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The Evaluation, Classification and Reporting of Unconventional Resources

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Abstract

The evaluation of unconventional resources presents many challenges, one of which is a need to evaluate all resource classes, not only Proved reserves. The evaluation of hydrocarbons is described as consisting of three steps: Estimation, Classification, and Reporting, with a concomitant requirement for auditing. The nature of estimates is discussed, in particular, that there is always an associated uncertainty and some fundamental principles of classification are reviewed. The classification of unconventional hydrocarbons is discussed, with an emphasis on Discovered Petroleum Initially-In-Place and Contingent Resources, which are formulated as a series of Decision rules. Information on production potential, either from tests or analogs, is of particular importance when classifying unconventional hydrocarbons, and the typical lack of defined pool boundaries requires that careful consideration be given to the area assigned to various resource categories, both of which points emphasise the need for an understanding of the detailed reservoir geology.

The Petroleum Resource Management System (PRMS), supplemented by the Canadian Oil and Gas Handbook (COGEH), has provided the basis for the discussion in this paper, but it is impossible in a short paper to capture these systems in full, and reference should be made to the original source documents for details. The emphasis in this paper is on recovery through wells, but some brief mention of mined hydrocarbon recovery is made. The exploitation of unconventional hydrocarbons is in its early stages, and evaluation procedures, including classification, are still under development. Many aspects of the evaluation process are not addressed in this paper, and those that are, are likely to require further development and modification**.**

Introduction

Rapidly increasing exploitation of so-called unconventional resources and a demand to evaluate categories of resource in addition to Proved (or sometimes Probable) reserves present new challenges to the evaluator. The most obvious challenge is the technical one of understanding the geology and production characteristics of new types of reservoir. Identification of the presence of an unconventional hydrocarbon accumulation through drilling, logging, and coring, is usually relatively straightforward. The determination of the production characteristics and of commercially viability is not straightforward, since it requires more extensive testing than for a typical conventional accumulation. The productive life of these accumulations is often long, and the development process is complex. The transition from other resource categories to reserves can be slow, and limiting the evaluation to only reserves fails to present an adequate picture. The need to assess other categories of resource than Proved (and sometimes Probable) reserves raises significant questions, especially on classification.

The discussion in this paper is centered on the 2007 Petroleum Resource Management System (PRMS) (PRMS 2007), leavened with considerations arising from Canadian experience in unconventional resource exploitation. There was little difference between the Canadian system and the predecessor of PRMS, the Society of Petroleum Engineers (SPE) resource classification system, prior to the issue of PRMS, and recent revisions to the Canadian system have brought them closer still. Since 2002, extensive guidance on evaluation in Canada has been provided in the Canadian Oil and Gas Evaluation Handbook (COGEH) (COGEH, 2007). Although originally written as a guide to good evaluation practice, COGEH is referred to in Canadian regulatory disclosure legislation (National Instrument 51-101) as the evaluation standard to be followed, and also by the Association of Professional Engineers, Geologists, and Geophysicists of Alberta (APEGGA) as the professional practice standard for oil and gas resource evaluation.

Conventional and Unconventional Hydrocarbon Accumulations

It is no more than a useful empirical and informal practice to classify hydrocarbon accumulations as "conventional" and "unconventional", since what is "unconventional" today will be "conventional" tomorrow. A more fundamental difference lies in the trapping mechanism and its influence on the production mechanisms. In brief:

For conventional accumulations, the trapping mechanism is dominated by hydrodynamic, or buoyancy, forces. As a consequence, the prime control on conventional accumulations is local structure and stratigraphy, which results in discrete pools with fairly well defined limits imposed by a caprock and fluid contacts. There are also many analogs.

Unconventional accumulations are the result of several different trapping mechanisms.

- Coal Bed Methane (CBM (also known as Coal Seam Methane, CSM, and Natural Gas from Coal, NGC) is trapped by adsorption in micropores in coal, and is released when a pressure differential develops between the coal and fractures. These fractures usually contain water and require "dewatering" before any gas can be recovered.

- Bitumen is immobile because of its high viscosity, and is either recovered by mining or an in-situ processes that reduces the bitumen viscosity to the point where the bitumen will flow to a wellbore. At the present time, all these in-situ processes are thermal and reduce viscosity by heating the bitumen.

- Shale Gas is trapped by adsorption on the solid hydrocarbon, kerogen, and on clay particles. Recovery relies on desorption from the matrix due to a pressure differential and drainage through natural or induced fractures.

- So-called "Tight Gas" is held in low permeability reservoirs, sometimes "basin-centered" and deep. There is debate about whether these are merely poor quality conventional hydrodynamic reservoirs or if some other trapping mechanism is involved. Whatever the trapping mechanism, recovery probably depends largely on natural or induced fractures or the presence of higher permeability intervals.

Recovery processes have been developed for, and there is considerable activity, on Coal Bed Methane, Bitumen, Shale Gas, and Tight Gas reservoirs. Some analogs are available but far fewer than for conventional hydrocarbons. There are other unconventional hydrocarbon accumulations for which viable recovery processes have not yet been developed. These include:

- Oil Shale. This is the extraction of liquid hydrocarbons by "cooking" shales containing the solid hydrocarbon, kerogen. Although some test projects have been carried out, none of them are known to be commercially viable.

- Methane Hydrates contain methane molecules trapped in a form of water ice molecular "cage" (clathrate structure). The total volume in this resource is probably greater than all other sources combined, but there are no viable recovery processes and investigations are still at a very early stage.

All of these "unconventional" hydrocarbon accumulations are held in "reservoirs" that are controlled primarily by regional stratigraphy and cover large areas. Changes in the facies in which the hydrocarbons occur, from hydrocarbon bearing to non-hydrocarbon bearing, tend to be transitional rather than abrupt, and there are usually no clearly defined margins. Because of this, these unconventional accumulations are sometimes called "dispersed" or "disseminated" accumulations.

The Nature of Estimates

The implications of the fact that reserves determination is an estimation process are often overlooked. The most fundamental implication, and a surprise to many, is that the only thing that you know for certain about any estimate is that it will be wrong! However, the important thing is not that it will be wrong, but to know how wrong it is likely to be, and to provide a measure of the variance. This variance is captured for reserves by the traditional Proved, Probable, and Possible reserves estimates, and for other categories by Low, Medium, and High estimates.

The nature of an estimate can be summarised by the relationship:

Estimated Value = Actual Value ± Measurement Error ± Bias

Actual Value is not known until the last day of production:

- Measurement Error is inherent in any estimation process, and is the realm of good practice and statistical concepts. A subset of this is Model Error, which is the application of a limited or inappropriate algorithm. For example, mapping a tidal channel sand as a (orthogonal) beach sand, or using an inappropriate shaly sand equation. Since virtually all of our quantitative models use simplifying assumptions, Model Error is common[1].

- Bias is a systematic error, which may be, but is not always, conscious or intentional. The limitation of disclosure to certain categories (e.g., only Proved reserves), may provide a motivational bias to evaluations since there is no other way for an organisation to capture and report the value of other categories, such as Probable reserves or Contingent resources.

This brief discussion does not cover many of the implications of the estimation process, in particular the aggregation or portfolio aspects. For instance in the absence of bias, as the number of properties increases the aggregated average reserves estimate per property converges to a single value, with minimal variance, as a consequence of the Central Limit Theorem. This provides some information on the variance that may be expected for a company of a particular size. (See also, Pet. Soc, 2004; Robinson & Elliott, 2004, 2005, for further discussion of aspects of uncertainty in reserves evaluation.)

Arguments are sometimes put forward against the use of statistical concepts in resource evaluation, because of limited data, sampling considerations, or a mistaken belief that the concept of probability is limited to that of repeated trials[2]. There may also be a belief that only a deterministic estimate is “accurate”.

An estimate is an attempt to convey information, and a clearer idea of what this means can be gained by a concept from information theory. The information in a data set (e.g., porosity) can be represented by a data set [0,1], with values from 0 to 1 that could be rescaled to represent, for instance, thickness, porosity, recovery factor, etc. (Figure 1). In the absence of any information, it is always possible to assign a minimum and maximum value, as the extremes of 0 and 1. This is shown graphically in Figure 1a, as a rectangular or uniform distribution in which the variance is a maximum, and all values between the maximum and minimum are equally likely. Perfect knowledge is represented in Figure 1b by a single value (in this case 0.5), and a variance of zero.

Almost every real case is one of imperfect knowledge, between complete ignorance and perfect knowledge, and can be represented by a probability distribution, as in Figure 1c. The imperfect knowledge distribution may be of any shape and may be continuous or discontinuous.

Methods of generating distributions exist, ranging from analytical to subjective (e.g., a Delphi process[3]) methods of various degrees of sophistication, for which, it is possible to calculate a mean value and a variance. This is not intended to discount the difficult of generating the distributions, which may be precluded by time and cost considerations. However, there is a big difference between saying, “it can’t be done”, and saying “it is not worth doing because of time and/or cost”.

In the absence of bias, there should be no significant difference between estimates made by different evaluators. The word “significant” is used here in a technical, not a colloquial, sense, and the magnitude of difference that may occur depends largely on the quality of the underlying data and of the analysis. Being within two standard deviations on a normal distribution 99 times out of 100, means that you will be outside 1 time out of 100! It is important to not confuse the meaning given here to the word “significant” with the concept of “material” as it is used in securities law. The two may or may not overlap.

[1] This is captured by the old joke, about simplification in building mathematical models, on modelling the performance of a dairy cow that starts, “Consider a Spherical Cow …”!
[2] Descriptions of probability concepts other than that of repeated trials can be found in many statistical texts.
[3] Delphi is a process of obtaining information from a group of experts that passes the opinions of the experts through several rounds of review. It is extensively used in business and military planning.

Principles of Classification

The fundamental reason for classification is to facilitate communication by grouping items with similar features. Although they must have similar features, the items within a class do not need to be identical and a class may be further sub-divided in a hierarchical system.

Classification is carried out for many things: for library books, living organisms, cloud types, grocery products (UPC), etc. More familiar examples might be the International Code For Stratigraphic Nomenclature, drilling bit types, or the subject of this paper, oil and gas resources. There has been considerable development of the principles of classification in many fields, the most fundamental ideas probably being in mathematics, in particular statistics and related fields such as pattern recognition, and perhaps the most useful, Decision Theory. An examination of these areas provides an insight into fundamental concepts behind the classification of oil and gas resources.

A key concept is that classes must be mutually exclusive, which implies that there must be decision rules that allow an assignment to an appropriate class.

A useful way of looking at the evaluation system is from a signal processing point of view in which the raw data (logs, cores, tests, etc.) is passed through a series of filters, each one containing a decision rule that divides the original signal into categories that indicate the stage and probability of recovery. (Figure 2)

A distinction must be made between the decision rule inside a filter and the information. We have limited control over the quality of the information but we can design a filter to handle different types and qualities of information, including uncertain information.

There is much confusion between the setting of a decision rule and the precision with which it can be used. A good example is the use of a probabilistic target, such as P90 for Proved reserves. The target is clear, but any single estimate may miss the target. However, the average of a large number of unbiased estimates should "hit" the bull's eye of the target. An analysis of Technical Revisions of Proved and Probable reserves in Canadian regulatory disclosure suggests that at the lowest level (zone or well) the variance in a reserves estimate is about ± 40 to 50%. Whilst this is larger than claimed by many, it is a reflection of the quality of the basic information, not of the quality of an evaluation. To put this in context, there would be nothing unusual about a small company with one or two wells that had a revision of its reserves by, say, ±25%. However, because of the portfolio effect, this could be an extreme outlier for a larger company (Robinson & Elliott, op. cit.)

The fact that erroneous decisions are inevitable, because of the quality of the data, simple error, or bias, is well recognised in decision theory, as Type I, and Type II Errors. As an example, suppose a decision rule applied to the assignment of pay is:

If $\phi \geq 8\%$ assign pay
If $\phi < 8\%$ assign no pay

There are four possible cases:

$\phi \geq 8\%$ and pay is assigned	True Positive	
$\phi < 8\%$ and pay is assigned	False Positive	Type I Error
$\phi < 8\%$ and pay is not assigned	True Negative	
$\phi \geq 8\%$ and pay is not assigned	False Negative	Type II Error

This is summarised in matrix form in Figure 3. An important objective of classification is to minimise the Type I and II errors by designing efficient decision rules. Many of the problems in resource evaluation can be attributed to ambiguous or unclear decision rules. Perhaps the most obvious example of an unclear decision rule is the term "reasonable certainty" used in the classification of Proved reserves. The interpretation of the term is subjective and prone to bias, and a survey on the term (Elliott, 2007) showed that there is such wide variance associated with the term "reasonable certainty", that it is, by any reasonable standard, unreliable as a decision rule.

What is the nature of the decision rules in the filters? In some cases, there is simple information and a clear decision rule, for instance, you either have a well or you do not. However, in many cases, information is uncertain and ambiguous and the decision rule is not so simple. It is important to design decision rules to handle this type of information.

The simplest decision rules are probably binary, such as the example of a porosity cut off given above or the requirement for a positive NPV for the assignment of reserves. Other filters appear to be less well defined, for instance:

> If the probability of regulatory approval ≥ 90%, then assign reserves.
> If the probability of regulatory approval < 90%, then assign contingent resources.

In this case, the decision rule is clear, but it is the determination of the probability of regulatory approval that is problematic and may be different for different evaluators.

Care must be taken in designing such “filters”. Porosity cut-offs, for instance are approximations that depend on a number of complex processes that are often poorly understood. Numerous other examples could be constructed and many examples of more sophisticated filters can be found in fields such as signal processing.

The Evaluation System

It is probably true to say that the evaluation of most conventional oil and gas reserves has become a formalised activity, following a fairly well defined course. The few exceptions rarely fall far outside general practice. The increasing exploitation of unconventional hydrocarbons presents many questions and triggers a need to step back and reconsider the evaluation process. This can be regarded as having three major sequential steps: Estimation, Classification, and Reporting. An additional, critical, but often neglected, step is the need to audit the results of evaluations. However, in practice, these steps too often tend to be inverted to:

> What do I need to report?
> Only Proved reserves…
> Limit the estimation to that, but try to maximize it …
> …. and no audit.

1. **Estimation.**

Estimation of resources takes place in a series of steps, such as:

- First, the total endowment of hydrocarbons in-place (Total Petroleum Initially In-Place).
- Second, Discovery Criteria.
- Third, the estimation of technically recoverable volumes.
- Fourth, the application of an economic criterion.

Each of these steps may be further broken down into smaller steps:

The estimate of Total Petroleum Initially In-Place is the output from a series of filters that are applied to the basic data of logs, cores, geological maps, etc, but is taken as the starting point for further discussion in this paper. The determination of discovery status, the estimation of technically recoverable volumes, and the application of an economic criterion can be regarded as the application of subsequent filters.

Drilling on unconventional hydrocarbon accumulations can be divided into two phases:

- Phase I. In-Place Estimation - Initial drilling to determine an in-place volume.

The petroleum industry has been making estimates of in-place volumes of conventional hydrocarbons for many years and many of the techniques are applicable to unconventional hydrocarbons. The number of wells required for an estimate depends strongly on the complexity of the geology, and the nature of the estimate, but in most cases, beyond a certain point, additional wells will yield no significant improvement in the estimate of an in-place volume. Typical drilling densities for conventional accumulations of one to four wells per square mile, for instance generally provide an adequate estimate of an in-place volume. The optimum drilling density can be further explored with geostatistical methods that allow an estimate (range) to be made beyond which increased drilling is not likely to result in a significant improvement in an estimate of in-place volume.

- Phase II. Recovery Process Design - Additional drilling to assess the recovery process.

The assessment and design of a recovery process requires a greater understanding and more detailed knowledge of a potential reservoir than does an estimate of Total Petroleum Initially In-Place. For unconventional reservoirs, this typically requires significant additional drilling beyond that required for the estimate of Total Petroleum Initially In-Place, in order to understand reservoir architecture and intrinsic reservoir properties and the consequent flow processes, and for mined bitumen, detailed mining design.

Test information is always required, but unlike most conventional accumulations this typically requires extensive and often expensive and prolonged pilot tests, which is the converse of most conventional activities, in which the identification of hydrocarbons in wells (exploration) is of greater prominence than testing. This is a major factor, and has significant implications when classifying unconventional resources.

2. Classification.

It is the usual practice to classify the results of an estimate, although it is quite possible to estimate recovery without classifying the result. The importance of this step is under-rated. Decision rules for resource classification in PRMS and COGEH are discussed in detail below, in Decision Rules for Resource Classification.

3. Reporting.

Much attention is paid to regulatory reporting, or disclosure, and in some cases, evaluation is driven by regulatory disclosure requirements. In many cases, there is no need for regulatory reporting, for instance, for NOCs and non-public companies, but the result of evaluation and classification must be reported to someone. Whenever reporting is carried out, the complexities of unconventional resource evaluation drive a need to provide additional explanation of the classification and of the uncertainties associated with a particular resource estimate. The details of this reporting are beyond the scope of this paper and are not discussed further.

4. Auditing.

The importance of auditing is often overlooked. Financial information is primarily historical, and resource estimates are forecast data, but there are basic similarities in the approach to auditing. There are two fundamental types of auditing tests:

- Procedural Tests examine the procedures and controls governing the preparation of resource estimates. Examples include the qualifications of staff preparing the estimates, whether the required information was fully supplied, document management and retention systems, review and sign-off procedures, etc.

- Substantive Tests are primarily numerical and fall into two main categories:

    - Auditing estimation procedures, for instance, has a production decline extrapolation been carried out properly, are calculations free of error, etc. This is referred to as “Tests of Detail” in Canadian GAAP (Generally Accepted Auditing Practice).

    - General tests that examine trends, ratios, etc., for example the ratio of PUD:Total Proved reserves, comparison of Technical Revisions against the industry norm, etc.

A significant difference from financial auditing is that the variance that is an inevitable aspect of any forecast must be considered in assessing the result of audits of oil and gas evaluations; because a parameter is outside normal variance does not necessarily mean that there is anything wrong with it … but there may be. However, the most important aspect of oil and gas resource auditing is the detection of bias, which is exercised in several ways, but often due to misclassification, for instance, as reserves instead of Contingent Resources.

Although there are some published auditing guidelines for reserves, they are primarily procedural. The author is not aware of published substantive tests, although some have been developed in house at the Alberta Securities Commission.

The Classification of Oil and Gas Resources

The reason for classification is communication, and for oil and gas resources, these purposes have been described (UNECE, 2005) as being for:

- Energy studies,
- Resources management,
- Corporate business processes and
- Financial standards.

Three classification systems are described briefly below.

1. Petroleum Resource Management System (PRMS).

PRMS is a two-dimensional system that differentiates between Classification and Categorization:

- Categorization represents the stage of exploitation by the chance of Commercialisation.
- Classification represents the volumes of hydrocarbons that are available for exploitation and that might be recovered in terms of the uncertainty within a Category.

For example, uncertainty within the Category Reserves is expressed by the Classes Proved, Probable, and Possible.

PRMS will probably become the international standard, especially, as is likely, if adopted by the International Accounting Standards Board (IASB) as the standard for financial reporting.

2. The Canadian Oil and Gas Evaluation Handbook (COGEH).

The Canadian Oil and Gas Evaluation Handbook (COGEH), Volume 1, Section 5, contains the resource classification system of the Reserves Definitions Committee of the Petroleum Engineering Society of the Canadian Institute of Mining, Metallurgy, which was revised in 2007 and is now almost identical to the PRMS (CIM 2007). One significant difference from PRMS, is that COGEH requires reported reserves to satisfy probabilistic criteria. However, COGEH provides considerable additional detail on evaluation practice, and could be regarded as PRMS with supplementary guidance. COGEH is also referred to for standards to be followed when preparing evaluations for public disclosure under Canadian legislation, National Instrument 51-101 Standards of Disclosure for Oil and Gas Activities.

3. The United Nations Framework Classification (UNFC).

The United Nations Framework Classification (UNFC) system is a three-dimensional system, with axes:

Economic and commercial viability (E).
Field project status and feasibility (F).
Geological knowledge (G).

Each axis is divided into numbered sections. This results in a three-dimensional array of boxes, that are labeled rather than named, to which other classification systems can be mapped. The box labeled E1; F1; G1 (or 111), for instance, would correspond to Proved reserves in the PRMS. This system is still under development and is not discussed further here.

Decision Rules for Resource Classification

1. The "As of a Given Date" Criterion.

The requirement that classification be "as of a given date" applies to all categories and classes, and means that an evaluation must be done with the information available at the date of the evaluation. This can be a significant factor for many unconventional accumulations.

This criterion sometimes gets forgotten, with the assumption that just because a hydrocarbon accumulation exists in the ground, a recovery process will be developed even though it does not exist at the present time.

2. The Use of Analog Information.

The evaluation of both conventional and unconventional hydrocarbons relies heavily on analog information. Because of the early stage of development of most unconventional hydrocarbons and the shortage of analogs, considerable care is warranted in their use. Although they are often used poorly, there are many thousands of analogs for conventional hydrocarbon accumulations, but many fewer for unconventional hydrocarbons. For instance, one of the most common methods of thermal bitumen recovery is Steam Assisted Gravity Drainage (SAGD), but there are only about 200 or so SAGD well pairs on which information is available, few of these have long production histories.

The exploitation of any new resource tends to start with the assumption of reservoir homogeneity, and analogs tend to be used in a simplistic way. This is compounded by the fact that the first areas to be exploited are usually the best and are often optimistic when used as analogs for later developments.

It is often forgotton or ignored that analogs provide information on a “most likely” case, and should not be used without adjustment for low case estimates such as Proved reserves. The SEC requirement for the use of analogs is that “An analogous reservoir is one having at least the same values or better for porosity, permeability, permeability distribution, thickness, continuity and hydrocarbon saturations.”. Additional discussion of analogs, and a disciplined approach to their use, may be found in Hodgin and Harrell, 2005.

3. The Term “In-Place”.

The term “In-Place” is a legitimate term in the evaluation process but should not be used for reporting without the appropriate qualifiers, such as “Discovered Petroleum” or “Undiscovered Petroleum”. All hydrocarbons are “In-Place” until produced, and when used alone, it can be misleading.

4. Total Petroleum Initially-In-Place.

The highest category of resource is “Total Petroleum Initially-In-Place”, which includes everything and is divided into “Discovered Petroleum Initially-In-Place” and “Undiscovered Petroleum Initially-In-Place”.

TOTAL PETROLEUM INITIALLY-IN-PLACE is defined in PRMS as, “that quantity of petroleum that is estimated to exist originally in naturally occurring accumulations. It includes that quantity of petroleum that is estimated, as of a given date, to be contained in known accumulations prior to production plus those estimated quantities in accumulations yet to be discovered (equivalent to “total resources”)”. It is not discussed further here since it is seldom estimated and even more seldom disclosed.

5. Discovered and Undiscovered Petroleum Initially-In-Place.

UNDISCOVERED PETROLEUM INITIALLY-IN-PLACE is defined (PRMS) as “that quantity of petroleum estimated, as of a given date, to be contained within accumulations yet to be discovered”. Prospective Resources are a potentially recoverable sub-category that is discussed below.

The concept of Undiscovered Petroleum Initially-In-Place often causes bewilderment in those who are not familiar with the many methods of making such an estimate. Estimates are made routinely as part of the exploration process, but are seldom made public and are not discussed further here.

DISCOVERED PETROLEUM INITIALLY-IN-PLACE is defined (PRMS) as, “that quantity of petroleum that is estimated, as of a given date, to be contained in known accumulations prior to production”.

The key criterion is the defined term, “known accumulation”, which is defined in PRMS as:

“An accumulation is an **individual body** of petroleum-in-place. The key requirement to consider an accumulation as “known,” and hence containing Reserves or Contingent Resources, is that it must have been discovered, that is, **penetrated by a well** that has **established through testing**, sampling, or logging the existence of a **significant quantity** of **recoverable** hydrocarbons (author’s emphasis).”

The definition of “known accumulation” in COGEH is:

“An accumulation that has been **penetrated by a well**. In general the well must have demonstrated the existence of hydrocarbons by **flow testing** in order for the accumulation to be classified as “known”. However, where log and/or core data exist and there is a **good analogy** to a nearby and geologically comparable known accumulation, this may suffice (author’s emphasis).”

This is more or less the same as PRMS except for the mention of a ‘good analogy”. It should be noted that the requirement is not just for an analogy, but for a <u>good</u> analogy.

These definitions suggest the following decision rules (Figure 4):

D1. Has the accumulation been penetrated by a well?
This test is quite clear and readily answered.
If no, then Discovered Petroleum Initially in Place = 0.
If yes, go to Test D2.

D2. Has a test demonstrated the existence of recoverable hydrocarbons?
If no, then Discovered Petroleum Initially in Place = 0.
If yes, go to Test D3.

The volume of hydrocarbons that must be recovered to demonstrate the “existence of recoverable hydrocarbons” is somewhat subjective, but a reasonable interpretation is that if not at economic levels, it should be sufficient to indicate a potential for this to be attained. At a minimum it should be a measurable volume, not a trace. For unconventional hydrocarbon accumulations, a flow test will probably require extensive pilot testing.

The PRMS definition requirement of “testing, sampling, or logging” suggests that any one of these may be sufficient, but only a test has the potential to unequivocally demonstrate the presence of recoverable hydrocarbons. In the absence of testing, it is most unlikely that logging and/or sampling alone would be sufficient, although they may be used with analog information. Even if test information is available, it may require the use of analogs to be convincing. The PRMS definition does not mention an analog as being able to provide support for classification as “known accumulation”, but analogs are discussed in PRMS Section 4.1.1, and it is assumed that their used is allowed.

D3. Does the flow test provide evidence for the existence of a significant quantity of recoverable hydrocarbons?
If no, then go to Test D4.
If yes, go to Test D5.

The criterion of “significant quantity” will depend on the situation. It does not mean that commercial viability must be established, but that hydrocarbons have been recovered in sufficient volume and at an adequate rate to provide an indication that it may be achievable. PRMS provides the following additional guidance:

“In this context, “significant” implies that there is evidence of a sufficient quantity of petroleum to justify estimating the in-place volume demonstrated by the well(s) and for evaluating the potential for economic recovery.”

D4. In the absence of test information in a well or wells on the accumulation of interest, is there a good analogy?
If no, then Discovered Petroleum Initially in Place = 0.
If yes, go to Test D5.

This requires log and sample information from wells on the accumulation of interest and a careful examination of the analog information to confirm the viability of an analog. Note that the requirement is not just for an analogy, but for a good analogy.

D5. Is there sufficient information to evaluate the potential of economic recovery?
If no, then Discovered Petroleum Initially in Place = 0.
If yes, go to Test D6.

A central concept of PRMS is that of the project, so this test is equivalent to asking if there is sufficient information to adequately define a project that may be evaluated. COGEH states "a basic requirement for the assignment of recoverable resources in any category is that it must be possible to define a technically feasible recovery project", although there is no expectation that all such projects will be commercially viable.

In rare cases, there is genuinely insufficient information to adequately define a project. This is most likely for mined bitumen projects that typically proceed through steps such as:

- Scoping study
- Pre-feasibility study
- Feasibility study

(See Pincock Perspectives No. 70, 2005, for a detailed discussion of these steps)

If this is the case, then it may be valid to classify the accumulation as "DISCOVERED PETROLEUM INITIALLY-IN-PLACE SUBJECT TO FURTHER EVALUATION". However, the evaluation should be underway and there should be considerable explanation of the evaluation process.

D6. Is it an "individual accumulation"?
This is a misleadingly simple requirement for unconventional accumulations, which tend not to have discrete boundaries that define an "individual accumulation". In the absence of defined physical boundaries, may be replaced be a distance test for a specific resource category.

What is the distance to which it is reasonable to extrapolate the discovered accumulation for a particular resource class?

It is tempting to prescribe a distance, such as one or more of the spacing units of one square mile common in North America, but not elsewhere. This artificial approach, which has no physical justification, may become a default position for regulatory reporting in an attempt to limit excessive extrapolation. The area over which it is reasonable to extrapolate the presence of an unconventional hydrocarbon accumulation is a function of the geology and the information available, and the formations that contain unconventional hydrocarbons can often be mapped convincingly over large areas. However, considerable caution is required, and claims for large areas of Discovered Petroleum Initially-In-Place should be subject to extensive, systematic, and disciplined, due diligence examination by qualified geologists. Note also, that an area of assignment of Discovered Petroleum Initially-In-Place is not necessarily the same as the area that may be assigned to a recoverable volume such as a Contingent Resource or a Proved Reserve.

If an estimate passes all the above tests, it will generally be viable to assign Discovered Petroleum Initially-In-Place. The claim is sometimes made that it is not possible to classify to a lower level because of the lack of available information. This paper does not address mined hydrocarbon recover, but mining convention generally requires the completion of a pre-feasibility or feasibility study, which may provide a valid argument for a not classififying below Discovered Petroleum Initially-In-Place until such studies are complete (Pincock Perspectives No. 70 op.cit.). This argument has limited force for non-mined recovery and it will generally be possible to estimate sub-classes such as contingent resources or reserves. This argument against classifying to a lower level appears to be most common when there is a lack of the flow information that is supposedly a requirement for classification as Discovered Petroleum Initially-In-Place in the first place, and may be an attempt to avoid a classification as Unrecoverable Discovered Petroleum Initially-In-Place. Neither PRMS nor COGEH address this question.

6. Contingent Resources.

CONTINGENT RESOURCES are defined (PRMS) as, "Those quantities of petroleum estimated, as of a given date, to be potentially recoverable from known accumulations by application of development projects, but which are not currently considered to be commercially recoverable due to one or more contingencies."

They may be further subdivided (PRMS **2.1.3.3)** into:

MARGINAL CONTINGENT RESOURCES, "those quantities associated with technically feasible projects that are either currently economic or projected to be economic under reasonably forecasted improvements in commercial conditions but are not committed for development because of one or more contingencies".

SUB-MARGINAL CONTINGENT RESOURCES, "those quantities associated with discoveries for which analysis indicates that technically feasible development projects would not be economic and/or other contingencies would not be satisfied under current or reasonably forecasted improvements in commercial conditions. These projects nonetheless should be retained in the inventory of discovered resources pending unforeseen major changes in commercial conditions".

CONTINGENT RESOURCES: ECONOMIC STATUS UNDETERMINED. It is also stated in PRMS that, "Where evaluations are incomplete such that it is premature to clearly define ultimate chance of commerciality, it is acceptable to note that project economic status is "undetermined." Additional economic status modifiers may be applied to further characterize recoverable quantities; for example, non-sales (lease fuel, flare, and losses) may be separately identified and documented in addition to sales quantities for both production and recoverable resource estimates (see also Reference Point, section 3.2.1). **Those discovered in-place volumes for which a feasible development project cannot be defined using current, or reasonably forecast improvements in, technology are classified as Unrecoverable."**

COGEH defines Contingent Resources as "those quantities of petroleum estimated, as of a given date, to be potentially recoverable from known accumulations using established technology or technology under development but which are not considered to be commercially recoverable due to one or more contingencies". COGEH also provides for the sub-classes:

ECONOMIC CONTINGENT RESOURCES "are those Contingent Resources that are currently economically recoverable", and are essentially equivalent to PRMS Marginal Contingent Resources.

SUB-ECONOMIC CONTINGENT RESOURCES, "are those Contingent Resources that are not currently commercially viable" and are essentially equivalent to PRMS sub-Marginal Contingent Resources.

CONTINGENT RESOURCES – ECONOMIC STATUS UNDETERMINED may be assigned if it is premature to identify the economic viability of a project and are essentially equivalent to PRMS Contingent Resources: Economic Status Undetermined.

PRMS describes contingencies (as Conditions) as "The economic, marketing, legal, environmental, social and governmental factors forecast to exist and impact the project during the time period being evaluated." Reference should also be made to the more extensive discussion on the distinction between reserves and Contingent Resources in COGEH Volume 1, Section 5.3.2, Commercial Status. Neither PRMS nor COGEH indicates further drilling or testing to be a contingency.

These definitions suggest the following decision rules for the further classification of a portion of Discovered Resource Initially-In-Place as Contingent Resources, summarized in Figure 5 as a flow diagram. The key to the use of these rules is a fundamental concept of PRMS the definition of a project based on sound engineering and geological analysis that can be subject to economic evaluation.

C1. Can a project be defined for the recovery of petroleum using established technology?

If yes, then Test C2.
If no, then Test C6.

C2. Are evaluations incomplete such that it is premature to clearly define ultimate chance of commerciality?
If yes, classify as Contingent Resources - Economic Status Undetermined. (COGEH, Contingent Resources – Economic Status Undetermined).
If no, Test C3.

This would be an uncommon situation for in-situ recovery, that would require extensive explanation. It would be more common for mined bitumen projects, although this would occur within established mining evaluation practice as evaluation moved through the accepted stages of scooping study, pre-feasibility study, feasibility study.

C3. Does this project indicate economic viability?
If yes, then Test C4.
If no, then Test C5.

C4. Are there contingencies that prevent production?
If yes, assign Marginal Contingent Resources (COGEH, Economic Contingent Resources).
If no, assign Reserves.

C5. Are there contingencies that prevent production?
If yes, assign Sub-Marginal Contingent Resources (Economic Contingent Resources).
If no, assign Unrecoverable Petroleum Initially-In-Place.

The contingencies in Tests C4 and C5 should be specific, not of a general nature, and should be for the accumulation of interest. Additional evaluation activities such as drilling or testing are not regarded as contingencies.

C6. If the answer to Test C1 is no, is there a technology under development that could lead to the development of a project for the recovery of petroleum?
If yes, then Test C2.
If no, then classify as Unrecoverable Petroleum Initially-In-Place.

COGEH makes allowance for "technology under development". The phrase "potentially recoverable" in the PRMS definition of Contingent Resources suggests that it is also allowed in PRMS. However, it is not specifically addressed, and it is not clear that this is correct. These tests have been developed assuming that this is the case.

The concept of "technology under development" should not be considered to be completely open-ended, and some conditions should be applied, such as, the technology should be:

- Under active development;
- For the specific accumulation of interest;
- A decision should be expected within a reasonable time, perhaps three years. Longer time frames may be reasonable in exceptional cases, but should require extensive justification.

These tests are given as a guideline and should not be used without reference to detailed requirements.

7. Prospective Resources.

PROSPECTIVE RESOURCES are defined (PRMS) as, "Those quantities of petroleum, which are estimated, as of a given date, to be potentially recoverable from undiscovered accumulations." Further explanation includes the following:

"Potential accumulations are evaluated according to their chance of discovery and, assuming a discovery, the estimated quantities that would be recoverable under defined development projects. It is recognized that the development programs will be of significantly less detail and depend more heavily on analog developments in the earlier phases of exploration."

COGEH defines Prospective Resources as: "Those quantities of petroleum which are estimated, as of a given date, to be potentially recoverable from undiscovered accumulations by application of future development projects".

Neither PRMS or COGEH contain significant discussion on Prospective Resources. However, both refer to two risks:

Chance of Discovery. For unconventional accumulations this is usually 100%. (This is far from the case for conventional accumulations, and it is the authors experience that the statistical aspects of this are poorly handled.)

Chance of Development. For unconventional accumulations, this is a major factor and warrants more discussion than can be given here, but the general criteria for Contingent Resources provide some guidance.

The variance on Prospective Resource estimates is usually large, and most often with a lower bound of zero. It is important that this be made clear when reporting these estimates.

8. Unrecoverable Resources.

This much-shunned category probably warrants more attention, since technical advances may, and historically have, resulted in significant volumes being transferred from the Unrecoverable Resources category to Reserves. There are a number of sub-categories within Unrecoverable Resources that are not currently part of any formal classification system, such as:

- Physically unrecoverable, such as residual saturations.
- Technology undefined, such as for Methane Hydrates.
- Technology in early stages, uneconomic.
- Infrastructure not expected to be available for many years, requiring long term technology development and/or extensive construction (e.g., Arctic pipelines)
- Political instability.

9. Reserves.

The decision rules for reserves are better defined than for other classes of resource. In keeping with the concept of evaluating all categories and classes, an evaluation should include both Proved and Probable reserves, and, ideally, also Possible reserves. This is most meaningful when carried out with clear probabilistic guidelines. For unconventional resources, many of the factors discussed above are relevant, in particular the extrapolation from existing wells, and the use of analogs.

Reporting

Whether the results of an evaluation are reported in a public arena (disclosure), or internally, there are some basic requirements:

- The evaluation should be carried out according to clear standards, such as set out in PRMS and COGEH.
- The results should be reported in full.
- There should be adequate explanation. Categorisation and classification often presents a simplified picture and additional explanation, especially of risks and uncertainties and timelines, is often essential in order to present a full and balanced account. This explanation should be specific and not of the “boiler-plate” type that is often seen. The Canadian prospectus requirement that it be “Full, True and Plain”, can be taken as good guidance to the quality of explanation that should be given.

NI 51-101 provides a template that may be used by both public and non-public organisations for part of their reporting needs. The Canadian securities requirement that prospectus disclosure be “Full, True, and Plain” can be taken as a good guide to the quality of explanation that should be provided.

The evaluation and classification process is complex and the ideas set out here are, in part, an attempt to summarize the procedures of PRMS and COGEH. They are not a replacement for the detail in PRMS or COGEH, which should be consulted when carrying out an evaluation.

The evaluation of unconventional resources, especially its extension to categories other than reserves is at a relatively early stage. The exploitation of unconventional resources tends to be lengthy, complex, and costly. For these reasons, the importance of adequate explanation cannot be sufficiently emphasized.

Conclusion

The physical nature of unconventional accumulations and the recovery processes requires a modification of the approaches to evaluation that is used for conventional resources. In particular, the emphasis for “discovery” shifts from exploration drilling, to testing, the converse of the situation for conventional resources. This generally leads to additional drilling beyond that usually required for an estimate of an in-place volume, to assess and design recovery processes, and extensive pilot testing. The typically ill-defined nature of the boundaries of unconventional resource accumulations necessitates that more attention be paid to the size of the areal assignments given to the various resource categories.

A full picture of an organisation’s assets necessitates the evaluation of other categories than reserves (full-spectrum evaluation). The often lengthy and complex process of unconventional resource development means that large volumes of potentially recoverable hydrocarbons (Contingent and Prospective Resources) are transferred to reserves only slowly.

This paper has attempted to summarise the implications of the above points and to provide a framework for evaluating unconventional resources, with particular attention paid to classification. The implementation of a new classification system such as PRMS and its application to new types of hydrocarbon accumulations is a complex undertaking, and it is likely that, in due course, the ideas presented here will require revision. No doubt other challenges will arise that have not been foreseen here.

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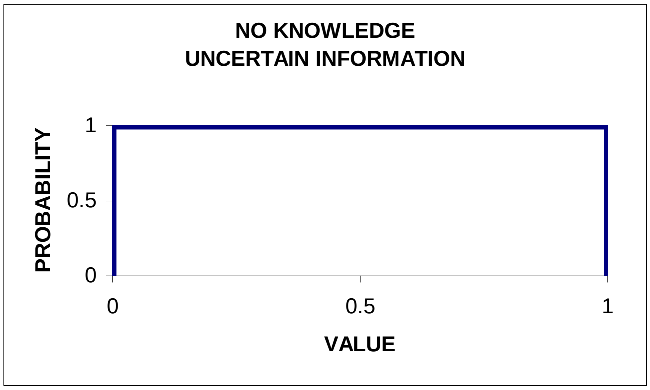
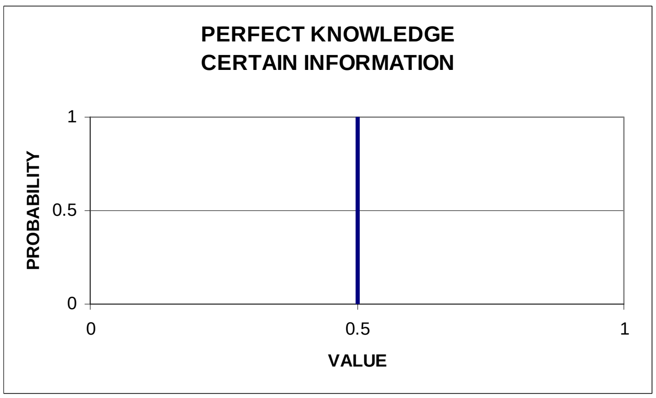
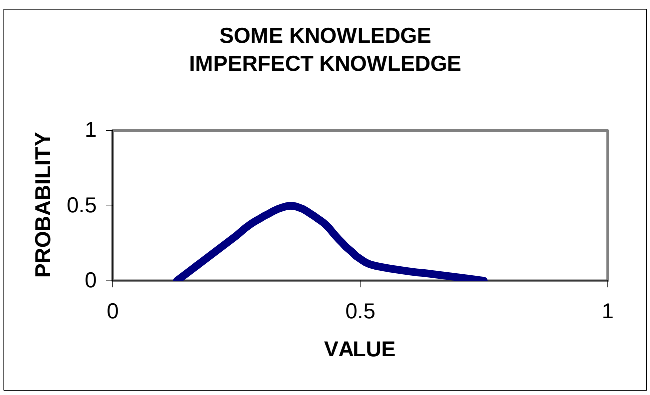


1a. No Knowledge. Uncertain Information. Only Maximum and Minimum Estimates can be made, Variance is a Maximum, and all Values Between 0 and 1 are Equally Likely.



1b. Perfect Knowledge, Certain Information. Zero Variance, No Other Values Possible Than (in this case) 0.5.



1c. Some Information (The Real World Case), Imperfect Knowledge, Between Uncertain and Perfect Knowledge.

Figure 1. Information Content of Data (This would have to be rescaled to represent read data)

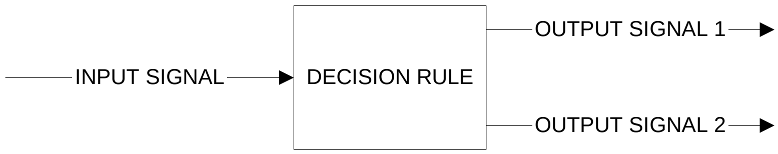


Figure 2. Decision Rule Within a Filter.

If $\phi \geq 8\%$ assign pay
If $\phi < 8\%$ assign no pay

There are four possible cases:

$\phi \geq 8\%$ and pay is assigned	True Positive	
$\phi < 8\%$ and pay is assigned	False Positive	Type I Error
$\phi < 8\%$ and pay is not assigned	True Negative	
$\phi \geq 8\%$ and pay is not assigned	False Negative	Type II Error

		ACTUAL	
		PAY	NO PAY
DECISION	PAY	True Positive	False Positive TYPE I ERROR
	NO PAY	False Negative TYPE II ERROR	True Negative

Figure 3. Decision Matrix showing Type I and Type II Errors.

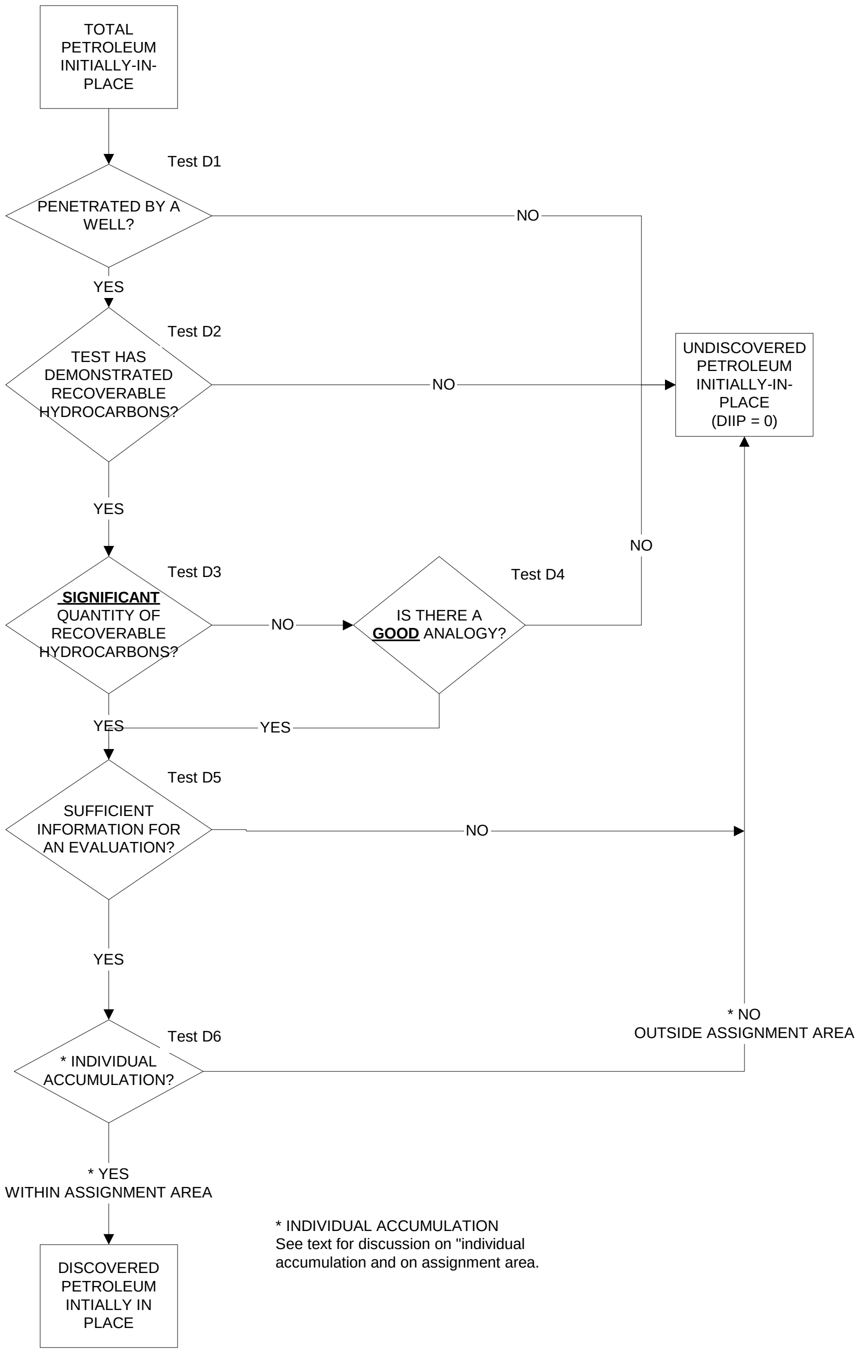


Figure 4. Flow Diagram illustrating PRMS Discovered Petroleum Initially-In-Place Resource Classfication. This diagram is illustrative only and should not be used without reference to the detailed descriptions in PRMS.

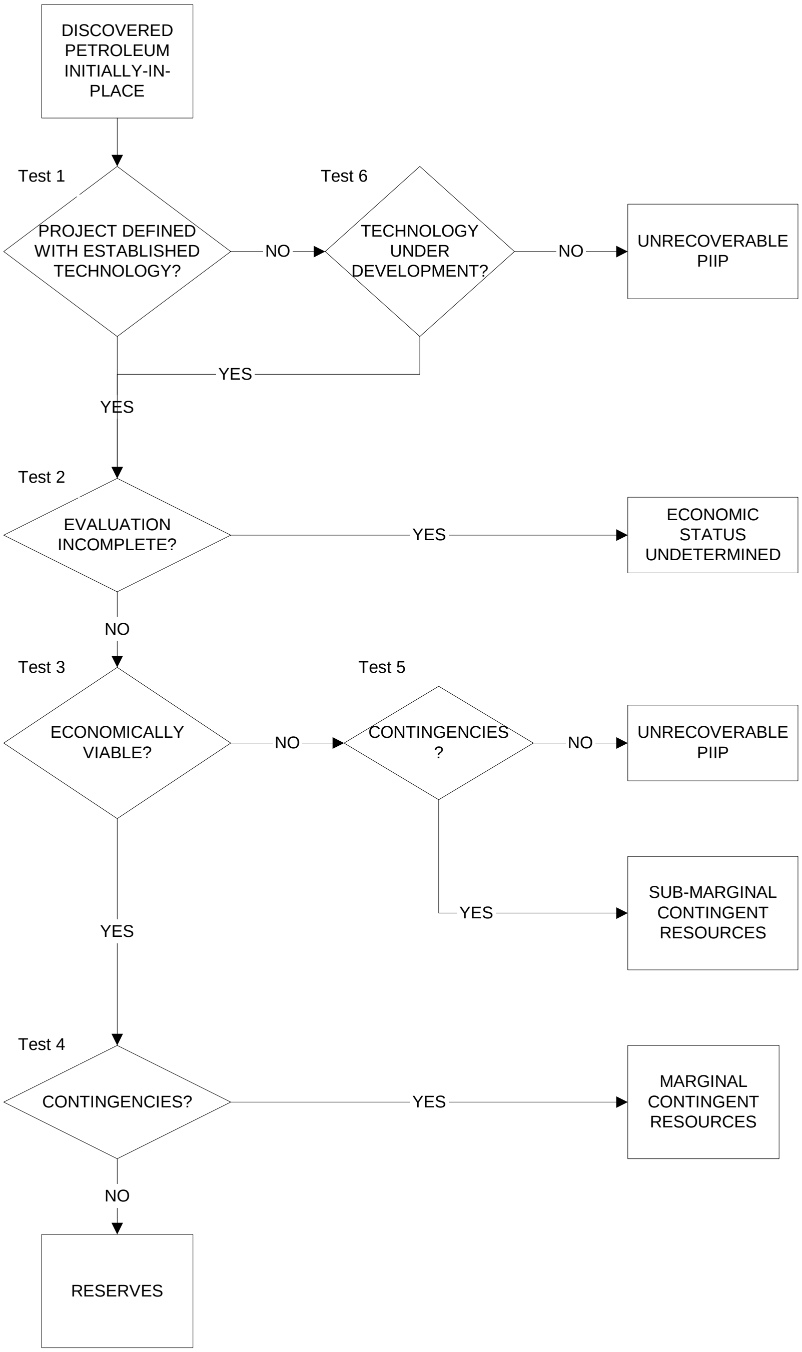


Figure 5. Flow Diagram Illustrating PRMS Contingent Resource Classification.
This diagram is illustrative only, and should not be used without reference to the detailed descriptions in PRMS. Although the terminology in COGEH is different, the concepts are the same.