Pwell
Drilling a Downdip Location: Effect on Updip and Downdip Resource Estimates and Commercial Chance

By

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Table of Contents

Table of Figures

List of Equations

List of Tables

Introduction

Drilling a Downdip Location: Effect on Updip and Downdip Resource Estimates and Commercial Chance was presented as a poster at the 2017 AAPG Annual Convention and Exhibition in Houston, Texas held April 2-5, 2017. The poster can be downloaded at the AAPG Datapages website using the Search and Discovery article number 42102. http://www.searchanddiscovery.com/pdfz/documents/2017/42102schneider/ndx_schneider.pdf.html

The original poster included three panels each 90" x 35" (229cm x 89cm). This format is too large to print and not easy to navigate on a laptop monitor. Therefore, we prepared this document to provide the content of the original poster presentation formatted as a paper for easy reading. There is a separate section for each of the three poster panels. All textboxes in the poster have been converted to standard text, while all equation boxes and figures are preserved as presented in the original poster presentation. A few typographical errors have been fixed and some text has been modified for additional clarity. For probabilistic distributions, the greater than or equal convention is used which means P90 is small relative to P10.

However, what is missing from the original poster was the additional discussions and explanations that the Rose and Associates (R&A) poster presenters provided. For example, the poster title explicitly addresses the effect on commercial chance, but the implication is that the effect on geologic chance at downdip locations must first be calculated.

Pwell is defined as the chance of geologic success at the downdip well location, but we also use the term to refer to the workflow described by the poster. We have added text to this document to provide additional context and clarity that was left out of the original poster knowing poster presenters would be available. To get more understanding and insight into the value of evaluating a downdip location in the manner presented here, and how it has been coded into prospect evaluation software, please contact Rose and Associates. https://www.roseassoc.com/

Abstract

A common method for choosing the drilling location for an exploration prospect is to simply drill the well on the crest of the structure. The main driver is to maximize the chance of discovering a hydrocarbon accumulation. However, a common situation for a crestal well is that the discovery of productive reservoir full-to-base with hydrocarbons has only proven a limited productive area. Therefore, the discovered resource volumes are too small to justify development and further downdip appraisal drilling is required, adding to exploration costs, and delaying possible development.

An alternative approach is to choose a well location where a discovery would exceed the minimum commercial field size (MCFS) needed to justify development. In practice, the drilling location is often based on a deterministic resource estimate using the mean value from a probabilistic assessment of resource volumes. A downdip discovery smaller than MCFS or even a dry hole with a thick, porous reservoir might tempt decision makers to sidetrack updip since the full probabilistic distribution of the updip resources had not been considered.

The poster demonstrates the advantages of choosing a location that considers the full probabilistic resource distributions for the updip and downdip volumes relative to the drilling location and the changing value of the chance of commercial success in the decision-making process. The overlap of the updip and downdip resource distributions can be significant. What might seem like a good drilling location based on the deterministic estimate exceeding MCFS might leave the decision maker with some regrets at the chosen location.

As the well location is moved further downdip, in addition to the modification of the distribution of discovered resources, the chance of geologic success decreases. This value is needed to calculate the chance of commercial success. The goals are to maximize the chance of a commercial discovery and to choose a drilling location that if a dry hole occurs there will be no regrets or reason to undertake an expensive updip sidetrack or drill another test updip. To accomplish this, multiple drilling locations need to be evaluated with this process and the results plotted to analyze trends. The results are ready to be

input into a decision tree for expected value calculations and allow answering management questions such as "If we drill 600 acres downdip of crest, what is the probability we make a commercial discovery and what is the probability of leaving commercial resource volumes updip? And how does this compare if we drill only 500 acres downdip?"

Panel 1: Investigate a Downdip Drilling Location with its Effect on Chance, EUR & EMV

When considering where to drill the first exploration well in a new prospect, several questions need to be asked. Some of the questions should include the following:

- Should I always drill a crestal well to maximize chance of a geologic discovery?
- What if the crestal well, if successful, cannot prove sufficient volumes for development requiring further appraisal, additional costs, and delayed development?
- How do I choose a downdip well location so that a discovery will find Estimated Ultimate Recoverable (EUR) exceeding the Minimum Commercial Field Size (MCFS)?
- What is a downdip well's location impact on chance of geologic and commercial success?
- How do I ensure if the downdip well is a dry hole that there will be "no regrets" about potential updip volumes tempting a decision-maker to drill a sidetrack or new well updip?
- Can I get additional insights if I consider the entire Updip and Downdip resource distribution relative to the chosen well location?
- Is there a downdip well location that maximizes Expected Monetary Value (EMV)?
- How does correlation between Area and Net Pay affect Updip and Downdip resources?

The prospect in Figure 1 and Figure 2 is used throughout this document. Figure 3 shows the Prospect EUR distributions. The productive area versus EUR plot in Figure 4 shows a wide range of area can result in the MCFS = 9.4 MMBO.

No single areal well location will validate all possible outcomes of exceeding MCFS. Besides area, the updip resources are a function of many parameters including the reservoir thickness, net-to-gross ratio, porosity, recovery factor and others—any of which can sample large or small values to determine the resources.

The "No Regrets" updip volume (defined as the well location's area multiplied by the mean average net pay and mean oil recovery yield) is useful to the decision-maker, however, it is an oversimplification.

For most downdip well locations, there remains a chance the updip volume will exceed MCFS. Therefore, it is important to consider the full probabilistic resource range for the drilling location's Updip and Downdip volumes along with the chances of success in the decision-making process.

A decision tree using the oversimplified case of exceeding MCFS or not is shown in Figure 5 to compare the EMV of drilling a well on the crest requiring an appraisal well with drilling a well downdip which, with discovery, leads directly to development without an appraisal well.

To answer the questions introduced earlier, we need a probabilistic evaluation for a specified well location analyzing the Updip and Downdip EUR distributions relative to the well location. Figure 6 shows results for a single well location; and Figure 7 shows results for multiple well locations covering a wide range of area.

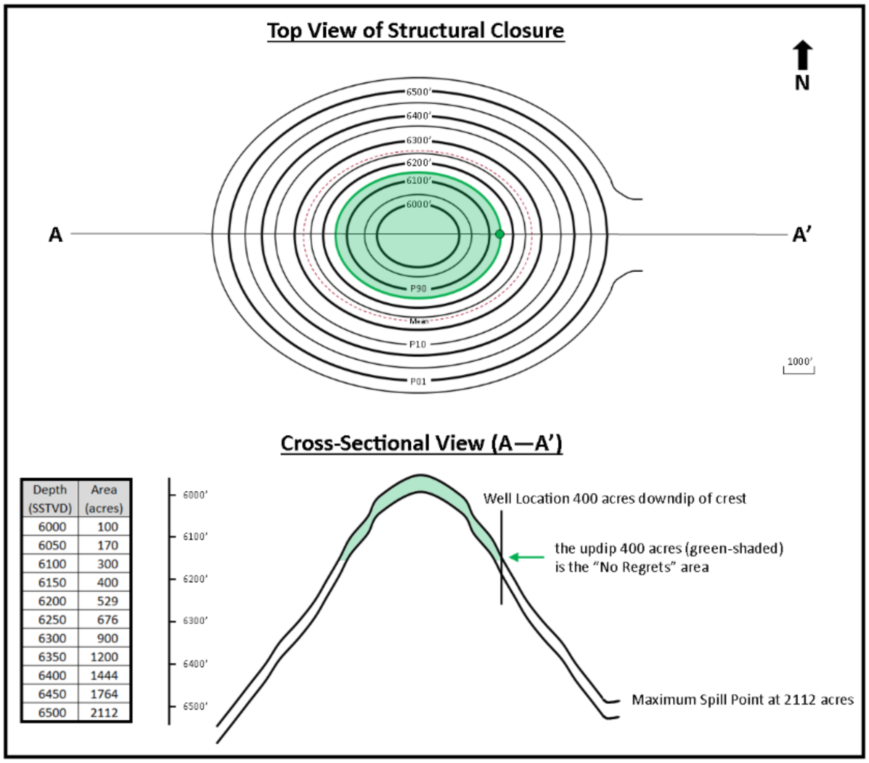

Figure 1 - Prospect Structure Map and Cross-Section through Crest.

A discovery at the crest with a full column of oil would be too small to justify development without additional appraisal (Figure 1). A discovery at a well location 400 acres downdip, as shown, would have a much higher chance that the discovery would lead to immediate development. The green shaded area ("No Regrets" area) is the updip gross rock volume that is not being tested by the well location in the event of a dry hole.

	Prospect Input Distributions			Prospect EUR Distributions (MMBO)		Updip & Downdip EUR Distributions (MMBO) for Well Location 400 acres downdip of crest		
	Area (ac) (lognormal)	Net Pay (ft) (lognormal)	Oil RY (BO/ac-ft) (simulated)	Geologic EUR Distribution	Commercial EUR Distribution (MCFS = 9.4 MMBO)	Geologic EUR Updip of Drilling Location	Geologic EUR Downdip of Drilling Location	Commercial EUR Downdip of Drilling Location
P99	171	19	230	2.5	9.5	1.7	4.3	9.5
P90	300	36	287	5.3	10.7	3.3	7.6	11.0
P50	600	59	375	13.0	17.1	6.5	15.6	17.7
Mean (P99->P01)	695	62	379	16.4	20.4	7.1	19.2	21.8
P10	1200	92	476	31.9	37.5	11.7	35.7	38.6
P01	2112	178	570	67.1	73.2	20.1	70.9	73.6
"No Regrets" EUR for well drilled 400 acres downdip of crest = 9.4 MMBO (400 ac x 62 ft x 379 BO/ac-ft)								
	Area-Net Pay Not Correlated r = 0		Chance of Success	Pg Chance of Geologic Success (>=P99 EUR)	Pc Chance of Comm Success (>=MCFS)	Pg Chance of Geologic Success (>=P99 EUR)	Pwell Chance of Finding HC at well location	Pc(well) Chance of Finding Comm HC at well location
				50%	34%	50%	43%	35%

Figure 2 - Summary of Prospect Input Distributions and Simulated Output EUR Distributions.

A summary of prospect input distributions and simulated EUR results are shown in Figure 2. The Chance of Geologic and Commercial Success for each EUR distribution are also shown. The Prospect EUR distributions represents the entire prospect from crest to spill point (note there is no Area – Net Pay correlation). The new EUR distributions discussed in this poster are the Updip and Downdip accumulation distributions relative to the drilling well location (e.g., 400 acres downdip of crest). The "No Regrets" EUR is defined as the area associated with the well location multiplied by the mean average net pay and mean oil recovery yield. At 400 acres downdip, the "No Regrets" EUR equals 9.4 MMBO (400 ac x 62 ft x 379 BO/ac-ft).

The prospect chance of geologic success (Pg) is 50% which includes the chance of trap (closure) of 80%. To be consistent with assessing Pg at the P99 EUR volume, the chance of trap is assessed at the P90 productive area. This is important for how the chance of geologic success for a downdip well location is calculated. Equation 1 honors the fact that a well drilled at the P90 productive area has the same Pg as the prospect because no adjustment is required for the well location.

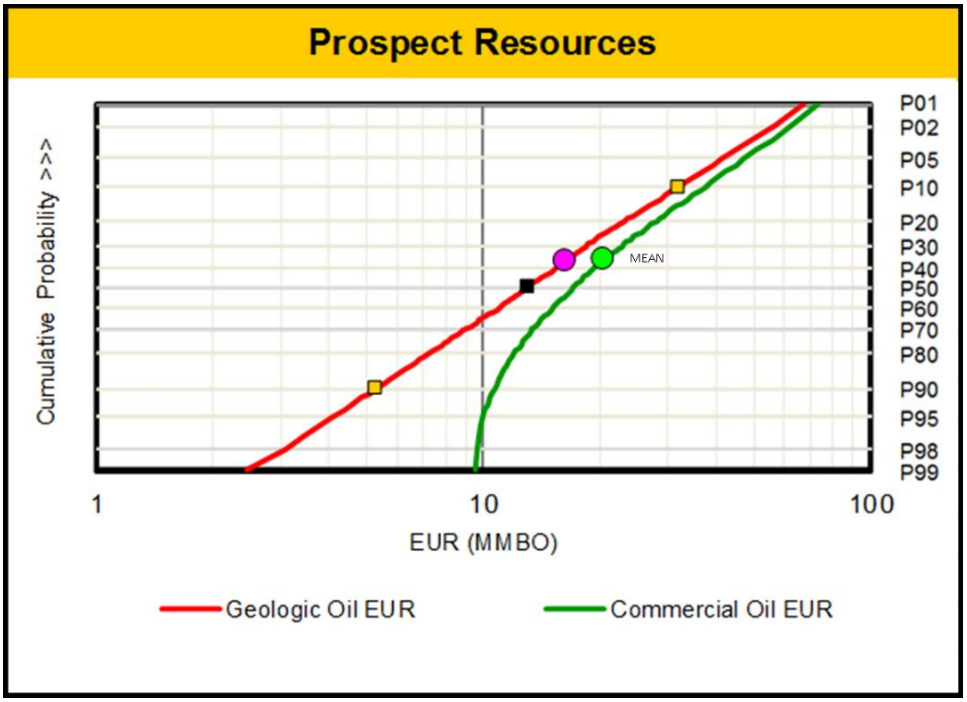

Figure 3 - Simulated Prospect Geologic and Commercial EUR Distributions. Commercial resources distribution based on MCFS = 9.4 MMBO.

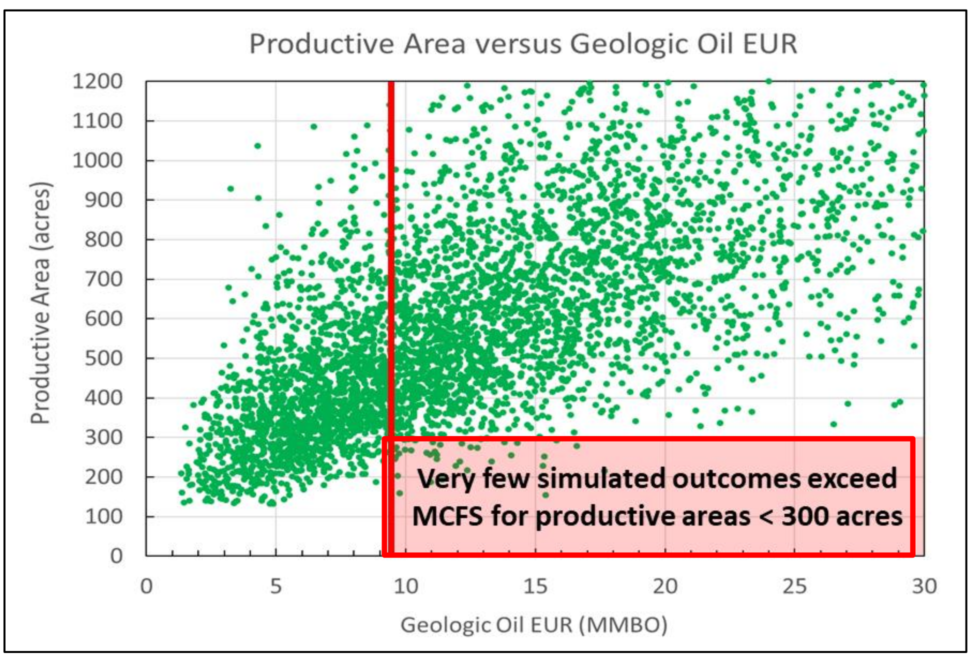

Figure 4 - Productive Area samples versus simulated Prospect Geologic Oil Resources.

Development is only approved if commercial volumes greater than the MCFS of 9.4 MMBO (the vertical red line) are discovered (Figure 4). The EUR of 9.4 MMBO is associated with productive areas from 200 to 1500 acres. EUR is a function of many parameters, not just area, so that large or small values for pay or porosity contribute to the wide EUR range. Notice there are very few simulated outcomes < 300 acres that exceed the MCFS. This suggests a well at this location would almost guarantee the need for downdip appraisal to determine commerciality.

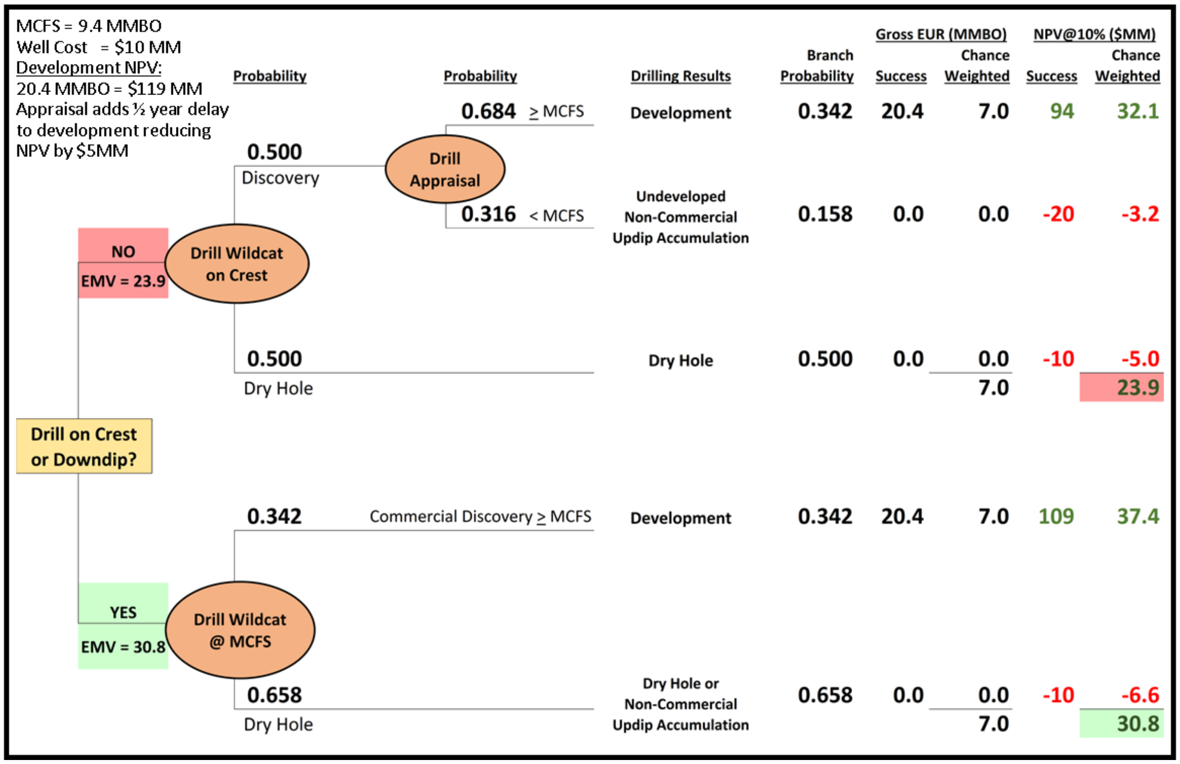

Figure 5 - Simple decision tree comparing the EMV for drilling exploration well on crest versus downdip.

The upper part of the decision tree (Figure 5) shows drilling a crestal well plus an appraisal well versus the lower part of the tree's commercially truncated EUR so that a discovery leads directly to development. The Commercial EUR from drilling a well at the MCFS without an appraisal increases EMV by 29%. The downdip well location is not specified because there is not a unique productive area for the MCFS (Figure 4) causing this evaluation to be too simplistic.

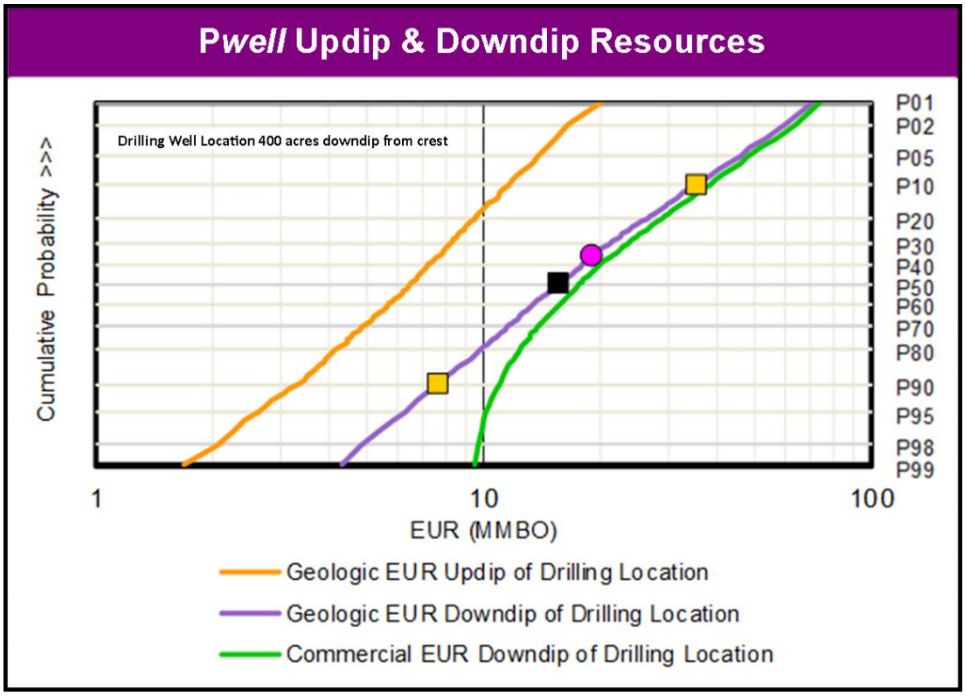

Figure 6 - Updip and Downdip Geologic EUR Distributions for a well located 400 acres downdip from crest.

The Downdip Commercial EUR distribution (green) is also shown with MCFS = 9.4 MMBO (Figure 6). Note the significant overlap of the Updip (orange) and Downdip (purple) EUR distributions.

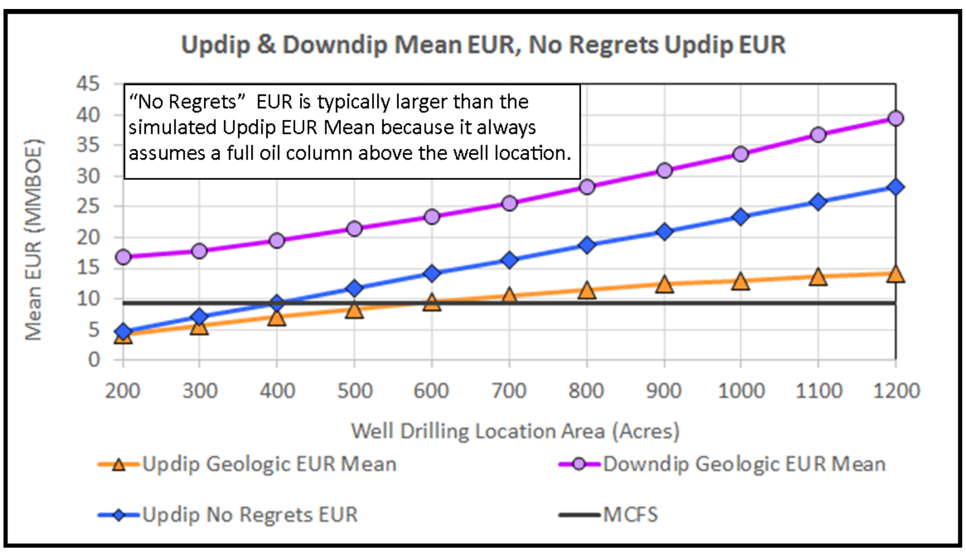

Figure 7 - Geologic Updip and Downdip Mean EUR resources and the Updip "No Regrets" EUR as a function of well drilling location.

The thick black horizontal line shown in Figure 7 is the MCFS of 9.4 MMBO. From this plot, a well at 700 acres is likely too far downdip as the orange Updip Mean EUR > MCFS and the blue "No Regrets" EUR is 16.4 MMBO. A dry hole at 700 acres would likely leave regrets leading to an updip appraisal well. The "No Regrets" EUR is always higher than the Updip Geologic Mean EUR because it does consider productive areas less than the well location and always uses the mean value for other input parameters.

Panel 2: Investigate a Downdip Drilling Location of an Uncorrelated Area – Net Pay Prospect Assessment

Panel 2 outlines the workflow to identify the optimum downdip well location, or a range of satisfactory locations. The final well location will be selected at a specific shotpoint. This panel presents the equations needed to adjust Pg, Pc and EMV for a downdip well location. A series of figures show the impact on well location from near the crest to a user defined downdip limit on metrics such as: -

- Downdip and Updip EUR Distributions
- Chance of Geologic Success at Well Location, Pwell
- Chance of Commercial Success at Well Location, Pc(well)
- Chance a Downdip Discovery has EUR > MCFS, Pmcfs(well)
- Chance a Dry Hole has Updip EUR > MCFS.

Finally, there is a figure with a decision tree for a specific well location and a sensitivity plot of EMV versus downdip well location to identify the downdip well location range with the highest EMV.

Pg, the probability of geologic success, is the chance of an active hydrocarbon system that provides oil and/or gas in quantities sufficient for sustainable flow and is associated with the P99 EUR. To be consistent with the P99 EUR, the geologic chance of a trap (closure) existing is evaluated at the P90 productive area. In this workflow, the Pg is held constant for productive areas less than the P90. The prospect Pg is independent of the well location and commerciality.

The chance of commercial success and commercial EUR volumes are required for economic evaluation. That is, an undeveloped discovery generates no revenue; so Pg alone is insufficient for decision-making.

Pc, the probability of commercial success, is the chance that a prospect will be drilled as a discovery and the EUR will exceed MCFS and justify development. Pmcfs is the chance that a discovery will exceed MCFS. Pc is equal to the product of Pg and Pmcfs as given in Equation 2.

A Decision Maker benefits from insightful information gained from a full probabilistic evaluation of both the Updip and Downdip accumulations relative to the proposed drilling well location and the chance of geologic and commercial success adjusted to the well location.

One of the more surprising insights is the large overlap of EUR between the Updip and Downdip distributions. This evaluation shows how to use this information to select a downdip well location that maximizes the chance that a well location will discover EUR > MCFS, but also in event of a dry hole, minimizes the chance the Updip EUR > MCFS to have no regrets about not sidetracking or drilling an appraisal well updip. The inherent uncertainties mean there is no single "best" well location, but a better-informed decision can be made.

It is important to adjust the EUR distributions and the prospect Pg and Pc for the downdip well location and use these adjusted probabilities in the fiscal calculation of EMV to maximize .

Equations used to calculate Pwell, Pc(well) and EMV based on the downdip well location are shown below.

Adjusting Pg for a Downdip Well Location:

$$Pwell = Pg \times \frac{Ptrap@well}{Ptrap} = Pg \times \frac{Ptrap@well}{0.90}$$

where:

Pwell = Probability of Discovery at the Drilling Well Location (if area updip of P90 Area, *Pwell* = *Pg*)

Pg = Probability of Geologic Success for the Prospect (i.e. P99 EUR or more)

Ptrap = Percentile used to assess geologic sub-factor for prospect trap (i.e. P90 Area)

Ptrap@well = Percentile from area distribution at well location representing trap with oil column (*Ptrap@well* $\leq$ *Ptrap*)

Equation 1 - Adjusting Pg for a Downdip Well Location (Pwell)

The chance of a geologic discovery at the well location (Pwell) is given by Equation 1. For the prospect being evaluated, let us look at Pwell for three different well locations. Recall from the Figure 2 discussion, that prospect Pg is 50%, which included a chance of trap (closure) of 80%. The prospect Pg of 50% is the chance of discovering the P99 EUR or more. The chance of trap of 80% is assessed at the P90 area since that is consistent with a P99 EUR. In Equation 1, we refer to the reference P90 area as Ptrap and use the fractional format 0.90 in the equation. The last variable in Equation 1 is Ptrap@well which is the percentile from the area distribution at the proposed well location expressed as a fraction. The example calculations in Table 1 show Pwell for three locations.

Table 1 - Pwell Calculation Examples

	Well Location	Percentile from	Equation 1						
Case	Area (ac)	Area Distribution	Pg	x	Ptrap@well	/	Ptrap	=	Pwell
1	300	P90	0.50	x	0.900	/	0.90	=	0.50
2	400	P77.5	0.50	x	0.775	/	0.90	=	0.43
3	600	P50	0.50	x	0.500	/	0.90	=	0.28

Case 1 is drilling the well at the P90 area which is the productive area used to assess the chance of trap which implies that the equation should not change the prospect Pg. Case 3 is drilling the well at the P50 area and notice that Pwell = 0.28. It is not 0.25 because the reference for Ptrap is the P90 area and not the P100 at crestal point.

Calculating Pc for a Downdip Well Location:

$$Pc = Pg \times Pmcfs$$

$$Pc(well) = Pwell \times Pmcfs(well)$$

where:

Pc = Probability of Commercial Success for the Prospect

Pmcfs = Probability a Discovery will find EUR $\geq$ MCFS

Pc(well) = Probability of Commercial Success for a Well drilled Downdip from crest (if the area is updip of P90 Area, Pc(well) = Pc)

Pmcfs(well) = Probability a Discovery from a Well drilled Downdip from crest will find EUR $\geq$ MCFS

Equation 2 - Adjusting Pc to Pc(well)

The chance that a prospect will be a commercial development at a downdip well location, Pc(well), is given in Equation 2. The probability a discovery has EUR greater than MCFS is referred to as Pmcfs(well) and is calculated from the simulation trial results. The calculations of Pc(well) for the same three well locations that were used to demonstrate Equation 1 are shown in Table 2.

Table 2 - Pc(well) Calculation Examples

	Well Location		Equation 2				
Case	Area (ac)	Pmcfs(well)	Pwell	x	Pmcfs(well)	=	Pc(well)
1	300	0.68	0.50	x	0.68	=	0.34
2	400	0.82	0.43	x	0.82	=	0.35
3	600	0.93	0.28	x	0.93	=	0.26

If Case 2 with a well drilled 400 acres downdip is used for economic evaluations, then the Pc(well) = 0.35 is the chance of commercial success needed to be used.

Just as Pwell is set equal to the Prospect Pg updip of the P90 area, the Pc(well) is also set equal to Prospect Pc from updip to P90 area. This is to avoid confusion so if a well is drilled at the crest, the Prospect Pg and Pc do not change using this workflow.

Calculating EMV for a Downdip Well Location:

$$EMV = (Pc(well) \times PVs) + (Pf \times PVf)$$

where:

EMV = Expected Monetary Value (chance-weighted PV*s* and PV*f*)

P*c*(*well*) = Probability of Commercial Success for a Well drilled Downdip from crest (if area updip of P90 Area, P*c*(*well*) = Pc)

PV*s* = Present Value of Commercial Success

P*f* = Probability of Commercial Failure (i.e. P*f* = 1 - P*c*(*well*))

PV*f* = Present Value of Commercial Failure (typically dry hole cost of exploration and appraisal wells)

Equation 3 - Calculating EMV for a Downdip Well Location.

Equation 3 is the expected value equation setup to calculate the Expected Monetary Value of drilling a well in a downdip location with the probability of success term renamed for the commercial success at the downdip drilling location, Pc(well).

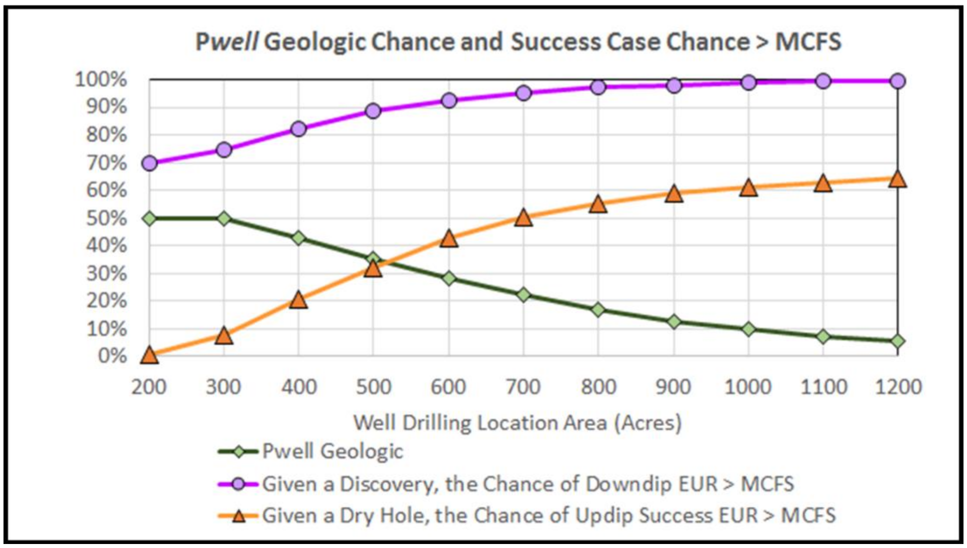

Figure 8 - Chance of Geologic Success at Well Location and Chance a Discovery for Updip and Downdip Distributions has EUR exceeding the MCFS as a function of well drilling location [Pmcfs(well)].

Pg is assessed at the P90 Area (300 acres for this prospect) with the prospect Pg held constant at 50% for areas less than 300 acres. The green chance of discovery at the well location (Pwell) decreases as you go downdip (Figure 8). The purple Downdip Pmcfs(well) curve shows as the well location is moved further downdip, a discovery confirms a larger oil column with the impact being that success case EUR has a greater chance of exceeding the MCFS, approaching 100% chance at 1000 acres downdip from the crest. The orange Updip Pmcfs(well) curve shows if the well location is very near the crest (in this example, 200 acres or less), there is effectively no chance that the updip volumes will exceed MCFS (Figure 8).

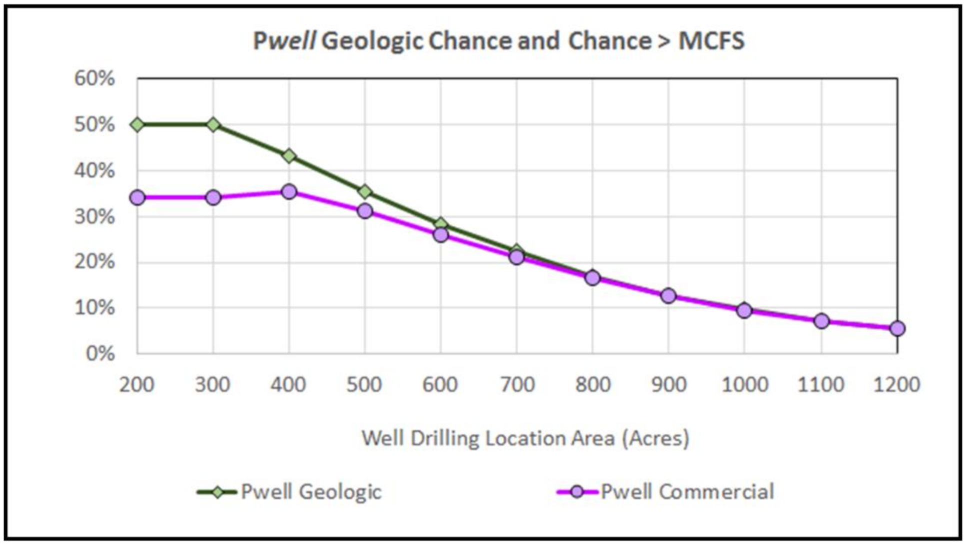

Figure 9 - Chance of Geologic and Commercial Success as a function of well drilling location.

Figure 9 presents the computed Pc(well) curve (purple) on the same plot as the Chance of Geologic Success at Well Location, Pwell, (Green curve) from Figure 8. The purple Chance of Commercial Success at the Well Location, Pc(well), is given by Equation 2.

Just as Pwell is set equal to the Prospect Pg updip of the P90 area, the Pc(well) is set equal to Prospect Pc from crest downdip to P90 area. Therefore, the Pwell and Pc(well) curves are both horizontal from crest to P90 area at 300 acres. Notice how the two curves converge as the well location moves further downdip. Although the Pmcfs(well) steadily increases as the well location shifts downdip and approaches 100% (Figure 8), the geological chance of success at the downdip location is decreasing more rapidly, driving the convergence of these curves.

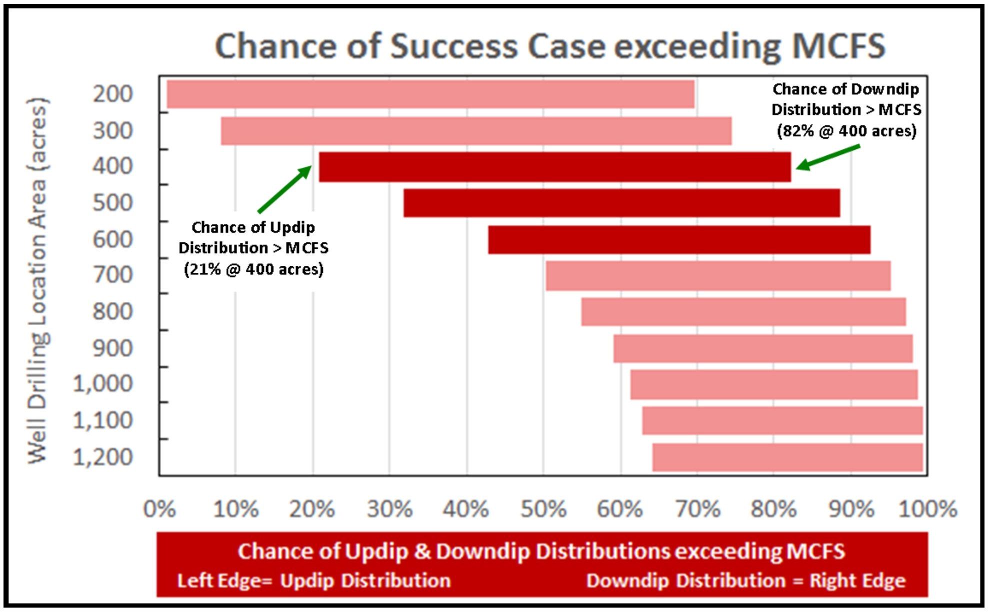

Figure 10 - Chance of Success Case exceeding MCFS [Pc(well)] range for Updip and Downdip Distributions as a function of well drilling location.

The bar chart in Figure 10 displays the information presented in Figure 8 in a different manner. The x-axis and y-axis of Figure 8 are reversed and the separation between the updip and downdip curves filled in as red bars. Dark red histogram bars focus on likely drilling well locations. For a "perfect" well location, a discovery would have 100% chance of exceeding MCFS, and a dry hole would leave the updip accumulation with 0% chance of exceeding MCFS (so bar extends from 0% to 100%). So, wider histogram bars (more distance between the endpoints) are desired for the drilling well location. This figure does a good job of showing the decision tradeoffs between maximizing the chance of commercial resources in the Downdip resources with minimizing the commercial chance in Updip resources.

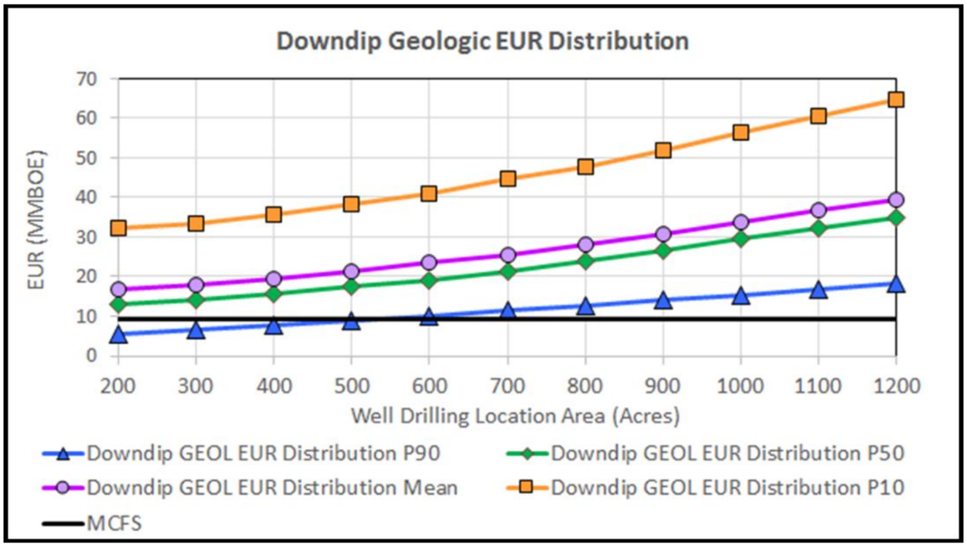

Figure 11 - Downdip Geologic EUR distribution key percentiles and Mean EUR as a function of well drilling location.

Figure 11 and Figure 12 reinforce that consideration of the full probabilistic EUR range is critical in understanding the consequences of any well drilling location. The thick black horizontal line in Figure 11 is the MCFS of 9.4 MMBO. Notice that for a downdip well located between 500 and 600 acres (blue curve), there is about a 90% chance a discovery will exceed MCFS. Successful wells drilled further downdip have a higher chance of the EUR exceeding MCFS, but is that increased downdip discovery size attractive given the tradeoff of a lower Pwell and leaving behind larger, and potentially commercial, Updip Resources, as shown in Figure 12?

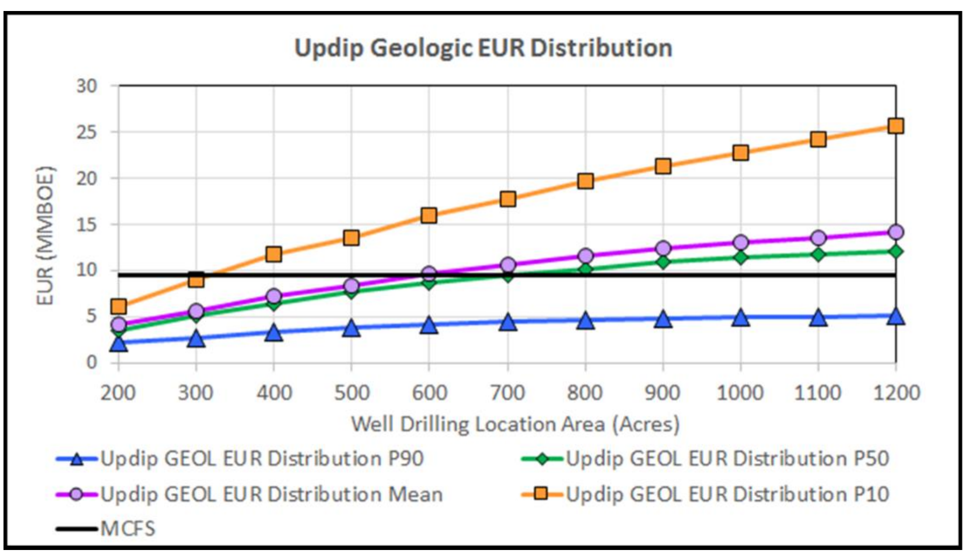

Figure 12 - Updip Geologic EUR distribution key percentiles and Mean EUR as a function of well drilling location.

The thick black horizontal line in Figure 12 is the MCFS of 9.4 MMBO. At about 600 acres, the Updip Mean EUR (purple) is a little larger than the MCFS. Can the decision maker tolerate a 40% chance (the percentile associated with the mean EUR, Figure 6) of commercial volumes in an updip position if the downdip well was a dry hole or would there be regrets resulting in an appraisal well and increased costs?

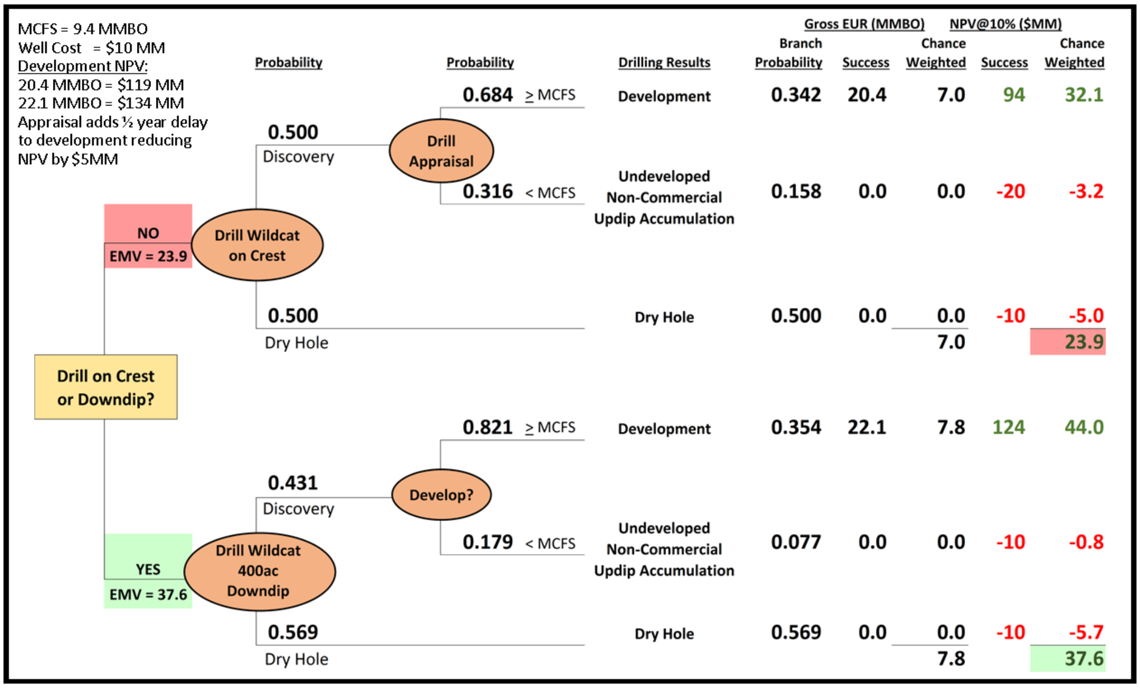

Figure 13 - Decision tree using the drilling well location at 400 acres downdip from crest.

The decision tree in Figure 13 is more complicated than the oversimplified one in Figure 5 because it uses Pwell, Pmcfs(well), and Pc(well) adjusted to a physical well location, 400 acres downdip from crest in this example. The 400-acre downdip well location has a higher EMV than drilling at the crest and also higher than the well drilled at the MCFS in Figure 5. This suggests a well location may exist that maximizes EMV. The EMV calculation in the decision tree can be prepared for the full range of productive areas associated with possible drilling well locations.

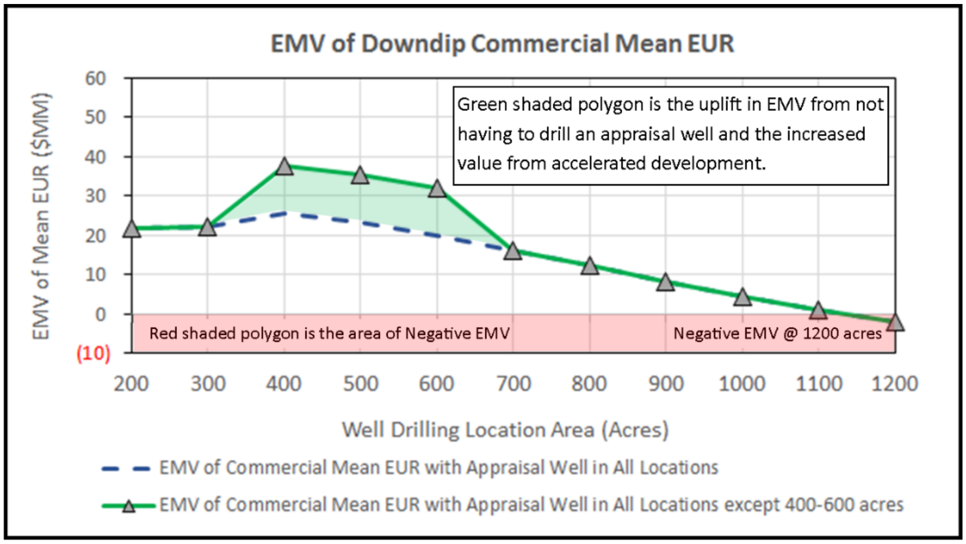

Figure 14 - Expected Monetary Value (EMV) as a function of well drilling location.

Figure 14 presents the EMV of a decision tree for each drilling location (e.g., the 400-acre EMV of $37.6MM without appraisal from Figure 13 is one of the data points on the green curve). A well location between 400 to 600 acres would not require appraisal whereas the green curve assumes appraisal is required if the exploration well is drilled $\leq$ 300 acres from crest (downdip appraisal) or $\geq$ 700 acres (a dry hole leads to an updip sidetrack). These assumptions maximize EMV at 400 acres. They need to be consistent with the decision-making process and need to be verified as reasonable as would all other assumptions made for accurate economic evaluation.

Panel 2 Observations

Observations from the prospect evaluation presented on these first two panels for selecting a drilling well location include:

1) The maximum Pc occurs at the P77.5 area distribution equal to 400 acres (Figure 9).

2) A well location at 400-500 acres would decrease the chance of a geologic discovery from 50% to about 40% with about 30% commercial chance (Figure 9).

3) What level of risk is tolerable for leaving Updip resources that would not be drilled? A maximum 20-30% chance of leaving behind Updip commercial resources suggests a 400-500 acre well location is appropriate. The tradeoff is that a discovery at these locations provide only an 80-90% chance of a commercial accumulation (Figure 10).

4) For a well location between 500 to 700 acres downdip, the P90 Downdip resources are equal to or more than the MCFS, but this is offset by Mean Updip resources around the MCFS (Figures 11 and 12). Drill further updip if this is too much to leave behind.

5) The maximum EMV occurs at 400 acres assuming that no appraisal well is drilled (Figure 14). Maximizing EMV is always a key metric.

6) For drilling well locations 700 acres or greater, the EMV is less than drilling on crest due to the negative impact for Pg adjustment to the well location (Figure 14).

Area – Net Pay Correlation Observations

The prospect presented on the first two poster panels has no Area – Net Pay correlation, that is, Area and Net Pay are fully independent of each other. Assuming no correlation between Area and Net Pay is not always a good assumption as discussed in Panel 3. Area versus Depth rock volume assessments often show a positive Area – Net Pay correlation that can be missed when using the Area x Average Net Pay method since the oil column increases in height as you go further downdip in area. Using the same prospect, but with an assumed strong Area – Net Pay correlation, is discussed on the third poster panel showing the importance of always including correlations in the evaluation when justified.

Panel 3: Investigate a Downdip Drilling Location of a Correlated Area – Net Pay Prospect Assessment

All previous discussion was for a prospect with no correlation between area and average net pay. This panel uses the same prospect, but with the assumption of a strong Area – Net Pay correlation to highlight the impact correlation has on the evaluation and the decision-making process for the well location. An Area – Net Pay positive correlation with r = 0.8 has been used to demonstrate the impact.

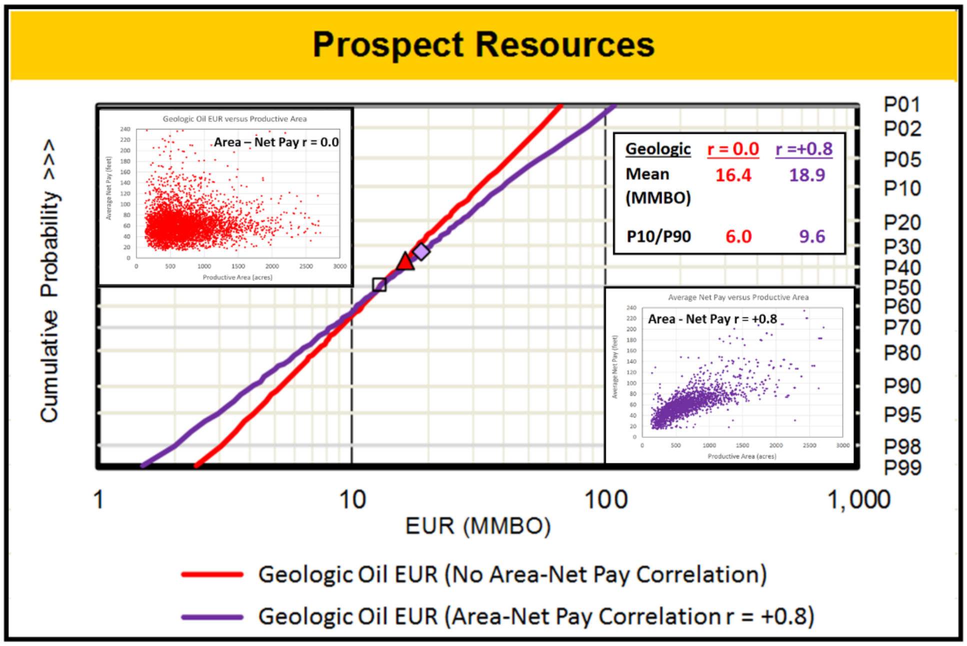

Figure 15 - Geologic EUR Distributions showing impact of Area – Net Pay correlation for r = 0.0 and r = +0.8.

Figure 15 compares the prospect EUR distributions with no Area – Net Pay correlation in red (r = 0.0) and a positive Area – Net Pay correlation in purple (r = +0.8). The positive correlation increases the Mean EUR by 15% and the EUR uncertainty expressed as the P10:P90 ratio by 60%. The embedded scatterplots visually show the Area – Net Pay relationship with and without correlation.

Figure 16 and Figure 17 show the prospect uncorrelated and correlated EUR distributions for the drilling location at 400 acres. Each figure displays the Updip (orange) and Downdip (purple) Geologic EUR distributions and the Downdip Commercial EUR (green) distribution.

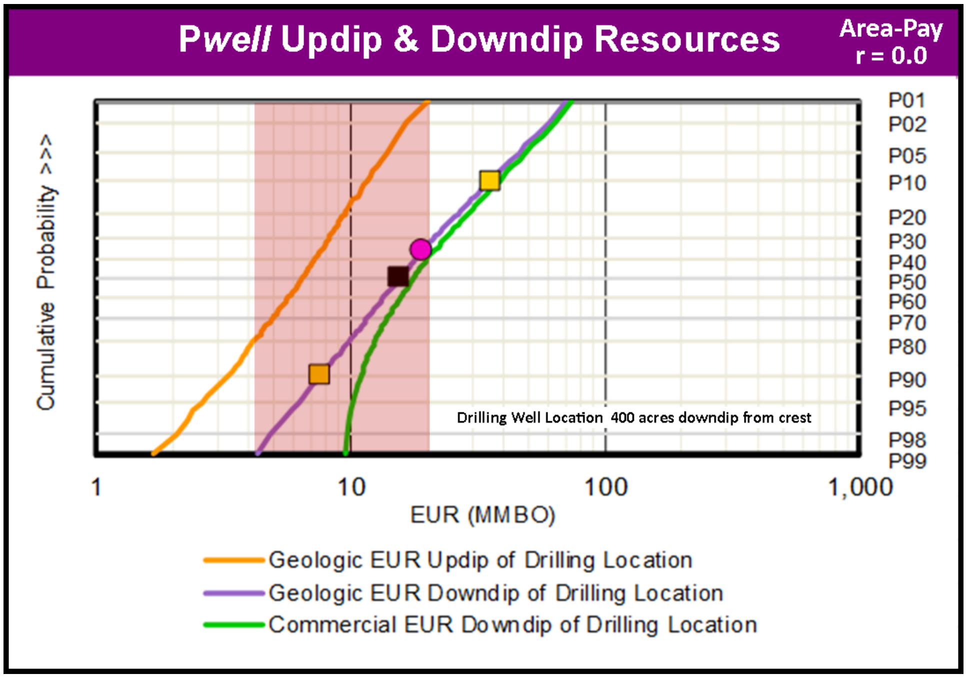

Figure 16 - Updip & Downdip Geologic and Commercial distributions with well location at 400 acres with no Area – Net Pay correlation.

Figure 16 with no Area – Net Pay correlation highlights the 68% overlap (tan rectangle) of the Updip and Downdip EUR distributions (P100 to P32 of Downdip Distribution). This significant EUR overlap is often surprising. A decision maker selecting a downdip well location to prove up MCFS, with the intention of not sidetracking if the well is a failure is probably not aware that the Updip EUR Distribution has a 21% chance of exceeding MCFS and the Updip P01 EUR = 20 MMBO. The insight from this makes for a better-informed decision with all the uncertainty quantified.

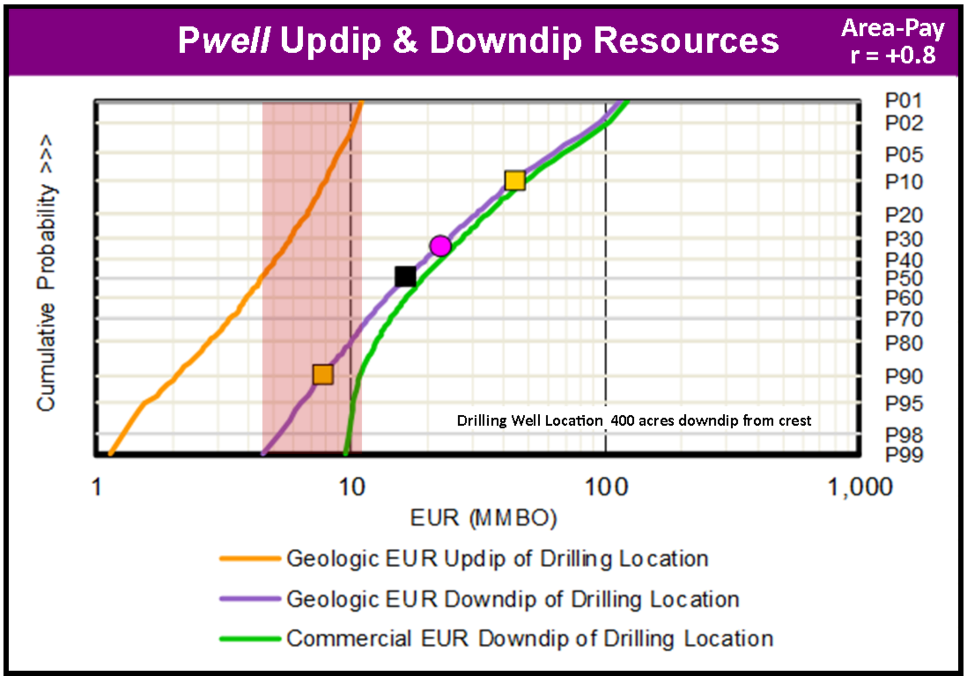

Figure 17 - Updip and Downdip Geologic and Commercial distributions with well location at 400 acres with Area – Net Pay correlated with r = +0.8.

Figure 17 with the positive Area – Net Pay correlation highlights how the EUR overlap (tan rectangle) is significantly reduced to only 26% (P100 to P74 of the Downdip distribution) with Updip P01 EUR = 11 MMBO. As always, this reinforces that strong correlations must be included in the assessment only when they are justified. The positive correlation's increased prospect Mean EUR and overlap reduction enables a more definitive decision on the well location.

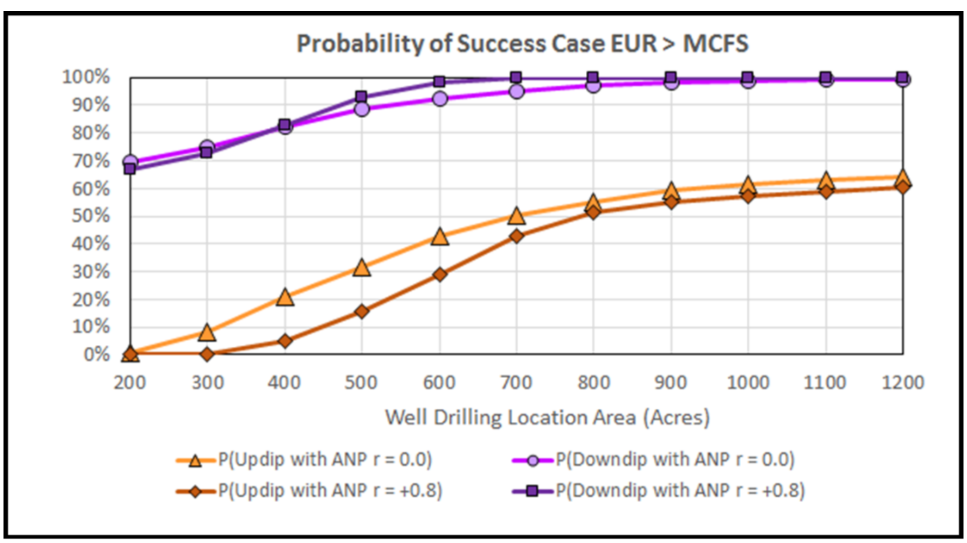

Figure 18 - Effect on Success Case Chance of a Positive Area – Net Pay Correlation.

Figure 18 compares the impact of correlation by showing the Pmcfs(well) of the drilling well location for the Updip and Downdip EUR distributions with both no Area – Net Pay correlation and a strong correlation. The Downdip EUR distributions are for the case of a discovery at the well location, while the Updip EUR distributions are for the updip attic assuming a dry hole at the well location. For the Downdip distribution with correlation, the chance of exceeding MCFS approaches 100% faster because of the thicker correlated pay with increasing oil column height. For the Updip distribution with correlation, the chance of exceeding MCFS in the updip attic of a dry hole is significantly reduced compared to evaluation without correlation for area less than 700 acres because of the thinner correlated pay with decreasing oil column height. For a dry hole at 400 acres, the Updip EUR distribution exceeding MCFS has reduced from 21% with no correlation to 5% when considering the strong correlation making decision-making easier.

Figures 19 – 26 follows the workflow in Panels 1 and 2, but with a strong Area – Net Pay correlation.

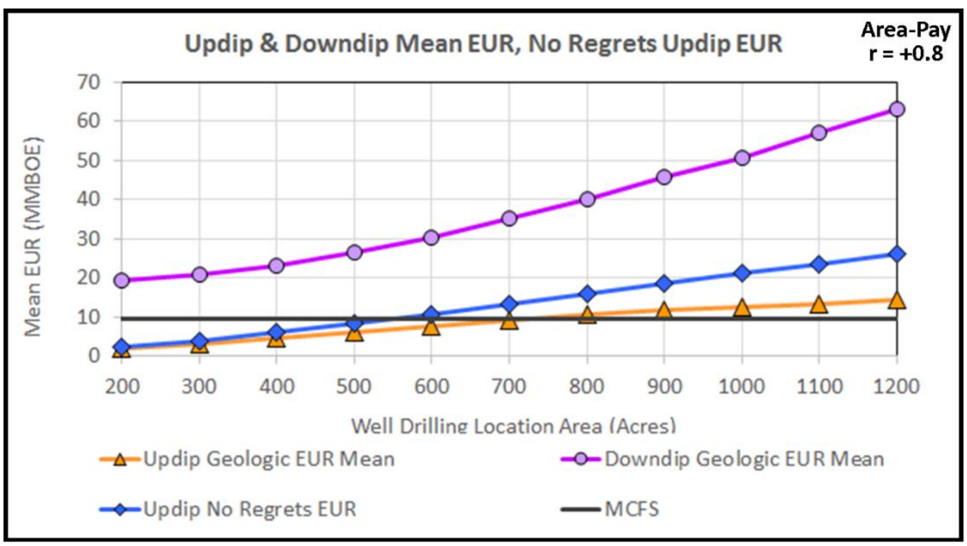

Figure 19 - Geologic Updip and Downdip Mean EUR and the Updip "No Regrets" EUR as a function of well drilling location.

The thick black horizontal line in Figure 19 is the MCFS of 9.4 MMBO. Recall that in Figure 7 at 700 acres, the uncorrelated Mean Updip EUR was greater than the MCFS, while here with the positive correlation the Mean Updip (orange) is slightly less than MCFS. The correlated Mean Downdip EUR (purple) increases faster with area due to the correlation with net pay.

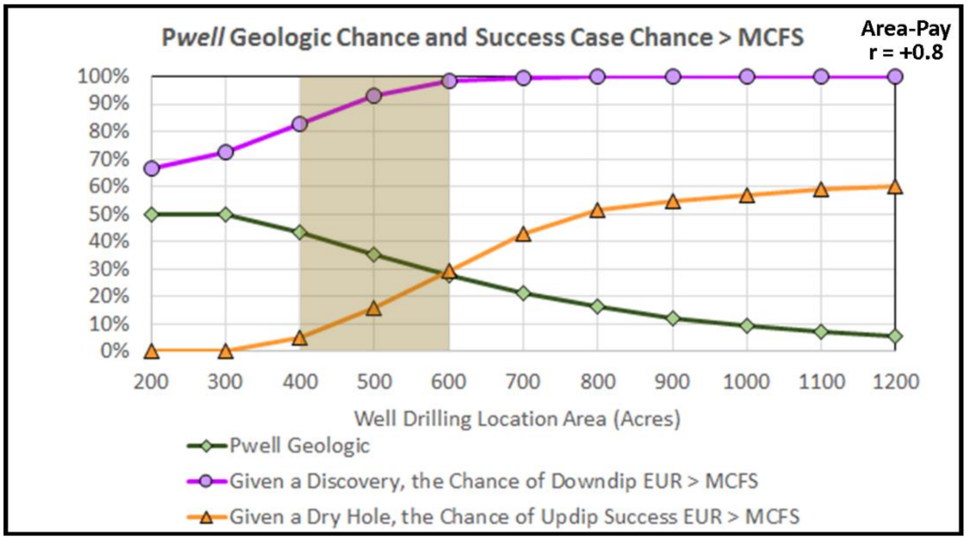

Figure 20 - Chance of Geologic Success and Chance a Discovery has EUR exceeding the MCFS.

In Figure 20, note the chance the Downdip EUR exceeds MCFS approaches 100% at 700 acres, while it is 1000 acres in Figure 8 for uncorrelated Downdip EUR.

Along with Figure 18, Figure 19 and Figure 21, this figure highlights how the positive correlation reduces the well location decision to the range from 400 to 600 acres with less potential for commercial regrets. This range from 400 to 600 acres has been highlighted in Figure 20 by the tan rectangle.

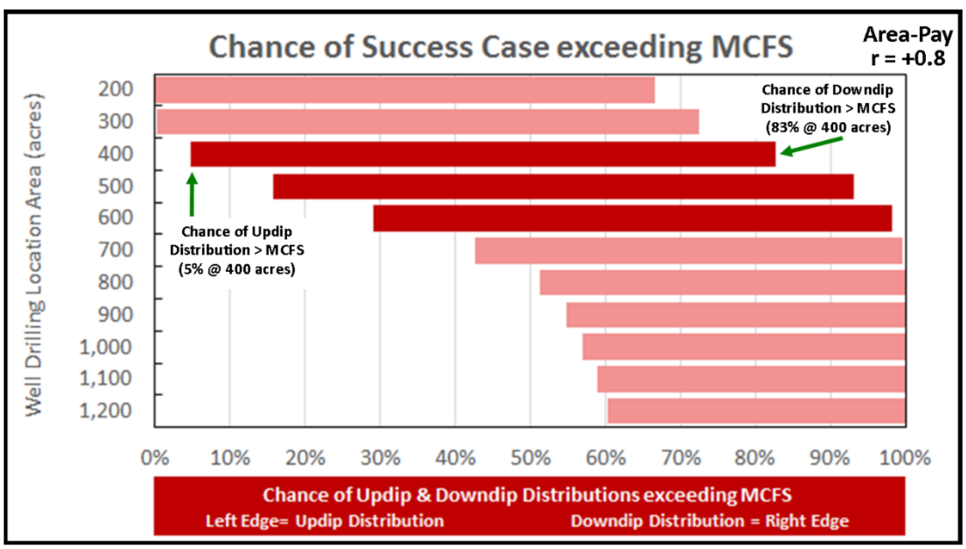

Figure 21 - Chance of Success Case exceeding MCFS range for Updip and Downdip Distributions.

Compared to Figure 10, the location choices between 400 - 600 acres with the correlation are more definitive (larger distance between the commercial chance endpoints).

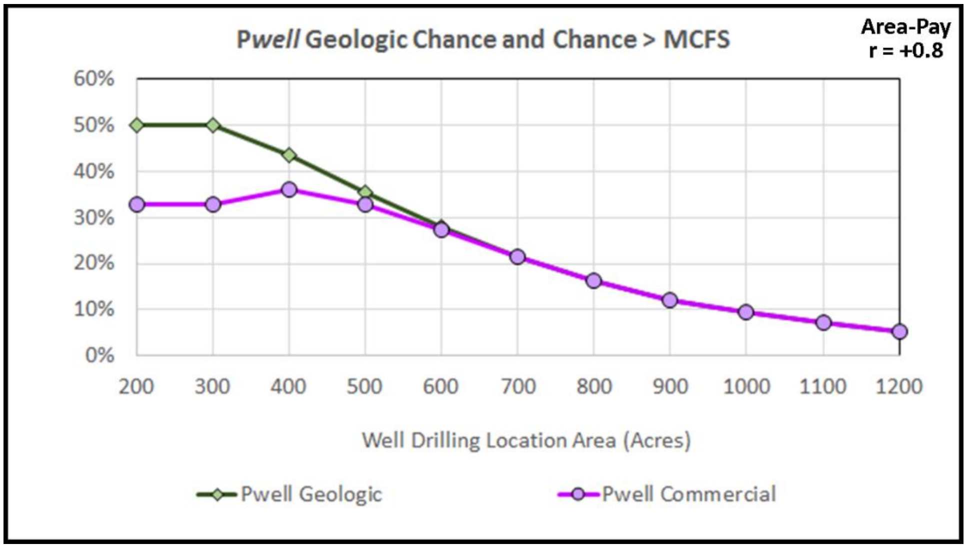

Figure 22 - Chance of Geologic and Commercial Success as a function of well drilling location.

The impact on Pg and Pc due to the Area – Net Pay correlation is small compared to Figure 9 showing same metrics without correlation.

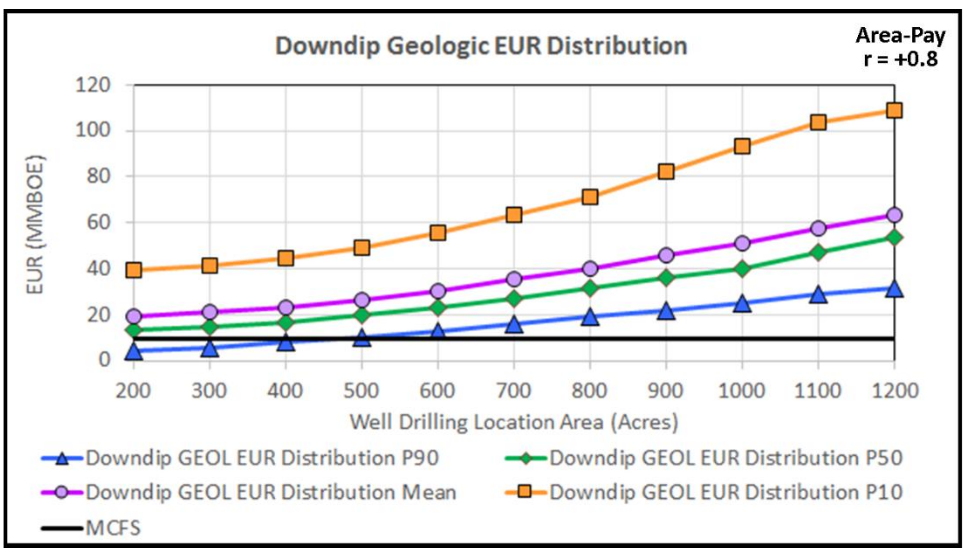

Figure 23 - Downdip Geologic EUR distribution key percentiles and Mean EUR as a function of well drilling location.

For a well located 400-500 acres downdip (smaller area range than the no correlation model in Figure 11), the blue P90 curve shows there is about a 90% chance a discovery will exceed MCFS (Figure 23).

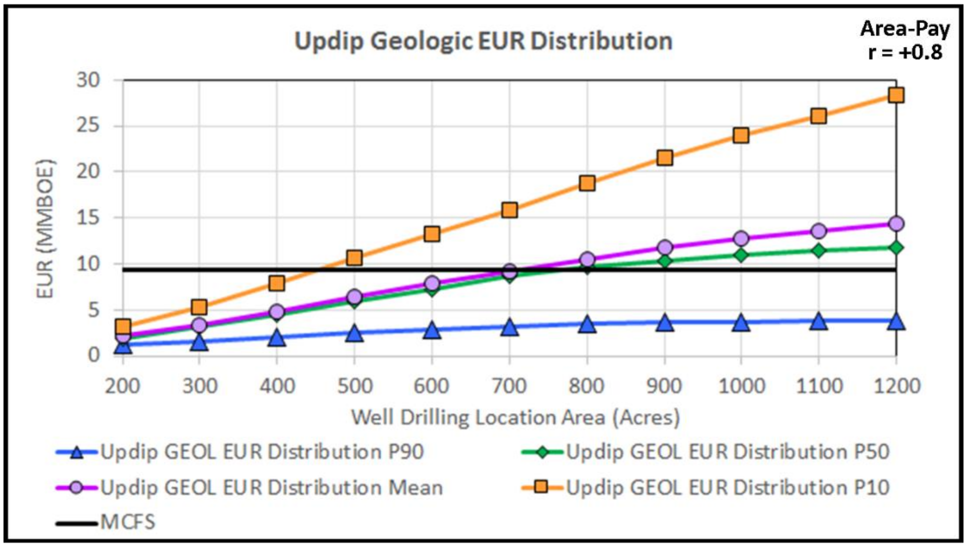

Figure 24 - Updip Geologic EUR distribution key percentiles and Mean EUR as a function of well drilling location.

Figure 24 shows for a well located at 400-500 acres, the orange P10 curve indicates there is about a 10% chance that a discovery updip of a dry hole will exceed MCFS (much smaller chance than if there is no correlation as shown in Figure 24).

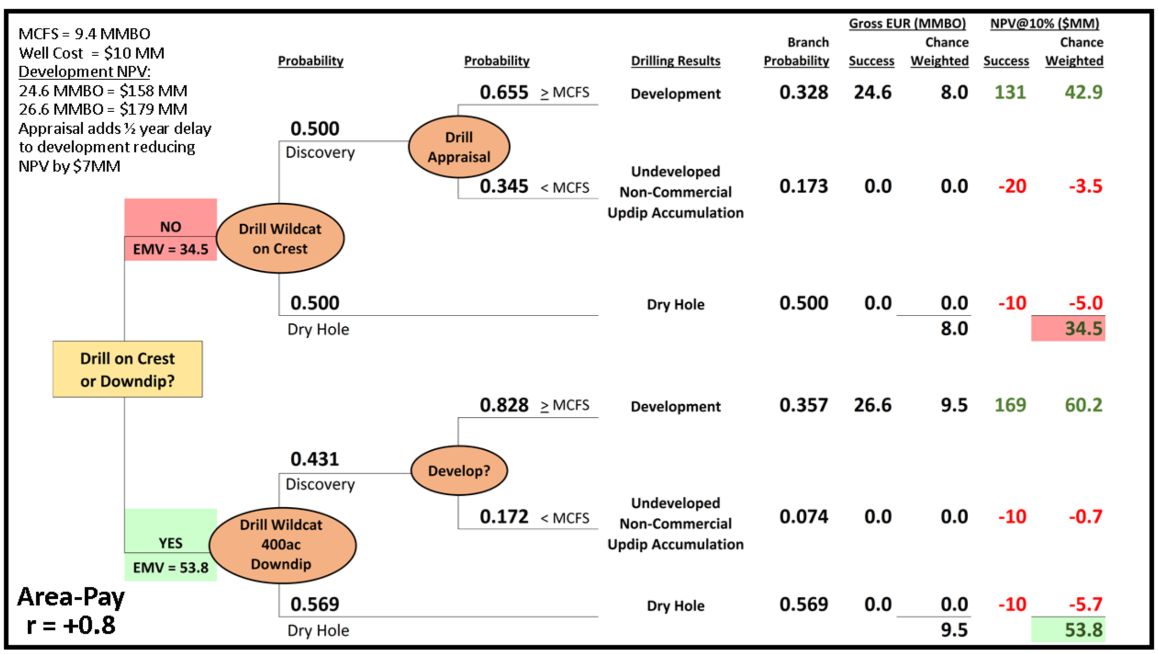

Figure 25 - Decision tree using the drilling well location at 400 acres with Area – Net Pay Correlation.

EMV for the correlated model of $53.8MM is 43% higher than the uncorrelated model in Figure 13 with a similar uplift versus the crestal well. The increased EMV is mainly due to the larger Commercial Mean EUR, but a larger Pmcfs(well) is also contributing.

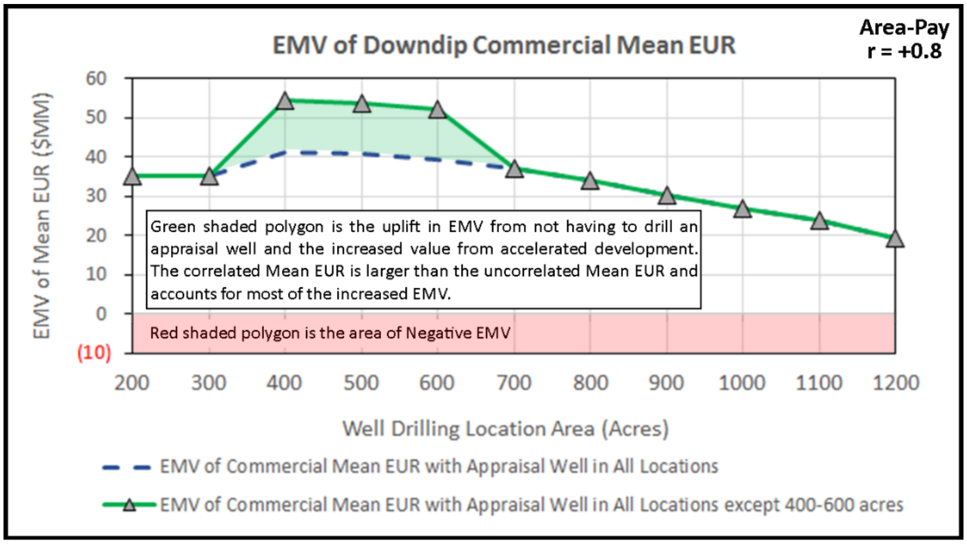

Figure 26 - Expected Monetary Value (EMV) as a function of well drilling location with Area – Net Pay Correlation.

Figure 26 presents the EMV with Area – Net Pay correlations and the other assumptions applied in Figure 14. Note at drilling well locations > 800 acres, the EMV is less than drilling on crest due to the negative impact for Pg adjustment to the well location (Figure 26).

Panel 3 Observations

Observations from the prospect evaluation presented in Panel 3 considering the impact of Area – Net Pay correlation for selecting a drilling well location include:

1) A positive Area – Net Pay correlation with r = +0.8 increased the Mean EUR by 15% and the EUR uncertainty expressed as the P10:P90 ratio by 60% relative to no correlation (Figure 15).

2) For a well drilled 400 acres downdip from crest with no Area – Net correlation, the Updip Distribution P01 EUR = 20 MMBO, while with a strong correlation the Updip Distribution P01 EUR = 11 MMBO. This large difference is because of the thinner correlated pay with decreasing oil column height and makes decision making relative to the updip attic potential easier after a downdip dry hole. (Figures 16 and Figure 17).

3) With no Area – Net Pay correlation, there is a 68% overlap of the Updip and Downdip EUR distributions (P100 to P32 of Downdip Distribution) making selection of an optimum downdip well location more difficult compared to the scenario with correlation when there

is only a 26% overlap of the distributions (P100 to P74) of Downdip Distribution (Figure 16 and Figure 17).

4) For the Downdip distribution given a discovery, the chance of exceeding MCFS approaches 100% faster with correlation because of the thicker correlated pay with increasing oil column height (Figure 18).

5) For the Updip distribution given a dry hole downdip, the chance of exceeding MCFS significantly reduces with correlation because of the thinner correlated pay with decreasing oil column height. For the prospect, a dry hole drilled at 400 acres will only have a 5% chance the Updip attic EUR will exceed MCFS, while there is a 21% in the case of no Area – Net Pay correlation (Figure 18).

6) The project EMV evaluated at a well location 400 acres downdip from crest has increased by $16.3MM which is a 43% increase relative to the evaluation with no correlation. The increased EMV is mainly due to the larger commercial Mean EUR, but a larger Pmcfs(well) is also contributing (Figure 25).

7) For drilling well locations greater than 800 acres, the EMV is less than drilling on crest due to the negative impact for Pg adjustment to the well location (Figure 26).

Conclusions

While other issues (e.g., seismic data quality, shallow drilling hazards, surface location, reservoir compartmentalization, complex traps, testing for oil and gas columns, block boundary, well cost) impact the downdip well location decision and the required number of appraisal wells — taking into account the Updip and Downdip chance of geologic and commercial success and the full range of EUR are critical for the decision maker to understand the benefits and risks of drilling at downdip locations.

The broad uncertainty of the input parameters and simulated output must always be taken into account. With these uncertainties in mind, there may not be a single "best" well location because of 1) risk tolerance of the decision makers , 2) different metrics to be taken into account and 3) impact of changes based on the input assumptions. With the additional insights provided here, more informed decisions can be made.

Drilling at a location where EMV is maximized – due to ability to eliminate an appraisal targeted downdip to confirm commerciality or targeted updip to chase potential left-behind resources – can be a winning strategy.