-555                     | Oct. 1966              |                |
| Compressor Station.....   | 556-557                     | Dec. 1966              |                |
| Number of Gas and Oil Wells.....  | 558                         | Dec. 69                |                |
| Field and Storage Lines.....  | 559                         | Dec. 69                |                |
| Gas Storage.....  | 560-561                     | Dec. 72                |                |
| Transmission Lines.....   | 562                         |                        |                |
| Manufactured Gas Production Statistics.....   | 563                         | Oct. 1966              |                |
| Liquefied Petroleum Gas Operations.....   | 564                         | Oct. 1966              |                |
| Transmission System Peak Deliveries.....  | 565                         | Dec. 1966              |                |
| Auxiliary Peaking Facilities.....   | 566                         | Oct. 1966              |                |
| Gas Account—Natural Gas.....  | 567-569                     | Oct. 1966              |                |
| Service Interruptions Occurring on the Pipeline System.....   | 570                         | Dec. 70                |                |
| System Map.....   | 571                         |                        |                |
| Research and Development Activities.....  | 572-572A                    | Dec. 72                |                |
| Attestation.....  | 573                         | Dec. 1965              |                |

Sheet 3

Figure 3.2.1-1 - (Continued)

Form 4-1341-4  
7-7-6

UNITED STATES  
DEPARTMENT OF THE INTERIOR  
BUREAU OF MINES  
WASHINGTON, D. C. 20241

2-6-42-RD32  
Received in the House of Representatives Oct. 1977

INDIVIDUAL COMPANY  
DATA—CONFIDENTIAL

 B24

SUPPLY AND DISPOSITION OF NATURAL GAS

*(Please correct if name or address has changed.)*

Report oil gas volumes at the pressure base of 14.73 pounds per square inch absolute or m.p.f.  
See instructions on reverse side.

This report is authorized by Public Law 92-366. While you are not required to respond, your cooperation is needed to make the results of this survey comprehensive, accurate and timely.

**1. STATE covered by this report**

## 12. Supply and disposition of natural gas during the year

| Item<br>1-11  | Code | Quantity<br>(Millions<br>of barrels) | Value<br>(Thousands<br>of dollars) |
|---|------|--------------------------------------|------------------------------------|
| <b>A. Supply of raw and residual gas:</b>   |      |                                      |                                    |
| 1. Crude gas production from leases operated by your company in State designated in Item 1 above:                       |      |                                      |                                    |
| a. Prove gas and condensate wells _____   | 161  | \$                                   |                                    |
| b. Prove oil wells (unassociated gas) _____   | 162  | \$                                   |                                    |
| 2. Recovery of gas from State designated in Item 1:   |      |                                      |                                    |
| a. From producing companies _____   | 163  | \$                                   |                                    |
| b. From pipeline companies<br>(Names of company) _____<br>_____   | 171  | \$                                   |                                    |
| 3. Recovery of gas from States other than the State designated in Item 1:<br>(Names of company) _____<br>_____          |      |                                      |                                    |
| 4. Withdrawals from underground storage _____   | 181  | \$                                   |                                    |
| 5. Total supply (Sum of 1, 2, 3, and 4) _____   | 199  | \$                                   |                                    |
| <b>B. Disposition of raw and residual gas:</b>  |      |                                      |                                    |
| 1. Expenditures here _____  | 261  | \$                                   |                                    |
| 2. Used in lease operations and as plant fuel _____   | 262  | \$                                   |                                    |
| 3. Returned to furnaces for reprocessing, producer maintenance,<br>and cycling _____                                    | 263  | \$                                   |                                    |
| 4. Vented to air or burned in flares _____  | 264  | \$                                   |                                    |
| 5. Used as fuel in your pipeline operations _____   | 265  | \$                                   |                                    |
| 6. Delivered to natural-gas processing plants other than your own _____   | 266  | \$                                   |                                    |
| 7. Delivered to pipeline and distributing companies<br>a. Within State named above<br>(Names of company) _____<br>_____ | 267  | \$                                   |                                    |
| b. Outside of State designated in Item 1:<br>(Names of company) _____<br>_____  |      |                                      |                                    |
| 8. Delivered directly to consumers:   |      |                                      |                                    |
| a. Residential consumers _____  | 271  | \$                                   |                                    |
| (1) Number of residential consumers<br>at end of year _____   | 271  | \$                                   |                                    |
| b. Commercial consumers _____   | 272  | \$                                   |                                    |
| (1) Number of commercial consumers<br>at end of year _____  | 272  | \$                                   |                                    |
| c. Industrial consumers _____   | 273  | \$                                   |                                    |
| d. Electric utilities _____   | 274  | \$                                   |                                    |
| e. Other consumers _____  | 275  | \$                                   |                                    |
| 9. Shared in underground storage _____  | 281  | \$                                   |                                    |
| 10. Unaccounted for _____   | 298  | \$                                   |                                    |
| 11. Total disposition (Sum of 1-10; should be the same as line A5 above) _____  | 299  | \$                                   |                                    |

Figure 3.2.2-1 - BoM Form 6-1341-A

## INSTRUCTIONS

Please provide the information requested on the reverse side of this form and return one copy as soon as possible in the enclosed envelope. It will be appreciated if this report can be returned before the 15th of February.

Quantity—Report all volumes in MILLION CUBIC FEET at the pressure base of 14.73 pounds per square inch absolute at 60°F.

Value—Report all values in THOUSANDS OF DOLLARS.

I State—File a separate report for each State in which your company operates.

II MIXED GAS OPERATIONS: In mixed gas operations only the natural gas component should be reported. If both natural and mixed gas are distributed, report natural gas operations and the natural gas portion of your mixed gas operations on separate forms. Adjust all volumes to the pressure base of 14.73 pounds per square inch absolute at 60°F.

IIA1 When leases are not wholly owned by the reporting company, it is requested that the operator of the facility report 100 percent of the production. Exclude any production from leases, which you own that are operated by others. Your company's gross production of gas should include royalty interests and gas used in own operations. Estimate if necessary.

Value of gross production at well includes the producer's realization from all products contained in the gas delivered to natural gas processing plants. Assign no value to that portion of gross production used for repressuring. Do not include gathering charges or State taxes. Ignore tax exempt interests and tax reimbursements.

IIA2 Receipts of gas from companies within the State covered by this report.

- Report total receipts of gas from other producers within the State.
- Receipts of gas from within the State, from natural gas processing plants other than your own, exchange gas, and gas received for transport, should be reported by individual company and amount received from each company.

IIA3 Receipts of gas from outside of the State should be shown by individual company, the bordering State from which the gas was received, and the amount received from each company.

IIA4 Withdrawals from underground storage—Report only company-owned gas withdrawn from storage.

IIB1, 2, 5 Value of gas used in lease operations, as plant fuel in your pipeline operations, and extraction loss, should represent the cost to your company or average wellhead price of the gas.

IIB1 Extraction loss—Total extraction loss for natural gas processing plants operated by your own company. This volume and value should agree with those reported on the Form 6-1343-A. Show disposition of residue gas from your own plants under proper use category, i.e., industrial sales to other companies, vented, return to formation.

IIB2 Include gas used in lease operations, as plant fuel and net use for gas lift.

IIB6 Total deliveries of natural gas to natural gas processing plants operated by companies other than your own.

IIB7a Include exchange gas and gas delivered for transport as well as gas sold to other pipeline and distributing companies within State. List companies and amount of each sale individually.

IIB7b Deliveries of gas outside of the State to pipeline or distribution companies should be listed by company and amount of each sale individually.

IIB8 Delivered directly to consumers:

- Residential—Include natural gas used in private households for heating, cooking, and other household uses.
- Commercial—Include natural gas used by non-manufacturing organizations, such as hotels, restaurants, retail stores, laundries, and other service enterprises; also gas used in agriculture, forestry and fisheries.
- Industrial—Gas sold directly to industrial consumers. Include gas used as fuel in chemical plants (your own and others), used to produce carbon black, and gas consumed by own company.
- Electric utilities—Natural gas used as fuel in electric utility plants including those operated by your company.
- Other consumers—Include deliveries to municipalities and government agencies for use in schools, institutions, street lighting, etc.

IIB9 Report only company-owned gas stored in underground storage.

Figure 3.2.2-1 - (Continued)

Table 3.3-1

Energy Consumption in Gas Pipelines,  
Intrastate and Interstate

| <u>Year</u> | <u>Fuel,<br/>MMSCF</u> | <u>Approximate Energy Consumption, Quads</u> |                     |                    |
|-------------|------------------------|--|---------------------|--------------------|
|             |                        | <u>1020 Btu/Scf</u>                          | <u>1075 Btu/Scf</u> | <u>960 Btu/Scf</u> |
| 1950        | 125,546                | 0.128  | 0.135               | 0.117              |
| 1955        | 245,246                | 0.250  | 0.264               | 0.228              |
| 1960        | 347,075                | 0.354  | 0.373               | 0.321              |
| 1965        | 500,524                | 0.511  | 0.538               | 0.465              |
| 1970        | 722,166                | 0.736  | 0.776               | 0.672              |
| 1974        | 666,834                | 0.682  | 0.717               | 0.620              |

Source: Data collected by BoM

the ERDA conversion factor of 0.98 trillion SCF per quadrillion Btu (Quad), taken from ERDA-48, the value of 1975 Btu/Scf used by BoM, and an approximate average lower heating value of 960 Btu/Scf.

Unfortunately, it is seldom clear from the presentation of the data what heating value is assumed, or how it is calculated. The calorimeters commonly used to measure heating value introduce the gas into the combustion chamber by bubbling through water, so that the gas is saturated with water vapor. Thus, when the combustion products are cooled to the original temperature and condensed, the latent heat of vaporization introduced by saturating the gas is also measured. The appropriate correction for this latent heat is taken as a part of the standard measuring technique. However, the amount of gas originally present is less than would be the case with dry gas, by the amount of dry gas which is displaced by the water vapor, but no correction is made for this effect. Thus, the higher heating value, on the dry basis, is about 20 Btu/Scf more than on the wet basis. Contracts are usually written on the wet basis, many times for an HHV of 1000 Btu/Scf. The gas is delivered dry, or nearly so, so that the delivered HHV is generally around 1020 Btu/Scf. The lower heating value (LHV) is approximately 90 Btu less than the HHV. The HHV is used in the table.

The figures presented in the last three columns of Table 3.3-1 are a good approximation to the total energy consumption in the gas pipeline industry. In addition to the uncertainty already mentioned in Section 3.2.2 as to completeness of coverage of all the intrastate pipelines, these figures contain three additional sources of error. The first additional source is just the cumulative result of the inherent imprecision in each of the constituent numbers which are added to make the total. The standard deviation of the sum is simply the rms of the sum of the individual variances.

The second error source is the variation in heating values of the fuel. The 1020 Btu/Scf which was used in the conversion from column 2 of Table 3.3-1 to column 3 was used in ERDA-48 as an approximation to the average value for pipeline-quality gas. However, the BoM uses 1075 Btu/Scf, and that value was used in column 4. A more realistic value would appear to be that based upon the lower heating value, as shown in the last column. The actual HHV varies of course but is generally in the neighborhood of the first two figures.

The third error source lies in the fact that the figures presented do not include other sources of compression energy besides gas. There is a small fraction of pipeline compressors which are electrically driven. For 1970-71, this fraction was estimated as 4.1 percent. However, the methodology employed in that reference is believed to contain a systematic error which would reduce this figure by something over 10 percent. The electric bills for electrically-driven compressor stations are reported on Schedules 556 and 557 of Form 2. Thus, if further refinement should become necessary or desirable, an estimate of this error could be made by totaling the figures from those schedules of the 81 Class A and B interstate companies. The uncertainty would then be reduced to the non-gas energy by intrastate and Class C and D interstate companies.

The first two of these errors sources are compensating and would tend to average out when taken over large blocks of data. The third is in the form of omissions, and thus makes the estimate low. Also, as has been noted, there are almost certainly some omissions from the original BoM compilations. Thus, it is likely that the best estimate is near the high side of the range. It is therefore suggested that a two-figure estimate of 0.71 Quad be used. For a single-figure estimate, 0.7 Quad is probably very good, i.e., the true value is more likely to be nearer to 0.7 than to 0.6 or 0.8.

The breakdown of energy consumed in the categories of collection, transmission, storage and distribution is not reported in terms of Btu consumed in each of these functions. However, the dollar values of energy consumed by the interstate companies are reported on FPC Form 2 and are broken into the first three of these categories. The task force which prepared the National Gas Survey complied these figures for the 10 regions defined earlier by the Future Gas Requirements Committee. These regions are shown in Figure 3.3-1. The task force compilations are shown in Table 3.3-2. It is immediately noted, though not unexpected, that there is no reported consumption for the distribution process, since the reporting companies are not engaged in distribution. Application of this same fractional breakdown to the total consumption previously quoted in Table 3.3-1, yields the approximate breakdown for 1974, which is shown in Table 3.3-3. The values for distribution were derived by simply assuming that function about equal to collection.

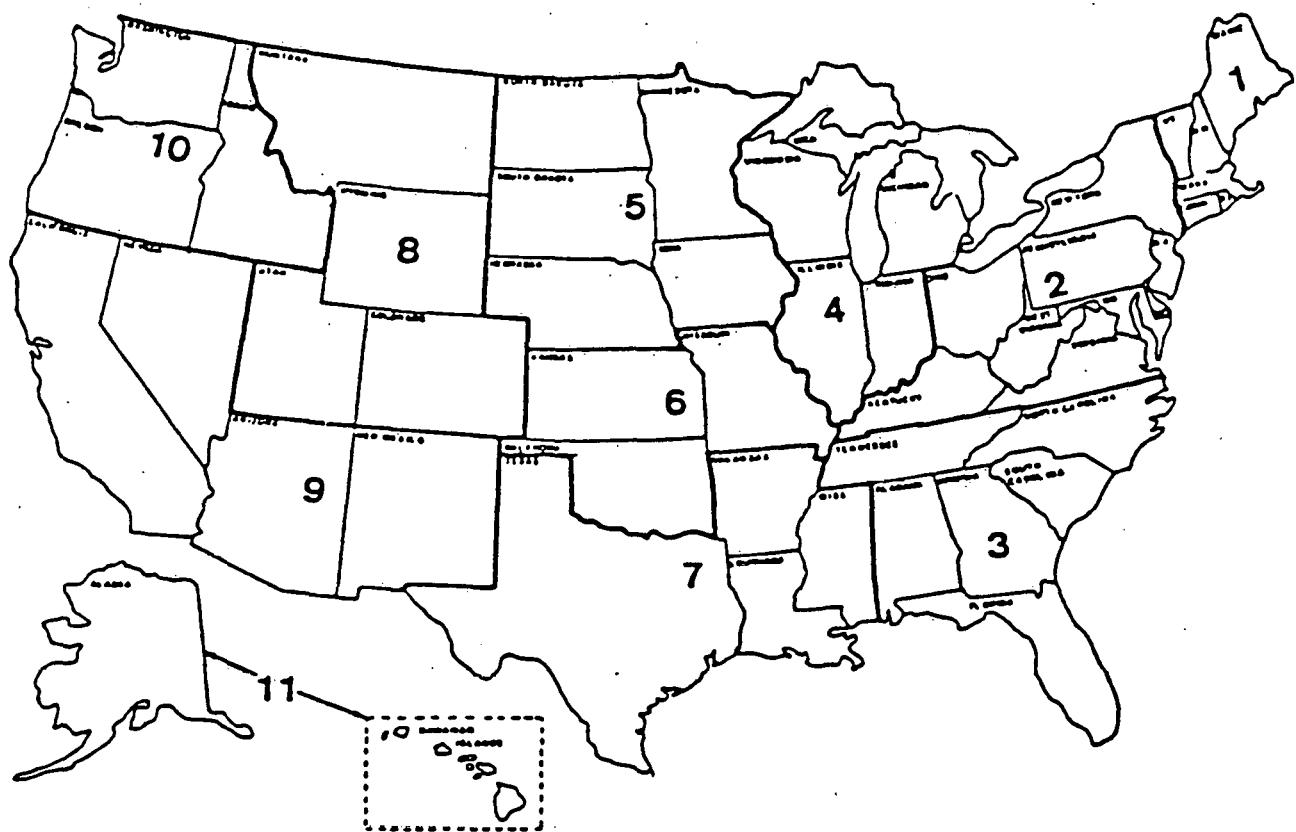
### 3.4 Estimate of Energy Intensity of Gas Pipelines

As was explained in Section 1.2 above, the energy intensity of a transportation mode is calculated from the formula

$$I_E = \frac{\text{energy consumed}}{\text{throughput} \times \text{distance.}}$$

The throughput can be expressed in any convenient way, e.g., as a mass, volume, or energy content but for purposes of comparison with other modes, the most useful term is mass. Thus, in the ancient English system of units, the EI is expressed usually in Btu/ton-mile, or Btu per ton per mile.

FUTURE GAS REQUIREMENTS COMMITTEE REGIONS



Source: FPC National Gas Survey, 1973, p. 104

Figure 3.3-1 - Regions Used in the Analysis

Table 3.3-2  
Distribution of Energy Cost, 1970, ¢/Mcf  
Major Companies Only

| <u>Region</u> | <u>Prod.</u> | <u>Coll'n.</u> | <u>Xmxn</u> | <u>Strg.</u> | <u>Dist.</u> | <u>Total</u> |
|---------------|--------------|----------------|-------------|--------------|--------------|--------------|
| 1             | 0.037        | 0              | 1.311       | 0.015        | 0            | 1.363        |
| 2             | 0.026        | 0.019          | 0.931       | 0.064        | 0            | 1.040        |
| 3             | 0.016        | 0.008          | 0.776       | 0.007        | 0            | 0.807        |
| 4             | 0.003        | 0.025          | 0.814       | 0.026        | 0            | 0.868        |
| 5             | 0.026        | 0.031          | 1.089       | 0.012        | 0            | 1.158        |
| 6             | 0.007        | 0.073          | 0.542       | 0.021        | 0            | 0.643        |
| 7             | 0.021        | 0.027          | 0.028       | 0.007        | 0            | 0.263        |
| 8             | 0.045        | 0.089          | 0.167       | 0.001        | 0            | 0.302        |
| 9             | 0.068        | 0.108          | 0.523       | 0.000        | 0            | 0.699        |
| 10            | 0.098        | 0.156          | 0.476       | 0.000        | 0            | 0.730        |
|               | —            | —              | —           | —            | —            | —            |
|               | 0.347        | 0.536          | 6.837       | 0.153        | 0            | 7.873        |
| §             | 4.41         | 6.81           | 86.84       | 0.02         | 0            | 100          |

Source: National Gas Survey, p. 107-110

Table 3.3-3

Approximate Breakdown of 1974 Energy Consumption  
in Gas Pipeline

| <u>Function</u> | <u>Fraction</u> | <u>Energy, Quads</u>                 |                                     |
|-----------------|-----------------|--------------------------------------|-------------------------------------|
|                 |                 | <u>ERDA Factor<br/>(1020 Btu/cf)</u> | <u>BoM Factor<br/>(1075 Btu/cf)</u> |
| Production      | 0.0441          | 0.0301                               | 0.0316                              |
| Collection      | 0.0681          | 0.0464                               | 0.0488                              |
| Transmission    | 0.8684          | 0.5922                               | 0.6227                              |
| Storage         | 0.0194          | 0.0133                               | 0.0139                              |
|                 | 1.0000          | 0.6820                               | 0.7170                              |

### 3.4.1 Industry-average Energy Intensity of Gas Pipelines

It is obvious that the average EI for the industry cannot be calculated from summary statistics. Although total energy consumed and total throughput are known with high precision, no figure for the distance exists. The distance figure that would possibly be the most interesting would be the sum of the throughput-weighted distances for each leg. In principle, it would be possible to calculate the throughput for every leg if there were a meter reading available at every branch point. Such readings probably exist for most trunkline branch points. The collection, compilation and reduction, and analysis of that data would exceed the cost limits of the present project, so it has not been attempted. The complexity and scope of such an undertaking can be appreciated by study of the gas pipeline map published by the Federal Power Commission. Moreover, as seen below, it is unnecessary for the present purpose, which is the first order estimate of gas pipeline EI.

It is well to note at this point an important distinction between the overall, industrywide EI and that which obtains for a specific route and haul. For example, in the case of railroads, if one takes the total locomotive energy consumed and divides it by the total ton-miles of transport, the result, for the year 1972, is

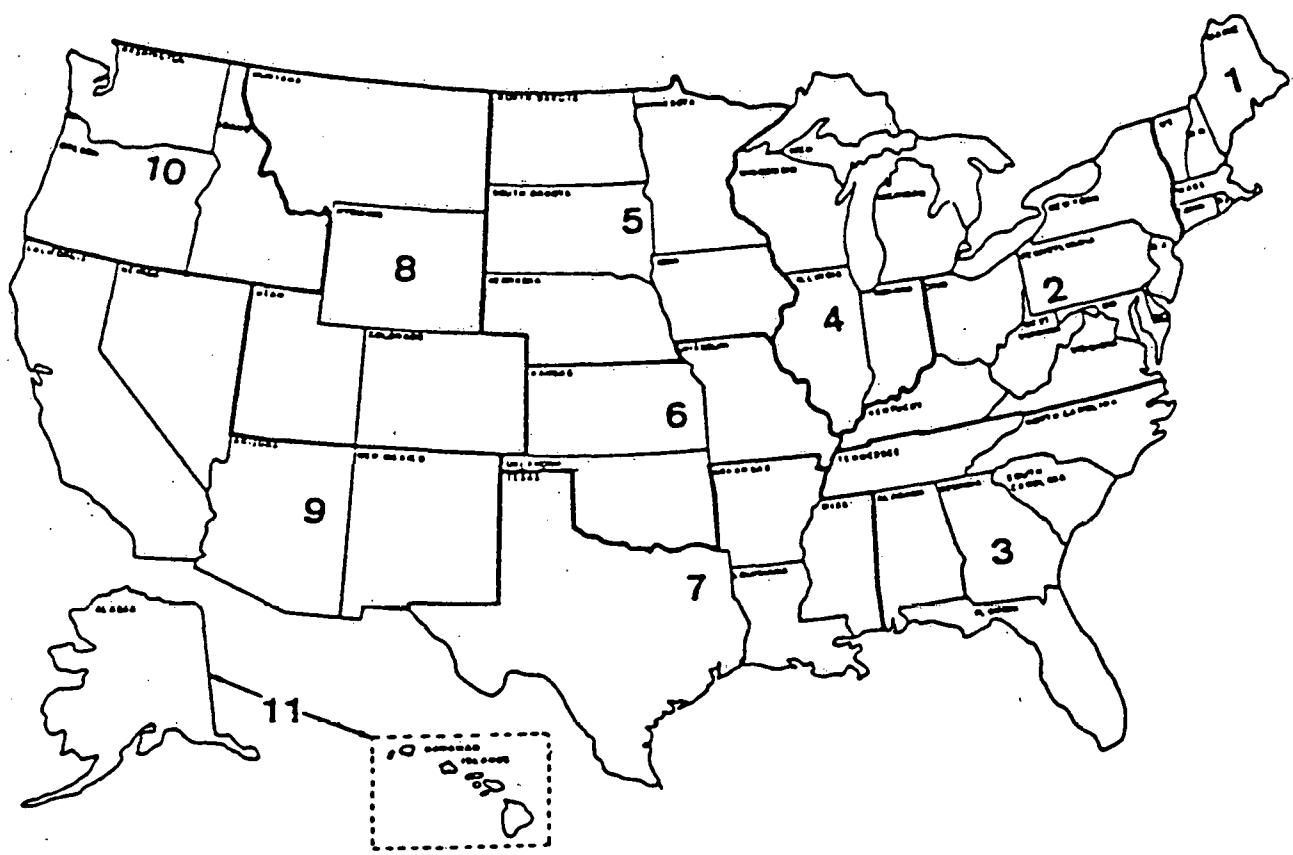
$$(I_E)_{\text{Rail}} = \frac{5.446 \times 10^{14} \text{ Btu}}{7.84 \times 10^{11} \text{ Ton-Mile}} \sim 700 \frac{\text{Btu}}{\text{Ton-Mile}}$$

However, if one examines a particular route and haul, one almost invariably obtains a much different figure. For example, Zandi (1974) used the railway engineers' handbook formula to calculate the EI of a railroad which would duplicate the haul of the Black Mesa slurry pipeline. He obtained a figure of 450 Btu/Ton-Mile.

Returning now to the case of the gas pipelines and considering first the industry-wide EI, in the absence of throughput data, it is necessary to make an estimate of the throughput.

In preparing the FPC National Gas Survey, the Task Force for Transmission Operations prepared estimates of the cost of service in 1970 to each of the ten regions, shown again in Figure 3.4.1-1. Referring once more to the national map R-5721 (FPC 74) one again appreciates the complexity of the national gas transmission network. However, it is observed that Region 1 is supplied almost exclusively by Tennessee Gas Pipeline Company (Tenneco) from wells on the coast of Texas and Louisiana. From the map, the separation of the center of collection and center of distribution is scaled to be approximately 1700 miles. This provides a first-order estimate of the distance.

An estimate of the fuel consumed per MCF of throughput is obtained from the Task Force estimate of the cost of service for Region 1, which is presented in Table 3.4.1-1. It is seen that the cost of fuel is estimated to be 1.311 ¢/MCF. Under FPC accounting, this gas is credited to purchases (or production) at whatever purchase price (or production cost) was paid. Reference to Schedule 529, Line 1, of the Form 2 filed by Tenneco for 1970 will reveal that figure. Since the 1970 figure is not readily at hand, for present illustrative purposes the national average figure is used. Reference to Gas Facts, 1975, p. 110, repeated here for convenience of the reader as Table 3.4.1-2, reveals that figure to be 17.1 ¢/MCF. That this figure is probably very close to what Tenneco paid in 1970 can be inferred from inspection of Table 3.4.1-3, where it is seen that the Texas-Louisiana average wellhead price for 1974 was very close, i.e., within less than 2%, to the national average. If the same were true for 1970, dividing the 17.1¢ value into the 1.311 ¢/MCF average fuel cost for transmission



Source: FPC National Gas Survey, 1973, p. 104

Figure 3.4.1-1 - Regions Defined by Future Gas Requirements Committee

Table 3.4.1-1

## COST OF SERVICE, 1970

Region 1

|              | Production<br>¢/MCF | Gathering<br>¢/MCF | Transmission<br>¢/MCF | Storage<br>¢/MCF | Distribution<br>¢/MCF | Total<br>¢/MCF |
|--------------|---------------------|--------------------|-----------------------|------------------|-----------------------|----------------|
| Operating    | 0.479               | 0                  | 3.062                 | 0.054            | 0                     | 3.595          |
| Fuel         | 0.037               | 0                  | 1.311                 | 0.015            | 0                     | 1.363          |
| Maintenance  | 0.086               | 0.002              | 1.183                 | 0.012            | 0                     | 1.283          |
| G & A        | 0                   | 0                  | 3.212                 | 0                | 0                     | 3.212          |
| Depreciation | 0.086               | 0                  | 8.992                 | 0.066            | 0                     | 9.144          |
| Income Taxes | 0.134               | 0                  | 4.074                 | 0.012            | 0                     | 4.220          |
| Other Taxes  | 0.148               | 0                  | 3.553                 | 0.015            | 0                     | 3.716          |
| Return       | <u>0.741</u>        | <u>0</u>           | <u>15.762</u>         | <u>0.074</u>     | <u>0</u>              | <u>16.577</u>  |
| Totals       | 1.711               | 0.002              | 41.149                | 0.248            | 0                     | 43.11          |

Region 4

|              |              |              |              |              |              |              |
|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Operating    | 0.197        | 0.126        | 1.460        | 0.411        | 0.055        | 2.249        |
| Fuel         | 0.003        | 0.025        | 0.814        | 0.026        | 0.000        | 0.868        |
| Maintenance  | 0.019        | 0.051        | 0.716        | 0.059        | 0.008        | 0.853        |
| G & A        | 0.000        | 0.000        | 1.513        | 0.000        | 0.000        | 1.513        |
| Depreciation | 0.084        | 0.227        | 3.051        | 0.158        | 0.026        | 3.546        |
| Income Taxes | 0.019        | 0.091        | 1.357        | 0.091        | 0.015        | 1.374        |
| Other Taxes  | 0.017        | 0.082        | 1.202        | 0.057        | 0.016        | 1.374        |
| Return       | <u>0.061</u> | <u>0.380</u> | <u>4.968</u> | <u>0.243</u> | <u>0.052</u> | <u>5.704</u> |
| Totals       | 0.400        | 0.982        | 15.081       | 1.045        | 0.172        | 17.68        |

Data extracted from FPC Forms 2, 2A, 15 15A.

Source: FPC National Gas Survey.

Table 3.4.1-2

Average Wellhead Price and Marketed Production of  
Natural Gas, 1950-1975<sup>a</sup>

| Year | Average<br>Wellhead Price<br>(cents per MCF) | Marketed Production       |                     |
|------|--|---------------------------|---------------------|
|      |  | Millions of<br>Cubic Feet | Trillions of<br>BTU |
| 1950 | 6.5  | 6,282,060                 | 6,753.0             |
| 1951 | 7.3  | 7,457,359                 | 8,016.7             |
| 1952 | 7.8  | 8,013,457                 | 8,614.5             |
| 1953 | 9.2  | 8,396,916                 | 9,026.7             |
| 1954 | 10.1   | 8,742,546                 | 9,398.2             |
| 1955 | 10.4   | 9,405,351                 | 10,110.4            |
| 1956 | 10.8   | 10,081,923                | 10,838.2            |
| 1957 | 11.3   | 10,680,258                | 11,481.0            |
| 1958 | 11.9   | 11,030,248                | 11,857.5            |
| 1959 | 12.9   | 12,046,115                | 12,949.5            |
| 1960 | 14.0   | 12,771,038                | 13,728.8            |
| 1961 | 15.1   | 13,254,025                | 14,248.1            |
| 1962 | 15.5   | 13,876,622                | 14,917.4            |
| 1963 | 15.8   | 14,746,663                | 15,852.7            |
| 1964 | 15.4   | 15,462,143                | 16,621.8            |
| 1965 | 15.6   | 16,039,753                | 17,242.7            |
| 1966 | 15.7   | 17,206,628                | 18,497.1            |
| 1967 | 16.0   | 18,171,325                | 19,534.2            |
| 1968 | 16.4   | 19,322,400                | 20,771.6            |
| 1969 | 16.7   | 20,698,240                | 22,250.6            |
| 1970 | 17.1   | 21,920,642                | 23,564.7            |
| 1971 | 18.2   | 22,493,012                | 24,180.0            |
| 1972 | 18.6   | 22,531,698                | 24,221.6            |
| 1973 | 21.6   | 22,647,549                | 24,346.1            |
| 1974 | 30.4   | 21,600,522                | 23,220.6            |
| 1975 | 44.5   | 20,108,661                | 21,616.8            |

<sup>a</sup> Marketed production as reported by the Bureau of Mines is equivalent to natural gas production usefully consumed. It includes natural gas sold by producers and other non-utilities to industrial consumers and includes natural gas mixed with manufactured gas for consumption.

Source: U. S. Bureau of Mines, Natural Gas Annual  
(Excerpted from AGA Gas Facts, 1975, p. 110)

Table 3.4.1-3

Average Wellhead Price and Marketed Production of  
Natural Gas, By State, 1974 and 1975

| Division and State   | 1974                                   |                            | 1975                                   |                            |
|----------------------|--|----------------------------|--|----------------------------|
|                      | Average Wellhead Price (cents per MCF) | Marketed Production (MMCF) | Average Wellhead Price (cents per MCF) | Marketed Production (MMCF) |
| United States        | 30.4                                   | 21,600,522                 | 44.5                                   | 20,108,661                 |
| New England          | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Middle Atlantic      | 44.6                                   | 87,627                     | 68.0                                   | 92,304                     |
| New Jersey           | 0.0                                    | 0                          | 0.0                                    | 0                          |
| New York             | 55.0                                   | 4,990                      | 74.0                                   | 7,628                      |
| Pennsylvania         | 44.0                                   | 82,637                     | 67.5                                   | 84,676                     |
| East North Central   | 49.0                                   | 162,800                    | 66.6                                   | 188,859                    |
| Illinois             | 40.0                                   | 1,436                      | 70.0                                   | 1,440                      |
| Indiana              | 14.0                                   | 176                        | 39.0                                   | 346                        |
| Michigan             | 50.4                                   | 69,133                     | 63.4                                   | 102,113                    |
| Ohio                 | 48.2                                   | 92,055                     | 70.6                                   | 84,960                     |
| Wisconsin            | 0.0                                    | 0                          | 0.0                                    | 0                          |
| West North Central   | 16.8                                   | 920,559                    | 17.5                                   | 871,006                    |
| Iowa                 | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Kansas               | 16.6                                   | 886,782                    | 17.2                                   | 843,635                    |
| Minnesota            | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Missouri             | 31.4                                   | 33                         | 34.0                                   | 30                         |
| Nebraska             | 34.0                                   | 2,538                      | 54.1                                   | 2,565                      |
| North Dakota         | 19.9                                   | 31,206                     | 23.0                                   | 24,786                     |
| South Dakota         | 0.0                                    | 0                          | 0.0                                    | 0                          |
| South Atlantic       | 36.5                                   | 247,672                    | 50.4                                   | 205,683                    |
| Delaware             | 0.0                                    | 0                          | 0.0                                    | 0                          |
| District of Columbia | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Florida              | 53.6                                   | 38,137                     | 97.3                                   | 44,383                     |
| Georgia              | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Maryland             | 24.0                                   | 133                        | 27.0                                   | 93                         |
| North Carolina       | 0.0                                    | 0                          | 0.0                                    | 0                          |
| South Carolina       | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Virginia             | 51.0                                   | 7,096                      | 51.5                                   | 6,723                      |
| West Virginia        | 32.8                                   | 202,306                    | 36.9                                   | 154,484                    |
| East South Central   | 44.7                                   | 178,545                    | 59.3                                   | 172,697                    |
| Alabama              | 74.3                                   | 27,865                     | 87.0                                   | 37,814                     |
| Kentucky             | 50.0                                   | 71,876                     | 54.0                                   | 60,511                     |
| Mississippi          | 29.5                                   | 78,787                     | 49.6                                   | 74,345                     |
| Tennessee            | 36.0                                   | 17                         | 43.0                                   | 27                         |
| West South Central   | 30.6                                   | 17,687,346                 | 45.6                                   | 16,298,056                 |
| Arkansas             | 26.0                                   | 123,975                    | 34.7                                   | 116,237                    |
| Louisiana            | 30.7                                   | 7,753,631                  | 42.3                                   | 7,090,645                  |
| Oklahoma             | 28.0                                   | 1,638,942                  | 32.0                                   | 1,605,410                  |
| Texas                | 31.1                                   | 8,170,798                  | 51.9                                   | 7,485,764                  |
| Mountain             | 29.3                                   | 1,821,684                  | 38.2                                   | 1,801,478                  |
| Arizona              | 20.0                                   | 224                        | 28.0                                   | 208                        |
| Colorado             | 20.0                                   | 144,629                    | 26.0                                   | 171,629                    |
| Idaho                | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Montana              | 25.3                                   | 54,873                     | 43.3                                   | 40,734                     |
| Nevada               | 0.0                                    | 0                          | 0.0                                    | 0                          |
| New Mexico           | 31.4                                   | 1,244,779                  | 40.5                                   | 1,217,430                  |
| Utah                 | 41.2                                   | 50,522                     | 48.0                                   | 55,354                     |
| Wyoming              | 24.5                                   | 326,657                    | 33.7                                   | 316,123                    |
| Pacific              | 40.0                                   | 494,289                    | 56.7                                   | 478,578                    |
| Alaska               | 17.0                                   | 128,935                    | 30.2                                   | 168,578                    |
| California           | 44.0                                   | 365,354                    | 70.0                                   | 318,308                    |
| Hawaii               | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Oregon               | 0.0                                    | 0                          | 0.0                                    | 0                          |
| Washington           | 0.0                                    | 0                          | 0.0                                    | 0                          |

<sup>a</sup> Reflects price at first point of transfer, representing sales made by producers.

Source: U. S. Bureau of Mines, Natural Gas Annual.

(Excerpted from AGA Gas Facts, 1975, p. 109)

to Region 1 yield a value of 7.667% for the ratio of gas consumed in compression to gas transported. Using 1020 Btu/Scf for the heating value and 41,000 Scf per ton then yields an EI of 3206 Btu/Ton-Mile for the energy intensity.

Repeating the process for Region 4, the average distance is scaled to be approximately 850 miles from the Texas-Oklahoma panhandles to the Chicago area, yielding a value of 2593 Btu/Ton-Mile for the EI. Further note of these estimated values will be taken at the end of the next section.

### 3.4.2 Specific-haul Energy Intensity of Gas Pipelines

The EI for a specific transmission system can be calculated with high precision if all the pertinent engineering design parameters are known with high precision, because the gas dynamics are thoroughly understood and well-documented steady flow correlations are available. Some of the more familiar correlations are:

- Weymouth - used in distribution and gathering systems. The flow calculated with this formula will result in conservative values and since the formula is not complex, it is suitable for preliminary sizing.
- Panhandle A - used extensively in the United States for large high-pressure transmission systems. The formula is suitable for use in a Reynolds number range of  $5 \times 10^6$  to  $11 \times 10^6$ .
- Revised Panhandle - used for high-pressure transmission systems. This formula is used in the Reynolds number range of  $4 \times 10^6$  to  $40 \times 10^6$ .

Each formula has as a variable the transmission factor on which is based the loss in pressure due to friction in the pipeline. The method for calculating this factor as well as the application of the formulas is noted in a flow

computation manual published by the American Gas Association. The Petroleum Engineer Pipeline Handbook contains the data required for solving the revised Panhandle formula in metric units.

The gas dynamics model used in this study is a proprietary computer code of Pipe Line Technologists, Inc., a participating company in this project. The code is available, for a royalty, to serve the needs of qualified investigators who may wish to verify or extend the results of this study. Figure 3.4.2-1 presents, for illustrative purposes only, the printout from the model for a particular system in a particular year of its operation, and for a particular market (throughput).

Elsewhere in Task 1 of this project, reference systems have been designed for each principal type of pipeline - gas, crude, products, slurry and water. The reference gas system was introduced in another report of this series, SSS-R-77-3024, Section 7.1, where some economic simulation results were presented. Between the reference system design and economic model is the gas dynamics model already described, which takes as input the system design parameters and the prescribed throughput (market forecast) and calculates the energy consumption and cost of compression.

Table 3.4.2-1 presents selected outputs from a series of full economic simulation runs. The third column is the EI for four throughputs. As would be expected, the EI is nearly proportional to the square of the flow. Thus, there is seen to be a wide variation in EI, within a range of reasonably expectable, or at least not highly unusual, market conditions.

• PIPE LINE TECHNOLOGISTS, INC. •  
 • STELLY STATE GAS •  
 • PIPELINE FLOW MODEL •

\*\*\* THIS IS THE ERCA EXAMPLE GAS PIPELINE \*\*\*  
 \*\*\* YEAR 3 \*\*\*

FLOWING PIPELINE SUMMARY

| SEGMENT<br>NO. | FROM<br>MILE<br>POST | TO<br>MILE<br>POST | FL.EV<br>FT | PRESS<br>PSIA | JULLET        |                   | CULLET        |               | AVERAGE           |                 |                |                     | LINE<br>PACK |
|----------------|----------------------|--------------------|-------------|---------------|---------------|-------------------|---------------|---------------|-------------------|-----------------|----------------|---------------------|--------------|
|                |                      |                    |             |               | TEMP<br>DEG.F | GAS RATE<br>MCF/D | FRESS<br>PSIA | TEMP<br>DEG.F | GAS RATE<br>MCF/D | VELO-<br>FT/SEC | PRSS<br>PSI/MI | STANDARD<br>MMSCF/D |              |
| 1              | 0.00                 | .00                | 0.          | 450.0         | 70.0          | 7139.61           | 450.0         | 70.0          | 7139.67           | 27.73           | 3.69           | 228.73              | 1.           |
| 2              | .00                  | 59.22              | 59.         | 936.0         | 194.6         | 4025.33           | 683.3         | 72.1          | 3413.53           | 14.54           | 1.80           | 226.80              | 56448.       |
| 3              | 59.22                | 88.00              | 29.         | 883.3         | 72.3          | 3413.93           | 831.0         | 69.1          | 3620.93           | 13.64           | 1.82           | 226.80              | 25240.       |
| 4              | 88.00                | 121.72             | -9.         | 831.0         | 69.0          | 3620.93           | 765.9         | 68.2          | 3557.53           | 14.68           | 1.92           | 226.80              | 31840.       |
| 5              | 121.72               | 152.00             | -4.         | 990.0         | 107.8         | 3306.67           | 940.4         | 75.3          | 3202.50           | 12.64           | 1.64           | 226.25              | 33112.       |
| 6              | 152.00               | 185.56             | 21.         | 949.4         | 74.3          | 3202.50           | 283.8         | 69.4          | 3374.65           | 12.75           | 1.69           | 226.25              | 36380.       |
| 7              | 185.56               | 250.23             | 40.         | 883.8         | 69.4          | 3374.65           | 762.7         | 68.2          | 3965.12           | 14.14           | 1.87           | 226.25              | 63247.       |
| 8              | 250.23               | 263.00             | 8.          | 990.0         | 108.3         | 3303.18           | 968.7         | 87.4          | 3190.63           | 12.63           | 1.66           | 225.69              | 13944.       |
| 9              | 263.00               | 315.69             | -9.         | 966.7         | 87.4          | 3198.63           | 881.5         | 69.3          | 3375.76           | 12.74           | 1.65           | 225.69              | 57257.       |
| 10             | 315.69               | 382.48             | -11.        | 881.5         | 69.3          | 3375.76           | 757.8         | 68.3          | 3584.10           | 14.17           | 1.86           | 225.69              | 64813.       |
| 11             | 382.48               | 398.00             | -7.         | 985.1         | 108.6         | 3315.09           | 959.6         | 84.7          | 3200.44           | 12.66           | 1.64           | 225.12              | 16870.       |
| 12             | 398.00               | 450.00             | -13.        | 959.6         | 84.7          | 3200.44           | 873.6         | 69.3          | 3900.59           | 12.79           | 1.65           | 225.12              | 55943.       |
| 13             | 450.00               | 518.39             | -18.        | 873.6         | 69.3          | 3400.59           | 745.5         | 68.2          | 4046.24           | 14.33           | 1.87           | 225.12              | 66679.       |
| 14             | 518.39               | 567.71             | -19.        | 262.2         | 108.5         | 3315.37           | 852.5         | 69.1          | 3483.40           | 13.26           | 1.68           | 224.56              | 71734.       |
| 15             | 567.71               | 658.00             | -18.        | 852.9         | 69.1          | 3483.40           | 717.4         | 68.2          | 4210.80           | 14.78           | 1.93           | 224.56              | 65264.       |
| 16             | 658.00               | 686.00             | -7.         | 932.6         | 108.3         | 3498.84           | 884.4         | 71.1          | 3403.07           | 13.40           | 1.72           | 224.00              | 26593.       |
| 17             | 686.00               | 758.00             | -14.        | 894.4         | 76.0          | 3403.07           | 803.2         | 69.4          | 1859.20           | 9.90            | 1.12           | 112.00              | 49754.       |
| 18             | 758.00               | 784.00             | 10.         | 803.2         | 69.4          | 1859.20           | 771.0         | 69.4          | 1545.44           | 10.61           | 1.20           | 112.00              | 16773.       |
| 19             | 784.00               | 822.00             | -7.         | 771.0         | 69.4          | 1545.44           | 682.2         | 68.2          | 2223.42           | 14.36           | 2.34           | 112.00              | 1P106.       |
| 20             | 822.00               | 837.00             | -15.        | 602.2         | 68.8          | 2223.42           | 643.3         | 68.7          | 2370.48           | 15.90           | 2.59           | 112.00              | 1458.        |
| 21             | 837.00               | 891.00             | -15.        | 643.3         | 68.7          | 2370.48           | 479.4         | 68.2          | 3291.17           | 18.97           | 2.13           | 112.00              | 19478.       |

800954.

DELIVERY SUMMARY

| MILE<br>POST | PRESS<br>PSIA | TEMP<br>DEG F | GAS RATE<br>MMSCF/D |
|--------------|---------------|---------------|---------------------|
| 1            | 450.00        | 70.0          | -228.73             |
| 2            | 626.00        | 76.0          | 112.00              |
| 3            | 891.00        | 474.37        | 68.3                |
| 22           | 891.00        | 474.37        | 68.3                |

Figure 3.4.2-1 - Pipetech Computer Printout, Sheet 1

## COMPRESSOR INVENTORY

| NO. | PIPE<br>POST | ELEVATION<br>FEET ABOVE<br>SEA LEVEL | SUCTION<br>PRESSURE<br>PSIA | SECTION<br>TEMP.<br>°F | DISCHARGE<br>PRESSURE<br>PSIA | DISCHARGE<br>TEMP.<br>°F | COMPRESSOR<br>OPERATING<br>HORSEPOWER | FUEL<br>REQUIRED<br>MMSCF/D | COOLING<br>REQUIRED<br>TONS | STATION<br>THROUGHPUT<br>MMSCF/D |
|-----|--------------|--------------------------------------|-----------------------------|------------------------|-------------------------------|--------------------------|---------------------------------------|-----------------------------|-----------------------------|----------------------------------|
|     |              |                                      |                             |                        |                               |                          |                                       |                             |                             |                                  |
| 1   | 40           | 50.0                                 | 450.0                       | 70.0                   | 940.0                         | 144.8                    | 1003.1                                | 1.526                       | 0.                          | 226.80                           |
| 2   | 121.72       | 152.0                                | 765.3                       | 65.3                   | 940.0                         | 107.8                    | 2084.                                 | .554                        | 0.                          | 226.25                           |
| 3   | 250.23       | 212.1                                | 762.7                       | 62.2                   | 940.0                         | 106.3                    | 2920.                                 | .562                        | 0.                          | 225.49                           |
| 4   | 382.48       | 200.5                                | 757.8                       | 68.3                   | 985.1                         | 108.6                    | 2935.                                 | .564                        | 0.                          | 225.12                           |
| 5   | 510.39       | 167.1                                | 745.5                       | 68.2                   | 969.2                         | 104.5                    | 2931.                                 | .563                        | 0.                          | 224.56                           |
| F   | 658.00       | 131.0                                | 717.4                       | 68.2                   | 932.6                         | 108.3                    | 2921.                                 | .561                        | 0.                          | 224.00                           |
|     |              |                                      |                             |                        |                               |                          | 24634.                                | 4.730                       | 0.                          |                                  |

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Figure 3.4.2-1 - Pipetech Computer Printout, Sheet 2

Table 3.4.2.-1  
Energy Intensity of Reference Gas System

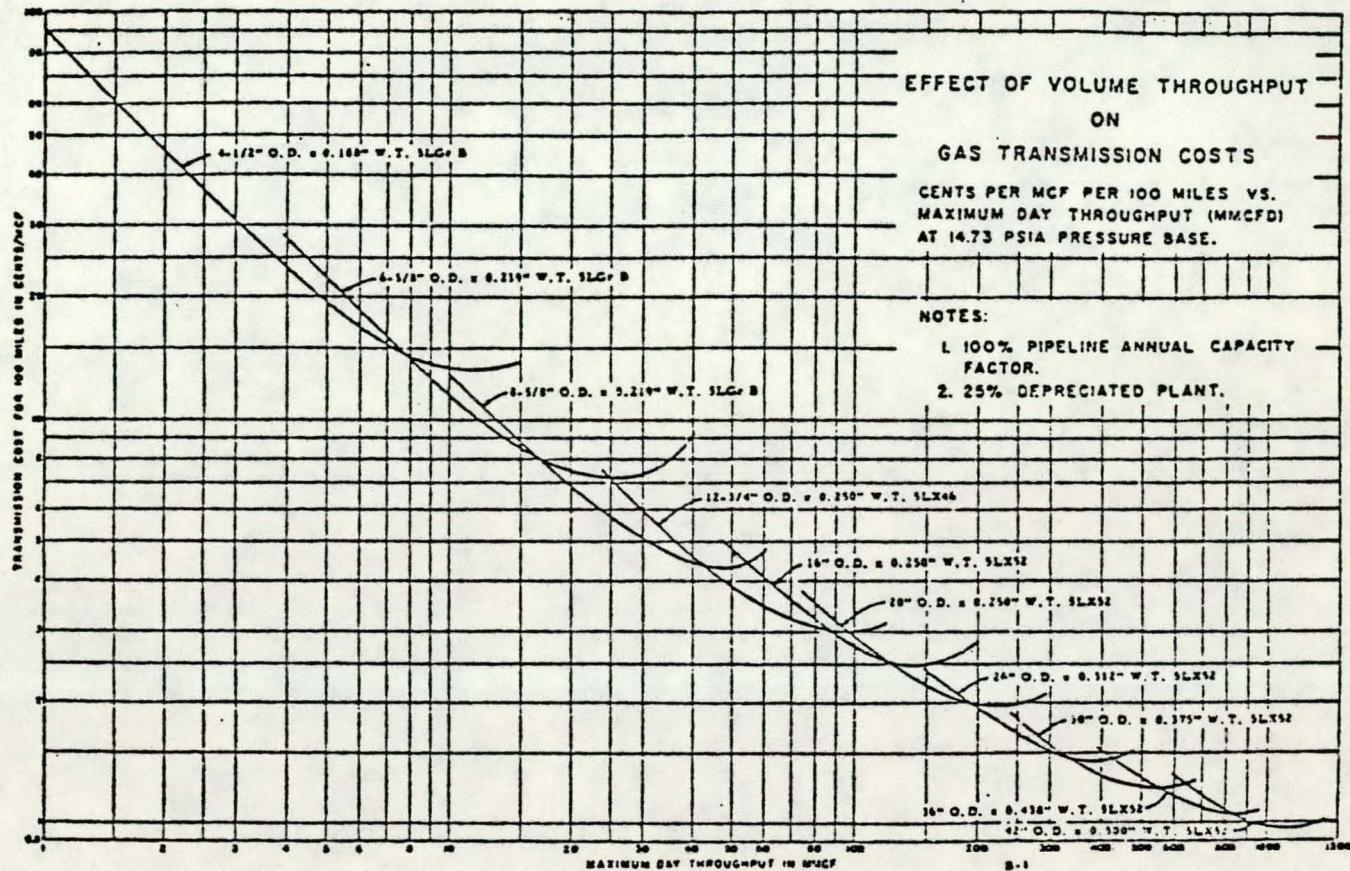
| <u>Throughput,<br/>10<sup>9</sup> Ton-Mile/Yr</u> | <u>Compression<br/>Energy, 10<sup>12</sup> Btu</u> | <u>IE<br/>Btu/Ton-Mile</u> |
|---|--|----------------------------|
| 1.363   | 1.528  | 1121                       |
| 1.868   | 4.312  | 2308                       |
| 2.3706  | 7.586  | 3125                       |
| 2.5313  | 10.447   | 4127                       |

This now raises the question of what is the EI most likely to be seen in practice. To the extent that pipeline operators understand their business and influence their own destiny, the answer must be that the most likely EI is that at which either the return to the operator is maximum or some cost is a minimum. For any line, the total unit cost of course is infinite for zero throughput, first decreasing as throughput increases, passing through a minimum, then increasing. The magnitude of the minimum cost, and the throughput at which it occurs, are sensitive to line diameter, as is seen in the example of Figure 3.4.2-2.

To investigate this question, a search for the optimum throughput(s) was made by conducting full 16-year simulations of pipeline operation at each throughput. All capital investment was made in year zero, and throughput was held constant for each case. Zero debt was taken, in an effort to expose the true economic effect in terms of return on ownership. Some selected results are tabulated in Table 3.4.2-2.

The first observation to be made is that the minimum-cost point is below even the lowest EI (and throughput) which was examined. It may be noted that the engineers who designed the system were not surprised at this result. It was their feeling that the minimum throughput condition, i.e., the  $1.363 \times 10^6$  Ton-Miles/Day which corresponds to the IE of 1121, is about at the minimum-cost operating point for this line.

More importantly, it may be observed that the operating point which yields maximum return to an owner-investor is at a much higher energy intensity. The price of fuel was taken to be the \$1.42/MCF recently set by the FPC, and even at this relatively high price, in terms of previous years, the maximum return operating point falls at an IE approximately



Source: Testimony, Docket No. AR61-2; Hearing Exhibit No. 59; Date Identified 12-10-63; Date Admitted 5-26-64;  
p. 2456-2462

Figure 3.4.2-2 - Throughput-diameter Relationships to Unit Cost for Gas Pipelines

Table 3.4.2-2  
Search for Economic Energy Intensity

| <u>IE,<br/>Btu/Ton-Mile</u> | <u>LAC*<br/>Mills/Ton-Mile</u> | <u>Book Profit*<br/>10<sup>6</sup> \$</u> | <u>Cash Flow*<br/>10<sup>6</sup> \$</u> |
|-----------------------------|--------------------------------|---|---|
| 1121                        | 5.17                           | 107                                       | 163                                     |
| 2308                        | 5.95                           | 134                                       | 204                                     |
| 3125                        | 7.36                           | 142                                       | 234                                     |
| 4127                        | 8.21                           | 133                                       | 227                                     |

\*16-year present value, discounted at 10%.

three times greater than that of the minimum-cost point. To bring the two together would require a gas price of several dollars per MCF.

It may also be noted that in none of the cases studied was the FPC profit limit reached, so that the cost to the consumer is the same all cases.

This area of investigation, i.e., the relationships between energy consumption, profit, and cost to the consumer, contains many interesting questions and warrants further investigation. In particular, when a plan is being developed for implementation of the recommendations of Task 2, Regulation and Tarriff, more detailed case studies will be needed. Further work is therefore recommended.

Referring again to Figure 3.4.2-1, it is seen to be consistent with the result just derived. For a 24-inch line, which is the diameter of the reference system, the figure indicates a minimum cost at about  $300 \times 10^6$  ft<sup>3</sup>/day, as opposed to the  $200 \times 10^6$  ft<sup>3</sup>/day which corresponds to the minimum-throughput point in Table 3.3.2-3. It seems quite reasonable that the increase in fuel prices since 1963 could account for this shift to lower flow.

Finally, it is observed that the maximum-return EI of approximately 3100 BTU/Ton-Mile for the reference system is not inconsistent with the 3200 derived in the previous section for Regional 1, New England. The Tenneco line consists of parallel pipes ranging in size from 24 to 30 inches. The lower figure of 2600 which was derived for Region 4 is also not inconsistent when it is recognized that the principal line from the Panhandle area to Chicago consists of 24 to 36 inch pipes. For the larger pipes, a lower energy intensity would be expected.

The foregoing calculations were sent to several pipeline companies for review. The responses were that the methodology and values seemed reasonable, but since they had never calculated EI, they could not comment upon the actual magnitudes. However, one large company performed the necessary research into their own records and calculated the EI for the trunkline portion of their system in 1976. The result was just over 1000 Btu/Ton-Mile. However, in earlier years, when the throughput was much higher, the EI was of course much higher, so that the EI for that system may well have been above 1500 Btu/Ton-Mile. This result, of course, leads to the suspicion that the estimates developed above are high.

Taking all of the foregoing discussion into account, it is concluded that the 1976 average EI lies between 1000 and 4000 Btu/Ton-Mile, at high confidence. Taking the geometric mean, in recognition of the skewed nature of the probability density function, yields a value of 2000 Btu/Ton-Mile. This is the estimate for energy intensity of gas pipelines.

## 4.0 ENERGY CONSUMPTION IN OIL PIPELINES

### 4.1 Oil Pipeline Industry Profile

#### 4.1.1 Pipeline History

On October 10, 1865, the first oil pipeline in the United States was completed. It was 5 miles of 2-inch, lap-welded, wrought iron pipe, held together by threaded couplings, and ran from Pithole to Miller's Farm in Pennsylvania. It reduced the cost of transporting crude oil from \$3 to \$1 per barrel. In the years immediately following, pipelines of 2 to 6 inch-diameter pipe were built.

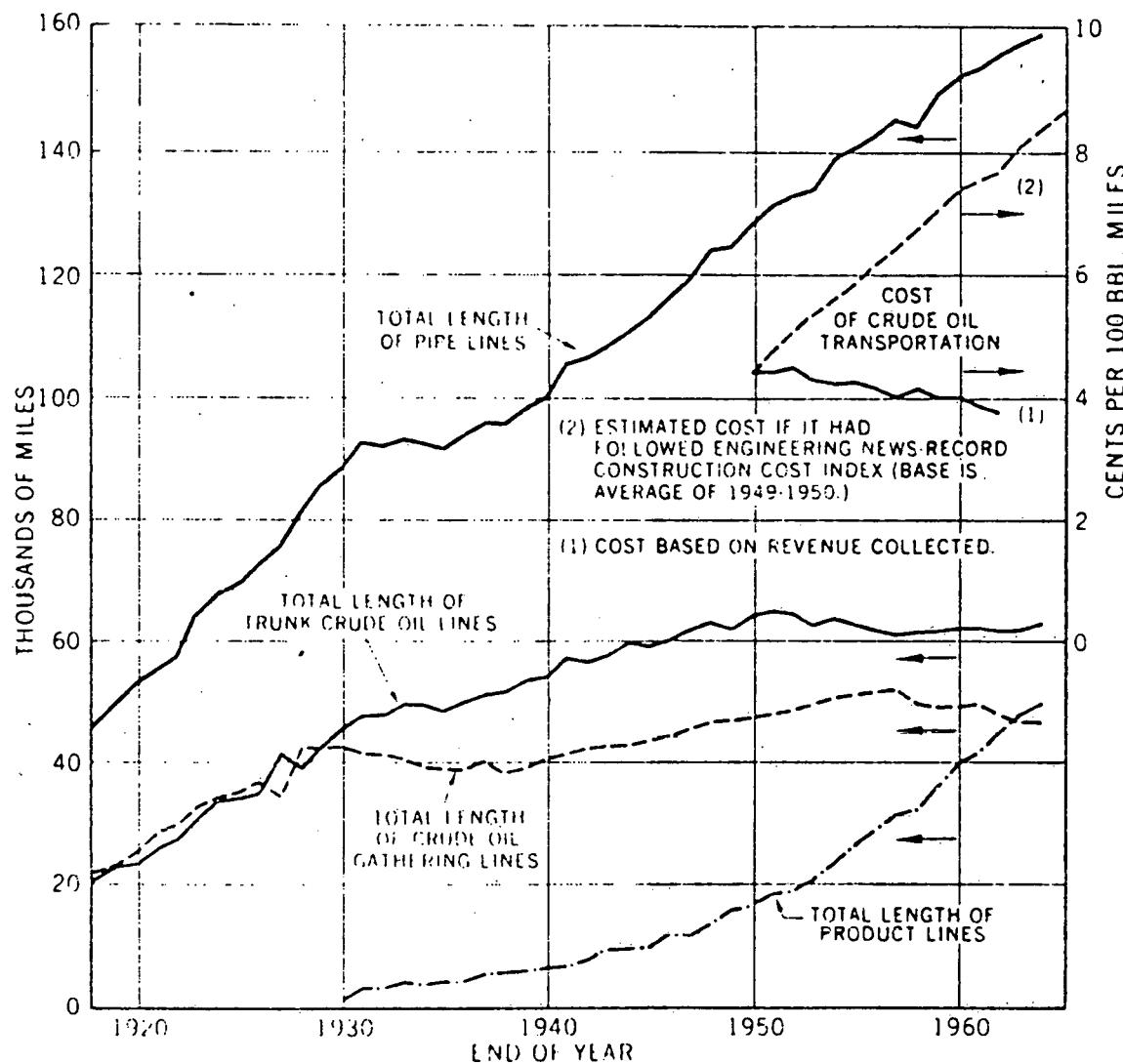
Table 4.1.1-1 is a statistical history of all oil pipeline miles in the United States from 1918 through 1964. Figure 4.1.1-1 shows the growth of various types of pipeline for the same period.

From 1900 to 1910, United States oil pipeline operators increased total trunkline length by 138%. In the decade from 1920 to 1930, the total length in operation was increased by 81%, while actual shipments in that period increased by 158%, due to the steadily increasing use of larger diameter pipe. The greatest technical gain of the 1920-30 decade for reducing operating costs was the increase in pipe diameter to 10 and 12 inches. With the exception of the Prairie Pipeline's 12-inch pipe in 1906 and Shell's 10-inch in 1916, the largest in the United States had been 8 inches.

During the 1930's, pipeline industry expansion was erratic, due no doubt to the depression. However, there were some important events. The first pipeline to cross the Continental Divide was built in this period. It was a 440-mile line, with 6- and 8-inch pipe, which ran from Lance Creek, Wyoming, to the Salt Lake plant of the Utah Oil Refining Co. Also, products pipelines started their major

Table 4.1.1-1  
 Pipeline Operations  
 in U. S. as Indicated  
 by Number of Miles of Pipeline in Operation  
 (Those Reporting to ICC - End of Year)

| YEAR | CRUDE OIL LINES |              | PRODUCT LINES |               |
|------|-----------------|--------------|---------------|---------------|
|      | TRUNK           | GATHERING    | TRUNK         | TOTAL         |
| 1918 | 22,157          | 23,415       | ....          | 45,572        |
| 1919 | 24,435          | 24,867       | ....          | 49,302        |
| 1920 | 25,330          | 27,663       | ....          | 52,993        |
| 1921 | 26,292          | 28,968       | ....          | 55,260        |
| 1922 | 27,325          | 30,024       | ....          | 57,349        |
| 1923 | 31,322          | 33,438       | ....          | 64,760        |
| 1924 | 34,072          | 34,113       | ....          | 68,185        |
| 1925 | 34,801          | 35,208       | ....          | 70,009        |
| 1926 | 35,515          | 37,331       | ....          | 72,846        |
| 1927 | 41,610          | 34,460       | ....          | 76,070        |
| 1928 | 39,422          | 42,254       | ....          | 81,676        |
| 1929 | 43,564          | 42,232       | ....          | 85,796        |
| 1930 | 45,388          | 42,806       | 534           | 88,728        |
| 1931 | 48,014          | 41,803       | 3,273         | 93,090        |
| 1932 | 48,133          | 41,378       | 3,271         | 92,782        |
| 1933 | 49,468          | 40,859       | 3,397         | 93,724        |
| 1934 | 49,837          | 39,665       | 3,568         | 93,070        |
| 1935 | 48,641          | 39,380       | 4,016         | 92,037        |
| 1936 | 50,263          | 39,600       | 4,148         | 94,011        |
| 1937 | 51,369          | 40,062       | 5,181         | 96,612        |
| 1938 | 51,781          | 38,874       | 5,283         | 95,938        |
| 1939 | 53,641          | 39,573       | 5,467         | 98,681        |
| 1940 | 54,084          | 40,300       | 5,772         | 100,156       |
| 1941 | 57,502          | 41,858       | 6,075         | 105,435       |
| 1942 | 56,762          | 42,318       | 7,405         | 106,485       |
| 1943 | 57,586          | 42,471       | 8,726         | 108,783       |
| 1944 | 59,259          | 43,276       | 9,080         | 111,615       |
| 1945 | 59,576          | 43,994       | 9,781         | 113,351       |
| 1946 | 60,120          | 44,862       | 11,562        | 116,544       |
| 1947 | 61,561          | 45,909       | 11,828        | 119,298       |
| 1948 | 63,364          | 47,036       | 13,692        | 124,092       |
| 1949 | 62,272          | 47,212       | 15,500        | 124,984       |
| 1950 | 64,622          | 47,593       | 16,374        | 128,589       |
| 1951 | 64,922          | 47,629       | 18,836        | 131,387       |
| 1952 | 64,888          | 48,522       | 19,305        | 132,715       |
| 1953 | 63,408          | 50,030       | 20,462        | 133,900       |
| 1954 | 64,145          | 50,689       | 24,128        | 138,962       |
| 1955 | 63,347          | 50,645       | 26,832        | 140,374       |
| 1956 | 61,885          | 51,336       | 29,465        | 142,686       |
| 1957 | 61,379          | 52,077       | 31,780        | 145,236       |
| 1958 | 61,702          | 49,787       | 32,865        | 144,354       |
| 1959 | 61,860          | 49,567       | 37,732        | 149,159       |
| 1960 | 62,059          | 49,401       | 40,508        | 151,968       |
| 1961 | 62,251          | 49,656       | 41,830        | 153,737       |
| 1962 | 61,702          | 48,063       | 45,288        | 155,053       |
| 1963 | 61,832 (est)    | 47,125 (est) | 47,855 (est)  | 156,812 (est) |
| 1964 | 63,139 (est)    | 46,777 (est) | 49,667 (est)  | 159,583 (est) |



Source: National Petroleum Council "Impact of New Technology on the U. S. Petroleum Industry, 1946-1965."

Figure 4.1.1-1 - Growth of U. S. Pipelines for 1918-1964

development during the depression, a noteworthy example being the construction of the 732-mile Susquehanna-Sun Oil Line system in 1930-31. By 1937 it was transporting gasoline at one-third the unit cost of railroad shipping. Statistics for this period are given in Table 4.1.1-2.

The importance of large pipe diameters is dramatic. For example, a 10-inch line will transport fluid at an average cost which is 37% lower than that for an 8-inch line. A 16-inch line can double the delivery rate and decrease the cost per barrel-mile by more than half in comparison to an 8-inch line. Of course, these savings are realized only if a certain minimum shipment level is maintained, and there are many instances in which the tradeoff of pipe costs, pumping requirements, and shipping volume favors the small-diameter pipeline.

By 1941, a 24-inch diameter pipeline was in operation. This was the Big Irish line, which extended from the Gulf Coast to the Eastern Seaboard, and whose purpose was to augment World War II tanker shipments. Table 4.1.1-3 shows the shift in oil transport methods from 1941 through 1945. Figures 4.1.1-2 and 4.1.1-3 show the 1950-1975 trends in terms of intercity freight and interstate pipeline shipments.

The Colonial system, built in 1963, was 2600 miles long, 1046 miles of which was made of 36-inch-diameter, high strength, thin wall pipe. Today the system has 4127 miles of pipe, some of which is 40 inches in diameter. Its trunkline shipping record for the year 1976 was over 591 billion barrel miles of petroleum products, the average haul distance is approximately 1040 miles.

From the first pipeline in 1865, 5 miles of 2-inch pipe in Pennsylvania, the United States today has over 170,000 miles of crude oil and petroleum products pipelines, and growth continues as shown in Table 4.1.1-4. It is of interest that the 9391 million barrels of crude oil shipped through trunklines in 1975 was an increase over that shipped in 1945 of approximately 5 to 1.

Table 4.1.1-2

Gasoline Production and Pipeline Shipments of Crude Oil  
and Petroleum Products, 1931-41 (Millions of bbl)

| Year | U. S. gasoline production * | Total gasoline pipeline shipments | Shipments originated on interstate common carrier lines |       |         |
|------|-----------------------------|-----------------------------------|---|-------|---------|
|      |                             |                                   | Products  | Crude | Total   |
| 1931 | 396.4                       |                                   | 15.7  | 489.1 | 504.8   |
| 1932 | 366.3                       | 29.9                              | 24.9  | 508.1 | 533.0   |
| 1933 | 376.2                       | 38.4                              | 29.0  | 537.6 | 566.6   |
| 1934 | 388.8                       | 45.5                              | 35.3  | 577.3 | 612.6   |
| 1935 | 426.8                       | 51.0                              | 43.6  | 723.0 | 766.6   |
| 1936 | 471.0                       | 58.9                              | 51.5  | 755.1 | 806.6   |
| 1937 | 519.8                       | 74.1                              | 63.0  | 885.4 | 948.4   |
| 1938 | 516.1                       | 85.6                              | 65.1  | 793.3 | 858.4   |
| 1939 | 556.9                       | 95.1                              | 70.2  | 802.8 | 873.0   |
| 1940 | 557.8                       | 97.1                              | 72.0  | 886.4 | 958.4   |
| 1941 | 623.3                       | 113.0                             | 82.4  | 971.1 | 1,053.5 |

\* Finished gasoline and naphtha, excluding natural gas liquids.  
Source: API, *Petroleum Facts and Figures*, 1959, 114, 170-171.

Table 4.1.1-3

Average Daily Petroleum Deliveries to the East Coast by  
Mode of Transportation (1941-45)

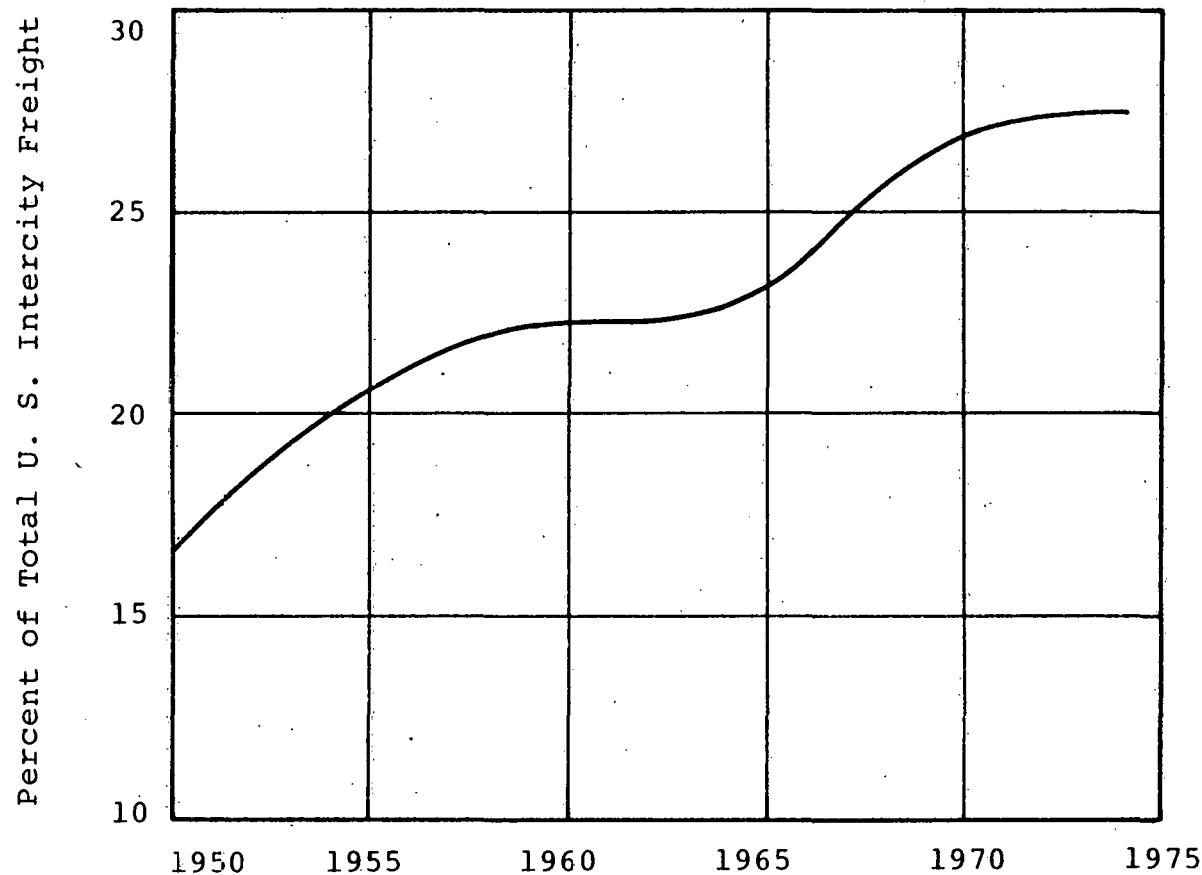
4-6

|                         | 1941             | 1942           | 1943             | 1944             | 1945 *           |
|-------------------------|------------------|----------------|------------------|------------------|------------------|
| Tank car                | 35,000 (2.3)     | 624,684 (51.3) | 851,905 (61.3)   | 646,113 (37.7)   | 504,497 (27.7)   |
| Pipeline                | 54,000 (3.5)     | 120,459 (9.9)  | 266,990 (19.2)   | 662,559 (38.7)   | 732,837 (40.3)   |
| Barges and lake tankers | 28,000 (1.8)     | 80,793 (6.6)   | 112,147 (8.1)    | 127,641 (7.5)    | 127,002 (7.0)    |
| Total overland          | 117,000 (7.5)    | 825,936 (67.9) | 1,231,042 (88.6) | 1,436,353 (84.0) | 1,364,336 (75.0) |
| Tanker                  | 1,421,000 (92.5) | 390,611 (32.1) | 159,563 (11.4)   | 275,766 (16.0)   | 450,665 (25)     |
| Total daily delivery    | 1,538,000        | 1,216,547      | 1,390,605        | 1,712,129        | 1,815,000        |

\* First six months.

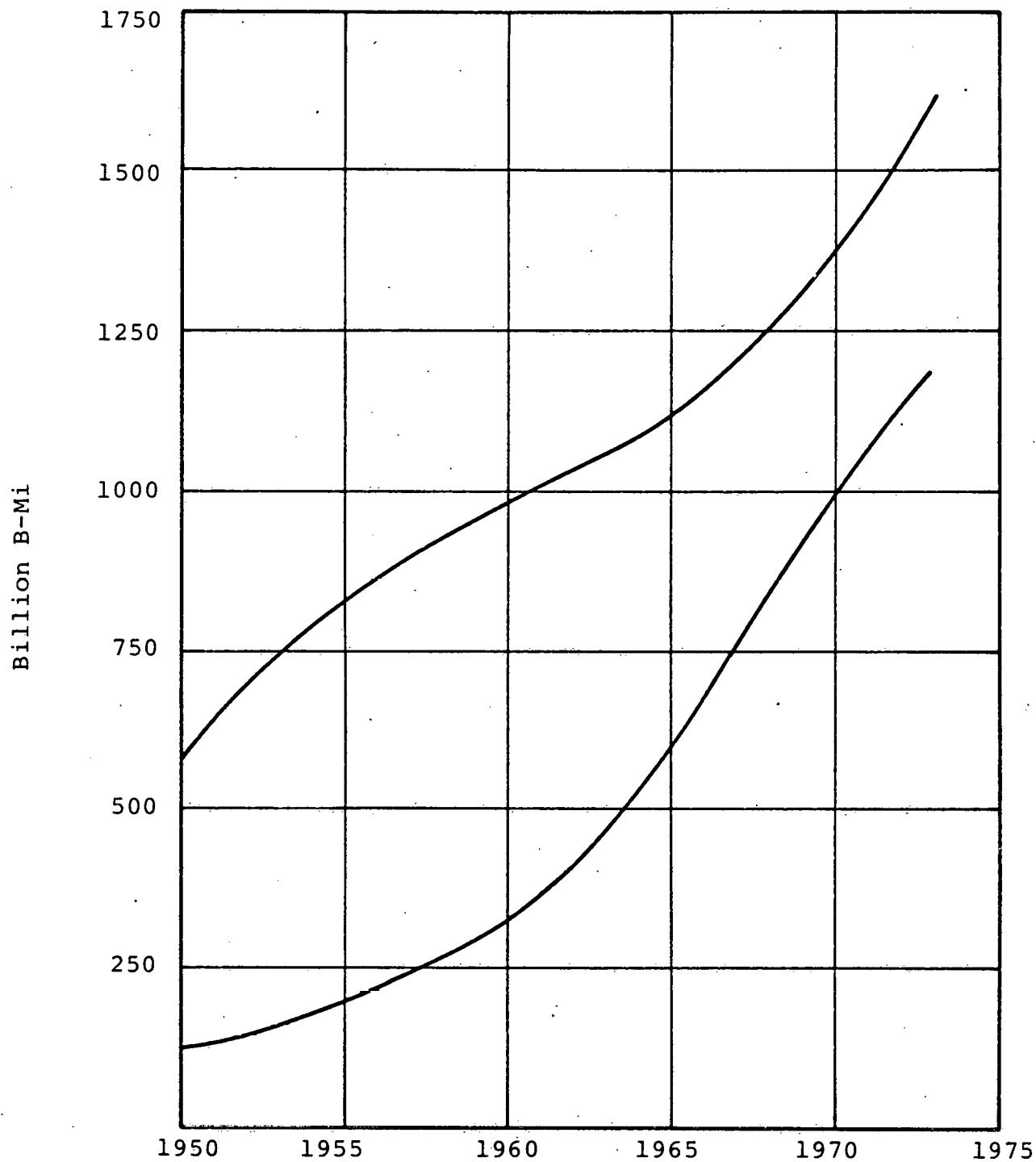
Source: Frey and Ide, *History of PAW*, 449.

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Source: ICC Annual Report, Statement No. 6103,  
1939-59 and Transport Economics, Quarterly

Figure 4.1.1-2 - U. S. Intercity Pipeline Oil Shipments  
Compared to All Freight Shipments



Sources: ICC, 1950 and Annual thereafter, Statistics of Oil Pipeline Companies and Transport Statistics in the U. S. Part 6, Annual

Figure 4.1.1-3 - U. S. Interstate Pipeline Trunkline Shipments

Table 4.1.1-4

## U. S. Pipeline Operations, Crude Oil and Petroleum Products

|   | <u>1974</u> | <u>1975</u> | <u>Increase</u> |
|---|-------------|-------------|-----------------|
| Miles of Pipeline                           | 169,116     | 170,749     | .96%            |
| Total Deliveries<br>(1000 B)                | 9,131,713   | 9,391,347   | 2.74%           |
| Total Trunkline Traffic<br>(1,000,000 B-Mi) | 2,631,849   | 2,892,129   | 9.89%           |

Source: Oil and Gas Journal - August 23, 1976

#### 4.1.2 Pipeline Fabrication

Early pipelines were welded, but only along the seam of the pipe during its manufacture. Lengths of pipe were joined by threaded couplings. The additional requirements of threading the pipe ends made this a costly process, particularly as pipe diameter increased. Coupling of pipes by welding began on a large scale in the 1920's. By that time also, seamless tubing has replaced the lap-welded pipe and electric arc welding had begun to replace oxyacetylene welding. Techniques for repairing lines while they contained oil or products were also being developed.

Large pipelines need either thicker or stronger steel than do the smaller lines. Further, the use of high pressures to increase fluid flow subjected the pipe to still higher stress. These requirements were met by the development of new alloys and heat treatments to increase pipe strength to above 100,000 psi. This also increased the weldability of the material.

There was still a major problem which has forced thick-wall pipe fabrication. The corrosion of external pipe had to be accommodated by extra thickness to overcome the electrolytic metal loss. This has been circumvented by the development of special coatings and cathodic protection. In products pipelines, some of the refined products have a corrosive effect on the internal surface of the pipe. Here again, techniques for protection have been developed, namely, the use of intense coatings to prevent wall corrosion and of product additives to decrease corrosiveness of the fluid.

#### 4.1.3 Pipeline Pumping Equipment

Pumping machinery evolved from steam engines through diesel engines to electrically driven centrifugal pumps. Electrical power for pipelines underwent its first major test in 1926 when a 30,000 barrel-per-day (B/D) main line station was successfully powered by electric pumps. In 1927, the Oklahoma Pipe Line Co. opened an all-electric 50,000 B/D station, and in 1928, Shell Oil followed with an almost completely electrically powered pipeline which was larger than the combination of the two just mentioned. This was soon superseded by Atlantics's 500-mile West Texas Line, which was exclusively powered by electricity.

In most cases today, electricity is used whenever it is available. When it is not available, or there is a capital equipment advantage in continuing to use older machinery, either diesel engines or gas turbines are used. In many cases the fuel is drawn from the pipeline. Table 4.1.3-1 shows the principal energy sources for five large companies selected for study in the Federal Energy Administration's Project Independence. It is seen that for these five companies, electricity was the principal fuel in an estimated 88% of the usage.

Table 4.1.3-1

Energy Intensity of  
Selected Petroleum Pipeline Companies

| Company                            | Btu per<br>Ton-Mile <sup>a</sup> | Principal Fuel      |
|------------------------------------|----------------------------------|---------------------|
| 1: 1970                            | 424.8                            | Electricity (87%)   |
|                                    | 424.8                            | Electricity (87%)   |
|                                    | 414.6                            | Electricity (90%)   |
|                                    | 414.6                            | Electricity (91.3%) |
| 2: 1971                            | 520.9                            | Electricity (100%)  |
|                                    | 358.4                            | Electricity (100%)  |
| 3: 1972                            | 432.5                            | Electricity (76.3%) |
|                                    | 445.7                            | Electricity (75.8%) |
| 4: 1970                            | 546.9                            | Electricity (87.5%) |
| 5: 1971                            | 1018.6                           | Electricity (75.6%) |
|                                    | 1067.9                           | Electricity (72.6%) |
| Estimated Weighted<br>Average 1972 | 432.91                           | 88%                 |
| Responding Companies               |                                  |                     |
| Estimate for All<br>Companies      | 550                              | 75-80%              |

<sup>a</sup>Adjusted to exclude fuel used on non-trunk operations since ton-miles were available only for trunkline movements. Btu's are on a production basis and represent Btu inputs to the utility plant when electricity is in the form of energy use (i.e., 11,586 Btu/kw-hr).

Source: Project Independence, Vol. II, 1974  
Federal Energy Administration

#### 4.1.4 Pipeline Control and Monitoring

Control and monitoring of oil and products pipeline flow are now effected by digital computer systems which control and meter flow, follow interfaces between products, record flow operations, sense faults, actuate the alarm systems when necessary, provide delivery information, and assist in customer billing. These systems have become highly precise and have contributed enormously to both quality and efficiency.

Operational parameters such as pressure, flow, and temperature, and equipment conditions such as temperature of bearings and electrical windings, are sensed. Corrective action such as a switch to standby equipment may be handled entirely by the control system.

Modern petroleum products shipments demand highly sophisticated batch separation equipment. This equipment must first select the sequence of the products which interface in the pipeline, then the proper flow characteristics to assure nonlaminar flow and thus prevent the products from intermixing must be maintained. Next, interface cutting, probably the most delicate of the operations performed by the equipment, must be performed. Aviation gasoline, for example, must be kept absolutely uncontaminated. To achieve this, the flow into the delivery truck cannot begin until the interface between the aviation gasoline and the product preceding it in the line has passed the outlet point. Near the end of the delivery, the valve must be closed before the next interface reaches the valve. Clearly, the more reliable the equipment for this procedure, the higher the economic efficiency. It may be noted that electrical machinery is most easily controlled.

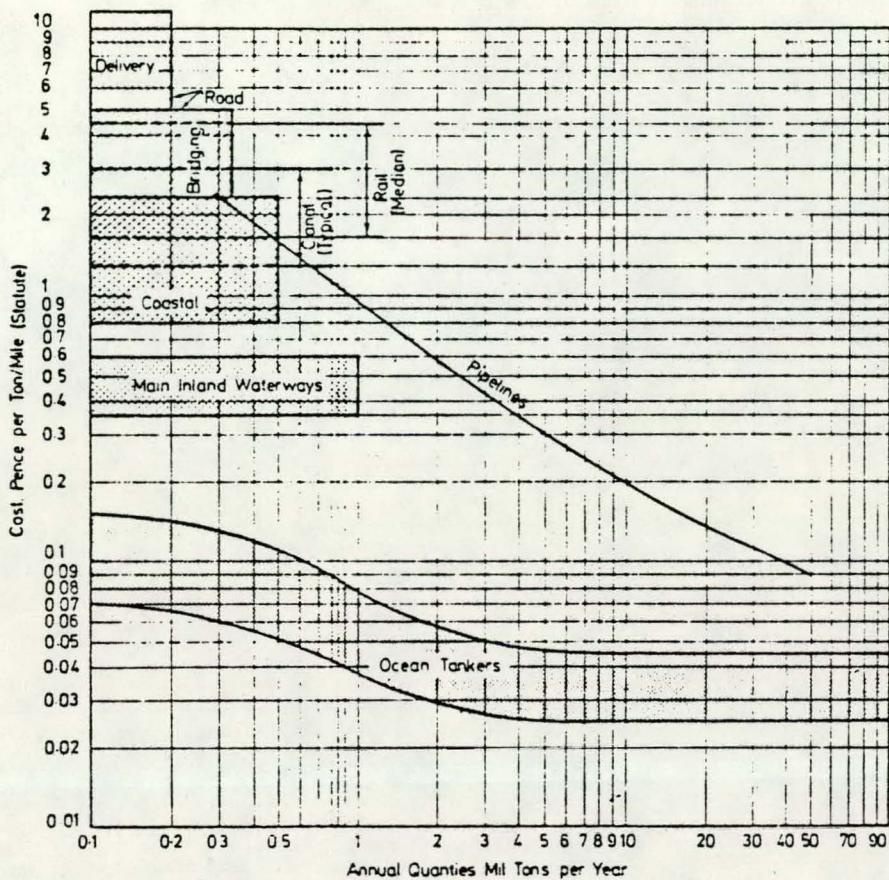
#### 4.1.5 Economic Considerations

Pipeline barrel-mile shipment cost decreases markedly with increased quantity. These costs, however, are not affected to any large extent by shipping distance, which is quite the opposite situation from that with rail or tanker transport. As with all methods of transport, some threshold shipment size is required for economical transportation by pipeline.

Figure 4.1.5-1 shows a comparison of cost vs. quantity for several modes of crude and products shipment to and within Europe. Figure 4.1.5-2 separates pipeline capabilities which were integrated in Figure 4.1.5-1 to show throughput as a function of pipeline size. Another interesting aspect of pipeline operation is shown in Figure 4.1.5-3 where throughput is a function of pipeline utilization. This indicated trend is consistent with that of Figure 4.1.5-1. Figure 4.1.5-3 is normalized to an ultimate minimum transportation cost. It shows unit cost of transporation for a pipeline designed to accommodate an initial throughput shown at A with a potential throughput as shown at B. Point C shows the unit cost increase caused by the addition of pumping machinery, and point D shows the advantage to both cost and throughput when the potential of the new line is fully utilized.

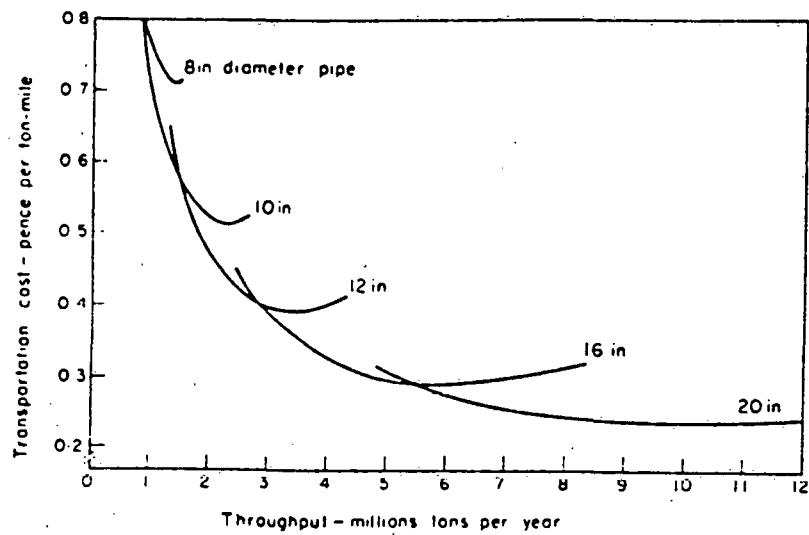
As noted in Section 4.1.4, the products pipeline makes much more stringent demands upon the control and monitoring system. This is particularly true in maintaining separation of the various products in the line. The intermixing of a small amount of one grade of crude oil with another is of small moment, whereas products batches must be precisely separated.

In crude oil lines, most of the personnel is concentrated at the point where the oil is gathered, gauged, and sent into the pipeline. Conversely, the products pipelines, personnel are most likely to be found at terminal points.



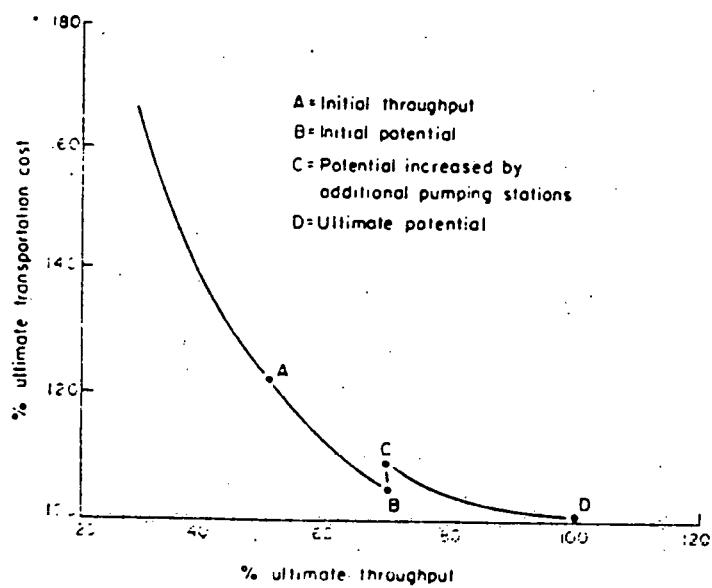
Source: Hobson and Pohl, "Modern Petroleum Technology"  
 The Institute of Petroleum, Great Britain, 1973

Figure 4.1.5-1 - Cost of Transport Relative  
 to Annual Quantities



Source: Hobson and Pohl, "Modern Petroleum Technology"  
The Institute of Petroleum, Great Britain, 1973

Figure 4.1.5-2 - Pipeline Diameter and Transportation Cost Related to Throughput



Source: Hobson and Pohl, "Modern Petroleum Technology"  
The Institute of Petroleum, Great Britain, 1973

Figure 4.1.5-3 - Transportation Cost Related to Utilization

#### 4.1.6 Pipeline Ownership

Although several large single-owned and non-shipper-owned pipelines exist, the general practice is joint ownership by a group of shippers who pool their investments and their shipments. Joint ownership in most cases has proved to be economically preferable. Management modes vary among jointly owned pipelines. For example, the giant Colonial Pipe Line Co. maintains a single tariff throughout the system, while in other systems, each owner establishes the tariff for his own shipments. Operations management also differs from one system to another. The two management schemes most prevalent are (1) operations management function performed by one of the pipeline owners groups, and (2) operations management by an outside company hired by the pipeline combine.

#### 4.1.7 Oil Pipeline Characteristics

Pipeline crude oil movements pass through two different steps or types of facilities. These are gathering systems and trunk systems. As the name implies, in a gathering system, crude oil is transported from the numerous production leases in an oil field to a pipeline trunk station or rail head. A gathering system might be compared to a series of small streams that feed into a river. It is in the gathering system that crude oil begins the first leg of its journey to market. Figures 4.1.7-1 and 4.1.7-2 show the two stages of the gathering system [Barbe, 74].

In most instances, wells in the same general area produce the same grade of oil which allows all feeder lines in a gathering system to flow together into a common stream into the trunk station. If two types of crude are produced in the same area and cannot be mixed together, it is necessary to construct a dual gathering system.

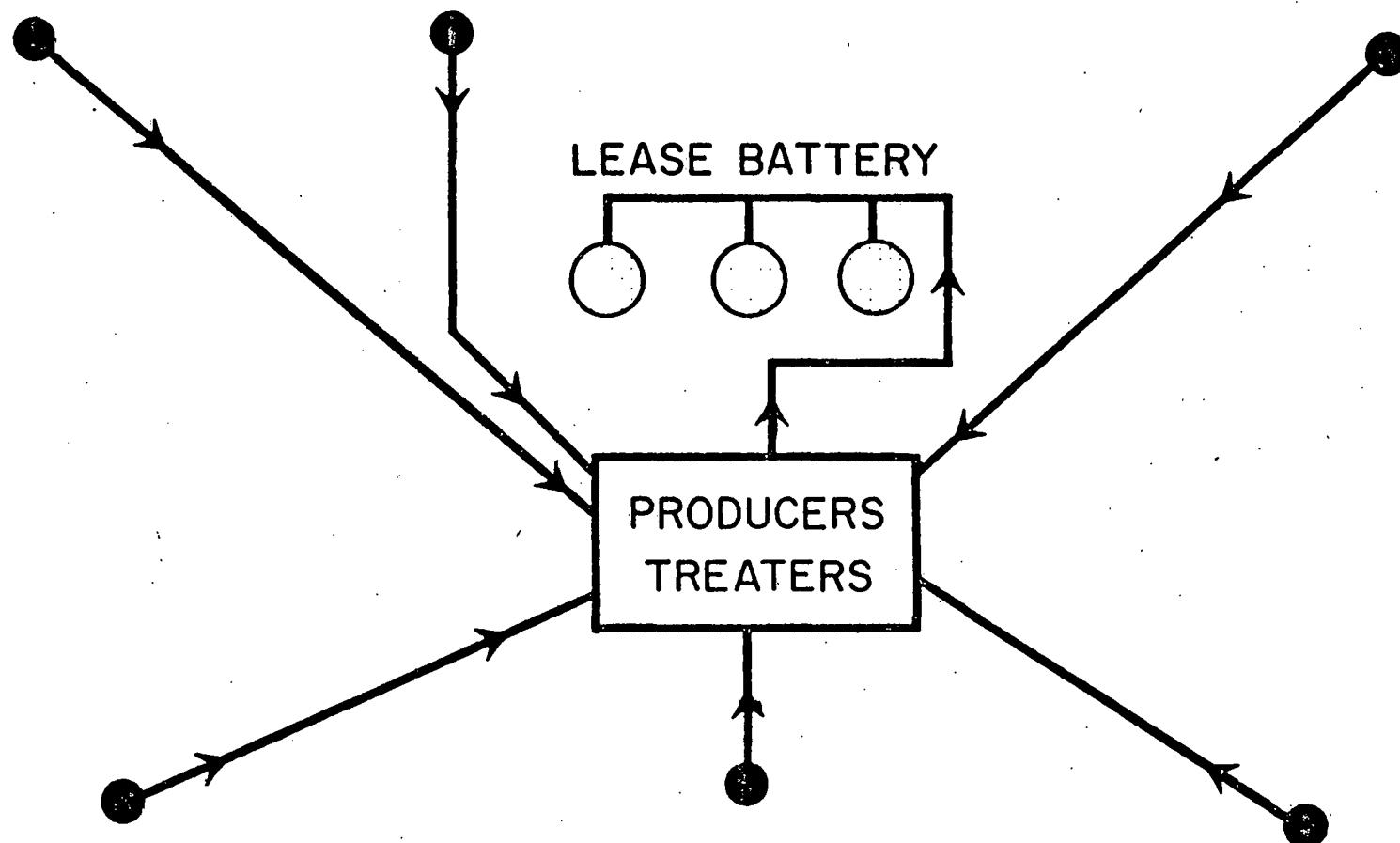


Figure 4.1.7-1 - Producing Wells and Lease Tank Battery

4-20

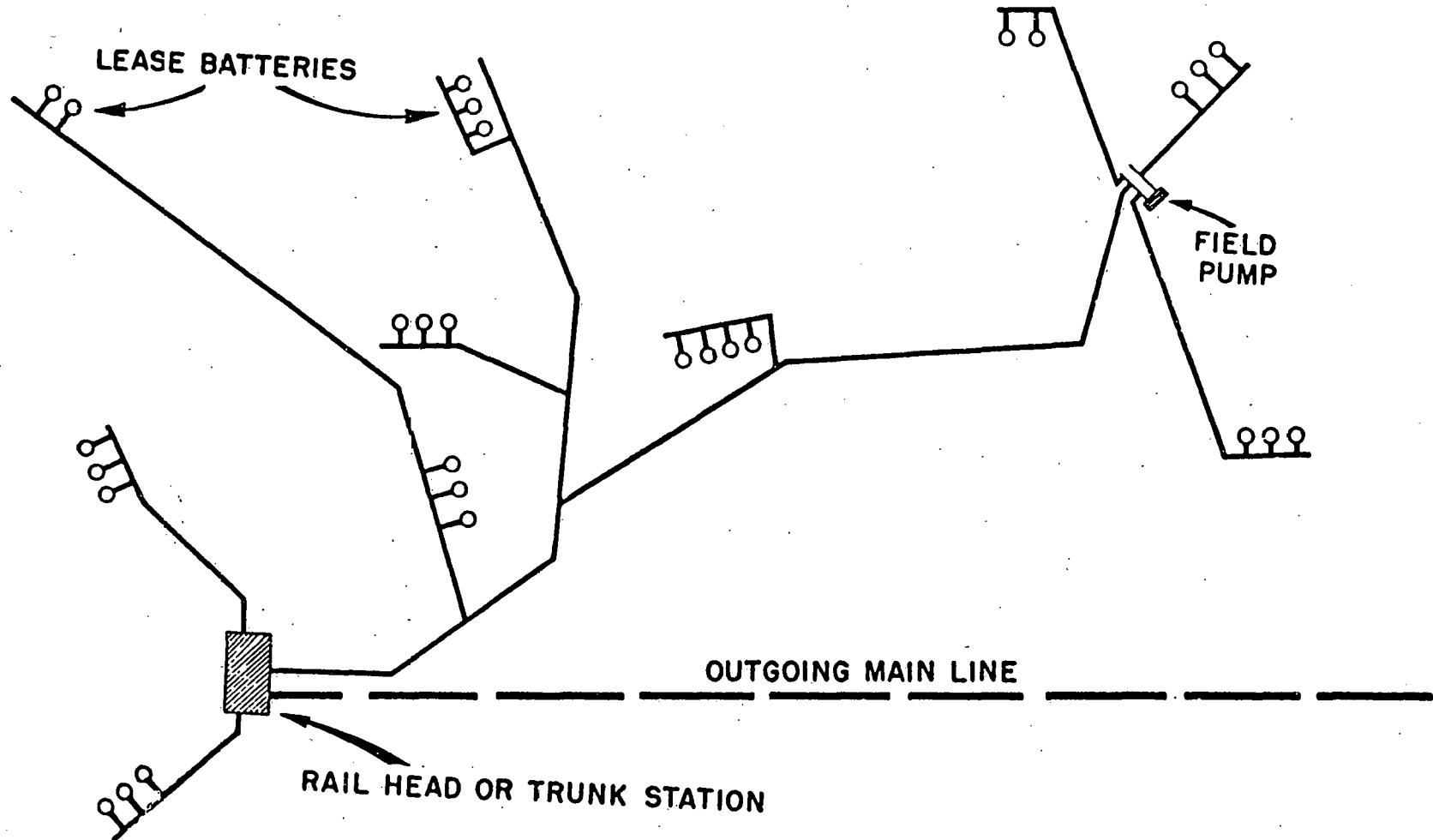


Figure 4.1.7-2 - Crude Oil Gathering System

R-77-3022

The collection of lease oil in gathering systems is performed by pipeline field people known as gaugers. When lease tanks have been filled the producer notifies the pipeline gauger who samples the oil for quality and verifies the quantity before turning it into the gathering system. The oil then moves by gravity or is pumped into tanks at the nearest trunk station. In a modern oil field, a very large percentage of the production from leases is transferred automatically from producer to pipeline through Lease Automatic Custody Transfer (LACT) equipment. Such equipment automatically pumps oil from a lease surge tank when the oil reaches a certain level in the tank, continuously monitors the oil for excess sediment and water content, measures the oil through a meter as it is transferred and continuously draws off a portion of sample of the oil into a container from which the gauger can determine quality later.

The trunk line station is usually provided with several tanks having capacity to:

- Store sufficient crude oil to maintain a constant flow to the next station.
- Receive the variable runs from gathering systems.
- Measure the receipts from connecting carriers.
- Accumulate suitable quantities of different grades for desired batch sizes.

A crude trunk line station is schematically illustrated in Figure 4.1.7-3, and Figure 4.1.7-4 illustrates the trunk line system [Barbe 74].

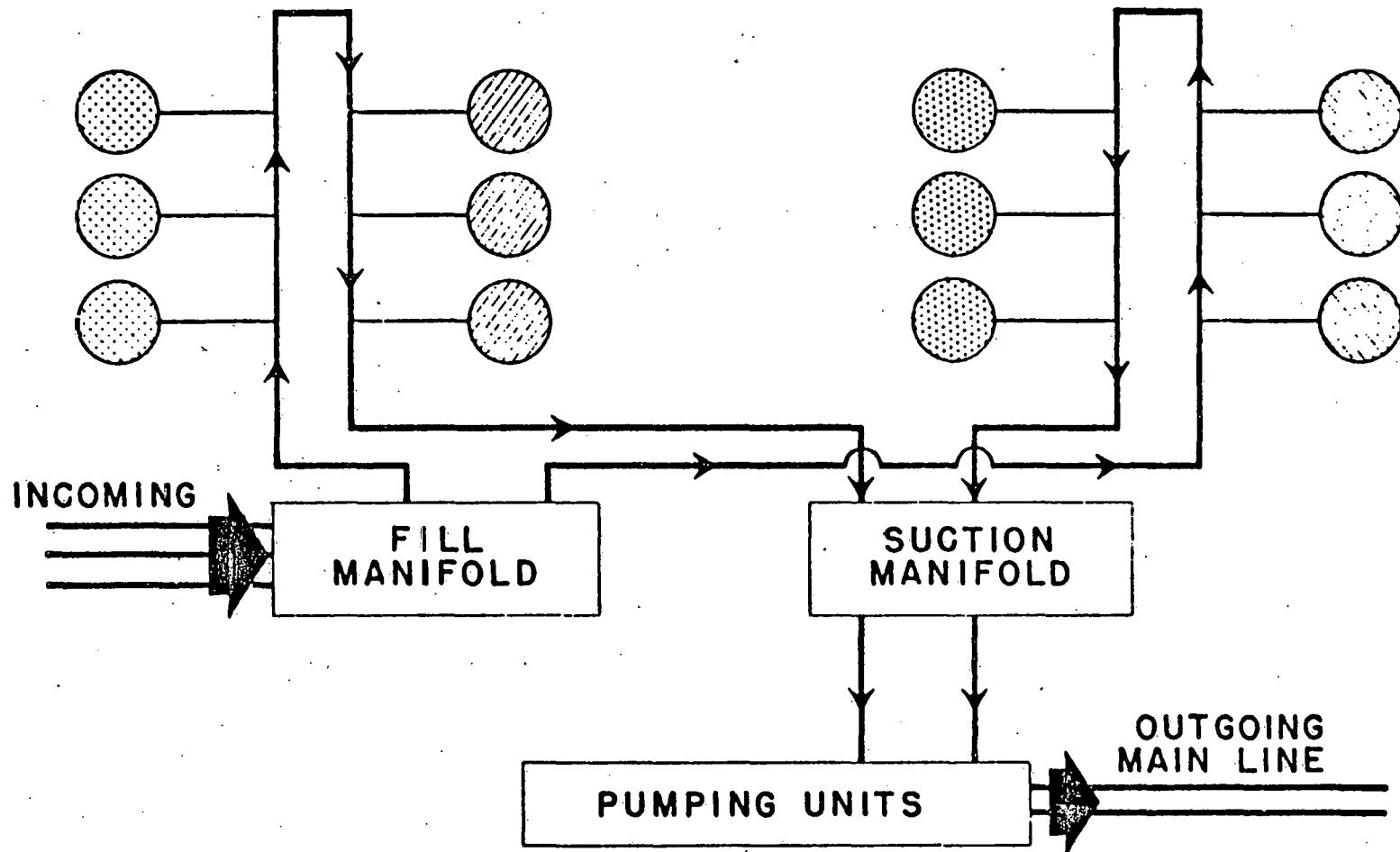


Figure 4.1.7-3 - Trunk Line Station

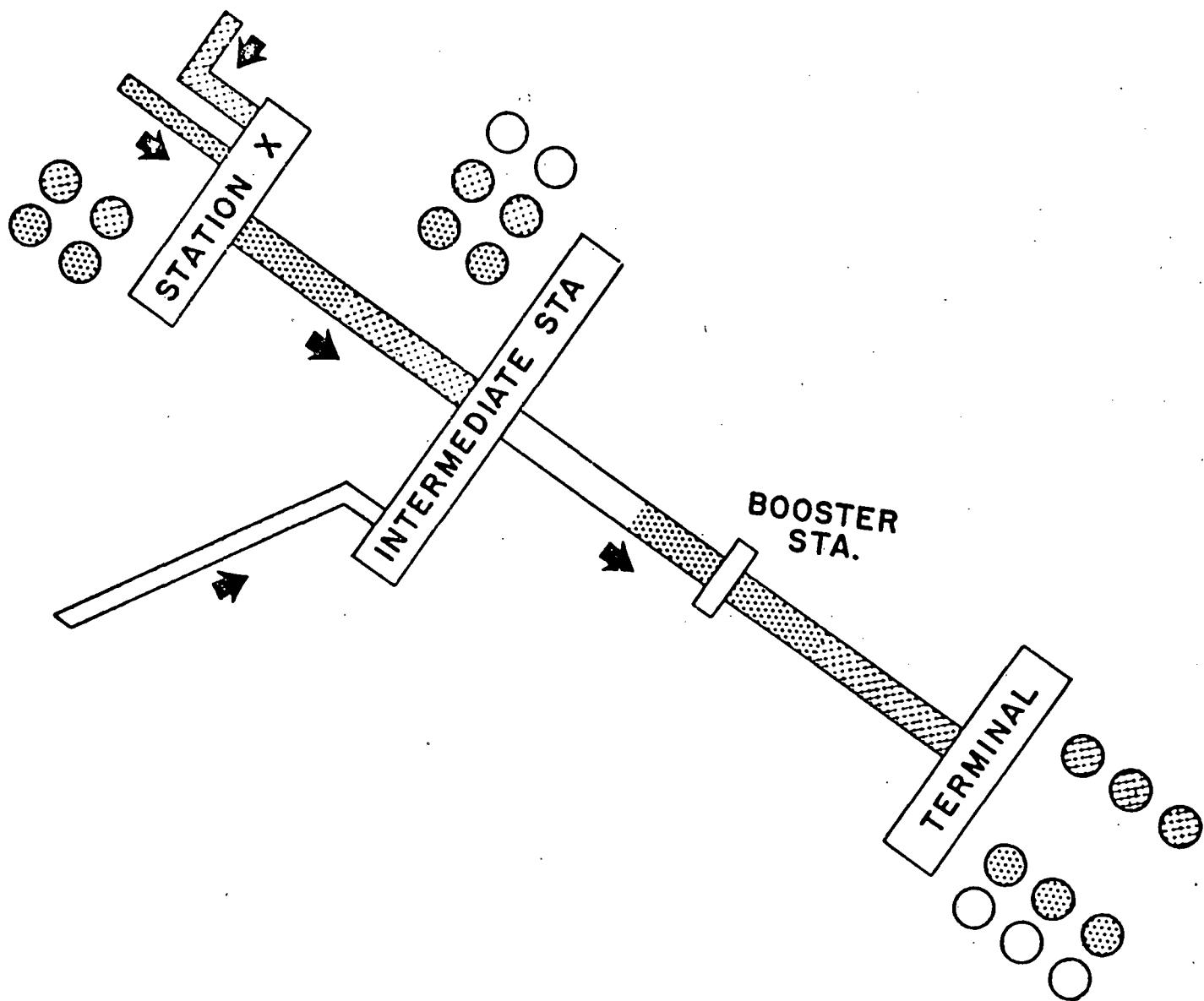


Figure 4.1.7.4 - Trunk Line System

A products trunk line is illustrated in Fig. 4.1.7-5. Many similarities are obvious [Carter 74]. However, there are some important differences. Crude oil lines, because of the higher viscosity of the oil, are generally of larger diameter pipe than product lines. Products temperatures do not greatly affect their viscosity; therefore pumping rates can remain nearly constant with temperature. Also, the temperature control problem is not severe. Crude oil operations, on the other hand, are very sensitive to temperature because of the higher viscosity. Thus, temperature becomes more critical in the crude lines and there are much greater demands for flexibility in the pumping machinery.

Corrosion on the internal surface is a problem chiefly confined to products pipelines. Treatment of the metal itself may help, but in most cases the products must be made less corrosive either by additives or dehydration. Crude oil lines suffer from paraffin deposits, which can build up to considerable thickness. While this has the advantage of protecting against corrosion, the paraffin must be scraped away periodically.

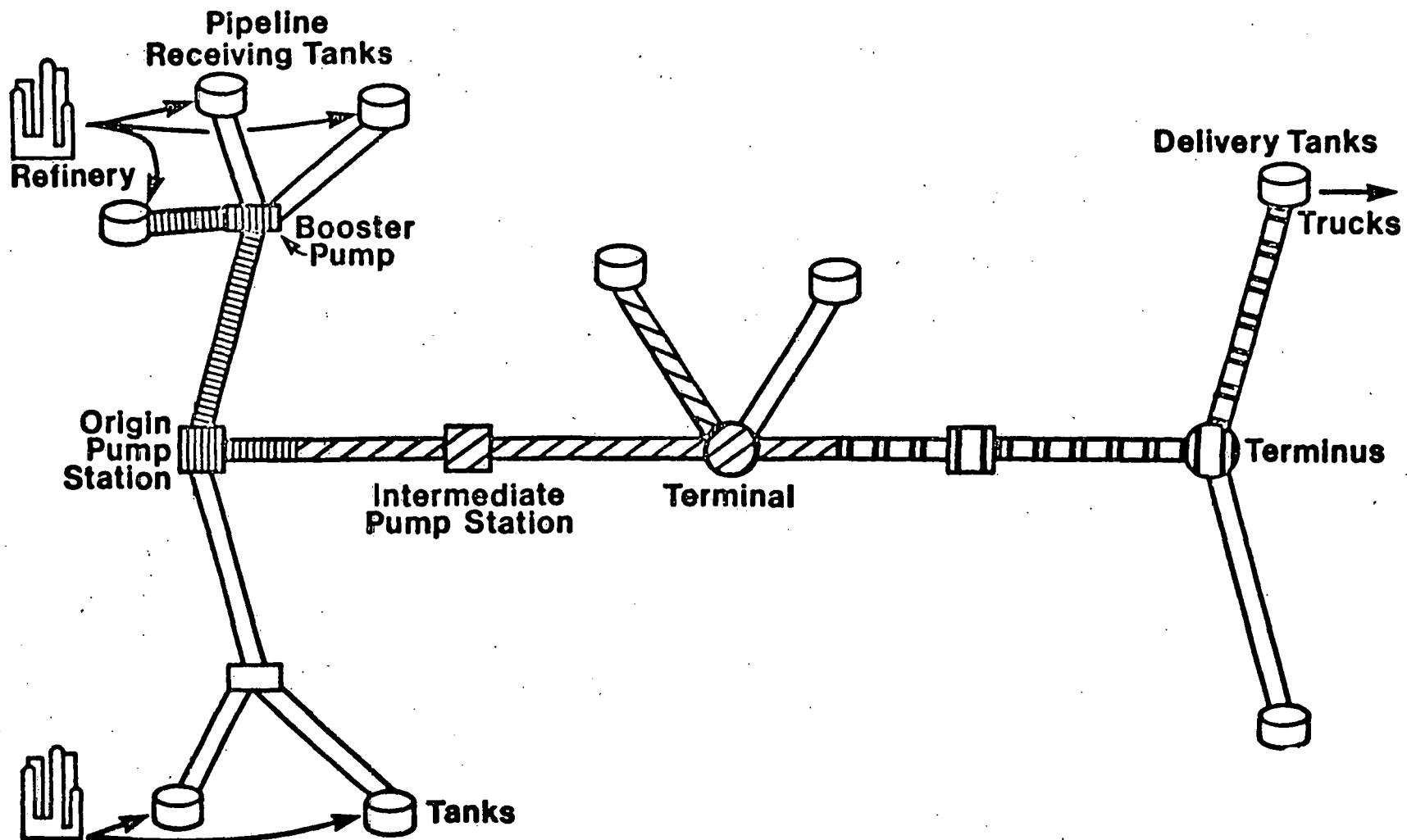


Figure 4.1.7-5 - Products Pipeline

#### 4.2 Oil Pipeline Data Sources

The data used in this study was obtained from two sources:

- (1) Reports to the ICC by the Companies
- (2) Interviews with several individual companies

Figures 4.2-1 and 4.2-2 are copies of pages from the ICC Report P, upon which the pipeline companies report their annual operating expenses, Item Number 320, and Statistics of Operation, Item Number 400. The cost of operating fuel and power is reported on Line 4, Figure 4.2-1. The barrel-miles are reported at the bottom of Figure 4.2-2.

The acquisition of data by interview was accomplished only with great difficulty, and only a few data values were obtained. However, it will be seen that those values are useful, and are believed to be very accurate.

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Carrier Initials

Year 19

## 310. OPERATING REVENUE ACCOUNTS

State the pipeline operating revenues of the respondent for the year, classified in accordance with the Uniform System of Accounts for Pipe Lines.

| Line No. | Operating revenue accounts<br>(a)         | Crude oil<br>(b) | Products<br>(c) | Total<br>(d) |
|----------|---|------------------|-----------------|--------------|
| 1        | (200) Gathering revenues _____            | \$ _____         | \$ _____        | \$ _____     |
| 2        | (210) Trunk revenues _____                |                  |                 |              |
| 3        | (220) Delivery revenues _____             |                  |                 |              |
| 4        | (230) Allowance oil revenue _____         |                  |                 |              |
| 5        | (240) Storage and demurrage revenue _____ |                  |                 |              |
| 6        | (250) Rental revenue _____                |                  |                 |              |
| 7        | (260) Incidental revenue _____            |                  |                 |              |
| 8        | Total _____                               |                  |                 |              |

## 320. OPERATING EXPENSE ACCOUNTS

State the pipeline operating expenses of the respondent for the year.

| Line No. | Operating expense accounts<br>(a)   | CRUDE OIL        |              |                 |              |
|----------|---|------------------|--------------|-----------------|--------------|
|          |   | Gathering<br>(b) | Trunk<br>(c) | Delivery<br>(d) | Total<br>(e) |
|          | <b>OPERATIONS</b>   | \$ _____         | \$ _____     | \$ _____        | \$ _____     |
| 1        | (300) Salaries and wages _____  |                  |              |                 |              |
| 2        | (310) Supplies and expenses _____   |                  |              |                 |              |
| 3        | (320) Outside services _____  |                  |              |                 |              |
| 4        | (330) Operating fuel and power _____  |                  |              |                 |              |
| 5        | (340) Oil losses and shortages _____  |                  |              |                 |              |
| 6        | <b>TOTAL OPERATIONS EXPENSES</b> _____  |                  |              |                 |              |
|          | <b>MAINTENANCE</b>  |                  |              |                 |              |
| 7        | (410) Salaries and wages _____  |                  |              |                 |              |
| 8        | (410) Supplies and expenses _____   |                  |              |                 |              |
| 9        | (420) Outside services _____  |                  |              |                 |              |
| 10       | (430) Maintenance materials _____   |                  |              |                 |              |
| 11       | <b>TOTAL MAINTENANCE EXPENSES</b> _____   |                  |              |                 |              |
|          | <b>GENERAL</b>  |                  |              |                 |              |
| 12       | (510) Salaries and wages _____  |                  |              |                 |              |
| 13       | (510) Supplies and expenses _____   |                  |              |                 |              |
| 14       | (520) Outside services _____  |                  |              |                 |              |
| 15       | (530) Rentals (p. 48) _____   |                  |              |                 |              |
| 16       | (540) Depreciation and amortization _____   |                  |              |                 |              |
| 17       | (550) Pensions and benefits _____   |                  |              |                 |              |
| 18       | (560) Insurance _____   |                  |              |                 |              |
| 19       | (570) Casualty and other losses _____   |                  |              |                 |              |
| 20       | (580) Pipeline taxes (p. 42) _____  |                  |              |                 |              |
| 21       | <b>TOTAL GENERAL EXPENSES</b> _____   |                  |              |                 |              |
| 22       | Grand Totals _____  |                  |              |                 |              |
| 23       | Operating ratio (ratio of operating expenses to operating revenues--percent). Gathering _____ |                  |              | Trunk _____     |              |

Pipeline Annual Report P

Figure 4.2-1 - ICC Annual Report Form -  
Item 320, Operating Expense Accounts - Sheet 1

Carrier Initials

Year 19

## 320. OPERATING EXPENSE ACCOUNTS—Continued

Classifying them in accordance with the Uniform System of Accounts for Pipe Lines.

| Line<br>No. | PRODUCTS         |              |                 |              | TOTAL            |              |                 |              |
|-------------|------------------|--------------|-----------------|--------------|------------------|--------------|-----------------|--------------|
|             | Gathering<br>(f) | Trunk<br>(g) | Delivery<br>(h) | Total<br>(i) | Gathering<br>(j) | Trunk<br>(k) | Delivery<br>(l) | Total<br>(m) |
| 1           | \$               | \$           | \$              | \$           | \$               | \$           | \$              | \$           |
| 2           |                  |              |                 |              |                  |              |                 |              |
| 3           |                  |              |                 |              |                  |              |                 |              |
| 4           |                  |              |                 |              |                  |              |                 |              |
| 5           |                  |              |                 |              |                  |              |                 |              |
| 6           |                  |              |                 |              |                  |              |                 |              |
| 7           |                  |              |                 |              |                  |              |                 |              |
| 8           |                  |              |                 |              |                  |              |                 |              |
| 9           |                  |              |                 |              |                  |              |                 |              |
| 10          |                  |              |                 |              |                  |              |                 |              |
| 11          |                  |              |                 |              |                  |              |                 |              |
| 12          |                  |              |                 |              |                  |              |                 |              |
| 13          |                  |              |                 |              |                  |              |                 |              |
| 14          |                  |              |                 |              |                  |              |                 |              |
| 15          |                  |              |                 |              |                  |              |                 |              |
| 16          |                  |              |                 |              |                  |              |                 |              |
| 17          |                  |              |                 |              |                  |              |                 |              |
| 18          |                  |              |                 |              |                  |              |                 |              |
| 19          |                  |              |                 |              |                  |              |                 |              |
| 20          |                  |              |                 |              |                  |              |                 |              |
| 21          |                  |              |                 |              |                  |              |                 |              |
| 22          |                  |              |                 |              |                  |              |                 |              |
| 23          | Delivery         |              | Total           |              |                  |              |                 |              |

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Figure 4.2-1 - (Continued) Sheet 2

Figure 4.2-2 - Item 400, Statistics of Operation

**400. STATISTICS OF OPERATIONS**

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1. Give particulars by States of origin for crude oil and for each kind of product received and transported during the year. Classify and list in column (a) by States of origin the refined products transported in the following order: 2910 Gasoline, jet fuels and other high volatile petroleum fuels, except natural gasoline, 2912 Kerosene, 2913 Diesel fuel oil, 2914 Lubricating and similar oils and derivatives, 2915 Residual fuel oil and other low volatile petroleum fuels, 2919 Products of petroleum refining, n.e.c.—Specify, and Total—products.

2. As used herein, the term crude oil means oil in its natural state, not altered, refined, or prepared for use by any process; and products means oils that have been refined, altered, or processed for use, such as fuel oil and gasoline.

3. Natural gasoline or other similar products, whenever blended with crude oil in transit, should be classified and reported as crude oil in this schedule.

4. In column (H) show all oils received by the respondent from connecting carriers reporting to the Interstate Commerce Commission. In column (I) show all oils originated on respondent's gathering lines and in column (J) all oils received into respondent's system from all sources, except receipts shown in columns (H) and (I). Entries in column (J) should be the sum of corresponding entries in columns (H), (I), and (J).

5. In column (D) show all oils delivered to connecting carriers reporting to the Interstate Commerce Commission. In column (G) show all oils terminated on respondent's gathering lines, and in column (H) all oils delivered out of respondent's system, except deliveries shown under columns (I) and (J). Entries in column (D) should be the sum of corresponding entries in columns (I), (G), and (H).

6. Returns in "Note" should be estimated if not actually shown on respondent's records.

| Line No.   | State of origin<br>(a)   | NUMBER OF BARRELS RECEIVED INTO SYSTEM |                           |                       |                                   | NUMBER OF BARRELS (H) SHIPPED OUT OF SYSTEM |                           |                       |                                      | Carrier Initials<br>Year 19 |
|--|--|--|---------------------------|-----------------------|-----------------------------------|---|---------------------------|-----------------------|--------------------------------------|-----------------------------|
|  |  | From connecting carriers<br>(B)        | ORIGINATED                |                       | Total received into system<br>(C) | To connecting carriers<br>(F)               | TERMINATED                |                       | Total delivered out of system<br>(I) |                             |
|  |  |  | On gathering lines<br>(D) | On trunk lines<br>(E) |                                   |   | On gathering lines<br>(G) | On trunk lines<br>(H) |                                      |                             |
| <b>CRUDE OIL</b>   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 1  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 2  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 3  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 4  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 5  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 6  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 7  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 8  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 9  |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 10   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 11   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 12   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 13   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| <b>TOTAL</b>   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| <b>PRODUCTS</b><br>(State of origin and product carried) |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 14   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 15   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 16   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 17   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 18   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 19   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 20   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 21   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 22   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 23   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 24   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 25   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 26   |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| <b>TOTAL GRAND TOTAL</b>                                 |  |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 27   | NOTE.—Total number of barrel-miles (trunk lines only): Crude oil _____     |  |                           |                       |                                   |   |                           |                       |                                      |                             |
| 28   | Total number of barrels of oil having trunk-line movement: Crude oil _____ |  |                           |                       |                                   |   |                           |                       |                                      |                             |

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#### 4.3 Estimation Methodology for Oil Pipelines

It was explained in Section 1.2 above that the accomplishment of this subtask reduces to an effort to estimate the three quantities on the right-hand side of the formula for the energy intensity,

$$I_E = \frac{E}{Q \times D}$$

where,

$I_E \triangleq$  energy intensity,  $\frac{\text{Btu}}{\text{Ton-Mile}}$

$E \triangleq$  energy consumed annually, Btu

$Q \triangleq$  quantity transported annually, Barrels

$D \triangleq$  distance transported annually, miles

Estimation of the numerator E constitutes an end in itself, since the total annual energy consumption is the first objective of this study. Information regarding the denominator is equally useful in the form of Q and D separately, or as the product (Q x D). It has been seen in the preceding section that oil pipelines report the data in the latter form, as barrel-miles. Unfortunately, they do not report ton-miles, nor average density. Thus, an imprecision of plus-or-minus five to ten percent is introduced by the use of any value for average density which is unsupported by considerable research.

It has also been seen in the preceding section that the direct measurements, in the form of recorded data, whose total would represent the numerator E in the formula, does not exist. The companies are not required to record or

maintain such data, and while some of them may do so, many do not. Accordingly, it becomes necessary to work with such data as does exist, which was seen to be the annual costs of energy, as reported on Line 4, Figure 4.2-1 above.

The general approach which was taken then, was to estimate the total energy by developing an estimate of the average unit cost of purchased energy and dividing that value into the total cost of power and fuel. To estimate energy intensity, the cost intensity is first calculated by dividing throughput, in barrel-miles into the total energy cost. Dividing this result by the estimate of average unit energy cost then yields the first-order estimate of energy intensity (EI) at the pumping station meter. Dividing by the efficiency of the electric generation and transmission system gives the EI at the boiler. Finally, the conversion from Btu/Barrel-Mile to Btu/Ton-Mile is made by multiplying by a reasonable value of energy inverse density in Barrels/Ton.

Unfortunately, the totals published in the ICC statistics are not broken into sufficient detail that this method can be applied directly to those statistics, because the only figure given for fuel and power costs includes gathering and distribution energy as well as trunkline energy. To obtain that breakdown, it is necessary to consult each of the 104 reports filed by the individual companies. As will be seen, that is neither convenient nor necessary, because highly representative samples of the population of companies could be constructed. Having applied the method to those samples, the intensity value thus obtained is then extrapolated back to the entire population.

Finally, it is well to note that the same inability to obtain an accurate estimate of energy intensity had been the result of an attempt by the National Petroleum Council Task Force (NPC 73). As reported in a Rand Corporation report (Anderson 75), "The NPC Group found no valid way to

correlate distance, volume, and cost, using historical information on transmission costs." The analysis presented here represents a first attack upon the problem.

#### 4.3.1 Selection of Samples for Analysis

The first step in the execution of this method is the selection of a sample from the population of 104 companies, use of the entire population being neither necessary or desirable. Since the viscosities of the crudes are generally different from those of the products, it was desired to analyze the statistics of crude oil pipeline companies and petroleum products pipeline companies separately, so that two samples were required. Since many companies operate both products and crude lines, it was necessary to sort them into three categories, i.e., those whose operations are predominantly one type or the other, and those which are significantly both. For convenience, a "prime" company in either the products or crude category was defined as one whose trunkline shipments in one of those two categories comprise at least 80% of its total trunkline shipments. It was found that, of the 104 interstate pipeline companies in the United States in 1976, 91 met this definition. Most of the 13 which did not were comparatively small, and for some, no trunkline traffic tabulated at all was reported.

The degree of specialization of the primes into the two categories was analyzed for 1975, the figures for 1976 not being available at the time. The results are presented in Table 4.3.1-1.

Table 4.3.1-1  
Prime\* Pipeline Companies, 1975

Degree of Specialization in Either Crude Oil or  
Petroleum Products Shipments

| <u>% of Specialization</u> | <u>No. of Companies</u> |
|----------------------------|-------------------------|
| 100                        | 70                      |
| 95-99                      | 10                      |
| 90-94                      | 4                       |
| 85-89                      | 4                       |
| 80-84                      | 2                       |

\*Prime Company - One whose trunkline shipments of crude or  
products comprise 80% of its total.

It is seen that the specialization is extremely high, indicating that the separation is virtually complete. When the 1976 figures appeared, the complete specialization analysis was not repeated, but it was verified that the specialization of the primes had not changed in any non-trival way.

After the primes in each category were identified, they were tabulated in order of trunkline barrel-miles of traffic for 1976. Then sufficient companies were taken in sequence from the top of the list to include at least 90% of the trunkline barrel-miles for all the primes in that category. This selection process yielded 21 crude and 14 products companies. Their 1976 market share is shown in Table 4.3.1-2.

Tables 4.3.1-1 and 4.3.1-2 together show that the two groups of selected companies are highly representative samples of their categories. Discussion of the analyses performed upon these samples will be presented in Section 4.4. First, however, the estimation of the cost of purchased power will be discussed.

#### 4.3.2 Estimation of Purchased Power Cost

Early inquiries had revealed that pipeline companies do not maintain explicit records of all their power consumption, although engineering departments from time to time may collect the figures for purposes of one study or another. A number of companies (more than a dozen) were then interviewed and asked if their energy consumption and energy intensity could be obtained. It was found that they do not collect the data or perform the calculations in the ordinary course of business, although engineering studies may from time to time become involved in such questions. They were then asked to provide their actual average cost of purchased electricity in dollars per kilowatt-hour. Most them declined; however, the information presented in Table 4.3.2-1 was obtained.

Table 4.3.1-2  
Market Share of Selected Companies, 1976

| <u>Group</u>    | <u>Trunkline Traffic, 10<sup>6</sup> B-Mi</u> |                    |
|-----------------|---|--------------------|
|                 | <u>Crude</u>                                  | <u>Products</u>    |
| All Companies   | 1,639,479                                     | 1,279,016          |
| Selected Sample | 1,447,949<br>(88%)                            | 1,017,999<br>(80%) |

Table 4.3.2-1  
Electricity Costs of Pipeline Companies

| <u>Type<br/>of<br/>Pipeline</u> | <u>Geographical<br/>Region</u> | <u>Average<br/>Electricity<br/>Cost,<br/>\$/Kw-hr</u> | <u>Time<br/>Period</u>                                       |
|---------------------------------|--------------------------------|---|--|
| 1. Large Crude                  | South-Southwest                | 0.0225  | 1976   |
| 2. Large Products               | Southwest                      | 0.0235  | 1976   |
| 3. Small Crude                  | West                           | 0.0230  | 1976   |
| 4. Small Products               | Far West                       | 0.0350  | 1976   |
| 5. Small Products               | Mid-West                       | 0.0125  | 1/73-3/74  |
| 6. Large Water                  | West-Central                   | 0.0200  | 1976   |
| 7. Large Sewage                 | Far-West                       | 0.03666<br>0.3594<br>0.03162<br>0.02289               | June 1977<br>6/1/76-6/1/77<br>6/1/75-6/1/76<br>6/1/74-6/1/75 |

The pattern of variation which is seen Table 4.3.2-1 is as would generally be expected. Pipelines in the gulf coast and southeast generally enjoy lower power costs than elsewhere. Water companies are able to obtain the lowest cost of all by virtue of the large storage capacity in their systems, which enables them to do most of their pumping at night and take advantage of the lowest power rates. And product lines generally have to pay somewhat higher rates than crude lines, because with their more drastic duty cycles they have higher peaking charges. An example utility rate schedule is presented in Figure 4.3.2-1.

The first two values in Table 4.3.2-1 are probably below the national average because they pass through the region which enjoys the lowest power cost. The national average cost of purchased electricity for the products lines is likely to be nearer to the average of the second and fourth figures than to the second. Hence, for the analysis, that average, 0.02925 \$/kw-hr was used. Reducing this value in the proportion of the first value in the table to the second then yields 0.0280 \$/kw-hr as the estimate for the national average cost of purchased power for crude lines. There are no obvious adjustments to be made for the water lines.

No defense of these estimates is offered, except that they are reasonable. They are certainly useful as first-order estimates and as a means to exercise the methodology. The research that would be necessary to refine them is discussed later in this report.

SAN DIEGO GAS & ELECTRIC COMPANY  
SAN DIEGO, CALIFORNIA

|              |                       |                       |        |
|--------------|-----------------------|-----------------------|--------|
| Revised      | Cal. P.U.C. Sheet No. | 2649-E                |        |
| Conciliating | Revised               | Cal. P.U.C. Sheet No. | 2462-E |

(Sheet 1 of 3)

## SCHEDULE A-6

GENERAL SERVICE - LARGEAPPLICABILITY

Applicable to general service including lighting, appliances, heating, and power, or any combination thereof, except as limited by Special Conditions 1., 7. and 10.

TERRITORY

Within the entire territory served by utility.

| RATES | Per Meter<br>Per Month |
|-------|------------------------|
|-------|------------------------|

## Energy Charge:

|  |            |
|--|------------|
| First 100 kWhr per kw of billing demand, per kWhr..... | \$ 0.04132 |
| Next 100 kWhr per kw of billing demand, per kWhr.....  | .03582     |
| Next 100 kWhr per kw of billing demand, per kWhr.....  | .02197     |
| All excess kWhr, per kWhr.....                         | .01907     |

## Minimum Charge:

The monthly minimum charge shall be \$7,000.00 but not less than \$1.40 per kw of billing demand.

## Energy Cost Adjustment:

An Energy Cost Adjustment, as specified in Section 9. of the Preliminary Statement, will be included in each bill for service. The Energy Cost Adjustment amount shall be the product of the total kilowatt-hours for which the bill is rendered multiplied by \$0.00761 per kilowatt-hour. (The Energy Cost Adjustment amount is not subject to any adjustment for serving voltage.)

## Fuel Collection Balance Adjustment:

A Fuel Collection Balance Adjustment, as specified in Section 10. of the Preliminary Statement, will be deducted from each bill for service. The Fuel Collection Balance Adjustment amount shall be the product of the total kilowatt-hours for which the bill is rendered multiplied by \_\_\_\_\_ per kilowatt-hour. (The Fuel Collection Balance Adjustment amount is not subject to any adjustment for serving voltage.)

(Continued)

|                                |                                     |
|--------------------------------|-------------------------------------|
| (To be concurred by utility)   | (To be issued by Cal. P.U.C.)       |
| Advice Letter No. <u>413-E</u> | ISSUED BY                           |
| Decision No. _____             | JOHN H. WOY                         |
|                                | VIA E PHILIMENT RATE & VALUATION    |
|                                | Date Filed <u>September 7, 1976</u> |
|                                | Effective <u>September 1, 1976</u>  |

E-1500

Figure 4.3.2-1 - Example of Electric Utility Rate Schedule

|   |                                  |  |        |
|---|----------------------------------|--|--------|
| SAN DIEGO GAS & ELECTRIC COMPANY<br>SAN DIEGO, CALIFORNIA | Revised<br>Revised<br>Cancelling | Cal. P.U.C. Sheet No.<br>2462-E<br>Cal. P.U.C. Sheet No.<br>2329-E | 2650-E |
|---|----------------------------------|--|--------|

(Sheet 2 of 3)  
SCHEDULE A-6 (Continued)

RATES (Continued)

Residual Oil Sales Adjustment:

A Residual Oil Sales Adjustment, as specified in Section 11. of the Preliminary Statement, will be deducted from each bill for service. The Residual Oil Sales Adjustment amount shall be the product of the total kilowatt-hours for which the bill is rendered multiplied by \_\_\_\_\_ per kilowatt-hour. (The Residual Oil Sales Adjustment amount is not subject to any adjustment for serving voltage.)

Franchise Fee Differential:

The franchise fee differential as indicated below will be applied to the monthly billings calculated under this schedule for all customers within the corporate limits as follows:

City of San Diego 1.9%

Such franchise fee differential shall be so indicated and added as a separate item to bills rendered to such customers.

SPECIAL CONDITIONS

1. Voltage. This schedule is applicable where the customer receives service at a standard voltage of the utility above 2 kv.

2. Primary Voltage Discount. When delivery hereunder is made and energy is received at an available standard voltage above 2 kv, the charges before power factor adjustment will be reduced as follows:

1 per cent in the range of 10.1 kv to 25 kv  
4 per cent above 25 kv

The utility retains the right to change its delivery voltage after reasonable advance notice in writing to any customer receiving a discount hereunder and affected by such change, and such customer then has the option to change his system so as to receive service at the new delivery voltage or to accept service without voltage discount after the change in delivery voltage, through transformers owned by the utility.

3. Voltage Regulators. Voltage regulators, if required by the customer, shall be furnished, installed and maintained by the customer.

4. Billing Demand. The billing demand will be based on kilowatts of maximum demand as measured each month, provided that the billing demand shall in no case be less than the highest of (a) 5,000 kw, (b) 80 per cent of the highest billing demand registered during the preceding eleven months, or (c) the diversified resistance welder load computed in accordance with the utility's Rule 2F-2b.

(Continued)

|                             |       |                                  |                              |
|-----------------------------|-------|----------------------------------|------------------------------|
| (To be inserted by utility) |       | (To be inserted by C.J. P.U.C.)  |                              |
| Advice Letter No.           | 413-E | ISSUED BY                        | Date Filed September 7, 1976 |
| Decision No.                |       | JOHN H. WOY                      | Effective September 1, 1976  |
|                             |       | VICE PRESIDENT-RATES & VALUATION | Resolution No. E-1500        |

Figure 4.3.2-1 - Continued (Sheet 2)

|   |         |                       |        |
|---|---------|-----------------------|--------|
| SAN DIEGO GAS & ELECTRIC COMPANY<br>SAN DIEGO, CALIFORNIA | Revised | Cal. P.U.C. Sheet No. | 2651-E |
|   | Revised |                       | 2329-E |
|   | Revised | Cal. P.U.C. Sheet No. | 2330-E |

SCHEDULE A-6 (Continued) (Sheet 3 of 3)

SPECIAL CONDITIONS (Continued)

4. Billing Demand. (Continued)

For maximum demands occurring between the hours of 10 p.m. to 7 a.m. of the following day, only 60 per cent of such maximum demand shall be considered.

5. Maximum Demand. The maximum demand in any month shall be the average kilowatt input during that 15 minute interval in which the consumption of electric energy is greater than in any other 15-minute interval in the month as indicated or recorded by instruments installed, owned and maintained by the utility.

In the case of hoists, elevators, furnaces and other loads where the energy demand is intermittent or subject to violent fluctuations, the utility may base the maximum demand upon a five-minute interval instead of a 15-minute interval.

6. Power Factor Adjustment. This schedule is based on service to loads having a maximum reactive kilovolt ampere demand not greater than 75 per cent of the maximum kilowatt demand. In the event that the reactive demand exceeds 75 per cent of the kilowatt demand, the customer shall, upon receiving written notice from the utility, install and operate such compensating equipment as may be necessary to reduce the reactive demand to 75 per cent or less of the kilowatt demand. Unless such correction of reactive demand is made within ninety days, there will be added to each monthly bill following the ninety day period a charge of 15 cents per kilovar of maximum reactive demand in excess of 75 per cent of the maximum kilowatt demand (whether on peak or off peak) for the month.

7. Limitation on Multi-family Service. This schedule is not applicable to service to multi-family housing projects or other services associated therewith, except housing on the premises of educational institutions, industrial plants and military establishments when such housing is associated with the operation of the establishment.

8. Contract. A contract for an initial period of ten years, and for subsequent periods of five years each thereafter, will be required for each customer served under this schedule. This contract may be cancelled at the end of the initial period or at the end of any subsequent period, provided written notice is given two years in advance of the end of any such period.

9. Customer's Right to Terminate. In the event the net bill for electric service to the customer is increased as a result of changes in this schedule, the customer shall have the right to terminate the contract upon written notice given one year in advance of the date such service is to terminate, and given within 90 days after the effective date of such change.

10. Miscellaneous. This schedule is not applicable to standby, auxiliary service or service operated in parallel with a customer's generating plant. Summetering or resale of energy will not be permitted.

|                                |                                     |
|--------------------------------|-------------------------------------|
| (To be inserted by utility)    | (To be inserted by Cal. P.U.C.)     |
| Advice Letter No. <u>413-E</u> | ISSUED BY <u>JOHN H. WOY</u>        |
| Decision No. <u></u>           | VICE PRESIDENT-RATES & VALUATION    |
|                                | Date Filed <u>September 7, 1976</u> |
|                                | Effective <u>September 1, 1976</u>  |
|                                | Resolution No. <u>E-1599</u>        |

Figure 4.3.2-1 - Continued (Sheet 3)

#### 4.4 Energy Estimates for Crude Oil Pipelines

The sample of 21 crude oil pipeline companies that were selected in Section 4.3.1 above are listed in Table 4.4-1, along with some of their statistics of interest. In 1976, they transported approximately 95% of all crude oil trunkline traffic by primes and 90% of that by the entire population. They were responsible for a combined shipment in 1976 of 4,054,845 thousand barrels in an average haul of 357 miles, for a total of 1,447,949 million barrel-miles shipped (columns 1, 2, and 8).

Before proceeding with the energy calculations, it is well to take note of column 4, shortages and losses. The reasons for the negative losses, which if real would represent gains, or inflows of oil into the system, are not known. It is presumed that this is an over-and-under account which is used to balance inventories. In that case, these figures have no direct significance in the present calculation, except as they may perhaps indicate something about the accuracy of the other figures in the report. The significance of these loss figures as indicators of physical leakage is further discussed in Section 9.0 of Report R-3025 of this series (See Table 1.1-1 above).

Column 5 is also interesting. It shows the total operations expense for each company. This total combines salaries and wages, supplies and expenses, outside services, operating fuel and power, and oil losses and shortages. By comparison with column 3, it is seen that energy is by far the largest component of operating expense, using 75% of the total. Column 9 shows the percentages of total operations expense for fuel and power costs for each company and, as in the other cases, provides the weighted average for all the companies listed.

Table 4.4-1 - Selected Crude Oil Companies

| Company                   | COST INTENSITY ANALYSIS |          |                         |                        |             |                     |                         |                                  |  |                      |   |                 |
|---------------------------|-------------------------|----------|-------------------------|------------------------|-------------|---------------------|-------------------------|----------------------------------|--|----------------------|---|-----------------|
|                           | Trunkline Shipments     |          |                         | Oil Losses & Shortages |             |                     | Total Operating Expense |                                  |  | Fuel & Power         |   |                 |
|                           | 1<br>MM B-Mi            | 2<br>M B | 3<br>Fuel & Power<br>\$ | 4<br>\$                | 5<br>\$     | 6<br>\$/MM,<br>B-Mi | 7<br>\$/M,<br>B         | 8<br>Avg.<br>Ship-<br>ment<br>Mi | 9<br>% of Tot.<br>Operating<br>Expense<br>Col. 3<br>Col. 4 | 10<br>\$/MM,<br>B-Mi | 11<br>Total<br>Operating<br>Expense<br>\$/MM,<br>B-Mi | 12<br>\$/M<br>B |
| Lakehead                  | 293,629                 | 391,540  | 18,507,533              | 832,231                | 23,206,770  | 63.03               | 47.27                   | 750                              | 79.8   | 3.6                  | 79.03   | 59.27           |
| Amoco                     | 190,548                 | 410,263  | 16,878,116              | -                      | 22,188,619  | 88.58               | 41.14                   | 464                              | 76.1   | -                    | 116.45  | 54.08           |
| Shell                     | 128,236                 | 368,829  | 9,987,771               | 4,628,156              | 17,888,104  | 77.89               | 27.08                   | 348                              | 55.8   | 25.9                 | 139.49  | 48.50           |
| Mid-Valley                | 107,986                 | 142,803  | 9,977,052               | 104,559                | 11,261,282  | 92.39               | 69.87                   | 766                              | 88.6   | 9.3                  | 104.28  | 78.86           |
| Texas Pipe<br>Line Co.    | 94,083                  | 335,957  | 6,668,842               | 397,358                | 9,143,089   | 70.88               | 19.85                   | 280                              | 72.9   | 4.3                  | 97.18   | 27.22           |
| Mobil                     | 93,114                  | 308,884  | 8,401,843               | 415,253                | 10,589,953  | 90.23               | 27.20                   | 301                              | 79.3   | 3.9                  | 113.73  | 34.28           |
| Arco                      | 81,258                  | 239,406  | 7,159,934               | 515,104                | 10,724,514  | 88.11               | 29.91                   | 339                              | 66.8   | 4.8                  | 131.98  | 44.80           |
| Marathon                  | 63,430                  | 256,586  | 5,646,913               | (1,950,054)            | 4,974,345   | 88.96               | 22.01                   | 247                              | 113.5  | (39.2)               | 78.36   | 19.39           |
| Exxon                     | 62,111                  | 445,637  | 6,178,988               | 1,417,716              | 10,988,270  | 99.48               | 13.87                   | 139                              | 56.2   | 12.9                 | 176.91  | 24.68           |
| Ashland                   | 52,542                  | 76,148   | 3,594,068               | 665,964                | 5,007,641   | 68.40               | 47.20                   | 690                              | 71.8   | 13.3                 | 95.31   | 65.76           |
| West Texas<br>Pipe Line   | 52,392                  | 131,873  | 2,255,450               | (90,901)               | 2,823,009   | 43.05               | 17.10                   | 397                              | 79.9   | (3.2)                | 49.19   | 21.41           |
| Southcap                  | 44,234                  | 69,378   | 2,393,579               | -                      | 2,649,767   | 54.11               | 34.50                   | 638                              | 90.3   | -                    | 59.90   | 38.19           |
| Platte                    | 35,357                  | 51,307   | 1,821,852               | -                      | 2,165,823   | 51.53               | 35.51                   | 689                              | 84.1   | -                    | 61.26   | 42.21           |
| Portland                  | 23,322                  | 140,242  | 3,082,864               | 872,086                | 4,173,679   | 132.19              | 21.98                   | 166                              | 73.9   | 20.9                 | 178.96  | 29.76           |
| Chicap                    | 23,285                  | 118,014  | 1,914,162               | -                      | 2,114,390   | 82.21               | 16.22                   | 197                              | 90.5   | -                    | 90.80   | 17.92           |
| Texaco-<br>Cities Service | 22,715                  | 109,398  | 1,915,815               | (51,751)               | 2,787,382   | 84.34               | 17.51                   | 208                              | 68.7   | (1.9)                | 122.71  | 25.48           |
| Pure                      | 20,939                  | 93,228   | 1,825,319               | 12,325                 | 2,861,435   | 87.17               | 19.58                   | 225                              | 63.8   | 4.3                  | 136.66  | 30.69           |
| Texas-NMex.               | 16,567                  | 155,154  | 1,183,487               | (30,687)               | 1,601,305   | 71.44               | 7.63                    | 107                              | 73.9   | (1.9)                | 96.66   | 10.32           |
| Owensboro-<br>Ashland     | 16,033                  | 54,348   | 538,092                 | (365,191)              | 373,886     | 33.56               | 9.90                    | 295                              | 143.9  | (97.6)               | 23.32   | 6.88            |
| Minnesota                 | 13,330                  | 51,304   | 2,553,828               | (126,291)              | 2,706,174   | 191.58              | 49.78                   | 260                              | 94.4   | (4.7)                | 203.01  | 52.75           |
| Cities<br>Service         | 12,788                  | 104,546  | 1,115,491               | (38.946)               | 1,629,096   | 87.23               | 10.67                   | 122                              | 68.5   | (2.4)                | 127.39  | 15.58           |
| Total/Avg.                | 1,447,949               | 4054,845 | 113,600,990             | 7,206,931              | 151,858,533 | 78.46               | 28.01                   | 357                              | 74.8   | 4.7                  | 104.87  | 37.45           |

Source: ICC Annual Reports "P", Pipeline Companies, 1976

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R-77-3022

Finally, columns 11 and 12 show individual company total operations expenses per million barrel-miles and per thousand barrels shipped, respectively. Weighted averages are again provided.

#### 4.4.1 Energy Consumption in Crude Oil Pipelines

The energy consumption of the sample may now be estimated. The point of departure is the total trunkline power and fuel cost, column 3, of \$113,600,990. Dividing this cost by the value derived in the preceding section for unit power cost, 0.0280 \$/kw-hr, yields  $4.057 \times 10^9$  kw-hr. This is the indicated consumption of energy at the pumping station meter.

To obtain the energy consumption at the electric generating station, it is necessary to divide this result by the appropriately - averaged efficiency of the generation and distribution network. This efficiency has been variously estimated between 20 and 25%, and for present purposes a value of 22% will be used. The result is  $1.8442 \times 10^{10}$  kw-hr, equal to  $6.293 \times 10^{13}$  Btu (0.063 Quad). This is the estimate for the energy consumption of the sample.

Similarly, an estimate for the energy consumption by the total national crude pipeline population may be derived, beginning with the 1976 fuel and power cost for all the companies of \$126,645,547.

$$\begin{aligned} \frac{126,645,547}{0.28 \times 0.22} &= 2.056 \times 10^{10} \text{ kw-hr} \\ &= 0.070 \text{ Quad} \end{aligned}$$

The foregoing calculation disregards the fact that some of the power is not purchased electricity. In Figure 4.1.3-1 above, it was seen that in five particular cases the average amount of non-electric power was 12%. Now, if the reason that most of the power is electric is that electricity is generally cheaper, then a somewhat higher unit power cost estimate than 0.0280 should be used for the non-electric fraction. However, there is an offsetting influence in that other prime movers tend to be more efficient energy converters than the electric generation and distribution systems. Since these two factors are both unknown and offsetting, there is no readily evident basis to modify the result to account for the non-electric prime movers.

#### 4.4.2 Energy Intensity of Crude Oil Pipelines

Referring again to Table 4.4-1, the trunkline energy cost intensity for the sample is seen at the bottom of column 6 to be \$78.46 per million Barrel-Miles. Taking a reasonable average specific gravity of 0.87 (6.58 barrels per ton) converts this cost intensity to \$516.27 per million Ton-Miles. So in the total energy calculation above, dividing by 0.028 \$/kw-hr yields 0.018438 kw-hr/Ton-Mile at the station meter. Dividing again by 0.22 yields 0.0838 kw-hr/Ton-Mile or 286 Btu/Ton-Mile at the generating station.

It is of further value to specialize to a specific pipeline system. It was explained in Section 4.2.2 above that some actual power cost experience information was obtained through interviews with individual companies. Taking this information and repeating the process yielded a value of 490 Btu/Ton-Mile, much more than obtained above for the national average. The calculation is not presented here to preserve the anonymity of the source.

The reasons for this large difference were not explored in depth, but the parameters of density, viscosity, speed, lengths and diameters for the system were reviewed and compared with those of other lines, and the difference was found to be not unreasonable. The sensitivity of the result to some of these parameters can be appreciated from Table 4.4.2-1.

This higher value for the specific case does of course lead to the suspicion that the estimate derived above may be low, but without further data and analysis there appears to be no basis to raise the estimate except by rounding. It is, therefore, concluded that the best single-figure estimate is 300, and the best two-figure estimate is 290. In view of the imprecision of the method, it is suggested that 300 Btu/Mile be used for both.

#### 4.5 Energy Estimates for Products Pipelines

The sample of 14 products pipeline companies that were selected in Section 4.3.1 above are listed in Table 4.5-1, along with some of their statistics of interest. In 1976, they transported approximately 94% of trunkline products traffic by the primes and 78% of that by the entire population. This table is the analog of Table 4.4-1, and the earlier general comments again apply.

##### 4.5.1 Energy Consumption in Products Pipelines

The estimation of energy consumption for the product lines is the parallel of that given earlier for the crude lines. The results are  $1.5508 \times 10^{10}$  kw-hr (0.053 Quad) and  $1.9780 \times 10$  kw-hr (0.068 Quad) respectively, for the sample and the national total. The 1976 total power and fuel cost as reported by the ICC, of \$127,284,960, and the average power cost from Section 4.2.3 were used in these calculations.

Table 4.4.2-1  
 Pipeline Energy Intensiveness  
 (Btu/ton-mile)

| Pipeline<br>diameter<br>(in) | Kinematic Viscosity<br>0.000010 ft <sup>2</sup> /sec <sup>a</sup> |     |      | Kinematic Viscosity<br>0.000075 ft <sup>2</sup> /sec <sup>b</sup> |                      |      | Kinematic Viscosity<br>0.00050 ft <sup>2</sup> /sec <sup>c</sup> |      |                      |   |   |   |
|------------------------------|---|-----|------|---|----------------------|------|--|------|----------------------|---|---|---|
|                              | Velocity<br>(ft/sec)  | 3   | 6    | 9   | Velocity<br>(ft/sec) | 3    | 6  | 9    | Velocity<br>(ft/sec) | 3 | 6 | 9 |
| 8                            | 180   | 590 | 1330 | 290   | 960                  | 1850 | 460  | 1500 | 2870                 |   |   |   |
| 20                           | 60  | 220 | 450  | 90  | 310                  | 660  | 140  | 490  | 980                  |   |   |   |
| 32                           | 30  | 130 | 260  | 50  | 170                  | 360  | 80   | 270  | 540                  |   |   |   |

<sup>a</sup>Kerosene at 80°F

<sup>b</sup>California crude oil at 80°F

<sup>c</sup>Light engine oil at 80°F

Source: Hirst, Eric, Energy Intensiveness of Passenger and Freight  
 Transportation Modes: 1950-1972, Oak Ridge National Laboratories,  
 April 1973 (ORNL-NSF-EF 44)

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COST INTENSITY ANALYSIS

| Company           | <u>Trunkline Shipments</u> |                  |                   | <u>Oil Losses &amp; Shortages</u> |                    |                     | <u>Total Operating Expense</u> |            | <u>Fuel &amp; Power</u> |            | Avg. Ship-<br>ment Mi | % of Tot.<br>Operating<br>Expense<br>Col. 3<br>Col. 4 | <u>Total Operating<br/>Expense</u><br>\$/MM,<br>B-Mi | <u>Total Operating<br/>Expense</u><br>\$/M<br>B |
|-------------------|----------------------------|------------------|-------------------|-----------------------------------|--------------------|---------------------|--------------------------------|------------|-------------------------|------------|-----------------------|---|--|---|
|                   | 1<br>MM B-Mi               | 2<br>M B         | 3<br>\$           | 4<br>\$                           | 5<br>\$            | 6<br>\$/MM,<br>B-Mi | 7<br>\$/M,<br>B                |            |                         |            |                       |   |  |   |
| Colonial          | 591,688                    | 569,396          | 56,503,564        | 127,388                           | 64,383,213         | 95.50               | 99.23                          | 1039       | 87.8                    | 0.2        | 108.81                | 113.07  |  |   |
| Plantation        | 105,640                    | 186,089          | 9,059,872         | 372,462                           | 13,682,728         | 85.76               | 48.69                          | 568        | 66.2                    | 2.7        | 129.52                | 73.52   |  |   |
| Texas Eastern     | 65,570                     | 115,518          | 5,090,446         | 657,295                           | 9,182,267          | 77.63               | 44.07                          | 568        | 55.4                    | 7.2        | 140.03                | 79.49   |  |   |
| Williams          | 62,453                     | 177,781          | 7,756,856         | -                                 | 14,029,105         | 124.18              | 43.63                          | 351        | 55.3                    | 0          | 224.60                | 78.91   |  |   |
| Mid-America       | 42,577                     | 103,648          | 3,971,866         | (478,014)                         | 6,249,930          | 93.29               | 38.32                          | 411        | 63.6                    | (7.6)      | 146.79                | 60.30   |  |   |
| Explorer          | 33,805                     | 59,029           | 1,730,074         | 623,459                           | 3,312,077          | 51.18               | 29.31                          | 573        | 52.2                    | 18.8       | 97.98                 | 56.11   |  |   |
| Southern Pacific  | 26,080                     | 206,846          | 4,648,535         | 67,154                            | 8,566,931          | 178.24              | 22.47                          | 126        | 54.3                    | 0.8        | 328.49                | 41.02   |  |   |
| Dixie             | 18,797                     | 29,078           | 2,155,141         | 445,103                           | 3,453,575          | 114.65              | 74.12                          | 646        | 62.4                    | 12.9       | 183.73                | 118.77  |  |   |
| Hydrocarbon       | 18,474                     | 27,364           | 3,670,318         | -                                 | 5,262,716          | 198.67              | 134.13                         | 675        | 69.7                    | 0          | 284.87                | 192.32  |  |   |
| Wolverine         | 13,009                     | 83,276           | 2,615,420         | 193,035                           | 3,855,490          | 201.05              | 31.41                          | 156        | 67.8                    | 5.0        | 296.37                | 46.30   |  |   |
| Olympic           | 12,838                     | 68,424           | 985,814           | -                                 | 1,724,286          | 76.79               | 14.41                          | 188        | 57.2                    | 0          | 134.31                | 25.20   |  |   |
| Santa Fe          | 9,683                      | 20,044           | 265,876           | -                                 | 7,954,109          | 27.46               | 13.26                          | 483        | 3.34                    | 0          | 821.45                | 396.83  |  |   |
| Yellowstone       | 8,918                      | 20,784           | 754,969           | (26,027)                          | 1,219,048          | 84.66               | 36.32                          | 429        | 61.9                    | (2.1)      | 136.70                | 58.65   |  |   |
| Laurel            | 8,457                      | 42,706           | 582,661           | 699,672                           | 2,146,303          | 68.90               | 13.64                          | 198        | 27.1                    | 32.6       | 253.79                | 50.26   |  |   |
| <u>Total/Avg.</u> | <u>1,017,999</u>           | <u>1,705,983</u> | <u>99,791,412</u> | <u>2,681,527</u>                  | <u>145,021,778</u> | <u>98.03</u>        | <u>58.49</u>                   | <u>597</u> | <u>68.8</u>             | <u>1.8</u> | <u>142.46</u>         | <u>84.81</u>  |  |   |

Source: ICC Annual Reports "P" Pipeline Companies, 1976.

Table 4.5.1 - Major Petroleum Pipeline Companies  
U. S. Trunklines, 1976

R-77-3022

#### 4.5.2 Energy Intensity of Products Pipelines

Continuing as before, and taking 0.80 (7.15 barrels per ton) as a reasonable average specific gravity, the average cost intensity of  $98.03 \$/10^6$  B-Mi from Table 4.5-1, column 6 becomes  $700.62 \$/10^6$  T-Mile, and the estimate for average energy intensity of the sample is 388 Btu/Ton-Mile at the generating station. This is also the best estimate for the population.

Again specializing to companies which were interviewed, energy intensities of 323, and 405 and 887 Btu/T-Mi were calculated. As before, the reasons for the variability were not researched in depth, but the parameters were reviewed and found to be reasonable. The very high number is not typical, but is due to particular operating circumstances, one of which is the kind of extreme duty cycle variation that is discussed in depth in Report R-3025 of this series. In fact, the only reason that the data were collected was that the power costs had risen so high that management had ordered a special engineering study of the situation. The results were used in an intensive internal education program for operating personnel and firstline supervision.

As before, rounding the value derived above leads to 390 and 400 as the best two-figure and single-figure estimates. In view of the imprecision of the method, the difference is not significant, and it is suggested that 400 Btu/T-Mi be used.

## 5.0 ENERGY CONSUMPTION IN WATER PIPELINES

Water systems may be placed into two classes - supply and waste. Generally, the supply system provides potable fresh water and the waste system is a sewage system. Their character is very different from that of other pipelines. Notably, a characteristic of large water systems is the fact that they are not pipelines at all over much of their span. For example, the largest such system, the California (Feather River) project, contains more canals than pipelines. Waste systems are likewise characterized by the fact that most of the flow is by gravity in hydraulically open channels under gravity, as opposed to full-pipe flow under imposed head. The energy input in both types of systems is almost exclusively by electrically-driven pumps at intermittent lift stations.

It was explained in the opening section of this report that the primary objective of this program is to assess the susceptibility of the pipeline industry to energy-conservative innovations, and to identify the opportunities for energy conservation. Report R-3025 of this series identifies those opportunities and recommends the R, D, and D programs to exploit them. That report identified few such opportunities for improvements in pipelines whose prime movers are electric motors. Moreover, the notable exception, i.e., use of fuel cells with DC motors, derives part of its attraction from two factors which are absent in water systems. These are extreme duty cycles and the possibility of transporting the fuel through the pipeline itself. Thus, no attractive energy-conservative opportunities have been identified for water pipelines.

### 5.1 Water Pipeline Industry Profile

Table 5.1-1 presents some interesting water industry statistics, to which reference will again be made later, in developing an estimate of industry energy consumption.

The best sourcebook for general information about the water industry is the Water Encyclopedia (Todd 70). Unfortunately, it is becoming somewhat out-of-date, and there are apparently no plans to republish. Most of the tables to follow are found there.

Table 5.1-2 presents the total water use in the U. S. in 1965. It is noted that about 81% of withdrawal (254,000 mgd of 314,470) is surface water and 19% is ground water. The nationwide per capita use, bottom of second column, was 1600 gpd, a very high figure because it includes all agriculture and industrial use. A better correlation is perhaps seen in the per capita withdrawals through supply systems, shown in Table 5.1-3. Table 5.1-4 presents the withdrawals and use for 1965, and Table 5.1-5 presents projections of those statistics to 1980. These projections were made in 1968. Table 5.1-6, which presents costs of municipally supplied water in the 1950's is interesting in that cost does not appear to particularly well correlated with abundance.

Table 5.1-7 shows the drilling activity in 1964, and Table 5.1-8 shows depths of the 1966 wells. The average depth may be calculated from these figures as approximately 153 feet, a figure that will be useful later in estimating energy consumption. Also useful will be the information in Tables 5.1-9 and 5.1-10.

Table 5.1-1  
 Water Industry Statistics  
 August, 1974

| <u>Public Water Supply Systems</u>                             | <u>Total</u>          |
|--|-----------------------|
|  | <u>United States</u>  |
| Number of Public Water Supply Systems                          | 40,000                |
| Municipal Systems, % of Total                                  | 70%                   |
| Private Systems, % of Total                                    | 30%                   |
| Miles of Pipe for Water Distribution                           | 12 million            |
| Population Served  | 180 million           |
| Replacement Value  | \$125 billion         |
| Capital Expenditures   | \$1.4 billion         |
| Metered Usage as Per Cent of Total<br>Delivery Water Delivered |                       |
| Municipal Systems  | 83%                   |
| Private Systems  | 73%                   |
| Number of Employees  | 180,000               |
| Average Per Capita Usage                                       | 150 gpd - 0.10417 gpm |
| Average Per Capita Residential Usage                           | 60 gpd                |
| <br><u>Total Water Supplies</u>                                |                       |
| Daily Withdrawal of Water From All<br>Sources                  | 370 bgd               |
| Fresh Surface  | 67%                   |
| Fresh Ground   | 18%                   |
| Saline Surface   | 14%                   |
| Saline Ground  | 1%                    |

Source: American Water Works Association

Table 5.1-2 - Water Used for Public Supplies in the United States, 1965

| State                                | Population<br>1,000's | Per<br>capita<br>use<br>(gpd) | Water withdrawn                        |        |                        |               |        |                        |             |         |        |                                   |                                   |                   |
|--------------------------------------|-----------------------|-------------------------------|--|--------|------------------------|---------------|--------|------------------------|-------------|---------|--------|-----------------------------------|-----------------------------------|-------------------|
|                                      |                       |                               | Including irrigation conveyance losses |        |                        |               |        |                        |             |         |        |                                   |                                   |                   |
|                                      |                       |                               | Ground water                           |        |                        | Surface water |        |                        | All sources |         |        | Excluding<br>conveyance<br>losses |                                   |                   |
|                                      |                       |                               | Fresh                                  | Saline | Fresh<br>and<br>saline | Fresh         | Saline | Fresh<br>and<br>saline | Sewage      | Fresh   | Saline | Fresh<br>and<br>saline            | Excluding<br>conveyance<br>losses | Water<br>consumed |
| Alabama . . . . .                    | 3,486                 | 1,900                         | 200                                    | 0      | 200                    | 6,300         | 0      | 6,300                  | 0           | 6,500   | 0      | 6,500                             | 6,500                             | 250               |
| Alaska . . . . .                     | 267                   | 540                           | 26                                     | 0      | 26                     | 120           | 1.0    | 120                    | 0           | 140     | 1.0    | 140                               | 140                               | 11                |
| Arizona . . . . .                    | 1,575                 | 4,000                         | 4,200                                  | 0      | 4,200                  | 2,100         | 0      | 2,100                  | .56         | 6,300   | 0      | 6,300                             | 5,100                             | 3,100             |
| Arkansas . . . . .                   | 1,941                 | 1,100                         | 1,200                                  | 0      | 1,200                  | .850          | 0      | .850                   | 0           | 2,100   | 0      | 2,100                             | 2,000                             | 1,100             |
| California . . . . .                 | 18,403                | 2,300                         | 14,000                                 | 140    | 14,000                 | 17,000        | 11,000 | 28,000                 | 400         | 31,000  | 11,000 | 42,000                            | 37,000                            | 17,000            |
| Colorado . . . . .                   | 1,986                 | 6,000                         | 1,600                                  | 6.3    | 1,600                  | 10,000        | 8.0    | 10,000                 | 0           | 12,000  | 14     | 12,000                            | 11,000                            | 5,800             |
| Connecticut . . . . .                | 2,832                 | 790                           | 110                                    | 0      | 110                    | 700           | 1,400  | 2,100                  | 0           | 810     | 1,400  | 2,200                             | 2,200                             | 160               |
| Delaware . . . . .                   | 503                   | 2,300                         | 59                                     | 0      | 59                     | 55            | 1,100  | 1,100                  | 0           | 110     | 1,100  | 1,200                             | 1,200                             | 17                |
| Florida . . . . .                    | 5,796                 | 2,300                         | 2,700                                  | 80     | 2,800                  | 4,100         | 6,100  | 10,000                 | 0           | 6,800   | 6,200  | 13,000                            | 13,000                            | 1,600             |
| Georgia . . . . .                    | 4,391                 | 730                           | 560                                    | 0      | 560                    | 2,000         | 620    | 2,700                  | 0           | 2,600   | 620    | 3,200                             | 3,200                             | 220               |
| Hawaii . . . . .                     | 710                   | 2,800                         | 780                                    | 37     | 820                    | 670           | 500    | 1,200                  | 0           | 1,500   | 540    | 2,000                             | 1,800                             | 570               |
| Idaho . . . . .                      | 693                   | 23,000                        | 3,000                                  | 0      | 3,000                  | 13,000        | 0      | 13,000                 | 0           | 16,000  | 0      | 16,000                            | 12,000                            | 5,500             |
| Illinois . . . . .                   | 10,641                | 1,600                         | 670                                    | 34     | 700                    | 16,000        | 0      | 16,000                 | 0           | 16,000  | 34     | 17,000                            | 17,000                            | 370               |
| Indiana . . . . .                    | 4,893                 | 2,000                         | 600                                    | 5.9    | 610                    | 9,000         | 0      | 9,000                  | 0           | 9,600   | 5.9    | 9,600                             | 9,600                             | 330               |
| Iowa . . . . .                       | 2,758                 | 770                           | 500                                    | 0      | 500                    | 1,600         | 0      | 1,600                  | 0           | 2,100   | 0      | 2,100                             | 2,100                             | 290               |
| Kansas . . . . .                     | 2,248                 | 1,600                         | 2,300                                  | .4     | 2,300                  | 550           | 0      | 550                    | 0           | 2,800   | 0      | 2,800                             | 2,500                             | 2,200             |
| Kentucky . . . . .                   | 3,173                 | 1,000                         | 150                                    | .6     | 150                    | 3,200         | .3     | 3,200                  | .2          | 3,300   | .8     | 3,300                             | 3,300                             | 150               |
| Louisiana . . . . .                  | 3,560                 | 1,900                         | 1,200                                  | 51     | 1,300                  | 5,100         | 340    | 5,400                  | 0           | 6,300   | 400    | 6,700                             | 6,400                             | 1,600             |
| Maine . . . . .                      | 986                   | 800                           | 44                                     | 0      | 44                     | 520           | 220    | 740                    | 0           | 570     | 220    | 760                               | 780                               | 57                |
| Maryland . . . . .                   | 3,534                 | 1,200                         | 120                                    | 0      | 120                    | 1,300         | 2,500  | 3,800                  | 130         | 1,500   | 2,500  | 4,100                             | 4,100                             | 200               |
| Massachusetts . . . . .              | 5,365                 | 620                           | 280                                    | 0      | 280                    | 1,300         | 1,700  | 3,100                  | 1.1         | 1,600   | 1,700  | 3,300                             | 3,300                             | 110               |
| Michigan . . . . .                   | 8,317                 | 1,100                         | 430                                    | 14     | 450                    | 8,400         | 0      | 8,400                  | 0           | 8,800   | 14     | 8,800                             | 8,800                             | 310               |
| Minnesota . . . . .                  | 3,562                 | 860                           | 510                                    | 0      | 510                    | 2,500         | 0      | 2,500                  | 0           | 3,100   | 0      | 3,100                             | 3,100                             | 280               |
| Mississippi . . . . .                | 2,309                 | 550                           | 600                                    | 0      | 600                    | 370           | 300    | 670                    | 0           | 970     | 300    | 1,300                             | 1,200                             | 330               |
| Missouri . . . . .                   | 4,492                 | 580                           | 370                                    | 6.8    | 380                    | 2,300         | 0      | 2,300                  | 0           | 2,700   | 6.8    | 2,700                             | 2,700                             | 320               |
| Montana . . . . .                    | 703                   | 6,500                         | 81                                     | 0      | 81                     | 6,600         | 0      | 6,600                  | 0           | 6,700   | 0      | 6,700                             | 6,400                             | 4,500             |
| Nebraska . . . . .                   | 1,459                 | 3,100                         | 1,900                                  | 0      | 1,900                  | 2,700         | 0      | 2,700                  | 0           | 4,600   | 0      | 4,600                             | 3,900                             | 2,700             |
| Nevada . . . . .                     | 470                   | 4,800                         | 560                                    | 2.7    | 560                    | 1,600         | 0      | 1,600                  | 1.2         | 2,200   | 2.7    | 2,200                             | 1,700                             | 1,300             |
| New Hampshire . . . . .              | 673                   | 720                           | 42                                     | 0      | 42                     | 300           | 140    | 440                    | 0           | 340     | 140    | 490                               | 490                               | 20                |
| New Jersey . . . . .                 | 6,781                 | 950                           | 590                                    | 9.0    | 600                    | 2,000         | 3,700  | 5,700                  | 0           | 2,600   | 3,700  | 6,300                             | 6,300                             | 470               |
| New Mexico . . . . .                 | 1,014                 | 3,000                         | 1,400                                  | 0      | 1,400                  | 1,600         | 0      | 1,600                  | 22          | 3,000   | 0      | 3,000                             | 2,600                             | 1,700             |
| New York . . . . .                   | 18,106                | 890                           | 830                                    | 15     | 840                    | 8,200         | 7,100  | 15,000                 | 0           | 9,000   | 7,100  | 16,000                            | 16,000                            | 620               |
| North Carolina . . . . .             | 4,935                 | 800                           | 420                                    | 0      | 420                    | 3,500         | 32     | 3,500                  | 0           | 3,900   | 32     | 4,000                             | 3,900                             | 360               |
| North Dakota . . . . .               | 652                   | 500                           | 48                                     | 6.7    | 54                     | 270           | 0      | 270                    | 0           | 320     | 6.7    | 330                               | 280                               | 170               |
| Ohio . . . . .                       | 10,203                | 1,500                         | 800                                    | 0      | 800                    | 14,000        | 0      | 14,000                 | 0           | 15,000  | 0      | 15,000                            | 15,000                            | 400               |
| Oklahoma . . . . .                   | 2,448                 | 480                           | 380                                    | 46     | 430                    | 850           | 17     | 870                    | 0           | 1,200   | 63     | 1,300                             | 1,300                             | 460               |
| Oregon . . . . .                     | 1,938                 | 3,400                         | 710                                    | 0      | 710                    | 5,900         | 0      | 5,900                  | 2.9         | 6,600   | 0      | 6,600                             | 5,100                             | 2,400             |
| Pennsylvania . . . . .               | 11,683                | 1,300                         | 680                                    | 0      | 680                    | 15,000        | 50     | 15,000                 | 0           | 15,000  | 50     | 15,000                            | 15,000                            | 390               |
| Puerto Rico . . . . .                | 2,633                 | 630                           | 150                                    | 1.7    | 150                    | 430           | 1,100  | 1,500                  | 0           | 580     | 1,100  | 1,700                             | 1,000                             | 270               |
| Rhode Island . . . . .               | 891                   | 500                           | 45                                     | 0      | 45                     | 110           | 300    | 400                    | 0           | 150     | 300    | 450                               | 450                               | 27                |
| South Carolina . . . . .             | 2,550                 | 690                           | 130                                    | 0      | 130                    | 1,500         | 150    | 1,600                  | 0           | 1,600   | 150    | 1,800                             | 1,800                             | 150               |
| South Dakota . . . . .               | 686                   | 630                           | 160                                    | 1.9    | 160                    | 270           | 1.0    | 270                    | 0           | 430     | 2.9    | 430                               | 340                               | 250               |
| Tennessee . . . . .                  | 3,850                 | 1,200                         | 350                                    | 0      | 350                    | 4,300         | 0      | 4,300                  | 0           | 4,600   | 0      | 4,600                             | 4,600                             | 350               |
| Texas . . . . .                      | 10,591                | 2,300                         | 13,000                                 | 2.2    | 13,000                 | 6,600         | 4,600  | 11,000                 | 7.4         | 20,000  | 4,600  | 25,000                            | 22,000                            | 12,000            |
| Utah . . . . .                       | 994                   | 4,100                         | 620                                    | 3.5    | 620                    | 3,400         | 6.1    | 3,400                  | 52          | 4,100   | 8.6    | 4,100                             | 3,400                             | 2,400             |
| Vermont . . . . .                    | 404                   | 320                           | 24                                     | 0      | 24                     | 110           | 0      | 110                    | 0           | 130     | 0      | 130                               | 130                               | 15                |
| Virginia . . . . .                   | 4,420                 | 1,200                         | 200                                    | 0      | 200                    | 3,900         | 1,300  | 5,200                  | 0           | 4,100   | 1,300  | 5,400                             | 5,400                             | 130               |
| Washington . . . . .                 | 2,973                 | 2,100                         | 720                                    | 0      | 720                    | 5,500         | 30     | 5,600                  | 0           | 6,200   | 31     | 6,300                             | 5,100                             | 2,400             |
| West Virginia . . . . .              | 1,815                 | 2,700                         | 160                                    | .4     | 160                    | 4,800         | 0      | 4,800                  | .1          | 4,900   | .4     | 4,900                             | 4,900                             | 190               |
| Wisconsin . . . . .                  | 4,086                 | 1,200                         | 460                                    | 0      | 460                    | 4,300         | 0      | 4,300                  | 0           | 4,800   | 0      | 4,800                             | 4,800                             | 160               |
| Wyoming . . . . .                    | 330                   | 15,000                        | 100                                    | .9     | 100                    | 4,800         | .1     | 4,800                  | 0           | 4,900   | 1.0    | 4,900                             | 3,600                             | 2,100             |
| District of Columbia . . . . .       | 802                   | 440                           | 1                                      | 0      | 1                      | 350           | 0      | 350                    | 0           | 350     | 0      | 350                               | 350                               | 15                |
| United States <sup>1</sup> . . . . . | 196,411               | 1,600                         | 61,000                                 | 470    | 61,000                 | 210,000       | 44,000 | 250,000                | 670         | 270,000 | 45,000 | 310,000                           | 290,000                           | 78,000            |

<sup>1</sup> Including Puerto Rico.

Table 5.1 -3 - Water Withdrawls Per Capita for Public and Individual Water Supply Systems in the United States

(Source: U.S. Water Resources Council, 1968)  
 (Gallons per capita per day)

| Year | Public Systems |        |            |            | Individual |         |
|------|----------------|--------|------------|------------|------------|---------|
|      | Domestic       | Public | Commercial | Industrial | Total      | Systems |
| 1965 | 73             | 20     | 28         | 36         | 157        | 51      |
| 1980 | 77             | 18     | 28         | 40         | 163        | 58      |
| 2000 | 81             | 16     | 28         | 43         | 168        | 71      |
| 2020 | 83             | 14     | 28         | 45         | 170        | 83      |

Table 5.1-4 - Withdrawals and Consumptive Use of Water in the United States, 1965

## A. Withdrawals

| Region                          | Rural<br>domestic | Municipal | Self-<br>supplied<br>industrial | Steam-electric<br>power |        | Agriculture |           | Total   | From<br>ground-<br>water<br>sources | From<br>saline<br>sources |
|---------------------------------|-------------------|-----------|---------------------------------|-------------------------|--------|-------------|-----------|---------|-------------------------------------|---------------------------|
|                                 |                   |           |                                 | Fresh                   | Saline | Irrigation  | Livestock |         |                                     |                           |
| North Atlantic . . . . .        | 390               | 5,446     | 9,499                           | 10,500                  | 11,400 | 151         | 81        | 37,467  | 2,562                               | 15,380                    |
| South Atlantic-Gulf . . . . .   | 504               | 1,980     | 3,360                           | 7,600                   | 3,700  | 3,270       | 146       | 20,560  | 4,221                               | 4,132                     |
| Great Lakes . . . . .           | 274               | 3,622     | 9,069                           | 12,000                  | —      | 75          | 79        | 25,119  | 963                                 | 25                        |
| Ohio. . . . .                   | 300               | 1,791     | 8,606                           | 17,400                  | —      | 24          | 134       | 28,255  | 1,760                               | 27                        |
| Tennessee. . . . .              | 64                | 253       | 1,076                           | 4,329                   | —      | 8           | 37        | 5,767   | 202                                 | —                         |
| Upper Mississippi . . . . .     | 203               | 1,103     | 1,664                           | 4,800                   | —      | 95          | 314       | 8,179   | 1,707                               | 18                        |
| Lower Mississippi . . . . .     | 58                | 470       | 1,884                           | 1,600                   | 200    | 1,320       | 39        | 5,571   | 1,671                               | 240                       |
| Souris-Red-Rainy . . . . .      | 14                | 36        | 98                              | 200                     | —      | 24          | 19        | 391     | 55                                  | —                         |
| Missouri. . . . .               | 106               | 969       | 462                             | 1,400                   | —      | 16,039      | 368       | 19,344  | 4,005                               | —                         |
| Arkansas-White-Red. . . . .     | 103               | 687       | 910                             | 600                     | —      | 6,960       | 150       | 9,410   | 5,598                               | 75                        |
| Texas-Gulf . . . . .            | 40                | 1,055     | 5,465                           | 2,100                   | 200    | 7,450       | 100       | 16,410  | 8,390                               | 3,300                     |
| Rio Grande. . . . .             | 10                | 254       | 215                             | 70                      | —      | 6,671       | 69        | 7,289   | 3,130                               | 133                       |
| Upper Colorado . . . . .        | 6                 | 60        | 40                              | 20                      | —      | 3,880       | 11        | 4,017   | 36                                  | —                         |
| Lower Colorado . . . . .        | 6                 | 342       | 140                             | 10                      | —      | 6,400       | 15        | 6,913   | 4,147                               | —                         |
| Great Basin . . . . .           | 15                | 274       | 225                             | 10                      | —      | 4,575       | 16        | 5,115   | 935                                 | —                         |
| Columbia-North Pacific. . . . . | 148               | 1,105     | 1,911                           | 8                       | —      | 26,400      | 59        | 29,631  | 4,289                               | 31                        |
| California. . . . .             | 90                | 4,010     | 1,250                           | 70                      | 5,600  | 26,200      | 80        | 37,300  | 13,610                              | 6,140                     |
| Alaska. . . . .                 | 8                 | 32        | 102                             | 20                      | —      | —           | —         | 162     | 25                                  | —                         |
| Hawaii. . . . .                 | 7                 | 115       | 112                             | —                       | 300    | 1,060       | 3         | 1,597   | 706                                 | 316                       |
| Puerto Rico . . . . .           | 5                 | 141       | 317                             | 1                       | 400    | 250         | 6         | 1,120   | 157                                 | 535                       |
| Total . . . . .                 | 2,351             | 23,745    | 46,405                          | 62,738                  | 21,800 | 110,852     | 1,726     | 269,617 | 58,169                              | 30,352                    |

## B. Consumptive Use

| Region                          | Rural<br>domestic | Municipal | Self-supplied<br>industrial | Steam-<br>electric power |        | Agriculture |           | Total  |
|---------------------------------|-------------------|-----------|-----------------------------|--------------------------|--------|-------------|-----------|--------|
|                                 |                   |           |                             | Fresh                    | Saline | Irrigation  | Livestock |        |
| North Atlantic . . . . .        | 186               | 905       | 555                         | 75                       | 83     | 150         | 69        | 2,023  |
| South Atlantic-Gulf . . . . .   | 472               | 363       | 260                         | 42                       | 19     | 1,400       | 139       | 2,695  |
| Great Lakes . . . . .           | 100               | 602       | 362                         | 95                       | —      | 68          | 72        | 1,199  |
| Ohio. . . . .                   | 200               | 230       | 410                         | 138                      | —      | 24          | 132       | 1,134  |
| Tennessee. . . . .              | 61                | 46        | 174                         | 6                        | —      | 8           | 36        | 331    |
| Upper Mississippi . . . . .     | 101               | 162       | 58                          | 61                       | —      | 83          | 305       | 770    |
| Lower Mississippi . . . . .     | 52                | 175       | 296                         | 16                       | 3      | 890         | 38        | 1,470  |
| Souris-Red-Rainy . . . . .      | 14                | 11        | 7                           | 2                        | —      | 24          | 19        | 77     |
| Missouri. . . . .               | 85                | 221       | 71                          | 24                       | —      | 9,798       | 355       | 10,554 |
| Arkansas-White-Red. . . . .     | 94                | 241       | 322                         | 41                       | —      | 5,030       | 146       | 5,874  |
| Texas-Gulf . . . . .            | 40                | 400       | 880                         | 57                       | 2      | 5,810       | 100       | 7,289  |
| Rio Grande. . . . .             | 7                 | 108       | 46                          | 9                        | —      | 4,165       | 68        | 4,403  |
| Upper Colorado . . . . .        | 3                 | 14        | 8                           | 13                       | —      | 1,934       | 10        | 1,982  |
| Lower Colorado . . . . .        | 5                 | 203       | 50                          | 8                        | —      | 3,170       | 12        | 3,448  |
| Great Basin . . . . .           | 9                 | 94        | 37                          | 2                        | —      | 2,100       | 11        | 2,253  |
| Columbia-North Pacific. . . . . | 134               | 182       | 100                         | —                        | —      | 10,050      | 55        | 10,521 |
| California. . . . .             | 60                | 1,320     | 110                         | 70                       | 44     | 19,290      | 50        | 20,944 |
| Alaska. . . . .                 | 1                 | 7         | 4                           | —                        | —      | —           | —         | 12     |
| Hawaii. . . . .                 | 7                 | 39        | 4                           | —                        | 3      | 477         | 3         | 533    |
| Puerto Rico. . . . .            | 5                 | 21        | 10                          | —                        | 3      | 225         | 6         | 270    |
| Total . . . . .                 | 1,636             | 5,244     | 3,764                       | 659                      | 157    | 64,696      | 1,626     | 77,782 |

(Million gallons per day)

(Source: U. S. Water Resources Council, 1968)

Table 5.1-5 - Projections of Withdrawals and Consumptive Use of Water in the United States, 1980

A. Withdrawals

| Region                           | Rural domestic | Municipal | Self-supplied industrial | Steam-electric power |        | Agriculture |           | Total   |
|----------------------------------|----------------|-----------|--------------------------|----------------------|--------|-------------|-----------|---------|
|                                  |                |           |                          | Fresh                | Saline | Irrigation  | Livestock |         |
| North Atlantic . . . . .         | 400            | 7,100     | 14,100                   | 10,900               | 22,100 | 230         | 90        | 54,920  |
| South Atlantic-Gulf . . . . .    | 380            | 3,300     | 4,900                    | 28,500               | 12,000 | 3,900       | 200       | 53,180  |
| Great Lakes . . . . .            | 257            | 5,030     | 16,700                   | 25,700               | —      | 110         | 96        | 47,893  |
| Ohio . . . . .                   | 350            | 2,330     | 11,600                   | 27,300               | —      | 40          | 129       | 41,749  |
| Tennessee . . . . .              | 128            | 358       | 1,600                    | 10,100               | —      | 18          | 48        | 12,252  |
| Upper Mississippi . . . . .      | 143            | 1,770     | 2,800                    | 9,500                | —      | 110         | 477       | 14,800  |
| Lower Mississippi . . . . .      | 80             | 647       | 2,500                    | 5,900                | 600    | 3,030       | 59        | 12,816  |
| Souris-Red-Rainy . . . . .       | 16             | 49        | 150                      | 500                  | —      | 200         | 21        | 936     |
| Missouri . . . . .               | 134            | 1,225     | 584                      | 1,500                | —      | 19,300      | 521       | 23,264  |
| Arkansas-White-Red . . . . .     | 213            | 1,418     | 1,880                    | 4,100                | 40     | 9,400       | 228       | 17,279  |
| Texas-Gulf . . . . .             | 70             | 1,890     | 9,340                    | 5,500                | 2,700  | 9,400       | 180       | 29,080  |
| Rio Grande . . . . .             | 10             | 430       | 910                      | 70                   | —      | 6,840       | 70        | 8,330   |
| Upper Colorado . . . . .         | 10             | 120       | 200                      | 30                   | —      | 5,300       | 15        | 5,675   |
| Lower Colorado . . . . .         | 7              | 520       | 210                      | 40                   | —      | 7,700       | 20        | 8,497   |
| Great Basin . . . . .            | 15             | 450       | 340                      | 30                   | —      | 6,200       | 20        | 7,055   |
| Columbia-North Pacific . . . . . | 148            | 1,304     | 4,478                    | 4,000                | —      | 31,400      | 77        | 41,407  |
| California . . . . .             | 90             | 5,090     | 1,660                    | 90                   | 18,300 | 30,950      | 110       | 56,290  |
| Alaska . . . . .                 | 11             | 120       | 200                      | 200                  | —      | 4           | —         | 535     |
| Hawaii . . . . .                 | 5              | 195       | 134                      | —                    | 900    | 1,420       | 4         | 2,658   |
| Puerto Rico . . . . .            | 7              | 250       | 740                      | 3                    | 2,700  | 300         | 10        | 4,010   |
| Total . . . . .                  | 2,474          | 33,596    | 75,026                   | 133,963              | 59,340 | 135,852     | 2,375     | 442,626 |

B. Consumptive Use

| Region                           | Rural domestic | Municipal | Self-supplied industrial | Steam-electric power |        | Agriculture |           | Total   |
|----------------------------------|----------------|-----------|--------------------------|----------------------|--------|-------------|-----------|---------|
|                                  |                |           |                          | Fresh                | Saline | Irrigation  | Livestock |         |
| North Atlantic . . . . .         | 200            | 1,210     | 850                      | 120                  | 180    | 230         | 80        | 2,870   |
| South Atlantic-Gulf . . . . .    | 355            | 600       | 380                      | 190                  | 80     | 1,600       | 190       | 3,395   |
| Great Lakes . . . . .            | 85             | 702       | 728                      | 184                  | —      | 95          | 87        | 1,881   |
| Ohio . . . . .                   | 250            | 300       | 550                      | 350                  | —      | 40          | 129       | 1,619   |
| Tennessee . . . . .              | 122            | 64        | 258                      | 65                   | —      | 16          | 47        | 572     |
| Upper Mississippi . . . . .      | 94             | 258       | 88                       | 166                  | —      | 95          | 392       | 1,103   |
| Lower Mississippi . . . . .      | 72             | 238       | 400                      | 60                   | 4      | 2,180       | 58        | 3,012   |
| Souris-Red-Rainy . . . . .       | 16             | 16        | 8                        | 4                    | —      | 150         | 21        | 215     |
| Missouri . . . . .               | 108            | 280       | 90                       | 80                   | —      | 12,100      | 502       | 13,160  |
| Arkansas-White-Red . . . . .     | 194            | 496       | 674                      | 95                   | —      | 6,800       | 223       | 8,482   |
| Texas-Gulf . . . . .             | 65             | 740       | 1,160                    | 180                  | 20     | 7,100       | 170       | 9,435   |
| Rio Grande . . . . .             | 7              | 220       | 90                       | 20                   | —      | 4,270       | 69        | 4,676   |
| Upper Colorado . . . . .         | 4              | 30        | 35                       | 17                   | —      | 2,600       | 14        | 2,700   |
| Lower Colorado . . . . .         | 5              | 310       | 80                       | 35                   | —      | 3,630       | 15        | 4,075   |
| Great Basin . . . . .            | 9              | 154       | 56                       | 25                   | —      | 3,040       | 15        | 3,299   |
| Columbia-North Pacific . . . . . | 134            | 219       | 244                      | 13                   | —      | 12,900      | 71        | 13,581  |
| California . . . . .             | 60             | 4,620     | 380                      | 80                   | 185    | 23,800      | 80        | 29,205  |
| Alaska . . . . .                 | 2              | 24        | 20                       | 1                    | —      | 3           | —         | 50      |
| Hawaii . . . . .                 | 5              | 65        | 5                        | —                    | 9      | 640         | 4         | 728     |
| Puerto Rico . . . . .            | 5              | 35        | 20                       | —                    | 20     | 270         | 10        | 360     |
| Total . . . . .                  | 1,792          | 10,581    | 6,126                    | 1,685                | 498    | 81,559      | 2,177     | 104,418 |

(Million gallons per day)

(Source: U. S. Water Resources Council, 1968)

Table 5.1-6 - Cost of Water from Municipal Systems in the United States

(Source: U.S. Public Health Service, 1959)

[Costs include operation, maintenance, and amortization]

|                                | Dollars per million gallons |                          | Dollars per million gallons |
|--------------------------------|-----------------------------|--------------------------|-----------------------------|
| Alabama . . . . .              | \$227                       | Nebraska . . . . .       | \$145                       |
| Arizona . . . . .              | 157                         | Nevada . . . . .         | 137                         |
| Arkansas . . . . .             | 302                         | New Hampshire . . . . .  | 209                         |
| California . . . . .           | 208                         | New Jersey . . . . .     | 196                         |
| Colorado . . . . .             | 229                         | New Mexico . . . . .     | 245                         |
| Connecticut . . . . .          | 214                         | New York . . . . .       | 190                         |
| Delaware . . . . .             | 128                         | North Carolina . . . . . | 229                         |
| District of Columbia . . . . . | 168                         | North Dakota . . . . .   | 302                         |
| Florida . . . . .              | 244                         | Ohio . . . . .           | 181                         |
| Georgia . . . . .              | 174                         | Oklahoma . . . . .       | 247                         |
| Idaho . . . . .                | 232                         | Oregon . . . . .         | 207                         |
| Illinois . . . . .             | 136                         | Pennsylvania . . . . .   | 180                         |
| Indiana . . . . .              | 184                         | Rhode Island . . . . .   | 195                         |
| Iowa . . . . .                 | 236                         | South Carolina . . . . . | 169                         |
| Kansas . . . . .               | 264                         | South Dakota . . . . .   | 281                         |
| Kentucky . . . . .             | 144                         | Tennessee . . . . .      | 233                         |
| Louisiana . . . . .            | 188                         | Texas . . . . .          | 244                         |
| Maine . . . . .                | 103                         | Utah . . . . .           | 184                         |
| Maryland . . . . .             | 136                         | Vermont . . . . .        | 382                         |
| Massachusetts . . . . .        | 193                         | Virginia . . . . .       | 187                         |
| Michigan . . . . .             | 151                         | Washington . . . . .     | 173                         |
| Minnesota . . . . .            | 175                         | West Virginia . . . . .  | 212                         |
| Mississippi . . . . .          | 219                         | Wisconsin . . . . .      | 153                         |
| Missouri . . . . .             | 180                         | Wyoming . . . . .        | 224                         |
| Montana . . . . .              | 185                         |                          |                             |

Table 5.1-7 - Number of Water Wells Drilled in the  
United States in 1964

(Source: U.S. Geological Survey)

| State                          | Estimated number<br>of wells drilled<br>1964 | State                    | Estimated number<br>of wells drilled<br>1964 |
|--------------------------------|--|--------------------------|--|
|                                |  |                          | 1964   |
| Alabama . . . . .              | 4,500  | Montana . . . . .        | 2,000  |
| Alaska . . . . .               | 1,001  | Nebraska . . . . .       | 6,005  |
| Arizona . . . . .              | 1,520  | Nevada . . . . .         | 825  |
| Arkansas . . . . .             | 5,000  | New Hampshire . . . . .  | 4,400  |
| California . . . . .           | 10,000                                       | New Jersey . . . . .     | 3,440  |
| Colorado . . . . .             | 5,911  | New Mexico . . . . .     | 3,150  |
| Connecticut . . . . .          | 6,500  | New York . . . . .       | 25,000                                       |
| Delaware . . . . .             | 3,440  | North Carolina . . . . . | 25,000                                       |
| District of Columbia . . . . . | 12   | North Dakota . . . . .   | 3,760  |
| Florida . . . . .              | 55,000                                       | Ohio . . . . .           | 18,622                                       |
| Georgia . . . . .              | 10,000                                       | Oklahoma . . . . .       | 5,000  |
| Hawaii . . . . .               | 21   | Oregon . . . . .         | 4,500  |
| Idaho . . . . .                | 1,400  | Pennsylvania . . . . .   | 16,220                                       |
| Illinois . . . . .             | 19,500                                       | Rhode Island . . . . .   | 250  |
| Indiana . . . . .              | 15,000                                       | South Carolina . . . . . | 5,400  |
| Iowa . . . . .                 | 16,000                                       | South Dakota . . . . .   | 5,426  |
| Kansas . . . . .               | 5,500  | Tennessee . . . . .      | 8,000  |
| Kentucky . . . . .             | 9,620  | Texas . . . . .          | 25,000                                       |
| Louisiana . . . . .            | 2,620  | Utah . . . . .           | 650  |
| Maine . . . . .                | 1,700  | Vermont . . . . .        | 1,460  |
| Maryland . . . . .             | 6,902  | Virginia . . . . .       | 16,000                                       |
| Massachusetts . . . . .        | 9,000  | Washington . . . . .     | 1,700  |
| Michigan . . . . .             | 25,000                                       | West Virginia . . . . .  | 5,900  |
| Minnesota . . . . .            | 9,000  | Wisconsin . . . . .      | 12,000                                       |
| Mississippi . . . . .          | 5,900  | Wyoming . . . . .        | 1,000  |
| Missouri . . . . .             | 9,990  | TOTAL . . . . .          | 433,700                                      |

Table 5.1-8 - Depths of Water Wells Drilled in the  
United States in 1966

(Source: Ground Water Age)

| Well Depth, feet | Percent of Drilled Wells |
|------------------|--------------------------|
| < 50             | 4.1                      |
| 51-100           | 26.9                     |
| 101-150          | 27.8                     |
| 151-200          | 20.6                     |
| 201-300          | 11.5                     |
| 301-400          | 4.4                      |
| 401-500          | 2.6                      |
| > 500            | 2.1                      |
|                  | 100.0                    |

Table 5.1-9 - Average Power to Pump Water

| <u>Wire-to-Water Efficiency,<br/>Percent</u> | <u>Power Required<br/>Kilowatt-Hours<br/>per 100 ft, per 1000 gpm</u> |
|--|---|
| 78   | 40  |
| 63   | 50  |
| 52   | 60  |
| 45   | 70  |

Source: Illinois State Water Survey

Table 5.1-10 - Useful Factors in Preliminary Planning of Small Pumping Plants

| Pump or pipe size, in. | Gallons per minute | Acre-inches per 24 hours | Pipe velocity, feet per second | Velocity head, $\frac{V^2}{2g}$ feet | Friction in feet per 100 feet of pipe | Horsepower required for 10 feet total head. Pump and transmission efficiency = 70 percent |
|------------------------|--------------------|--------------------------|--------------------------------|--------------------------------------|---------------------------------------|---|
| 6                      | 400                | 21.2                     | 4.54                           | 0.32                                 | 2.21                                  | 1.4   |
| 6                      | 600                | 31.8                     | 6.72                           | 0.70                                 | 4.7                                   | 2.2   |
| 6                      | 800                | 42.4                     | 9.08                           | 1.28                                 | 8.0                                   | 2.9   |
| 6                      | 1,000              | 53.0                     | 11.32                          | 1.99                                 | 12.0                                  | 3.6   |
| 8                      | 900                | 47.7                     | 5.75                           | 0.52                                 | 2.46                                  | 3.2   |
| 8                      | 1,100              | 58.3                     | 7.03                           | 0.77                                 | 3.51                                  | 4.0   |
| 8                      | 1,300              | 68.9                     | 8.32                           | 1.07                                 | 4.72                                  | 4.7   |
| 8                      | 1,500              | 79.5                     | 9.60                           | 1.43                                 | 6.27                                  | 5.4   |
| 10                     | 1,200              | 63.6                     | 4.91                           | 0.38                                 | 1.46                                  | 4.3   |
| 10                     | 1,600              | 84.8                     | 6.56                           | 0.67                                 | 2.35                                  | 5.8   |
| 10                     | 2,000              | 106.1                    | 8.10                           | 1.02                                 | 3.65                                  | 7.2   |
| 10                     | 2,400              | 127.3                    | 9.73                           | 1.47                                 | 5.04                                  | 8.7   |
| 12                     | 2,000              | 106.1                    | 5.60                           | 0.48                                 | 1.43                                  | 7.2   |
| 12                     | 2,500              | 132.6                    | 7.00                           | 0.77                                 | 2.28                                  | 9.0   |
| 12                     | 3,000              | 159.1                    | 8.40                           | 1.10                                 | 3.15                                  | 10.8  |
| 12                     | 3,500              | 185.6                    | 9.80                           | 1.49                                 | 4.10                                  | 12.6  |
| 14                     | 2,000              | 106.1                    | 4.20                           | 0.27                                 | 0.66                                  | 7.2   |
| 14                     | 3,000              | 159.1                    | 6.30                           | 0.61                                 | 1.47                                  | 10.8  |
| 14                     | 4,000              | 212.1                    | 8.40                           | 1.09                                 | 2.47                                  | 14.4  |
| 14                     | 5,000              | 265.2                    | 10.50                          | 1.71                                 | 3.92                                  | 18.0  |
| 16                     | 3,600              | 190.9                    | 5.74                           | 0.51                                 | 1.10                                  | 13.0  |
| 16                     | 4,400              | 233.3                    | 7.01                           | 0.76                                 | 1.58                                  | 15.9  |
| 16                     | 5,200              | 275.8                    | 8.29                           | 1.08                                 | 2.16                                  | 18.8  |
| 16                     | 6,000              | 318.2                    | 9.56                           | 1.42                                 | 2.60                                  | 21.6  |
| 18                     | 4,500              | 238.6                    | 5.70                           | 0.50                                 | 0.93                                  | 16.2  |
| 18                     | 5,500              | 291.7                    | 6.96                           | 0.75                                 | 1.32                                  | 19.8  |
| 18                     | 6,500              | 344.7                    | 8.22                           | 1.05                                 | 1.82                                  | 23.4  |
| 18                     | 8,000              | 424.2                    | 10.02                          | 1.56                                 | 2.65                                  | 28.9  |
| 20                     | 5,000              | 265.2                    | 5.13                           | 0.41                                 | 0.68                                  | 18.0  |
| 20                     | 6,500              | 344.7                    | 6.66                           | 0.69                                 | 1.06                                  | 23.4  |
| 20                     | 8,000              | 424.2                    | 8.17                           | 1.03                                 | 1.63                                  | 28.9  |
| 20                     | 10,000             | 530.3                    | 10.40                          | 1.68                                 | 2.53                                  | 36.1  |
| 24                     | 8,000              | 424.2                    | 5.68                           | 0.50                                 | 0.66                                  | 28.9  |
| 24                     | 10,000             | 530.3                    | 7.07                           | 0.78                                 | 0.98                                  | 36.1  |
| 24                     | 12,000             | 636.4                    | 8.50                           | 1.12                                 | 1.40                                  | 43.3  |
| 24                     | 14,000             | 742.4                    | 9.95                           | 1.54                                 | 1.87                                  | 50.5  |
| 30                     | 12,000             | 636.4                    | 5.44                           | 0.46                                 | 0.47                                  | 43.3  |
| 30                     | 16,000             | 848.5                    | 7.36                           | 0.84                                 | 0.83                                  | 57.7  |
| 30                     | 20,000             | 1061.0                   | 9.09                           | 1.29                                 | 1.22                                  | 72.2  |
| 30                     | 24,000             | 1273.0                   | 10.90                          | 1.86                                 | 1.71                                  | 86.6  |

Source: U. S. Department of Agriculture

## 5.2 An Example Water System

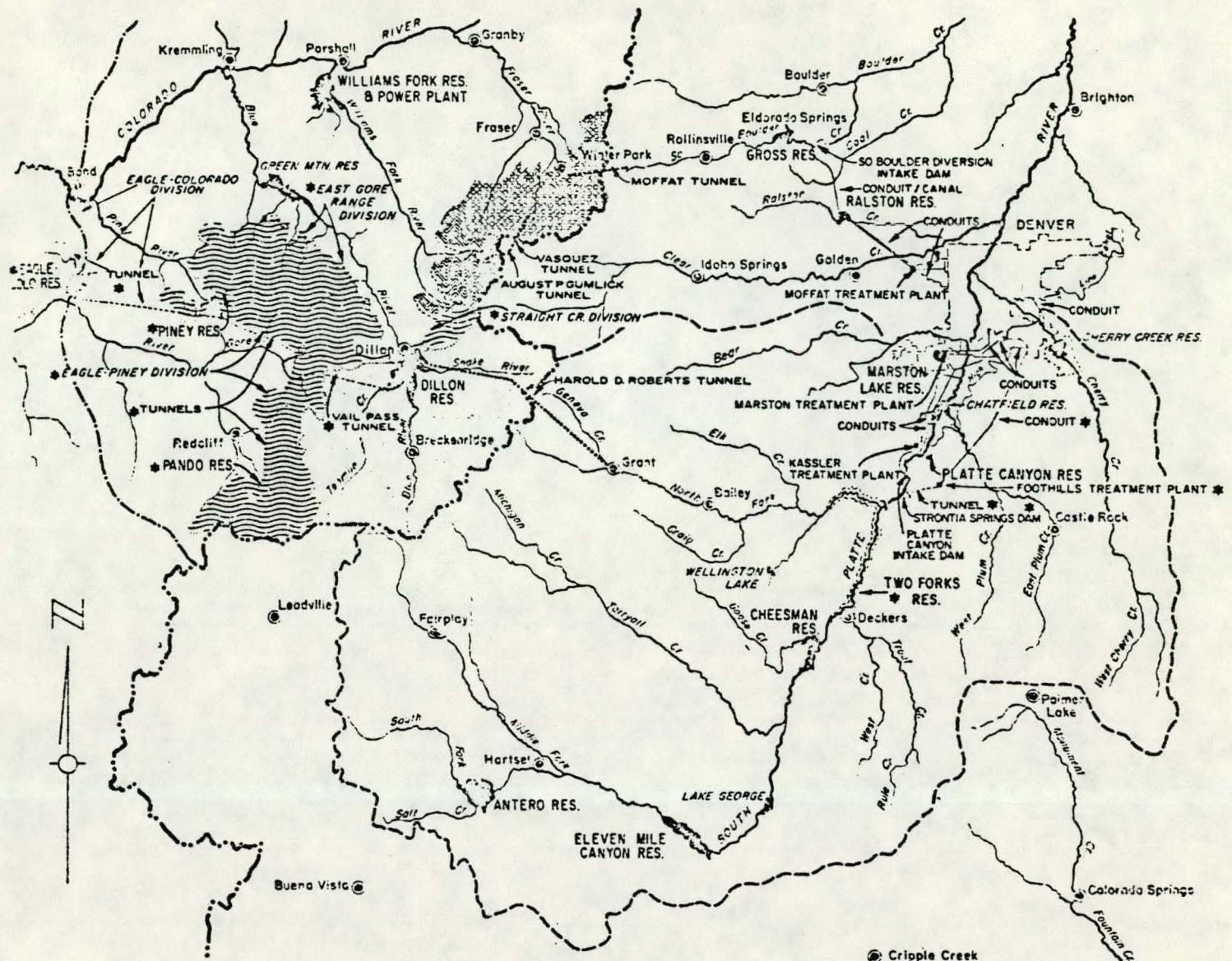
The 1976 Annual Report of the Denver Board of Water Commissioners for the city and county of Denver, Colorado, reflects a very well engineered and capably managed water system. Figure 5.2-1 shows their supply system, and Figure 5.2-2 shows the major distribution facilities. Table 5.2-1 lists the pumping station capacities. Table 5.2-2 is their 1976 water report, Table 5.2-3 is the 1976 power report and Table 5.2-4 is the summary of water and power costs. Figure 5.2-3 shows the 1976 pump energy rate in kw-days through the year. Figure 5.2-4 shows power cost history for the two water systems under their jurisdiction.

Although operation of what is called their Master System (36,511 million gallons per year) and the Outside Contract System (13,770 million gallons per year) is under the same management group, fiscal jurisdiction is, in some aspects, separate.

The daily operating pumps for both systems are all electrical. There are some gas engine pumps for standby operation only. It is interesting that they have tunneled under the Continental Divide for some of their water lines, the total length of which is 1800 miles. They have a 4-stage lift with some purification done at each plateau. The highest lift for any given line is 400 feet, while the average lift for the total system is 160 feet.

## 5.3 Water Pipeline Data Sources

The data sources used in the estimation of water system energy consumption were those presented in the preceding sections. The national total and unit energy consumption will be estimated from the data in Section 5.1 above.



## LEGEND

- CONTINENTAL DIVIDE
- \* UNDER DEVELOPMENT
- BOUNDARY SOUTH PLATTE WATERSHED
- BOUNDARY EAGLE-COLORADO COLLECTION SYSTEM WATERSHED (U.D.)



MOFFAT TUNNEL (FRASER RIVER) COLLECTION SYSTEM WATERSHED



ROBERTS TUNNEL COLLECTION SYSTEM WATERSHED



WILLIAMS FORK COLLECTION SYSTEM WATERSHED



WILLIAMS FORK COLLECTION SYSTEM WATERSHED (U.D.)

DENVER BOARD of WATER COMMISSIONERS

WATER SUPPLY SYSTEM

Approved by the City of Denver

Figure 5.2-1 - Water Supply System

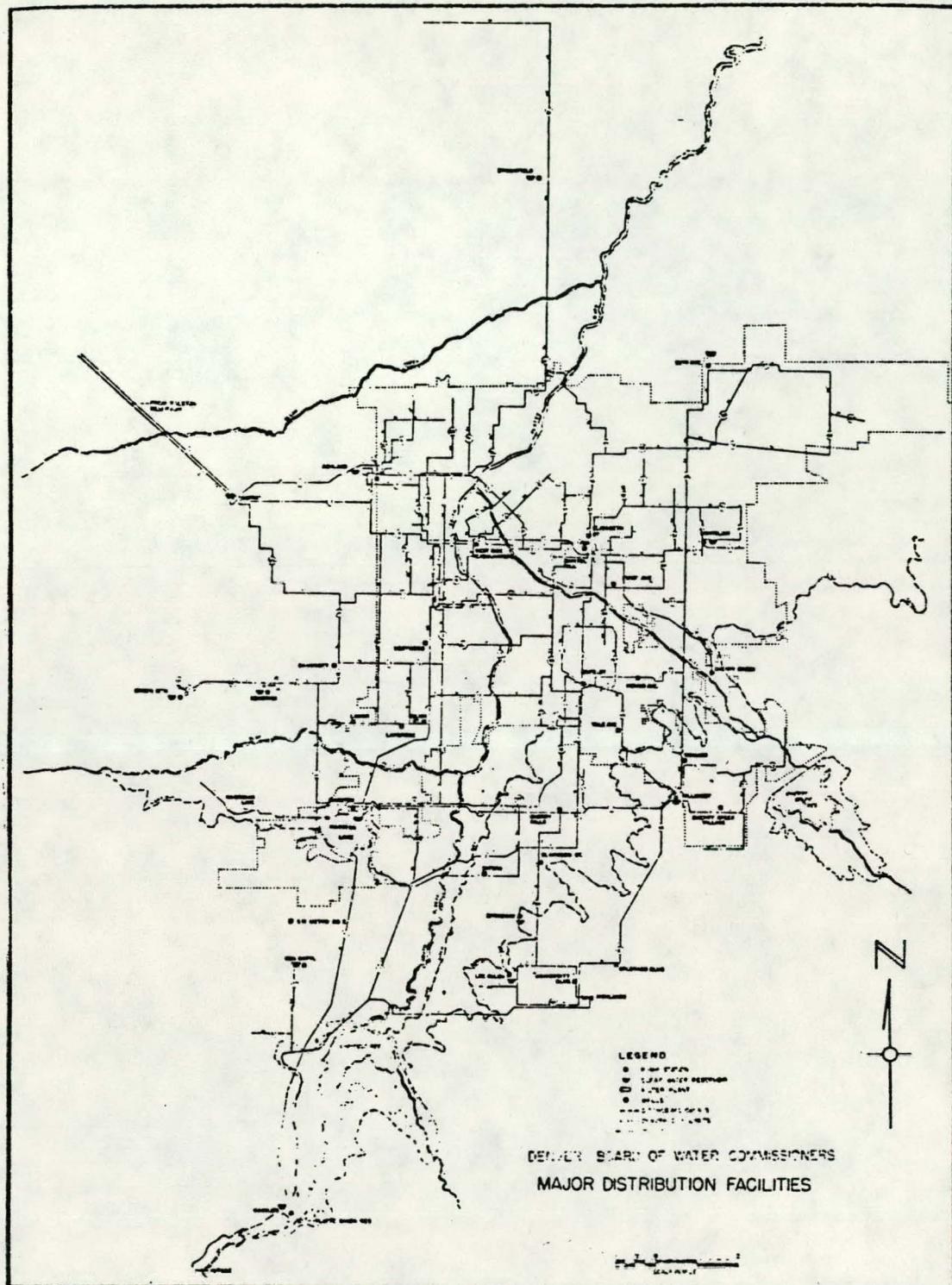


Figure 5.2-2 - Major Distribution Facilities

| Pump Station  | Pump Number | Make of Pump    | Make of Motor      | Horse Power | Head In Feet | Capacity In M.G.D. | Method Operat. |
|---|-------------|-----------------|--------------------|-------------|--------------|--------------------|----------------|
| ASHLAND (5406)<br>5260 W. 29th Ave.                 | 3           | DeLaval         | General Electric   | 250         | 140          | 8.0                | M              |
|   | 5           | Cameron         | General Electric   | 550         | 175          | 15.0               | M              |
|   | 6           | Cameron         | Westinghouse       | 150         | 175          | 3.5                | M              |
|   | 7           | Cameron         | Westinghouse       | 200         | 175          | 5.0                | M              |
|   | 8           | Fairbanks Morse | Fairbanks Morse    | 300         | 265          | 5.0                | M              |
|   | 9           | Fairbanks Morse | Fairbanks Morse    | 300         | 265          | 5.0                | M              |
|   |             | Total           |                    | 1,750       |              | 41.5               |                |
| BANCROFT (5495)<br>1500 S. Pierce St.               | 1           | Fairbanks Morse | Fairbanks Morse    | 200         | 254          | 3.6                | M              |
|   | 2           | Aurora          | Lincoln            | 60          | 115          | 2.2                | M              |
|   |             | Total           |                    | 260         |              | 5.8                |                |
| BROADWAY (5525)<br>6549 S. Broadway                 | 1           | Peerless        | Elliot Electric    | 25          | 80           | 1.4                | M A            |
|   | 2           | Peerless        | Newman             | 100         | 112          | 4.4                | M A            |
|   |             | Total           |                    | 125         |              | 5.8                |                |
| BROOMFIELD (5326)<br>9265 Washington St.            | 1           | Patterson       | Ideal Electric     | 450         | 350          | 5.0                | M R            |
|   | 2           | Patterson       | Ideal Electric     | 450         | 350          | 5.0                | M R            |
|   | 3           | Patterson       | Ideal Electric     | 450         | 350          | 5.0                | M R            |
|   |             | Total           |                    | 1,350       |              | 15.0               |                |
| CAPITOL HILL (5401)<br>1000 Elizabeth St.           | 3           | Wheeler Economy | General Electric   | 800         | 175          | 20.0               | M              |
|   | 4           | Byron Jackson   | General Electric   | 400         | 175          | 12.0               | M              |
|   | 5           | Cameron         | General Electric   | 700         | 164          | 20.0               | M              |
|   | 6           | Byron Jackson   | Westinghouse       | 600         | 175          | 17.0               | M              |
|   | 7           | Byron Jackson   | Westinghouse       | 800         | 175          | 23.0               | M              |
|   |             | Total           |                    | 3,300       |              | 92.0               |                |
| CHERRY CREEK VILLAGE (5550)<br>4298 S. Tamarac Dr.  | 1           | Aurora          | Marathon Electric  | 40          | 173          | 0.8                | M A            |
|   | 2           | Aurora          | Marathon Electric  | 20          | 173          | 0.3                | M A            |
|   | 3           | Allis Chalmers  | Allis Chalmers     | 50          | 160          | 1.3                | M A            |
|   |             | Total           |                    | 110         |              | 2.4                |                |
| CHERRY HILLS (5380)<br>1590 Radcliff Ave.           | 1           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   | 2           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   | 3           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   | 4           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   | 5           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   | 6           | Worthington     | General Electric   | 1,000       | 220          | 20.0               | M R            |
|   |             | Total           |                    | 6,000       |              | 120.0              |                |
| CLARKSON STREET (5482)<br>5300 S. Clarkson St.      | 1           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   | 2           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   | 3           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   | 4           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   | 5           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   | 6           | Fairbanks Morse | Fairbanks Morse    | 150         | 234          | 2.1                | M A R          |
|   |             | Total           |                    | 900         |              | 12.6               |                |
| COLORADO BOULEVARD (5620)<br>7595 S. Colorado Blvd. | 1           | Allis Chalmers  | Allis Chalmers     | 50          | 160          | 1.3                | M A            |
|   | 2           | Fairbanks Morse | Fairbanks Morse    | 75          | 200          | 1.4                | M A            |
|   | 3           | Fairbanks Morse | Fairbanks Morse    | 75          | 200          | 1.4                | M A            |
|   | 4           | Fairbanks Morse | Fairbanks Morse    | 75          | 160          | 1.4                | M A            |
|   |             | Total           |                    | 275         |              | 5.5                |                |
| DATURA (5430)<br>5695 S. Datura St.                 | 1           | Fairbanks Morse | United States      | 125         | 165          | 3.0                | M A R          |
|   | 2           | Fairbanks Morse | United States      | 125         | 165          | 3.0                | M A R          |
|   |             | Total           |                    | 250         |              | 6.0                |                |
| EINFELDT (5360)<br>1900 S. University Blvd.         | 2           | Wheeler Economy | General Electric   | 800         | 175          | 20.0               | M R            |
|   | 3           | Byron Jackson   | General Electric   | 600         | 175          | 17.0               | M R            |
|   | 4           | Byron Jackson   | General Electric   | 400         | 175          | 12.0               | M R            |
|   | 5           | Byron Jackson   | Westinghouse       | 200         | 175          | 5.3                | M R            |
|   | 6           | Worthington     | Electric Machinery | 800         | 175          | 20.0               | M R            |
|   | 7           | Wheeler Economy | General Electric   | 800         | 175          | 20.0               | M R            |
|   |             | Total           |                    | 3,600       |              | 94.3               |                |

(U.S.G.S. Elevations in parentheses)

\* Vault Type Structure (underground)

Legend for Method of Operation:

M - Manual A - Automatic R - Remote

Table 5.2-1 - Denver Water System - Pumping Station Capacities

| <u>Pump Station</u>   | <u>Pump Number</u> | <u>Make of Pump</u> | <u>Make of Motor</u> | <u>Horse Power</u> | <u>Head In Feet</u> | <u>Capacity In M.G.D.</u> | <u>Method of Operation</u> |
|---|--------------------|---------------------|----------------------|--------------------|---------------------|---------------------------|----------------------------|
| ELIZABETH STREET (5380)<br>1200 Elizabeth St.                   | 1                  | Ingersoll-Rand      | Reliance             | 125                | 53                  | 10.0                      | M R                        |
|   | 2                  | Ingersoll-Rand      | Reliance             | 125                | 53                  | 10.0                      | M R                        |
|   | 3                  | Ingersoll-Rand      | Reliance             | 125                | 53                  | 10.0                      | M R                        |
|   | 4                  | Ingersoll-Rand      | Reliance             | 125                | 53                  | 10.0                      | M R                        |
|   | 5                  | Ingersoll-Rand      | Reliance             | 125                | 53                  | 10.0                      | M R                        |
|   |                    | Total               |                      | 625                |                     | 50.0                      |                            |
| FIFTY-SIXTH AVENUE (5203)<br>5355 56th Ave.                     | 1                  | Allis Chalmers      | Ideal Electric       | 1,750              | 450                 | 15.0                      | M R                        |
|   | 2                  | Allis Chalmers      | Ideal Electric       | 1,750              | 450                 | 15.0                      | M R                        |
|   | 3                  | Allis Chalmers      | Ideal Electric       | 1,750              | 450                 | 15.0                      | M R                        |
|   | 4                  | Allis Chalmers      | Ideal Electric       | 1,750              | 450                 | 15.0                      | M R                        |
|   | 5                  | Allis Chalmers      | Ideal Electric       | 1,750              | 450                 | 15.0                      | M R                        |
|   |                    | Total               |                      | 8,750              |                     | 75.0                      |                            |
| FIRST AVENUE (5338)<br>5555 1st Ave.                            | 1                  | Fairbanks Morse     | Fairbanks Morse      | 50                 | 70                  | 2.9                       | M A R                      |
|   | 2                  | Peerless            | Marathon Electric    | 30                 | 70                  | 1.8                       | M A R                      |
|   | 3                  | Peerless            | Marathon Electric    | 30                 | 70                  | 1.8                       | M A R                      |
|   | 4                  | Peerless            | Marathon Electric    | 30                 | 70                  | 1.8                       | M A R                      |
|   | 5                  | Peerless            | Marathon Electric    | 60                 | 70                  | 2.9                       | M A R                      |
|   |                    | Total               |                      | 200                |                     | 11.2                      |                            |
| GREEN MOUNTAIN (5837)<br>12400 W. Jewell Ave.                   | 1                  | Patterson           | General Electric     | 700                | 260                 | 10.0                      | M R                        |
|   | 2                  | Patterson           | General Electric     | 350                | 260                 | 5.0                       | M R                        |
|   | 3                  | Patterson           | General Electric     | 350                | 260                 | 5.0                       | M R                        |
|   | 4                  | Patterson           | General Electric     | 700                | 260                 | 10.0                      | M R                        |
|   |                    | Total               |                      | 2,100              |                     | 30.0                      |                            |
| HIGHLANDS (5722)<br>8100 S. University Blvd.                    | 1                  | Fairbanks Morse     | United States        | 125                | 165                 | 3.0                       | M A R                      |
|   | 2                  | Fairbanks Morse     | United States        | 125                | 165                 | 3.0                       | M A R                      |
|   | 3                  | Fairbanks Morse     | United States        | 125                | 165                 | 3.0                       | M A R                      |
|   | 4                  | Fairbanks Morse     | United States        | 125                | 165                 | 3.0                       | M A R                      |
|   | 5                  | DeLaval             | Ideal Electric       | 350                | 165                 | 10.0                      | M A R                      |
|   | 6                  | DeLaval             | Ideal Electric       | 350                | 165                 | 10.0                      | M A R                      |
|   | 7                  | DeLaval             | Ideal Electric       | 350                | 165                 | 10.0                      | M A R                      |
|   |                    | Total               |                      | 1,550              |                     | 42.0                      |                            |
| HILLCREST (5602)<br>(Low Pressure)<br>4200 S. Happy Canyon Rd.  | 1                  | Allis Chalmers      | Allis Chalmers       | 50                 | 169                 | 1.0                       | M A R                      |
|   | 2                  | Allis Chalmers      | Allis Chalmers       | 100                | 167                 | 2.0                       | M A R                      |
|   | 3                  | DeLaval             | Electric Machinery   | 200                | 163                 | 5.0                       | M R                        |
|   | 4                  | DeLaval             | Electric Machinery   | 400                | 163                 | 11.0                      | M R                        |
|   | 5                  | DeLaval             | Electric Machinery   | 400                | 163                 | 11.0                      | M R                        |
|   | 6                  | Worthington         | Fairbanks Morse      | 400                | 163                 | 11.0                      | M R                        |
|   | 7                  | Worthington         | Fairbanks Morse      | 400                | 163                 | 11.0                      | M R                        |
|   |                    | Total               |                      | 1,950              |                     | 52.0                      |                            |
| HILLCREST (5602)<br>(High Pressure)<br>4200 S. Happy Canyon Rd. | 8                  | American Marsh      | Westinghouse         | 75                 | 320                 | 0.8                       | M A R                      |
|   | 9                  | DeLaval             | Electric Machinery   | 200                | 318                 | 2.5                       | M A R                      |
|   | 10                 | DeLaval             | Electric Machinery   | 350                | 313                 | 4.8                       | M R                        |
|   | 11                 | DeLaval             | Electric Machinery   | 800                | 315                 | 10.5                      | M R                        |
|   | 12                 | DeLaval             | Electric Machinery   | 800                | 315                 | 10.5                      | M R                        |
|   | 13                 | Patterson           | Ideal Electric       | 900                | 320                 | 10.0                      | M R                        |
|   |                    | Total               |                      | 3,125              |                     | 39.1                      |                            |
| JULIAN STREET (5452)<br>2570 S. Julian St.                      | 1                  | Fairbanks Morse     | Fairbanks Morse      | 75                 | 120                 | 2.9                       | M A R                      |
|   | 2                  | Allis Chalmers      | Allis Chalmers       | 50                 | 118                 | 2.0                       | M A R                      |
|   | 3                  | Wheeler Economy     | Ideal Electric       | 50                 | 120                 | 1.7                       | M A R                      |
|   | 4                  | Fairbanks Morse     | Fairbanks Morse      | 75                 | 120                 | 2.9                       | M A R                      |
|   |                    | Total               |                      | 250                |                     | 9.5                       |                            |
| KASSLER (5496)<br>At Waterton                                   | 1                  | Gould               | Electric Machinery   | 1,250              | 325                 | 15.0                      | M A R                      |
|   | 2                  | Worthington         | Fairbanks Morse      | 800                | 325                 | 10.0                      | M A R                      |
|   | 3                  | Gould               | Electric Machinery   | 1,250              | 325                 | 15.0                      | M A R                      |
|   | 4                  | Worthington         | Fairbanks Morse      | 800                | 325                 | 10.0                      | M A R                      |
|   | 5                  | Gould               | Electric Machinery   | 1,250              | 325                 | 15.0                      | M A R                      |
|   |                    | Total               |                      | 5,350              |                     | 65.0                      |                            |

V.G.S. Elevations in parentheses  
air-type structure (Underground)

Legend for Method of Operation: M - Manual A - Automatic R - Remote

Table 5.2-1 - Continued (Sheet 2)

| Pump Station  | Pump Number | Make of Pump    | Make of Motor      | Horse Power | Head In Feet | Capacity In M.G.D. | Method of Operation |
|---|-------------|-----------------|--------------------|-------------|--------------|--------------------|---------------------|
| KENDRICK (5615)<br>(Low Pressure)<br>9380 W. Jewell Ave.  | 1           | Patterson       | Ideal Electric     | 300         | 120          | 10.0               | M R                 |
|   | 2           | DeLaval         | General Electric   | 300         | 117          | 10.0               | M A R               |
|   | 3           | Worthington     | General Electric   | 75          | 119          | 2.9                | M A R               |
|   | 4           | Worthington     | General Electric   | 75          | 119          | 2.9                | M A R               |
|   | 5           | Worthington     | General Electric   | 75          | 119          | 2.9                | M A R               |
|   |             | Total           |                    | 825         |              | 28.7               |                     |
| KENDRICK (5615)<br>(High Pressure)<br>9380 W. Jewell Ave. | 7           | Worthington     | Electric Machinery | 800         | 260          | 10.0               | M A R               |
|   | 8           | Worthington     | Electric Machinery | 800         | 260          | 10.0               | M A R               |
|   | 9           | Patterson       | Ideal Electric     | 700         | 260          | 5.0                | M A R               |
|   | 10          | DeLaval         | Ideal Electric     | 400         | 260          | 5.0                | M A R               |
|   | 11          | Patterson       | Ideal Electric     | 700         | 260          | 10.0               | M A R               |
|   |             | Total           |                    | 3,400       |              | 40.0               |                     |
| LAKERIDGE (5520)<br>2700 S. Raleigh St.                   | 1           | American        | United States      | 50          | 120          | 1.7                | M A R               |
|   | 2           | Pacific         | Ideal Electric     | 75          | 120          | 2.9                | M A R               |
|   | 3           | Pacific         | Ideal Electric     | 75          | 120          | 2.9                | M A R               |
|   | 4           | Allis Chalmers  | Allis Chalmers     | 50          | 120          | 2.0                | M A R               |
|   |             | Total           |                    | 250         |              | 9.5                |                     |
| • LAMAR (5443)<br>6301 W. Yale Ave.                       | 1           | Worthington     | Marathon Electric  | 100         | 120          | 2.9                | M A R               |
|   | 2           | Worthington     | Marathon Electric  | 100         | 120          | 2.9                | M A R               |
|   |             | Total           |                    | 200         |              | 5.8                |                     |
| LEE GULCH (5510)<br>7615 S. Broadway                      | 1           | Peerless        | Marathon Electric  | 75          | 125          | 2.3                | M A                 |
|   | 2           | Peerless        | Marathon Electric  | 75          | 125          | 2.3                | M A                 |
|   |             | Total           |                    | 150         |              | 4.6                |                     |
| MARSTON (5485)<br>(Low Pressure)<br>5700 W. Quincy Ave.   | 1           | Worthington     | General Electric   | 700         | 166          | 20.0               | M R                 |
|   | 2           | Worthington     | General Electric   | 700         | 166          | 20.0               | M R                 |
|   | 3           | Worthington     | General Electric   | 700         | 166          | 20.0               | M R                 |
|   | 4           | Worthington     | General Electric   | 700         | 166          | 20.0               | M R                 |
|   | 5           | Worthington     | General Electric   | 700         | 166          | 20.0               | M R                 |
|   |             | Total           |                    | 3,500       |              | 100.0              |                     |
| MARSTON (5485)<br>(High Pressure)<br>5700 W. Quincy Ave.  | 7           | Fairbanks Morse | Fairbanks Morse    | 200         | 320          | 2.9                | M R                 |
|   | 8           | Patterson       | Ideal Electric     | 400         | 260          | 6.5                | M R                 |
|   | 9           | Patterson       | Ideal Electric     | 900         | 260          | 10.0               | M R                 |
|   | 10          | Patterson       | Ideal Electric     | 900         | 260          | 10.0               | M R                 |
|   | 11          | Patterson       | Ideal Electric     | 900         | 260          | 10.0               | M R                 |
|   |             | Total           |                    | 3,300       |              | 39.4               |                     |
| MEXICO AVENUE (5428)<br>4740 Mexico Ave.                  | 1           | Peerless        | Marathon Electric  | 50          | 95           | 1.7                | M A R               |
|   | 2           | Peerless        | Marathon Electric  | 50          | 95           | 1.7                | M A R               |
|   | 3           | Peerless        | Marathon Electric  | 50          | 95           | 1.7                | M A R               |
|   | 4           | Wheeler Economy | Marathon Electric  | 75          | 95           | 2.9                | M A R               |
|   | 5           | Wheeler Economy | Marathon Electric  | 75          | 95           | 2.9                | M A R               |
|   |             | Total           |                    | 300         |              | 10.9               |                     |
| • MONACO (5546)<br>3490 S. Monaco St.                     | 2           | Peerless        | United States      | 50          | 120          | 2.1                | M A                 |
|   |             |                 |                    |             |              |                    |                     |
| MONTCLAIR (5376)<br>1105 Quebec St.                       | 1           | Fairbanks Morse | General Electric   | 400         | 165          | 10.0               | M R                 |
|   | 2           | Byron Jackson   | General Electric   | 200         | 160          | 5.0                | M R                 |
|   | 3           | Warner Goulds   | Electric Machinery | 600         | 165          | 15.0               | M R                 |
|   | 4           | Worthington     | Electric Machinery | 600         | 175          | 15.0               | M R                 |
|   |             | Total           |                    | 1,800       |              | 45.0               |                     |
| SOUTHWEST METRO NO. 2(5594)<br>8775 W. Coal Mine Rd.      | 1           | Hightrust       | Vertical           | 150         | 250          | 2.6                | M A R               |
|   | 2           | Fairbanks Morse | Fairbanks Morse    | 100         | 250          | 2.1                | M A R               |
|   |             | Total           |                    | 250         |              | 4.7                |                     |

(U.S.G.S. Elevations in parentheses)  
Vault Type Structure (Underground)

Legend for Method of Operation: M - Manual A - Automatic R - Remote

Table 5.2-1 - Continued (Sheet 3)

| <u>Pump Station</u>   | <u>Pump Number</u> | <u>Make of Pump</u> | <u>Make of Motor</u> | <u>Horse Power</u> | <u>Head In Feet</u> | <u>Capacity In M.G.D.</u> | <u>Method of Operation</u> |
|---|--------------------|---------------------|----------------------|--------------------|---------------------|---------------------------|----------------------------|
| UNIVERSITY BOULEVARD (5653)<br>2395 Mineral Ave.                | 2                  | Fairbanks Morse     | Fairbanks Morse      | 10                 | 76                  | 0.4                       | M A                        |
|   | 3                  | Fairbanks Morse     | Fairbanks Morse      | 10                 | 76                  | 0.4                       | M A                        |
|   |                    | Total               |                      | 20                 |                     | 0.8                       |                            |
| WESTWOOD (5490)<br>3305 W. Mississippi Ave.                     | 1                  | Worthington         | Century              | 30                 | 120                 | 1.3                       | M A R                      |
|   | 3                  | American            | United States        | 50                 | 120                 | 1.7                       | M A R                      |
|   | 4                  | Fairbanks Morse     | Fairbanks Morse      | 100                | 130                 | 2.9                       | M A R                      |
|   |                    | Total               |                      | 180                |                     | 5.9                       |                            |
| YALE AVENUE (5414)<br>(Low Pressure)<br>2701 S. Colorado Blvd.  | 1                  | Worthington         | Westinghouse         | 25                 | 68                  | 1.4                       | M A R                      |
|   | 2                  | Worthington         | Westinghouse         | 25                 | 68                  | 1.4                       | M A R                      |
|   | 3                  | Pacific             | Delco Electric       | 60                 | 93                  | 2.9                       | M A R                      |
|   | 4                  | Fairbanks Morse     | Fairbanks Morse      | 60                 | 93                  | 2.9                       | M A R                      |
|   |                    | Total               |                      | 170                |                     | 8.6                       |                            |
| YALE AVENUE (5414)<br>(High Pressure)<br>2701 S. Colorado Blvd. | 2                  | Allis Chalmers      | General Electric     | 30                 | 170                 | 0.7                       | M A R                      |
|   | 3                  | Fairbanks Morse     | Fairbanks Morse      | 125                | 170                 | 3.4                       | M A R                      |
|   | 4                  | Fairbanks Morse     | Fairbanks Morse      | 60                 | 170                 | 1.4                       | M A R                      |
|   | 5                  | Fairbanks Morse     | Fairbanks Morse      | 60                 | 170                 | 1.4                       | M A R                      |
|   | 6                  | Worthington         | Howell Electric      | 125                | 170                 | 2.9                       | M A R                      |
|   | 7                  | Fairbanks Morse     | Robbins              | 125                | 170                 | 2.9                       | M A R                      |
|   |                    | Total               |                      | 525                |                     | 12.7                      |                            |
|   |                    | Totals              |                      |                    | 56,740              | 1,093.4                   |                            |

Total Clear Water Pumped, 1976:

50,713,670,000 Gallons

Total Consumption, 1976:

68,430,620,000 Gallons

Pumpage by Lifts, 1976:

First Lift, 37,310,340,000 Gallons

Second Lift, 8,835,680,000 Gallons

Third Lift, 4,453,350,000 Gallons

Fourth Lift, 114,300,000 Gallons

Table 5.2-1 - Continued (Sheet 4)

ANNUAL WATER REPORT

|  |                  | <u>PERCENT FILTERED</u>                   |
|--|------------------|---|
| Woffat M. G. Filtered                            | <u>16,328.53</u> | <u>23.81</u>                              |
| Marston M. G. Filtered                           | <u>44,405.49</u> | <u>54.77</u>                              |
| Kassler M. G. Filtered                           | <u>7,833.65</u>  | <u>11.42</u>                              |
| Total Filtered                                   | <u>68,567.67</u> | <u>Total %</u> <u>100.00</u>              |
| Master Contract Total Pumpage                    | <u>36,511.48</u> | M. G.                                     |
| Outside Contract Total Pumpage                   | <u>13,769.78</u> | M. G.                                     |
| Grant Total, Both Pumpage Contracts for the Year | <u>50,281.26</u> | M. G.                                     |
| Percent of First Lift Pumped                     | <u>53.94%</u>    | M. G. Pumped <u>36,982.98</u>             |
| Percent of Second Lift Pumped                    | <u>12.92%</u>    | M. G. Pumped <u>8,861.49</u>              |
| Percent of Third Lift Pumped                     | <u>06.38%</u>    | M. G. Pumped <u>4,376.29</u>              |
| Percent of Fourth Lift Pumped                    | <u>00.08%</u>    | M. G. Pumped <u>60.50</u>                 |
|  |                  | <u>Total M.G. Pumped</u> <u>50,281.26</u> |

Average M. G. Pumped Per Day During 1975 123.54Average M. G. Pumped Per Day During 1976 137.76

Table 5.2-2 - 1976 Water Report, Denver Water System

ANNUAL POWER REPORT

Master Contract Annual Charge 602,611.72 Cost Per KWH 0.0180217 Total KWH Used 33,438,104.  
Outside Contract Annual Charge 400,795.04 Cost Per KWH 0.0234905 Total KWH Used 17,061,941  
Cost of Electric & Gas (Small Bills) of Vaults & Stations 45,591.38 Total  
Peak Occurred Majority of peaks occurred between 15th & 30th of each month.  
Total Annual Expenditures Allocated for Power, Electric and Gas \$ 1,048,998.14  
PDP-8 Logger in Operation \_\_\_\_\_ Days; Off \_\_\_\_\_ Days  
PDP-11/45 In Operation 360 Days; Off 5 Days

## SUMMARY OF WATER AND POWER COSTS - 1976

Total Consumption - - - 68,430.62 M.G.

Total Water Produced - - 68,567.67 M.G.

## FILTER PLANT PRODUCTION

|         | M.G.            | DAILY AVERAGE | % OF TOTAL    |
|---------|-----------------|---------------|---------------|
| Moffat  | 16,328.53       | 44.74         | 23.81%        |
| Marston | 44,405.49       | 121.65        | 64.77%        |
| Kassler | <u>7,833.65</u> | <u>21.46</u>  | <u>11.42%</u> |
| Totals: | 68,567.67       | 187.85        | 100.00%       |

Total water pumped: 50,281.26

Master contract total pumpage ----- 36,511.48

Outside contract total pumpage ----- 13,769.78

Percent pumped to total consumption -- 73.47%

| Pumpage by lift:               | M.G.      | % PUMPED OF<br>TOTAL PRODUCED | COST<br>PER LIFT |
|--------------------------------|-----------|-------------------------------|------------------|
| First                          | 36,982.98 | 53.93%                        | \$ 560,935.61    |
| Second                         | 8,861.49  | 12.92%                        | 218,111.51       |
| Third                          | 4,376.29  | 6.38%                         | 99,765.18        |
| Fourth                         | 60.50     | 0.08%                         | 2,374.19         |
| Metro Sewer                    |           |                               | 15,342.58        |
| * Power Consumed other Sources |           |                               | 106,877.69       |
| Small Bills, Elect. & Gas      |           |                               | <u>45,591.38</u> |
| Total:                         |           |                               | \$ 1,048,998.14  |

## \* Power Consumed Other Sources (Master Contract):

- a. 1200 Shoshone
- b. 1600 W. 12th (Meters)
- c. Kassler Filters
- d. Marston Lake (Filter)
- e. Waterton Pump
- f. Moffat

POWER

|   |                          |
|---|--------------------------|
| Master Contract KWH Consumed  | 33,438,104               |
| Outside Contract KWH Consumed   | 17,061,961               |
| Total Consumed:   | <u>50,500,045 K.W.H.</u> |
| Master Contract Total Cost  | \$ 602,611.72            |
| Outside Contract Total Cost   | \$ 400,795.04            |
| Cost of electricity and gas (small bills for vaults and stations)<br>amounted to: | \$ 45,591.38             |
| Total cost all bills, 1976  | \$ 1,048,998.14          |

Table 5.2-4 - Power Cost History

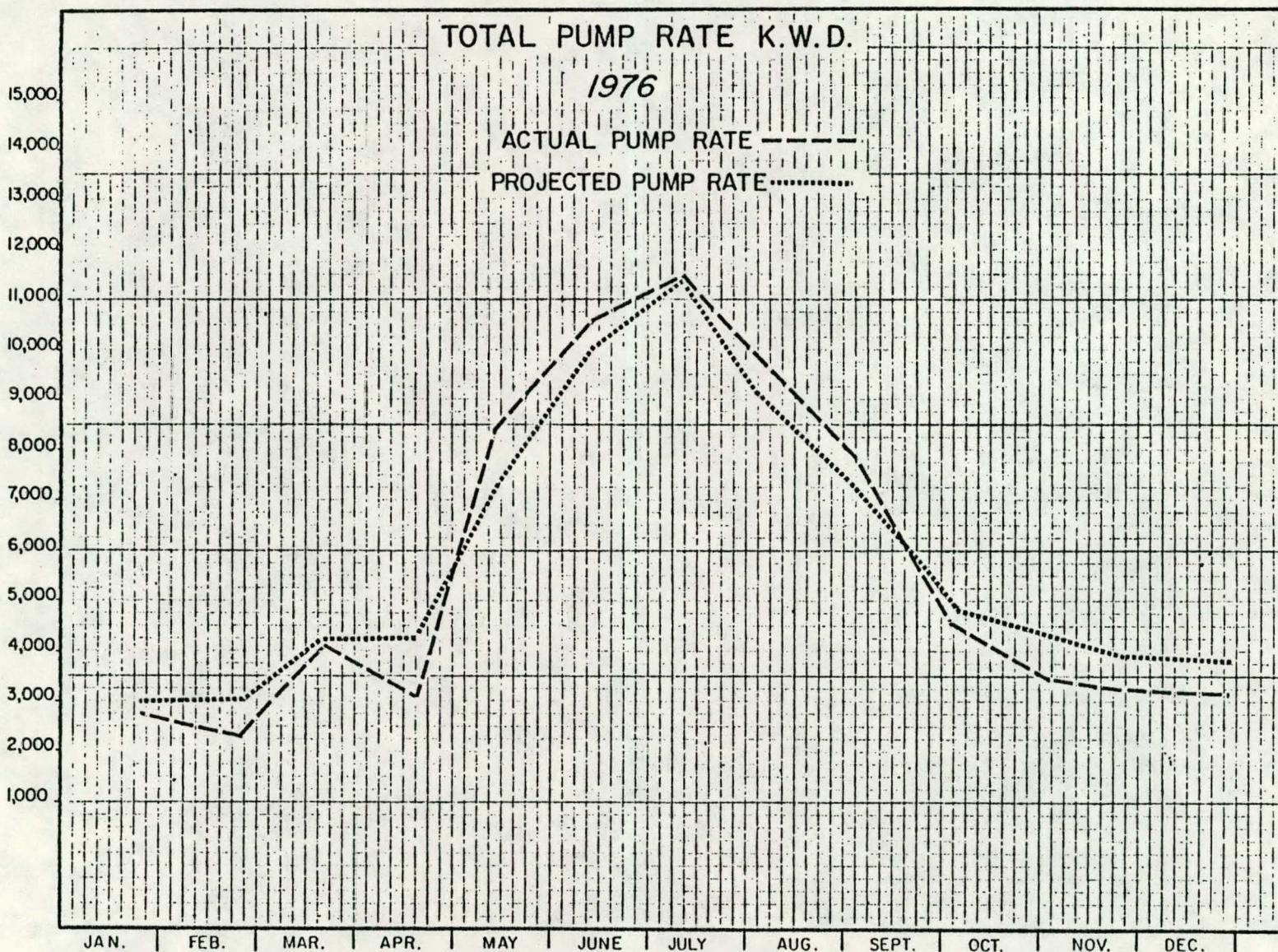


Figure 5.2-3 - Denver Water System - 1976 Power Consumption  
Kilowatt-days

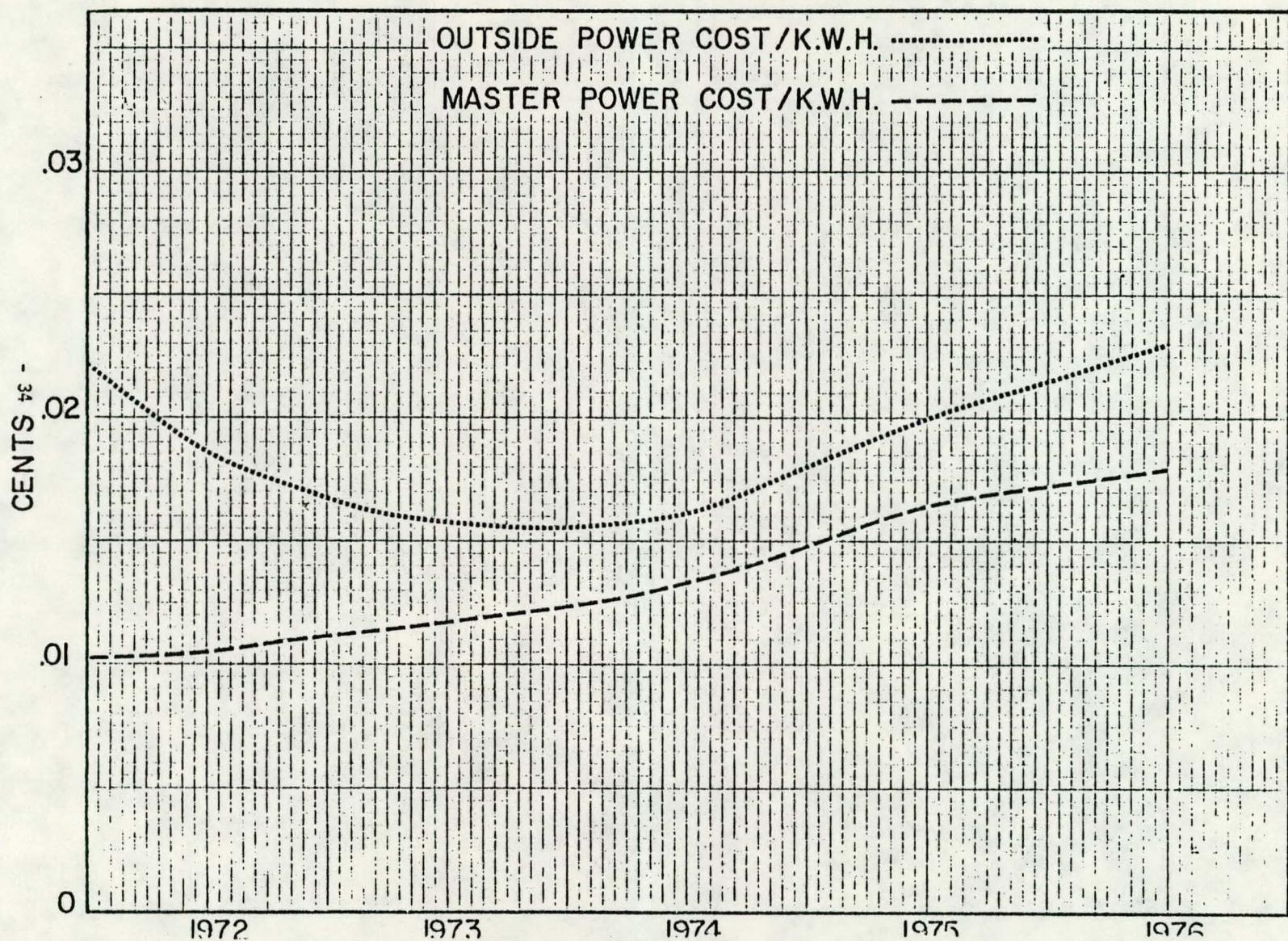


Figure 5.2-4 - Denver Water System - Power Cost History

## 5.4 Energy Estimates for Water Supply Systems

In this study, an energy intensity in kilowatt-hours per gallon per foot of head will be estimated. From this, an estimate of total energy consumption in kilowatt-hours can be derived. This approach is necessitated by the fact that in water distribution systems, unlike petroleum pipelines, the fluid is not pumped through from source to destination. Instead, the water is pumped up to a high-level storage tank, from which it flows by gravity through the distribution lines to consumers. Since all the energy is input to the system as work to raise the water to the storage reservoirs, the energy intensity for water systems is defined as energy per unit of mass per unit of lift. When calculating the EI, head which is dissipated in the lift pipe and the unrecovered dynamic head must of course be included.

### 5.4.1 Energy Intensity of Water Supply Systems

For water distribution systems, the energy intensity just defined is calculated by the formula

$$I_E \triangleq \frac{\text{Power (Kw)}}{\text{Flow (1000 gpm) x Head (100 ft)}} \\ = 10^{-5} \frac{\text{Kw-Min}}{\text{Gal-Ft}}$$

For 1000 gallons per minute of water at 8.328 lb/gal pumped against a total of 100 ft, the power into the water is

$$P_w = 1000 \frac{\text{Gal}}{\text{Min}} \times 8.328 \frac{\#}{\text{Gal}} \times 100 \text{ ft.} \times \frac{1}{778} \frac{\text{Btu}}{\text{Ft}\#} \\ \times \frac{1}{3412.14} \frac{\text{Kw-Hr}}{\text{Btu}} \times 60 \frac{\text{Min}}{\text{Hr}} = 18.823 \text{ Kw} \\ = 25.23 \text{ Hp}$$

At a wire-to-water efficiency of 67%, the power into the motor is

$$P_m = 28.09 \text{ Kw} = 36.66 \text{ Hp}$$

And at a 22% efficiency for the generating and transmission system, the power into the boiler at the generating station is

$$P_b = 127.70 \text{ Kw} = 171.18 \text{ Hp}$$

Thus, the energy intensity at the boiler, for the elevation head alone, is

$$I_E \text{ (Lift)} = 127.7 \frac{\text{Kw-Min}}{10^5 \text{ Gal-Ft}}$$

Referring again to Table 5.1-9 a total power requirement of about 46 Kw is indicated at the pump efficiency of 67% which was used above. This would indicate that in general the velocity head and friction head together are about equal to the elevation head. Inspection of Table 5.1-10 shows that velocity head is generally small, less than two feet for typical velocities. The friction head is several feet per hundred feet, so that it is easy to see why the values in Table 5.1-9 should be reasonable. The total intensity then is

$$I_E = \frac{46}{0.22} = 209.09 \frac{\text{Kw-Min}}{10^5 \text{ Gal-Ft}}$$

It is interesting to compare this with the Denver experience. That system was seen in Table 5.2-3 above to consume 50,500,045 (33,438,104 plus 17,061,941) kw-hr to move a throughput of (Table 5.2-2) 50,281.26 million gallons. The energy intensity is

$$\frac{50,500,045 \text{ Kw-hr}}{50,281.26 \times 10^6 \text{ Gal} \times 160 \text{ ft}} \times 60 \frac{\text{Min}}{\text{Hr}} = 37.663 \frac{\text{Kw-Min}}{10^5 \text{ Gal-Ft}}$$

at the motor, or

$$\frac{37.66}{0.22} = 171 \frac{\text{Kw-Min}}{10^5 \text{ Gal-Ft}}$$

at the boiler.

#### 5.4.2 Energy Consumption in Water Supply Systems

Referring again to Table 5.1-1 above, it is seen that in 1974 the industry served approximately 180 million people, consuming 150 gpd per capita, or  $27 \times 10^9$  gpd. Also in that table, and in Table 5.1-2, it was seen that about 20% of the supplies are taken from ground water, i.e., wells. Also, from Table 5.1-8, an average well depth of 153 feet was calculated. There is no data available on average lift from the surface, but if the 160 feet average at Denver is typical, then the energy consumption, at the generating station boiler is

$$E = 27 \times 10^9 \frac{\text{Gal}}{\text{Day}} \times \frac{1}{1440} \frac{\text{Day}}{\text{Min}} \times \frac{209.1}{10^5} \frac{\text{Kw-Min}}{\text{Gal-Ft}}$$

$$\times (0.2 \times 153 + 160) \text{ ft} \times 8760 \frac{\text{Hr}}{\text{Yr}}$$

$$= 6.54 \times 10^{10} \frac{\text{Kw-hr}}{\text{Yr}} = 0.233 \text{ Quad}$$

If the Denver experience ( $I_E = 171$ ) is more typical than the  $I_E$  of 132 which was calculated earlier, then

$$E = 6.54 \times 10^{10} \times \frac{171}{209} = 5.35 \times 10^{10} \frac{\text{Kw-hr}}{\text{Yr}} = 0.183 \text{ Quad}$$

If the Denver experience ( $I_E = 171$ ) is typical, then

$$E = 6.54 \times 10^{10} \times \frac{171}{209} = 5.35 \times 10^{10} \frac{\text{Kw-hr}}{\text{Yr}} = 0.183 \text{ Quad}$$

The average would appear to be near 0.2 Quad.

Two comments are in order.

First, if the 0.2 Quad is at all accurate, it is somewhat surprising, in that it is several times larger than the estimates for the other liquid pipelines. It therefore merits further scrutiny.

Second, the principal uncertainty in the methodology is clearly in the estimate of average lift. In the above examples, the principal questions involve the representativeness of the Illinois Water Survey, Table 5.1-9, which is the basis of the EI of 209.9, and of the Denver lift of 160 feet. While it might be expected that the per-capita consumption might not vary widely, perhaps by a factor of two or three across the population of systems, it is easy to see how the average lift could vary by a factor of ten. Clearly, refinement of the estimate would require further research regarding these two factors, the average lift being particularly important.

#### 5.4.3 First-order Refinement of the Estimate

Stimulated by the considerations just discussed, J. S. Moore (1977) of Mueller Associates obtained information about the Baltimore, Washington, D. C. and New York City systems, and found the per-capita consumption for those systems to be approximately 140, 150, and 200 gpd respectively. The geometric mean of these values is 143 gpd, quite close to the value of 150 in Table 5.1-1.

Moore also found, somewhat surprisingly, that only 43, 73, and 10 percent respectively of those systems water supplies were pumped. That is, New York apparently obtains 90% of its water by gravity. Thus, it appears unlikely that the average lift for any of these three systems even approaches the 160 feet of the Denver system. Since more specific information is not available for these systems, if they are to be useful in developing national estimates, another approach must be taken.

The per-capita energy consumptions for the Baltimore and Washington systems were found by Moore to be 18.89 and 7.64 Kw-Hr in 1976. By contrast, the 1976 per-capita energy consumption of the Denver system is approximately 48 Kw-Hr. Extrapolating from the 180 million population estimated to be served in 1974 (Table 5.1-1) to 1976 at the same growth rate as that seen in the standard metropolitan areas over the preceding two years (Statistical Abstract of the U. S., 1976, Table 18), yields 183.3 million for the 1976 population served. Taking the geometric mean of the three per-capita energy figures above and multiplying by the population served yields  $1.193 \times 10^{13}$  Kw-Hr consumed at the pump-motor junction boxes. As before, dividing by 0.22 for the efficiency of the electrical generation and transmission system yields  $5.42 \times 10^{13}$  as the estimate for the total energy consumption. The rounded, single-figure estimate of 0.05 Quad is suggested.

## 5.5 Energy Consumption in Waste-water Systems

Some recent energy experience of the San Diego sewage system is summarized in Table 5.5-1. This is the pump station through which all the metropolitan sewage is pumped to the treatment plant, from which it is discharged several thousand feet out into the ocean bottom. There are some 70 other pump stations in the San Diego system, many of them very tiny. The power consumption and cost data for all these plants exists, but has not been reduced or analyzed. The power for all other stations combined is believed to be not more than two-thirds that for station 2.

Table 5.5-2 shows a tabulation of the sewage plants in 1962. Taking the 1962 population served of 118,371,919 from that table, ratioing up in proportion to general population growth to 1976, and applying the San Diego per-capita energy consumption yields an estimate for the energy consumption of 0.017 Quad.

No defense of a single-point estimate such as this is offered. It is simply the first step in what could be, if they were needed, a series of successive refinements. If in the future, such refinements are desired, the methodology for the necessary research is now clear.

Table 5.5-1

## City of San Diego Sewage Pump Station No. 2

|                                 | FY75    | FY76    | FY77      |
|---------------------------------|---------|---------|-----------|
| Throughput, mgpd                | 111.457 | 112.155 | 119.931   |
| Energy, Kw-hr x 10 <sup>3</sup> | 29,557  | 30,504  | 31,176    |
| Energy cost, \$                 | 676,468 | 964,597 | 1,120,611 |
| Unit Energy Cost,<br>\$/Kw-hr   | 0.02289 | 0.03162 | 0.03594   |

FY is July through June

| STATES                  | Total       |                           | Separate    |                           | Combined    |                           | Both        |                           | Not stated  |                           |
|-------------------------|-------------|---------------------------|-------------|---------------------------|-------------|---------------------------|-------------|---------------------------|-------------|---------------------------|
|                         | Num-<br>ber | Popula-<br>tion<br>served |
| Alabama . . . . .       | 216         | 1,495,043                 | 214         | 1,493,218                 | .....       | .....                     | .....       | .....                     | 2           | 1,825                     |
| Alaska . . . . .        | 21          | 61,620                    | 8           | 3,260                     | .....       | .....                     | 13          | 58,360                    | .....       | .....                     |
| Arizona . . . . .       | 74          | 710,649                   | 72          | 689,734                   | 1           | 20,000                    | .....       | .....                     | 1           | 915                       |
| Arkansas . . . . .      | 161         | 792,675                   | 141         | 705,285                   | 2           | 64,300                    | .....       | .....                     | 18          | 23,090                    |
| California . . . . .    | 506         | 11,458,492                | 477         | 9,359,536                 | 17          | 2,057,910                 | .....       | .....                     | 12          | 41,046                    |
| Colorado . . . . .      | 176         | 1,421,106                 | 170         | 1,309,431                 | 3           | 107,000                   | .....       | .....                     | 3           | 4,675                     |
| Connecticut . . . . .   | 91          | 1,491,656                 | 66          | 574,837                   | 15          | 490,919                   | 9           | 421,900                   | 1           | 4,000                     |
| Delaware . . . . .      | 16          | 267,241                   | 9           | 25,158                    | 1           | 2,700                     | 5           | 238,520                   | 1           | 863                       |
| District of Columbia    | 1           | 1,323,470                 | .....       | .....                     | .....       | .....                     | 1           | 1,323,470                 | .....       | .....                     |
| Florida . . . . .       | 346         | 2,170,514                 | 333         | 2,111,239                 | 2           | 21,500                    | .....       | .....                     | 11          | 37,775                    |
| Georgia . . . . .       | 276         | 2,268,492                 | 262         | 1,083,157                 | 6           | 914,515                   | 4           | 268,920                   | 4           | 1,900                     |
| Hawaii . . . . .        | 27          | 362,166                   | 27          | 362,166                   | .....       | .....                     | .....       | .....                     | .....       | .....                     |
| Idaho . . . . .         | 91          | 302,999                   | 79          | 244,894                   | 10          | 48,905                    | 2           | 9,200                     | .....       | .....                     |
| Illinois . . . . .      | 472         | 7,908,321                 | 329         | 1,227,256                 | 107         | 4,833,140                 | 26          | 1,835,280                 | 10          | 12,645                    |
| Indiana . . . . .       | 321         | 2,867,845                 | 103         | 364,915                   | 206         | 2,445,065                 | 3           | 36,040                    | 9           | 21,825                    |
| Iowa . . . . .          | 438         | 1,576,800                 | 400         | 983,090                   | 18          | 184,760                   | 10          | 402,350                   | 10          | 6,600                     |
| Kansas . . . . .        | 335         | 1,468,250                 | 325         | 1,180,005                 | 2           | 107,000                   | 3           | 176,400                   | 5           | 4,845                     |
| Kentucky . . . . .      | 161         | 1,263,145                 | 134         | 563,080                   | 20          | 658,620                   | 7           | 41,445                    | .....       | .....                     |
| Louisiana . . . . .     | 161         | 2,100,673                 | 158         | 2,095,553                 | .....       | .....                     | .....       | .....                     | 3           | 5,120                     |
| Maine . . . . .         | 109         | 479,453                   | 37          | 68,720                    | 39          | 198,650                   | 32          | 210,608                   | 1           | 1,475                     |
| Maryland . . . . .      | 72          | 1,352,909                 | 54          | 1,327,134                 | 7           | 16,800                    | 3           | 2,500                     | 8           | 6,475                     |
| Massachusetts . . .     | 144         | 4,389,580                 | 81          | 619,165                   | 40          | 931,760                   | 10          | 2,828,605                 | 13          | 10,050                    |
| Michigan . . . . .      | 236         | 6,170,560                 | 110         | 570,100                   | 66          | 4,252,685                 | 58          | 1,292,275                 | 2           | 55,500                    |
| Minnesota . . . . .     | 404         | 2,062,595                 | 373         | 857,145                   | 27          | 1,185,710                 | 3           | 19,690                    | 1           | 50                        |
| Mississippi . . . . .   | 168         | 779,456                   | 164         | 755,056                   | .....       | .....                     | 1           | 18,600                    | 3           | 5,800                     |
| Missouri . . . . .      | 466         | 2,643,725                 | 411         | 1,065,225                 | 6           | 44,945                    | 24          | 1,411,960                 | 25          | 121,595                   |
| Montana . . . . .       | 114         | 385,220                   | 103         | 299,680                   | 4           | 19,600                    | 7           | 65,940                    | .....       | .....                     |
| Nebraska . . . . .      | 300         | 802,230                   | 275         | 517,470                   | 13          | 26,790                    | 6           | 245,150                   | 6           | 12,820                    |
| Nevada . . . . .        | 37          | 314,030                   | 33          | 233,430                   | 4           | 80,600                    | .....       | .....                     | .....       | .....                     |
| New Hampshire . .       | 78          | 283,460                   | 19          | 45,660                    | 29          | 91,350                    | 27          | 144,200                   | 3           | 2,250                     |
| New Jersey . . . . .    | 210         | 4,504,015                 | 169         | 2,314,640                 | 9           | 366,375                   | 5           | 1,311,185                 | 27          | 511,815                   |
| New Mexico . . . . .    | 76          | 599,821                   | 76          | 599,821                   | .....       | .....                     | .....       | .....                     | .....       | .....                     |
| New York . . . . .      | 548         | 13,443,148                | 389         | 2,709,148                 | 53          | 519,525                   | 87          | 10,192,945                | 19          | 21,530                    |
| North Carolina . . .    | 359         | 1,751,365                 | 355         | 1,742,940                 | 1           | 1,020                     | .....       | .....                     | 3           | 7,405                     |
| North Dakota . . . . .  | 185         | 321,175                   | 127         | 118,930                   | 48          | 196,855                   | .....       | .....                     | 10          | 5,390                     |
| Ohio . . . . .          | 441         | 6,776,295                 | 241         | 1,856,930                 | 117         | 1,735,680                 | 59          | 3,110,420                 | 24          | 73,265                    |
| Oklahoma . . . . .      | 284         | 1,452,524                 | 279         | 1,438,724                 | .....       | .....                     | .....       | .....                     | 5           | 13,800                    |
| Oregon . . . . .        | 165         | 927,080                   | 116         | 270,110                   | 37          | 610,280                   | 6           | 46,100                    | .....       | 3,590                     |
| Pennsylvania . . . . .  | 682         | 9,559,417                 | 439         | 2,687,262                 | 137         | 707,915                   | 95          | 6,144,115                 | 11          | 20,125                    |
| Puerto Rico . . . . .   | 69          | 121,634                   | 69          | 121,634                   | .....       | .....                     | .....       | .....                     | .....       | .....                     |
| Rhode Island . . . . .  | 22          | 561,975                   | 18          | 174,385                   | .....       | .....                     | 3           | 386,470                   | 1           | 1,120                     |
| South Carolina . . .    | 221         | 927,114                   | 221         | 927,114                   | .....       | .....                     | .....       | .....                     | .....       | .....                     |
| South Dakota . . . . .  | 181         | 378,257                   | 154         | 343,162                   | 20          | 15,925                    | 7           | 19,170                    | .....       | .....                     |
| Tennessee . . . . .     | 135         | 1,478,443                 | 126         | 1,122,268                 | 5           | 195,125                   | 2           | 142,100                   | 2           | 18,950                    |
| Texas . . . . .         | 832         | 6,602,147                 | 826         | 6,486,007                 | 1           | 55,000                    | 3           | 58,100                    | 2           | 3,040                     |
| Utah . . . . .          | 75          | 695,635                   | 75          | 695,635                   | .....       | .....                     | .....       | .....                     | .....       | .....                     |
| Vermont . . . . .       | 52          | 186,157                   | 8           | 8,390                     | 7           | 8,555                     | 36          | 165,812                   | 1           | 3,400                     |
| Virginia . . . . .      | 231         | 1,866,241                 | 202         | 1,481,817                 | 1           | 180,000                   | 5           | 181,050                   | 23          | 23,374                    |
| Washington . . . . .    | 230         | 1,628,330                 | 133         | 373,650                   | 46          | 825,505                   | 15          | 302,030                   | 36          | 127,145                   |
| West Virginia . . . . . | 176         | 726,181                   | 98          | 168,460                   | 48          | 425,471                   | 19          | 87,970                    | 11          | 44,280                    |
| Wisconsin . . . . .     | 392         | 2,668,315                 | 306         | 712,268                   | 34          | 1,315,600                 | 51          | 640,147                   | 1           | 300                       |
| Wyoming . . . . .       | 71          | 222,276                   | 68          | 221,155                   | .....       | .....                     | .....       | .....                     | 3           | 1,120                     |
| Total . . . . .         | 11,655      | 118,371,919               | 9,462       | 57,309,049                | 1,209       | 25,964,055                | 647         | 33,836,027                | 337         | 1,262,788                 |

(Source: U. S. Public Health Service)

Table 5.5-2 - Municipal Sewage Treatment Plants in the United States

| Treated |                   | Untreated |                   | Minor  |                   | Primary |                   | Intermediate |                   | Secondary |                   |
|---------|-------------------|-----------|-------------------|--------|-------------------|---------|-------------------|--------------|-------------------|-----------|-------------------|
| Number  | Population served | Number    | Population served | Number | Population served | Number  | Population served | Number       | Population served | Number    | Population served |
| 144     | 1,231,420         | 72        | 263,623           | .....  | .....             | 69      | 711,560           | .....        | .....             | 75        | 519,860           |
| 1       | 10,000            | 20        | 51,620            | .....  | .....             | 1       | 10,000            | .....        | .....             | .....     | .....             |
| 69      | 684,699           | 5         | 25,950            | .....  | .....             | 17      | 35,274            | .....        | .....             | 52        | 649,425           |
| 137     | 618,475           | 24        | 174,200           | .....  | .....             | 73      | 173,155           | .....        | .....             | 64        | 445,320           |
| 484     | 11,399,057        | 22        | 59,435            | 1      | 4,000             | 102     | 7,769,699         | 4            | 384,880           | 377       | 3,240,478         |
| 149     | 1,397,736         | 27        | 23,370            | .....  | .....             | 33      | 52,205            | 1            | 550,000           | 115       | 795,531           |
| 82      | 1,438,816         | 9         | 52,840            | 2      | 8,000             | 47      | 1,091,093         | 2            | 113,400           | 31        | 226,323           |
| 13      | 262,978           | 3         | 4,263             | .....  | .....             | 11      | 259,022           | .....        | .....             | 2         | 3,956             |
| 1       | 1,323,470         | .....     | .....             | .....  | .....             | .....   | .....             | .....        | .....             | 1         | 1,323,470         |
| 328     | 2,106,749         | 18        | 63,765            | 3      | 68,000            | 81      | 836,155           | 2            | 39,760            | 242       | 1,162,834         |
| 199     | 1,722,370         | 77        | 546,122           | .....  | .....             | 112     | 346,015           | 1            | 584,155           | 86        | 792,200           |
| 17      | 60,091            | 10        | 302,075           | .....  | .....             | 8       | 26,320            | .....        | .....             | 9         | 33,771            |
| 64      | 261,039           | 27        | 41,960            | 1      | 450               | 37      | 143,040           | .....        | .....             | 26        | 117,549           |
| 444     | 7,672,861         | 28        | 235,460           | .....  | .....             | 72      | 475,850           | 2            | 26,060            | 370       | 7,170,951         |
| 190     | 2,598,375         | 131       | 269,470           | .....  | .....             | 40      | 452,870           | 1            | 5,800             | 149       | 2,139,705         |
| 372     | 1,302,430         | 66        | 274,370           | .....  | .....             | 32      | 221,405           | 1            | 4,000             | 339       | 1,077,025         |
| 322     | 1,312,440         | 13        | 155,810           | .....  | .....             | 38      | 143,300           | .....        | .....             | 284       | 1,169,140         |
| 112     | 1,159,600         | 49        | 103,545           | .....  | .....             | 30      | 630,970           | 3            | 151,265           | 79        | 377,365           |
| 127     | 827,058           | 34        | 1,273,615         | .....  | .....             | 11      | 212,895           | .....        | .....             | 116       | 614,163           |
| 17      | 43,995            | 92        | 435,458           | .....  | .....             | 14      | 28,795            | .....        | .....             | 3         | 15,200            |
| 53      | 1,317,744         | 19        | 35,165            | 2      | 4,650             | 30      | 114,359           | .....        | .....             | 21        | 1,198,735         |
| 85      | 3,544,635         | 59        | 844,945           | 10     | 1,752,215         | 22      | 1,249,235         | 1            | 430               | 52        | 542,755           |
| 213     | 6,109,385         | 23        | 61,175            | 2      | 6,030             | 109     | 4,835,900         | 3            | 87,200            | 99        | 1,180,255         |
| 344     | 1,997,715         | 60        | 64,880            | .....  | .....             | 84      | 273,685           | 1            | 1,041,700         | 259       | 682,330           |
| 118     | 353,976           | 50        | 425,480           | .....  | .....             | 35      | 40,450            | .....        | .....             | 83        | 313,526           |
| 366     | 912,990           | 100       | 1,730,735         | .....  | .....             | 24      | 98,170            | .....        | .....             | 342       | 814,820           |
| 106     | 361,920           | 8         | 23,300            | .....  | .....             | 32      | 241,400           | 2            | 11,800            | 72        | 108,720           |
| 225     | 477,675           | 75        | 324,555           | .....  | .....             | 43      | 95,065            | 1            | 1,100             | 181       | 381,510           |
| 33      | 307,390           | 4         | 6,640             | .....  | .....             | 7       | 8,990             | .....        | .....             | 26        | 298,400           |
| 19      | 59,610            | 59        | 223,850           | .....  | .....             | 9       | 48,050            | .....        | .....             | 10        | 11,560            |
| 203     | 4,450,220         | 7         | 53,795            | .....  | .....             | 60      | 2,602,610         | 6            | 479,000           | 137       | 1,368,610         |
| 75      | 598,721           | 1         | 1,100             | .....  | .....             | 6       | 5,196             | .....        | .....             | 70        | 593,525           |
| 407     | 11,420,209        | 141       | 2,022,939         | 6      | 298,680           | 247     | 3,158,624         | 6            | 92,610            | 148       | 7,870,295         |
| 255     | 1,299,980         | 104       | 451,385           | .....  | .....             | 128     | 165,245           | .....        | .....             | 127       | 1,134,735         |
| 170     | 270,755           | 15        | 50,420            | .....  | .....             | 33      | 54,740            | .....        | .....             | 137       | 216,015           |
| 351     | 6,416,805         | 90        | 359,490           | .....  | .....             | 102     | 895,110           | 27           | 1,148,015         | 222       | 4,373,680         |
| 276     | 1,443,474         | 8         | 9,050             | .....  | .....             | 36      | 204,685           | 1            | 1,200             | 239       | 1,237,589         |
| 146     | 866,480           | 19        | 60,600            | .....  | .....             | 51      | 596,050           | .....        | .....             | 95        | 270,430           |
| 384     | 8,389,337         | 298       | 1,170,080         | 1      | 4,920             | 114     | 957,890           | 6            | 2,419,465         | 263       | 5,007,062         |
| 59      | 94,954            | 10        | 26,680            | .....  | .....             | 34      | 74,880            | 1            | 235               | 24        | 19,839            |
| 15      | 557,890           | 7         | 4,085             | .....  | .....             | 7       | 187,790           | .....        | .....             | 8         | 370,100           |
| 175     | 616,442           | 46        | 310,672           | 5      | 10,040            | 105     | 192,825           | 1            | 170               | 64        | 413,407           |
| 159     | 332,202           | 22        | 46,055            | .....  | .....             | 36      | 27,245            | .....        | .....             | 123       | 304,957           |
| 112     | 899,447           | 23        | 578,996           | .....  | .....             | 42      | 312,085           | .....        | .....             | 70        | 587,362           |
| 825     | 6,565,152         | 7         | 36,995            | .....  | .....             | 116     | 189,851           | .....        | .....             | 709       | 6,375,301         |
| 55      | 465,045           | 20        | 230,590           | .....  | .....             | 19      | 20,170            | .....        | .....             | 36        | 444,875           |
| 14      | 74,902            | 38        | 111,255           | .....  | .....             | 13      | 66,402            | .....        | .....             | 1         | 8,500             |
| 178     | 1,783,249         | 53        | 82,992            | 2      | 185,980           | 69      | 978,016           | .....        | .....             | 107       | 619,253           |
| 193     | 1,094,455         | 37        | 533,875           | 1      | 7,000             | 86      | 687,825           | 2            | 10,600            | 104       | 389,030           |
| 46      | 294,195           | 130       | 431,986           | .....  | .....             | 32      | 201,935           | .....        | .....             | 14        | 92,260            |
| 386     | 2,661,425         | 6         | 6,890             | 1      | 880               | 107     | 483,615           | 8            | 239,705           | 270       | 1,937,225         |
| 60      | 212,940           | 11        | 9,335             | .....  | .....             | 7       | 46,115            | 2            | 16,400            | 51        | 150,425           |
| 9,378   | 103,684,978       | 2,277     | 14,686,941        | 37     | 2,350,845         | 2,672   | 32,733,831        | 85           | 7,408,950         | 6,584     | 61,191,352        |

(Source: U. S. Public Health Service)

Table 5.5-2 - Continued (Sheet 2)

## 6.0 ENERGY CONSUMPTION IN SLURRY PIPELINES

Report R-3025 of this series (See Table 1.1-1 above) contains a technical discussion of slurry pipelines, and a description of the only operating U.S. line for long-distance transport, the Black Mesa Line. Report 3023 discusses the economics and politics of slurry pipelines in depth. Therefore, no profile is presented here.

In analyzing energy consumption in the Black Mesa pipeline, it is necessary to consider the three distinct operations:

- (1) The extraction of the water from the ground and delivery to the pipeline head. These operations are conducted by the Peabody Coal Company.
- (2) Slurrification and transportation of the coal. These operations are conducted by the Black Mesa Pipeline, Incorporated.
- (3) Deslurrification and consumption of the coal. These operations are conducted by the Southern California Edison Company.

### 6.1 Energy in Slurry Water

The water for the Black Mesa pipeline is taken from wells near the head of the line. The depth of the lift varies between 2000 and 2200 feet. Taking 2100 feet as an average, and allowing another 200 feet for friction and velocity brings the total head to about 2300 feet.

The proportion of (bone-dry) coal to water is 48 to 52 [Montfort, 1977]. The moisture content of the coal is specified by contract at 10.74%, and the content of the as-mined coal averages very close to this figure. Thus, a ton of contract coal contains

$$2000 \times (1-0.1074) = 1785$$

lb of dry coal. The slurry proportions vary slightly from day to day, but average about 48% dry coal to 52% water. Thus, a ton of contract coal entering the slurrifier emerges as

$$\frac{1785}{0.48} = 3719$$

lb of slurry, of which 2000 lb is the original contract coal and 1719 lb is water which must be added to form the slurry.

Taking as before 64% for motor-pump efficiency and 22% for the electric grid, the energy investment in the water per ton of coal is

$$\frac{1719 \times 2300}{778 \times 0.64 \times 0.22} = 36,093 \text{ Btu/ton}$$

at the power plant boiler.

### 6.2 Energy in Pipeline Operation

The Black Mesa pipeline operation requires 22 Kw-hr per ton of coal at the station meter [Montfort, 1977]. Again (Sec. 4.4-1) allowing 22% efficiency for the electric grid yields

$$\frac{22 \times 3412}{0.22} = 341,200 \text{ Btu/ton}$$

of coal transported, at the power plant boiler.

### 6.3 Energy in Deslurrification

Deslurrification energy must be very carefully calculated. There are many operations involved, as can be seen from Table 6.3-1. Some of these operations would be required with dry coal, though to a different degree. The Southern California Edison engineers have calculated that the energy consumed in deslurrification is about 63,000 Btu/ton of coal. This energy is electrical power to the motors which drive the equipment. The energy which must be input to the boiler to supply this power is, for a station heat rate of 11,100

TABLE 6.3-1

ENERGY CONSUMED IN/CHARGEABLE TO DESLURRIFICATION

Active storage

Booster pumps to active storage  
Agitators  
Slurry transfer pumps  
Water pump to primary treatment  
Water pump to evaporation pond

Boiler fuel preparation

Centrifuges  
Pulverizer mills  
Steam cycle efficiency loss, 32% moisture vs 10.74%  
Clariflocculator agitators  
Underflow pump  
Underflow injection pump

Reslurry from inactive storage

Conveyor motors  
Vibrator motors  
Reslurry pump, primary  
Reslurry pump, final

Btu/Kw hr [Dina, 1977],

$$63,000 \times \frac{11,100}{3412} = 204,953 \text{ Btu/ton.}$$

Additionally, the steam cycle efficiency suffers under the requirement to reduce the moisture from the 32% to which it is reduced in the initial separation to the 10.74% contract value [Dina, 1976]. Taking

$$1173.8 - 34.08 = 1135.7 \text{ Btu/lb}$$

of water as the sensible and latent enthalpy to heat the moisture between the approximate conditions of 70F entering and 280F stack gas exit,

$$1135.7(0.32-0.1074) \times 2000 = 482,900 \text{ Btu/ton.}$$

#### 6.4 Slurry Pipeline Energy Intensity

The energy components described above are summed on Table 6.4-1. In 1976, the line transported 4,174,694 tons of coal. Thus the energy consumption was approximately

$$4,174,694 \times 1,065,000 = 4.446 \times 10^{12} \text{ Btu}$$

$$= 0.0044 \text{ Quad.}$$

The energy intensity is obtained by dividing the energy per ton by the 273.16-mile length of the pipeline.

$$\frac{1,065,000}{273.16} = 3899 \sim 4000 \text{ Btu/ton-mile.}$$

Two of the energy components in Table 6.4-1 require explanation. First, the pumping energy is that required to add approximately 7500 ft of head to the slurry as it moves through the pipe. However, it must be noted that the line falls 2600 ft from its head to its critical elevation 12 mi

TABLE 6.4-1

Energy consumption - Black Mesa Pipeline  
(Btu/ton of coal)

|  |                |
|--|----------------|
| Slurry Water Supply                      | 36,000         |
| Pipeline Operation                       |                |
| Pumping energy                           | 186,000        |
| Slurry preparation<br>& other operations | <u>155,000</u> |
|  | 341,000        |
| Deslurification                          |                |
| Initial separation                       | 205,000        |
| Moisture correction,<br>32 to 10.74%     | <u>483,000</u> |
|  | <u>688,000</u> |
| Total                                    | 1,065,000      |

from its terminal. Thus, if the purpose were an equal elevation comparison with other transport modes, it would be necessary to use

$$186,000 \times \frac{7500 + 2600}{7500} = 250,480 \text{ Btu/ton}$$

for the pumping energy.

Second, an estimated 80% of the energy for slurry preparation and other operations is used in grinding the coal, which would be necessary if the coal were transported in any other way, and therefore cannot fairly be charged to transportation. If allowance is made for that fact, only about

$$155,000 \times 0.2 = 31,000 \text{ Btu/ton}$$

would be charged to transportation. When these adjustments are made, the adjusted energy consumption given in Table 6.4-2 is obtained.

Several comments are in order. First, it must be recognized that all of the energy chargeable to the slurry pipeline mode of transport is still not in the calculation. For example, about a million dollars worth of chemicals per year are required in the deslurification process. Some energy is required to manufacture those chemicals, but the amount has not been determined, and thus is not included in the calculation. It is believed to be insignificant.

Second, it is interesting to compare magnitudes. The reader will recall from Sections 4.4.1 and 4.5.1 above that the energy consumption of the crude and products pipeline networks was estimated at 0.070 and 0.068 Quad respectively. Thus it has just been concluded that when all the energy that must be consumed has been taken into account, this single pipeline consumes a tenth as much energy as either the entire crude oil pipeline network or the products network.

TABLE 6.4-2

Adjusted energy consumption - Black Mesa Pipeline  
(Btu/ton of Coal)

|                     |                |
|---------------------|----------------|
| Slurry water supply | 36,000         |
| Pipeline operation  |                |
| Pumping energy      | 250,000        |
| Other operations    | <u>31,000</u>  |
|                     | 281,000        |
| Deslurification     |                |
| Initial separation  | 205,000        |
| Moisture correction | <u>483,000</u> |
|                     | <u>688,000</u> |
| Total               | 1,005,000      |

Third, it may be observed that the energy consumed in pumping the slurry is small compared to the deslurrification energy.

Fourth, the conclusion reached earlier in this program regarding the future of coal-slurry pipelines is supported. In report R-3025 of this series (see Table 1.1-1 above), the conclusion was reached that the coal slurry pipeline is a cost-effective and energy-effective mode of transport, but not in the coal-water form. The coal-methanol form offers promise of eliminating the energy penalties in the deslurrification process, and at the same time reducing the water requirement by a factor of three or four. Clearly, as was recommended in that report, the concept merits further study.

Finally, if one accepts the estimate of Zandi [1974] of 544 Bru/ton-mile for the energy intensity of a railroad to move the coal between the same two points, one sees an apparent large energy advantage for the railroad. However, this should not be extrapolated to future pipelines. As an example, Table 6.4-3 presents the energy consumption estimate of Energy Transportation Systems, Inc. (ETSI) for a 25 million ton/year, 1000-mi water slurry pipeline using advanced technology.

When these figures are adjusted on the same basis as used in Table 6.4-2, except that a gravity boost of 3000 ft was taken, the estimate shown in Table 6.4-4 is obtained. In Table 6.4-5, these results are rearranged to provide a direct comparison with the Black Mesa figures from Table 6.4-2. A dramatic sixfold reduction in EI is seen to result from the combined effects of greater distance (factor of four), greater scale (factor of six), later technology (10 years), and much less moisture to be removed (factor of 2.5).

TABLE 6.4-3

ETSI energy estimate  
(25 million tons coal/yr, 1000 mi)

|                      | <u>Energy</u>                         |  |
|----------------------|---------------------------------------|--|
|                      | $10^6 \frac{\text{kwhre}}{\text{yr}}$ | $10^{12} \frac{\text{Btu}}{\text{yr}}$ |
| Electric energy      |                                       |  |
| Slurrification       | 301                                   |  |
| Pumping              | 502                                   |  |
| Dewatering           | 146                                   |  |
| Water supply         | <u>40</u>                             |  |
| Subtotal             | 989                                   |  |
| Less grinding credit | <u>-226</u>                           |  |
| Net electric energy  | 763 =                                 | 2.60                                   |
| Steam energy         |                                       | <u>1.50</u>                            |
| Total energy         |                                       | 4.1                                    |

TABLE 6.4-4

Adjusted energy estimate - ETSI pipeline  
(25 million tons coal/yr, 1000 mi)

|   | <u>Energy</u>                      |                          |
|---|------------------------------------|--------------------------|
|   | 10 <sup>6</sup> <u>kwhre</u><br>yr | <u>Btu</u><br><u>ton</u> |
| Electric energy from grid<br>( $\eta = 0.22$ )  |                                    |                          |
| Slurification, net  | 340                                | 47,000                   |
| Pumping   | 2,572                              | 351,000                  |
| Water supply  | 182                                | 25,000                   |
| Electric energy from customer<br>power plant lines, initial<br>separation (station heat rate<br>= 11,100 Btu/kwhre) | 475                                | 65,000                   |
| Moisture correction, 32 to 26%  |                                    | <u>136,000</u>           |
|   |                                    | 624,000                  |

TABLE 6.4-5  
Comparison of adjusted energy consumption  
(Btu/ton of coal)

|                               | Black Mesa             | ETSI           |
|-------------------------------|------------------------|----------------|
| 273 mi                        | 1000 mi                |                |
| 10.74% moisture               | 26% moisture           |                |
| $4 \times 10^6$ tons          | $25 \times 10^6$ tons  |                |
| <u>1967 technology</u>        | <u>1977 technology</u> |                |
| Slurry water supply           | 36,000                 | 25,000         |
| Pipeline operation            |                        |                |
| Pumping energy                | 250,000                | 351,000        |
| Other operations              | <u>31,000</u>          | <u>47,000</u>  |
|                               | 281,000                | 398,000        |
| Deslurification               |                        |                |
| Initial separation            | 205,000                | 65,000         |
| Moisture correction           | <u>483,000</u>         | <u>136,000</u> |
|                               | <u>688,000</u>         | <u>201,000</u> |
| Total                         | 1,005,000              | 624,000        |
| Length of pipeline (mi)       | 273                    | 1,000          |
| Energy intensity (Btu/ton-mi) | 3681                   | 624            |

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