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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8404

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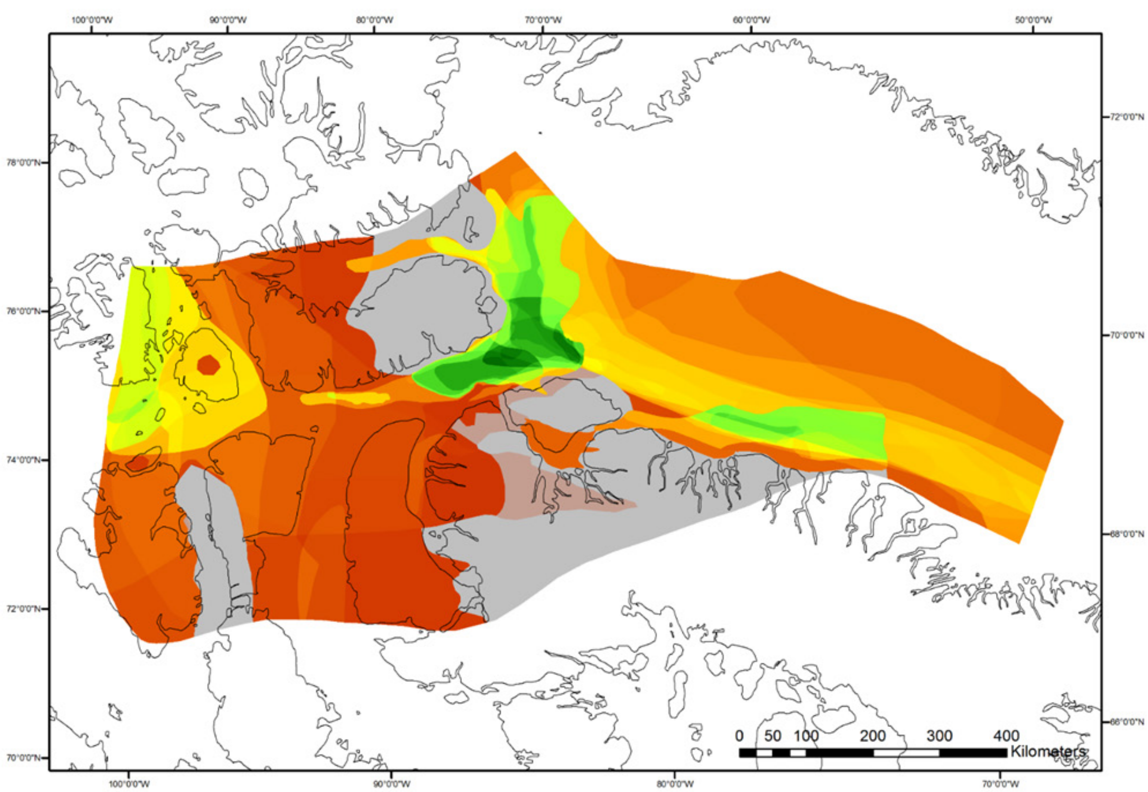
C.J. Lister, H.M. King, E.A. Atkinson, L.E. Kung, and R. Nairn



2018

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Publications in this series have not been edited; they are released as submitted by the author.

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1.0 INTRODUCTION

Natural Resources Canada (NRCan) has been tasked, under the Marine Conservation Targets (MCT) initiative announced in Budget 2016, with evaluating the petroleum resource potential for areas identified for protection as part of the Government of Canada's commitment to conserve 10% of its marine areas by 2020. These resource assessments are being conducted by the Geological Survey of Canada (GSC), within NRCan.

The timelines of the MCT initiative require a rapid yet rigorous approach to performing resource assessments. A qualitative approach is preferred, both for the time consideration and to maximize available information, especially in areas where data density is insufficient to support a more detailed quantitative assessment.

A major issue with qualitative assessment is its inherent subjectivity; this leads to issues with reproducibility and consistency. To mitigate these issues, the GSC has adapted a probabilistic assessment method from the petroleum industry using Esri®'s ArcGIS®. Qualitative assessments are best used to highlight regional potential and to help focus quantitative resource analysis.

Qualitative assessments in ArcGIS® provide a defensible, repeatable method of estimating resource potential. The key benefits of this method include:

- *consistency* – maps have the same normalised scale across different areas and multiple assessments can be combined and compared;
- *transparency* – final maps can be broken down into intermediate products and all maps contain metadata that provide justification and explanation of the inputs;
- *repeatability* – proper application of the chance of success *(COS)* scale reduces subjectivity and improves reproducibility.

The purpose of this report is to 1) explain to a non-technical audience what is meant by a probabilistic assessment; and 2) to illustrate for geoscientists how to execute a probabilistic petroleum resource assessment in ArcGIS®. We accomplish our first objective through a thought experiment to show the general application of this method (Section 2.0, see below). We then illustrate the steps taken to generate a progression of maps showing the petroleum potential of Lancaster Sound, Nunavut, from a specific petroleum play into a final combined map (Section 3.0).

2.0 A SIMPLIFIED APPROACH TO PROBABILISTIC ASSESSMENT (A THOUGHT EXPERIMENT)

In everyday life, you perform simple probabilistic assessments without even realizing it. For example, when you want to go on a trip, you check the forecast to pick the days with the best weather. The probabilistic assessment method can also be used for more complex problems.

The first step when approaching a complex problem is to break it down into manageable components. If the components act as independent variables, they can be assessed individually and then combined to make a qualitative prediction.

Probabilistic assessment is widely used throughout the petroleum industry, from new ventures through development. Delineating and understanding nuances within key petroleum systems elements (source, reservoir, trap, and seal) can take from days to years depending on the scale of the challenge, the amount of data available, and the potential capital being invested. To avoid the inherent complexity in petroleum systems analysis, while illustrating the concept of probabilistic assessment, consider the following thought experiment:

Sauvignon Sally's Vineyard has been foreclosed by the bank and you are considering buying it with the intention to produce and sell wine grapes -and turn a profit. You have limited time, money, and resources to analyse the opportunity, and you have to buy the land as is, without conditions.

For this thought experiment, we will assume that four independent variables influence the growth of grapes: (1) grape vine presence, (2) sufficient sunlight, (3) sufficient irrigation, and (4) soil condition. In order to have a productive and profitable vineyard, each variable must have a reasonable *"Chance Of Success"* (*COS*), where success is meeting a minimum adequate threshold for the variable, and these *COS* values must occur together over a large area.

The combined chance of success, *CCOS*, of four independent events occurring together is given by:

$$CCOS = COS_1 * COS_2 * COS_3 * COS_4 \qquad \text{(Equation 1)}$$

Simply put, this means that the *CCOS* is the product of all the individual *COS's*. For example, if each of the variables had an 80% COS over an area (i.e. $COS_1 = COS_2 = COS_3 = COS_4 = 0.8$), that area would have a *CCOS* of 40.96% (i.e. *0.8 x 0.8 x 0.8 x 0.8 x 100%*). A ~41% *CCOS* may seem intuitively low, but in many fields (such as petroleum exploration) a 41% *CCOS* is considered high, and very attractive for investment.

How do you determine the *COS* for each independent variable in the most objective way possible? The short answer is to use, analyze, and assess all available data. The following sections outline how to conduct a probabilistic assessment for Sauvignon Sally's Vineyard: understand the Chance of Success *(COS)* assessment scale (§2.1); define area of interest (§2.2); identify independent variables and assign *COS* (§2.3); combine *COS* maps to create a combined chance of success *(CCOS)* map (§2.4); and apply a subjective scale to account for real-world complexities (§2.4). The product of this method is a map which will help you decide whether or not to invest in this property.

2.1 Understand the Scale

Estimating *COS* is inherently subjective. In order to remain as consistent and objective as possible, the GSC Chance of Success scale (Figure 1) was created by modifying an existing risk matrix developed by Peter Rose (Rose, 2001) and republished in Rose & Associates's Lognormal Solutions Inc. training manuals. Understanding how to use this scale is paramount to the successful application of this method.

COS is chosen based on an assessed confidence in your data. Data caliber, data density, and data confirmation are the controlling factors in determining this confidence level. Data comes in many forms: they can be directly measured (e.g. the temperature of a cup of coffee as measured by a thermometer) or inferred from other information (e.g. the temperature of a cup of coffee as inferred by the steam rising from the cup). Directly measured data instills a higher confidence than data that have been inferred. The data you are considering must be relevant to what you are trying to study, e.g. if you are trying to measure the caffeine content of the coffee, knowing its temperature is irrelevant. Data caliber is a reflection of the quality of the data (either inferred or measured). Data density is a reflection of how much data you have to work with (either inferred or measured) and their spatial distribution. Data confirmation is a reflection of how much measured data you have to validate your interpretations and observations.

To put this in context, imagine you find some grapes in a greenhouse on the property. You realize you can use these grapes to figure out how flavourful your wine might be. Figure 2 illustrates how the data caliber can change your confidence level depending on whether you bring your grapes to a grape expert (Figure 2a) or simply bring them to your friend who has limited experience working at a vineyard (Figure 2b). The expert examination produces a more confident analysis in the quality of your grapes. Figure 3 illustrates how the data density and data confirmation affect your confidence levels. Figure 3a depicts the same situation as in Figure 2a where you have high data caliber, data density, and data confirmation resulting in high confidence. However, in Figure 3b the same expert is analyzing grapes that have started to go bad. Not only do you not have the full grape sample required to run a complete analysis, you also lack the quantity of grapes required to characterize their flavour.

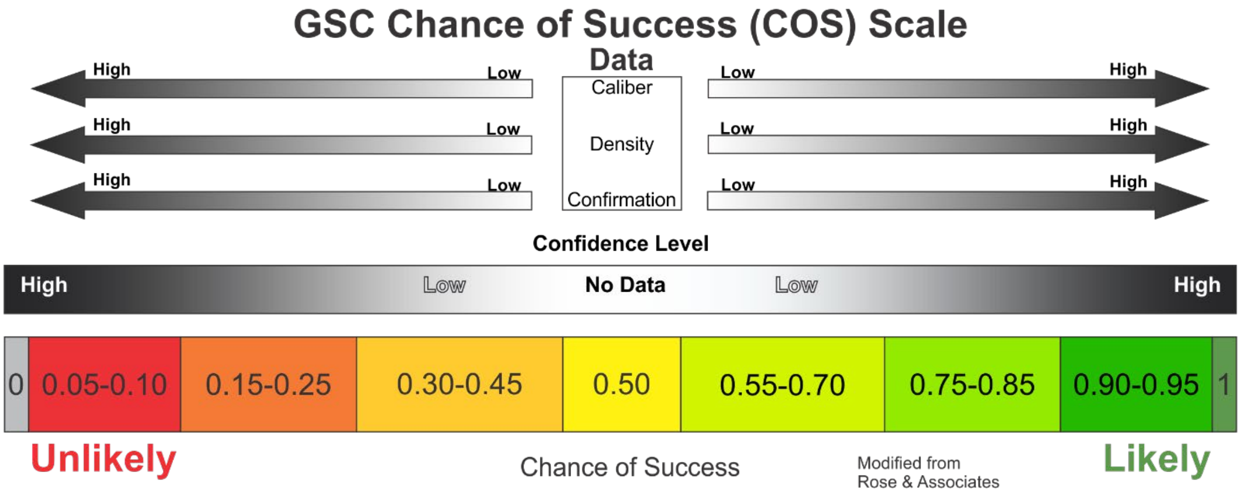

Figure 1. GSC Chance of Success Scale for assigning probabilities of success to individual variables (modified from Rose, 2001, p. 38). Success is defined as meeting an appropriate minimum threshold for the variable. Chance of Success values are chosen in increments of 0.05; 0 and 1 represent absolute certainty in an outcome. A wider range of *COS* values exist for lower confidence situations to encompass the larger uncertainty – for example, for low confidence positive information, you can pick from the range 0.55 to 0.7, compared to high confidence positive information where you would pick 0.90 or 0.95.

This is a simplification of what can be an extremely complex process, but it is meant to illustrate how the data that you have to work with will affect your confidence levels, and ultimately your final choice in a chance of success. This process can reduce subjectivity by filtering possible chances of success based on how confident you are in the data you have. Being in the correct confidence range and its related coloured *COS* box (Figure 1) is more impactful than choosing a specific number inside the box. Values in increments of 0.05 should be chosen because this assessment method does not have the precision required for greater detail. If you have no relevant data, you have no confidence to lean either positively or negatively and the chance of success is 0.50 (50%) or a coin toss. The impact of having no information on any of your four parameters would generate a *CCOS (0.5*0.5*0.5*0.5*100) = 6.25%.*

Now that you understand how to assign a chance of success using the scale (Figure 1), we can evaluate if it makes sense to purchase the vineyard. To do this, you must identify and assess what independent variables control grape yield, and their spatial distribution.

2.2 Define the Area of Interest *(AOI)*

Decide on the extent of the region you will evaluate. In Sauvignon Sally's Vineyard, the area of interest *(AOI)* is the area defined by the property boundaries (Figure 4). Unfortunately, it's winter and there is a heavy snow cover over the vineyard. It is therefore difficult to check any ground features for yourself, so your confidence levels may be lowered.

2.3 Identify Independent Variables and Assign *COS*

For the purpose of this report, we have simplified the grape growing process into the four independent variables mentioned above (vine presence, sufficient sunlight, sufficient irrigation, and soil condition). You need to determine how each of these four factors vary throughout the *AOI.* To do this, you need to assemble all relevant available data and understand how the data caliber, data density, and data confirmation affect your confidence level.

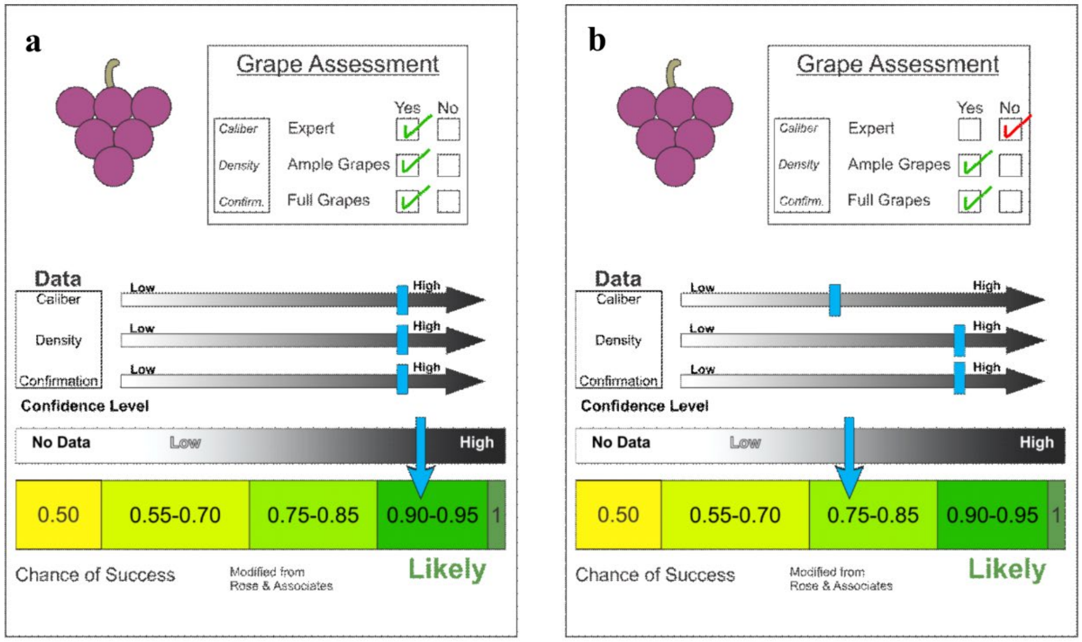

Figure 2. Grape assessment for wine flavour illustrated by two scenarios show how varying caliber [(a) expert examination vs. (b) layman examination] affects *COS*. The scale is shown on the positive end because the grapes had been previously confirmed to be tasty.

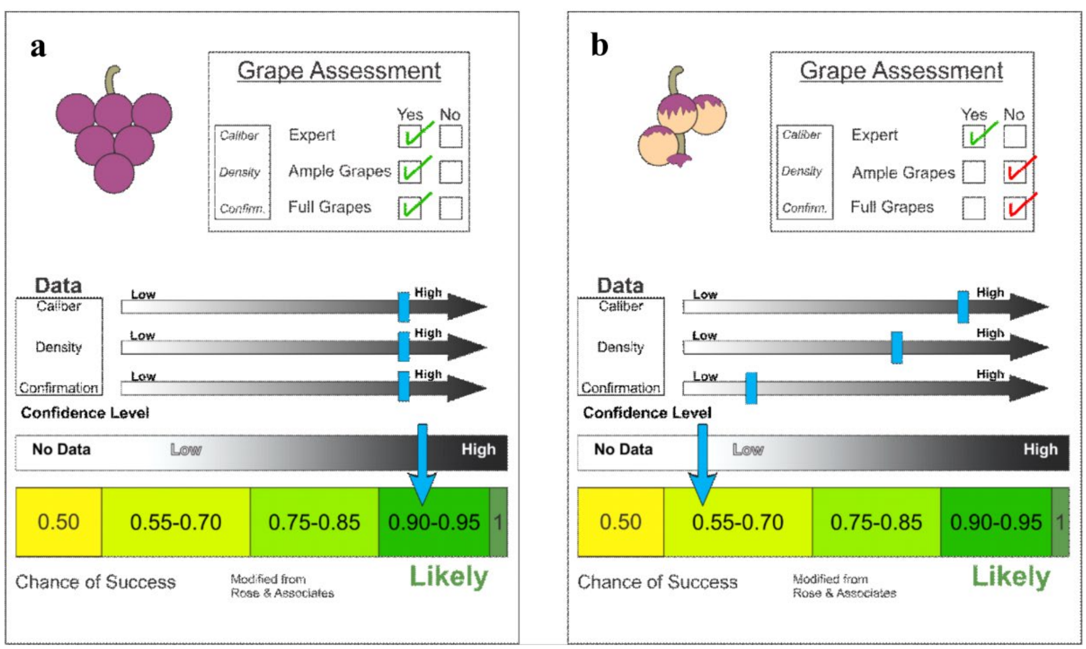

Figure 3. Grape assessment for wine flavour illustrated by two scenarios show how (a) varying quantity (number of grapes) and (b) control (whether you have entire grape to test) affects *COS*. The scale is shown on the positive end because the grapes had been previously confirmed to be tasty.

Figure 4. The defined area of interest *(AOI)*. The vineyard has been foreclosed on by the bank and is now for sale. The defined area of interest *(AOI)* is the snow-covered property's boundaries. The vineyard buildings (hatched) are located to the eastern side of the property. Major variables affecting vine growth must be identified and assessed within the whole area.

You have been given four maps to help assess the property (discussed below). Using the method described in §2.1, you can estimate the chance of success values for each of the variables across the property. Note that the building is always assigned a *COS* of zero.

Vine distribution: The vine distribution map (Figure 5a) shows three zones. There is a zone of reported good vine distribution over most of the property (light grey, Figure 5a). A neighbour reported that somewhere along the right edge of the property, they may have run low on vines (medium grey in Figure 5a). Near the building, there are plowed areas where vine presence is unlikely (dark grey, Figure 5a). For this variable, snow cover lowers our confidence over most areas. The zone of good vine distribution was given a positive, medium-confidence *COS* (green, Figure 5b); the zone which may have run low of vines was given a negative, low-confidence *COS* (orange, Figure 5b); the plowed area was given a negative but high-confidence *COS* (red, Figure 5b).

Sufficient Sunlight: The sufficient sunlight distribution map shows three zones. Most of the property sits in a zone of ample sunlight (light grey, Figure 6a). Some of the property is affected by the shadow of the building: an area of near-permanent shadow and an area with variable shadow depending on time of day (dark and medium grey, Figure 6a). Weather varies year to year, so sufficient sunlight for a certain crop year cannot have high confidence. The zone of ample sunlight was given a positive, medium-confidence chance of success (green, Figure 6b); the zone with variable shadow was given a negative, low-confidence chance of success (orange, Figure 6b); the zone with near-permanent shadow was given a negative, high-confidence chance of success (red, Figure 6b).

Soil Condition: The soil condition distribution map is the most complex (Figure 7a). Most of the property tested positively for good soil; however one sample may have been compromised lowering confidence. A cluster of samples in the lower corner tested negatively for good soil. Soil quality is uncertain in areas between the sample points; data can be extrapolated, but confidence decreases further from control points (i.e. data confirmation). The chance of success map shows high- to medium-confidence over the directly sampled areas, except for the compromised sample which was given a positive, low-confidence (light green but not visible, Figure 7b). Most areas between sample points have a positive, low-confidence because soils in the area are known to be good for growing grapes, but confidence is lower further away from the actual sample points due to increased uncertainty. An area of negative, low-confidence was interpreted around the high density, negative sample point. The transition between the bad soil in the lower corner and the good soil on the rest of the property is unknown; a band of no data confidence (yellow, Figure 7b) was interpreted on the map.

Sufficient Irrigation: The irrigation map shows two zones: a zone with a delineated sprinkler system and working pump (diagonal lines, Figure 8a) and an area where no sprinkler or pump are known (solid grey, Figure 8a). The sprinkler system and pump were installed professionally and were recently inspected. The corresponding *COS* map (green, Figure 8b) shows a positive, high-confidence zone in the areas where the irrigation system is known to be present. The area where no map or pump are known is considered to be no data (yellow, Figure 8b).

2.4 Combined Chance of Success *(CCOS)* Maps

Now that you have four maps illustrating chance of success for each variable controlling grape growth, it's easy to combine them to see how successful (or unsuccessful) the vineyard might be. Equation 1 shows all you have to do is multiply your individual *COS* maps together (this can be accomplished in ArcGIS®, discussed in §3). Figure 9 shows the resulting *CCOS* map. The *CCOS* map shows areas of mostly low to moderate potential (see Figure 9 for greater detail). Based on this assessment of the available data, it's unlikely you would want to buy this property.

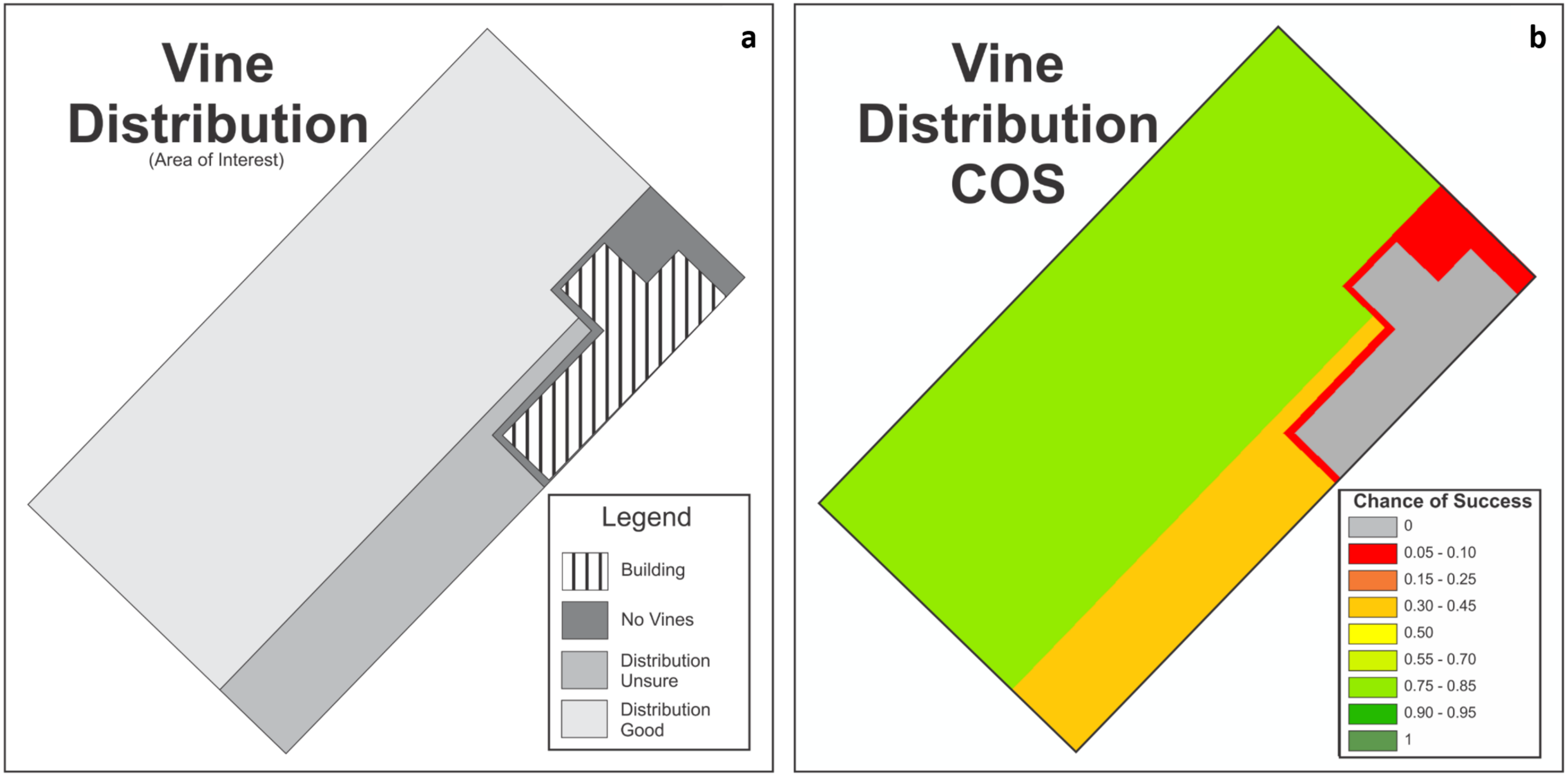

Figure 5. The vine distribution map (a) and the vine distribution *COS* map (b). a. This map shows three zones: good vine distribution (light grey), unsure distribution (medium grey), and unlikely vine presence (dark grey). b. Vine distribution *COS* map. Snow cover lowers our confidence over most areas. The zone of good vine distribution was given a positive, medium-confidence *COS* (green), the zone which may have run low of vines was given a negative, low-confidence *COS* (orange), and the plowed area was given a negative, high-confidence *COS* (red). The building has a chance of success of zero (grey).

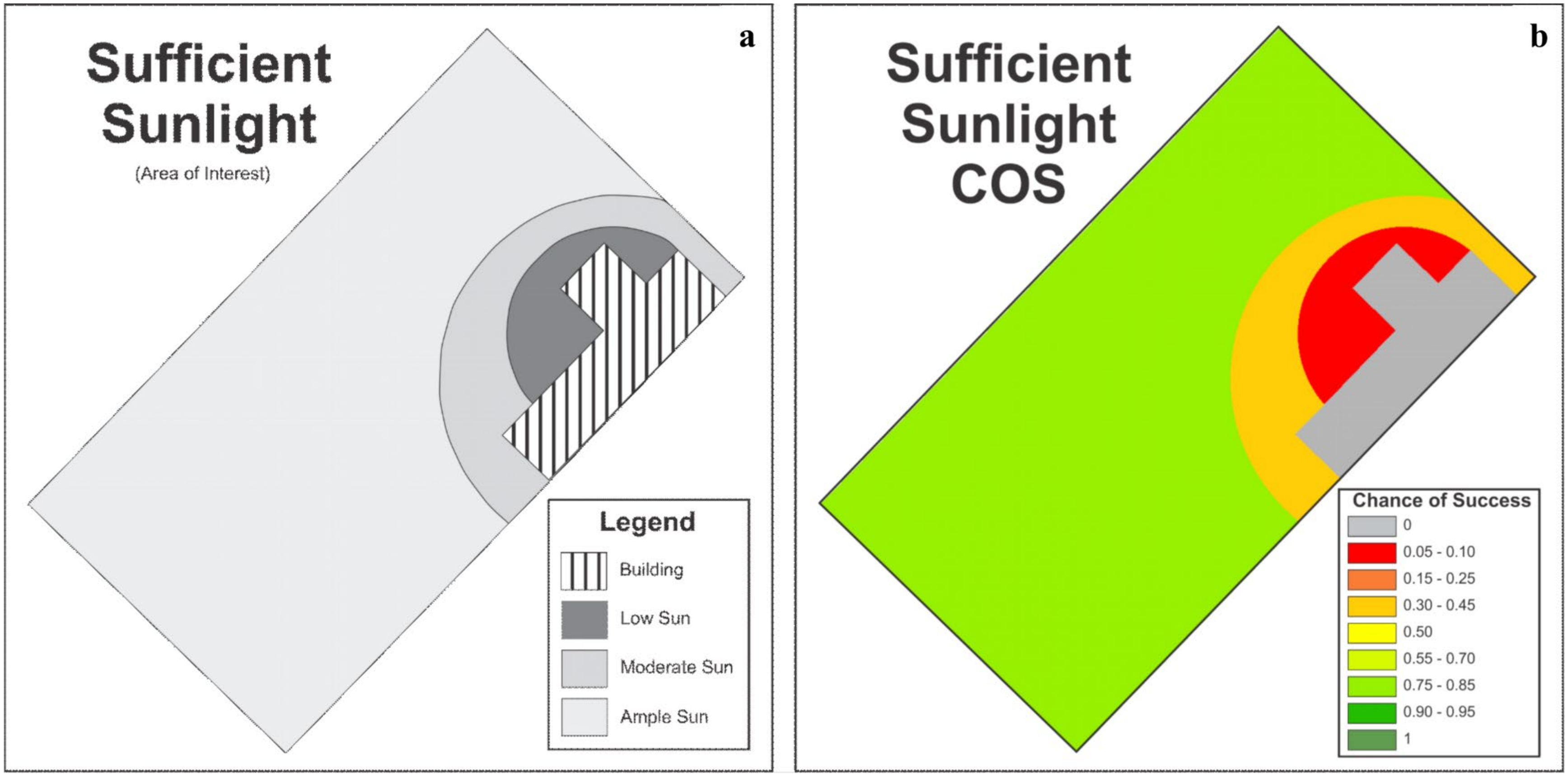

Figure 6. The sufficient sunlight distribution map (a) and the sufficient sunlight *COS* map (b). a. This map shows three zones: ample sunlight (light grey), moderate sun (medium grey), and low sun (dark grey). b. Sufficient sunlight *COS* map. The weather can be unpredictable so even areas with sufficient sunlight cannot have high confidence. The zone of ample sunlight was given a positive, medium-confidence chance of success (green); the zone with variable shadow was given a negative, low-confidence chance of success (orange); and the zone with near-permanent shadow was given a negative, high-confidence chance of success (red). The building has a chance of success of zero (grey).

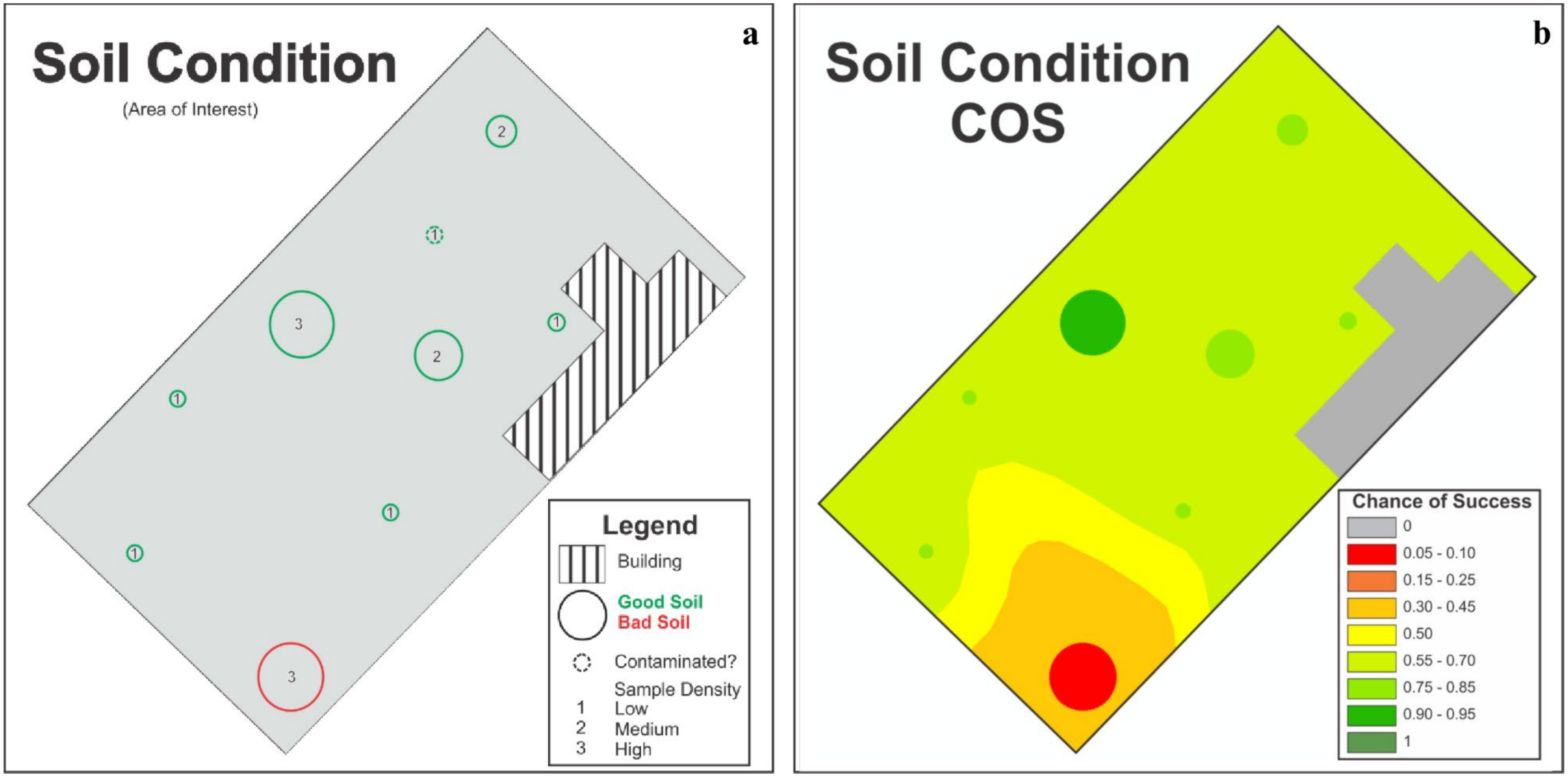

Figure 7. Soil condition distribution map (a) and soil condition *COS* map (b). a. Most of the property tested positively for good soil (green circles); however one sample may have been compromised (dotted green circle). A cluster of samples in the lower corner tested negatively for good soil (red circle). b. Soil condition *COS* map. Soil quality is uncertain areas between the sample points; data can be extrapolated, but confidence decreases further from control points. The chance of success map shows high- to medium- confidence over the directly sampled areas (darker greens), except for the contaminated sample which was given a positive, low-confidence (lightest green, has disappeared into the background). Most areas between sample points have a positive, low-confidence because soils in the area are known to be good for growing grapes. An area of negative, low-confidence (orange) was interpreted around the high density, negative sample point (red). The transition between the bad soil in the lower corner and the rest of the property is unknown so a band of no data (yellow) was interpreted on the map. The building has a chance of success of zero (grey).

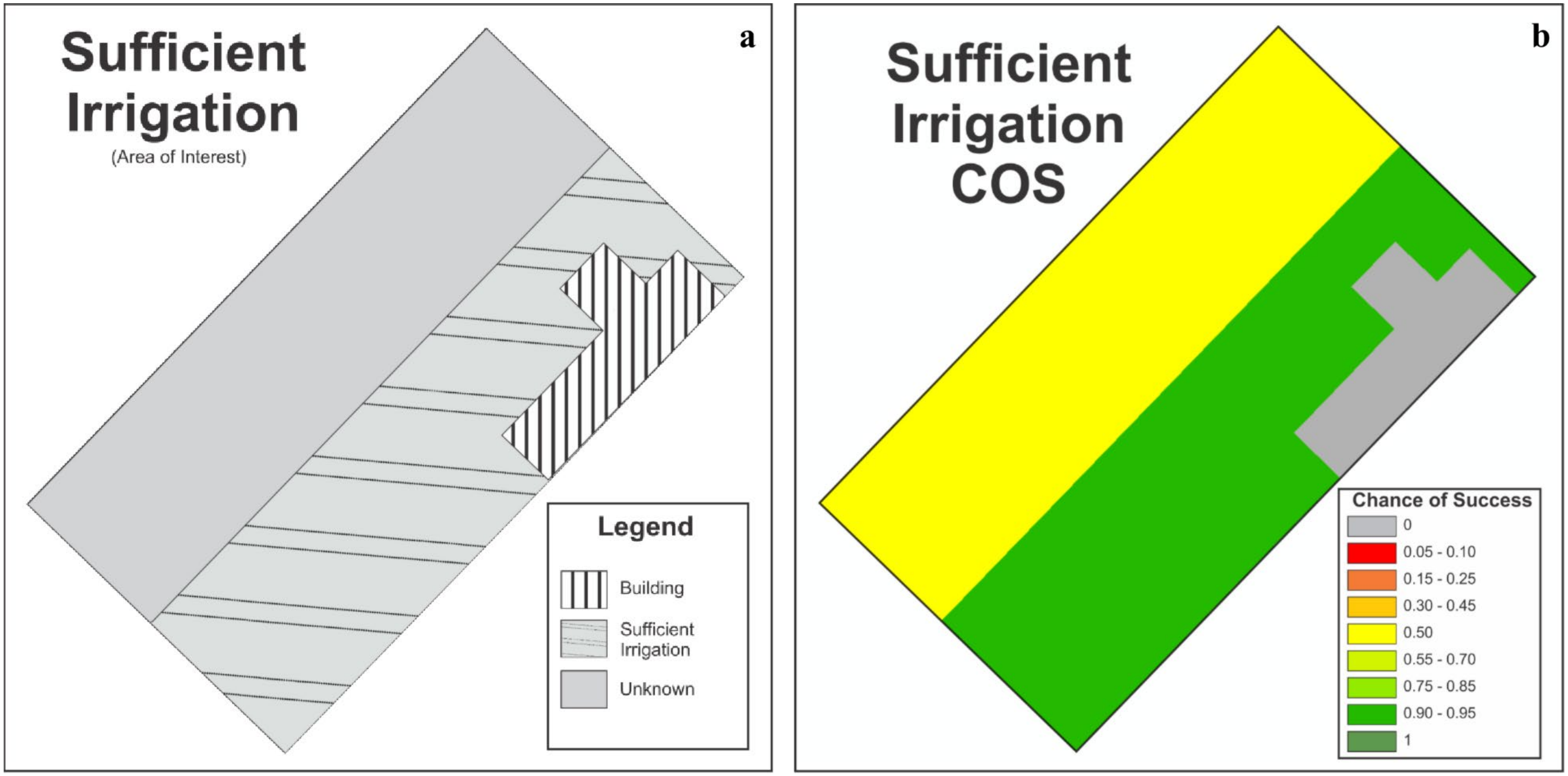

Figure 8. Sufficient irrigation distribution map (a) and corresponding *COS* map (b). a. This map shows two zones: a zone with a delineated sprinkler system and working pump (diagonal double lines) and an area where no map or pump are known (solid grey). The sprinkler system and pump were installed professionally and have been recently inspected. The corresponding *COS* map (b) shows a positive, high-confidence zone in the areas where the irrigation system is known to be present (dark green). The area where no map or pump are known is considered to be no data (yellow). The building has a chance of success of zero (grey).

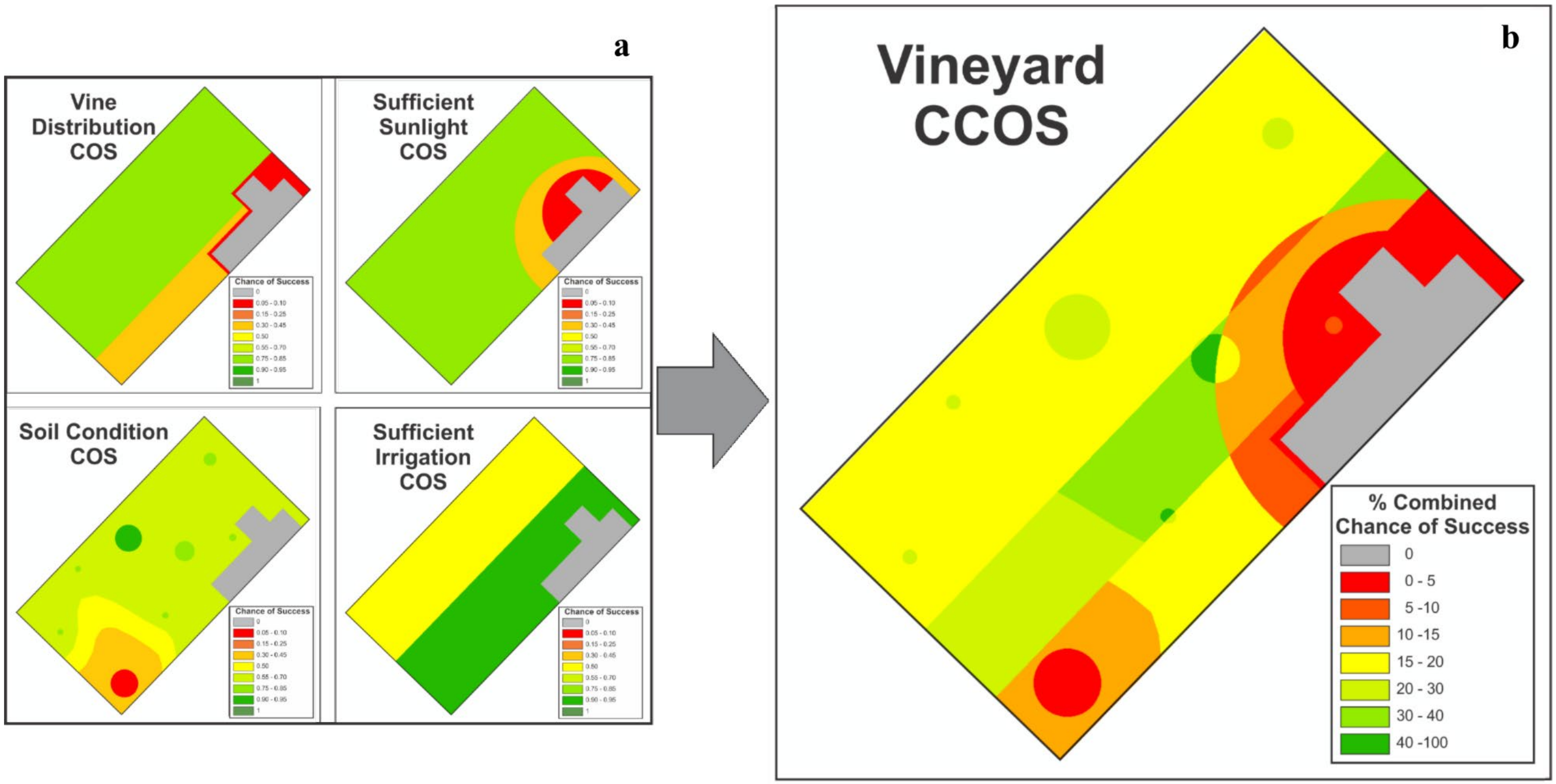

Figure 9. Individual *COS* inputs (a) which are multiplied together to create the Combined Chance of Success *(CCOS)* map (b). The *CCOS* map shows a limited area of higher potential (greens), but most of the potential is low to moderate (red, orange, yellow). As expected, the final map contains imprints from the original *COS* inputs (e.g. circular features related to the soil samples). Areas with low *COS* values remain low in the *CCOS* map, however areas with high *COS* values do not necessarily remain prospective. It's important to note that the yellow in the *CCOS* figure no longer represents no data confidence, it represents a combined chance of success between 15% and 20%. The *CCOS* indicates that the grape yield from the vineyard may not be sufficient to achieve profitability, as we assume that we need more than 20% combined chance of success over most of the area (a 20% *CCOS* is considered prospective in oil and gas exploration and we are assuming the same the vineyard).

Note that although the colours here are similar to the *COS* maps, the scales are different. The *COS* scale is based on the linear assessment scale in Figure 1, while the *CCOS* scale is non-linear and represents an overall prospectivity.

2.5 A Visual Demonstration on the Impact of New Data on a *CCOS* Map

At the current state of knowledge the vineyard is not prospective enough to purchase. However, two weeks after the first *CCOS* map was created, a second inspection by the irrigation expert revealed a second pump and a map of the sprinkler system covering the second half of the vineyard (Figure 10a). The sufficient irrigation *COS* map is now positive, high-confidence everywhere (green, Figure 10b). What effect will this have on your *CCOS* map, and your decision to buy? Let's see!

The *CCOS* map in Figure 11 is much more prospective. It now is mostly higher potential (greens) and is now a much more attractive purchase.

2.6 Apply a Subjective Scale to Estimate Volumetric Success

Congratulations! After purchasing Sauvignon Sally's vineyard based on your *CCOS* map (Figure 11b) you decide to open a bottle of champagne to celebrate. But before you can pop the cork there is a phone call from the grape expert you consulted earlier; he has some bad news. When you sent the grapes for flavour testing he had a suspicion that these grapes, although delicious, are better suited for a different climate. Of his own volition, he performed a series of tests to determine the provenance of these grapes and discovered that they grow best in Burgundy, France. What does this mean for the future of Sauvignon Sally's Vineyard?

The grape expert says that you can expect your grapes to grow to 25% to 75% of their ideal density (grapes per bunch). To see the effect of this new information, you apply a Global Scale Factor *(GSF)* over the entire vineyard *CCOS* map to generate Technical Chance of Success *(TCCOS)* maps (Figure 12, "technical" as in "having special and usually practical knowledge especially of a scientific subject", merriam-webster.com). The purpose of the *GSF* is to compare the probabilities of successful grape growth *(CCOS)* to the probability of successful, dense grape growth *(TCCOS)* in a subjective manner, i.e. to normalize your particular case to a global standard. In other words, although grapes may successfully grow on the property, can they grow densely enough to sustain a business? The results of these *TCCOS* maps are discouraging, as the subjective scalar reduces the likelihood of voluminous grape yield at the vineyard.

Good news! The grape expert called back the next day and says that further testing shows the grapes will grow to 75% of their ideal density. After the multiplier of 0.75 is applied, the *TCCOS* map remains positive (Figure 12b).

Probabilistic assessment is a powerful tool; it can be used to delineate prospective areas from non-prospective areas. Maps and associated *COS* values can be updated when new data becomes available. ArcGIS® is a powerful software package that we recommend for this type of probabilistic assessment; the following section (§3) will explain the process through which chance of success maps can be generated in ArcGIS®.

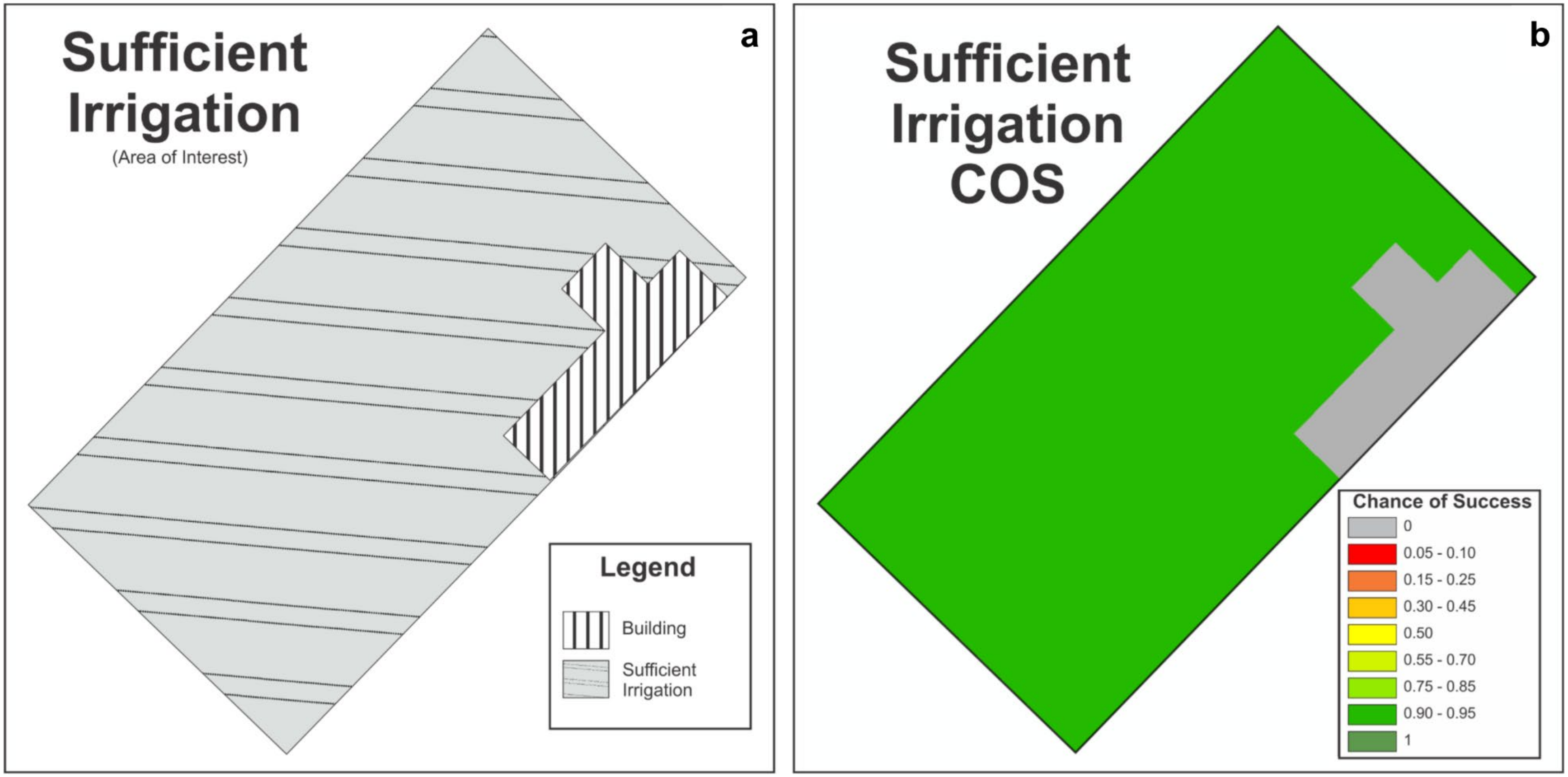

Figure 10. Updated sufficient irrigation distribution map (a) and the corresponding *COS* map (b). a. An updated sufficient irrigation distribution map showing only a zone with a delineated sprinkler system and working pump (diagonal double lines); b. The corresponding *COS* map shows a positive, high-confidence zone in the areas where the irrigation system is known to be present (dark green). The building has a chance of success of zero (grey).

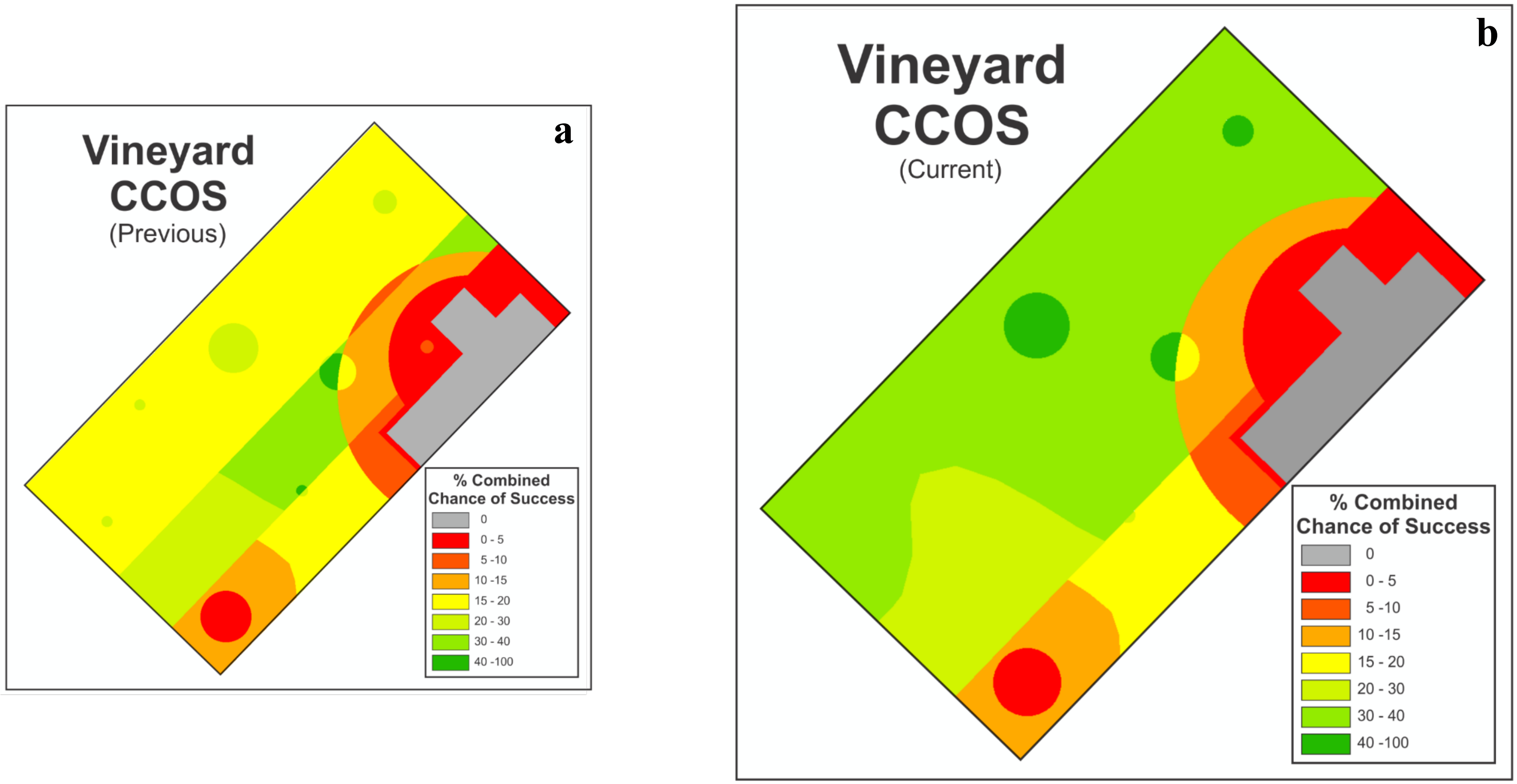

Figure 11. Old *CCOS* map (a) vs. updated *CCOS* map (b). The new *CCOS* map shows a greater area of higher potential (greens) and a lesser area of low to moderate potential (red, orange, yellow). It's important to note that the yellow in the *CCOS* figure no longer represents no data. The updated *CCOS* map (b) indicates that the grape yield from the vineyard might be sufficient for profitability (more greens).

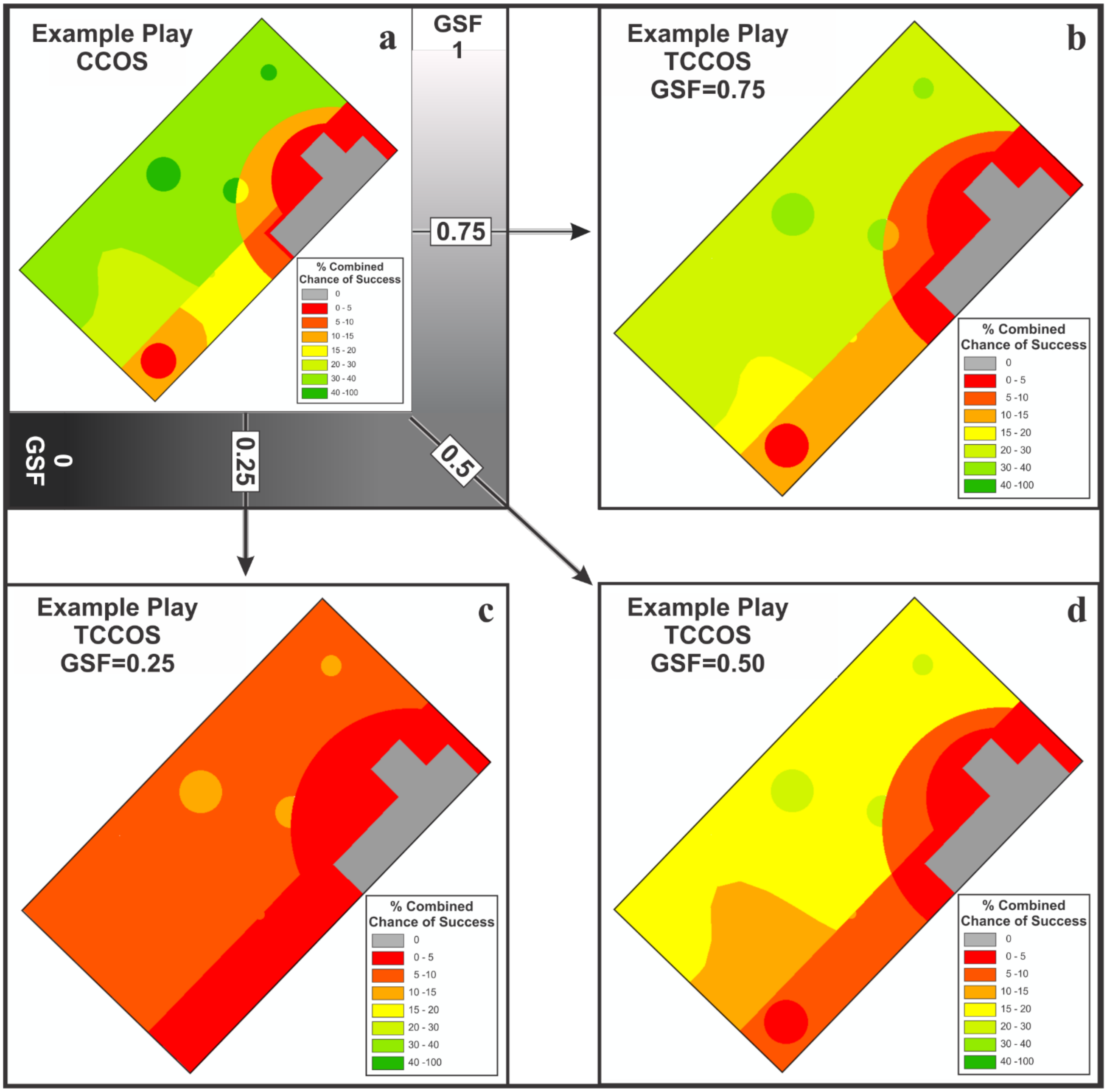

Figure 12. How a *CCOS* map (a) changes when the *GSF* is varied to produce Technical Combined Chance of Success *(TCCOS)* maps (b-d). The purpose of the *GSF* is to compare the probabilities of successful grape growth *(CCOS)* to the probability of successful, dense grape growth *(TCCOS)* in a subjective manner where judgment is used to estimate what this scaling factor should be. This figure shows how decreasing values of a *GSF* produce decreasingly prospective maps. The growth factor of 75% (*GSF* = 0.75, b) represents what the grape expert found to be most appropriate for the climate.

3.0 ArcGIS® AS A TOOL FOR PROBABILISTIC ASSESSMENT (PETROLEUM SYSTEMS EXAMPLE)

The previous section used a thought experiment to illustrate the general procedure when performing a probabilistic assessment using our qualitative methodology. To summarize, chance of success (COS) for a variable is chosen based on an assessed confidence in your data. Data caliber, data density, and data confirmation are the key factors in determining this confidence level and *COS* is chosen from the scale shown in Figure 1. *COS* maps for play element variables are multiplied together to create combined chance of success *(CCOS)* maps. You can apply a scaling factor to the *CCOS* map to generate a *TCCOS* map.

This section will walk through the process of creating chance of success maps in ArcGIS® (Figure 13). Specifically, we will show how we used ArcGIS® to produce qualitative (conventional) petroleum potential maps, but this method can be modified to assess any system containing independent variables. Atkinson et al. (2017), *Qualitative Assessment of the Petroleum Potential in Lancaster Sound Region*, will be referenced as a geologic example of qualitative probabilistic assessment. However, Figure 1 of Atkinson et al. (2017) did not use ArcGIS® and an explicit *CCOS* method; at the time of preparation, the authors did not have the time nor resources to apply this method. The method used by Atkinson et al. (2017) was based on their previous professional experience with *CCOS* (but not this method explicitly) to generate a qualitative map. We have reassessed this area using the *CCOS* method and will use the results to illustrate the process in ArcGIS®.

3.1 Why ArcGIS®?

Although probabilistic assessment using simple tools such as mylar and markers is possible, in the modern world, software such as ArcGIS® can make the process more precise and dynamic. Assessments are performed over geographic regions, so it is logical to use a widely available GIS tool that can perform math on georeferenced data sets. The version of ArcGIS® at the time of this work is Esri 2018. ArcGIS® Desktop: Release 10.2.2 Redlands, CA: Environmental Systems Research Institute (ArcGIS®). Similar workflows could be developed in other Geographic Information Systems software. A basic understanding of ArcGIS® terminology is assumed throughout this discussion.

3.2 Define Area of Interest *(AOI)*

Create a new polygon feature class and define the limits of your *AOI* (more detail can be found in Appendix B). The *AOI* for Lancaster Sound was determined by an international boundary to the east and geologic boundaries to the north and west; the southern boundary was arbitrarily chosen to optimize the assessment area (Figure 14).

3.3 Identify Variables and Assign *COS*

Copy the *AOI* polygon for each element in every play as needed. Make copies of this polygon for every play element required. In the attributes table, add two new fields for each play element: a description field and a value field. It is best practice to name them to reflect the variable being assessed (e.g. if soil condition is being assessed the columns would be labeled *COS_Soil*, and *Soil_Description* respectively). See Appendix B for more detail.

GSC Qualitative Probabilistic Assessment Flowchart for ArcGIS®.

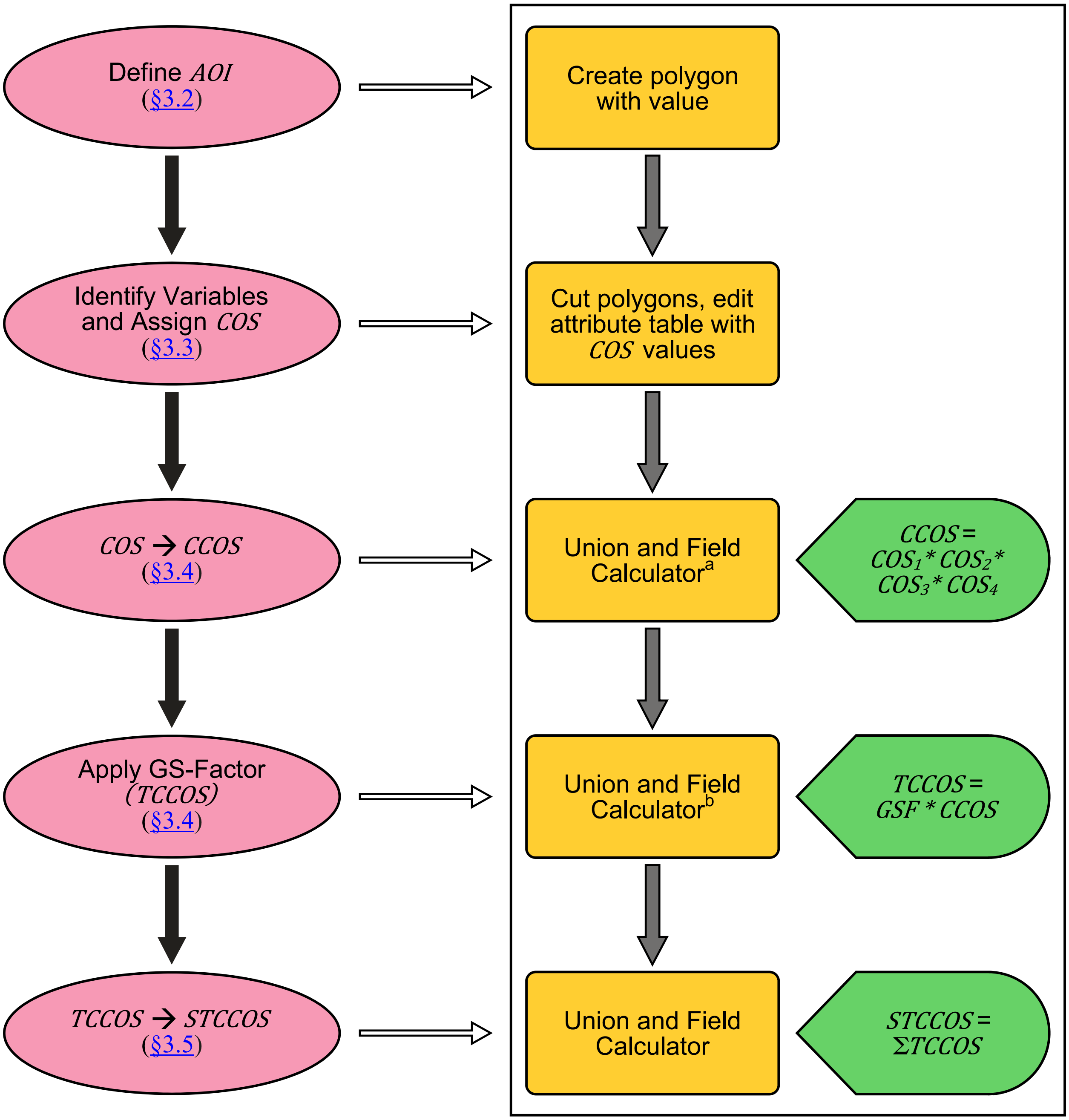

Figure 13. Flowchart illustrating the process to create *COS*, *CCOS*, *TCCOS*, and *STCCOS* maps in ArcGIS®.
[a, b] Models have been created to streamline these processes (see procedure for creating these calculators in Appendix C).

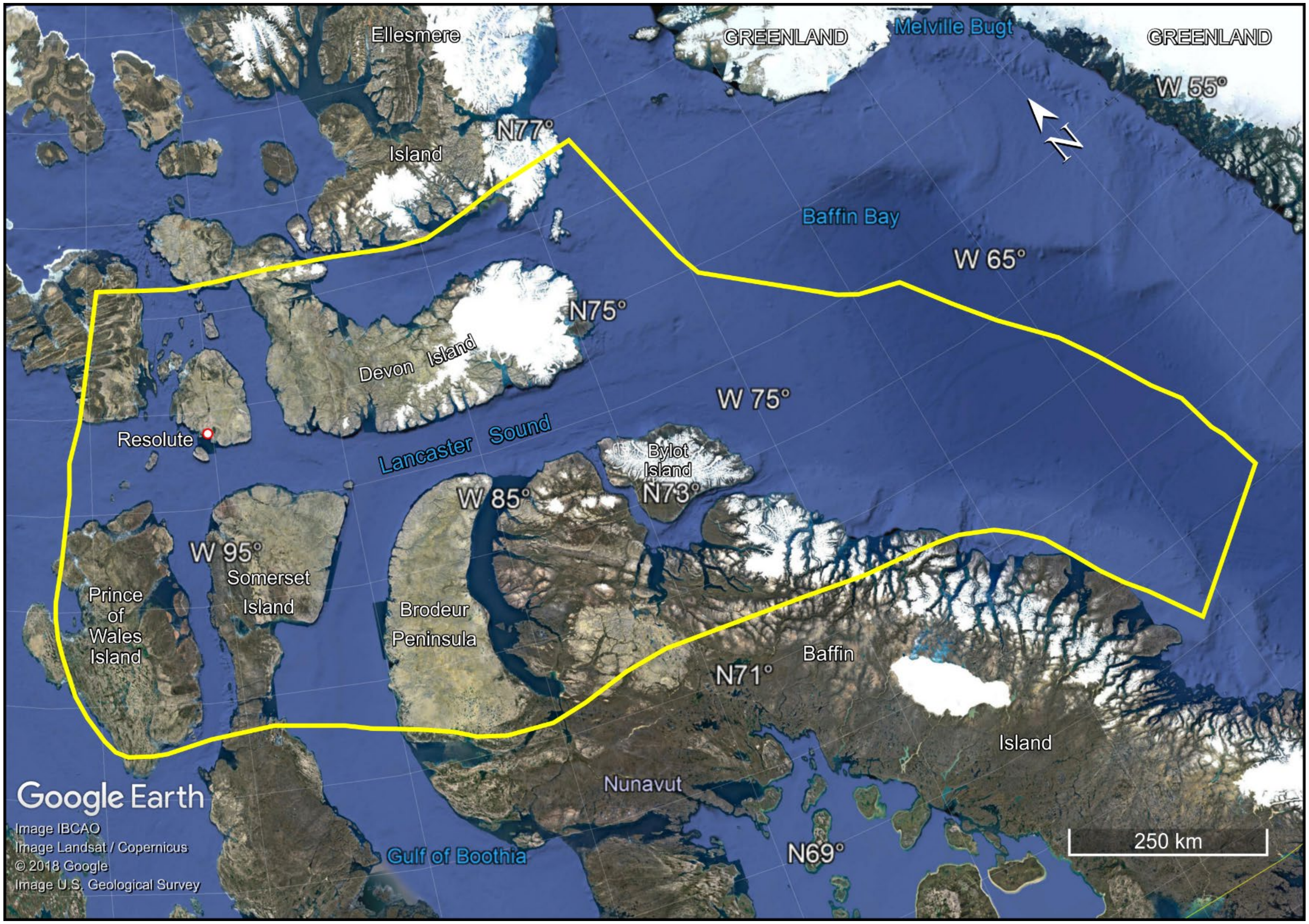

Figure 14. Lancaster Sound study area (outlined in yellow, *modified from* Atkinson et al., 2017).

When assessing a variable, divide the *AOI* into polygons based on similar data caliber, data density, and data confirmation for each play element (source, reservoir, trap, and seal). In areas between collected data points, you must use your knowledge and insight to infer what is happening (e.g. Figure 7, soil condition, bottom corner); this lowers your overall confidence, but it is essential when creating a regional assessment. In the world of petroleum exploration, there is an accepted range of 4-6 independent variables: source, migration, reservoir presence, reservoir quality, trap (or closure), and seal (see Appendix A). The hydrocarbon deposits or pools that result from a similar geologic history and interaction of these variables is considered a play. The GSC assessment method focuses on four independent variables per play: source (including migration), reservoir (including presence and quality), trap, and seal. Petroleum system analysis can become complex and detail oriented and basin models help elucidate their complex interactions. When assessing petroleum system elements, the goal is to understand their depositional environments, lithologies, stratigraphic position, geographic distribution, and the timing of relevant processes. Confidence of your assessment for each petroleum system element is directly proportional to the caliber, density, and confirmation of available data.

Source

Source rock analysis is done to determine what, if any, rocks could generate hydrocarbons. The presence of a generating (working) source rock is the most important factor in a petroleum system. Generally, a confident analysis would require Total Organic Carbon (TOC) values and more specific pyrolysis data (i.e. RockEval). Vitrinite reflectance would help determine thermal maturity. Basin modelling can predict the timing of maturation relative to the formation of other petroleum system elements.

The source rock for the example play in Lancaster Sound (Figure 15a) was assessed based on the data available: previously published onshore field data extrapolated offshore, seismic and seismic derived indicators, slick-like features, video of the Scott Inlet oil seep, and analog data (see Atkinson et al., 2017, their Appendix 2). The majority of the play area is positive for source presence and migration (greens in Figure 15a), but confidence varies based on caliber, density, and confirmation of source indicators. Low confidence (lightest green) exists in areas with low density and caliber of source indicators (low quantity of slick-like features in Atkinson et al., 2017, Figure 3); medium confidence (medium green) exists where there is higher density and caliber of source indicators (combination of more slick-like features as well as seismic direct hydrocarbon indicators and proximity to known petroleum seeps, in Atkinson et al., 2017, Figure 3); high confidence (dark green) exists over areas with good caliber and confirmation (i.e. confirmed seeps in Buchan Gulf and Scott Inlet, in Atkinson et al., 2017, Figure 3).

Reservoir

Reservoir analysis is key to determine where geologic units exist that allow the free movement of petroleum and space for the petroleum to accumulate. Confident reservoir analysis requires knowledge of porosity, permeability, water saturation, and reservoir pressure.

Reservoir for the example play in Lancaster Sound (Figure 15b) was assessed based on onshore outcrop, environment of deposition, seismic interpretations based on the work of Brent et al. (2013), and summaries of previous work found in Atkinson et al., 2017 (their Appendix 2). Although there is relatively dense seismic coverage in Lancaster Sound, there are limited tested data for reservoir parameters such as exposed Cretaceous sandstones are found in a graben on Bylot Island (Atkinson et al., Figure 3). Due to the limited data caliber, density, and confirmation, there is low, positive confidence of reservoir presence in the vicinity of Lancaster Sound (light green, Figure 15b). Reservoir *COS* becomes increasingly negative further outboard (orange to red, Figure 15b) as confidence increases due to knowledge of the depositional environment and tectonic setting (see Atkinson et al., 2017). The yellow area in the north of the map was assigned to be a no data confidence area for reservoir. A high quality reservoir interval becomes more prospective when its geometry becomes favourable to retain hydrocarbons (usually through a structural or stratigraphic variation).

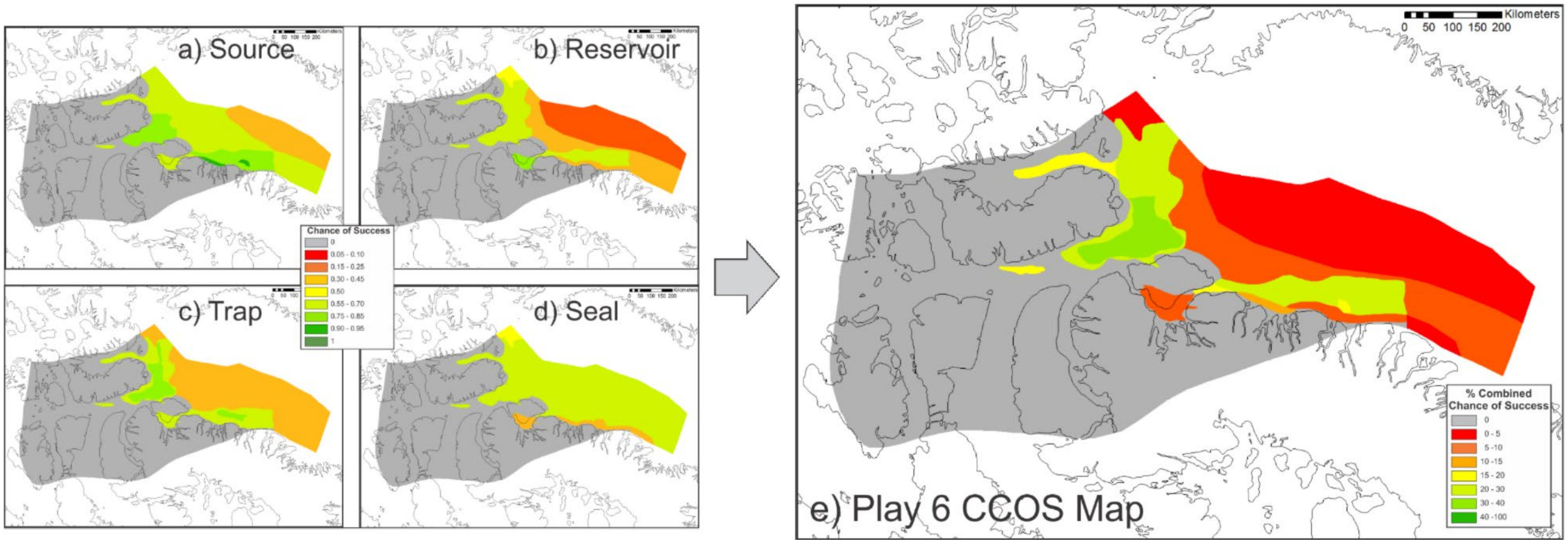

Figure 15. Four petroleum system element input Chance of Success *(COS)* maps (a-d) multiplied to create a Combined Chance of Success *(CCOS)* map (e). The *CCOS* map (e) shows petroleum potential on a play level. Note that the colours are the same for all maps, but the scales are different for *COS* and *CCOS* maps. *CCOS* values no longer reflect the confidence scale (Figure 1) but represent the combined chance of success for all the play elements. The *CCOS* map still represents a mathematically valid chance of success; however, values that are considered prospective are much lower than for individual elements due to the combination. In general, reds reflect lower prospectivity while greens reflect higher prospectivity. See §3.4.

Trap

Trap analysis involves identifying areas that have geometries (structural or stratigraphic) favourable for accumulating hydrocarbons. Trap presence can be inferred from the geologic and tectonic history of the region. However, confidence increases with confirmation from available seismic and well data.

Traps in the example play for Lancaster Sound were assessed mainly with seismic data, previously published work, collaboration with GSC area experts and the incorporation of the regional tectonic history (see Atkinson et al., 2017). Areas that have positive *COS* (greens in Figure 15c) were mapped, but have low to medium confidence because they were based on relatively low to medium density 2D seismic. Areas that have negative *COS* are low confidence (orange in Figure 15c) because of low seismic density and/or poor or absent imaging of traps. The presence of an appropriate geometry to focus hydrocarbons still requires a seal to ensure containment.

Seal

Seal analysis determines if there is sufficient impermeable rock to contain hydrocarbon in the reservoir/trap configuration. This is accomplished by understanding depositional environment, tectonic history, and lithology of the unit. The sealing capacity of a unit is controlled by a combination of its lithology, permeability, pressure, and thickness.

Seal in the example play for Lancaster Sound was assessed for presence and lithology using the interpreted paleo-environment and limited well data, and for thickness using seismic (see Atkinson et al., 2017). Confidence was low across the study area due to limited data confirmation. Figure 15d shows positive, low confidence over most of the play (light green). Near the seeps, seal confidence is negative and low (orange, Figure 15d) because there is recorded hydrocarbon leakage; however, this does not necessarily imply seal failure. The yellow area in the north of the map was assigned to be a no data area for seal.

After assessing the four petroleum systems elements for the example Lancaster Sound play, the four ArcGIS® layers are combined into a play map *(CCOS*, Figure 15e).

3.4 Combine *COS* Maps to Create Combined Chance of Success *(CCOS)* and Technical Combined Chance of Success *(TCCOS)* Maps

The four *COS* maps (source, reservoir, trap, seal) are multiplied together (Equation 1) in ArcGIS® using the Union tool (Figure 13) to determine the Combined Chance of Success for the whole play. A simple calculation in Field Calculator using Equation 1 will generate *CCOS* values for the play (see Appendix C for more detail).

The resulting *CCOS* map is coloured using a different scale than the *COS* maps. This is necessary since *CCOS* values no longer reflect the confidence scale (Figure 1) but represent the combined chance of success for all the play elements. The *CCOS* map still represents a mathematically valid chance of success; however, values that are considered prospective are much lower than for individual elements due to the combination. For example, a value of 0.2 would be considered prospective at the play level *(CCOS)*, but would represent a negative, medium-confidence value at the system element level *(COS)*. The *CCOS* map for Play 6 in Lancaster Sound (Figure 15e) shows high and moderate potential (yellows and greens) near the mouth of Lancaster Sound and lowering potential (oranges and reds) further outboard. This process is repeated for every play in the region (Lancaster Sound examples, Figure 16).

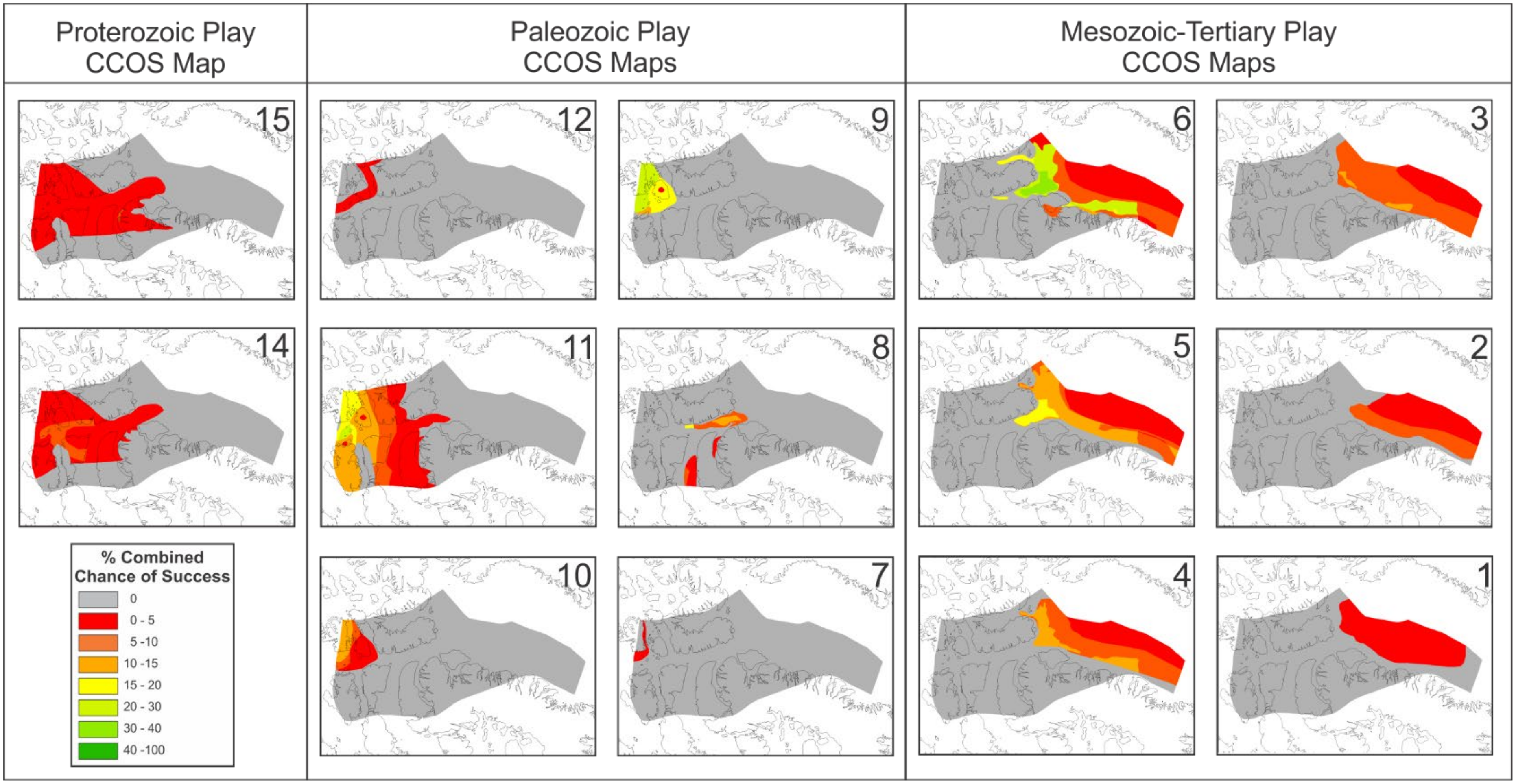

Figure 16. Combined Chance of Success *(CCOS)* maps generated in ArcGIS® for all 14 plays in the Lancaster Sound study area. Play numbers correspond to those reported in Table 1 of Atkinson et al., 2017.

So far, our combined map tells us about the chance of success, but does not address relative potential volumes of hydrocarbon accumulation. A petroleum play that has a high chance of successfully producing only small pools is much less enticing than a play that has a moderate chance of producing very large pools. In order to compare, and subsequently stack plays we therefore need to consider chance of voluminous success, not just chance of success. We must compare "apples" to "apples" (or, more aptly, "grapes" to "grapes"). To accomplish this, we scale each play against a (subjective) global standard.

In our vineyard example, we introduced the Global Scale Factor *(GSF)*. The size of bunches of grapes in Burgundy were the "Global Standard" of 100%, and our local opportunity was subjectively scaled by a factor of 0.75 (or 75%) of that size. For petroleum plays, we must also define a "Global Standard": plays capable of producing a giant field (> 500 MMBOE (~8 x 10^7 m^3)) and having at least three good opportunities to produce large fields (> 300 MMBOE (~5 x 10^7 m^3)), are judged to meet the 1.0 (or 100%) standard, and plays producing smaller opportunities are proportionately normalized with a lower percentage. In making these judgements, we are estimating what is "typical" (P50) for a play, not the extreme upside. Analog plays from areas with similar geology and geological history in other places in the world are very helpful in making these estimates.

The *GSF* estimate is subjective because it is part of a qualitative mapping process. It is based on geoscientific knowledge and experience. If the *GSFs* were calculated more formally, the process would take much longer (e.g. statistical analysis, basin analog studies, prospect studies, etc.) and may become as time consuming as the quantitative process normally used for resource assessment. A *GSF* is estimated for every play in the region (Atkinson et al., 2017, their Table 1) and the *CCOS* map is multiplied by the *GSF* to produce a normalized Technical Combined Chance of Success *(TCCOS)* map for every play (Figure 17).

3.5 Multiple *TCCOS* maps over an area? The Stacked Technical Combined Chance of Success *(STCCOS)* and Maximum Technical Combined Chance of Success *(MTCCOS)* Maps

In the Vineyard example, there was only one play. However, in the real world (e.g. Lancaster Sound) it is possible to have multiple plays that exist over the same area, overlapping (or stacking) with one another. It is simple to represent each play by individual *CCOS* and *TCCOS* maps (Figures 16 and 17), but a single combined map is a more effective communication tool.

We have created *TCCOS* maps for each play that combine the geologic chance of success with a relative volumetric scalar (the *GSF*) for each play; they can now be added to create a Stacked Technical Combined Chance of Success Map *(STCCOS)* which captures the petroleum potential from all plays in the region (Figure 18). The final map is displayed with a colour bar where two large plays (or several smaller plays stacked in the same location) have very high potential (dark green).

In this method, a series of lower volume potential stacked plays can combine to form a map area with higher potential. On our final main petroleum potential map *(STCCOS*, Figure 18), it is impossible to distinguish an area with few stacked high volume potential plays from an area with many stacked lower volume potential plays. Many smaller plays may still be attractive, as stacked plays can be co-produced making a quite successful field. However, in order to highlight the very best high volume opportunities, a second map can be produced. Maximum *TCCOS (MTCCOS)* analyses all the input *TCCOS* maps and plots only the highest value found in an area, using the same scale as the *TCCOS* maps (Figure 19). This is done in ArcGIS® using the method outlined in Appendix B.

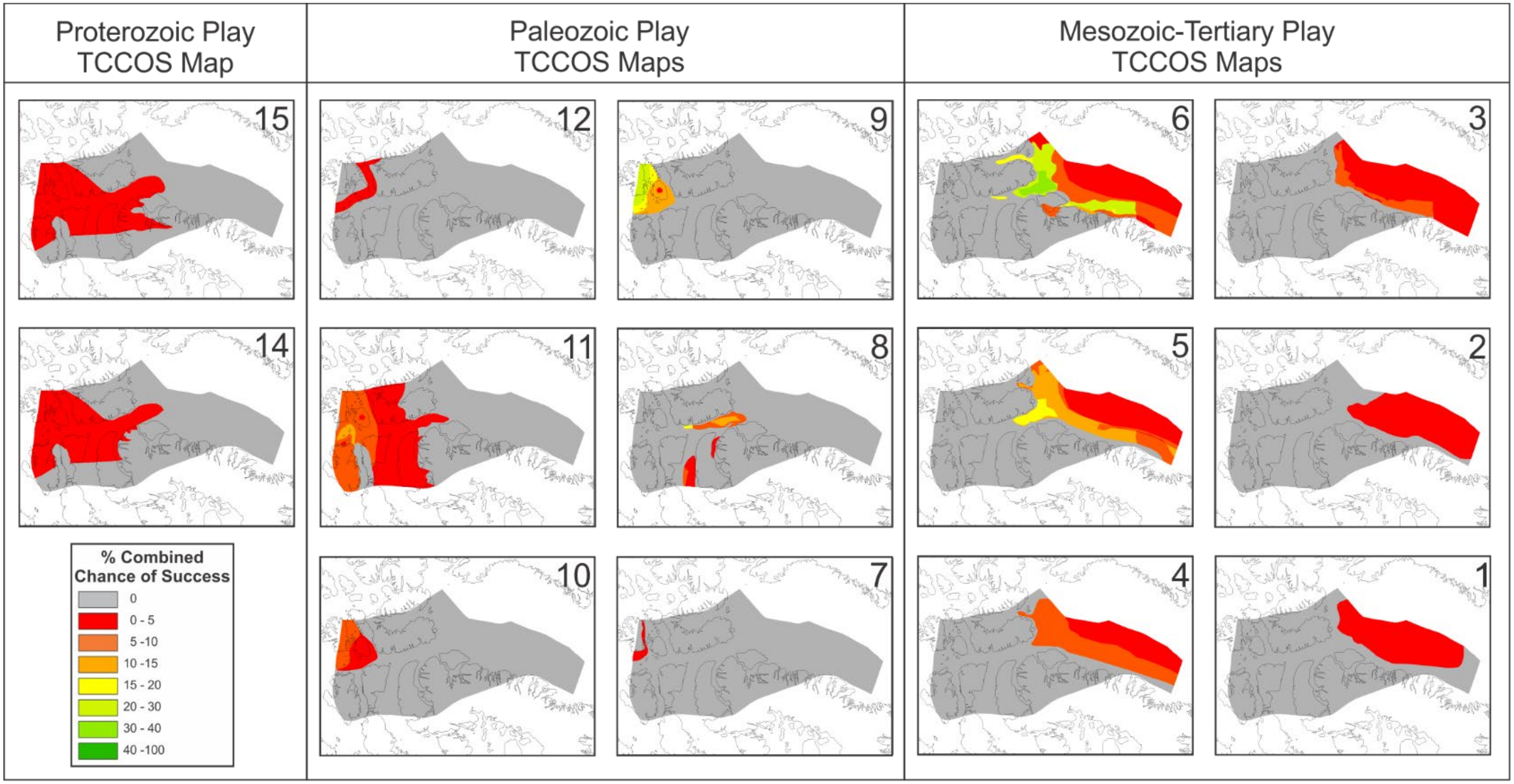

Figure 17. Technical Combined Chance of Success *(TCCOS)* maps generated in ArcGIS® for all 14 plays in the Lancaster Sound study area. Play numbers correspond to those reported in Table 1 in Atkinson et al., 2017.

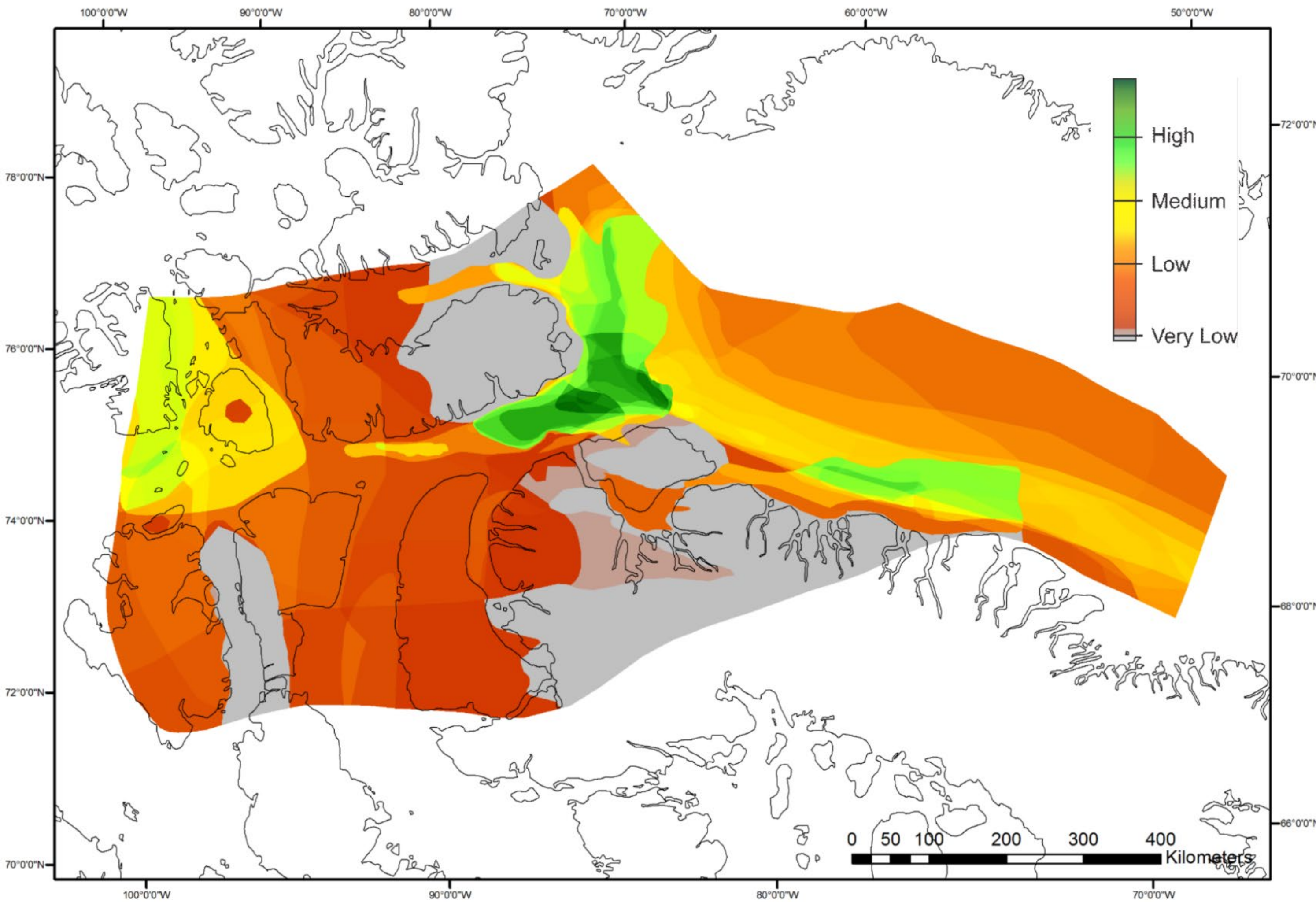

Figure 18. Stacked Technical Combined Chance of Success ***(STCCOS)*** **map illustrating the result of the addition of scaled** ***TCCOS*** **maps ([Figure 17](#)).**

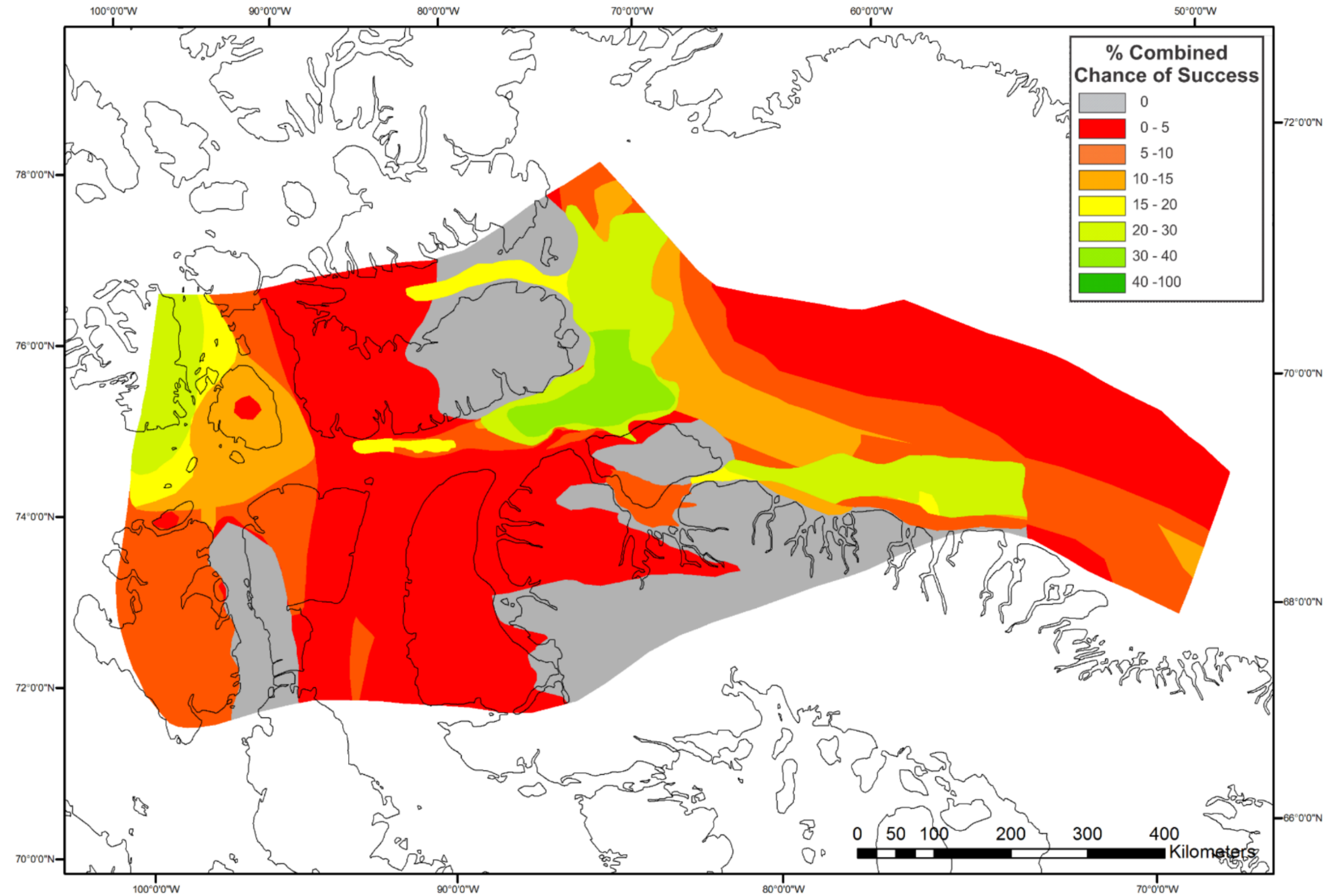

Figure 19. Maximum Technical Combined Chance of Success *(MTCCOS)* map illustrating the spatial distribution of the highest petroleum potential of all plays.

3.6 Comparison of ArcGIS® vs IHS Kingdom® (Atkinson et al., 2017 map)

The Lancaster Sound map generated in IHS Kingdom® software (Atkinson et al., 2017) compares favourably to our *STCCOS* map generated in ArcGIS® (Figure 20). This means that each play was assessed at a *TCCOS* level and then stacked; both maps are the result of the summation of play-level assessments. However, the ArcGIS® method explicitly evaluates *COS* at the petroleum system element level where the Kingdom® method used an approximation of chance of success at the play level. For the original Kingdom® method, individual petroleum system elements were researched; however no *COS* maps where generated.

Both maps use the same colour scale, but the new ArcGIS® *STCCOS* map has not been smoothed. Due to the differing method of map generation, there are minor differences between the Kingdom® map and the ArcGIS® map (Figure 20), for example:

(1) The area of highest potential (dark green) south and east of Devon Island is not as extensive on the new *STCCOS* map.
(2) In the vicinity of Scott Inlet (eastern part of Figure 20), the *STCCOS* map captures more potential (more extensive green area) than the Kingdom® map.
(3) The *STCCOS* map captures a slightly higher potential on and south of Bathurst Island (western end of Figure 20).
(4) While re-evaluating the Lancaster plays to apply this method, a redundancy was found within the Proterozoic plays: a reservoir interval was mistakenly filled twice. Therefore, one Proterozoic play (play 13 from Atkinson et al., 2017, Table 1) was removed from the *STCCOS* map.

4.0 CONCLUSIONS

The qualitative probabilistic assessment method previously described is adapted from a widely used petroleum industry practice for qualitatively evaluating a region's potential. This method can be used from new ventures through to development. As more knowledge is gained, increased data caliber, density, and confirmation informs more confident assessments. The purpose of this method is to provide a transparent, consistent, and repeatable approach for qualitative petroleum resource assessment across various regions.

Although the detailed examples in Section 3 are focused on its application within petroleum assessment (where a $CCOS \geq 20\%$ is considered prospective), one could imagine using this method to evaluate the geologic chance of success for geothermal energy or mineral occurrence. To determine what *CCOS* would be considered prospective for other geologic processes further research and development would be required to understand how data confidence, density, and confirmation affect the identified independent variables involved. This method could also be taken out of the geologic world entirely and into more diverse scenarios (e.g. Sauvignon Sally's Vineyard).

As long as independent variables can be identified and evaluated, this probabilistic assessment method can be applied. Using ArcGIS® as a tool for the geospatial referencing of pertinent information and for the applications of simple mathematical functions allows the user to view initial inputs, intermediate steps, final products, and associated metadata.

Historically, quantitative resource assessment has been the standard practice of the GSC. However, tight deadlines arising from the MCT initiative forced an innovative approach to assessing resources. A method was needed that was consistent, transparent, and repeatable which was also not as time-consuming as a full quantitative assessment. It is important to note that although this qualitative method is not a substitute for a full quantitative evaluation, it is a utilitarian and expeditious approximation that effectively highlights the resource potential of an area. Where the data quality and density are reasonable, this qualitative analysis could be a first step, and could be followed up with a more robust quantitative calculation, at least over specific areas of interest.

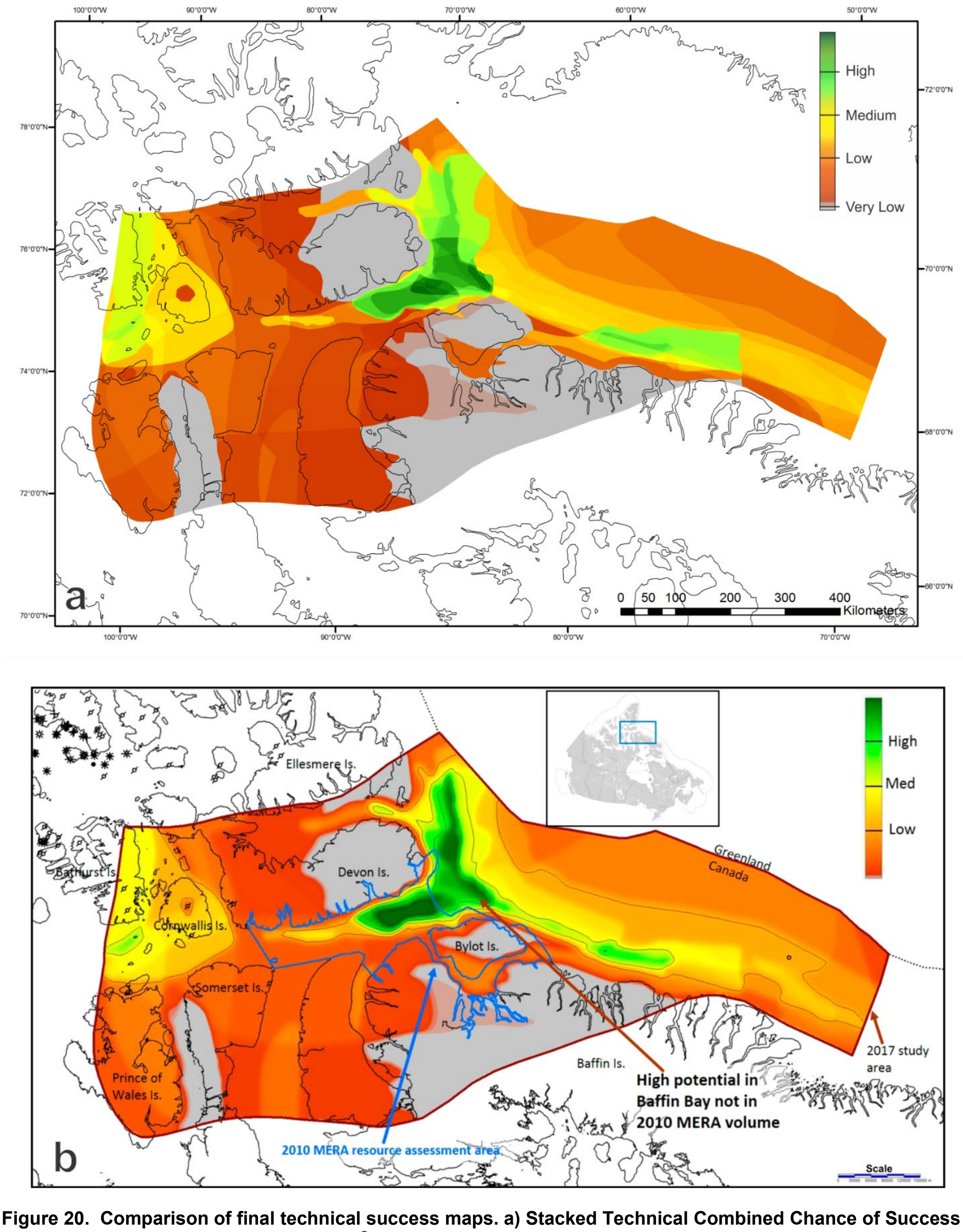

Figure 20. Comparison of final technical success maps. a) Stacked Technical Combined Chance of Success *(STCCOS)* map generated with the ArcGIS® probabilistic assessment method outlined in this document. b) Petroleum potential map generated in IHS Kingdom® (published in Atkinson et al., 2017). The Atkinson et al. (2017) had a smoothing filter applied, resulting in softer transitions as petroleum potential changes.

ACKNOWLEDGEMENTS

We would like to thank: Christine DeBlonde for her technical support with ArcGIS®; Marian Hanna for her encouragement to create this product and faith throughout its development process; Keith Dewing and Jim Dietrich for their scientific input and constructive criticism; Tom Brent for his thorough review and suggestions; Dave Sargent for drafting support; and the rest of the MCT team for allowing us to test drive our prototypes. Peter Hannigan and Jim Dietrich were also very helpful in explaining past GSC approaches to Resource Assessment. We also thank Rose & Associates for their expertise with quantitative Resource Assessment software and for their support in adapting it to the needs of the GSC; training and discussions with Jim Gouveia and David Cook have helped both our qualitative and quantitative analyses.

LIST OF FIGURES

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APPENDIX A – GLOSSARY OF TERMS

(* from or modified from Schlumberger Limited's's on-line dictionary, "*The Oilfield Glossary*": http://www.glossary.oilfield.slb.com)

***Acronyms**:

COS: Chance of Success

CCOS: Combined Chance of Success

TCCOS: Technical Combined Chance of Success

STCCOS: Stacked Technical Combined Chance of Success

MTCCOS: Maximum Technical Combined Chance of Success

GSF: Global Scale Factor

***Formation**: A body of rock that is sufficiently distinctive and continuous, and can be mapped.

***Maturation**: The process of a source rock becoming capable of generating oil or gas when exposed to appropriate pressures and temperatures.

***Migration:** The movement of hydrocarbons from their source into reservoir rocks.

Petroleum Potential (or Prospectivity) Maps: When assessing the petroleum potential of a region a family of maps is required. These maps represent high (green) to low (red) potential.

COS **Map**: Chance of success maps of a petroleum system element – created by spatially assigning probabilities using the chance of success scale (Figure 1)

CCOS **Map**: Combined (Geologic) Chance of success map of a play – created by multiplying COS maps of the independent variables.

TCCOS **Map**: Technical combined chance of success map of a play – created by multiplying the CCOS maps by the Global Scale Factor to normalize plays.

STCCOS **Map:** Stacked technical combined chance of success map when all technical success maps are added together.

MTCCOS **Map:** Spatial distribution of maximum technical chance of success for any play.

***Petroleum System**: Geologic components and processes necessary to generate and store hydrocarbons, including a mature source rock, migration pathway, reservoir rock, trap and seal. Appropriate relative timing of formation of these elements and the processes of generation, migration and accumulation are necessary for hydrocarbons to accumulate and be preserved.

Play: A family of prospects and/or discovered pools that share a common history of hydrocarbon generation, migration, reservoir development, and trap configuration; forms a natural geological population limited to a specific area.

***Reservoir**: A subsurface body of rock having sufficient porosity and permeability to store and transmit fluids. Sedimentary rocks are the most common reservoir rocks as they have more porosity than most igneous and metamorphic rocks and form under temperature conditions at which hydrocarbons can be preserved. A reservoir is a critical component of a complete petroleum system.

***Seal**: A relatively impermeable rock, commonly shale, anhydrite or salt that forms a barrier or cap above and around reservoir rock such that fluids cannot migrate beyond the reservoir. A seal is a critical component of a complete petroleum system.

***Source rock**: A rock rich in organic matter which, if heated sufficiently, will generate oil or gas. Typical source rocks, usually shales or limestones, contain about 1% organic matter and at least 0.5% total organic carbon (TOC), although a rich source rock might have as much as 10% organic matter.

***Trap**: A configuration of rocks suitable for containing hydrocarbons and sealed by a relatively impermeable formation through which hydrocarbons will not migrate. Traps are described as structural traps (in deformed strata such as folds and faults) or stratigraphic traps (in areas where rock types change, such as unconformities, pinch-outs and reefs). A trap is an essential component of a petroleum system.

APPENDIX B – CREATING PROBABILISTIC ASSESSMENT MAPS IN ARCGIS®

The following is a summary of the process the GSC used in creating qualitative petroleum resource assessments in ArcGIS® (see Figure 13 for flowchart).

B.1 Setting up the project in ArcGIS®

- Choose and set a suitable map projection and datum for the area of interest *(AOI)*. It is best practice to select a spatial reference system that preserves the area extent and provides minimal distortion to the *AOI*. Typically, projections and datums can be inferred from the loaded data, but for additional assistance, please refer to the Esri manual.
- Load all maps and relevant geospatial data required to inform analysis

B.2 Creating polygons and *COS* maps for probabilistic assessment

Create a new polygon feature class within a file geodatabase with the chosen map projection for your area of interest. Draw area of interest to create *AOI* polygon. Make copies of this polygon for every play element required. Cut the polygons and assign chance of success and metadata in the attribute table according to data available. See Figure B-1 for an example of a petroleum system element polygon.

B.3 GSC naming convention for system element polygons:

- *TypeAge_Element* (e.g. Type = Play, Age = 092, Element = Reservoir: *Play092_Reservoir*)

B.4 GSC naming and field format convention for polygon columns and associated metadata (for use with play calculators):

This naming convention works with the Play calculators described in Appendix C. It is particularly important to follow the convention for the columns containing numerical values.

- Petroleum System Element Polygons (2 important columns)
  1. *COS* (float or long) column
     - Label column header with appropriate name (e.g. *COS_Reservoir*)
  2. Description (250 Characters) column
     - Label column header with appropriate name (e.g. *Play092_Reservoir_Description*)
- Global Scale Factor Polygon (2 important columns)
  1. *GSF* (float or long)
     - Label column header with appropriate descriptor *(GSF)*
  2. Description (250 Characters)
     - Label column header with appropriate descriptor (e.g. *GSF_Description*)

Display the maps using the colour bar shown in Figure D-1 (Appendix D). For assistance in adding or altering fields, please refer to the Esri Manual

B.5 Checking data integrity and quality control (topology checks and validations)

Ensure that topology checks and validations for data integrity and quality control are performed often throughout the method. Topologies define the relation and/or arrangement of feature points, lines, and polygons to one another. Topology checks and validations can account for errors such as gaps, dangles, and/or duplicates which can then be resolved. This can ensure that final cuts are correct in the *STCCOS* map and no errors are carried forward. Please refer to the Esri manual for creating and using topologies in ArcGIS®.

Table

Mar20_P092_Reservoir

OBJECTID *	SHAPE *	COS_Reservoir	Play092_Reservoir_Description	SHAPE_Length	SHAPE_Area
1	Polygon	0	Outside play area	4664354.958855	402602412859.50641
2	Polygon	0.7	Isolated Graben, preserved Cretaceous?	204193.840841	1176394177.777771
3	Polygon	0.7	Seismically mapped Cretaceous	1595893.407997	42330649393.946907
4	Polygon	0.7	Seismically mapped Cretaceous	979729.143871	20563296405.725426
5	Polygon	0.4	Unsure of lithology, distal	680377.523261	23548122063.865211
6	Polygon	0.2	Outboard muds	1620797.966626	92742777713.189453
7	Polygon	0.45	Cretaceous is at seafloor	268771.699956	1674073463.691719
8	Polygon	0.5	No idrea. Near confluence of inputs	366071.900745	5603222704.196112
9	Polygon	0.45	Cretaceous is at seafloor	301012.244616	3154991850.873795
10	Polygon	0.45	Cretaceous is at seafloor	528337.727759	4352848683.570862
11	Polygon	0.4	Proximal to Outboard muds?	1479386.222009	32307781341.835121
12	Polygon	0.8	L Currie, Mapped sands on Bylot Is.	372639.902987	4849383138.07936

1 (0 out of 12 Selected)

Mar20_P092_Reservoir

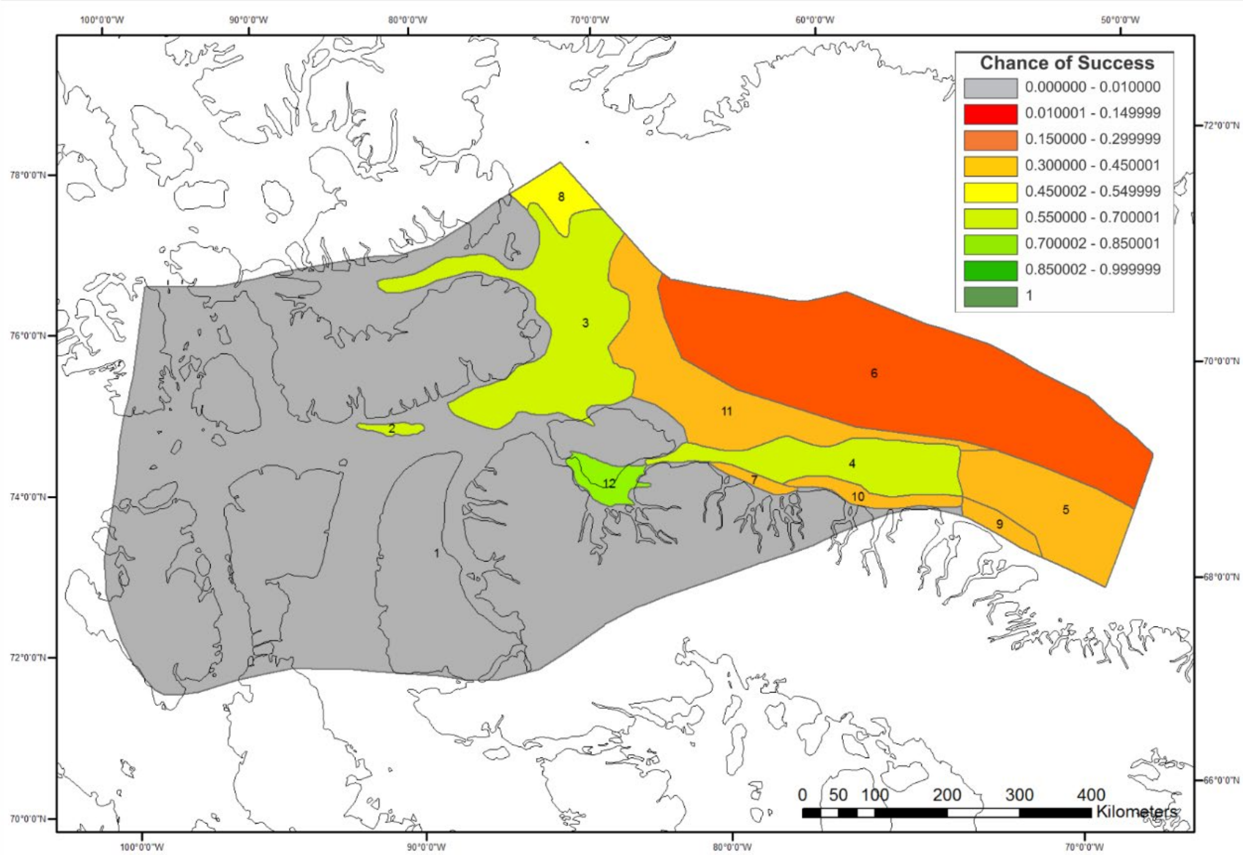

Figure B-1. Example attribute table with values and metadata for the Play 092 reservoir in Lancaster Sound. Polygons are labeled with their *FIDs* from the attribute table.

B.6 Creating Combined Chance of Success *(CCOS* and *TCCOS)* Maps

Once all system elements polygons are cut and assigned chance of success, they are multiplied together using the Union tool. We developed a calculator to streamline and simplify this process (see Appendix C). This could also be done manually using a similar process.

Display the maps using the colour bar shown in Figure D-2 (Appendix D).

B.7 Creating Stacked Technical Combined Chance of Success *(STCCOS)* Map

Combine all *TCCOS* layers using the Union tool. Add a field (float or long) and label *STCCOS*. Right click and use the Field Calculator to add the values as shown in Figure B-2.

Display the maps using the colour bar shown in Figure D-5 (Appendix D).

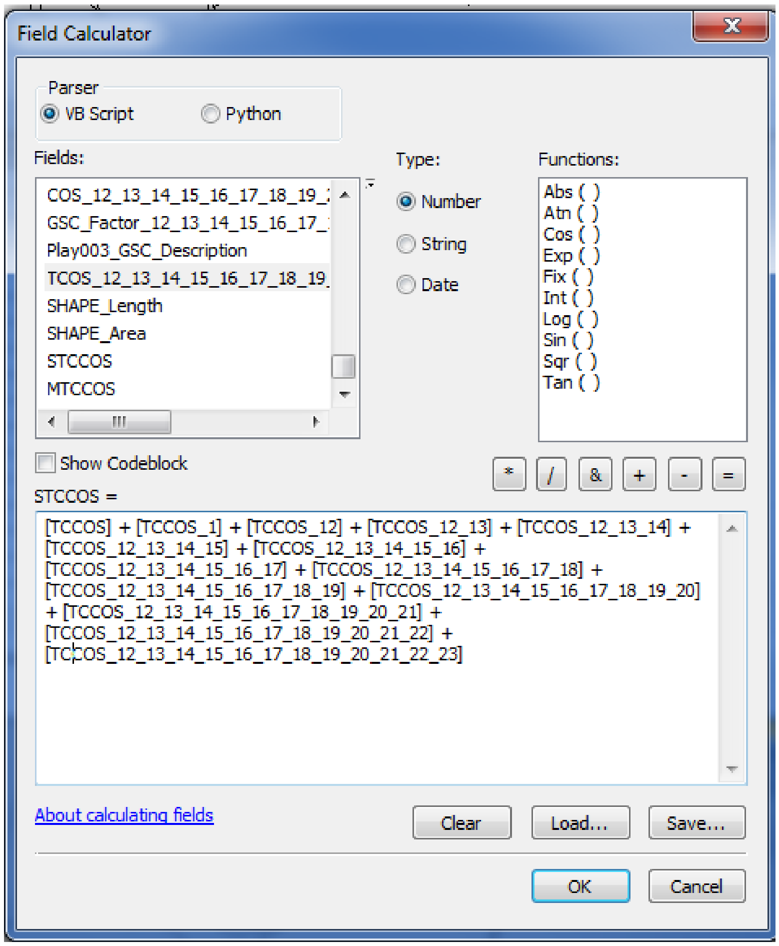

Figure B-2. Field calculator showing the addition of *TCCOS* values for the 14 plays of Lancaster Sound.

B.8 Creating Maximum Technical Combined Chance of Success *(MTCCOS)* Map

Create a column in the *STCCOS* polygon called Maximum (all the *TCCOS* values are preserved from the Union of the polygons).

Use the *Field Calculator* to calculate the maximum value of the *TCCOS* using the Python syntax in Figure B-3.

Display the maps using the colour bar shown in Figure D-2.

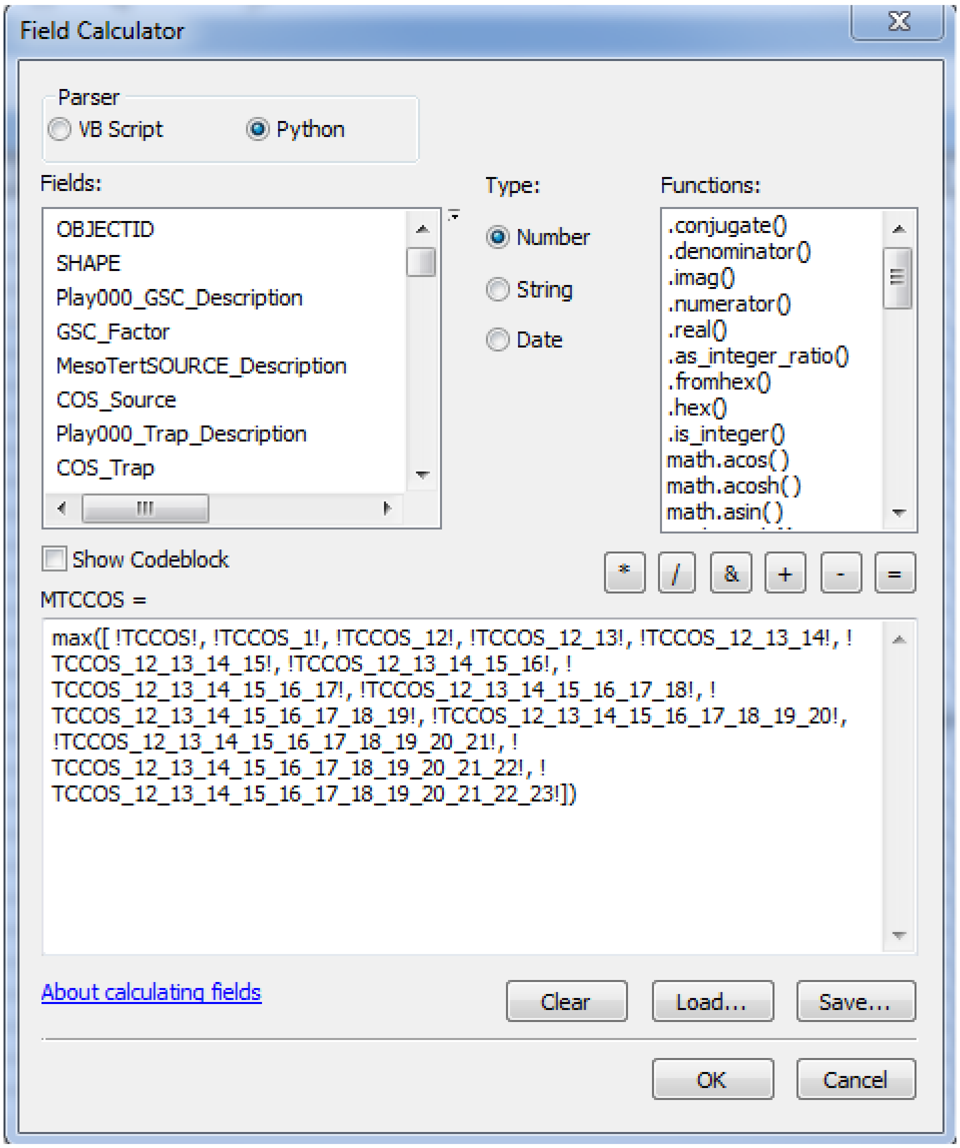

Figure B-3. Python script to generate maximum value for *TCCOS* (14 plays).

APPENDIX C – CREATING PLAY *CCOS* AND *TCCOS* CALCULATORS

C.1 *PlayCCOS_calc:*

Create a new toolbox in desired folder.

1. Create new model in toolbox (*PlayCOS_calc*):

    Right Click ➔ New

2. Create generic field addition calculator (Figure C-1):

    a) Drag and drop the *Union (Analysis)* Tool into the model builder
        i) Right click on *Union* ➔ Make Variable ➔ From Parameter ➔ Input Features
        ii) Right click on *Input Features* ➔ Model Parameter
        iii) Right click on *Output Features* ➔ Model Parameters

    b) Drag and drop the *Add Field (Data Management)* Tool

    c) Use connector  to join the output to *Add Field* ➔ Input Table

    d) Drag and drop *Calculate Field (Data Management)* Tool

    e) Connect second output to *Calculate Field* ➔ Input Table

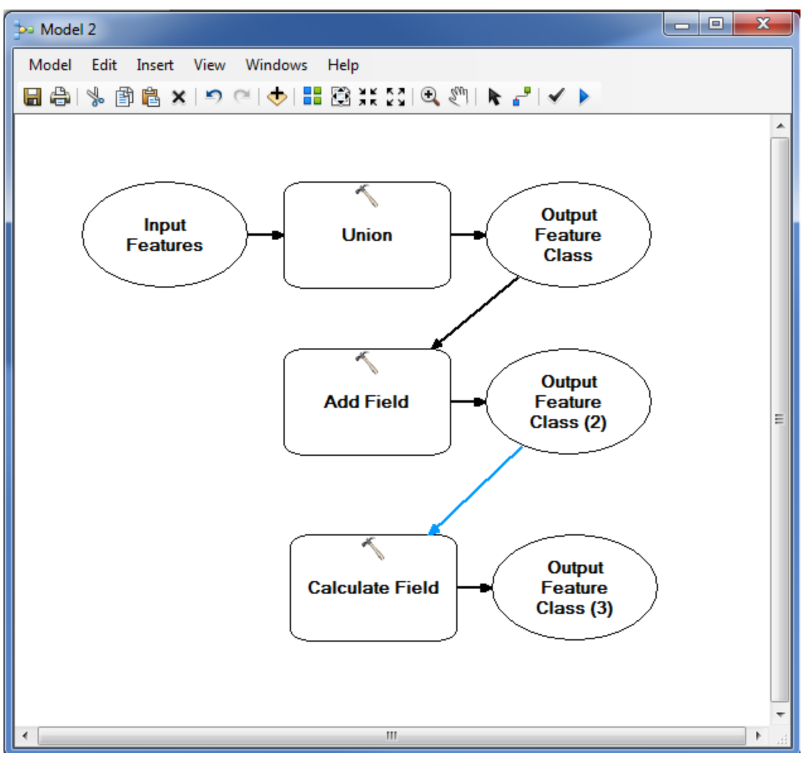

Figure C-1. Generic field calculator tool.

3. Double click *Input Features* (Figure C-2):

Add polygons for Source, Reservoir, Trap, and Seal ➔ OK

4. Double click *Union* (Figure C-3):

a) Change output feature class location.
b) Join Attributes ➔ No *FID*
c) Output Feature Class [make sure this is into a geodatabase or the tool will produce an error]
d) Click OK

5. Double click *Add Field* (Figure C-4):

a) Change Field name = *CCOS*
b) Change Field Type = FLOAT
c) Click OK

6. Double click *Calculate Field* (Figure C-5):

a) Change Field Name = *CCOS*
b) Create expression found in Figure C-5.
c) Click OK Twice

[This sequence of steps should have created a specific play *CCOS calculator* (Figure C-6); inputs must be removed so calculator will be able to calculate *CCOS* for any play.]

7. Validate and run the model (Under Model). Debug if necessary.

8. Generate Final Play *CCOS* Calculator:

a) Double click *Input Features*
b) Delete inputs ➔ OK (will create generic *Play COS calculator*, Figure C-7)
c) Save As *'PlayCCOS_Calculator'*

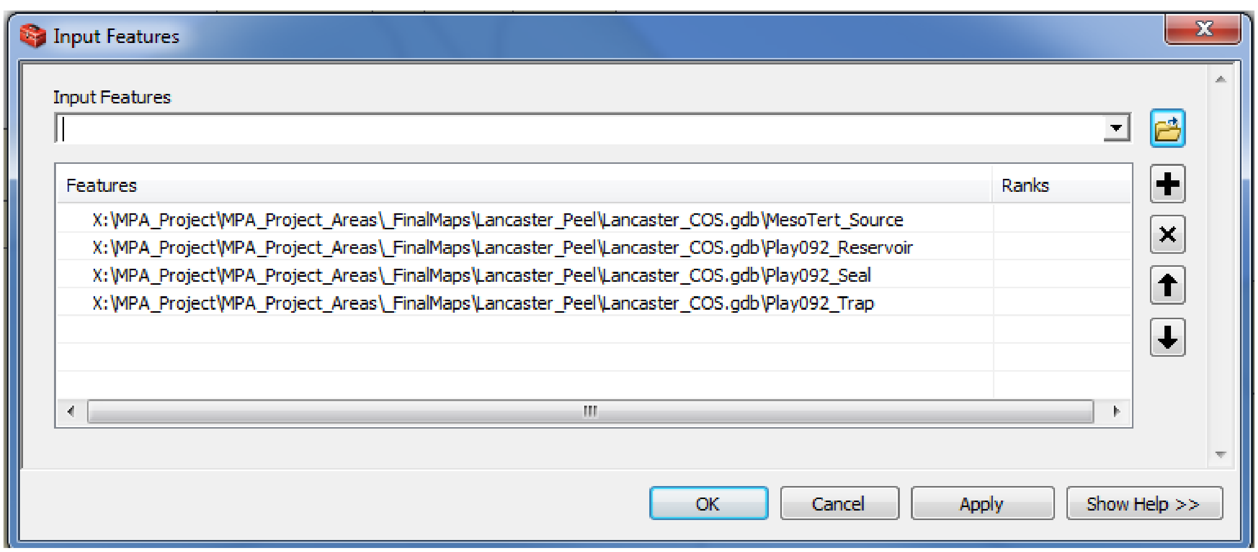

Figure C-2. Setting up the *Input Features* for the *PlayCCOS_calc*.

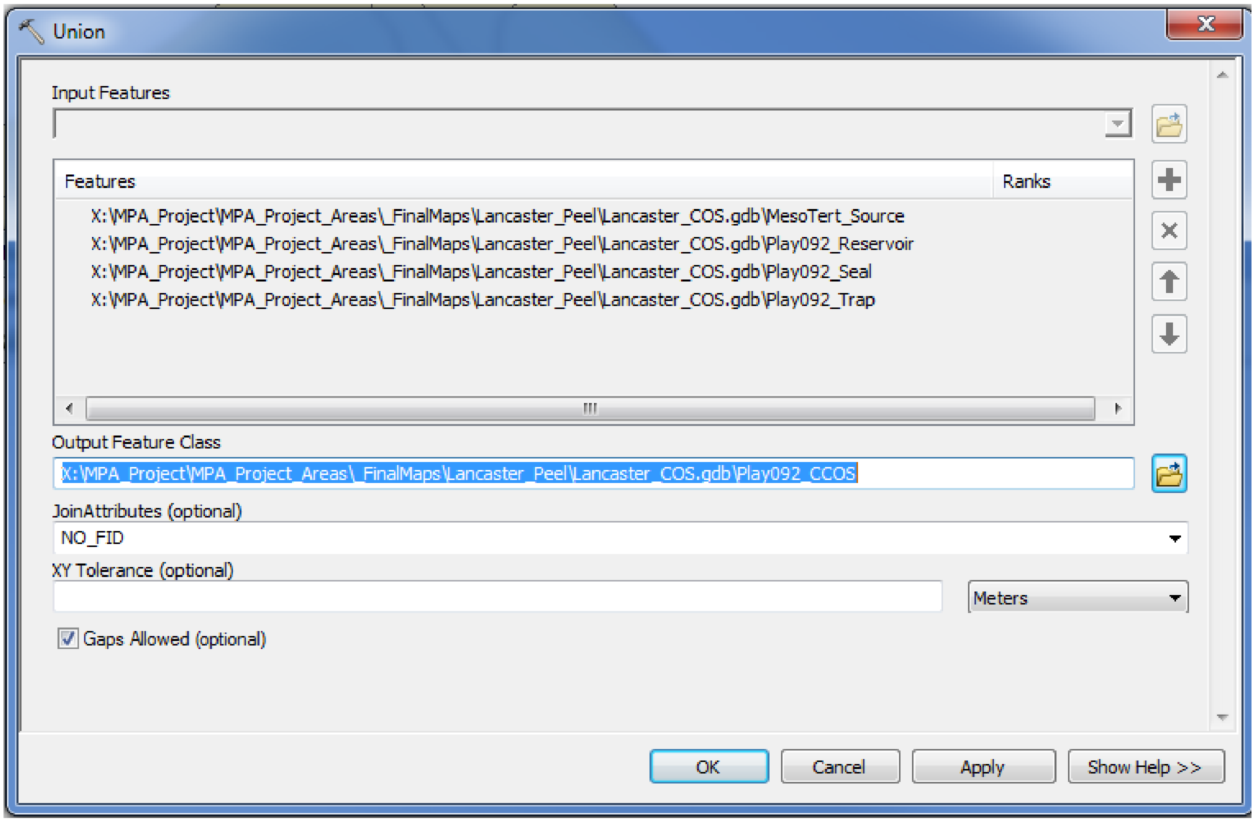

Figure C-3. Specifying parameters for *Union* for the *PlayCCOS_calc*.

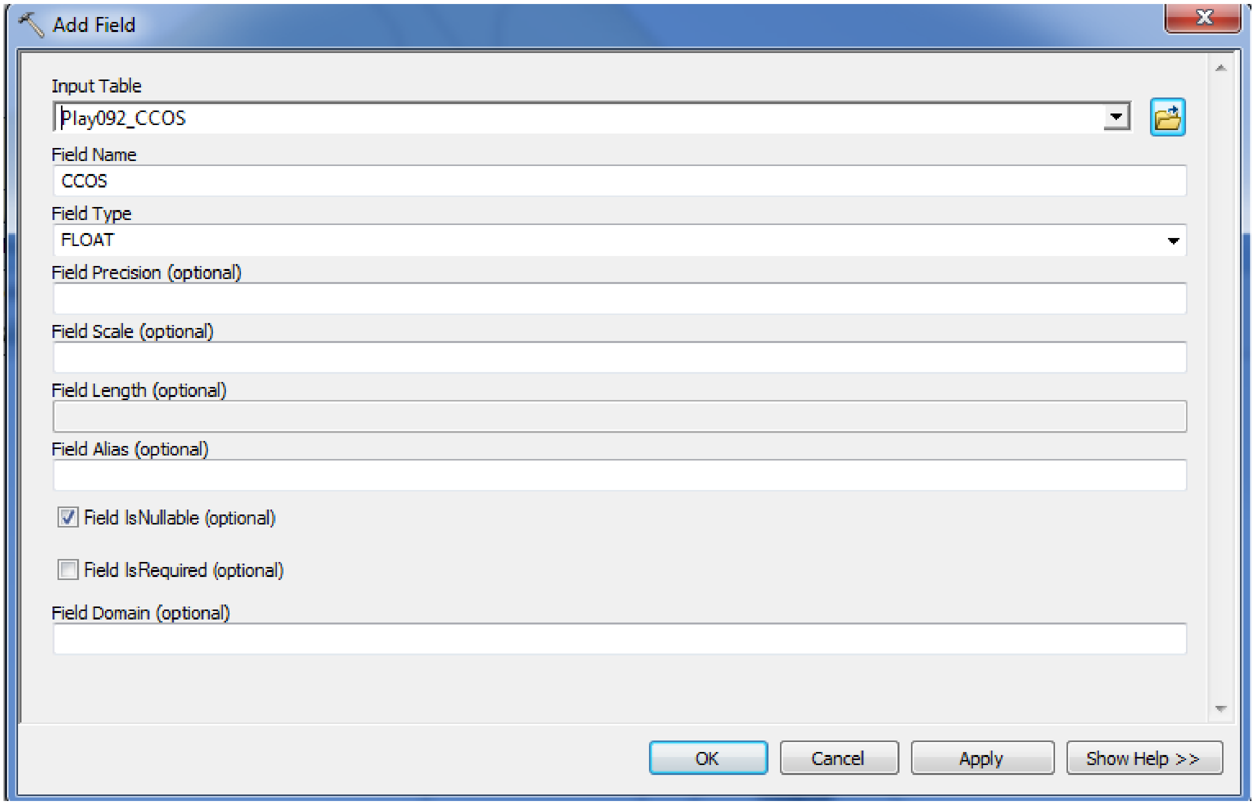

Figure C-4. Specifying parameters for *Add Field* for the *PlayCCOS_calc*.

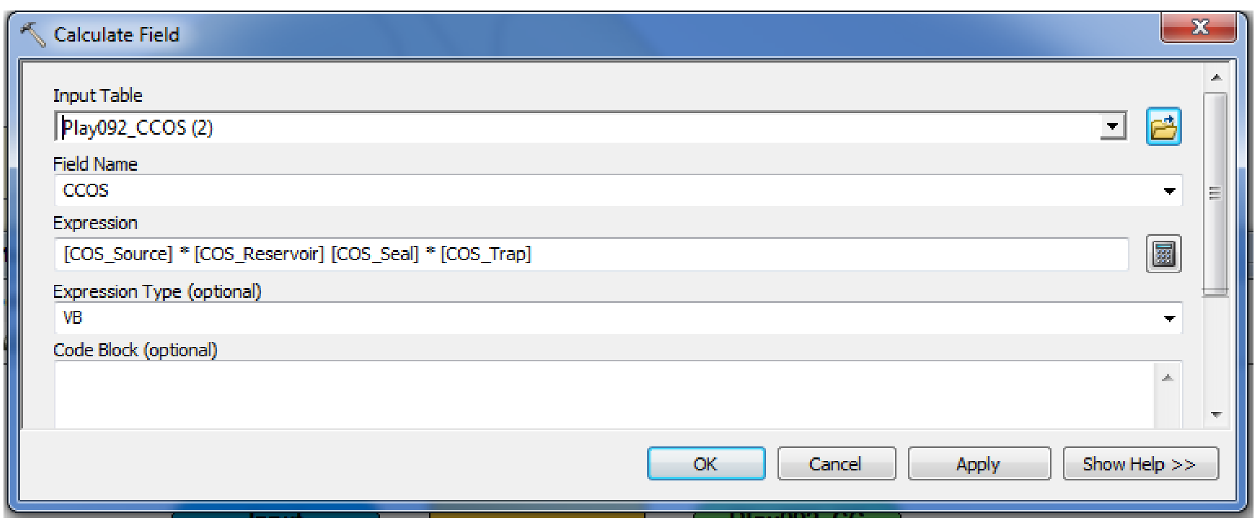

Figure C-5. Specifying parameters for *Calculate Field* for the *PlayCCOS_calc*.

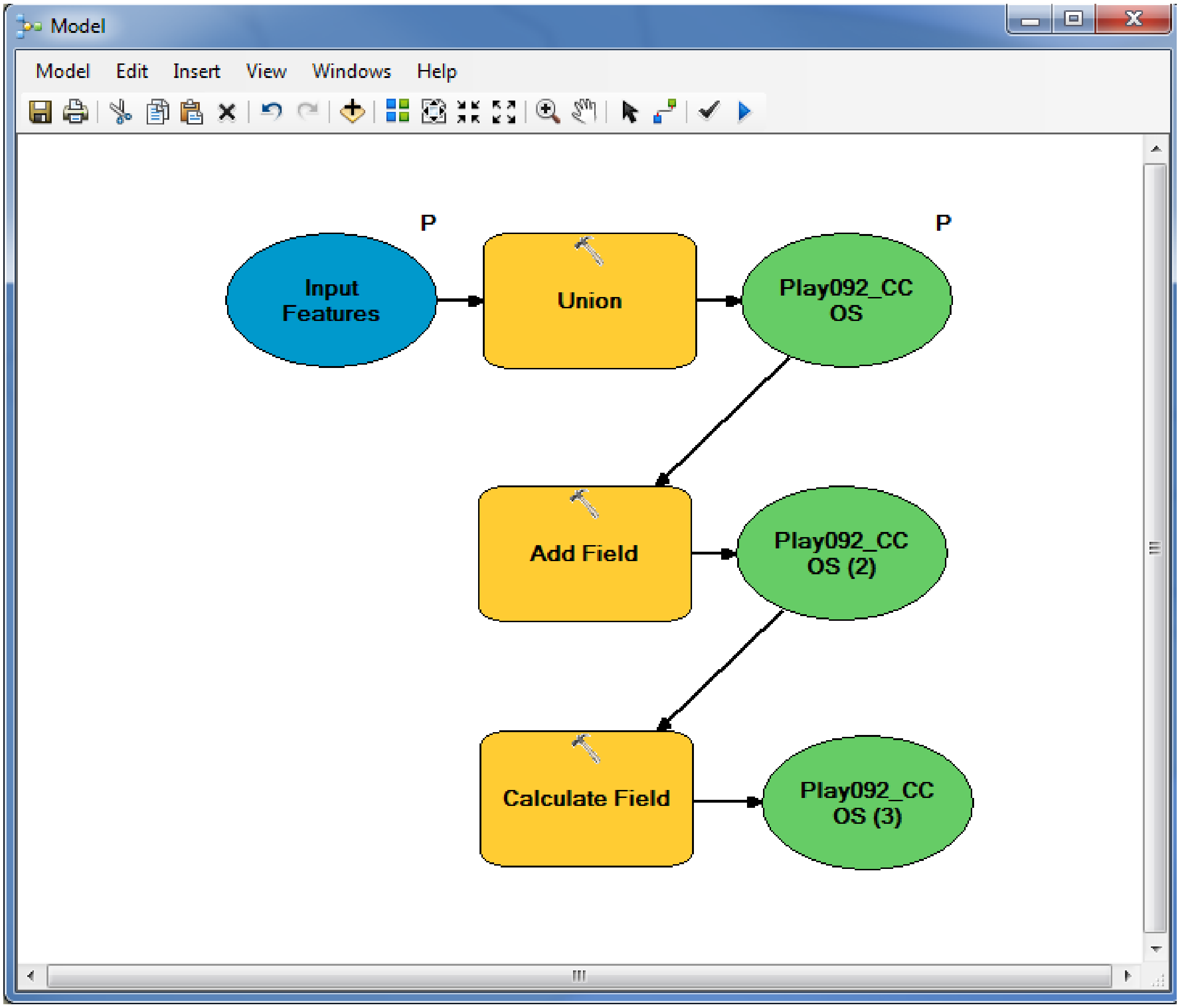

Figure C-6. Intermediate calculator with specific *Input Features* for the *PlayCCOS_calc*.

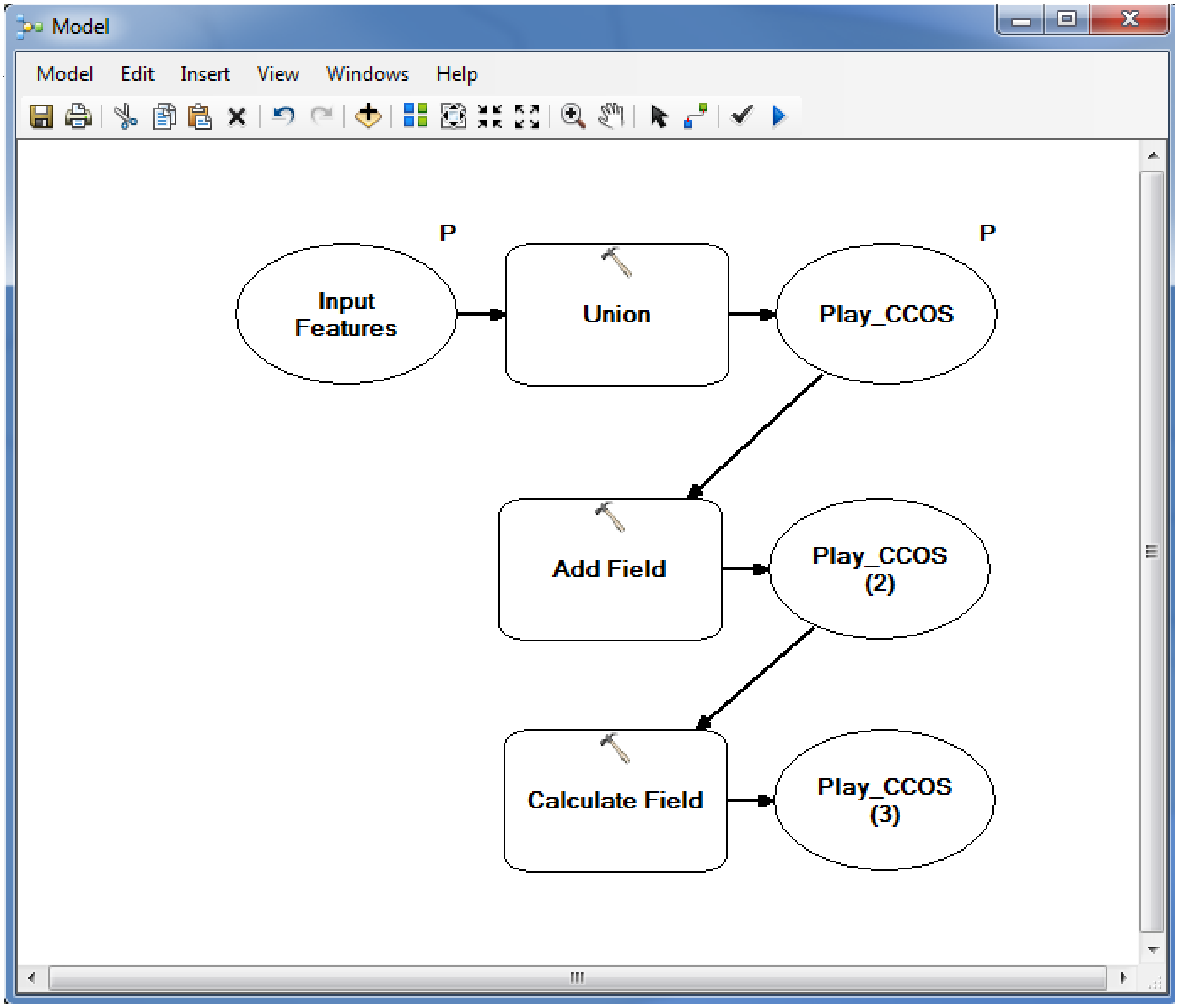

Figure C-7. Final Play *CCOS calculator* (generic).

C.2 *PlayTCCOS_calc*

1-2. Same as described in Appendix C.1.

3. Double click *Input Features:*

Add polygons for *PlayCCOS* and *Play_GSF* ➔ OK

4. Double click *Union* (Figure C-8):

a) Change output feature class location.
b) Join Attributes ➔ No *FID*
c) Output Feature Class ➔ [make sure this is into a geodatabase or the tool will produce an error]

5. Double click *Add* Field (Figure C-9):

a) Change Field Name = *TCCOS*
b) Change Field Type = FLOAT ➔ OK

6. Double click *Calculate Field* (Figure C-10):

a) Change Field Name = *CCOS*
b) Create expression found in Figure C-10 ➔ OK
[This sequence of steps should have created a specific play *TCCOS* calculator (Figure C-11); inputs must be removed so calculator will be able to calculate *TCCOS* for any play.]

7. Validate and run the model (Under Model). Debug if necessary.

8. Generate Final Play *TCCOS* Calculator:

a) Double click *Input Features*
b) Delete inputs ➔ OK (will create generic Play *TCCOS* calculator, Figure C-12)
c) Save As "*PlayTCCOS_Calculator*"

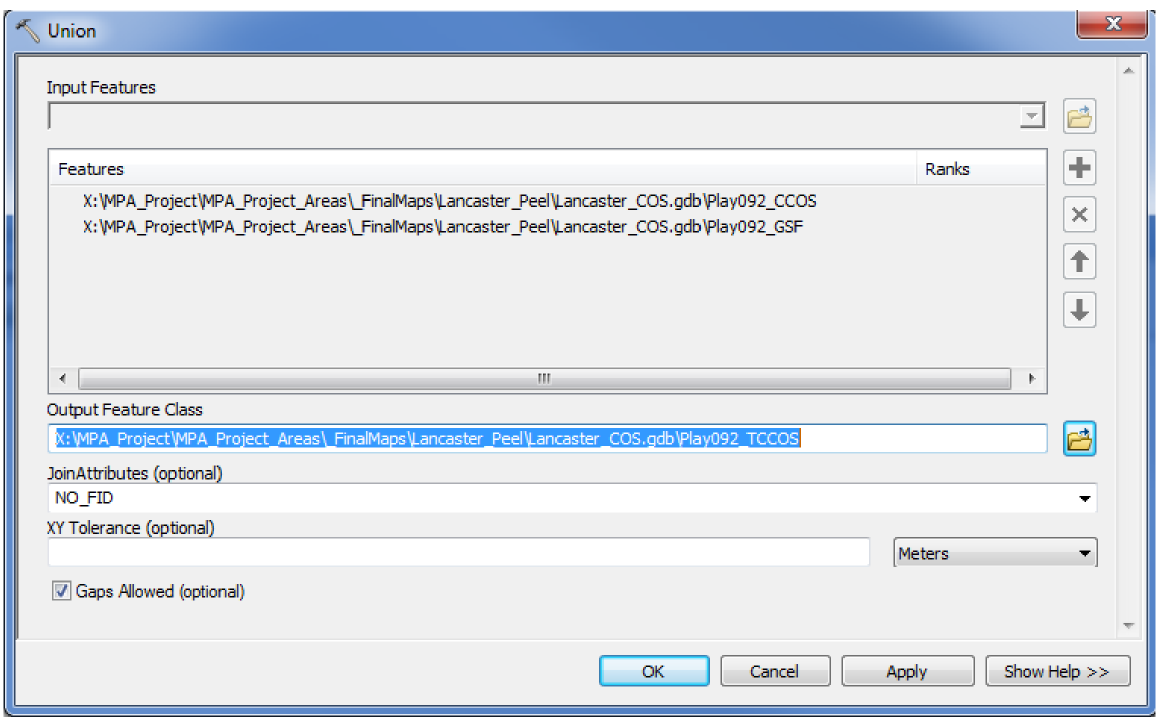

Figure C-8. Setting up the input and union features for the *PlayTCCOS_calc*.

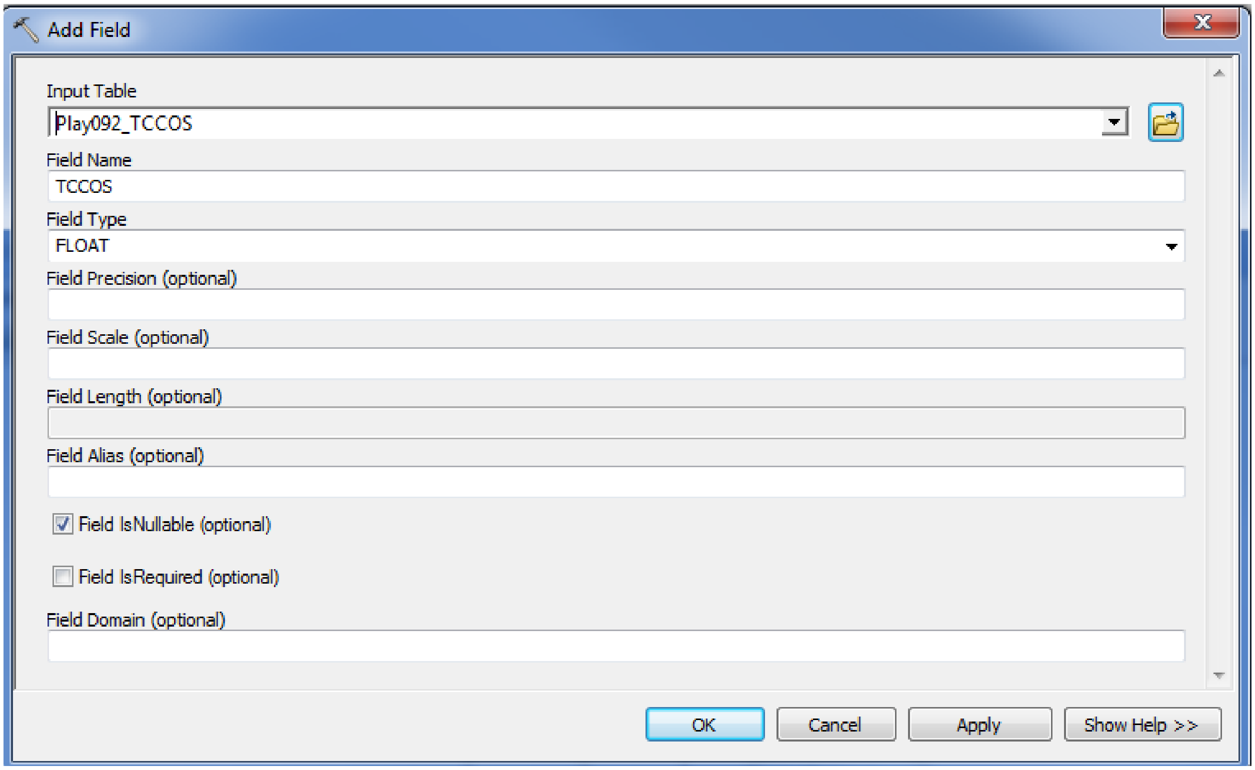

Figure C-9. Specifying parameters for *Add Field* for the *PlayTCCOS_calc*.

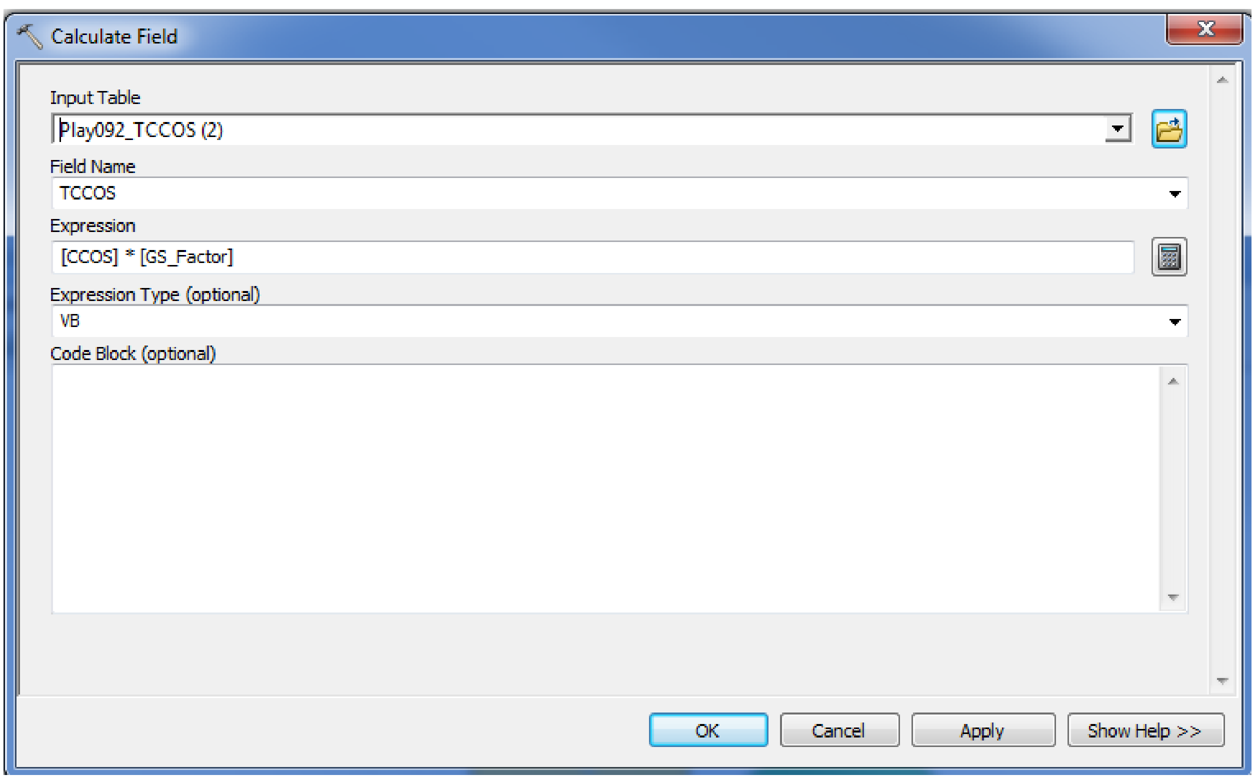

Figure C-10. Specifying parameters for *Calculate Field* for the *PlayTCCOS_calc*.

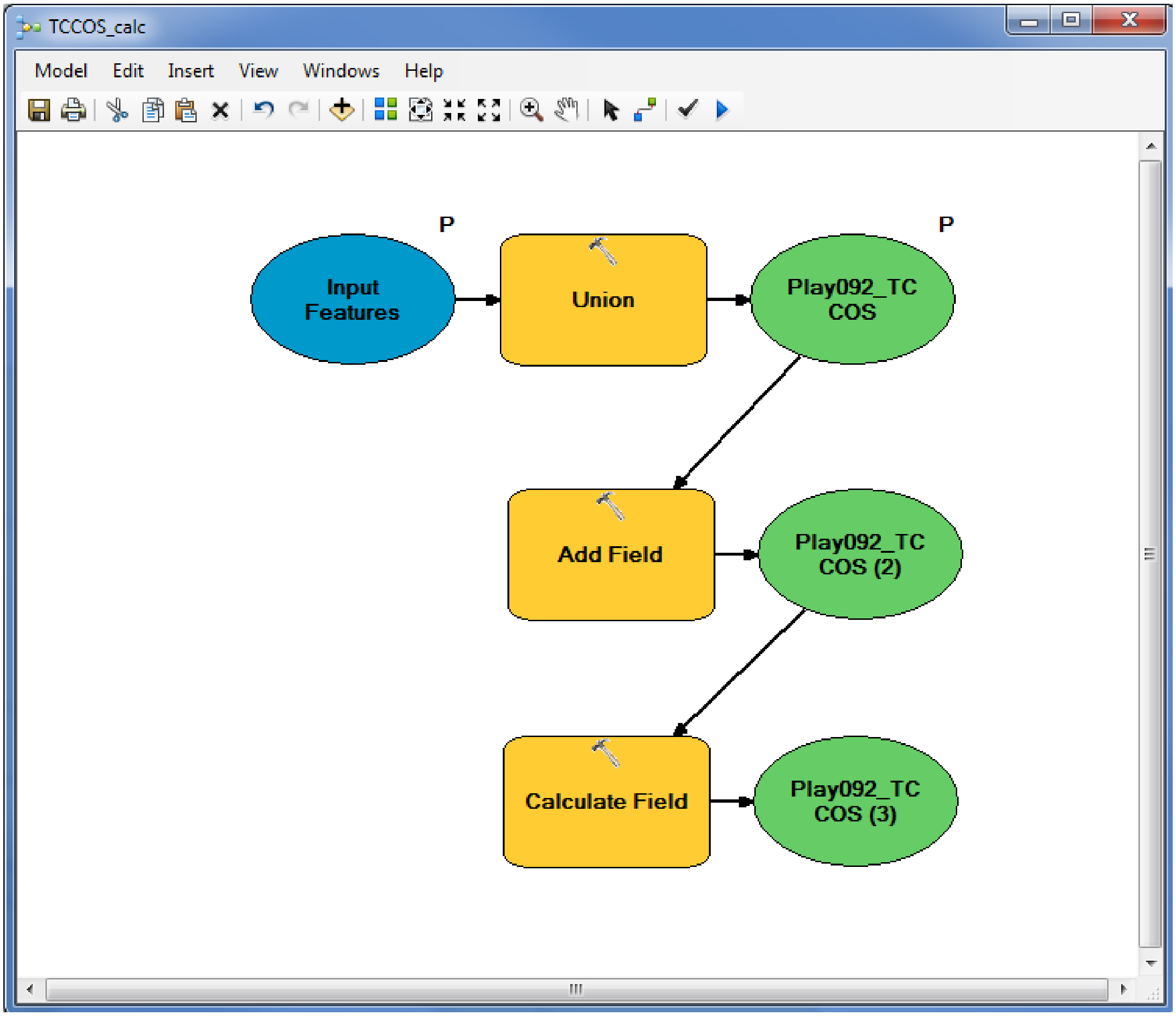

Figure C-11. Intermediate calculator with specific *Input Features* for the *PlayTCCOS_calc*.

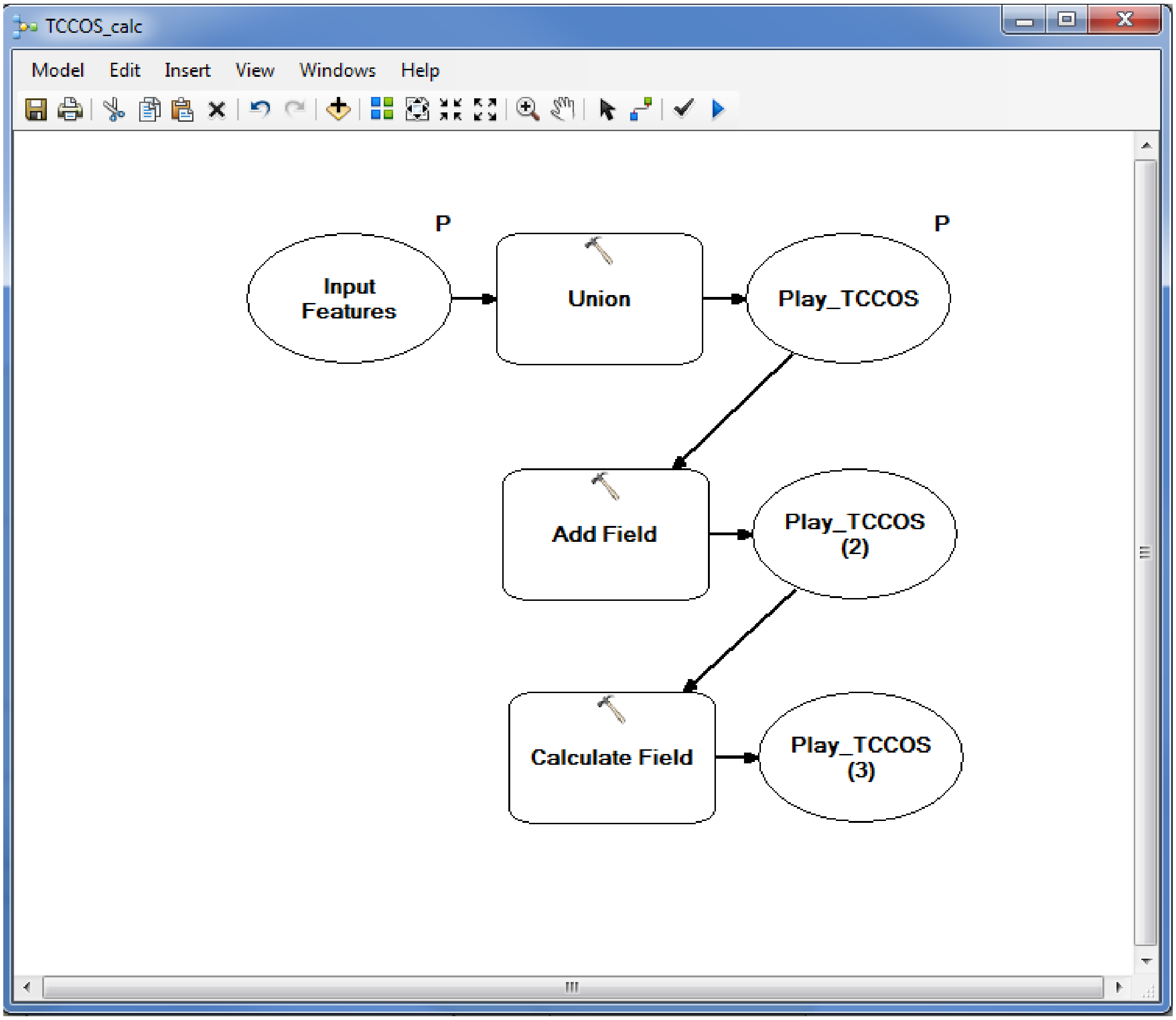

Figure C-12. Final Play *TCCOS calculator*.

APPENDIX D – COLOUR BARS

NOTE: The Canadian spelling of colour is used throughout this document; however, figures containing screenshots from ArcGIS® contain the American spelling.

Several binning and colour schemes were used to derive the colour bars used in our petroleum assessments. They are shown in Figures D-1, D-2, D-3, D-4, and D-5.

R-G-B	Chance of Success
179-179-179	0.000000 - 0.010000
255-0-0	0.010001 - 0.149999
255-84-0	0.150000 - 0.299999
255-170-0	0.300000 - 0.450001
255-255-0	0.450002 - 0.549999
209-245-0	0.550000 - 0.700001
148-235-0	0.700002 - 0.850001
36-186-0	0.850002 - 0.999999
94-153-78	1

Figure D-1. Colour bar used for *COS* maps.

R-G-B	% Combined Chance of Success
179-179-179	0.000000
255-0-0	0.000001 - 0.049999
255-84-0	0.050000 - 0.099999
255-170-0	0.100000 - 0.149999
255-255-0	0.150000 - 0.199999
209-245-0	0.200000 - 0.299999
148-235-0	0.300000 - 0.399999
36-186-0	0.400000 - 1.000000

FigureD-2. Colour bar used for *CCOS*, *TCCOS*, and *MTCCOS*.

A custom colour bar was created for the final stacked maps. Create the custom colour bar using the Style Manager in ArcGIS® (under Customize):

Styles ➔ Create New Style ➔ Save As NAME ➔ OK

In NAME Folder ➔ Colour Ramps ➔ Right Click ➔ New ➔ Multipart Colour Ramp

Multipart Colour Ramp ➔ Add 4 Algorithmic Colour Ramps (Figure D-3)

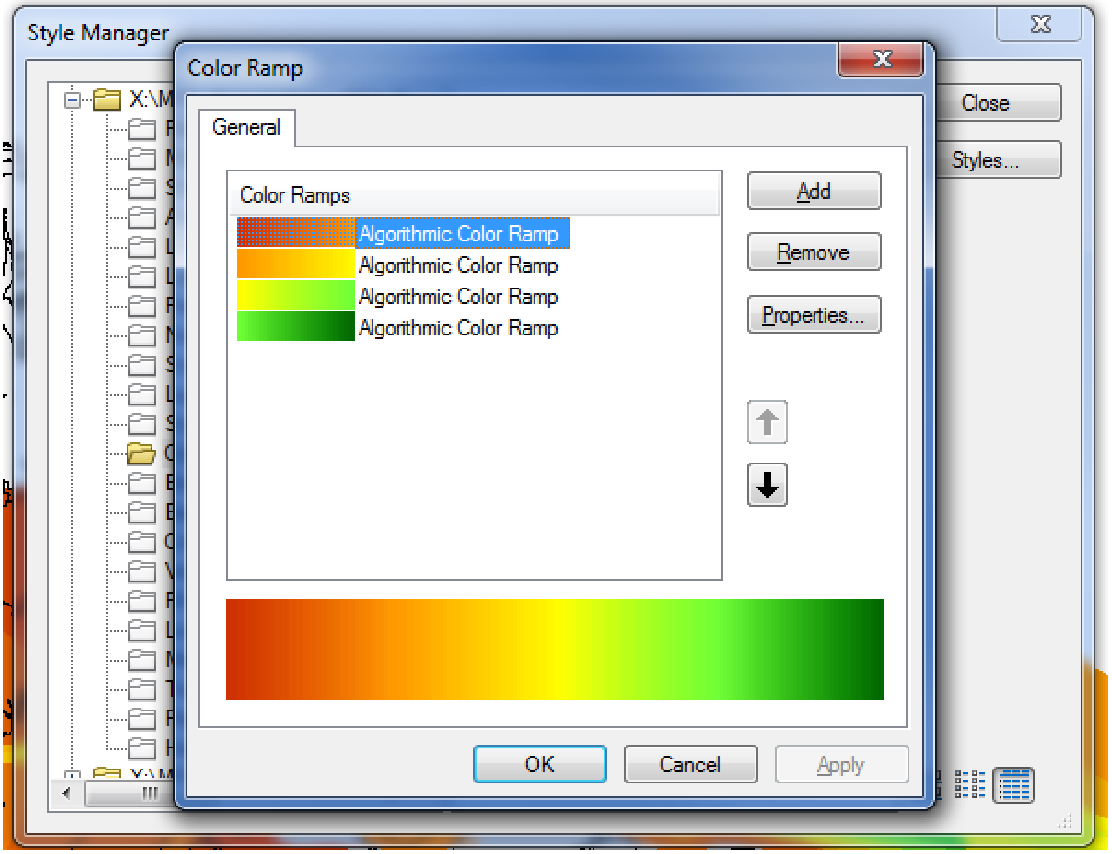

Figure D-3. Screenshot of creating colour ramps.

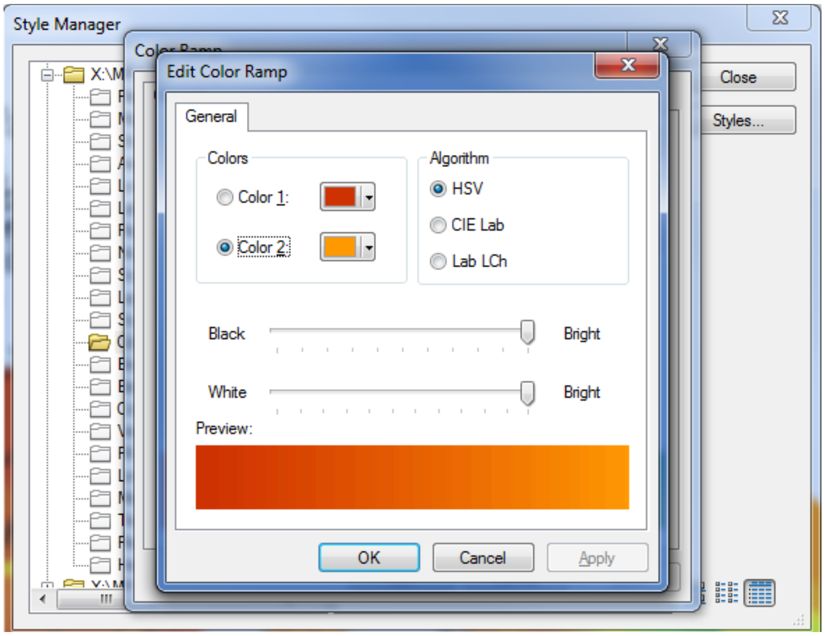

Figure D-4. Screenshot of editing colour ramps.

Edit each colour ramp in the following way:

- Algorithmic Colour Ramp 1 ➔ Properties (e.g. Figure D-4)

  Colour 1: R-G-B 207-50-2
  Colour 2: R-G-B 255-153-0

- Algorithmic Colour Ramp 2 ➔ Properties

  Colour 1: R-G-B 255-153-0
  Colour 2: R-G-B 255-251-0

- Algorithmic Colour Ramp 3 ➔ Properties

  Colour 1: R-G-B 255-251-0
  Colour 2: R-G-B 111-255-54

- Algorithmic Colour Ramp 4 ➔ Properties

  Colour 1: R-G-B 111-255-54
  Colour 2: R-G-B 0-105-0

  OK

Ensure the colour ramp is selected in the project [Style Manager ➔ Styles ➔ Check on List (If not there, click Add Style to List) ➔ OK]

Use 205 bins. First two bins will be changed to R-G-B 192-192-192 and 196-158-145 with numbers shown in Figure D-5.

Figure D-5. Colour bins for the final colour bar.