AN OPTIMIZATION PROGRAM TO MINIMIZE
THE COST OF NATURAL GAS

by

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B.S., Kansas State University, 1979

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A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1984

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ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

In the Natural Gas Industry production rate decisions are
dependent upon many factors. Ideally, all of these should be
considered when determining final production rates for individual
wells.

For example, it is desirable to attempt to produce wells
rateably. That is, to produce more from the underproduced wells
and less from the overproduced wells. The final goal of this
method of determining production rates is to have all wells
depleted at the same point in the future.

At the same time, it is desirable to minimize take-or-pay.
Take-or-pay is the penalty resulting from the underproduction of
a well. The amount of take-or-pay depends upon contractual
agreements between the producer and the owner of the well. In
addition, some amount of take-or-pay can usually be recovered by
overproduction at some future time. This again depends upon
contractual agreements. Since take-or-pay is, in effect, paying
for gas not received, its minimization is very important.

Another consideration to be made when determining production
rates for sources is system capacity. It is necessary to
consider the range of flow rates that each part of the
transportation system is physically capable of handling.
Minimizing take-or-pay may require a maximum production rate from

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every source in one field, while requiring a minimum production rate from every source in another field. It is possible that these rates will not be within the acceptable range of operating rates for the available transportation system.

Finally, because the Natural Gas Industry is highly competitive, it is important to minimize cost. Minimization is necessary if a competitive price for natural gas is to be maintained.

Each of the factors discussed thus far, when considered individually, will give different answers. Ultimately, a weighted solution is desired. The first step in the development of such a solution involves the development of methods for handling each of the factors individually.

To further improve this weighted method of flow rate determination, it is desirable to consider that the flow rate from each source may be changed monthly, and that a desirable solution over several time steps, or months, is necessary. In other words this solution should be applicable not only to one month studies, but to studies covering longer time periods as well. This type of temporal analysis can be used for planning future production programs.

As a first step in the solution of this very large problem, this paper presents a method of determining flow rates for a large number of natural gas sources over as many as sixty time steps. The program developed determines the flow rates for a minimum final cost of natural gas taking into consideration:

1) the time value of money

2) the changing prices of gas from existing wells
3) the decrease in reserves and maximum flow rates as a
   result of gas taken from a well
4) the need for each well to have the ability to have a
   unique minimum flow rate
5) the need for the user of the program to have the ability
   to change the desired rate for each time period.

Chapter II of this thesis is devoted to a discussion of the literature review that was undertaken. Nearly all of this review involved the use of the computerized search service available through Farrell Library. Four of the data bases which were searched are discussed.

In Chapter III, a discussion of the logic used to develop the final program can be found. This discussion carries the reader through the entire program, describing each of the inportant points.

Finally, Chapter IV presents the final results of this research project. Several special data sets are introduced, run through the program, and the results discussed.

CHAPTER II

LITERATURE REVIEW

At the onset of this project, the author of this paper had no feel for the amount of work that had already been done in this area. To insure that a solution had not already been published, an extensive literature search was undertaken. The majority of the search was done using the Computerized Search Service available through Farrell Library. A discussion of the results of these searches follows.

COMPENDEX DATABASE

Initially, a search was made of the COMPENDEX database. This database is the machine readable version of the Engineering Index. It covers approximately 3500 journals, engineering society and organization publications, conference proceedings and government reports. Using key words of

       1) Extremum of Function or Optimize or Maximize or Minimize and

       2) Natural Gas or Well and

       3) Production

resulted in 51 abstracts that appeared at first glance to be related to the problem under study. Of these abstracts, only one proved to be of any value. This article, entitled "Computerized System to Optimize Daily Oil and Gas Production in Kuwait" by

Cain and Shehata appeared by title to be precisely the type of article desired. Acquisition of the article proved discouraging in that it covered the optimization of scheduling regular maintenance with production schedules. Although not the same problem as the one under study, the solution arrived at by Cain and Shehata was one requiring the use of linear programming techniques. Theirs was a much smaller scale problem than the one considered here. They state that "The full-size problem normally consists of 400 to 500 constraints and between 1,300 and 1,500 variables." Further, they indicate that the solution process may be rather time consuming "In operation, 1 to 1 1/2 hours is allowed for running the model and dispatching the results to the field". It is impossible to know how much of the time alloted was necessary for the problem solution and how much was for dispatching the results. However, even if only 30 minutes of the time was required for problem solution, it becomes evident that a problem of the magnitude being considered in this thesis could not be solved in the same manner without requiring an excessive amount of computer time.

As is often the case, the paper by Cain and Shehata contained a reference in its Bibliography to another publication that was more helpful than the original. This publication was entitled "Mathematical Models to Help Manage the Oil Resources of Kuwait" by Ali, Beasley, Batchelor, and Beale. This article proved to be more along the lines of the problem being considered here. Although the problem was not exactly like that being studied, there were enough similarities to confirm that the method of

solution being used was an accepted method. The Ali, Beasley, Batchelor, and Beale article states: " The first joint development was a model to specify a schedule of wells to use in meeting a given daily total production rate. The schedule has to operate within the capacity limits of the plant, produce oil of the right quality, satisfy demands on the various gas streams and optimize liquid gas production while attempting to meet reservoir engineering requirements: This is a natural application of linear programming,...". Even though this description sounds very much like the problem under study, there was one very important difference, that being again, the magnitude of the problem. The Ali, Beasley, Batchelor, and Beale article stated, near it's conclusion " The latest problem solved has 2336 constraints and 4392 linear programming variables. So...each new problem still requires several hours of CPU time on the Univac 1108 Computer." If 4392 variables required several hours of CPU time, the time required by 300,000 variables was sure to be prohibative.

At this point in the search, two articles had been found that described problems similar to that being studied, both used typical linear programming techniques, and both indicated that a considerable amount of computer time was required for a small number of variables.

INSPEC DATABASE

Another database known as the INSPEC was searched. This database covers the fields of physics, electrotechnology,

computers, and control. This database includes: journal papers, conference proceedings, technical reports, books, patents, and university thesis. Using key words of

1) Gas and

2) Natural Gas or Well and

3) Automatic Control or Computer Control or Computer Optimization or Computer Production

resulted in 40 abstracts. Many of these dealt with topics much different than the one being studied. Some of the areas brought out by this search included:

1) Geothermal Wells

2) Microprocessor based controls

3) Automatic Pipeline Control and

4) Chemical Controls

None of these were of any value. However, several did mention optimization problems that required the use of linear programming techniques.

DOE ENERGY DATABASE

Finally, the DOE ENERGY database was searched, and abstracts were received. This database is one of the worlds largest sources of literature references on all aspects of energy and related topics. It provides coverage of journal articles, report literature, conference papers, books, patents, dissertations and translations. Using the key words of

1) Production and

2) Natural Gas or Well and

3) Computer Optimization

resulted in 34 abstracts. Of these 34, two were those already discussed, namely the Cain and Shehata article, and the Ali, Beasley, Batchelor, and Beale article. Additionally, an article entitled "Seeking Optimum-Profit Production Decisions" by Cavaroc and Sylla was discovered. This article discussed a solution to a problem very similar to the one being studied. It summarized the problem as one which requires the "determination of production rates that will yeild the maximum profit from this reservoir, subject to the unit allowable and production characteristic limitations." Although never stated, the problem discussed by Cavaroc and Sylla was probably much smaller in scope than the one to which this thesis addresses itself. Several places, the use of a matrix solution was mentioned. The authors stated: "Another advantage of this approach is the simplicity of the mathematics involved, which consists merely of a logical and systematic algebraic expression of the problem, supplemented with a limited knowledge of matrix algebra." A matrix solution, although very common, is unreasonable to use for a problem of the size being considered here. It's use by Cavaroc and Sylla only strengthens the belief that a solution to a problem of this magnitude had not been published.

APALIT DATABASE

A short search through APALIT database was conducted. This data base covers all aspects of information dealing with the American Petroleum Institute. It primarily covers journal articles, conference proceedings, books, and reports dealing with petroleum and petroleum products from the wellhead through the

pipeline. This search revealed so little that a copy of abstracts was not even requested. Although this search produced nothing of any value the fact that it was conducted, and that the American Petroleum Institute database gave no worthwhile references is worth mentioning.

In addition to the computerized literature searches, many text and other reference books were used to complete this thesis.

The literature search conducted as part of the completion of this project has been informative. It has indicated that this specific problem, in this magnitude has not previously been considered. Algorithms exist which handle much smaller sets of data. However, for this problem, the increase in problem size brought on the realization that previously used techniques of matrix solutions were not applicable.

CHAPTER III

METHODS AND PROCEDURES

A set of equations were developed which describe the relationship between the amount of gas taken from each source in each time step and the overall gas cost. These equations were supplemented by a large number of constraints that limited the solution to the problem. Since the problem was a linear one, linear programming techniques were investigated, and were partially used in the development of the final computer program. The steps followed from initial equation development to final program results will be detailed in this chapter.

Theoretical

Cost Equation

Linear problems that need to be maximized or minimized must first be formulated into an equation. This equation must relate all of the unknown variables to the parameter being maximized or minimized. In this case, an equation needed to be developed that related the total cost of the gas produced over "m" time periods to the rate of gas production from "n" sources in each of those time periods.

Several considerations were made in the development of the cost equation to make it more realistic. The equation in its simplest form is shown below.

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$$\text{Cost} = R_{1,1}(C_{1,1}) + R_{1,2}(C_{1,2}) + R_{1,3}(C_{1,3}) + \dots +$$
$$R_{1,n}(C_{1,n}) + R_{2,1}(C_{2,1}) + R_{2,2}(C_{2,2}) +$$
$$R_{2,3}(C_{2,3}) + \dots + R_{2,n}(C_{2.n}) + \dots +$$
$$R_{m,1}(C_{m,1}) + R_{m,2}(C_{m,2}) + R_{m,3}(C_{m,3}) + \dots +$$
$$R_{m,n}(C_{m,n})$$

Where R-rate of flow from any given source
C-cost of the gas
m-total number of time periods being considered
n-total number of sources being considered

The first subscript on each of the terms refers to the time period being considered (up to 60), while the second subscript refers to the source being considered (up to 5000).

In order to make the individual cost terms more realistic, several factors were introduced. Each gas source was assigned an initial gas cost for time period one. This cost was then adjusted for each subsequent time period, taking into consideration the time value of money, and the actual escalation of natural gas prices.

The magnitude of the escalation factor was dependent upon the Natural Gas Policy Act (NGPA) code assigned to the source, and in some cases upon the month of the year. Each of these escalated prices were then brought back to present worth using the equation:

$$P = F\ [1/(1+i)^n]$$

Where P- present worth of the cost term
F- future worth of the cost term
i- inflation rate per time period
n- number of time periods

The individual cost terms in the overall cost equation can be mathematically described by:

$$C_{m,n} = C_{1,n}(\text{escalation factor})^{m-1}$$
$$(\text{inflation factor})^{m-1}$$

Constraints

Earlier, introduction of constraints used to limit the problem were mentioned. One of these constraints was a specified flow rate to be achieved in each time period. The sum of the rates from each source in a given time period must be equal to this specified rate. The user of the program must specify these desired rates.

Once specified, these rates were labeled $R(1)$, $R(2)$, $R(3)...R(m)$. In equation form

$$R(1) = R_{1,1} + R_{1,2} + R_{1,3} + \cdots + R_{1,n}$$
$$R(2) = R_{2,1} + R_{2,2} + R_{2,3} + \cdots + R_{2,n}$$
$$R(m) = R_{m,1} + R_{m,2} + R_{m,3} + \cdots + R_{m,n}$$

These desired rate equations were used to eliminate the highest priced gas source from the cost equation. The highest priced source was the one chosen to be eliminated for several reasons. First, since the cost was to be minimized, the highest priced source was the least likely to be assigned a gas flow above its minimum required flow. Second, eliminating the highest priced source resulted in all negative coefficients in the overall cost equation. The need for negative coefficients will become clear later.

The desired rate equations were rewritten to isolate the highest priced source. If the subscript "k" is used to indicate

the highest priced source then

$$R_{1,k} = R(1) - R_{1,1} - R_{1,2} - R_{1,3} \cdots - R_{1,k-1} - R_{1,k+1} \cdots - R_{1,n}$$

$$R_{2,k} = R(2) - R_{2,1} - R_{2,2} - R_{2,3} \cdots - R_{2,k-1} - R_{2,k+1} \cdots - R_{2,n}$$

$$R_{m,k} = R(m) - R_{m,1} - R_{m,2} - R_{m,3} \cdots - R_{m,k-1} - R_{m,k+1} \cdots - R_{m,n}$$

Substituting these into the cost equation results in the equation below.

$$
\begin{aligned}
Cost = &R_{1,1}(C_{1,1}) + R_{1,2}(C_{1,2}) + R_{1,3}(C_{1,3}) \\
&+ \ldots + R_{1,k-1}(C_{1,k-1}) + [R(1) - R_{1,1} - R_{1,2} \\
&- R_{1,3} \cdots - R_{1,k-1} - R_{1,k+1} \cdots - R_{1,n}]C_{1,k} \\
&+ R_{1,k+1}(C_{1,k+1}) + \ldots + R_{1,n}(C_{1,n}) + \ldots \\
&R_{2,1}(C_{2,1}) + R_{2,2}(C_{2,2}) + R_{2,3}(C_{2,3}) \\
&+ \ldots + R_{2,k-1}(C_{2,k-1}) + [R(2) - R_{2,1} - R_{2,2} \\
&- R_{2,3} \cdots - R_{2,k-1} - R_{2,k+1} \cdots - R_{2,n}]C_{2,k} \\
&+ R_{2,k+1}(C_{2,k+1}) + \ldots + R_{2,n}(C_{2,n}) + \ldots \\
&R_{m,1}(C_{m,1}) + R_{m,2}(C_{m,2}) + R_{m,3}(C_{m,3}) \\
&+ \ldots R_{m,k-1}(C_{m,k-1}) + [R(m) - R_{m,1} - R_{m,2} - \\
&- R_{m,3} \cdots - R_{m,k-1} - R_{m,k+1} \cdots - R_{m,n}]C_{m,k} \\
&+ R_{m,k+1}(C_{m,k+1}) + \ldots + R_{m,n}(C_{m,n})
\end{aligned}
$$

Regrouping terms gives the equation below.

$$
\begin{aligned}
Cost = &R(1)C_{1,k} + R(2)C_{2,k} + R(3)C_{3,k} + \ldots + R(m)C_{m,k} + \\
&R_{1,1}(C_{1,1} - C_{1,k}) + R_{1,2}(C_{1,2} - C_{1,k}) + R_{1,3}(C_{1,3} - C_{1,k}) + \ldots + \\
&R_{1,k-1}(C_{1,k-1} - C_{1,k}) + R_{1,k+1}(C_{1,k+1} - C_{1,k}) + \ldots + R_{1,n}(C_{1,n} - \\
&C_{1,k}) + R_{2,1}(C_{2,1} - C_{2,k}) + R_{2,2}(C_{2,2} - C_{2,k}) + R_{2,3}(C_{2,3} - \\
&C_{2,k}) + \ldots + R_{2,k-1}(C_{2,k-1} - C_{2,k}) + R_{2,k+1}(C_{2,k+1} - C_{2,k}) + \ldots + \\
&R_{2,n}(C_{2,n} - C_{2,k}) + \ldots + R_{m,1}(C_{m,1} - C_{m,k}) + R_{m,2}(C_{m,2} - C_{m,k}) + \\
&R_{m,3}(C_{m,3} - C_{m,k}) + \ldots + R_{m,k-1}(C_{m,k-1} - C_{m,k}) +
\end{aligned}
$$

$$R_{m,k+1}(C_{m,k+1}-C_{m,k})+\cdots+R_{m,n}(C_{m,n}-C_{m,k})$$

This substitution has resulted in the cost equation having several interesting and helpful characteristics. First, the first "m" terms represent the maximum possible cost of the gas. In other words, these represent the cost of the gas if, in each time step, the gas was all taken from the highest priced source. This is a worst case situation that can only be improved. Second, each of the rate coefficients has taken on a negative value. Each of these coefficients is the difference between the cost of gas for a given source in a given time period and the cost of gas from the highest priced source in the same time period. Clearly, upon reflection, to minimize the overall cost, or to decrease the large positive number at the beginning of the cost equation, it will be necessary to take as much gas as possible from the source with the next largest negative coefficient. This process should be repeated until all flow requirements are met.

The introduction of a limited production range for each source is another constraint used to contain the problem. The user must specify an initial minimum and maximum allowable production rate. The minimum rate remains constant throughout the study while the maximum rate decreases as the supply of natural gas available decreases.

Solution Format

Problems similar to the problem under study are usually solved through the use of linear programming techniques. However, such an approach gives rise to a matrix solution. In addition, this appproach requires the introdution of slack

variables into the problem. Slack variables are variables used to remove inequalities from restraint equations. For example, the equation

$$R_{1,1} + R_{2,1} + R_{3,1} + R_{4,1} < R(1)$$

would become, with the introduction of slack variables, the following two equations

$$R_{1,1} + R_{2,1} + R_{3,1} + R_{4,1} + S_1 = R(1)$$
$$0 < S_1 < R(1)$$

One such variable is required for each constraint that involves an inequality. Since the rate of gas flow from each source is constrained by a maximum and a minimum desired flow rate, these constraints are all inequalities. As a result, one slack variable would have to be introduced for each unknown rate. Since the problem at hand could involve up to 300,000 unknowns (5000 sources * 60 time steps) before any slack variables are introduced, a matrix solution seemed impractical, hence a solution requiring less active storage space on the computer was desired.

Computer Programs

The solution used required the development of a series of two computer programs capable of handling a problem containing up to 300,000 unknown variables without using an excessive amount of active computer memory. Copies of these programs can be found in Appendix I. The final programs developed use two data files to handle all of the necessary information. The first data file contains one card for each desired rate (up to 300,000 cards) while the second data file contains one card for each source (up

to 5000 cards).

The desired rate cards contain four pieces of data: namely

        1) The source number

        2) The time step being considered

        3) The coefficient for the rate term in the
            cost equation

        4) The desired rate (the unknown)

These cards are generated by the program rather than being
supplied by the user.

The source cards contain nine pieces of data: namely

        1) The state code

        2) The field code

        3) The source name (well name)

        4) A flag to indicate whether the well is deep
            or shallow

        5) The allowable production rate for the source

        6) The minimum production rate

        7) The maximum production rate

        8) The price of the gas in time period one

        9) A flag to indicate whether the NGPA code
            is 102 or 108, or not 102 or 108

The information required for these cards is supplied by the user.

The desired rate cards are created and sorted. Following
this, they are accessed only once. The source cards, on the
other hand, are created and then referenced up to 60 times each
in an unpredictable order. As a result, the source card file is
a direct access input/output file (Direct Access I/O). The
desired rate file is a sequential file.

Each of the pieces of data on these two data cards deserves particular discussion.

The first two items on the desired rate cards fully describe the case being determined. For example, one card may refer to the 67th source in the 23rd time period, while another may refer to the 68th source in the 23rd time period. The third item is the actual coefficient as it would be determined for the cost equation. This would be the coefficient that would appear in the final form of the cost equation. The last item is the desired output of the program, the answer.

The first three items on the source cards fully identify the gas source. The cards are in a particular order, and the source number used on the desired rate cards corresponds to the position in the data file of the source card. For example, the first source card would have a source number of one, the third a source number of three etc. As a result, it is not necessary to have the source number as one of the identifying pieces of data on the source card. The fourth item on the source card is a flag indicating the relative depth of the source. This piece of information is used to calculate the initial reserves for a given source. A shallow well (depth indicator = 1) is assumed to have initial reserves equal to 20 years production at the monthly allowable rate or 240*Allowable.

A deep well (depth indicator = 0) is assumed to have initial reserves equal to 10 years production at the monthly allowable rate or 120*Allowable.

The fifth item on the source card is the allowable monthly

production rate for the well. This value is used along with the depth indicator to calculate the initial reserves for the source.

The sixth item is the minimum production rate for the well. This value corresponds to the smallest amount of gas that can be taken from a source in any given time period without violating contractual agreements between the producer and the company buying the gas.

The seventh item is the maximum production rate. This maximum rate decreases as gas is taken from a source. This decrease is calculated by finding the percentage decrease in the reserves, and applying that same percentage decrease to the maximum rate.

The eighth item is the initial price of the gas. The calculation of the coefficient for the cost equation depends upon this value.

The last item is the NGPA code flag. All wells are escalated in price .5% per month. In addition, wells with an NGPA code of 102 or 108 (NGPA code flag=1) are escalated in price an additional 4% each December. These considerations go into the calculation of the cost equation coefficients.

Two flow charts showing the basic steps followed by the computer programs in solving the problem are shown the Appendix II. As shown in the first flow chart, the user must supply several pieces of data. These include:

    1) The number of sources being considered

    2) The number of time steps being considered

    3) The beginning month (1-12 January-December)

4) The monthly inflation factor to be used

5) The desired rates for each of the time steps

6) The information for the source cards.

Once items one through five above have been accepted by the program, the first source card is read in. The allowable rate and the depth indicator from that source card are used to calculate the initial reserves for the source. The source is then tested to see if it is the highest priced source encountered thus far. If it is, the source number (the number of source cards thus far read in) is saved, along with the price and the NGPA code associated with that source. As a final step, before the source card is created, the minimum rate for this source is added to a running total of all of the minimum's for all of the sources being studied. Finally, a card in the source data file is created using the information from this source. This cycle is repeated once for each source in the study.

When completed, all of the data cards in the source file have been created, the highest priced source has been identified, and the algebraic sum of all of the required minimum flow rates has been calculated. The source number, initial price and NGPA code for the highest priced source have also been identified and saved.

Once the source file has been created, the program begins the process of creating the desired rate file. The source file is referenced one element at a time, beginning with the first element and proceeding sequentially through the file. A month

flag is set to the initial month (specified by the user at the beginning of the program), and the Price and NGPA code are read off of the source card. A check is made to insure that the source being considered is not the highest priced source. If such is the case, the program skips out of the loop, and selects the next source card. Finally, the coefficient for the source being considered is calculated for this time period using the initial price, the escalation factor (based on NGPA code), the inflation factor and current time period for the source being considered as well as for the highest priced source. This coefficient is then used to create a data file element. Additionally, an initial rate equal to the minimum required rate is written to the data card. The desired rate card contains, at this point, the source number, the time step number, the calculated coefficient, and the desired rate (initially set to the minimum required rate).

The steps described above are repeated once for each time step to be considered without changing the source. Before each pass through the loop, the time step number and month are incremented by one. When the first set of these passes is completed, the desired rate file contains a number of data cards equal to the number of time steps being considered. Each data card has the same source number and the same desired rate, but different time step numbers and different coefficients.

The process, beginning with the reading of a source card, is repeated until all source cards have been read. This, when completed will have resulted in the creation of the entire

desired rate file. At this point, the file contains data cards
arranged by source number and time step, with all desired rates
set at the sources minimum acceptable flow rates.

As discussed earlier, all of the coefficients should be
negative and will need to be dealt with in order of decreasing
absolute value. The program deals with this problem by using a
Sort Processor to sort the data cards of the desired rate file.
This new sorted desired rate file is organized in such a manner
that its elements are in order of cost equation coefficients, but
can be linked to a particular source and time step by the first
two pieces of data on each card.

Before the second program deals with the sorted desired rate
file, the first program calculates the large positive number at
the beginning of the cost equation and saves that information.
This number represents the cost of the gas if all of the gas for
each time step is taken from the most expensive source.

Once all of the above steps have been completed, the second
program begins execution, and the first
desired rate card can be dealt with. This card should represent
the source and time step with the largest negative coefficient,
or in other words, the least expensive gas available. This card
will contain information relating it to a particular source. The
source card for that source must also be used in the
determination of a final desired rate.

Several things must be considered when determining the final
desired rate for a source. Namely:

> 1) Is the overall desired rate for this time step
>   satisfied? ·

    2) If the overall desired rate is not satisfied, is it less than the maximum allowable rate for this source?

    3) Are the reserves for this source depleted?

    4) If the reserves are not depleted, are they less than the maximum allowable rate for this source?

Taking into consideration all of these things, the final desired rate is determined.

Once a final desired rate has been determined, several of the parameters of the problem must be adjusted. These include:

    1) The desired rate for the time step

    2) The reserves of the source

    3) The maximum allowable rate for the source

The last two of these changes replace previous values, and are written back to the source card file with the other source information.

As a final set of steps in this portion of the program, the final results are printed out, and the total cost term is adjusted by the product of the coefficient of this source and its final desired rate. This product will be a negative number and will decrease the large positive number at the beginning of the cost equation.

The entire process is repeated until all of the coefficient cards have been examined in their sorted order. At this point in the solution process, a final desired rate has been assigned to all of the sources for each of the time steps with the exception of the highest priced source. This source is assigned a rate above its minimum rate only if, after all of the other sources

have been assigned final rates, the desired rate for any time period is still not satisfied.

Finally, the program prints out the final overall cost.

CHAPTER IV

RESULTS AND DISCUSSION

This thesis has presented, to this point, the logic used
and steps followed in the development of a computer program to
minimize the cost of natural gas from a large number of sources
over a long time frame. The program was written to handle as
many as 5000 gas sources over as many as 60 time steps.

To show that the original objective of the project has been
met, several special sets of data were used. The results of
these special cases will be discussed in this chapter. All of
the numbers used in the data sets are realistic numbers, but have
been identified by source names that cannot be traced to actual
gas sources. This has been done to protect against the release
of any proprietary information which may have been used in the
development of this program.

The first data set used consisted of seventy-one gas sources
and used the full 60 time step range. A copy of this data set,
labeled DATA SET I can be found in Appendix III. This was the
largest set of data used, and it was intended to show several
desired results. First of all, the program was handling, with
this data set, 4260 unknowns. This is a number comparable with
several of the data sets discussed in Chapter II . The total
time required by the program to execute when dealing with this

number of unknowns was four minutes and thirteen seconds. This is a very short execution time when compared with any of the programs discussed in Chapter II. Undoubtedly the amount of time required to execute the program with the largest possible data set would be very large, but this program appears to be much more efficient than those already in existence.

A second result that can be shown from this large data set is that the desired rate specified in the data cards is met. An entry in Appendix III labeled DESIRED RATE SUM FOR ALL FIELDS IN TIME PERIOD ONE (DATA SET I) shows this. On this summary sheet are all of the assigned rates for the first time period. One rate is given for each source in the study. Their sum is the desired rate specified in the input data set.

A second data set almost exactly the same as the first was used to show that the program does indeed minimize cost. In this data set, the least expensive gas source was given a minimum and a maximum flow rate of zero. This should have forced the program to satisfy the required rates by using more expensive gas than would have been necessary with the first data set. As a result, the final cost of the gas should have risen slightly to indicate that the program was responding as expected. The total cost of the gas when utilizing the cheapest source was $393,810,044.00, while the cost of the gas when the cheapest source was restrained was $394,187,640.00. An entry in Appendix III entitled "Final Costs For 60 * 71 Data Sets" shows these final costs. This slight increase in cost was precisely what was expected.

The last three data sets were smaller than the first two,

and were used to show that cost of the gas was calculated properly, that the program followed given constraints and that the desired rates were satisfied.

The first of these smaller data sets restrained all but the cheapest of twelve sources. As a result only the least expensive source should have been assigned a flow rate. A copy of this data set (labeled DATA SET II), and part of the results printed out by the program (labeled RESULTS OF DATA SET II) are shown in Appendix III.

Similarly, in the second of the samller data sets, all of the sources except an intermediate priced well were restrained. This should have resulted in only the intermediate priced well receiving an assigned flow rate. Again, the results proved to be what was expected. Part of the results printed out by the program (labeled Results of Data Set III) are shown in Appendix III.

Finally, the last of the smaller data sets restrained all but the most expensive of the twelve sources, and had the expected results. Part of these results are shown in Appendix III (labeled Results of Data Set IV).

Several results from the last three data sets discussed deserve particular attention.

The final costs resulting from these data sets should be in an expected order, with the least expensive source producing the lowest final cost, the intermediate source producing an intermediate final cost, and the highest priced source producing the highest final cost. Copies of the computer printout showing

these total costs can be found in Appendix III (labled Final Costs for Data Sets II, III, and IV). The actual results are shown in the table below.

<u>TOTAL</u> <u>COST</u> <u>TABLE</u> <u>FOR</u> <u>DATA</u> <u>SETS</u> <u>II</u>,<u>III</u>, <u>AND</u> <u>IV</u>

Description of Data	Total Final Cost
Data Set II	$11,023.98
Data Set III	$72,959.63
Data Set IV	$105,023.67

These results are exactly what was expected.

Also worthy of mention is the match between the actual assigned rates for the sources and the desired rates specified by the input data set. For example, Data set II (Appendix III) shows a desired rate for time period three as $1.8 * 10^3$. The output for Data set II (Appendix III) shows time step three with an assigned rate of 1800 units.

Finally, the order of the assigned rates on the printout is of particular significance. Since, in this particular data set, (Data set II) the starting month was specified as month 4, and since it is being compared with the highest priced source for coefficient calculations, the ninth month or December has the largest coefficient. This results because the highest priced source is one that is escalated an extra 4% in December.

As a last check, sample calculations for the determination of the maximum flow rate reduction, and for the calculation of a coefficient are included in Appendix IV. The computer printout showing the actual maximum flow rate reduction (labeled Data Supporting Maximum Flow Rate Reduction Calculations) can be found in Appendix IV. Similarly, the actual coefficient given by the

program is shown in Appendix III (labeled Results of Data Set II), and agrees with the calculation in Appendix IV.

CHAPTER V

RECOMMENDATIONS

At the onset of this project, an objective statement was set forth which was

> "To develop a program to minimize the cost of natural gas from a large number of sources over a long time frame."

The results presented by this paper satisfy this objective. However, as with any problem, there are a number of modifications which could be made to make the program more realistic.

The greatest room for improvement in the solution that the author sees lies with the problem of December price escalation. This escalation causes flow rates to be assigned to some sources in an order that is not chronological. The problem with this unordered assignment of flow rates results from the fact that the maximum rate allowed any source is decreased after each flow rate is assigned. As a result, the maximum rate and reserves for some sources are not in the proper order. As an example, the results from Data set II shown in Appendix III give the reserves for source one as 569,520 in time step 9, and 567,520 in time step 1. In actuality, the reserves must decrease with time.

Another area that could be modified is the method used to calculate initial reserves. The method used in this solution assumes that every well has at least ten years reserves

29

available. A more satisfactory solution would result if actual well data could be analyzed for each source so that a more realistic number could be used. This was not done, primarily, in an effort to protect proprietary information from publication.

The method used to decrease maximum allowable flow rates following each rate assignment could also be improved. The percentage decrease used in this program is better than allowing the maximum rate to remain constant, but the author believes a better method exists. This is an area that could be the subject of further investigation.

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APPENDIX I

COMPUTER PROGRAM NUMBER I

```
      DIMENSION R(60)
      CHARACTER*20 NAME
      REAL MIN,MAX
      IRCDS=100
      INO=5
      OPR1=0.
      IONGPA=0
      COST=0.
      TMIN=0.
      LS=0
      NSCC=1
      IRECL=70
      ICCT=1
      BESCAL=1.005
      DECESC=1.045
      OPEN(14,ACCESS='DIR',RECL=IRECL,RCDS=IRCDS,FORM='FORMATTED')
C     BESCAL-BASE ESCALATION FACTOR (PER MONTH)
C     DECESC-DECEMBER ESCALATION FACTOR
C     MEXP-COUNTER INDICATING THE NUMBER OF DECEMBERS THAT HAVE PASSED
C     R(I)-DESIRED RATE FOR EACH TIME PERIOD
C     INO-SOURCE FROM WHICH DATA IS READ
C     OPRI-PRICE OF THE HIGHEST PRICED GAS
C     IONGPA-NGPA CODE OF THE HIGHEST PRICED GAS
C     NS-NUMBER OF SOURCES
C     NTS-NUMBER OF TIME STEPS
C     MONTH-(A NUMBER) THE MONTH OF THE FIRST TIME STEP
C     FACINF- INFLATION FACTOR
C     ALL-ALLOWABLE
C     MIN-MINIMUM FLOW FOR A GIVEN SOURCE
C     MAX-MAXIMUM FLOW FOR A GIVEN SOURCE
C     ISTCD-STATE CODE
C     IFLDCD-FIELD CODE
C     NAME-WELL NAME
C     IDPTH-INDICATES A DEEP (0) OR A SHALLOW (1) WELL
C     PRICE1-PRICE OF THE GAS IN THE SOURCE BEING CONSIDERED
C     NGPACD- NGPA CODE FOR THE SOURCE BEING CONSIDERED.   102 OR 108
C         NGPACD=1  OTHERWISE NGPACD=0
C     NSU-NUMBER OF SOURCES USED.  A COUNTER
C     COEFF- COEFFICIENT FOR THE COST EQUATION ( AN ARRAY)
C     COST-COST OF THE GAS OVER ALL TIME PERIODS.( TO BE MINIMIZED)
C     RES-WELL RESERVES
C     TMIN-TOTAL OF MINIMUM TAKES
C     LS-IDENTIFYING NUMBER FOR THE HIGHEST PRICED SOURCE
C     MONO-ORIGINAL STARTING MONTH
C     NSCC-NUMBER OF SORTED CARDS COUNTED
C     NCS-NUMBER OF SORTED CARDS
C     ICCTR-COEFFICIENT COUNTER
C
C     READ IN NUMBER OF SOURCES, NUMBER OF TIME STEPS, BEGINNING
C        MONTH, MONTHLY INFLATION FACTOR, AND DESIRED MONTHLY RATES
C        AND WRITE TO UNIT 17
C
      READ(INO,1000) NS,NTS,MONTH,FACINF
      READ(INO,2000) (R(I),I=1,NTS)
      WRITE(17,1000)NS,NTS,MONTH,FACINF
      WRITE(17,2000)(R(I),I=1,NTS)
C
C     SEARCH FOR HIGHEST PRICED GAS AND SAVE INFO ON THAT WELL,
C        DO RESERVE CALCULATIONS, FIND THE SUM OF THE MINIMUMS AND
C        WRITE DATA TO A RECORD
C
      DO 80 I=1,NS
      READ(INO,3000) ISTCD,IFLDCD,NAME,IDPTH,ALL,MIN,MAX,PRICE1,NGPACD
      IF(IDPTH.EQ.1) GO TO 120
      RES=120.*ALL
      GO TO 130
  120 RES=240.*ALL
  130 CONTINUE
      IF(PRICE1.LE.OPR1) GO TO 90
      OPR1=PRICE1
      LS=NS      *LABEL THIS SOURCE AS THE HIGHEST PRICED SOURCE
      IONGPA=NGPACD    *SAVE THE NGPA CODE OF THE HIGHEST PRICED SOURCE
   90 TMIN=TMIN+MIN
```

COMPUTER PROGRAM NUMBER I

CONTINUED

```
C
C       STORE SOURCE INFO IN A DIRECT ACCESS FILE
C
        WRITE(14'I,3000) ISTCD,IFLDCD,NAME,IDPTH,RES,MIN,MAX,PRICE1,NGPACD
   80 CONTINUE
C
C       WRITE LS,OPR1,ICNGPA, AND TMIN TO POSITION 1 OF THE COEFFICIENT FILE
C
        WRITE(17,3500)LS,OPR1,IONGPA,TMIN
C
C       CALCULATION OF COEFFICIENTS
C
        MONO=MONTH
        NSU=1    ICOUNTER FOR NUMBER OF SOURCES USED
   60 READ(14'NSU,310C) PRICE1,NGPACD
        MONTH=MONO
        IF(NSU.EQ.LS) GO TO 140  DELIMINATE HIGHEST PRICED GAS
        DO 50 J=1,NTS
        IF(NGPACD.EQ.1)GO TO 300 DIS THIS SOURCE NGPA 102 OR 108
        KFLAG=0
        GO TO 310
  300 KFLAG=1
  310 IF(IONGPA.EQ.1) GO TO 320 DIS HIGHEST PRICED SOURCE NGPA 1C2 OR 108
        LFLAG=0
        GO TO 330
  320 LFLAG=1
  330 CONTINUE
        IF(KFLAG.NE.0.OR.LFLAG.NE.0) GO TO 340
        COEFF=-OPR1*BESCAL**(J-1)/FACINF**(J-1)+PRICE1*BESCAL**(J-1)/
       AFACINF**(J-1)
        GO TO 460
C
C       DETERMINE THE NUMBER OF DECEMBERS THAT THE STUDY HAS PASSED THROUGH
C
  340 MEXP=MONTH/12
        IF(LFLAG.NE.0) GO TO 410
        COEFF=-OPR1*BESCAL**(J-MEXP-1)*DECESC**MEXP/FACINF**(J-1)+PRICE1
       A*BESCAL**(J-MEXP-1)*DECESC**MEXP/FACINF**(J-1)
        GO TO 460
  410 IF(LFLAG.EQ.0) GO TO 420
        COEFF=-OPR1*RESCAL**(J-MEXP-1)*DECESC**MEXP/FACINF**(J-1)+PRICE1
       A*BESCAL**(J-MEXP-1)*DECESC**(J-MEXP-1)/FACINF**(J-1)
        GO TO 460
  420 COEFF=-OPR1*RESCAL**(J-1)/FACINF**(J-1)+PRICE1*BESCAL**(J-MEXP-1)
       A*DECESC**MEXP/FACINF**(J-1)
  460 CONTINUE
        ICCTR=ICCTR+1
        TAKE=MIN $INITIAL RATE FOR EACH IS MIN
        MONTH=MONTH+1
   50 WRITE(15,4000)NSU,J,COEFF,TAKE
  140 IF(NSU.EQ.NS) GO TO 70
        NSU=NSU+1
        GO TO 60
   70 CONTINUE
C
C       CALCULATE INITIAL COST AND WRITE THAT COST TO COEFFICIENT FILE
C
        MONTH=MONO
        DO 110 I=1,NTS
        IF(IONGPA.NE.1) GO TO 141
        MEXP=MONTH/12
        COST=COST+OPR1*DECESC**MEXP*BESCAL**(I-1-MEXP)/FACINF**(I-1)*R(I)
        GO TO 110
  141 COST=COST+OPR1*PESCAL**(I-1)/FACINF**(I-1)*R(I)
  110 MONTH=MONTH+1
C
        WRITE(17,3700) COST
 1000 FORMAT(I4,I2,I2,F5.3)
 2000 FORMAT(6E13.5)
 3000 FORMAT(I2,I4,A20,I1,F10.0,F10.C,F10.0,F6.4,I1)
 3100 FORMAT(57X,F6.4,I1)
 3500 FORMAT(I4,F6.4,I1,F15.0)
 3700 FORMAT(F15.2)
 4000 FORMAT(I4,I2,F8.4,F10.0)
        STOP
        END
```

COMPUTER PROGRAM NUMBER II

```
      DIMENSION R(60)
      CHARACTER*20 NAME
      REAL MIN,MAX
      IRCDS=100
      INO=5
      OPR1=0.
      IONGPA=0
      COST=0.
      TMIN=0.
      LS=0
      NSCC=1
      IRECL=70
      ICCTR=1
      OPEN(14,ACCESS='DIR',RECL=IRECL,RCDS=IRCDS,FORM='FORMATTED')
C     MEXP-COUNTER INDICATING THE NUMBER OF DECEMBERS THAT HAVE PASSED
C     R(I)-DESIRED RATE FOR EACH TIME PERIOD
C     INO-SOURCE FROM WHICH DATA IS READ
C     OPR1-PRICE OF THE HIGHEST PRICED GAS
C     IONGPA-NGPA CODE OF THE HIGHEST PRICED GAS
C     NS-NUMBER OF SOURCES
C     NTS-NUMBER OF TIME STEPS
C     MONTH-(A NUMBER) THE MONTH OF THE FIRST TIME STEP
C     MIN-MINIMUM FLOW FOR A GIVEN SOURCE
C     MAX-MAXIMUM FLOW FOR A GIVEN SOURCE
C     ISTCD-STATE CODE
C     IFLDCD-FIELD CODE
C     NAME-WELL NAME
C     IDPTH-INDICATES A DEEP (0) OR A SHALLOW (1) WELL
C     PRICE1-PRICE OF THE GAS IN THE SOURCE BEING CONSIDERED
C     NGPACD- NGPA CODE FOR THE SOURCE BEING CONSIDERED.  102 OR 108
C            NGPACD=1   OTHERWISE NGPACD=0
C     NSU-NUMBER OF SOURCES USED.  A COUNTER
C     COST-COST OF THE GAS OVER ALL TIME PERIODS.( TO BE MINIMIZED)
C     RES-WELL RESERVES
C     TMIN-TOTAL OF MINIMUM TAKES
C     LS-IDENTIFYING NUMBER FOR THE HIGHEST PRICED SOURCE
C     MONO-ORIGINAL STARTING MONTH
C     NSCC-NUMBER OF SORTED CARDS COUNTED
C     NCS-NUMBER OF SORTED CARDS
C     ICCTR-COEFFICIENT COUNTER
C
C     READ IN NUMBER OF SOURCES, NUMBER OF TIME STEPS, BEGINNING
C     MONTH, MONTHLY INFLATION FACTOR, AND DESIRED MONTHLY RATES
C
      READ(17,1000) NS,NTS,MONTH,FACINF
      READ(17,2000) (R(I),I=1,NTS)
C
      NCS=(NS-1)*NTS
C
C     READ IN HIGHEST PRICED SOURCE, THAT SOURCES PRICE AND NGPA CODE
C        THE SUM OF THE MINS, AND THE COST
C
      READ(17,3300)LS,OPR1,IONGPA,TMIN,COST
      WRITE(6,3900) COST
C
C     DECREASE THE DESIRED RATE FOR EACH TIME PERIOD BY THE SUM OF
C        THE MINIMUM TAKES
C
      DO 220 I=1,NTS
      R(I)=R(I)-TMIN
      IF(R(I).GT.0.0) GO TO 220
      WRITE(6,7000) I
      GO TO 9600
  220 CONTINUE
C
C     BRING IN SORTED COEFFICIENT CARDS ONE AT A TIME
C
  160 ICCTR=ICCTR+1
      READ(16,4000)NSU,J,COEFF,TAKE
C
C     READ SOURCE CARD CORRESPONDING TO SOURCE NUMBER NSU
C
      READ(14'NSU,3300)ISTCD,IFLDCD,NAME,RES,MIN,MAX
```

COMPUTER PROGRAM NUMBER II

CONTINUED

```
C
C       CALCULATE THE AMOUNT OF GAS TO TAKE FROM A SOURCE
C
        TAKE=MAX
        IF(R(J).GT.0.0) GO TO 210
        TAKE=MIN
        GO TO 211
  210   IF(TAKE.GT.R(J)) TAKE=R(J)+MIN
        MAX=MAX-TAKE/RES=MAX
        RES=RES-TAKE
  211   CONTINUE
C
C       REDUCE THE DESIRED RATE BY THE AMOUNT OF THE TAKE
C
        R(J)=R(J)-TAKE+MIN
C
C       PRINT OUT RESULTS
C
        IF(NSCC.EQ.1) WRITE(6,5000)
        WRITE(6,6000) ISTCD,IFLDCD,NAME,NSU,J,COEFF,TAKE,RES
C
C       WRITE DATA BACK TO SOURCE CARD DATA BASE
C
        NCS=(NS-1)*NTS
        WRITE(14'NSU,3300) ISTCD,IFLDCD,NAME,RES,MIN,MAX
        COST=COST+COEFF*TAKE
        IF(NSCC.EQ.NCS) GO TO 170
        NSCC=NSCC+1
        GO TO 160
  170   CONTINUE
C
C       READ INFO ON HIGHEST PRICED SOURCE AND ASSIGN TAKES TO THAT SOURCE
C
        READ(14'LS,3300) ISTCD,IFLDCD,NAME,RES,MIN,MAX
        DO 190 I=1,NTS
        IF(R(I).LE.0.0) GO TO 200
        TAKE=MAX
        IF(TAKE.GT.R(I)) TAKE=R(I)+MIN
        MAX=MAX-TAKE/RES=MAX
        RES=RES-TAKE
        R(I)=R(I)-TAKE+MIN
        IF(R(I).GT.0.0) WRITE(6,9000) I
        WRITE(14'I,3300) ISTCD,IFLDCD,NAME,RES,MIN,MAX
        WRITE(6,9500) ISTCD,IFLDCD,NAME,LS,I,TAKE,RES
        GO TO 190
  200   TAKE=MIN
        WRITE(6,9500) ISTCD,IFLDCD,NAME,LS,I,TAKE,RES
  190   CONTINUE
        WRITE(6,8000) COST
 1000   FORMAT(I4,I2,I2,F5.3)
 2000   FORMAT(6E13.5)
 3200   FORMAT(I2,I4,A20,1X,F10.0,10X,F10.0)
 3300   FORMAT(I2,I4,A20,1X,F10.0,F10.0,F10.0)
 3800   FORMAT(I4,F6.4,I1,F15.0,F15.2)
 3900   FORMAT(F15.2)
 4000   FORMAT(I4,I2,F8.4,F10.0)
 5000   FORMAT(1X,'STATE',1X,'FIELD',1CX,'NAME',10X,'NSU',2X,'PERIOD',
       A6X,'COEFF',5X,'TAKE',10X,'RES',//1X,'CODE',2X,'CODE')
 6000   FORMAT(2X,I2,3X,I4,2X,A20,2X,I4,3X,I2,4X,F8.4,2X,F10.0,2X,
       AF10.0)
 7000   FORMAT(///,'DESIRED RATE FOR TIME PERIOD ',I2,' WAS LESS THAN',
       A'THE MINIMUM REQUIRED FLOW RATE')
 8000   FORMAT('-',2X,'THE FINAL COST OF THE GAS IS ',F15.2)
 9000   FORMAT(///,' DESIRED RATE FOR TIME PERIOD ',I2,' COULD NOT BE MET')
 9500   FORMAT(2X,I2,3X,I4,2X,A20,2X,I4,3X,I2,14X,F10.C,2X,F10.0)
 9000   CONTINUE
        STOP
C       DEBUG INIT,UNIT(21)
        END
```

APPENDIX II

FLOW CHART FOR PROGRAM
NUMBER I

```
┌─────────────────────────┐
│ Read:Number Of Sources, │
│  Number Of Time Steps,  │
│     Beginning Month,     │
│     Inflation Factor,    │
│  Monthly Desired Rates  │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Write Data Above To File│
│   17 For Reference By   │
│       Program II        │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Read Data For One Source│
│        At A Time         │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│ Calculate Reserves Based│
│        On Depth          │
└─────────────────────────┘         YES
            │
            ▼
┌────────────────────────────────┐   ┌──────────────┐
│ Does This Source Have The Highest│──▶│ Save Source  │
│   Price Encountered Thus Far?    │   │Number, Price │
└────────────────────────────────┘   │And NGPA Code │
            │                          └──────────────┘
            │        NO                      │
            ▼                                │
┌─────────────────────────┐◀───────────────┘
│  Increase Total-Minimum │
│    By This Minimum      │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│Write This Sources Information│
│     To Source File       │
└─────────────────────────┘
            │
  NO        ▼
┌───────[Is This The Last Source?]
│            │ YES
│            ▼
│  ┌───────────────────────────────┐
│  │Write, For Source With Highest Cost:│
│  │  Source Number, Price, and    │
│  │      NGPA Code Flag and       │
│  │  Total Of Minimum Flow Rates  │
│  │ To File 17 For Reference By   │
│  │        Program II             │
│  └───────────────────────────────┘
│            │
│            ▼  CONTINUED
```

FLOW CHART FOR PROGRAM NUMBER I
CONTINUED   .

FLOW CHART FOR PROGRAM NUMBER 1
CONTINUED

```
            ↓
┌─────────────────────────┐
│ Calculate The Initial Cost │
│    Based On The Highest    │
│       Priced Source        │
└─────────────────────────┘
            ↓
┌─────────────────────────┐
│ Write Initial Cost To File 17 │
│       For Reference By        │
│          Program II           │
└─────────────────────────┘
```

FLOW CHART FOR PROGRAM
NUMBER II

```
┌─────────────────────────────────┐
│ Read From File 17: Number Of    │
│   Sources, Number Of Time       │
│   Steps, Starting Month,        │
│   Inflation Factor, And         │
│        Desired Rates            │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│ Set The Number Of Coefficients  │
│        To Be Sorted at          │
│           (NS-1)*NTS            │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│ Read In Highest Priced Source   │
│   Information From File 17      │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│ Decrease The Desired Rate For   │
│   Each Time Step By The Sum     │
│        Of The Minimums          │
└─────────────────────────────────┘
                 │           YES
                 ▼        ┌──────────────┐
┌─────────────────────────┐   │ Print Out    │
│ Are Any Of The New Desired│──▶│ Error Message│
│ Rates Less Than Zero    │   │ And End      │
└─────────────────────────┘   └──────────────┘
                 │ NO
                 ▼
┌─────────────────────────────────┐
│ Read Coefficient Cards In       │
│   The Order That They           │
│   Appear In The Sorted          │
│      Coefficient File           │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│ Read Source Card Corresponding  │
│ To Coefficient Card Just Read   │
└─────────────────────────────────┘
                 │
                 ▼
┌─────────────────────────────────┐
│ Calculate The Maximum Take      │
│   Considering The Reserves,     │
│   Maximum Allowable Rate,       │
│      And Desired Rates          │
└─────────────────────────────────┘
                 │
                 ▼        CONTINUED
```

∧

FLOW CHART FOR PROGRAM NUMBER II
CONTINUED

Reduce The Desired Rate For The Time
Step Represented By The Last
Coefficient By An Amount Equal
To The Take Assigned

Print Out The Results For This
Source/Time Step Combination

Write Information Back To The Source Card
File, Including Changed Values For
The Source Reserves and Maximum
Allowable Flow Rate

Adjust The Total Cost Term
For This Take

Increment #
Of Sorted
Coefficients
Counted

NO

Have All Sorted Coefficients
Been Considered?

YES

Read Information On The Highest
Priced Source, And Assign
A Take For Each Time Step

Print Out Each Source/Time Step
Results

Print Out Final Cost

APPENDIX III

DATA SET I

```
CO7160091.01C
    4.98060E 06   4.95060E 06   4.9806CE 06   4.98060E '06   4.95060E 06   4.98060E 06
    4.9806OE 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06   4.98060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06   4.98060E 06
    4.9306CE 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06   4.98060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.95060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.95060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06
    4.98060E 06   4.98060E 06   4.98060E 06   4.98060E 06   4.9806CE 06   4.98060E 06   4.98060E 06
011000COFIELD ONE            1     2373.    1000.     2567. .43340
021100CFIELD TWO             1     2888.     300.     2833. .47620
031200CFIELD THREE           1   176997.    1000.   173666. .49870
031300CFIELD FOUR            1  1605205.    1000.  1575000. .57800
031400CFIELD FIVE            1   300658.    1CCC.    295000. .61381
021500CFIELD SIX             0     8228.    1000.     8093. .65690
0316COFIELD SEVEN            C    18430.    1000.    18093. .67210
0117COFIELD EIGHT            1    80060.    1000.  2817128. .74510
011400CFIELD NINE            0    25819.    1000.   514000. .78990
021900CFIELD TEN             1    523858.   800.    25333. .74691
032000CFIELD ELEVEN          0    25819.    800.    33C00. .95310
022100CFIELD TWELVE          0    46967.    800.    59C00.1.10940
042200CFIELD THIRTEEN        0     2038.    1000.     2200.1.12450
032300CFIELD FOURTEEN        1   155000.    1000.   152093.1.16461
032400CFIELD FIFTEEN         1   31C000.    1000.   304167.1.33900
022500CFIELD SIXTEEN         0   113893.    1000.   122925.1.49500
032600CFIELD SEVENTEEN       0    44334.    1000.    43500.1.61960
022700CFIELD EIGHTEEN        0   162134.    1CCC.   215511.1.67650
032800CFIELD NINETEEN        0   145403.    1000.   232500.1.77440
022900CFIELD TWENTY          0    7C493.     6CC.   117000.1.88110
031000CFIELD TWENTY-ONE      0     8918.     6CC.     8750.2.1035C
0231COFIELD TWENTY-TWO       9    66077.    1000.    594685.2.15861
0132COFIELD TWENTY-THREE     0     2545.    1000.    5C0C.2.22831
0133COFIELD TWENTY-FOUR      0     4841.    1000.     4750.2.33000
0434COFIELD TWENTY-FIVE      0   110921.    1000.    108933.2.35930
0535COFIELD TWENTY-SIX       0   769440.    1000.   195C000.2.40000
0136COFIELD TWENTY-SEVEN     0     1359.    1CCC.     1344.2.45370
0237COFIELD TWENTY-EIGHT     0     1784.     3C0.     4247.2.6C330
023500FIELD TWENTY-NINE      0   104041.    1000.   114750.2.67510
023900COFIELD THIRTY         0    18770.    4C0.    24000.2.74750
03400CFIELD THIRTY-ONE       0   202222.    1000.   200000.2.73300
0241COFIELD THIRTY-TWO       0     7644.    1000.    7509.2.80001
0342COFIELD THIRTY-THREE     0     3058.    1000.     3000.2.86830
0243COFIELD THIRTY-FOUR      0    49635.    4CC.    244665.2.9C200
0144COFIELD THIRTY-FIVE      0    10786.    100.   10583.2.94710
0445COFIELD THIRTY-SIX       0     2463.    1000.    2417.2.99230
0446COFIELD THIRTY-SEVEN     0     8758.    1000.    9258.3.03980
0447COFIELD THIRTY-EIGHT     0    42975.    1000.    46383.3.08660
0248COFIELD THIRTY-NINE      0     8153.    1000.   10000.3.12000
0149COFIELD FORTY            0    16477.    500.    2C750.3.16491
025500CFIELD FORTY-ONE       0    68200.    1000.    67032.3.20950
0151COFIELD FORTY-TWO        0    36775.    1000.    36083.3.21141
0252COFIELD FORTY-THREE      0      340.    100.     333.3.22910
0453COFIELD FORTY-FOUR       0      934.    917.     917.3.28290
0254COFIELD FORTY-FIVE       0    54951.    900.   155000.3.29440
0155COFIELD FORTY-SIX        0      255.    1C0.     275.3.3C001
025600CFIELD FORTY-SEVEN     0    11466.    1000.   11250.3.35691
0257COFIELD FORTY-EIGHT      0    25544.    300.   461221.3.41650
0153CCFIELD FORTY-NINE       0    34822.    7C0.   163023.3.46030
0159CCFIELD FIFTY            C     2373.    1CCC.    3C00.3.53711
06600CFIELD FIFTY-ONE        0     1529.    1000.     1650.3.53711
0461CCFIELD FIFTY-TWO        0    50789.    1000.    54813.3.59460
0463COFIELD FIFTY-FOUR       0    10192.    1000.   11C00.3.69250
0164COFIELD FIFTY-FIVE       0     2205.    1000.    3C00.3.73221
0265COFIELD FIFTY-SIX        0     6285.    3C0.    11000.3.76591
0166COFIELD FIFTY-SEVEN      0      697.    100.     1C00.3.80521
0467COFIELD FIFTY-EIGHT      0    32359.    1000.   34925.3.83931
026800CFIELD FIFTY-NINE      0    13079.    1000.   13000.3.96001
02590COFIELD SIXTY           0    16789.    4CC.    19416.4.04171
02700CFIELD SIXTY-ONE        0    34567.    100.    35300.4.05001
0671COFIELD SIXTY-TWO        0     1757.    1CCC.     1497.4.07691
0672CCFIELD SIXTY-THREE      0     6270.    1000.    6875.4.15731
0273COFIELD SIXTY-FOUR       0    10192.    1000.   11000.4.27CC1
0274COFIELD SIXTY-FIVE       0    15283.    1000.   13000.4.44C01
0275COFIELD SIXTY-SIX        0    32492.    1000.   34200.4.5C001
0476COFIELD SIXTY-SEVEN      C    10701.    1000.   11550.4.57231
0777COFIELD SIXTY-EIGHT      0    64493.    1000.   45000.4.70000
0678CCFIELD SIXTY-NINE       0    39575.    1000.   3C000.4.81620
0679COFIELD SEVENTY          C   1500000.   1000.  4982000.5.10110
03900COFIELD SEVENTY-ONE     C    14560.    1000.  -14583.7.00000
```

DESIRED RATE SUM FOR ALL FIELDS IN TIME PERIOD ONE

DATA SET I

Field	Assigned Rate	Field	Assigned Rate
1	2567.	37	1000.
2	2833.	38	1000.
3	173666.	39	1000.
4	1575000.	40	500.
5	295000.	41	1000.
6	8083.	42	1000.
7	18083.	43	100.
8	2817128.	44	917.
9	12490.	45	900.
10	25333.	46	100.
11	800.	47	1000.
12	800.	48	300.
13	1000.	49	700.
14	1000.	50	1000.
15	1000.	51	1000.
16	1000.	52	1000.
17	1000.	53	1000.
18	1000.	54	1000.
19	1000.	55	1000.
20	600.	56	300.
21	600.	57	100.
22	1000.	58	1000.
23	1000.	59	1000.
24	1000.	60	400.
25	1000.	61	100.
26	1000.	62	1000.
27	1000.	63	1000.
28	300.	64	1000.
29	1000.	65	1000.
30	400.	66	1000.
31	1000.	67	1000.
32	1000.	68	1000.
33	1000.	69	1000.
34	400.	70	1000.
35	100.	71	1000.
36	1000.	Total Rate	4980600.

DATA SET II

```
0C1220041.010
   2.C0000E 03   1.70000E 03   1.90000E 03   1.70000E 03   1.60000E 03   1.50000E 03
   1.40000E 03   1.30000E 03   1.20000E 03   1.10000E 03   1.10000E 03   1.1000CE 03
   1.10000E 03   1.10000E 03   1.10000E 03   1.10000E 03   1.10000E 03   1.10000E 03
   1.10000E 03   1.10000E 03
011000FIELD ONE            1      2378.      1000.      2567, .43340
031400FIELD FIVE           1    300653.      0000.    000000. .61361
032000FIELD ELEVEN         0     25819.      CCC.      00000. .95910
022500FIELD SIXTEEN        0    113898.      0000.    0000000.1.49500
023100FIELD TWENTY-TWO     0     66077.      0000.    000000.2.15361
013600FIELD TWENTY-SEVEN   0      1359.      00C0.      0000.2.45370
034200FIELD THIRTY-THREE   0      3058.      0000.      0000.2.86830
044700FIELD THRITY-EIGHT   0     42975.      0000.     00000.3.08660
045300FIELD FORTY-FOUR     0       934.       000.      000.3.28290
015800FIELD FORTY-NINE     0     34822.       00C.    000000.3.46030
016500FIELD FIFTY-SIX      0      2208.      0000.      0000.3.73231
027100FIELD SIXTY-TWO      0     34567.      0000.     00000.4.05001
```

RESULTS OF DATA SET II

STATE CODE	FIELD CODE	NAME	NSU	PERIOD	COEFF	TAKE	RES
1	1000	FIELD ONE	1	9	-3.6307	1200.	569520.
1	1000	FIELD ONE	1	1	-3.6166	2000.	567520.
1	1000	FIELD ONE	1	10	-3.6128	1100.	566420.
1	1000	FIELD ONE	1	2	-3.5987	1900.	564520.
1	1000	FIELD ONE	1	11	-3.5949	1100.	563420.
1	1000	FIELD ONE	1	3	-3.5809	1800.	561620.
1	1000	FIELD ONE	1	12	-3.5771	1100.	560520.
1	1000	FIELD ONE	1	4	-3.5632	1700.	558820.
1	1000	FIELD ONE	1	13	-3.5594	1100.	557720.
1	1000	FIELD ONE	1	5	-3.5455	1600.	556120.
1	1000	FIELD ONE	1	14	-3.5418	1100.	555020.
1	1000	FIELD ONE	1	6	-3.5280	1500.	553520.
1	1000	FIELD ONE	1	15	-3.5242	1100.	552420.
1	1000	FIELD ONE	1	7	-3.5105	1400.	551020.
1	1000	FIELD ONE	1	16	-3.5068	1100.	549920.
1	1000	FIELD ONE	1	17	-3.4931	1300.	548620.
1	1000	FIELD ONE	1	18	-3.4894	1100.	547520.
1	1000	FIELD ONE	1	19	-3.4721	1100.	546420.
1	1000	FIELD ONE	1	20	-3.4550	1100.	545320.
1	1000	FIELD ONE	1	20	-3.4379	1100.	545320.
3	1400	FIELD FIVE	2	1	-3.4364	0.	72157920.
3	1400	FIELD FIVE	2	2	-3.3919	0.	72157920.
3	1400	FIELD FIVE	2	3	-3.3466	0.	72157920.
3	1400	FIELD FIVE	2	4	-3.3003	0.	72157920.
3	1400	FIELD FIVE	2	5	-3.2530	0.	72157920.
3	1400	FIELD FIVE	2	9	-3.2487	0.	72157920.
3	1400	FIELD FIVE	2	6	-3.2048	0.	72157920.
3	1400	FIELD FIVE	2	10	-3.1969	0.	72157920.
3	1400	FIELD FIVE	2	7	-3.1556	0.	72157920.
3	1400	FIELD FIVE	2	11	-3.1439	0.	72157920.
3	2000	FIELD ELEVEN	3	9	-3.1265	0.	3098280.
3	2000	FIELD ELEVEN	3	10	-3.1110	0.	3098280.
3	1400	FIELD FIVE	2	8	-3.1052	0.	72157920.
3	2000	FIELD ELEVEN	3	11	-3.0956	0.	3098280.
3	2000	FIELD ELEVEN	3	1	-3.0919	0.	3098280.
3	1400	FIELD FIVE	2	12	-3.0897	0.	72157920.
3	2000	FIELD ELEVEN	3	12	-3.0803	0.	3098280.
3	2000	FIELD ELEVEN	3	2	-3.0766	0.	3098280.
3	2000	FIELD ELEVEN	3	13	-3.0650	0.	3098280.
3	2000	FIELD ELEVEN	3	3	-3.0614	0.	3098280.
3	2000	FIELD ELEVEN	3	14	-3.0498	0.	3098280.
3	2000	FIELD ELEVEN	3	4	-3.0462	0.	3098280.
3	2000	FIELD ELEVEN	3	15	-3.0347	0.	3098280.
3	1400	FIELD FIVE	2	13	-3.0342	0.	72157920.
3	2000	FIELD ELEVEN	3	5	-3.0311	0.	3098280.
3	2000	FIELD ELEVEN	3	16	-3.0197	0.	3098280.
3	2000	FIELD ELEVEN	3	6	-3.0161	0.	3098280.
3	2000	FIELD ELEVEN	3	17	-3.0048	0.	3098280.
3	2000	FIELD ELEVEN	3	7	-3.0012	0.	3098280.
3	2000	FIELD ELEVEN	3	18	-2.9899	0.	3098280.
3	2000	FIELD ELEVEN	3	8	-2.9863	0.	3098280.
3	1400	FIELD FIVE	2	14	-2.9774	0.	72157920.
3	2000	FIELD ELEVEN	3	19	-2.9751	0.	3098280.
3	2000	FIELD ELEVEN	3	20	-2.9604	0.	3098280.
3	1400	FIELD FIVE	2	15	-2.9192	0.	72157920.
3	1400	FIELD FIVE	2	16	-2.8595	0.	72157920.
3	1400	FIELD FIVE	2	17	-2.7993	0.	72157920.
3	1400	FIELD FIVE	2	18	-2.7356	0.	72157920.

FINAL COSTS FOR 60 * 71 DATA SETS

Lowest Priced Source Takes Gas

3	6000	FIELD SEVENTY-ONE	71 58	1000.	1783200.
3	6000	FIELD SEVENTY-ONE	71 59	1000.	1783200.
3	6000	FIELD SEVENTY-ONE	71 60	1000.	1783200.

THE FINAL COST OF THE GAS IS   393510044.00

Lowest Priced Source Does Not Take Gas

3	8000	FIELD SEVENTY-ONE	71 58	1000.	1783200.
3	8000	FIELD SEVENTY-ONE	71 59	1000.	1783200.
3	6000	FIELD SEVENTY-ONE	71 60	1000.	1783200.

THE FINAL COST OF THE GAS IS   394197640.00

RESULTS OF DATA SET III

```
FIELD THIRTY-THREE      7    9   -1.2906    1200.      365760.
FIELD THIRTY-THREE      7   10   -1.2342    1100.      364660.
FIELD THIRTY-THREE      7   11   -1.2779    1100.      363560.
FIELD THIRTY-THREE      7   12   -1.2715    1100.      362460.
FIELD THIRTY-THREE      7   13   -1.2653    1100.      361360.
FIELD THIRTY-THREE      7   14   -1.2590    1100.      360260.
FIELD THIRTY-THREE      7   15   -1.2529    1100.      359160.
FIELD THIRTY-THREE      7   16   -1.2466    1100.      358060.
FIELD THIRTY-THREE      7   17   -1.2404    1100.      356960.
FIELD TWENTY-TWO        5    9   -1.2381      0.      7929240.
FIELD THIRTY-THREE      7   18   -1.2342    1100.      355860.
FIELD THIRTY-THREE      7   19   -1.2281    1100.      354760.
FIELD THIRTY-THREE      7   20   -1.2221    1100.      353660.
FIELD TWENTY-TWO        5    7   -1.2026      0.      7929240.
FIELD THIRTY-THREE      7    1   -1.1817    2000.      351660.
FIELD THIRTY-THREE      7    2   -1.1759    1900.      349760.
FIELD THIRTY-THREE      7    3   -1.1700    1800.      347960.
FIELD THIRTY-THREE      7    4   -1.1642    1700.      346260.
FIELD THIRTY-THREE      7    5   -1.1585    1600.      344660.
FIELD THIRTY-THREE      7    6   -1.1527    1500.      343160.
FIELD THIRTY-THREE      7    7   -1.1470    1400.      341760.
FIELD THIRTY-THREE      7    8   -1.1414    1300.      340460.
FIELD TWENTY-TWO        5   10   -1.1062      0.      7929240.
```

RESULTS OF DATA SET IV

```
FIELD SIXTY-TWO        12    1              2000.      4146040.
FIELD SIXTY-TWO        12    2              1900.      4144140.
FIELD SIXTY-TWO        12    3              1800.      4142340.
FIELD SIXTY-TWO        12    4              1700.      4140640.
FIELD SIXTY-TWO        12    5              1600.      4139040.
FIELD SIXTY-TWO        12    6              1500.      4137540.
FIELD SIXTY-TWO        12    7              1400.      4136140.
FIELD SIXTY-TWO        12    8              1300.      4134840.
FIELD SIXTY-TWO        12    9              1200.      4133640.
FIELD SIXTY-TWO        12   10              1100.      4132540.
FIELD SIXTY-TWO        12   11              1100.      4131440.
FIELD SIXTY-TWO        12   12              1100.      4130340.
FIELD SIXTY-TWO        12   13              1100.      4129240.
FIELD SIXTY-TWO        12   14              1100.      4128140.
FIELD SIXTY-TWO        12   15              1100.      4127040.
FIELD SIXTY-TWO        12   16              1100.      4125940.
FIELD SIXTY-TWO        12   17              1100.      4124840.
FIELD SIXTY-TWO        12   18              1100.      4123740.
FIELD SIXTY-TWO        12   19              1100.      4122640.
FIELD SIXTY-TWO        12   20              1100.      4121540.
```

FINAL COSTS FOR DATA SETS II, III, & IV

Data Set II

THE FINAL COST OF THE GAS IS   11023.98

Data Set III

THE FINAL COST OF THE GAS IS   72059.67

Data Set IV

THE FINAL COST OF THE GAS IS   105023.67

APPENDIX IV

MAXIMUM FLOW RATE REDUCTION

CALCULATIONS

USING THE LARGEST DATA SET (60*71),

FIELD 1   TIME PERIOD 1

MAXIMUM FLOW RATE ALLOWABLE = 2567.0

FLOW RATE ASSIGNED BY PROGRAM = 2567.0

INITIAL RESERVE CALCULATIONS:

240*ALLOWABLE=240*2378=570720

% DECREASE IN RESERVES CALCULATION:

$2567/570720=4.4978*10^{-3}$

% DECREASE IN MAXIMUM ALLOWABLE FLOW RATE=$4.4978*10^{-3}$

NEW MAXIMUM ALLOWABLE CALCULATIONS:

$MAX=MAX(1-4.4978*10^{-3})$

$=2567.0(1-4.4978*^{-3})$

$=2555.45$

THIS RESULT CHECKS WITH THE MAXIMUM ALLOWABLE FLOW RATE
LISTED BY THE PROGRAM FOR SOURCE 1 IN TIME PERIOD
2.

COEFFICIENT CALCULATIONS

     THIS SAMPLE CALCULATION USES THE SMALLEST DATA SET (21*12), AND CALCULATES THE COEFFICIENT FOR THE FIRST FIELD IN THE ELEVENTH TIME PERIOD.

     FIELD ONE HAS AN NGPA CODE THAT IS NOT 102 OR 108. THEREFORE, THE PRICE OF THE GAS FROM THAT SOURCE IS NOT ESCALATED AN EXTRA FOUR PERCENT IN DECEMBER.

     FIELD SIXTY-TWO HAS AN NGPA CODE THAT IS 102 OR 108. THEREFORE, THE PRICE OF THE GAS FROM THAT SOURCE IS ESCALATED AN EXTRA FOUR PERCENT IN DECEMBER.

     SINCE THIS PARTICULAR STUDY BEGAN IN MONTH FOUR, OR APRIL, MONTH ELEVEN REPRESENTS FEBRUARY, AND THE STUDY HAS PASSED THROUGH A DECEMBER.

```
COEFF=    PRESENT WORTH OF THE                   PRESENT WORTH OF THE
        - COST ASSOCIATED WITH        +         COST ASSOCIATED WITH
          THE HIGHEST PRICED                     THIS WELL
          WELL
```

```
          ┌─(initial cost of highest priced source)
          │   ┌─(escalation factor for months other than Dec)
          │   │   ┌─(escalation factor for December past)
          │   │   │  ┌─(initial cost of source 1)
          │   │   │  │   ┌─(escalation factor for all
          │   │   │  │   │        months)
          ▼   ▼   ▼  ▼   ▼
```

$$COEFF = \frac{-(4.0500) * (1.005)^9 * (1.045)^1 + .4334 * (1.005)^{10}}{(1.01)^{10} \qquad\qquad (1.01)^{10}}$$

```
                ▲                         ▲
                └──────(inflation factor for all months)
```

COEFF= -3.5949

DATA SUPPORTING MAXIMUM FLOW RATE REDUCTION CALCULATIONS

STATE CODE	FIELD CODE	NAME	NSU	PERIOD	COEFF	TAKE	RES
1	1000	FIELD ONE	1	1		2567.	5671.
1	1000	FIELD ONE	1	1		2551.	54559 8.
2	1000	FIELD TWO	2	2		2552.	5902 97.
1	1100	FIELD ONE	1	1		2542.	5430 14.
3	1200	FIELD THREE	3	3		17366.	42305 6.
1	1100	FIELD ONE	2	1		2611.	5874 66.
2	1000	FIELD TWO	1	2		2553.	5605 21.
1	1100	FIELD ONE	2	3		17200.	4213 2658.
3	1100	FIELD THREE	1	3		2809.	5844 57.
2	1000	FIELD TWO	2	1		2522.	5579 99.
1	1200	FIELD ONE	4	2		17224.	41960 409.
3	1100	FIELD THREE	5	4		2798.	6819 59.
3	1300	FIELD THREE	3	5		157900.	3836 72200.
1	1200	FIELD ONE	1	2		2511.	5554 88.
2	1100	FIELD TWO	2	7		17154.	4178 8864.
2	1300	FIELD TWO	4	5		2787.	6790 72.
3	1100	FIELD THREE	5	2		156855.	3921 05640.
1	1400	FIELD FOUR	1	7		295000.	7186 20920.
3	1000	FIELD ONE	3	5		2500.	5529 88.
1	1200	FIELD THREE	2	3		170344.	4161 8020.
2	1100	FIELD TWO	2	6		2776.	6752 96.

VITA

Margaret A. Yaege

Candidate for the Degree of

Master of Science

Thesis: AN OPTIMIZATION PROGRAM TO MINIMIZE THE COST OF NATURAL
         GAS

Major Field: Mechanical Engineering

Biographical:

   Personal Data: Born in Wichita, Kansas, June 8, 1957, the
      daughter of Joseph M. and Jo Ann Grady. Married Kris
      E. Yaege on December 31, 1977 in Manhattan, Kansas.
      One son, Kyle born January 12, 1982.

   Education: Attended grade school in Manhattan, Kansas;
      graduated from Manhattan High School in 1975; received
      the Bachelor of Science Degree from Kansas State
      University, with a major in Mechanical Engineering in
      May 1979; completed requirements for the Master of
      Science degree in March, 1984. While attending Kansas
      State, was a member of Tau Beta Pi, Pi Tau Sigma, Phi
      Kappa Phi, and Steel Ring honoraries.

   Professional Experience: Was employed by Panhandle Eastern
      Pipeline Company during the summers between 1975 and
      1979.   Upon completion of the B.S.M.E. degree, was
      employed full time by ARCO Pipeline Company as an
      engineer. During the three years in which the Master
      of Science degree was completed, taught full time in
      the Engineering Technology Department at Kansas State
      University.

AN OPTIMIZATION PROGRAM TO MINIMIZE
THE COST OF NATURAL GAS

by

MARGARET ANN YAEGE

B.S., Kansas State University, 1979

————————————————

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1984

In the natural gas industry, profitable production depends upon many factors. These factors can include such things as the cost of the gas from each source, the rate of increase of that cost, the applicability of take-or-pay, and the desire for rateable production. This study considered one of these, namely the problem of cost minimization. In addition to minimizing cost, this study was structured such that the resulting computer program was capable of handling a large number of sources through many time steps. These additional problem requirements made this study different from other small scale cost minimization problems.

Initially, a thorough literature search was completed. The search showed that very few problems of this type had been solved. Those sources produced by the literature search, dealt with problems that were magnitudes smaller than the problem addressed by this paper. Without exception, the articles found presented a matrix solution. Because the solution to this problem was to be capable of handling up to 5000 sources, and up to 60 time steps, the use of matrices in the solution was unacceptable. A solution requiring less active computer space as well as less execution time was required.

The solution obtained required sequential use of two programs. The first program developed a coefficient file that contained one element for every source/time step combination. This file could, therefore, contain up to 300,000 unknowns.

The coefficient file was sorted using a sort processor after the first program had completed execution. The second program processed data from the sorted coefficient file and determined appropriate flow rates.

During the execution of the second program, such things as variable maximum flow rates, well reserves, and desired flow rates for a given time step were considered. Each of these variables was constantly changing throughout the execution of the program.

The problem for which this program was developed was except in magnitude, a typical linear programming problem. However, because of the magnitude of the problem, the solution, in form, was atypical.