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An Analytic Probabilistic Methodology for Resource Appraisal of Undiscovered Oil and Gas Resources in Play Analysis

by

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AN ANALYTIC PROBABILISTIC METHODOLOGY FOR RESOURCE APPRAISAL OF UNDISCOVERED OIL AND GAS RESOURCES IN PLAY ANALYSIS

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INTRODUCTION

An analytic method using probability theory was developed for petroleum resource appraisal of undiscovered oil and gas in an assessment area. An objective was to replace an existing Monte Carlo simulation method in order to increase the efficiency of the petroleum resource appraisal process. The resulting analytic method is a geo-stochastic system for estimating the undiscovered oil and gas potential of a geologic play and an aggregation of plays. Play analysis is a general term for various geologic models and probabilistic methods for analyzing a geologic play.

A geologic model for the quantity of undiscovered petroleum resources in a play involves uncertainty due to the incomplete or fragmentary geologic information generally available. The geologic model used in this study was developed by the U.S. Department of the Interior and applied by the U.S. Geological Survey in petroleum assessments of the National Petroleum Reserve in Alaska and the Arctic National Wildlife Refuge (U.S. Department of the Interior, 1979; White, 1979). The probabilistic methodology used in those two assessments was a Monte Carlo simulation method.

GEOLOGIC MODEL

In play analysis a petroleum assessment area is partitioned into geologic plays, and the individual plays are analyzed. A play consists of a collection of prospects having a relatively homogeneous geologic setting. A prospect is a potential hydrocarbon accumulation. A hydrocarbon accumulation is a discrete oil or gas deposit, which may consist of one or more pools depending upon the specific play concept. A prospect is modeled by separately considering the uncertainty as to the presence of a hydrocarbon accumulation, and its size if present. An accumulation of hydrocarbon is modeled as either crude oil with its dissolved gas or nonassociated gas. The amount of dissolved gas present in an accumulation of oil is calculated from a gas-oil ratio. Because gas refers to either nonassociated gas or dissolved gas, the amount of gas in a play is the sum of the two types of gas from the prospects. There are three sets of geologic attributes or random variables involved in this play-analysis approach; these are for the play, the prospect, and the hydrocarbon volume. The play and prospect attributes are concerned with the presence or absence of certain geologic characteristics at the play and prospect levels, respectively. The hydrocarbon-volume attributes are concerned with the size of the hydrocarbon accumulation.

The play attributes are (1) existence of a hydrocarbon source, (2) favorable timing for migration of hydrocarbons from source to trap, (3) potential migration paths, and (4) existence of potential reservoir facies. The presence of all four play attributes (in which case the play is said to be "favorable") is a necessary, but not sufficient, condition for the existence of oil or gas deposits in the play. Thus, if one or more of these attributes is not present, all the prospects within the play are dry. Subjective judgments are made by experts for estimating the probability of the presence of each play attribute. Assuming independence, the product of these four probabilities is the probability that the play is favorable for the existence of hydrocarbon accumulations and is called the marginal play probability.

The prospect attributes are (1) trapping mechanism, (2) effective porosity, and (3) hydrocarbon accumulation. Given a favorable play, the presence of all three prospect attributes is a necessary and sufficient condition for the existence of a hydrocarbon accumulation in the prospect. Subjective judgments are made by experts for estimating the probability of the presence of each prospect attribute. Assuming independence, the product of these three probabilities is the probability that a prospect is a hydrocarbon accumulation, given the play is favorable, and is called the conditional deposit probability.

The hydrocarbon-volume attributes are (1) area of closure, (2) thickness of reservoir rock, (3) effective porosity, (4) trap fill, (5) depth to reservoir, and (6) hydrocarbon saturation. The hydrocarbon-volume attributes jointly determine the volume of the hydrocarbon accumulation within the prospect. The following reservoir engineering equations are used to calculate the in-place volumes of oil and nonassociated gas, respectively:

Oil in place = $7,758*1,000*A*F*H*P*S_H/B_O$

Nonassociated gas in place = $1,537.8*1,000*A*F*H*P*S_H*(P_E/T)*(1/Z)$

where A = area of closure (1,000 acres)

F = trap fill (decimal fraction)

H = reservoir thickness (feet)

P = effective porosity (decimal fraction)

S_H = hydrocarbon saturation (decimal fraction)

B_O = oil formation volume factor

P_E = original reservoir pressure

T = reservoir temperature (degrees rankine)

Z = gas compressibility factor

Both equations consist of a product of factors that are functions of the hydrocarbon-volume attributes. The attributes are treated as continuous independent random variables, with the exception of effective porosity which is approximately perfectly positively correlated with hydrocarbon saturation. The probability distribution for an attribute is determined from subjective judgments made by experts, usually geologists, based either on actual geological and geophysical data, when available, or on the experience and knowledge of the experts using analog data and geologic extrapolations when data is unavailable. The probability distribution for each attribute is described by a complementary cumulative distribution function determined from seven estimated fractiles (100th, 95th, 75th, 50th, 25th, 5th, 0th). (The 5th fractile, for example, is an attribute value such that there is a 5% chance of at least that value.) In each play analyzed the seven fractiles are estimated for all of the hydrocarbon-volume attributes, except hydrocarbon saturation whose seven fractiles are one of two possible sets of fixed values depending upon the expected reservoir lithology, which is estimated by the geologists as either sandstone or carbonate. The experts also estimate the hydrocarbon-type probabilities which are the respective probabilities of a given accumulation being either oil or nonassociated gas; however, if the reservoir depth is greater than a specified depth, say for example 15,000 feet, the accumulation is always assumed to be nonassociated gas.

The number of drillable prospects in the play is treated as a discrete random variable, and seven fractiles are estimated.

Probability judgments concerning each of the three sets of attributes are developed by experts familiar with the geology of the area of interest. The experts first review all existing data relevant to the appraisal, identify the major plays within the assessment area (e.g., basin or province), and then assess each identified play. All of the geologic data required by this model for a play is entered on an oil and gas appraisal data form (Figure 1). Information from the data form is entered into computer data files as the input for a computer program based on a method of analysis.

Figure 1.--Oil and gas appraisal data form. (Modified from U.S. Department of Interior, 1979.)

Oil and Gas Appraisal Data Form

Evaluator : ______________________ Play Name ______________________

Date Evaluated: ______________________

	Attribute		Probability of Favorable or Present	Comments
Play Attributes	Hydrocarbon Source			
	Timing			
	Migration			
	Potential Reservoir Facies			
	Marginal Play Probability			
Prospect Attributes	Trapping Mechanism			
	Effective Porosity (>3%)			
	Hydrocarbon Accumulation			
	Conditional Deposit Probability			
Hydrocarbon Volume Parameters	Reservoir Lithology	Sand		
		Carbonate		
	Hydrocarbon	Gas		
		Oil		

	Fractiles / Attribute	Probability of equal to or greater than							
		100	95	75	50	25	5	0	
Hydrocarbon Volume Parameters	Area of Closure ($x10^3$ Acres)								
	Reservoir Thick-ness/vertical closure (Ft)								
	Effective Porosity %								
	Trap Fill (%)								
	Reservoir Depth ($x10^3$ Ft)								
	No. of drillable prospects (a play characteristic)								
	Proved Reserves ($x10^6$ Bbl; TCF)								

ANALYTIC METHOD OF PLAY ANALYSIS

An analytic method using probability theory is proposed as a more efficient alternative to the costly and time-consuming Monte Carlo simulation method for petroleum play analysis. The analytic method is based upon the same geologic model, same type data, and same probability assumptions as the simulation method.

The analytic method was developed by the application of many laws of expectation and variance in probability theory. The analytic method systematically tracks through the geologic model, computes all of the means and variances of the appropriate random variables, and calculates all of the probabilities of occurrence. The lognormal distribution is used as a model for various unknown distributions in order to arrive at probability fractiles. Oil, nonassociated gas, dissolved gas, and gas resources are each assessed in turn. Separate methodologies have been developed for analyzing individual plays and for aggregating the plays.

The basic steps of the analytic method of play analysis are:

1. Select the play.

2. Select oil as the first resource to be assessed.

3. Compute the mean and variance of each of the following hydrocarbon-volume attributes: (1) area of closure, (2) thickness of reservoir rock, (3) effective porosity, (4) trap fill, (5) depth to reservoir, and (6) hydrocarbon saturation. Determine the mean and variance from the estimated seven fractiles, assuming a uniform distribution between fractiles, that is, a piecewise uniform probability density function (as was done in the case of the simulation method). Recall that the hydrocarbon saturation distribution depends on whether the estimated reservoir lithology is sandstone or carbonate. Calculate the mean and variance of the product of effective porosity and hydrocarbon saturation, assuming they are approximately perfectly positively correlated. Also compute the mean and variance for the reciprocal of the oil formation volume factor, which is a function of reservoir depth through a series of formulas.

4. Compute the mean and variance of the accumulation size of oil in place using a reservoir engineering equation. The equation involves the product of a constant, area of closure, reservoir thickness, trap fill, effective porosity, hydrocarbon saturation, and the reciprocal of the oil formation volume factor. Various laws of expectation and variance are involved in the calculations.

5. Model the accumulation-size distribution by the lognormal probability distribution with mean and variance from step 4. Calculate various lognormal fractiles of the accumulation size for oil.

6. Compute the probability that a prospect has an oil accumulation, given the play is favorable. This is called the conditional prospect probability of oil. This probability is the product of the conditional deposit probability, the probability that the reservoir depth is less than 15,000 feet, and the hydrocarbon-type probability of oil.

7. Compute the mean and variance of the conditional prospect potential for oil, which is the quantity of oil in a prospect, given the play is favorable. They are arrived at by applying the conditional prospect probability of oil to the mean and variance of the accumulation size of oil.

8. Compute various fractiles of the conditional prospect potential for oil by a transformation to appropriate lognormal fractiles of the accumulation size of oil using the conditional prospect probability of oil.

9. Compute the mean and variance of the number of prospects from the estimated seven fractiles, assuming a uniform distribution between fractiles (as is also the case in the simulation method).

10. Compute the mean and variance of the number of oil accumulations, given the play is favorable. They are arrived at by applying the conditional prospect probability of oil to the mean and variance of the number of prospects.

11. Compute the mean and variance of the conditional (A) play potential for oil, which is the quantity of oil in the play, given the play is favorable. They are determined from the probability theory of the expectation and variance of a random number (number of prospects) of random variables (conditional prospect potential).

12. Compute the conditional play probability of oil, which is the probability that a favorable play has at least one oil accumulation, and is a function of the conditional prospect probability of oil and the number-of-prospects distribution.

13. Compute the mean and variance of the conditional (B) play potential for oil, which is the quantity of oil in the play, given the play is favorable and there is at least one oil accumulation within the play. They are arrived at by applying the conditional play probability of oil to the mean and variance of the conditional (A) play potential for oil.

14. Compute the unconditional play probability of oil, which is the probability that the play has at least one oil accumulation, and is the product of the conditional play probability of oil and the marginal play probability.

15. Compute the mean and variance of the unconditional play potential for oil, which is the quantity of oil in the play. They are arrived at by applying the unconditional play probability of oil to the mean and variance of the conditional (B) play potential for oil.

16. Model the probability distribution of the conditional (B) play potential for oil by the lognormal distribution with mean and variance from step 13. Calculate various lognormal fractiles.

17. Compute various fractiles of the conditional (A) play potential for oil by a transformation to appropriate lognormal fractiles of the conditional (B) play potential for oil using the conditional play probability of oil.

18. Compute various fractiles of the unconditional play potential for oil by a transformation to appropriate lognormal fractiles of the conditional (B) play potential for oil using the unconditional play probability of oil.

19. Select nonassociated gas as the second resource to be assessed. Repeat steps 3 through 18, substituting nonassociated gas for oil, with two basic modifications as follows. A reservoir engineering equation is used to calculate the accumulation size of nonassociated gas in place. The conditional prospect probability of nonassociated gas is equal to the conditional deposit probability minus the conditional prospect probability of oil.

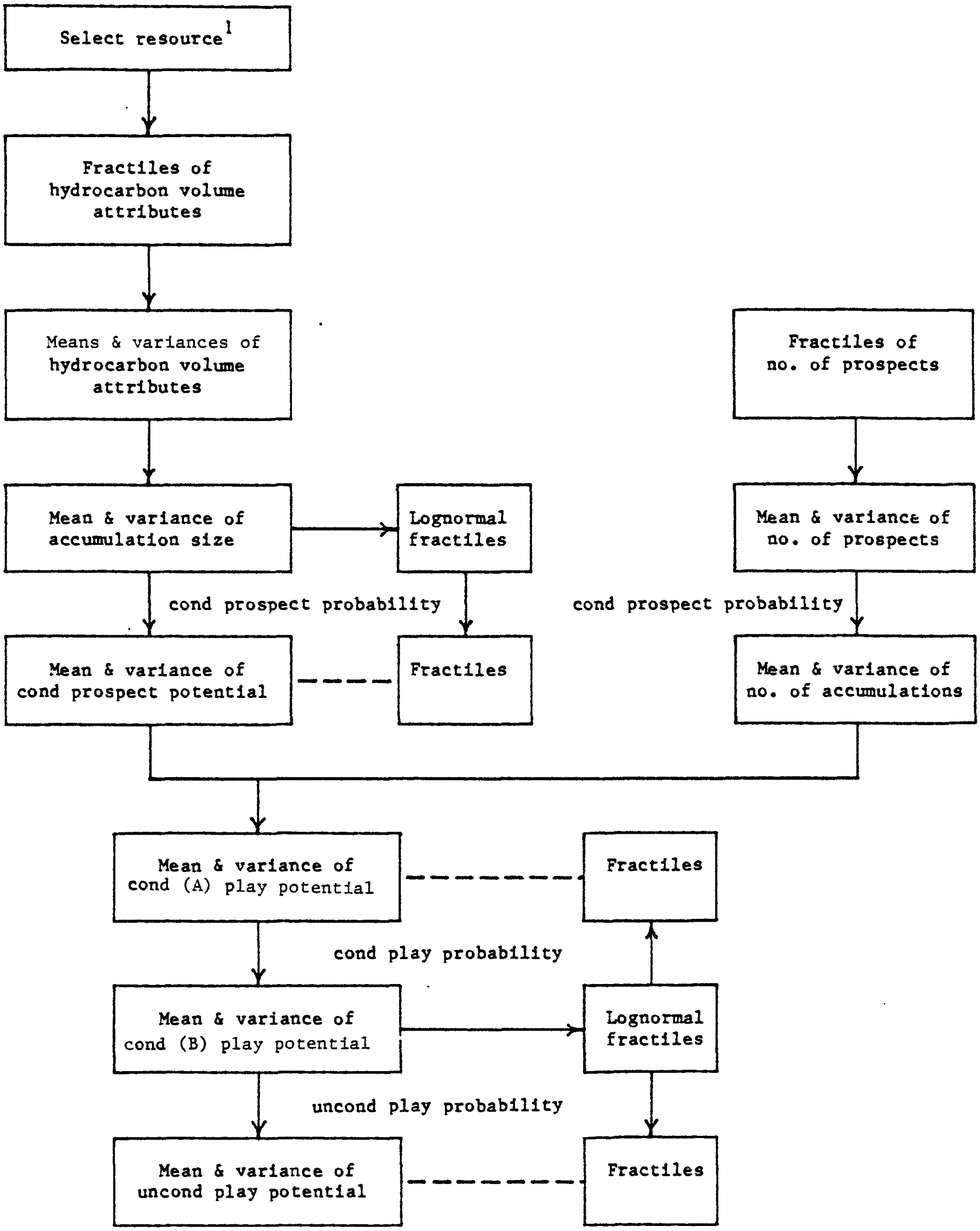
20. Select dissolved gas as the third resource to be assessed. Repeat steps 3 through 18, substituting dissolved gas for oil, with two basic modifications as follows. The reservoir engineering equation for the accumulation size of oil in-place is multiplied by a gas-oil ratio which is a function of reservoir depth. The conditional prospect probability of dissolved gas is the same as the conditional prospect probability of oil.

21. Select gas as the fourth resource to be assessed. Repeat steps 4 through 18, substituting gas for oil, with two basic modifications as follows. Replace step 4 to compute the mean and variance of the accumulation size of gas in-place by using conditional probability theory and conditioning on the type of gas. The conditional prospect probability of gas is the same as the conditional deposit probability.

A simplified flow chart of the analytic method of play analysis is presented in Figure 2.

On the basis of the analytic method, a computer program was designed and called the Fast Appraisal System for Petroleum (FASP). Because both cost and running time are negligible, FASP allows for quick feedback evaluation of geologic input data. FASP can be easily adapted to most mainframe computers and microcomputers.

Figure 2.--Flow Chart of Analytic Method of Play Analysis



[1] Oil, nonassociated gas, dissolved gas, and gas resources are each assessed in turn.

NUMERICAL EXAMPLE OF PLAY ANALYSIS

A numerical example of the application of the analytic method of play analysis is illustrated using an actual resource assessment of an individual play, Sag River. The play is from a U.S. Geological Survey assessment of an area in Alaska (U.S. Department of the Interior, 1979). The completed oil and gas appraisal data form used in that study is given in Figure 3 as filled out by the USGS resource appraisal team of experts for that study. The data has now been reanalyzed by the analytic method of play analysis using the computer program FASP. The probability histogram of porosity for Sag River is given as an example in Figure 4, and the corresponding complementary cumulative distribution is given in Figure 5. The input data and calculated parameters of the geologic variables and probabilities of occurrence for one play, Sag River, are given as printed by FASP in Table 1. Estimates of undiscovered in-place petroleum resources for the Sag River play are presented in FASP output form in Table 2. The corresponding graphs of the complementary cumulative distribution functions, again in direct computer output form, are displayed in Figures 6 through 25.

Figure 3.--Data used in appraisal of Sag River play, Alaska, developed during U.S. Department of Interior Study, 1979.

Oil and Gas Appraisal Data Form

Evaluator : Resource Appraisal Team   Play Name Sag River

Date Evaluated: 5/21/79

	Attribute	Probability of Favorable or Present	Comments
Play Attributes	Hydrocarbon Source	1.0	Oil shows in Barrow 12, 17, and 19
	Timing	1.0	
	Migration	1.0	
	Potential Reservoir Facies	.7	New core data shows low perm.
	Marginal Play Probability	.7	
Prospect Attributes	Trapping Mechanism	.3	
	Effective Porosity (>3%)	.9	
	Hydrocarbon Accumulation	.9	
	Conditional Deposit Probability	.243	
Hydrocarbon Volume Parameters	Reservoir Lithology — Sand	1.0	
	Reservoir Lithology — Carbonate	0	
	Hydrocarbon — Gas	.2	
	Hydrocarbon — Oil	.8	

Attribute \ Fractiles (Probability of equal to or greater than)	100	95	75	50	25	5	0	Comments
Area of Closure ($x10^3$ Acres)	.6	1	3	6	8	10	25	Lease prospect is potentially large stratigraphic trap
Reservoir Thickness/vertical closure (Ft)	5	30	60	90	120	140	170	
Effective Porosity %	3	8	10	12	15	20	25	Glauconitic ss; standard porosity vs. permeability relations may not hold
Trap Fill (%)	1	15	30	45	55	70	95	
Reservoir Depth ($x10^3$ Ft)	2	5	8	9	10	11	13	
No. of drillable prospects (a play characteristic)	4	5	6	8	12	15	20	
Proved Reserves ($x10^6$ Bbl; TCF)							0	

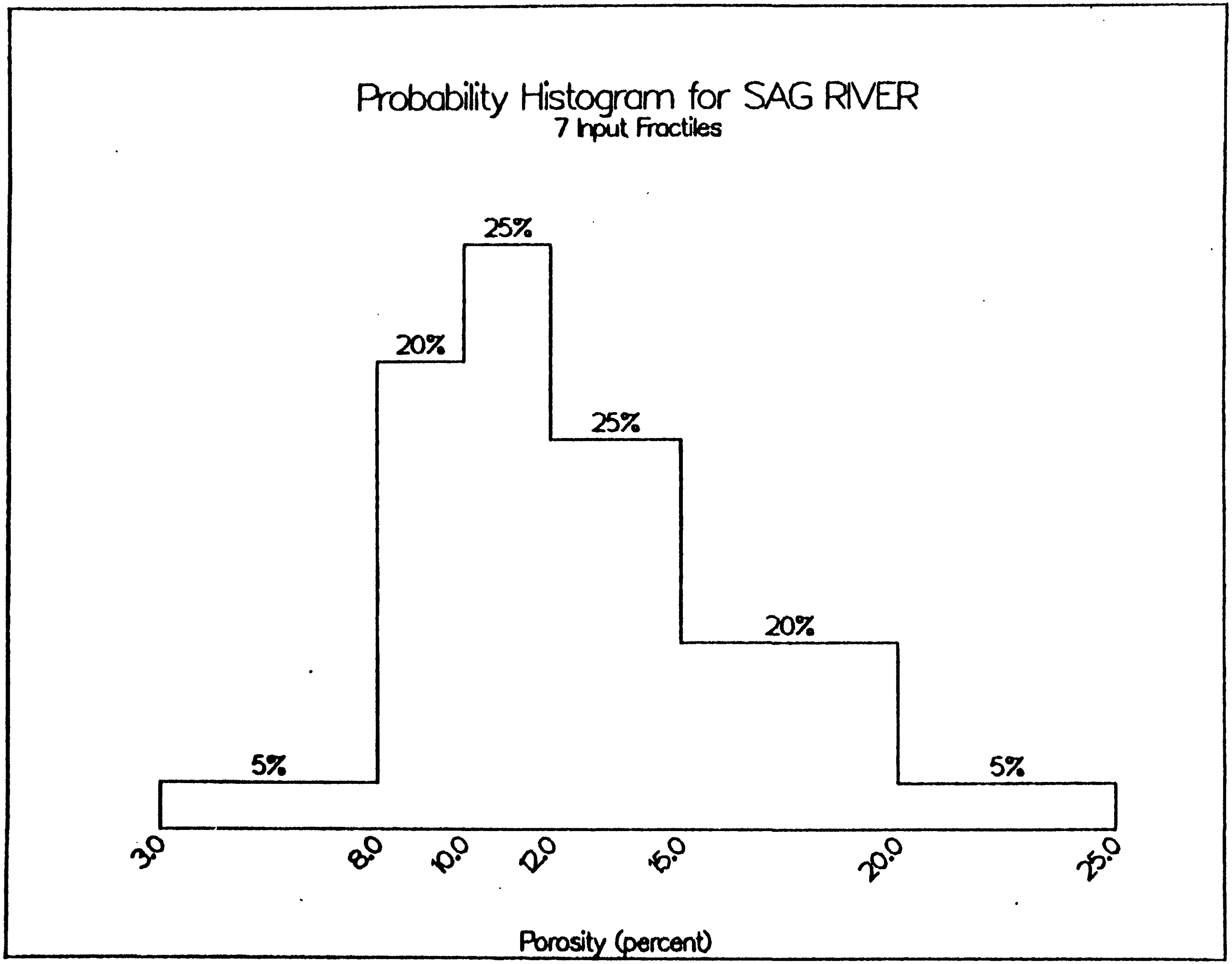


Figure 4.--Probability histogram of porosity (percent) for Sag River.

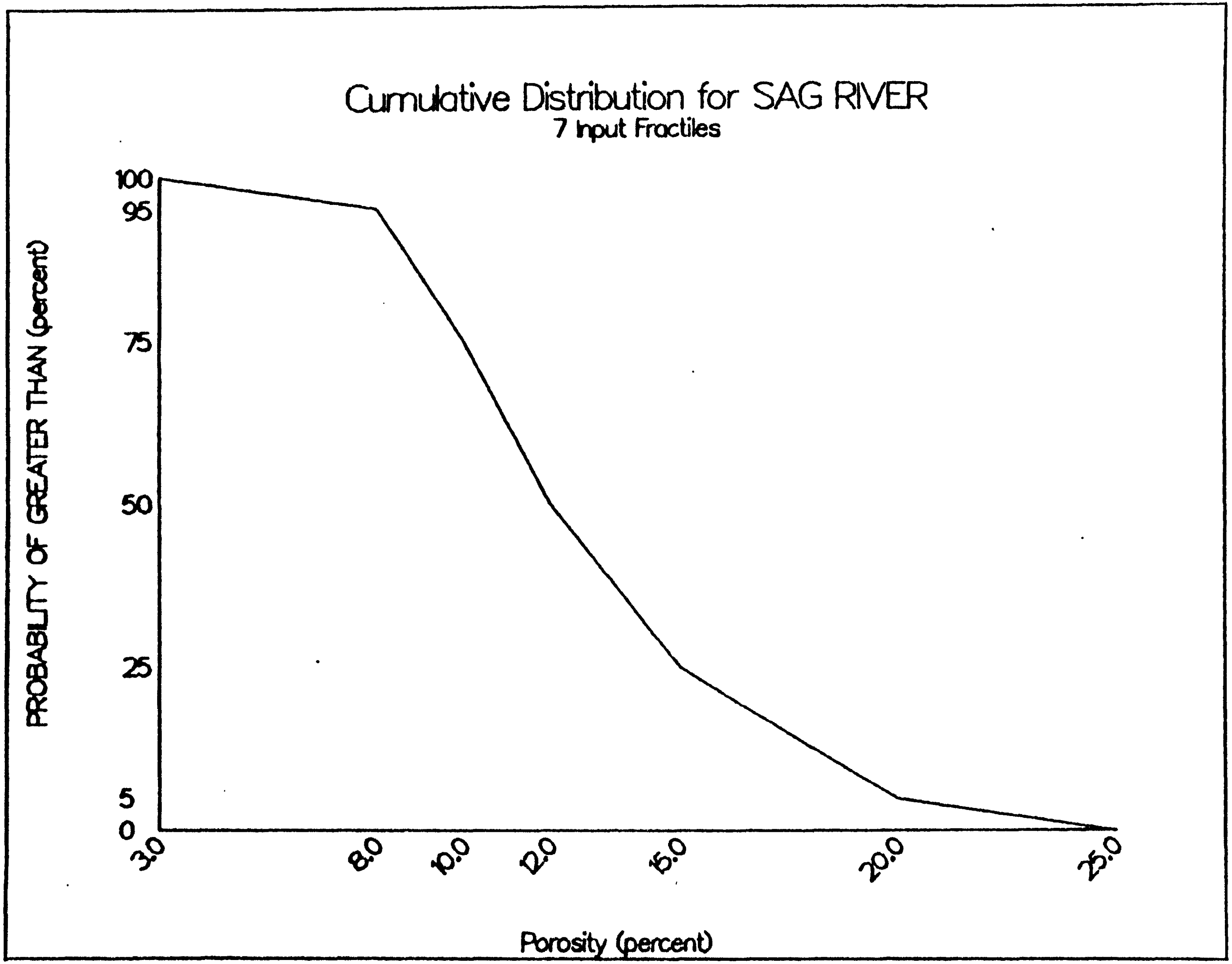


Figure 5.--Complementary cumulative distribution of porosity (percent) for Sag River.

Table 1.--Input data and parameters of geologic variables for one play, Sag River. Data required and printed by the computer program FASP.

National Petroleum Reserve of Alaska

Sag River — INPUT SUMMARY

Play Attribute Probabilities				Prospect Attribute Probabilities		
Hydrocarbon Source	Timing	Migration	Potential Res. Facies	Trapping Mechanism	Effective Porosity	Hydrocarbon Accumulation
1.000	1.000	1.000	0.700	0.300	0.900	0.900

Marginal Play Probability	Conditional Deposit Probability	Reservoir Lithology	Hydrocarbon Prob. Gas	Hydrocarbon Prob. Oil
0.700	0.243	sand	0.200	0.800

Geologic Variables	F100	F95	F75	F50	F25	F05	F0
Closure (thousand acres)	.6000	1.000	3.000	6.000	8.000	10.00	25.00
Thickness (feet)	5.000	30.00	60.00	90.00	120.0	140.0	170.0
Porosity (percent)	3.000	8.000	10.00	12.00	15.00	20.00	25.00
Trap Fill (percent)	1.000	15.00	30.00	45.00	55.00	70.00	95.00
Depth (thousand feet)	2.000	5.000	8.000	9.000	10.00	11.00	13.00
HC Saturation (percent)	35.00	52.00	64.00	71.00	75.00	88.00	95.00
Number of Prospects	4	5	6	8	12	15	20

Sag River — GEOLOGIC VARIABLES and PROBABILITIES OF OCCURRENCE

	Mean	Std. Dev.
Closure	5.99000	3.88835
Thickness	88.6250	37.0836
Porosity	12.8250	4.07055
Trap Fill	43.4000	18.3496
Depth	8.67500	1.98605
HC Saturation	0.69775	0.11190
Prospects	8.65000	3.60012
Accumulations	2.10195	1.53509

'Dry Hole' Risk = 0.8299
Prob. Depth <= 15,000 ft. = 1.0000

	RESOURCE: Oil	NA Gas	D Gas	Gas/HC
Cond. Prob. Prospect has	0.1944	0.0486	0.1944	0.2430
Cond. Play Prob.	0.8028	0.3400	0.8028	0.8679
Uncond. Play Prob.	0.5620	0.2380	0.5620	0.6076

Table 2.--Estimates of undiscovered in-place petroleum resources for one play, Sag River. Data output from the computer program FASP.

Sag River	Mean	Std. Dev	F95	F75	F50	F25	F05
			ESTIMATED RESOURCES IN PLACE				
OIL (Millions of BBLs)							
Number of Accumulations	1.68156	1.35811	0	1	1	2	4
Accumulation Size	114.255	137.625	15.374	38.535	72.982	138.22	346.44
Cond. Prospect Potential	22.2113	75.6735	0.	0.	0.	0.	135.58
Cond. (B) Play Potential	239.317	241.602	42.414	95.681	168.42	296.44	668.74
Cond. (A) Play Potential	192.127	236.491	0.	47.572	129.59	254.45	611.70
Uncond. Play Potential	134.489	216.567	0.	0.	60.285	189.36	522.22
NON-ASSOCIATED GAS (Billions of CuFt)							
Number of Accumulations	0.42039	0.65618	0	0	0	1	2
Accumulation Size	210.570	252.560	28.531	71.327	134.84	254.92	637.30
Cond. Prospect Potential	10.2337	71.7649	0.	0.	0.	0.	0.
Cond. (B) Play Potential	260.335	300.464	37.520	91.645	170.48	317.11	774.57
Cond. (A) Play Potential	88.5214	214.258	0.	0.	0.	95.602	448.75
Uncond. Play Potential	61.9650	183.794	0.	0.	0.	0.	358.20
DISSOLVED GAS (Billions of CuFt)							
Number of Accumulations	1.68156	1.35811	0	1	1	2	4
Accumulation Size	93.6232	117.057	11.854	30.394	58.478	112.51	288.48
Cond. Prospect Potential	18.2004	63.5330	0.	0.	0.	0.	110.31
Cond. (B) Play Potential	196.101	203.115	33.440	76.578	136.21	242.27	554.80
Cond. (A) Play Potential	157.433	198.011	0.	37.585	104.30	207.36	506.66
Uncond. Play Potential	110.203	180.695	0.	0.	47.839	153.48	431.28
GAS (Billions of CuFt)							
Number of Accumulations	2.10195	1.53509	0	1	2	3	5
Accumulation Size	117.013	160.958	12.630	34.336	68.805	137.88	374.84
Cond. Prospect Potential	28.4340	93.8836	0.	0.	0.	0.	160.68
Cond. (B) Play Potential	283.380	298.850	47.017	108.82	194.99	349.39	808.65
Cond. (A) Play Potential	245.954	294.484	0.	75.373	165.23	316.68	762.71
Uncond. Play Potential	172.168	270.940	0.	0.	87.475	236.80	649.20

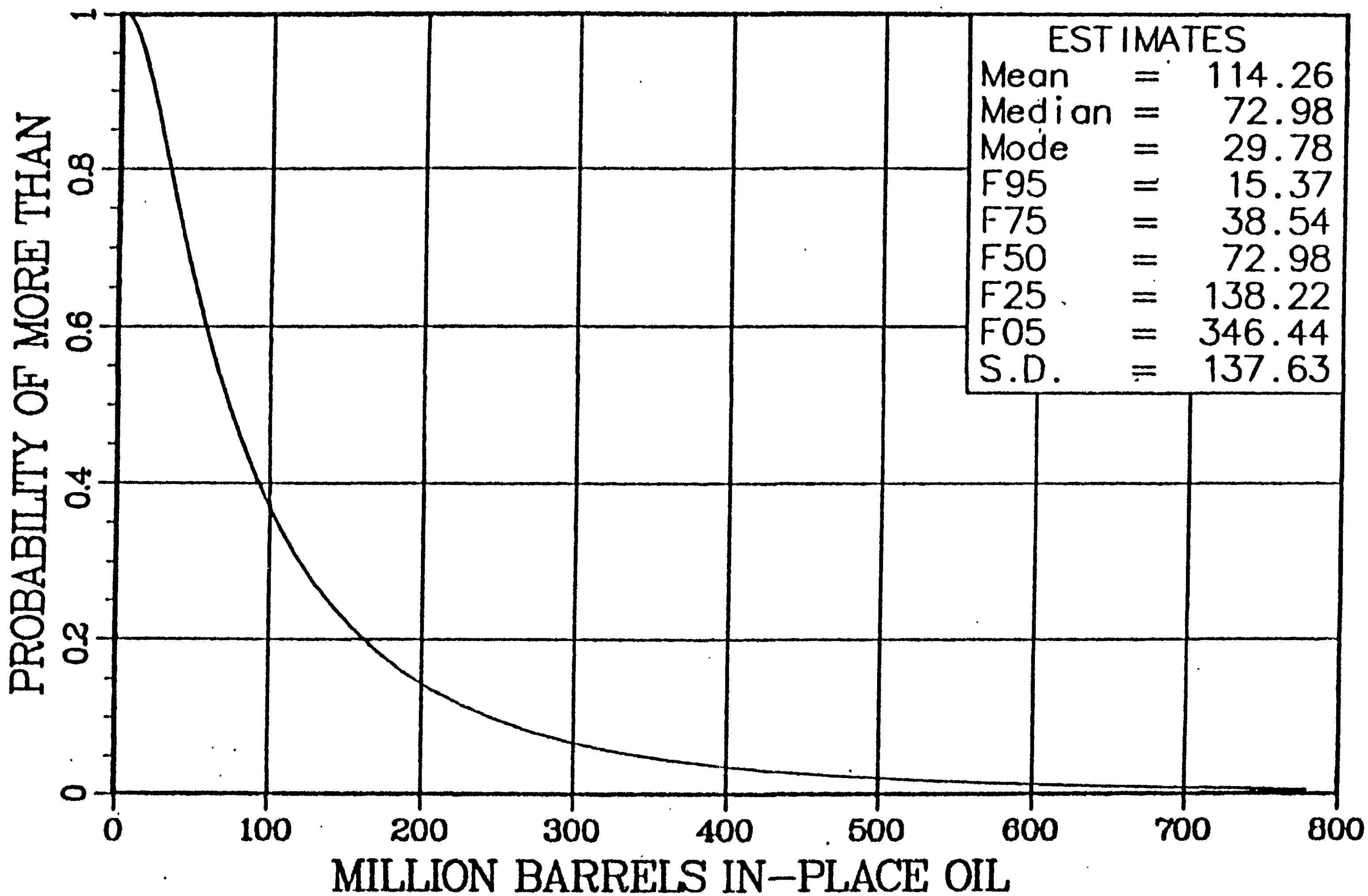


Figure 6.--Accumulation size of oil for Sag River.

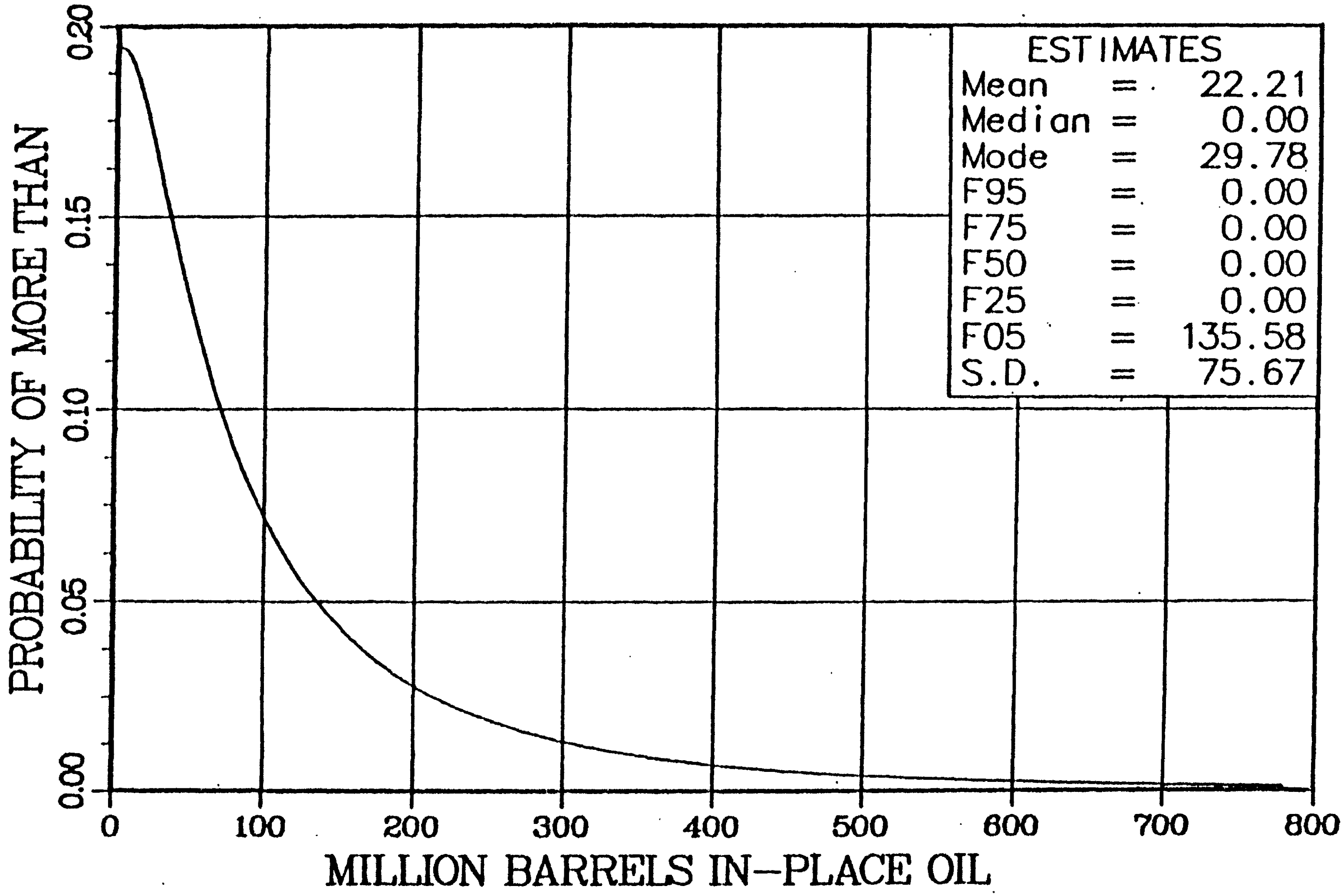


Figure 7.--Conditional prospect potential of oil for Sag River.

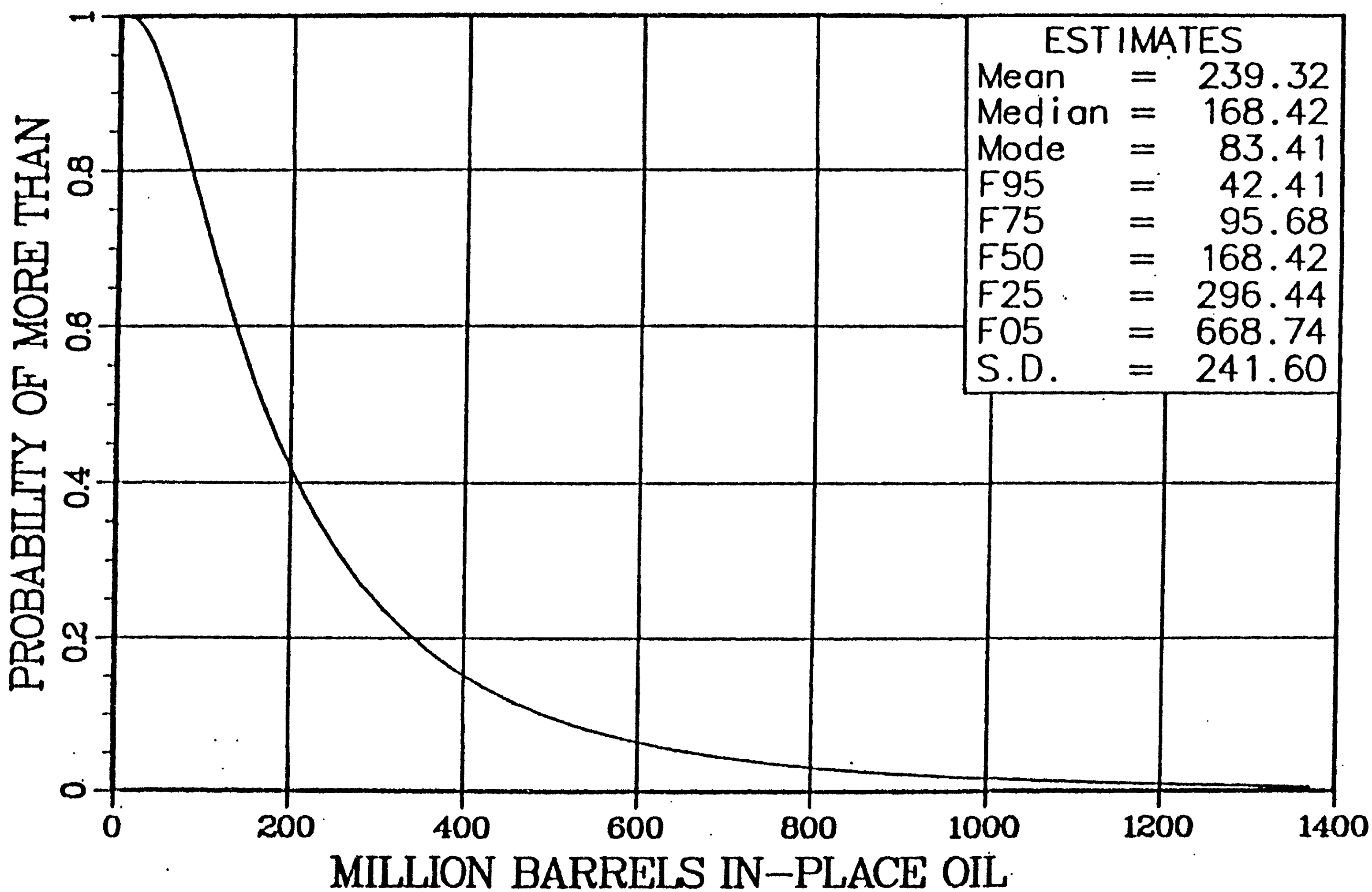


Figure 8.--Conditional (B) play potential of oil for Sag River.

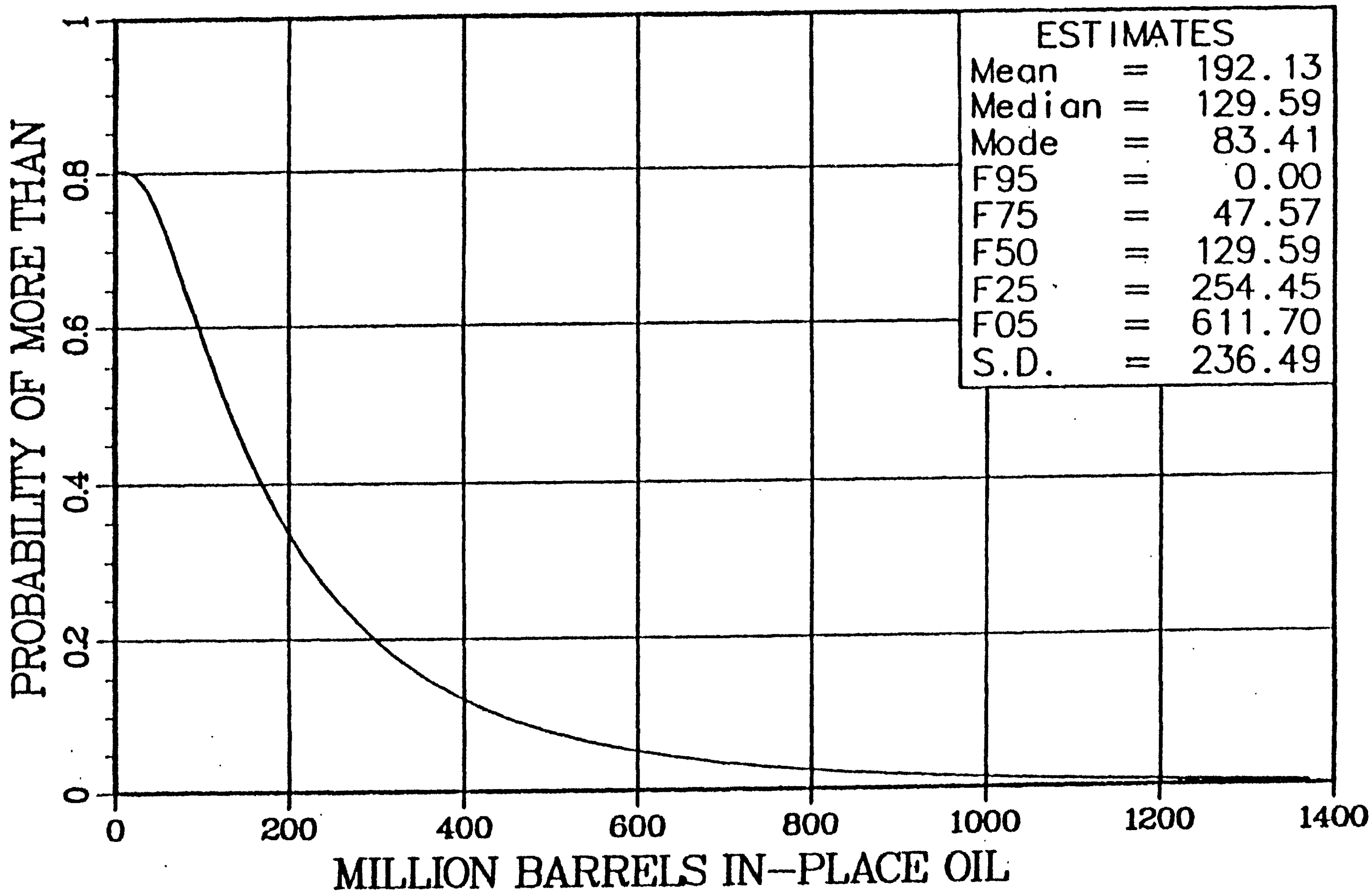


Figure 9.--Conditional (A) play potential of oil for Sag River.

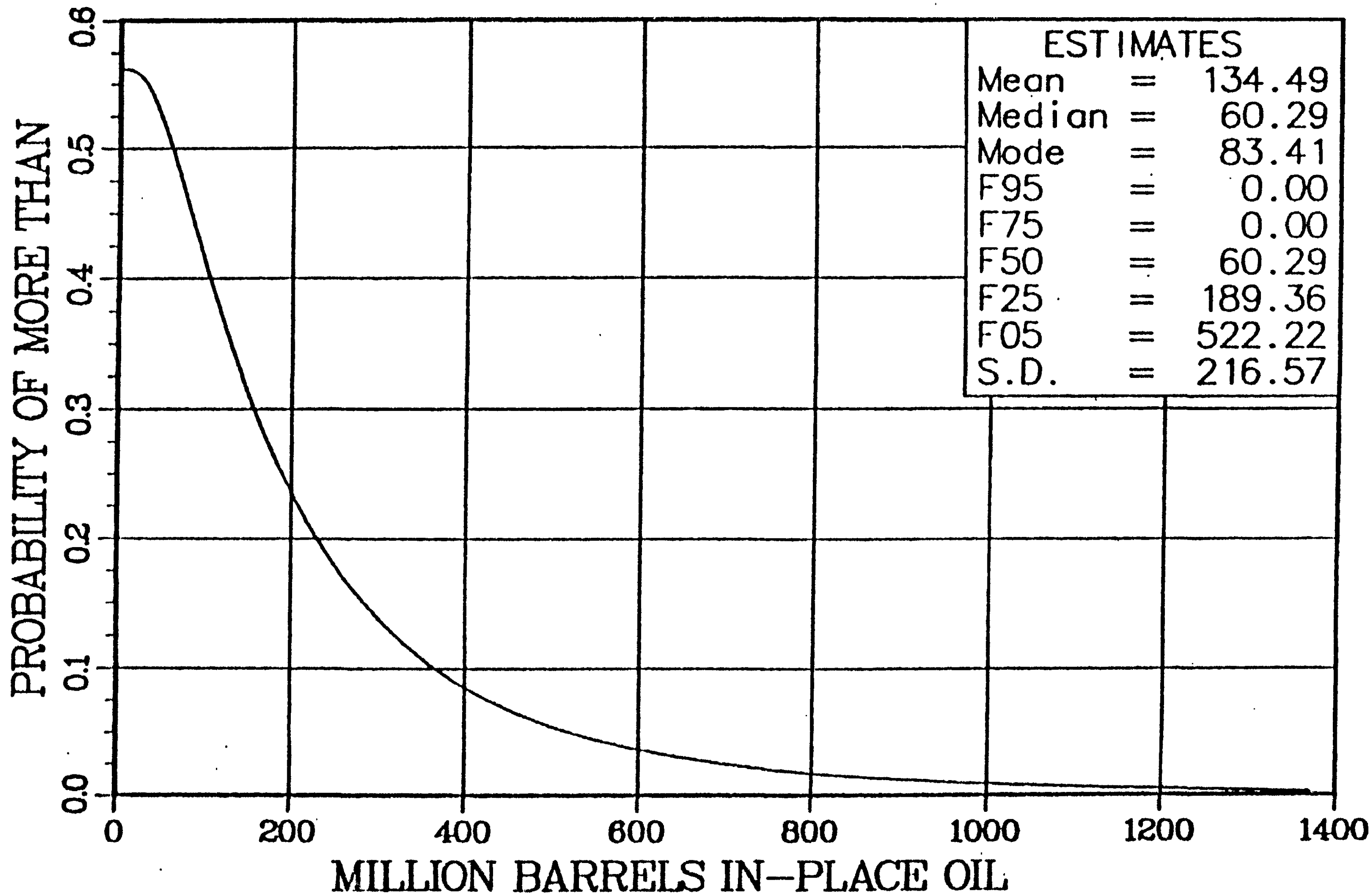


Figure 10.--Unconditional play potential of oil for Sag River.

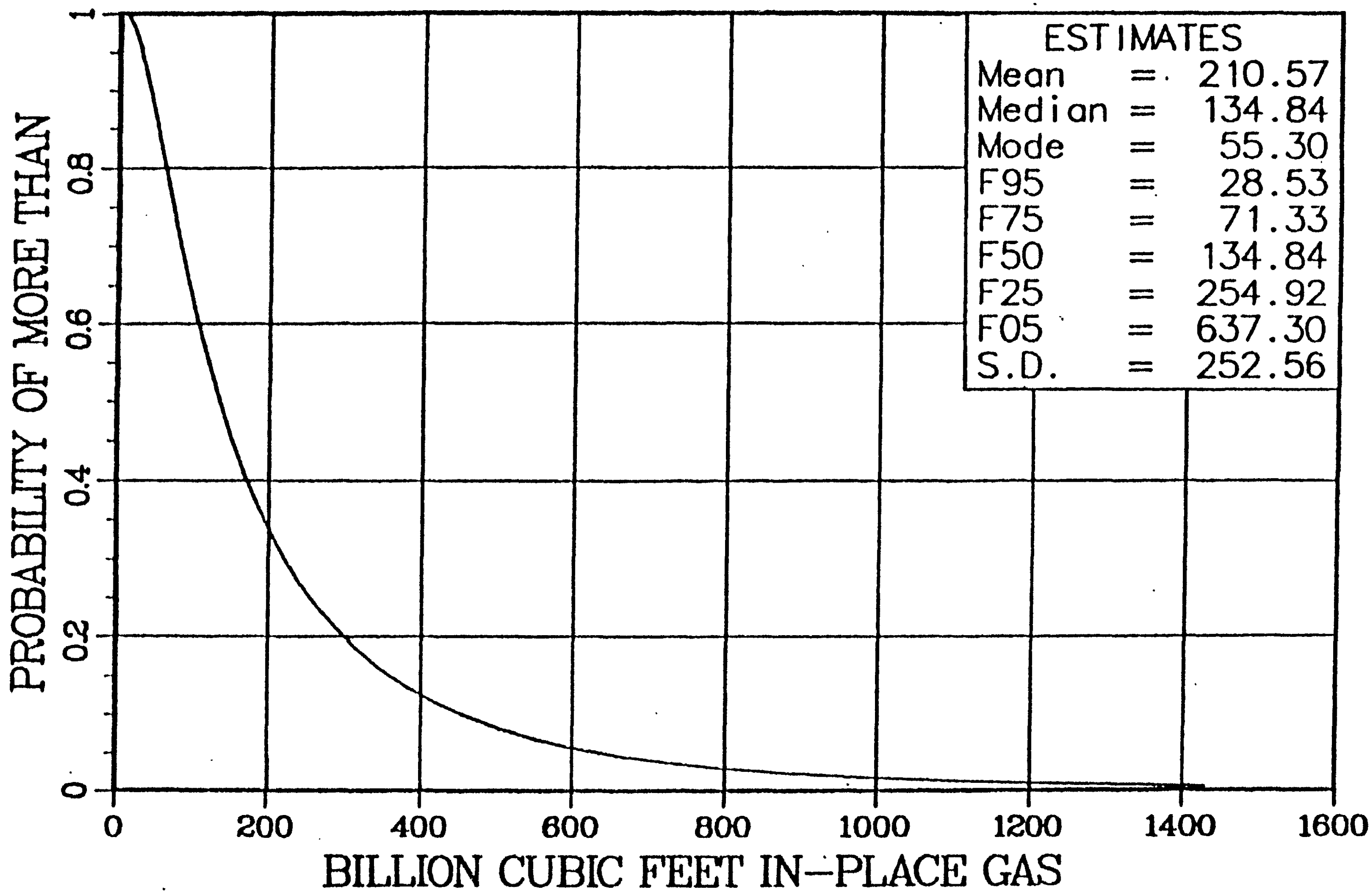


Figure 11.--Accumulation size of non-associated gas for Sag River.

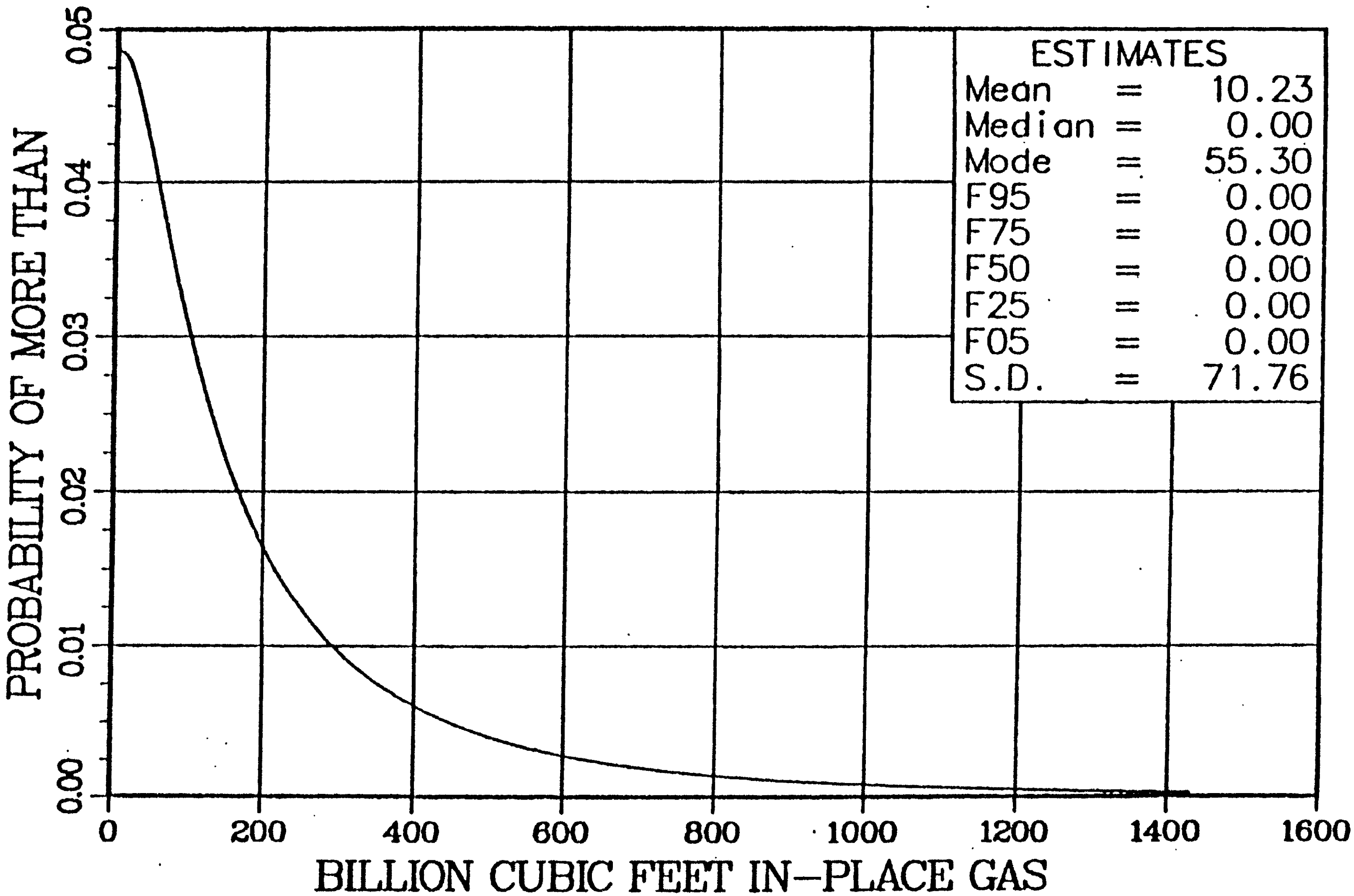


Figure 12.--Conditional prospect potential of non-associated gas for Sag River.

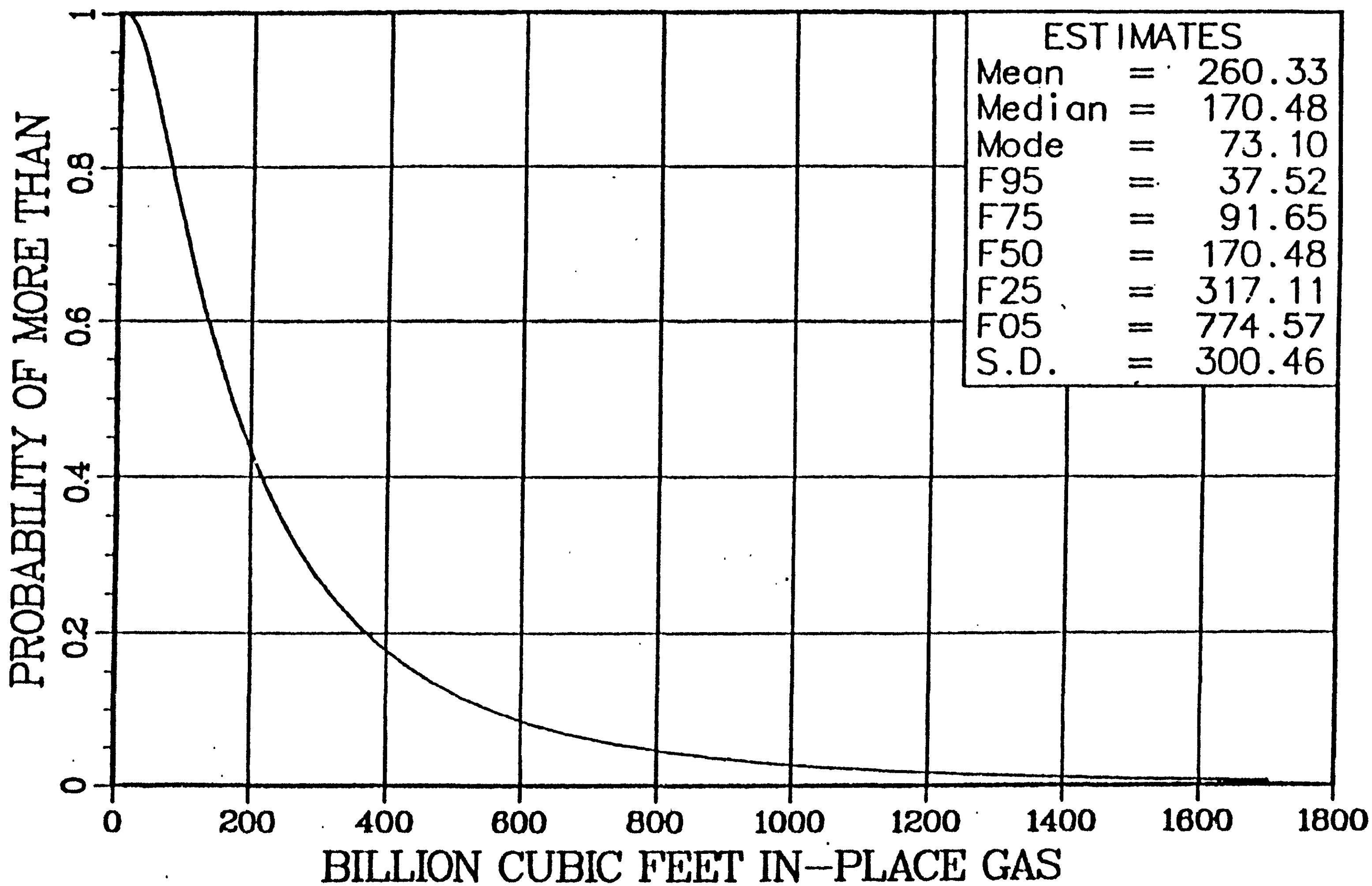


Figure 13.--Conditional (B) play potential of non-associated gas for Sag River.

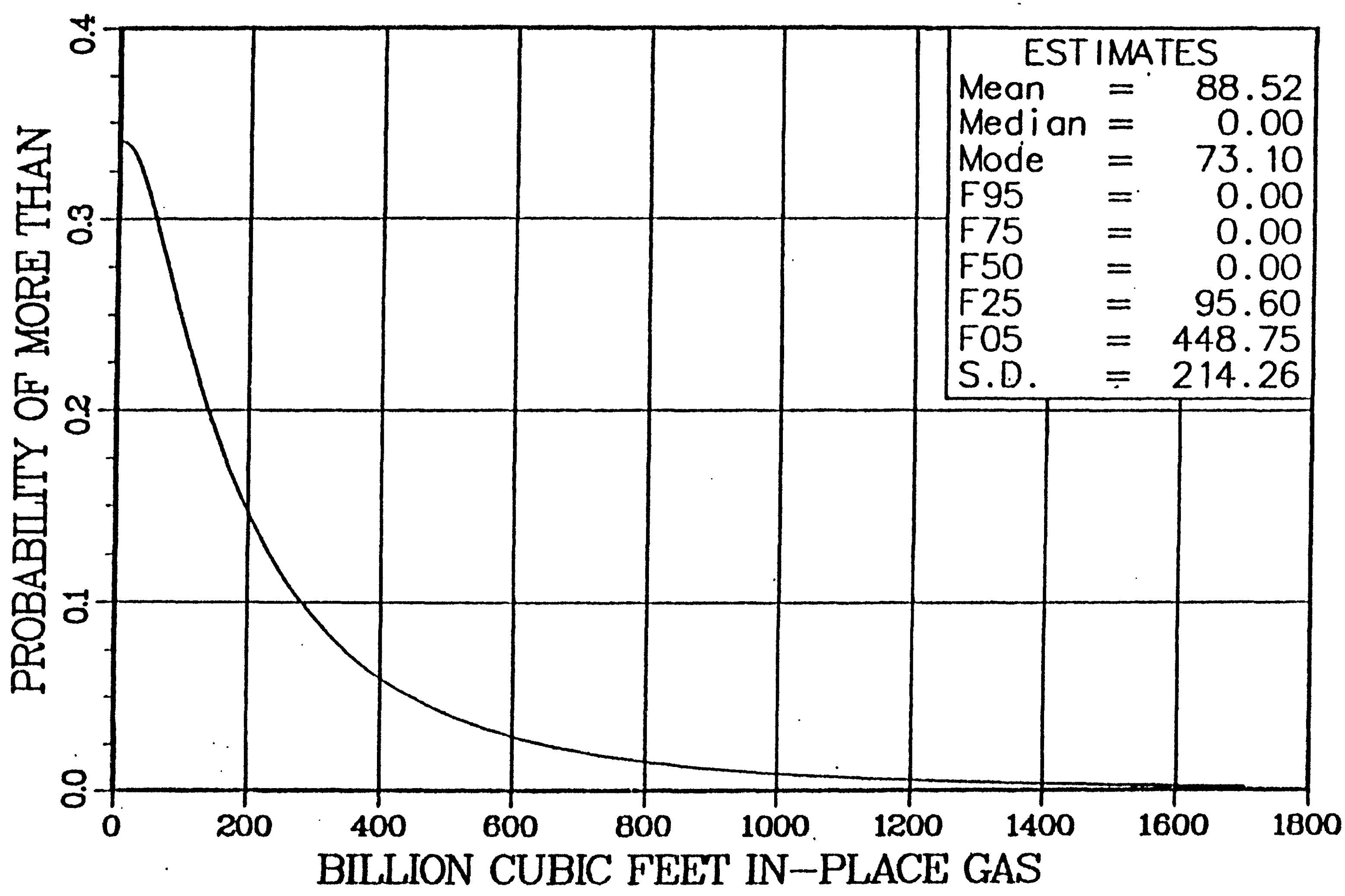


Figure 14.--Conditional (A) play potential of non-associated gas for Sag River.

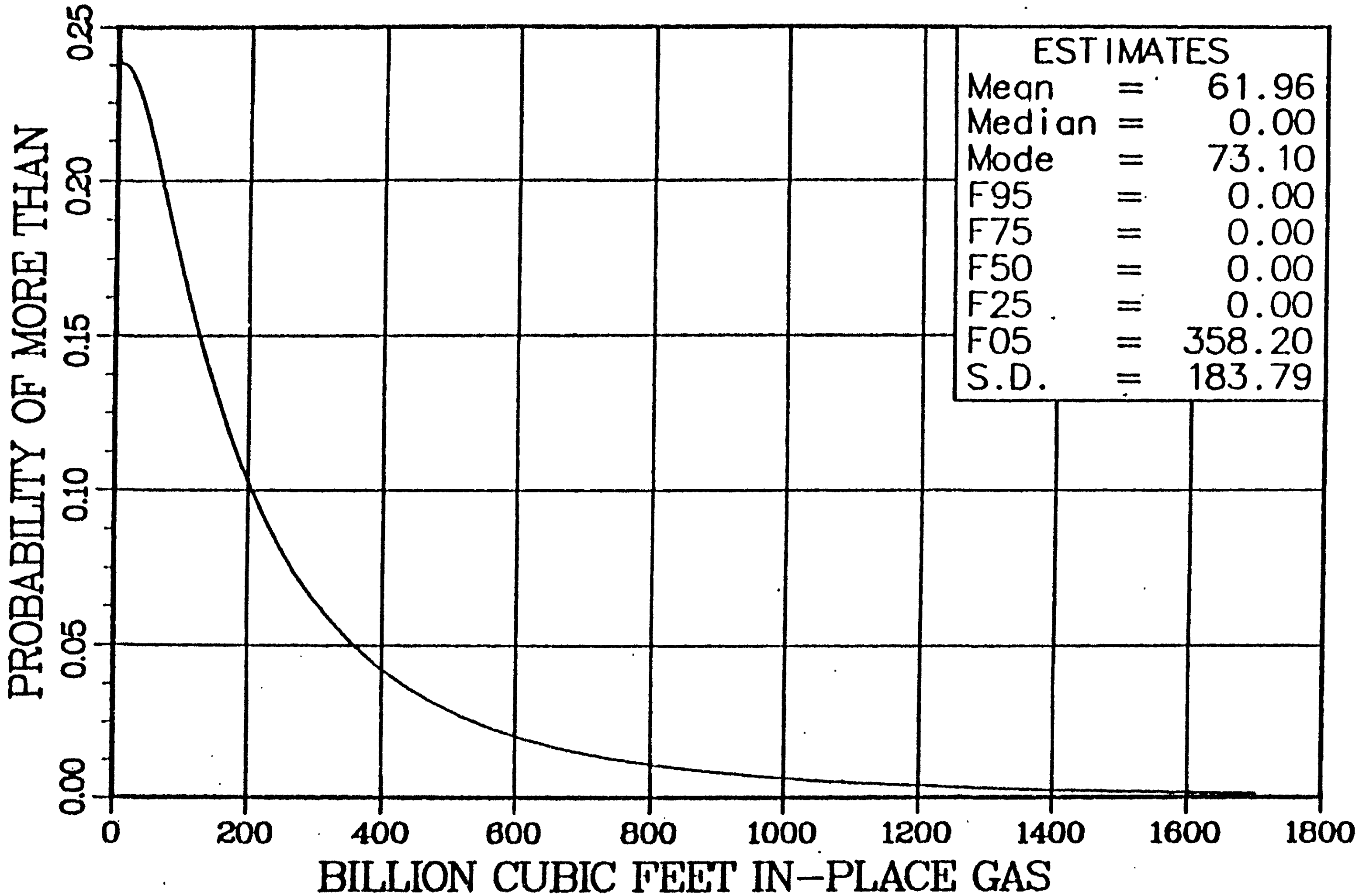


Figure 15.--Unconditional play potential of non-associated gas for Sag River.

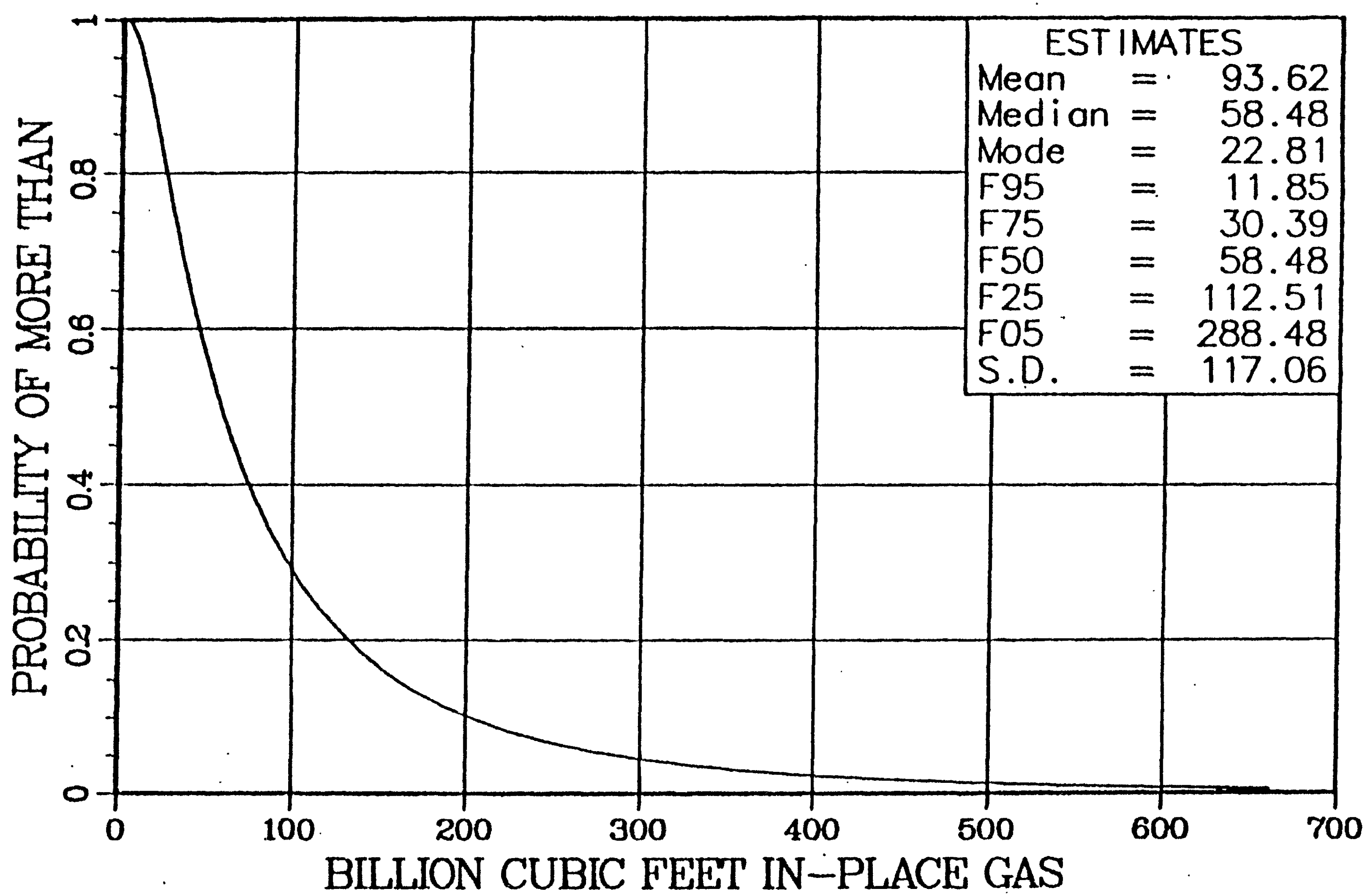


Figure 16.--Accumulation size of dissolved gas for Sag River.

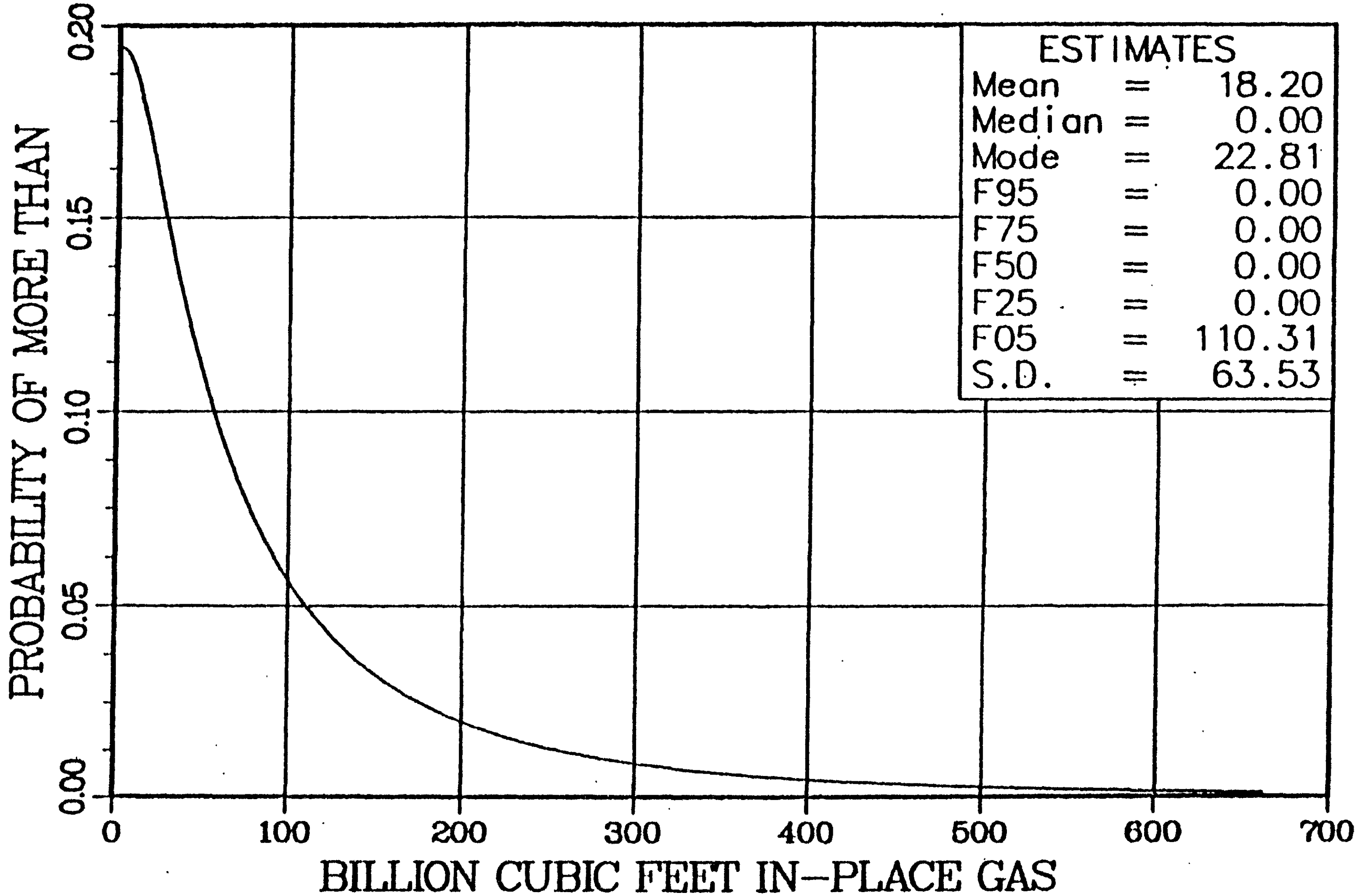


Figure 17.--Conditional prospect potential of dissolved gas for Sag River.

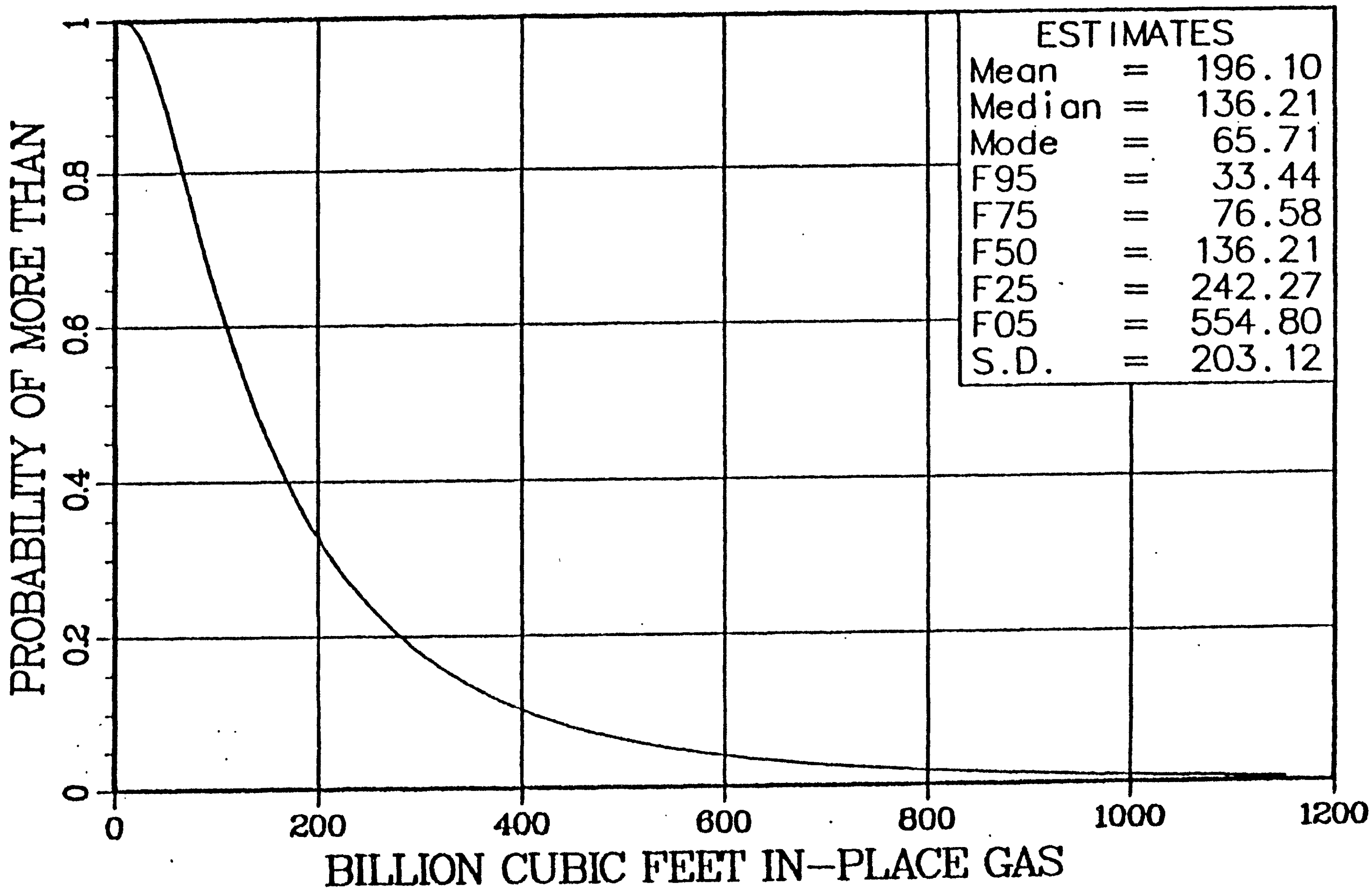


Figure 18.--Conditional (B) play potential of dissolved gas for Sag River.

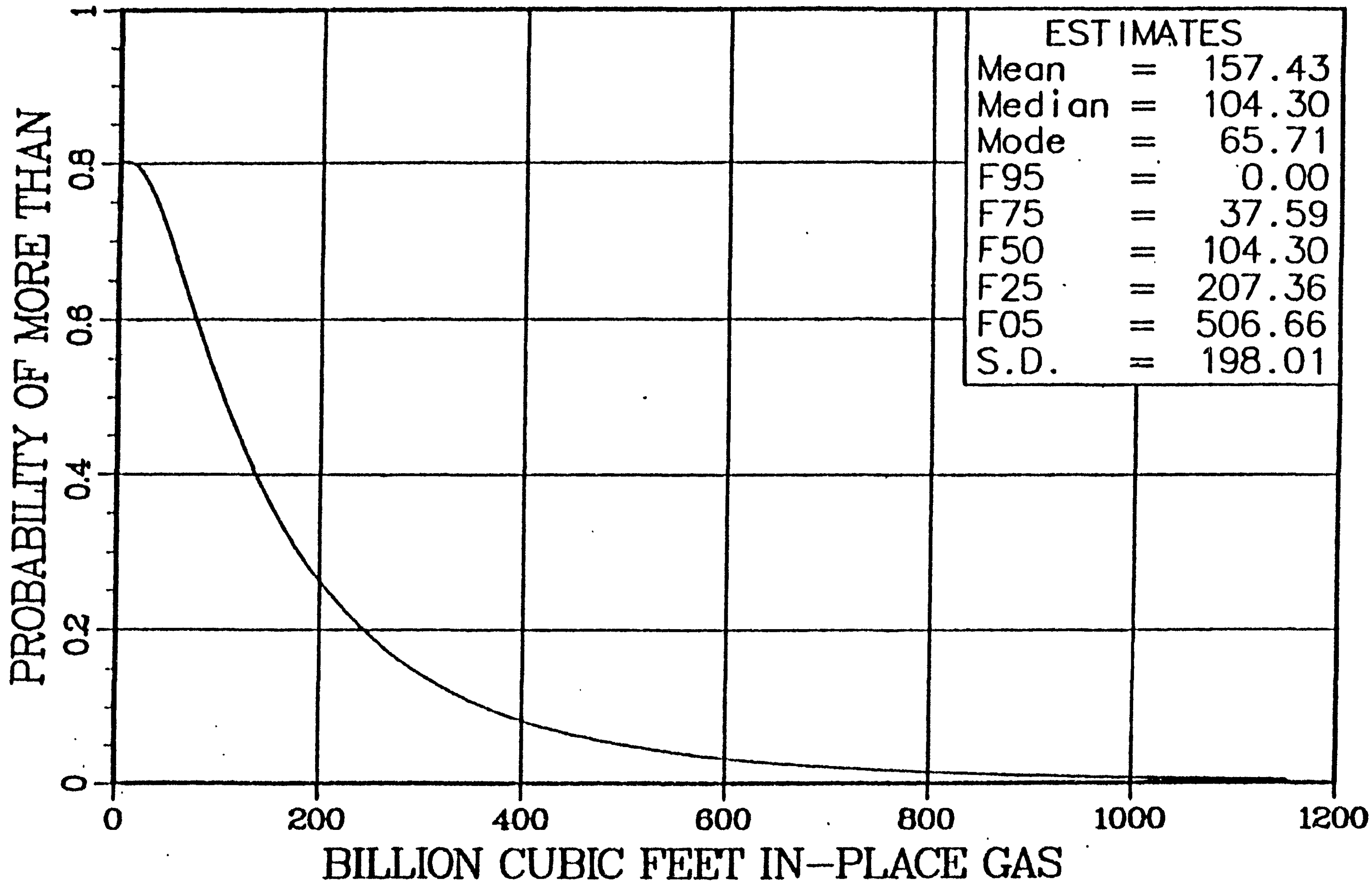


Figure 19.--Conditional (A) play potential of dissolved gas for Sag River.

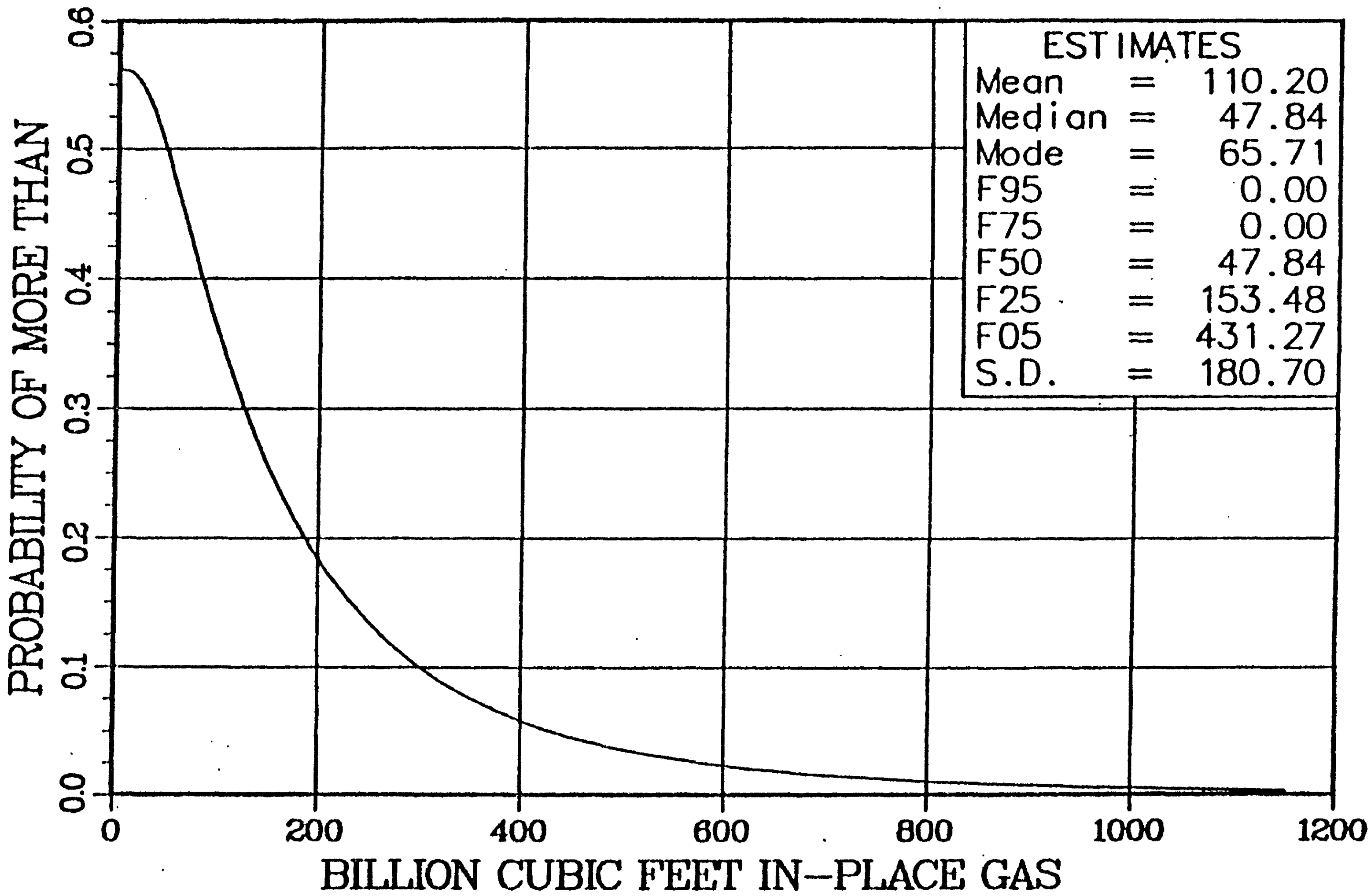


Figure 20.--Unconditional play potential of dissolved gas for Sag River.

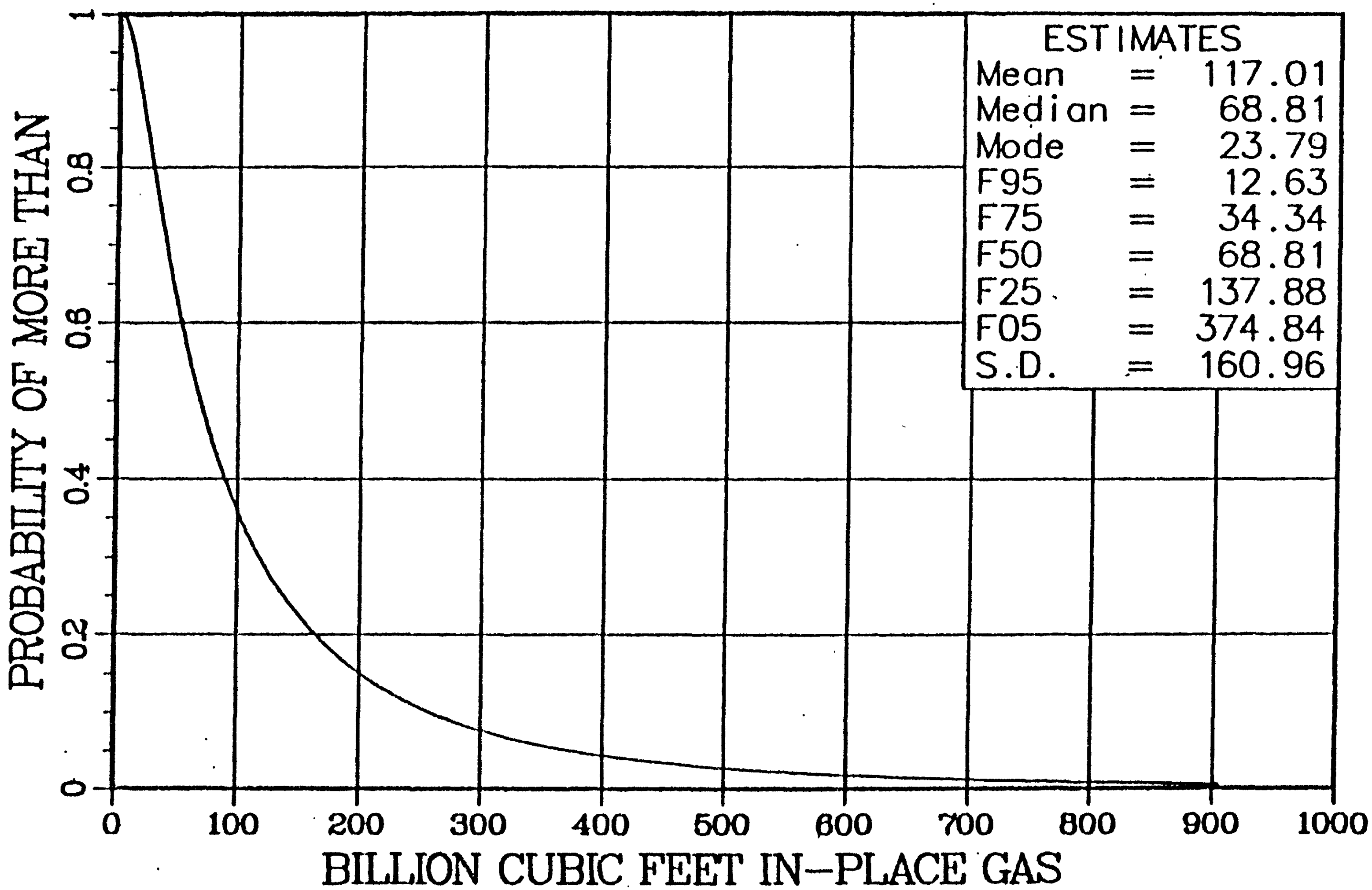


Figure 21.--Accumulation size of gas for Sag River.

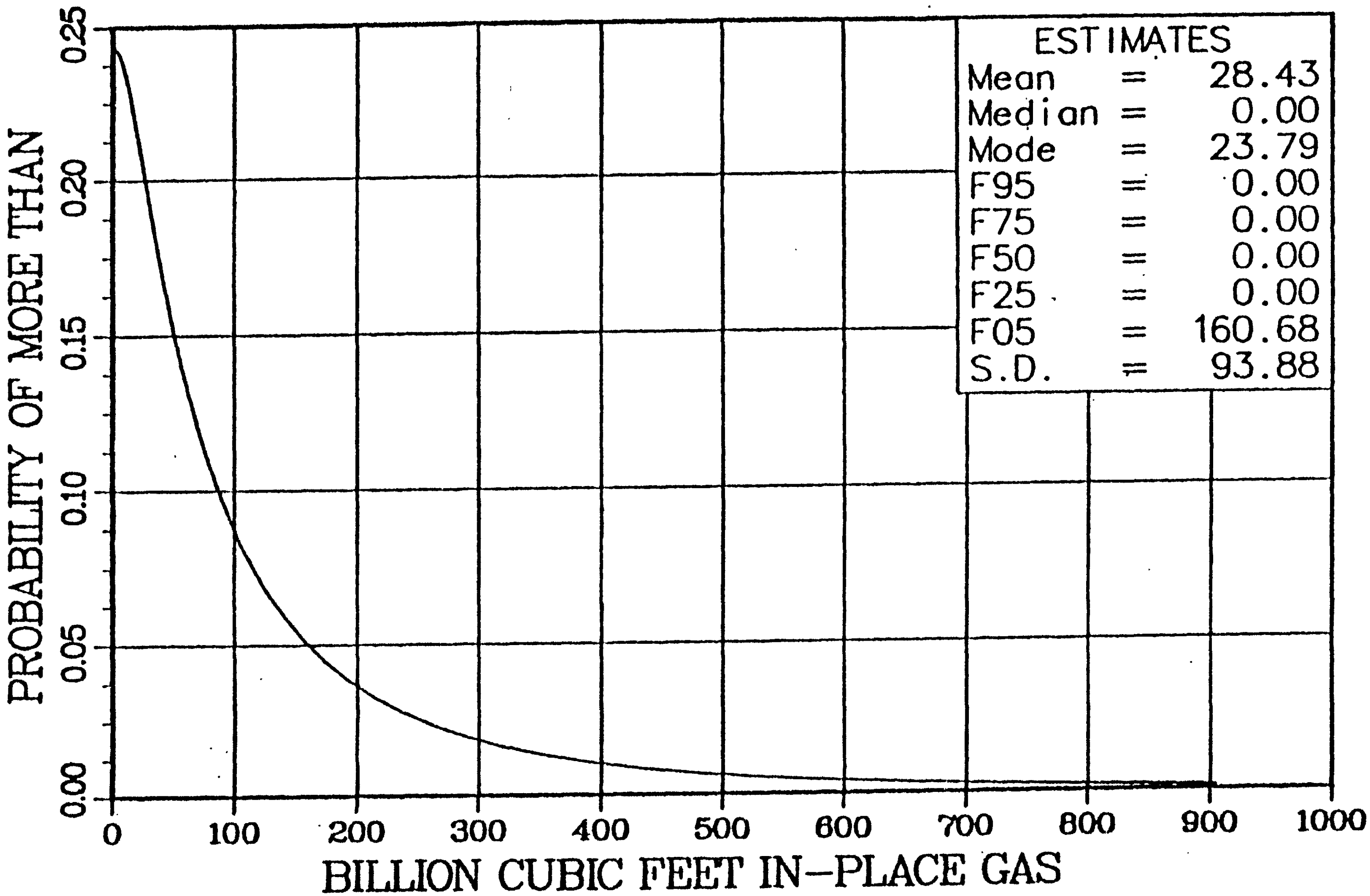


Figure 22.--Conditional prospect potential of gas for Sag River.

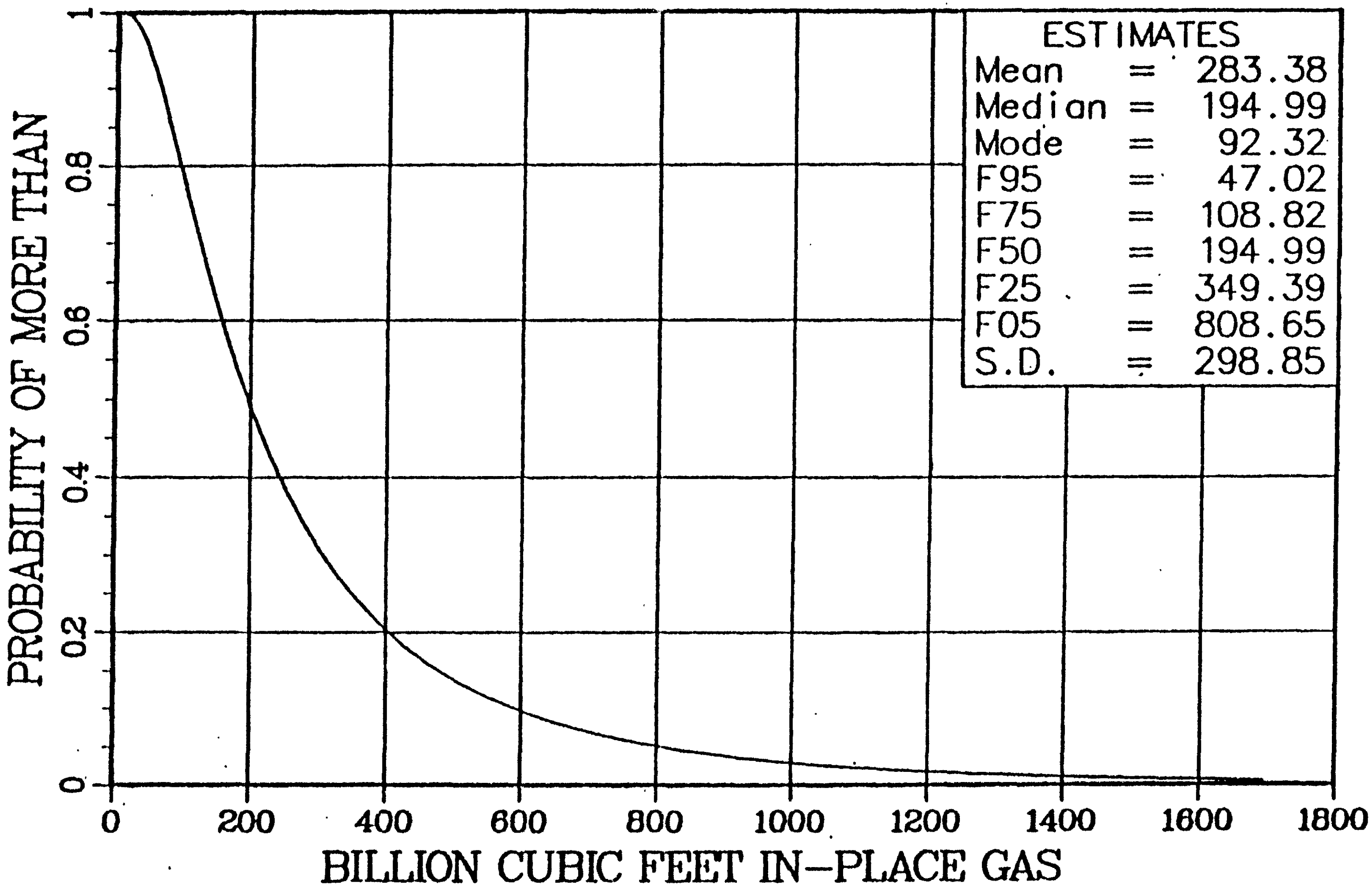


Figure 23.--Conditional (B) play potential of gas for Sag River.

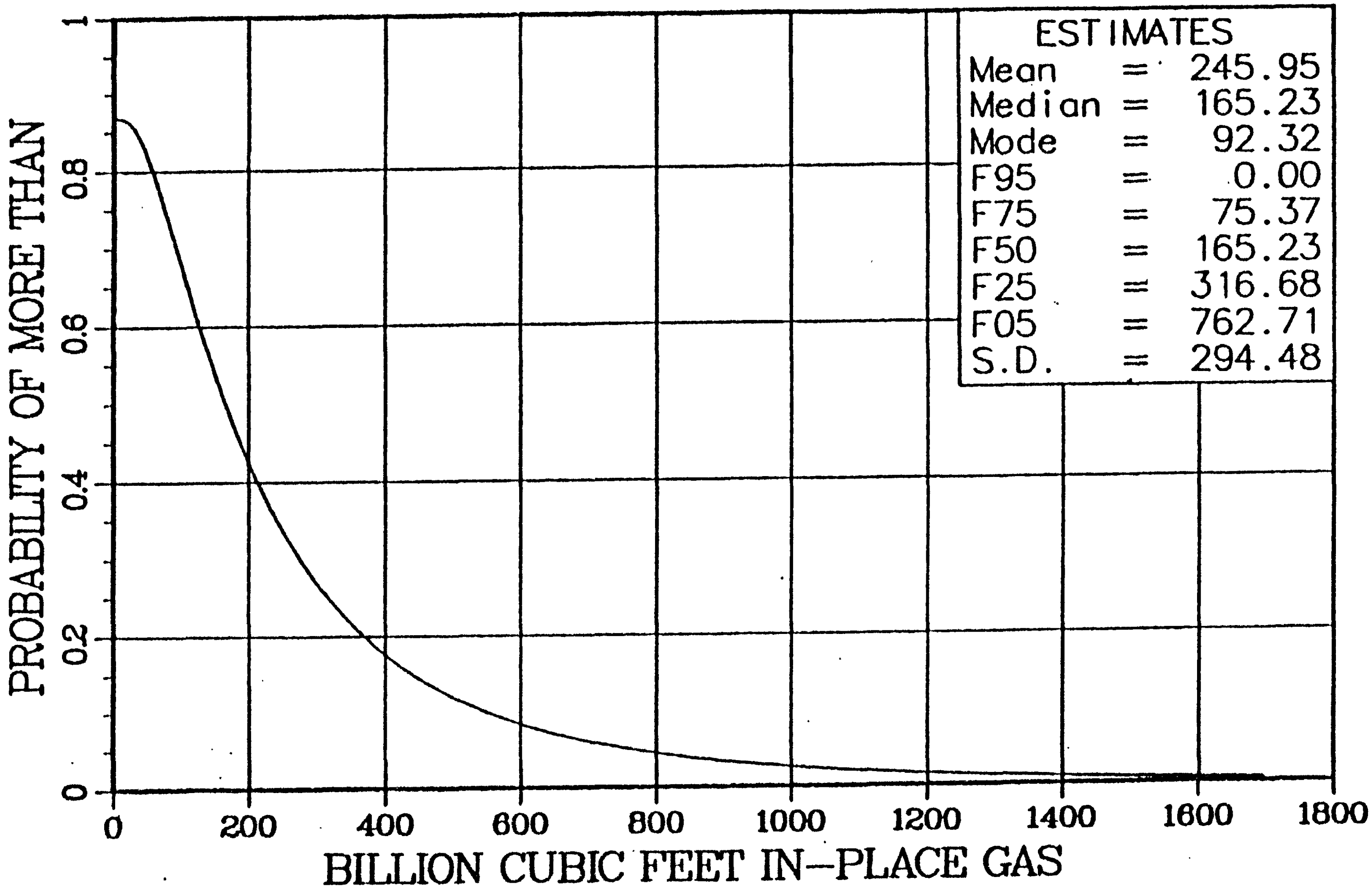


Figure 24.--Conditional (A) play potential of gas for Sag River.

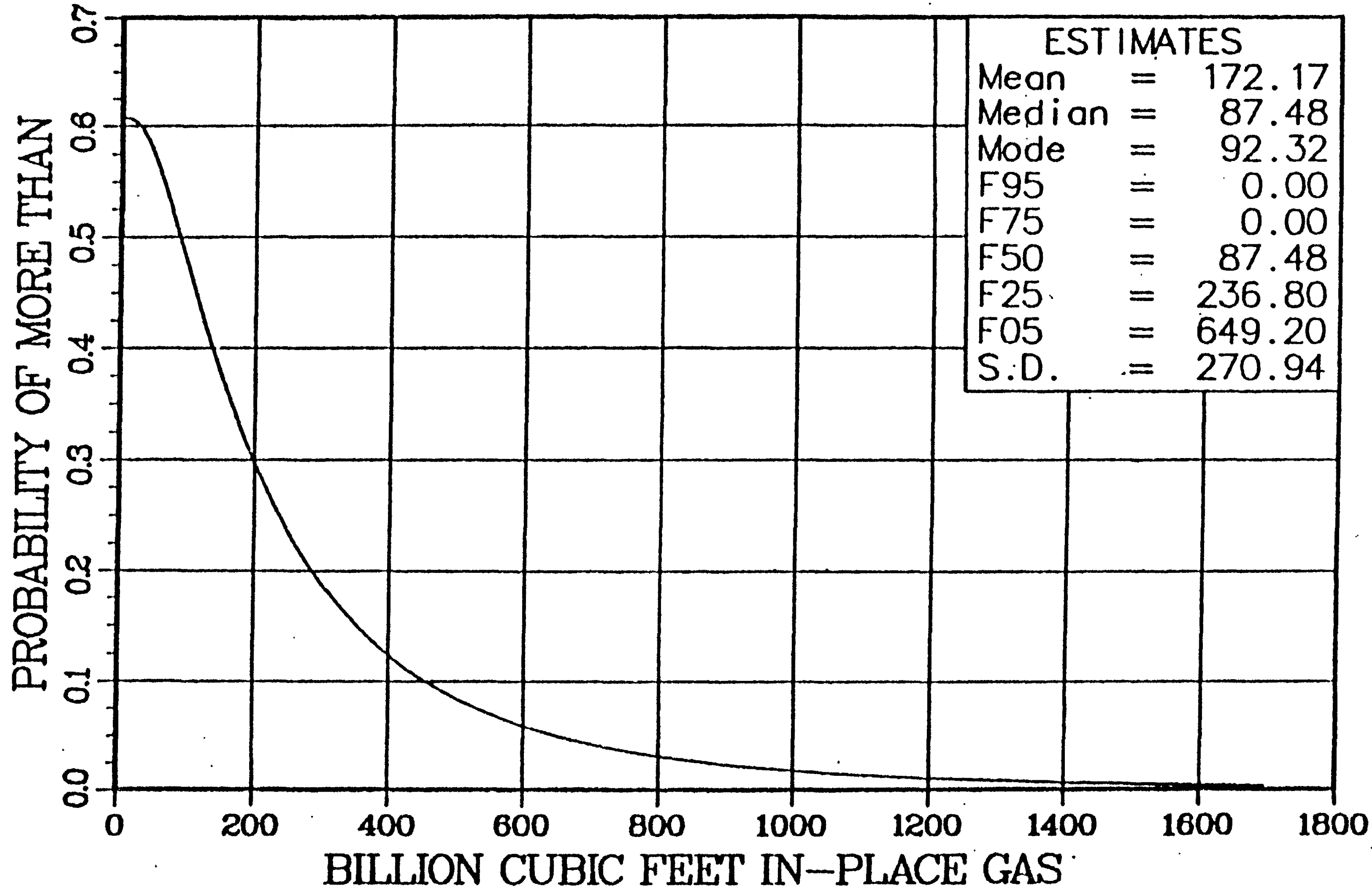


Figure 25.--Unconditional play potential of gas for Sag River.

ANALYTIC METHOD OF PLAY AGGREGATION

A separate methodology was developed for estimating the aggregaton of a set of plays. In this method the resource estimates of the individual plays from the analytic method of play analysis using the FASP program are aggregated by means of probability theory. Oil, nonassociated gas, dissolved gas, and gas resources are each aggregated in turn.

The basic steps of the analytic method of play aggregation are:

1. Select plays to aggregate.

2. Select oil as the first resource to be aggregated.

3. Compute the mean and variance of the unconditional aggregate potential for oil, which is the quantity of oil in the assessment area. They are determined by adding all of the individual play means and variances of the unconditional play potential for oil, respectively, assuming independence among the plays.

4. Compute the unconditional aggregate probability of oil, which is the probability that the assessment area has at least one play with oil, and is a function of the individual unconditional play probabilities of oil.

5. Compute the mean and variance of the conditional aggregate potential for oil, which is the quantity of oil in the assessment area, given the assessment area has at least one play with oil. These are arrived at by applying the unconditional aggregate probability of oil to the mean and variance of the unconditional aggregate potential for oil.

6. Model the probability distribution of the conditional aggregate potential for oil by the lognormal distribution with mean and variance from step 5. Calculate various lognormal fractiles.

7. Compute various fractiles of the unconditional aggregate potential for oil by a transformation to appropriate lognormal fractiles of the conditional aggregate potential for oil using the unconditional aggregate probability of oil.

8. Select nonassociated gas as the second resource to be aggregated. Repeat steps 3 through 7 using play analysis estimates of nonassociated gas, namely the individual play means and variances of the unconditional play potential for nonassociated gas, along with the individual unconditional play probabilities of nonassociated gas.

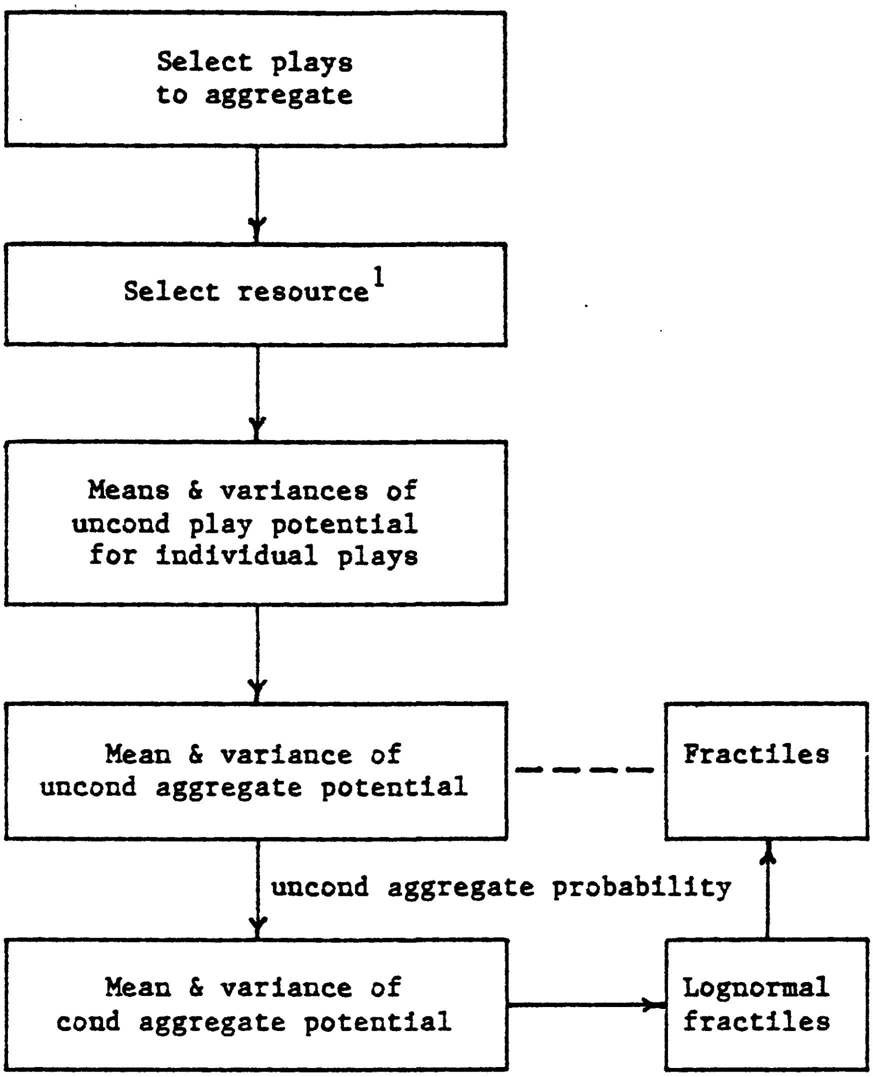
9. Select dissolved gas as the third resource to be aggregated. Repeat steps 3 through 7 using play analysis estimates of dissolved gas, namely the individual play means and variances of the unconditional play potential for dissolved gas, along with the individual unconditional play probabilities of dissolved gas.

10. Select gas as the fourth resource to be aggregated. Repeat steps 3 through 7 using play-analysis estimates of gas, namely the individual play means and variances of the unconditional play potential for gas, along with the individual unconditional play probabilities of gas.

A simplified flow chart of the analytic method of play aggregation is presented in Figure 26.

A computer program was designed on the basis of the analytic method for the aggregation of plays and called the Fast Appraisal System for Petroleum Aggregation (FASPA). FASPA interfaces with FASP as follows. FASP not only generates a file of resource estimates for an individual play, but also outputs a second file of results which consists of the mean and standard deviation of the unconditional play potential for each of the four resources, along with the corresponding unconditional play probabilities. The second file is needed for an aggregation of plays and forms an input file for FASPA. Therefore, after FASP is run on each play in a set of plays, any subset of plays can be aggregated by running FASPA on the corresponding subset of aggregation input files. FASPA not only generates a file of resource estimates for an aggregation of plays, but also outputs a second file of results needed for an aggregation of aggregations, which forms yet another input file for FASPA. Hence, after FASPA is run on each aggregation in a set of aggregations, any subset of aggregations can be aggregated at once. Compared to the simulation method, the application of FASPA can result in tremendous savings of time and cost, especially when analyzing many aggregations involving hundreds of plays. FASPA also possesses the capacity of aggregating a set of plays under a dependency assumption. In which case, all of the individual play standard deviations (instead of the variances) of the unconditional play potential for a resource are added together.

Figure 26.--Flow Chart of Analytic Method of Play Aggregation



[1] Oil, nonassociated gas, dissolved gas, and gas resources are each aggregated in turn.

NUMERICAL EXAMPLE OF PLAY AGGREGATION

A numerical example of the application of the analytic method of play aggregation is illustrated using an actual resource assessment involving an aggregation of ten plays. The data is from a U.S. Geological Survey assessment of an area in Alaska (Mast, R. F., and others, 1980). The assessment area had been partitioned into ten geologic plays. An oil and gas appraisal data form (Figure 1) had been filled out for each of the ten plays by USGS resource appraisal experts (U.S. Department of Interior 1980, written commun.). The data for the aggregation was analyzed by the analytic method of play analysis using the computer program FASP for the ten individual plays, and then FASPA for their aggregation. The aggregation input files from the ten individual plays to be aggregated is given as printed by FASPA in Table 3. Estimates of undiscovered in-place petroleum resources for the aggregation of the ten plays, assuming independence among the plays, are presented in FASPA output form in Table 4. The corresponding graphs of the complementary cumulative distribution functions are displayed, again in direct computer output form, in Figures 27 through 34.

Table 3.--Aggregation input files from ten individual plays to be aggregated. Data required and printed by the computer program FASPA.

INPUT SUMMARY

Play	OIL			NON-ASSOC GAS			ASSOC-DISS GAS			GAS		
	Mean	S.D.	Marg P	Mean	S.D.	Marg P	Mean	S.D.	Marg P	Mean	S.D.	Marg P
1	1034.20	2967.40	0.535	1027.10	3231.20	0.535	356.72	1223.50	0.535	1383.80	3461.20	0.775
2	2129.00	3920.30	0.786	2309.40	5334.60	0.641	1777.20	3606.40	0.786	4086.60	6437.20	0.927
3	1363.20	4045.20	0.501	3279.70	8574.00	0.595	1325.00	4200.50	0.501	4604.70	9614.40	0.780
4	103.26	356.49	0.625	139.31	564.06	0.520	100.37	370.46	0.625	239.69	676.01	0.812
5	55.62	387.72	0.129	231.24	1113.00	0.242	61.52	444.12	0.129	292.76	1201.60	0.333
6	132.51	735.97	0.137	732.99	2373.70	0.346	135.22	790.07	0.137	868.21	2512.60	0.426
7	21.63	234.40	0.059	226.05	1042.40	0.271	22.08	251.68	0.059	248.13	1075.10	0.306
8	28.00	226.12	0.076	320.59	1091.50	0.335	30.75	257.08	0.076	351.34	1126.80	0.374
9	11.49	224.31	0.034	149.87	1186.80	0.172	14.07	278.90	0.034	163.94	1220.60	0.196
10	0.56	40.20	0.002	2.27	119.87	0.004	0.68	50.02	0.002	2.95	129.90	0.006
Aggregation	4879.47	6443.21	0.988	8418.52	11104.25	0.994	3823.61	5771.97	0.988	12242.12	12569.82	1.000

Table 4.--Estimates of undiscovered in-place petroleum resources for the aggregation of ten plays. Data output from the computer program FASPA.

AGGREGATION OF TEN PLAYS	ESTIMATED RESOURCES IN PLACE						
	Mean	Std. Dev.	F95	F75	F50	F25	F05
OIL (Billions of BBLs)							
Cond Aggregate Potential	4.937508	6.459270	0.5800	1.5288	2.9985	5.8813	15.503
Uncond Aggregate Potential	4.879470	6.443208	0.5136	1.4860	2.9560	5.8382	15.464
NON-ASSOCIATED GAS (Trillions of CuFt)							
Cond Aggregate Potential	8.473074	11.11940	0.9900	2.6148	5.1355	10.086	26.638
Uncond Aggregate Potential	8.418521	11.10425	0.9293	2.5750	5.0957	10.053	26.642
ASSOCIATED-DISSOLVED GAS (Trillions of CuFt)							
Cond Aggregate Potential	3.869090	5.791027	0.3612	1.0344	2.1494	4.4662	12.792
Uncond Aggregate Potential	3.823610	5.771975	0.3165	1.0031	2.1164	4.4311	12.758
GAS (Trillions of CuFt)							
Cond Aggregate Potential	12.24323	12.56985	2.1157	4.8201	8.5426	15.140	34.492
Uncond Aggregate Potential	12.24212	12.56982	2.1124	4.8195	8.5418	15.158	34.582

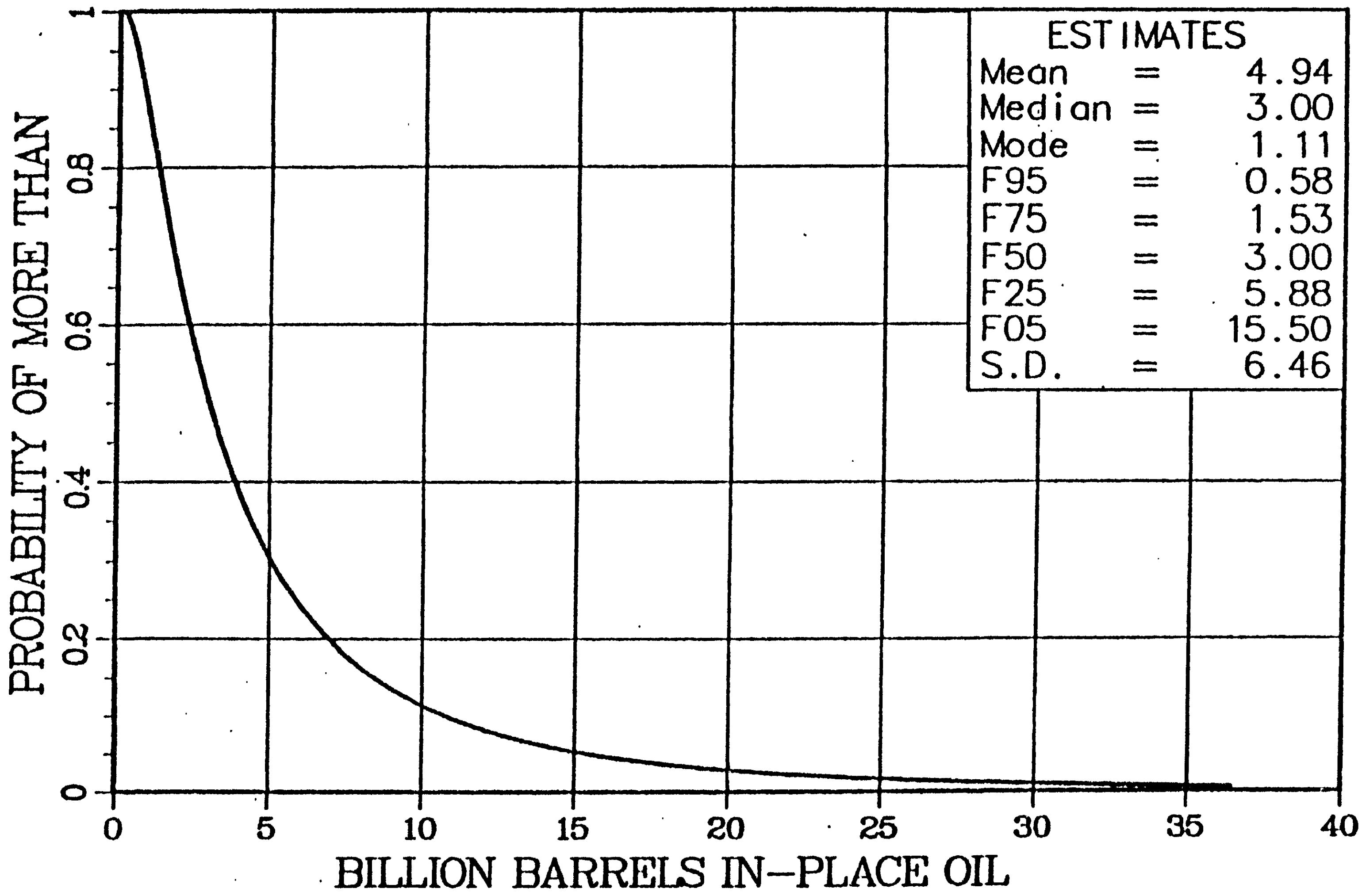


Figure 27.--Conditional aggregate potential of oil for aggregation of ten plays.

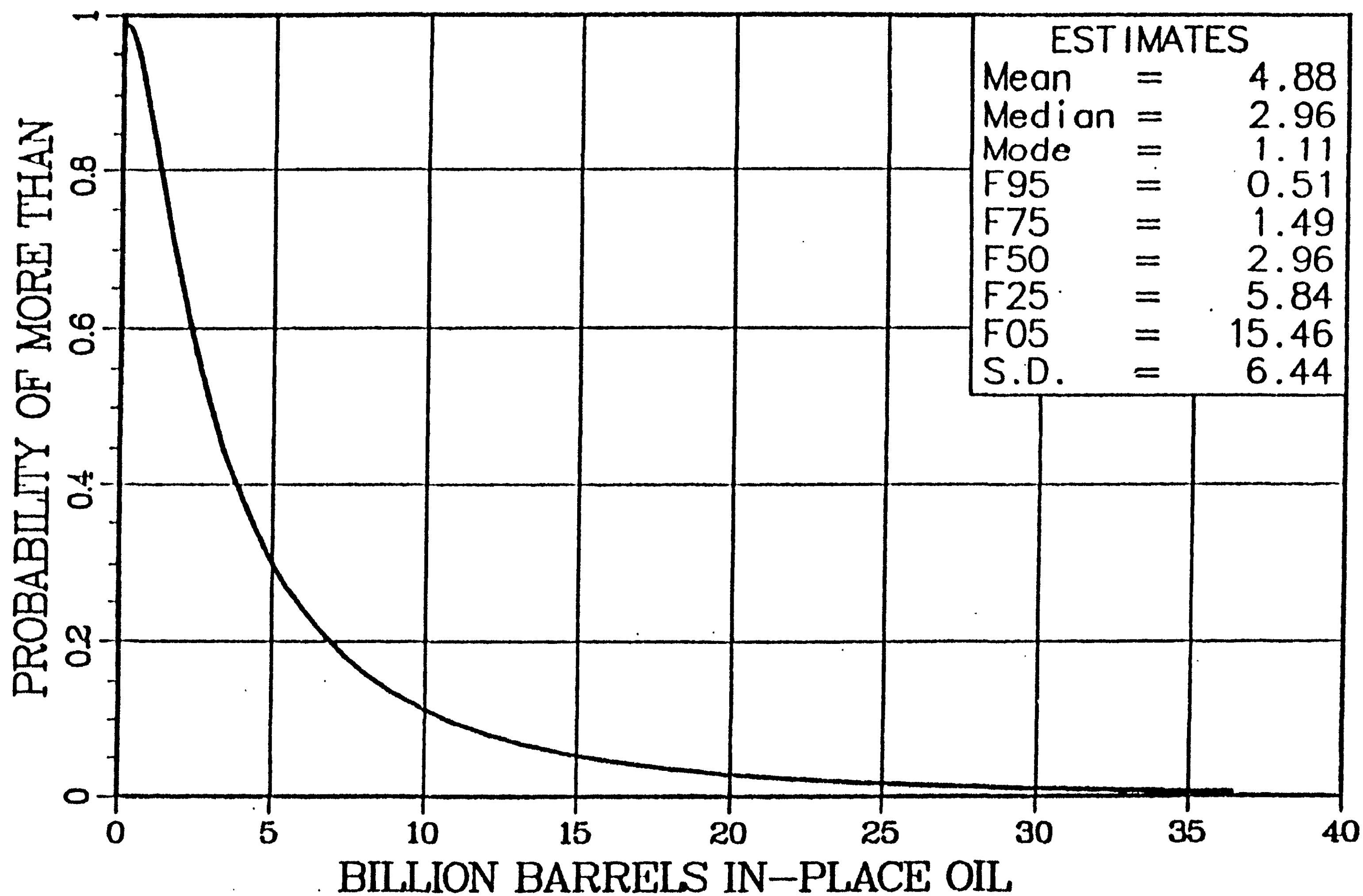


Figure 28.--Unconditional aggregate potential of oil for aggregation of ten plays.

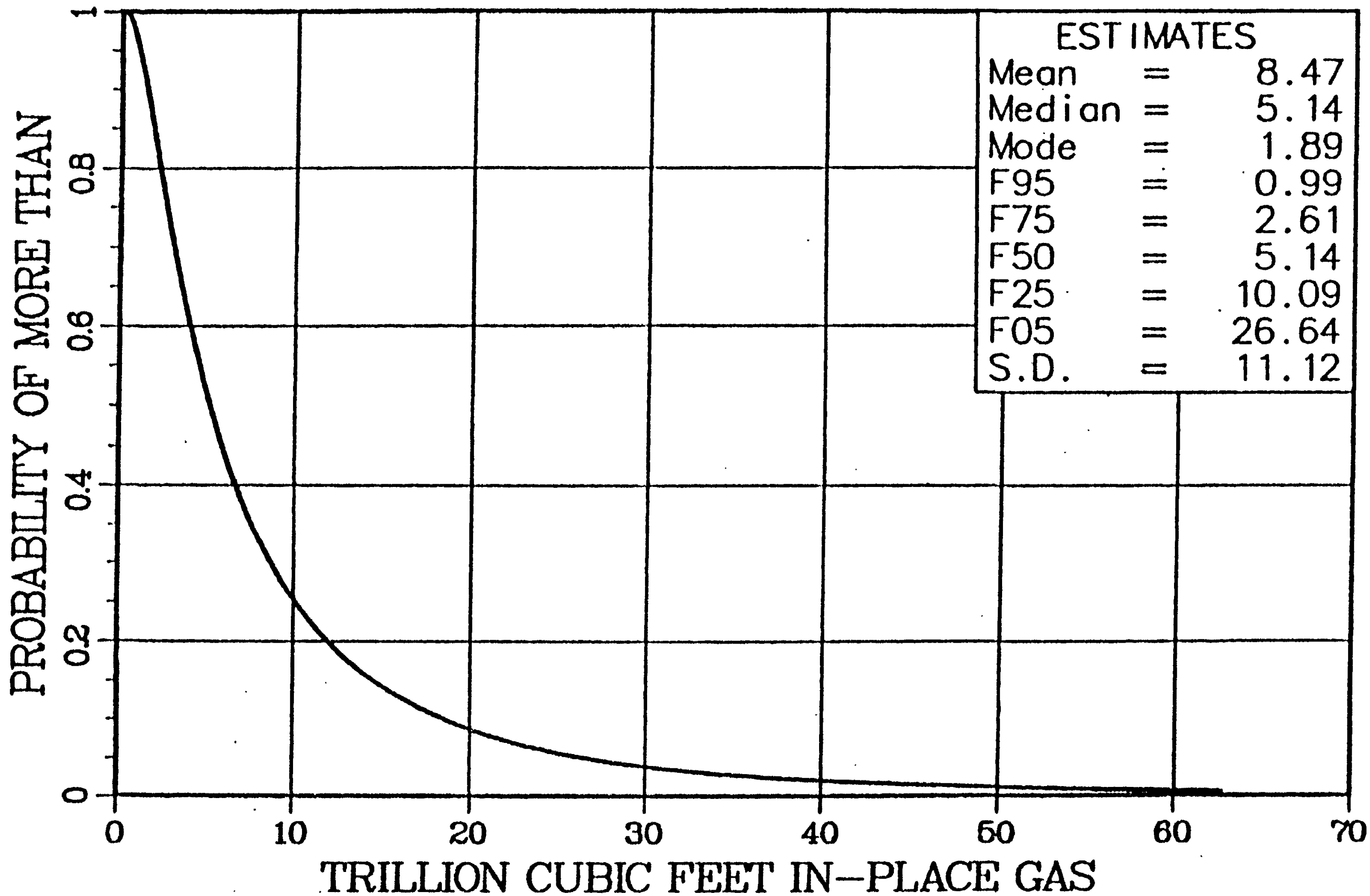


Figure 29.--Conditional aggregate potential of non-associated gas for aggregation of ten plays.

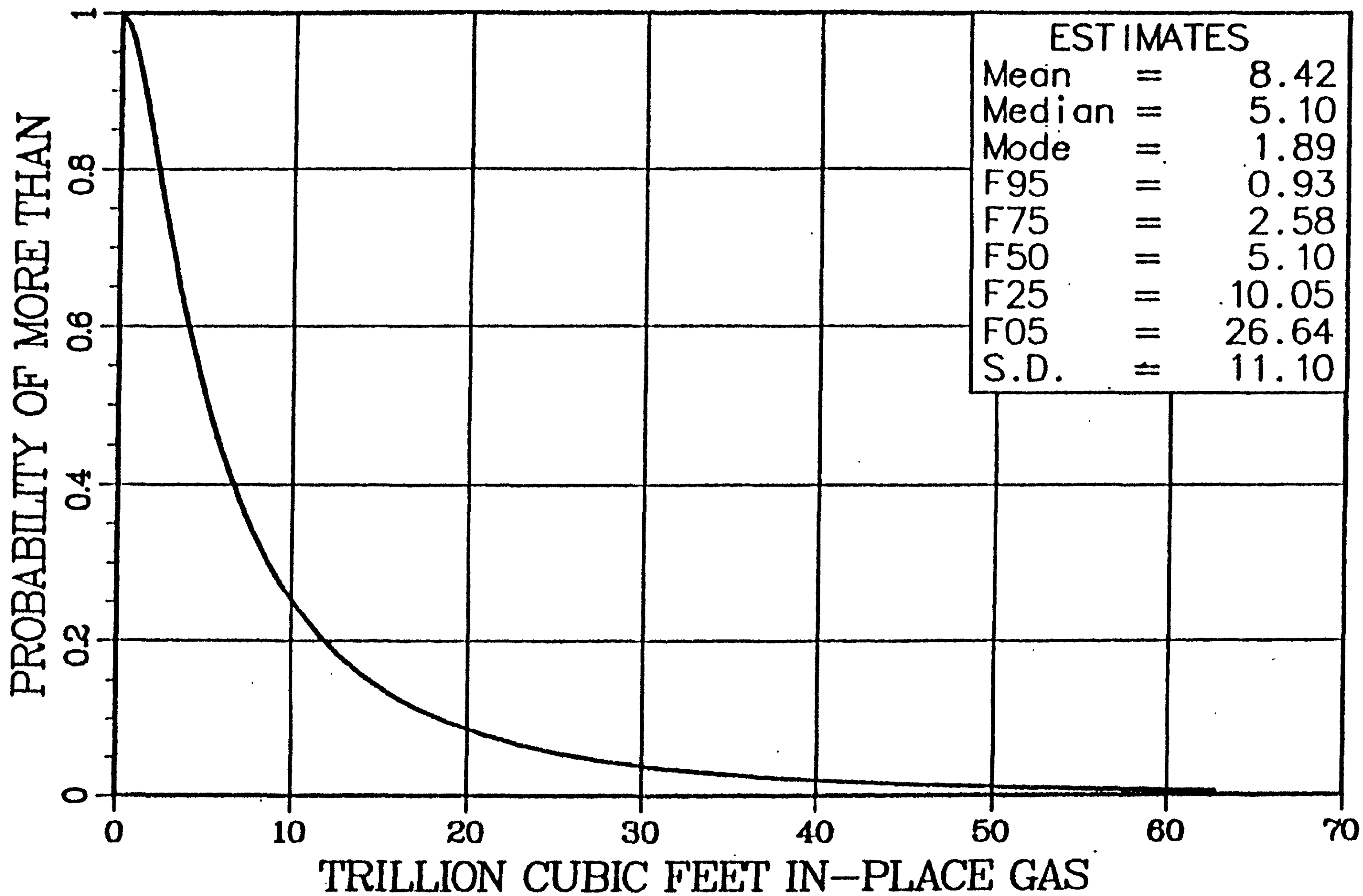


Figure 30.--Unconditional aggregate potential of non-associated gas for aggregation of ten plays.

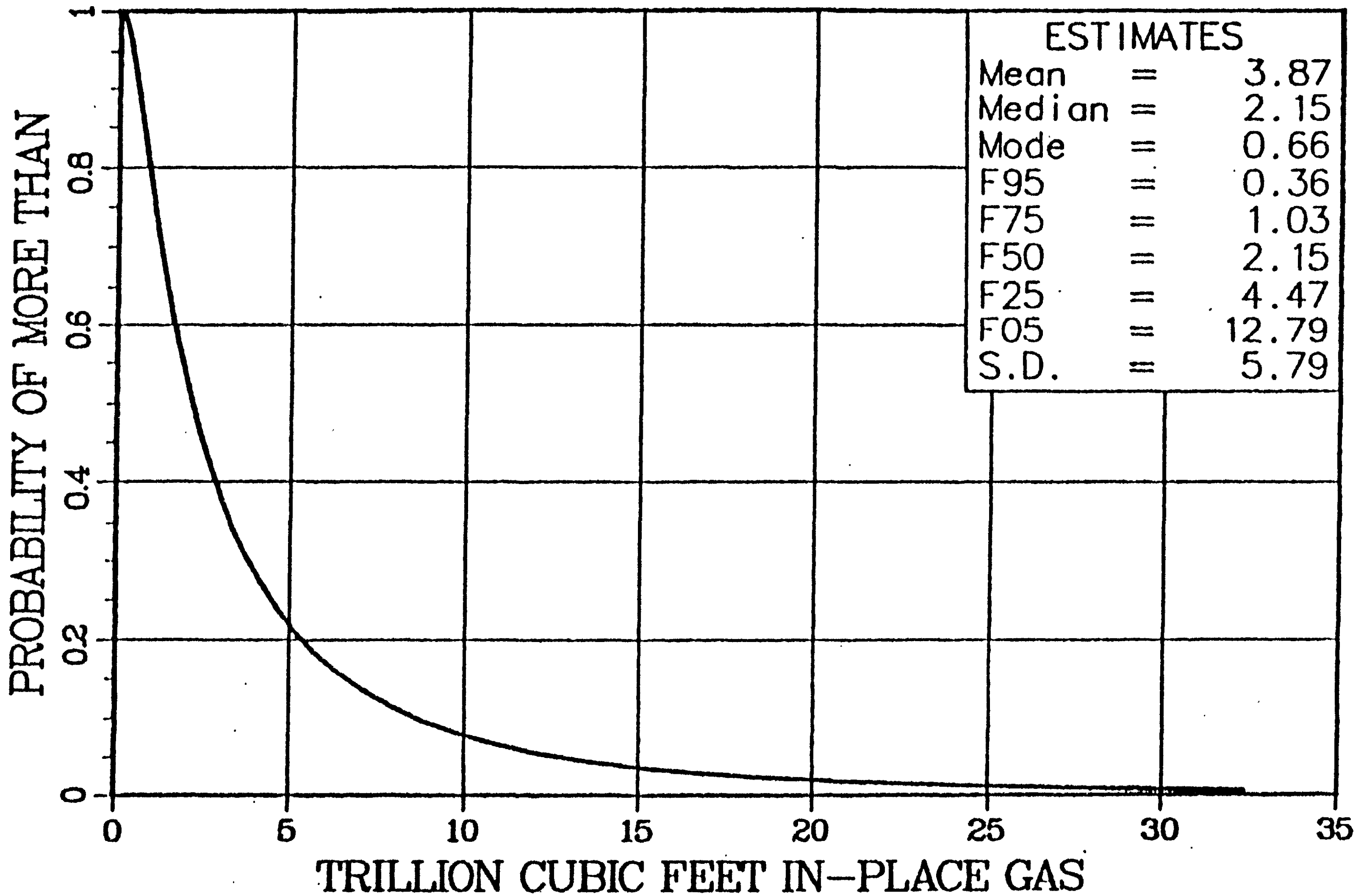


Figure 31.--Conditional aggregate potential of dissolved gas for aggregation of ten plays.

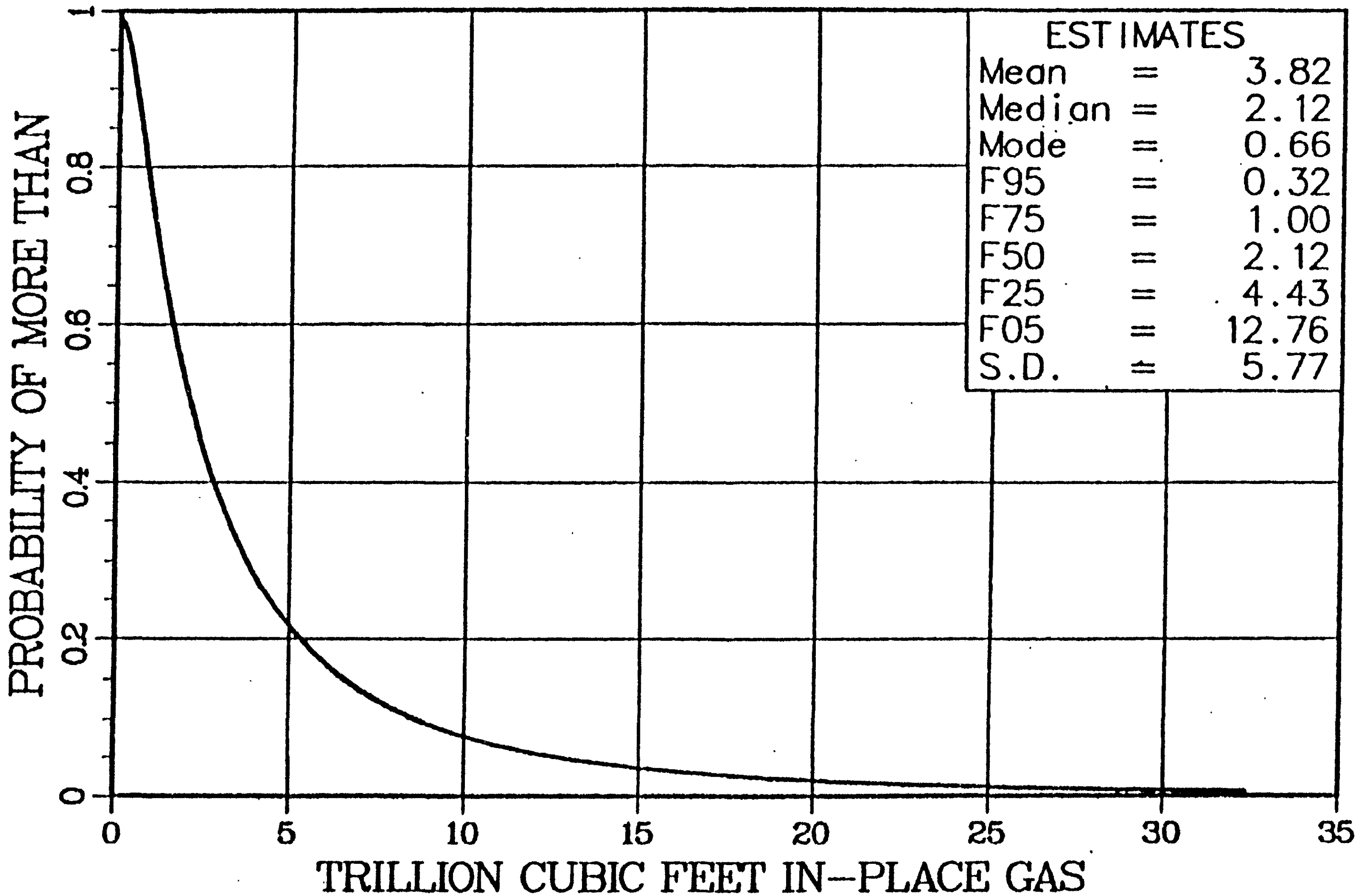


Figure 32.--Unconditional aggregate potential of dissolved gas for aggregation of ten plays.

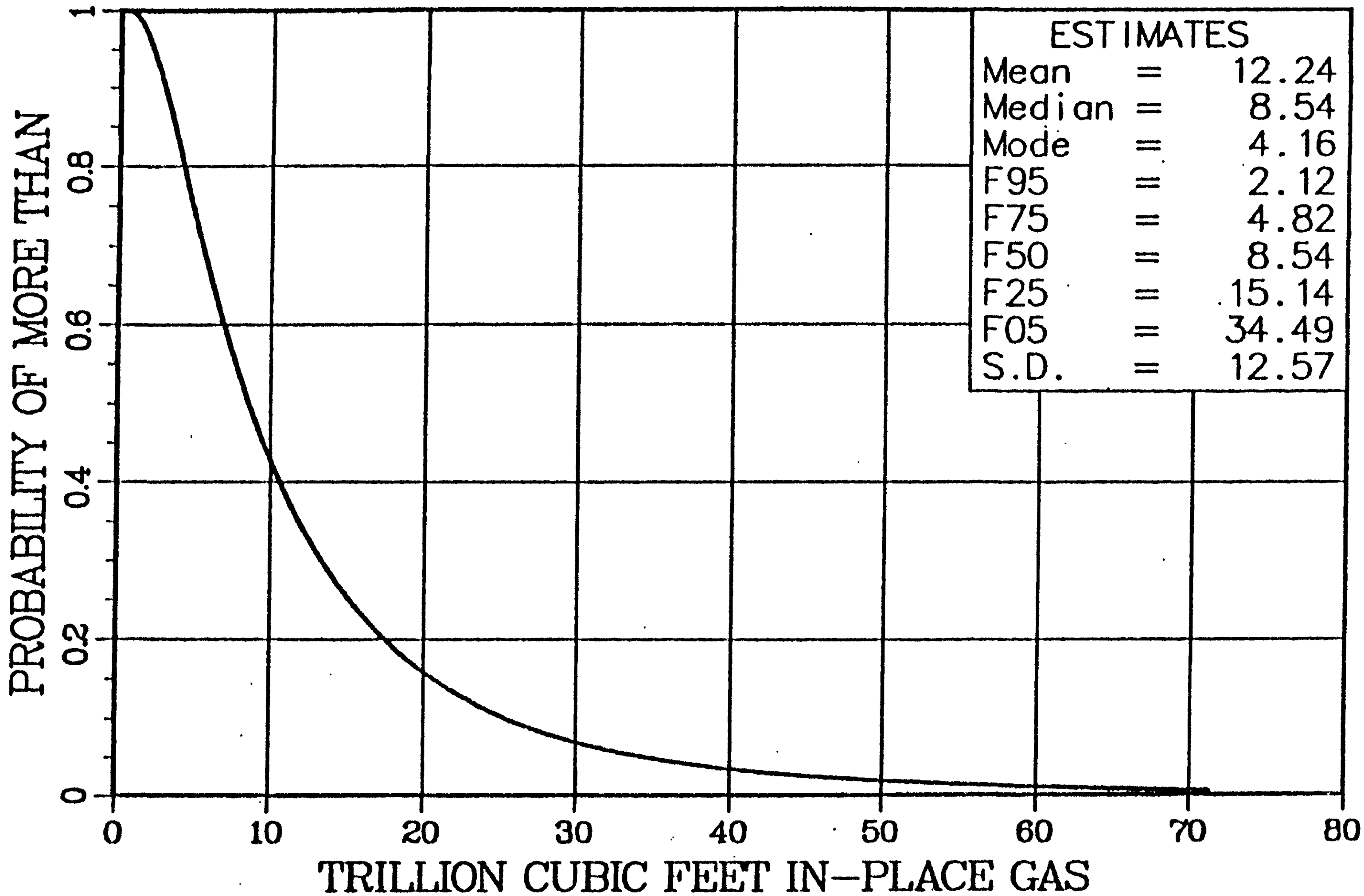


Figure 33.--Conditional aggregate potential of gas for aggregation of ten plays.

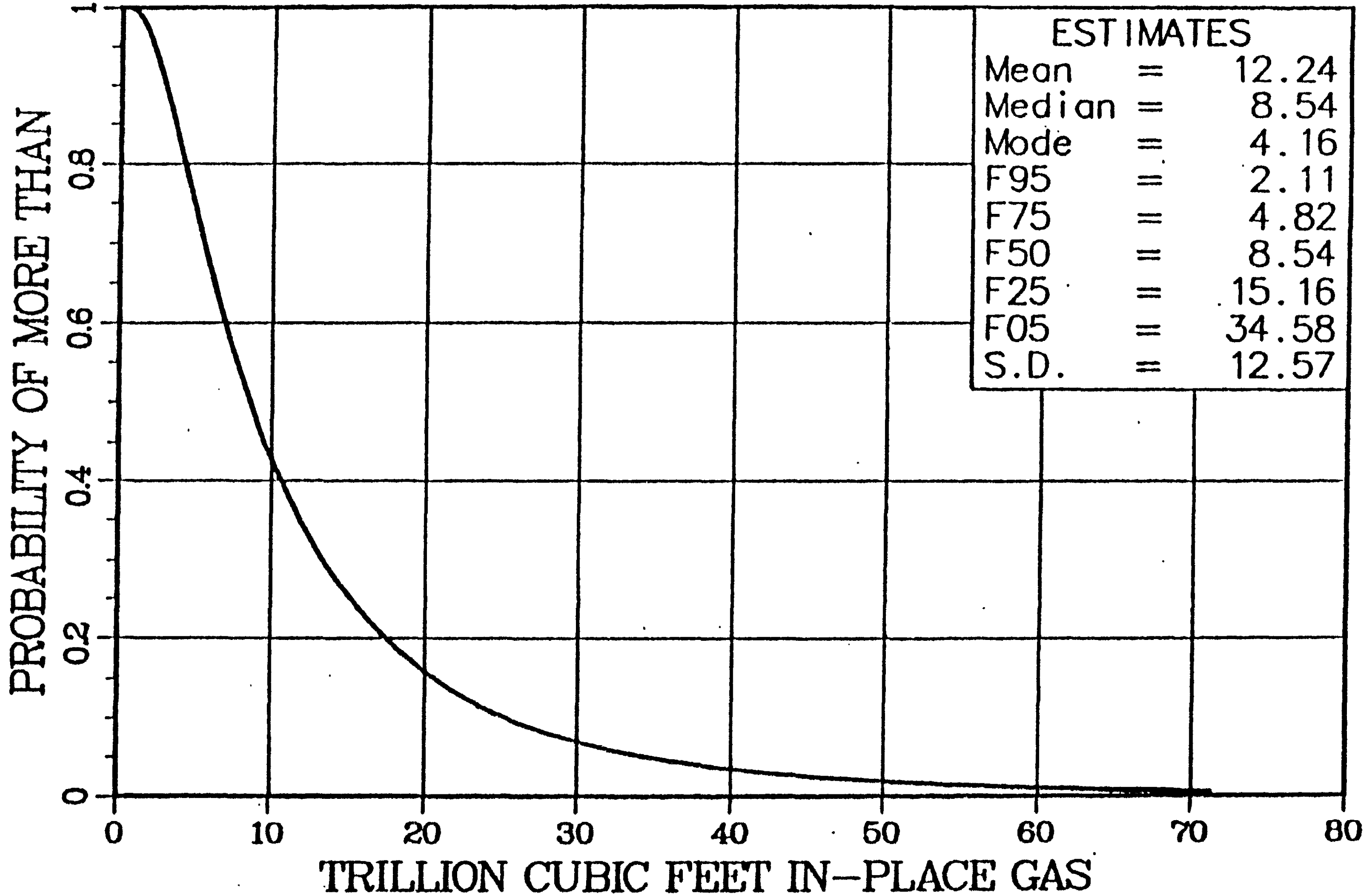


Figure 34.--Unconditional aggregate potential of gas for aggregation of ten plays.

CONCLUSIONS

The analytic method using probability theory is a practical alternative to the simulation method for petroleum play analysis. The computer program FASP based on the analytic method operates thousands of times faster than the computer program RASP based on the simulation method. Because the cost and running time are negligible, FASP allows for quick feedback evaluation of the estimated geologic data, a feature which is invaluable during actual resource assessment meetings. Moreover, FASP and FASPA can be adapted to most microcomputers; they need no system-dependent subroutines or unusual library functions. The analytic method produces not only numerical estimates of petroleum resources, but also mathematical equations of probabilistic relationships involving these resources; whereas the simulation method produces no such equations.

A tremendous savings of time and cost can result using FASP, especially when analyzing hundreds of individual plays. However, the greater advantage of the analytic method might lie in the aggregation of a set of plays, especially if the set is large and there are many combinations of aggregations required. The computer program FASPA based on the analytic method can aggregate any subset of plays almost instantly, and it can aggregate aggregations. FASPA has considerable flexibility, even aggregating under a dependency assumption.

ACKNOWLEDGMENT

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