Assessment of yet-to-find-oil in the Pre-Salt area of Brazil

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Abstract

In 2011, the authors of this work presented the results of the first assessment of the yet-to-find (YTF) oil potential in the Brazilian pre-salt region, utilizing an exploration modeling tool and a stochastic simulation method (Monte Carlo) for estimating potential accumulations discovered and remaining to be discovered. The 2011 assessment provided the first indication of potential YTF recoverable resources, based on a robust methodology validated by other assessment studies with the same methodology. Prior to that study, estimates of the YTF oil potential of the pre-salt region had been variously touted as being anywhere from 60 billion to over 100 billion barrels of recoverable oil and gas resources, but did not cite the methodology employed for reaching those numbers. The total recoverable resources indicated by the 2011 assessment were far superior to even the most optimistic values mentioned up until then. However, as new discoveries and revaluations of existing accumulations were announced, more information became available, which has now been used to update that study, utilizing the same methodology. The results of the current assessment suggest that the initial results were not unreasonable, despite being significantly higher than most other estimates cited. The new results suggest that within probabilistic confidence levels of 90% and 10%, field sizes of YTF accumulations in the pre-salt area range approximately from 240 million to 5.9 billion barrels, and total recoverable YTF accumulations range approximately from 119 billion to 217 billion barrels, respectively. These new figures represent a narrowing of the prior estimates (accumulation sizes between 166 million and 8 billion barrels, and total YTF recoverable resources between 114 and 288 billion barrels), which suggests that the prior estimates were good approximations at the time, and that the methodology employed is valid. The new figures also serve to confirm the importance of the pre-salt region to Brazil, and its significance in terms of future sources of new global production of oil and gas.

Introduction

The Brazilian Pre-Salt region (Figure 1) has legal boundaries defined by law, but they do follow approximately the known limits of the occurrence of the geological evaporate sequence in the Santos, Campos and Espírito Santo Basins, which generally extend beyond the legal limits. (**Erro! Fonte de referência não encontrada.**).

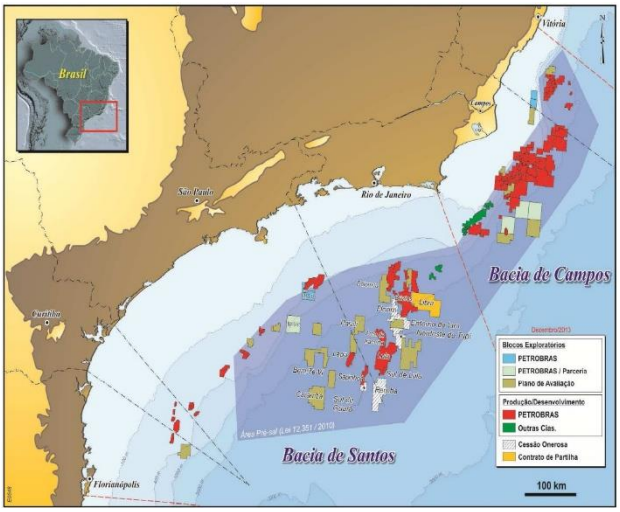

Figure 1 – Legal boundary of the Pre-Salt region in Brazil, and some major oil and gas fields identified so far (PETROBRAS, 2014)

Geologists in Brazil have long known about the existence of the evaporate sequence and the pre-salt province, since the same pre-salt rocks occur as outcrops in the Northeast of Brazil. They also recognized their possible hydrocarbon accumulation potential, but it was only when seismic technology finally allowed better resolution of features below thick salt layers, that pre-salt exploration blocks were included in the second Brazilian bidding round conducted by ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, the Brazilian oil regulatory agency), in 2000.

This region attracted much attention since the first major discoveries were confirmed by Petrobras, in 2006. Since then, discoveries in the region have ranked among the largest in the world in the last ten years, including Lula (formerly Tupi), Iara, Libra and others. This led to various estimates, from within and outside the government and Petrobras, which mentioned extremely large total possible accumulations, ranging from 50 to over 300 billion barrels of recoverable oil in the "Picanha Azul" region, a legal boundary of approximately 150 thousand square kilometers (approximately 800km by 200km). Since none of these estimates were accompanied by technical data or a description of the methodology used, in 2010 the authors of this work carried out the first assessment of the YTF oil potential in the Brazilian pre-salt region. An exploration modeling tool (GeoX®, from Schlumberger) and a stochastic simulation method (Monte Carlo) were utilized

for estimating the potential accumulations discovered and remaining to be discovered in that region (JONES & CHAVES, 2011).

The 2011 assessment provided the first indication of potential YTF recoverable resources, based on a robust methodology used in other assessment studies utilizing the same methodology (JONES, CHAVES & DOURADO, 2009), and later validated by more recent discoveries (JONES & CHAVES, 2010). The authors had already conducted prior studies of YTF oil dating back to 1984, when Chaves et al. (1984a, 1984b) used the concept of exploration modeling applied to historical and geological data about a play, in order to determine its relative exploratory maturity, which allowed exploratory efforts to be guided more rationally.

In fact, the importance of YTF oil assessments is to provide operators, regulatory agencies, government policy makers (federal, state and local), as well as academic researchers and the public, with more reliable and accurate information on the number, size and total volume of potential resources in an assessment region. Only with such information can discussions, policy and decisions be rationally conducted.

Prior to the 2011 assessment, estimates of the YTF oil potential of the pre-salt region had been variously touted as being anywhere from 60 billion to over 100 billion barrels of recoverable oil and gas resources, but did not cite the methodology employed for reaching those numbers. Surprisingly, the total recoverable resources indicated by the 2011 assessment were far superior to even the most optimistic values mentioned up until then. However, as new discoveries and revaluations of existing accumulations were announced, more information became available, which has now been used to update that study, utilizing the same methodology.

Modeling Tool Methodology

The methodology used for the current assessment employed the GeoX® software tool, which models the exploration process by employing Monte Carlo simulations for the values of parameters utilized in order to calculate the number of YTF accumulations, their size, and the ultimate recoverable resource base of oil and gas (URR). The total recoverable YTF accumulation of oil and gas resources is merely the URR less the already discovered recoverable resources. The exploration process modeling tool considers the entire pre-salt assessment area as an assessment play, and individual discoveries or prospects as segments of that play. These, in turn, are assessed based on volumetric and geological parameters available for each.

For discoveries announced, the input parameters included information regarding the discovery well (location, completion date, water depth and total depth), and the estimated volume of recoverable accumulations announced (direct volume estimation method). If no direct volume estimates were provided for recoverable resources, but other parameters used for volume estimation were available, then the derived volume estimation method was used. In this case, in order to arrive at recoverable volume estimates, the parameters used were area, thickness, geometric factor, net-gross, porosity, oil and gas saturations, gas-oil ratio, and recovery factor.

Wells that found oil and gas indications but for which no volume or other parameters used for volume estimations were provided, were treated as prospects, and assessed as such. Prospect assessment involves estimates of direct or derived volume accumulations, as well as of play and prospect risking parameters that describe the geological uncertainties of the play and the individual prospect in the play. The prospect risking parameters allow the assessment to consider geological risk factors, such as occurrence of each of the essential petroleum system elements (source rock, migration route, reservoir rock, seal and trap) and processes (generation, migration, accumulation and preservation).

Dry holes were included as data entry points in order to provide a means of risking the play assessment. They also serve to help estimate a value for the exploration efficiency factor, which is used in order to build an appropriate discovery sequence forecast.

Overall play assessment parameters entered included the area of the entire play (149,000 km2); lower resource accumulation limits for establishing minimum screening thresholds for oil and gas accumulations; upper accumulation limits for establishing play assessment parameters; number of mapped and postulated features in the entire play, used in order to build the field size distribution curve used in the assessment; overall minimum economic resource volumes for the play, in order to assess only economical play volume cases; and an exploration efficiency factor estimate, in order to adequately extrapolate the discovery sequence curve.

Theoretical Assessment Concepts

The concept of YTF oil involves the estimation of the number and the size of YTF accumulations. In order to carry out assessments of YTF oil potential, two main characteristics of the assessed play are essential: the distribution of the sizes of the accumulations (Field Size Distribution - FSD) and the order of discovery of those accumulations (Discovery Sequence). The YTF assessment methodology considers that all accumulations discovered in a given play represent a sample of the universe of existing accumulations, so their size distribution must follow that of the universe of all existing accumulations, including those that have not yet been made. In general, for all basins, the exploratory experience strongly suggests that the largest accumulations will be discovered first, which is quite intuitive, even if exploratory efforts were to be random. The fact that they are supposedly guided by intelligent geological and engineering knowledge about the basin implies an even more strongly size ordered aspect of the sequence of expected future discoveries (DREW, et al., 1980). The better the exploration efficiency factor of a play, the more size ordered that experience will be.

The discovery sequence forms an exhaustion curve approaching the limit when discoveries are exhausted (100% of accumulations having been discovered). As discoveries approach this limit, the play is deemed to be a

mature exploratory play. Given this exhaustion curve, as well as the field size distribution, at any point of the exploration sequence one can determine the expected new discoveries to be found for a given number of additional exploratory wells drilled. The concepts of Discovery Sequence and FSD are important for explorationists because they establish the way in which cumulative discoveries evolve as new exploratory efforts are carried out (new wells drilled). Since their behavior reflects geologic conditions of the assessed basin, as well as the degree of success of the exploratory campaign in an area being assessed (exploratory efficiency), one merely has to make simulations based on the information contained in those curves, in order to obtain forecasts for the entire play, including future discoveries (KONTOROVICH, DYOMIN & LIVSHITS, 2001).

Thus, the assessment of a play (such as the pre-salt area) consists of the following steps: establishing the Discovery Sequence; determining the FSD; estimating the number of possible accumulations of economic interest; quantifying the geological uncertainties governing exploratory risk; and conducting simulations of the individual sampled parameters, in order to build a probabilistically defined result. That result is a reflection of the extrapolations based on the information used, and consists of probabilistically defined values for number of YTF accumulations, their sizes, and the total YTF volumes (YTF oil).

The software tool employed to conduct the simulations makes use of Monte Carlo simulations for sampling and estimating each parameter. Since the total YTF oil potential, is the result of the product of independent variables (number and size of fields) which can take on random values determined by their probability functions, it cannot be estimated by directly multiplying individual values of independent variables. A stochastic simulation of the product is required, and in order to do that the modeling tool selected utilizes Monte Carlo simulations.

Likewise, in prospect assessment, the resulting size of the individual YTF oil accumulation being assessed depends on the result of the product of numerous independent variables, so again, a stochastic simulation of the product is required. The GeoX® modeling software also allows some variables to be modeled with correlation, since not all of them may be entirely independent.

Based on the number of accumulations and accumulation size, the total YTF oil potential can be calculated, and based on the Discovery Sequence and the FSD, future discovery sizes and the order of discovery can be estimated.

Data Entry

For segment assessment, inputting information into the software tool, in order to run Monte Carlo simulations, involves establishing probability distribution curves for each parameter for each data entry set, whether using the direct volume estimation method or the volumetric method. For the direct volume estimation method, probability distribution curves are inputted for the accumulation size parameter. For the derived volume estimation method, probability distribution curves for each volumetric variable used are inputted, as well as play and prospect risking parameters, as described in the description of the modeling tool methodology.

For play-level assessment, past exploratory results help determine the probability distributions for the total number and size of undiscovered fields, according to the concepts of exploratory experience and FSD. The input parameters include the total area of the play, and parameters describing the number and size of potential accumulations.

In the GeoX® modeling tool, different templates are used for data entry for segment level and play level information. Each template is built to reflect common parameters used and their usual values, but data entry was customized for some identified prospects and discovered fields, in order to reflect individual characteristics.

The 2011 pre-salt assessment did not have as many information points available as in prior assessments made utilizing a similar methodology, but the intense exploration activity in the region has resulted in significant additional data points being made available since 2010, as well as revaluations of some of the original information used. In addition, many segments (discoveries and prospects) underwent changes in names, consolidation, and segregation of field areas. Even so, the current pre-salt assessment still utilizes significantly less data entry sets than prior assessments made by the authors with the same methodology.

As in the 2011 assessment, the information used to feed data into the modeling tool was obtained from various sources, since no one source provides all the information required on all exploratory efforts in the region. Among these were: BDEP (Banco de Dados de Exploração e Produção da ANP), the public database of wells drilled in Brazil, maintained by ANP; public declarations of discoveries by Petrobras and other companies operating in the region; as well as other sources of information, such as news items and commentaries by authorities.

Unfortunately, the lack of standardization in the form, type and content of information furnished by the companies and agencies involved make it very difficult to accurately build a complete set of information for most discoveries and prospects announced. It is indeed possible that inaccurate, duplicate or overlapping information may have been entered, and others may have been missed or omitted. Still, given the relatively large number of data entry points (48 in all, being 19 discoveries, 19 prospects, and 10 non-commercial), it is expected that such inaccuracies will not have a very significant effect upon the overall results presented.

Monte Carlo Simulations

At the segment level, Monte Carlo simulations were carried out by the GeoX® modeling tool on the stochastic variables used for assessing prospects. Their probabilistic distributions were randomly sampled 2,000 times, and these individual values were multiplied together as a deterministic calculation, in order to obtain values for the resulting size of the segment being modeled. These values were then plotted in order to obtain a probabilistic

distribution of values for the size of accumulations. The process is described in Figure **2**, below.

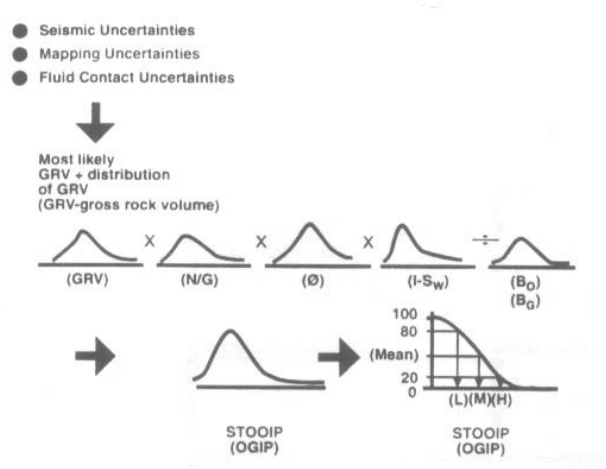

Figure 2 – Description of the Monte Carlo method used to obtain a distribution curve for the size of an accumulation being modeled (NORMAN, 2015)

At the play level, Monte Carlo simulations were carried out by the GeoX® modeling tool on the stochastic variables (number of accumulations and size of accumulations) used to estimate all resulting parameters: number of YTF accumulations, size of YTF accumulations, and total volume of YTF oil. From the probability distributions for the total number and size of accumulations in the assessment area, numerous (2,000) random samplings of each parameter were made. Then, each set of samples obtained for the two variables are individually multiplied as a deterministic calculation and the results are plotted, thus obtaining a probabilistic distribution of values for the total YTF oil potential. This iteration process is similar to the approach carried out by the US Geological Survey (USGS, 2002) in its World Petroleum Assessment 2000 (WA2000).

In this assessment, 2,000 repetitions (simulations) were carried out by the simulation tool, which provided sufficiently smooth probability distribution curves for the variables assessed.

Finally, pertinent points were extracted from the resulting distribution of the plotted values for total YTF accumulation, such as that representing the P90 level (level expected with 90% confidence), equivalent to a total YTF accumulation with 90% likelihood of being at least this amount. Likewise, a P10 level (level expected with 10% confidence) can be produced, equivalent to a total YTF accumulation with only 10% likelihood of exceeding this value. The P50 level corresponds to the median value (50% confidence level), a volume of YTF oil with 50% likelihood of exceeding this value or being below this same value.

Similar confidence levels can be presented for the two other modeled variables, number of accumulations and the size of accumulations. In general, the above three confidence levels (or other confidence levels, such as P95-P50-P05) can be used to describe the probability function of any variable modeled, and still convey a good idea of its distribution function.

Results

After inputting segment level and play level information, the software tool, running Monte Carlo simulations modeled the exploration process in the Pre-Salt region, producing a discovery sequence chart (Figure 3Figure 3), as well as a FSD plot (Figure 4).

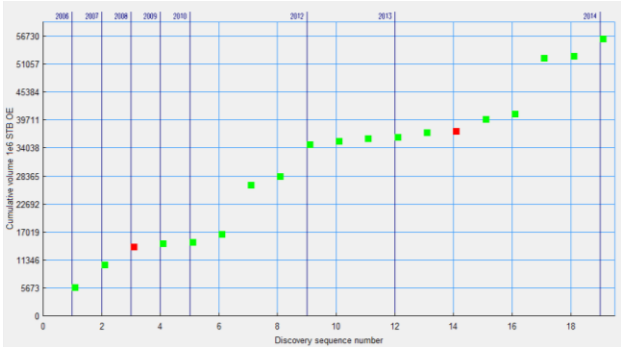

Figure 3 –Discovery Sequence chart produced from the information entered into the modeling tool

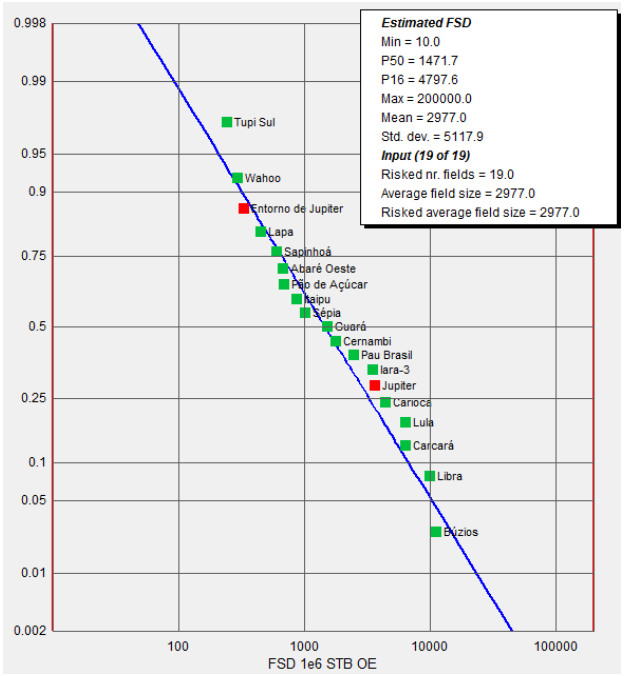

Figure 4 – FSD chart generated by the information entered into the modeling tool

Applying the concepts of discovery sequence and FSD, and with the geological estimates for parameters of the number and size of accumulations, the modeling tool furnished a probability distribution for the number and expected size of individual accumulations (fields) yet to be discovered, as well as for the total accumulation of recoverable YTF oil in the region. While the 2011 pre-salt assessment had a relatively large range of values for the results, the current assessment produced a narrower distribution of values, as would be expected as more

information is available for the assessed area, and individual estimates assume values with less uncertainty.

In view of the fact that the pre-salt region is still a relatively new frontier, where only larger accumulations are likely to be considered for development for a long time, screening thresholds were established for oil and gas accumulations. This allows the modeled results to exclude small and uneconomical accumulations from the calculations, which could be numerous, and could distort results.

Running the simulations with the GeoX® software, the results suggest that within the probabilistic confidence range between the 90% and 10% confidence levels, the number of additional fields (recoverable accumulations) expected to be discovered above the screening threshold will range from 56 (P90) to 83 (P10); field sizes above the screening threshold will range from 239.9 million (P90) to 5.90 billion barrels (P10) of recoverable accumulations; and total recoverable accumulations above the screening threshold will range from 118.9 billion (P90) to 216.5 billion barrels (P10) of recoverable resources (**Erro! Fonte de referência não encontrada.**, **Erro! Fonte de referência não encontrada.**, **Erro! Fonte de referência não encontrada.**).

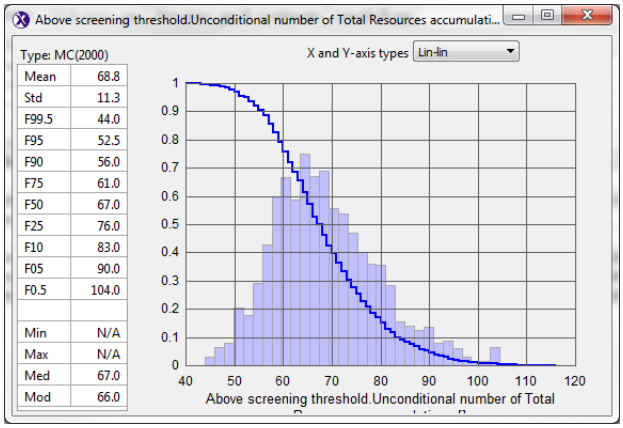

Figure 5 – Copy of screen with results for the expected number of additional fields above the screening threshhold

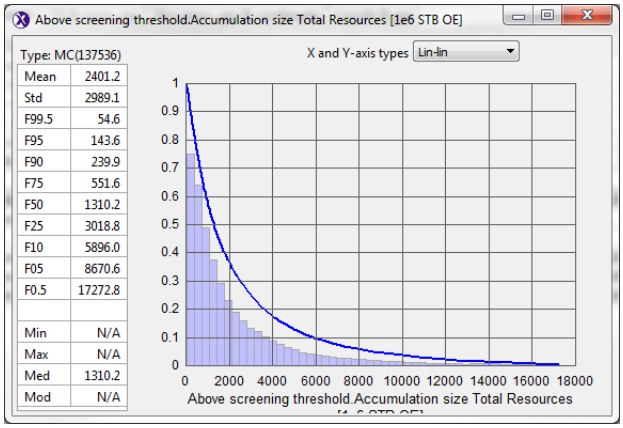

Figure 6 - Copy of screen with results for the expected size of the fields above the screening threshhold

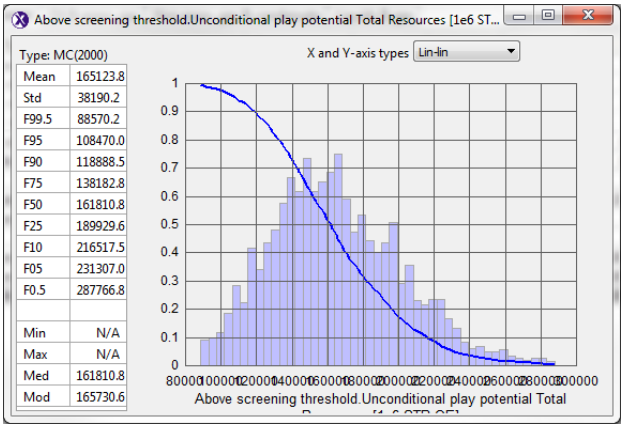

Figure 7 - Copy of screen with results for the expected total recoverable YTF oil, from fields above the screening threshhold

The results obtained are summarized and compared with the prior results from the 2011 assessment in the table below (Table 1).

Table 1 – Summary of results for the current YTF oil assessment for the entire Pre-Salt region and the prior 2011 assessment

	Assessment	90% Confidence Level	50% Confidence Level	10% Confidence Level
Number of Additional Fields	2011	42,5	63	83
	2015	56	67	83
Size of Recoverable Accumulations	2011	165.6 million barrels	1.13 billion barrels	7.99 billion barrels
	2015	239.9 million barrels	1.31 billion barrels	5.90 billion barrels
Total Recoverable Accumulations (YTF Oil)	2011	114.5 billion barrels	194.6 billion barrels	288.3 billion barrels
	2015	118.9 billion barrels	161.8 billion barrels	216.5 billion barrels

The future discovery sizes and order of discovery of can be estimated from the resulting simulations carried out by the modeling tool. Thus, a diagram of likely future discoveries and their sequence can be portrayed as a “Rosy Future” diagram (Figure 8). This reflects the fact that even from this point in the exploration process of the pre-salt region, the larger YTF oil accumulations are expected to be discovered first, while later in the exploration history of the region (after most exploration wells are drilled), only marginal accumulations will be found, tending towards the limits of the total value for that variable. It must be noted that in this case, the exploration history is measured not in time, but in exploratory effort (number of new exploratory wells). This measure is not likely to correlate to time, except to the extent that the number of new exploratory wells is relatively constant in each time period considered.

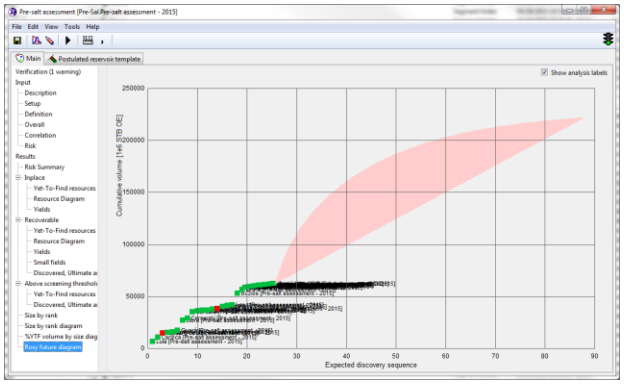

Figure 8 - Copy of screen with results for the evolution of total recoverable YTF oil volume in the assessed area, from fields above the screening threshold, as future exploratory efforts are made

Conclusions/Discussion

Given the significance of royalties and other forms of the government share of oil and gas revenues to federal, state and local governments in Brazil, as well as the need for all stakeholders involved to have access to reliable information on resource bases of interest, assessments of YTF oil potential are an especially important tool for guiding policy and decisions.

The difficulties still encountered in carrying out such an assessment highlight the need for more standardization and more complete disclosure, when operators involved make the required official declarations to the ANP regarding oil and gas discoveries. A greater transparency and better methodological approach to information of strategical importance to the country would benefit those who research such information and provide a basis for all stakeholders to make sound decisions.

The results of the current assessment of the YTF oil potential of the pre-salt region suggests that the estimates from the 2011 assessment were good approximations at the time, and that the methodology employed is valid. It also refined those estimates to narrower ranges within the original estimates.

The very large volumes and sizes of YTF accumulations expected also serve to confirm the importance of the pre-salt region to Brazil, and its significance in terms of future sources of new global production of oil and gas. The results suggest that Brazil should indeed be able to reach and maintain significant levels of oil and gas production from the pre-salt for a very long time, based on the total recoverable YTF resource volumes indicated. This could also be a source of more positive fundamental country and industry assessments for Brazil, based on the potential to become a major oil and gas producer, since the present results suggest that its recoverable resource base rivals that of leading oil resource countries. In addition, these resources consist of conventional oil and gas of generally good quality, able to be produced with proven technology that is already being successfully employed.

Acknowledgments

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