Reservoir Uncertainty Calculation by Large Scale Modeling

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It is important to have a good estimate of the amount of oil or gas in a reservoir. The uncertainty in reserve estimates affects decision and risk assessment, resource/reserve classification and investment decisions. Decision-makers need to make the best decisions that use an appropriate level of technical analysis with the acquisition of appropriate data. Current methods of estimating resource uncertainty are spreadsheet or Monte Carlo simulation software using distributions for each variable. 3D models may be constructed, but they do not consider uncertainty in all variables. The proposed method in this paper will consider using 2D and 3D models of heterogeneity in variables plus the uncertainties in those variable values. This research aims to improve reserve evaluation in the presence of geologic uncertainty. The main objectives are to: a) select the best modeling scale for making decisions, b) understand parameters that play a key role in reserve estimations, c) investigate how to reduce uncertainties, and d) show the importance of accounting for parameter uncertainty in reserves assessment.

Introduction

An accurate estimate of the reservoir volume is important for optimal decision making. The first decision to make in any geostatistical study is the modeling scale. High resolution 3-D models are appropriate for modeling heterogeneity and providing input to flow simulation. They can't be used for uncertainty quantification. While Global statistical analysis is appropriate for checking and providing input to parameter uncertainty but it does not permit uncertainty assessment for specific locations or patterns. Best reserves estimations can be undertaken with 2-D modeling of parameters like structure, thickness (h), net-to-gross (NTG), average porosity (ϕ), and average water saturation (Sw).

Reserves volumes have significant uncertainty due to sparse well data and uncertainty in structural surfaces. In this report, reservoir data was used to develop a classical geostatistical approach to surface simulation and uncertainty assessment. The top surface structure of a reservoir, subsequent layer thickness, and oil water contact depths are uncertain. The main controls on the uncertainty assessment are (1) the possible deviations from the base case seismic predicted surfaces, that is, a distribution of the possible deviations from the base case, and (2) a variogram that specifies how fast the uncertainty increases away from the well locations.

Reservoirs consist of stratigraphic layers constrained by a top seal. The Gross Rock Volume (GRV) is the volume of a reservoir trapped between the top and bottom surfaces above the oil water contact (OWC), see Figure 1. Generally, the top and bottom structure surfaces are obtained from seismic interpretation, while the OWC can be estimated quite accurately. Seismic interpretation is performed in the time domain and transferred to depth with a time-to-depth conversion using some type of velocity model. There is no unique surface in units of depth because of uncertainties in the interpretation (in time) and uncertainties in the time-to-depth conversion. In general, the further away from the well locations is, the larger the uncertainties in the surfaces are, see Figure 2. Therefore, the calculated GRV is uncertain. This uncertainty is often recognized but not quantified. Simulation methods are implemented to assess the uncertainty in the GRV calculation.

Uncertainty in HIIP

In this section, the methodology of quantifying the uncertainty in reservoir structures surfaces will be described in details with briefly explaining for the method used to quantify uncertainty in petrophysical properties. Then, quantifying uncertainty in HIIP with parameter uncertainty will be explained, which means with a variable mean of parameter uncertainty.

Methodology

The estimation of Hydrocarbon Initially in Place (HIIP) can be calculated by multiplying GRV by Net-to-Gross ratio (NTG) by porosity (ϕ) by hydrocarbon saturation (1-Sw). A reserve requires an estimate of recovery and an economic feasibility study. There is interdependence between these parameters. For example, the NTG is often correlated with thickness (h), porosity (ϕ), and water saturation (Sw). Another consideration is the uncertainty in parameters, plus the disparate data types such as seismic and sparse well data.

Figure 3 summarizes the procedure proposed in this paper. It shows the flowchart for the proposed methodology. Structure and thickness uncertainty must be assessed in all reservoir uncertainty studies.

As mentioned before that this paper is mainly to quantify the uncertainties in estimating the reserve/resource volumes in the presence of geologic uncertainty. Even though, the uncertainties of other petrophysical properties will be investigated. To be completed, three steps have to be done. First step is to quantify the uncertainty in the structure surfaces (such as Top/Bottom surfaces, reservoir thickness, and fluid contacts). Second one is to quantify the uncertainties in some petrophysical properties (such as NTG, ϕ, and Sw). Third step is to find the uncertainty in HIIP calculated from the results of the first two steps combined. These steps will be conducted to quantify uncertainties without parameter uncertainty (with a mean of zero for parameter uncertainty).

Uncertainties in Reservoir Structure Surfaces

Structure and thickness uncertainty must be assessed in all reservoir uncertainty studies. A basic assumption is that the base case surface is unbiased and that deviations from the base case follow a Gaussian distribution. Reservoirs consist of stratigraphic layers constrained by a top seal. GRV is the volume of a reservoir trapped between the top and bottom surfaces and above the hydrocarbon-water contact, sometimes, a reservoir is bounded by stratigraphic pinch-outs or faults, see Figure 1. The uncertainty in GRV is due to sparse well data and uncertainty in structural surfaces and faults interpreted from seismic data, while OWC can be estimated quite accurately.

The first step is to study the uncertainty in estimating GRV; therefore, the top and bottom surfaces from seismic interpretation were considered as reference surfaces, which have been fitted to well data. Away from well locations, there exist uncertainties in the reference surfaces. The deviations from the reference surfaces are assumed to follow a known distribution (Gaussian as mentioned above). The deviation will be zero at the well locations and increase away from the well locations. Such deviations can be simulated by a Sequential Gaussian Simulation with conditioning data at the well locations to be zeros. Then the deviations can be added to the reference surfaces/layer thicknesses, see Figure 2. Such simulation provides alternative scenarios, which quantifies the uncertainty in the HIIP and provides us with a distribution of HIIP. In addition, the uncertainty in GOC/OWC level is investigated by determining its level, then a normal distribution generated randomly with a zero mean and some standard deviations. So many realizations can be generated to quantify the uncertainty in the fluid contact surfaces.

Uncertainties in Petrophysical Properties

The Net Pay or NTG can be inferred usually from well logs. Generally, the procedure involves exclusion of log intervals of the gross rock section judged to be noncommercial, the remainder being considered net pay. The relationship between the NTG and porosity has to be considered in the simulation. First, the minimum or cutoff porosity usually selected based on a correlation between permeability and porosity, where cutoff porosity corresponds to the minimum permeability judged to be commercial.

In this step, NTG and porosity realizations can be generated individually/ simultaneously by cosimulating the parameter(s) of interest with thickness obtained from seismic data. The hydrocarbon property can be treated the same way since it can be correlated to thickness, NTG, and porosity. In this paper, the realizations were generated by cosimulating NTG and Porosity simultaneously with thickness using an *ultimate_sgsim* code. This code was generated by CCG Group for collocated cokriging using super secondary variable (Babak and Deutsch, 2007).

Parameter Uncertainty

It is important to account for parameter uncertainty in the uncertainty calculations to get a fairly global uncertainty. There are several techniques for calculating parameter uncertainty in a required input histogram. These techniques include conventional bootstrap (BS), spatial-bootstrap (SBS), and Condition finite-Domain (CFD). A comparison between these approaches has been conducted and published by Babak and Deutsch (2006).

Any of the three techniques can be applied to quantify the uncertainty in the mean of each variable. Uncertainty in the mean is of primary importance; the details of the histogram are of second order importance compared to the mean. Uncertainty in the variogram is sometimes considered; however, it is also of second order importance. Uncertainty in the mean of each parameter will be quantified with the three techniques mentioned above and will be compared to choose the optimum technique for quantifying full uncertainties in HIIP with parameter uncertainty for this case study.

Case Study

The following case study is based on data set of Hekla reservoir, a portion of a large North Sea fluvial deposit offshore Norway. The Hekla data set is suitable for demonstrating the proposed approach. The data are available in two data files. The first file contains seismic data defining reservoir geometry, while the second file contains 20 well data including Well ID, X-Coordinate, Y-Coordinate, Depth, Log Porosity, and Log Permeability.

By analyzing the seismic data, it is obvious that the reservoir consists of two major layers, H1 and H2. It is also gridded horizontally into a 101 by 131 cells, and each cell represents 50 meters in two directions, X and Y, see Table-1.

From the seismic data, 2D and 3D views of H1 top surface are shown in Figure 4 gives an idea about the field structures and trends. Figure 5 shows a contour map for the top surface depth H1 with the distribution of the twenty well locations. From the 3D view, it was noticed that the low thickness-thin areas crossing the field have two faults.

Table 2 summarizes well locations, depth of top structure of each layer (H1, H2, and H3), and thickness of the two layers (H1 and H2) for all wells while Well No. 8 was eliminated from the data since it is a horizontal well with length of about 1000 m. Therefore, the thickness found does not reflect the actual vertical thickness in the layers especially H2 layer since H3 top structure is unknown. So, the study will be based on data of 19 wells only.

The histograms for all top structure depths from logs/well data were generated for the three top structures, H1, H2, and H3 layers. There are two populations in the histograms and they have the log-normal shape. The reason of the two populations might be due to the faults available in the field.

In this study, the uncertainties of eight parameters and their effects on HIIP were investigated individually and combined all together in a seventh case. First case studied the effects of structure surface uncertainties on HIIP. Second and third cases studied the effects of first and second layer thickness uncertainties on HIIP individually. While the effects of OWC level uncertainties were studied in the fourth case. The fifth and sixth cases investigated the effect of NTG uncertainties for the two layers on HIIP individually. While the seventh and eighth cases investigated the effect of porosity uncertainties for the two layers on HIIP individually. The last case combined the effects of all parameter uncertainties on HIIP. The study results were as the following:

CASE-1: Uncertainty of Top/Bottom Surfaces

This case investigated the effects of Layers structures, top and bottom surfaces uncertainties on HIIP. GSLIB software was used first in the method to generate the variogram of the well data using a *gamv2004* code for the Top structure of H1 Layer. The variograms were calculated in the omnidirection due to sparse data. Then the *vmodel* code was used to obtain the best variogram model fitting the variogram result trends. The equation of the H1 Top Surface variogram model, as shown in Figure 6, is:

$$\gamma(h) = 0.001 + 0.999 * sph \quad (1)$$
$$av = 1$$
$$ah1 = 2400$$
$$ah2 = 2400$$

By getting the variogram model parameters, the conditional Gaussian simulation was ran using a *sgsim* code with conditioning data at the well locations to be zeros. 100 realizations were generated where each realization gives a Gaussian distribution with a mean of zero and a standard deviation of one. The results then were analyzed with MATLAB codes by multiplying the results with some standard deviations then adding the new results to the reference data, see Equation (2). The standard deviation of the distributions should be estimated by referring to seismic interpretation, and it was assumed to be 15 meters for the reference top and bottom surfaces in this study. Finally, the uncertainties in HIIP were estimated by calculating the HIIP of each realization and generating a distribution plot.

$$z^l(u) = z_b(u) + y^l(u) * \sigma_\Delta * f(u) \quad (2)$$

Three runs were conducted with different assumed OWC level; its level depth was assumed at 2050m in the first run, 2100m in the second run, and 2150m in the third one in order to investigate the impact of OWC level depth on the calculations; since calculating HIIP relays not only on the top and bottom surfaces, but also on OWC level. The influence of surface deviations on HIIP is restricted by OWC level. By comparing the results, see Figure 7. The OWC is fixed at 2150m in all cases studying uncertainties in other parameters, see Table 3. In reality, OWC should be determined by logs or should be assumed at the lowest known hydrocarbon level, if not detected.

CASE-2: Uncertainty in H1-Layer Thickness

In this case, the effects of H1 layer thickness uncertainties on HIIP were investigated. Simulated thicknesses are obtained for each layer by adding the reference thicknesses and normally distributed deviations. Similarly to what have been done in investigating the top/bottom surfaces structures, the deviations can be generated by a sgsim code with zero values at well locations. The problem in running this case is that the variogram model could not be generated due to a decreasing trend of the experimental variograms obtained from H1 layer thicknesses at well locations. Therefore, the variogram model obtained from top surface structure was used in case-2 to generate the Sequential Gaussian simulation conditioned to be zero at well locations. The standard deviation for H1 layer thickness was assumed to be 3m. 100 realizations were run to get the HIIP distributions. The results of HIIP distributions were obtained and summarized in Table-4.

CASE-3: Uncertainty in H2-Layer Thickness

It was similar to what was conducted in the previous case, but the variogram model used in this case was generated using H2-Layer thickness data at all well locations, see the second plot in Figure-10; where the equation of the H2 Thickness variogram model is:

$$\gamma(h) = 0.001 + 0.999 * sph \quad (3)$$
$$av = 1$$
$$ah1 = 4000$$
$$ah2 = 4000$$

Then the deviations were generated by a sgsim code with a zero mean value and a standard deviation of one and conditioning values at well locations to be zeros. The standard deviation was assumed in this case to be 3m; and by generating 100 realizations, the HIIP distributions were obtained and summarized in Table-4.

CASE-4: Uncertainty in Oil/Water Contact Level

In this case, the effects of OWC level uncertainties on HIIP were investigated by generating deviations randomly assuming a normal distribution with a mean of zero and standard deviations of 1, 2, 4, and 8m. The deviations were added to the reference OWC level at 2150m. For each standard deviation, 100 realizations were also run to get the HIIP distributions above OWC as shown in Figure 8 and Table-4.

As expected that, the bigger the standard deviation is, the more the uncertainty in HIIP becomes. The parameters of the fourth run in this case with a standard deviation of 8m were selected to be used in Case-9 when full uncertainty is quantified.

CASES-5 and 6: Uncertainty in NTG for H1 and H2 Layers

The NTG data on well locations was inferred from well logs. It was based on assuming a porosity cutoff of 10% in this study. Table-3 shows the net pay and NTG for each layer in all 19 wells based on this cutoff with some statistical analysis for this data.

100 NTG realizations were generated by cosimulating NTG and Porosity simultaneously with thickness obtained from seismic data using an *ultimate_sgsim* code. The HIIP distributions were obtained and summarized in Table-4 for the effects of H1 layer NTG uncertainty and H2 layer NTG uncertainty individually.

CASES-7 and 8: Uncertainty in Porosity (ϕ) for H1 and H2 Layers

As mentioned in above that porosity cutoff was assumed to be 10% in this study. Figure 9 shows the histogram of porosity obtained from logs data. As mentioned in last two cases, 100 porosity realizations were also generated for both layers using an *ultimate_sgsim* code by cosimulating NTG and porosity with thickness data obtained from Seismic data for each layer. The HIIP distributions were also obtained and summarized in Table-4 for the uncertainty effects of H1 layer porosity and H2 layer porosity individually on HIIP.

CASE-9: Full Uncertainty Quantification

In this case, multiple realizations should be drawn with uncertainty attached to all parameters, surface structures, layer thicknesses, OWC levels, NTG, and Porosity for each layer. The deviations were generated without parameter uncertainty (with a mean of zero) for all parameters and standard deviations of 15m for surface structure depths, 3m for each layer thicknesses, and 8m for OWC level depth. 100 realizations were generated to get the HIIP distributions above OWC level of 2150m as shown in Figure 10.

Figure 11 shows a tornado charts for all parameters affecting HIIP distribution for H1 layer. The results were similar where thickness uncertainty was the most effective parameter on HIIP distribution. Then the uncertainty in the structure of top and bottom surfaces was the second most effective parameter on HIIP distribution. From these results, it is obvious that ignoring the uncertainty in reservoir structure surfaces might lead to underestimating of the global uncertainty and making bad decisions. The thickness and structure surface uncertainties had more effective on HIIP distribution than Petrophysical properties. While the uncertainty in OWC depth level was the last as the least effective parameter on HIIP distribution.

On the other hand, comparing the effects of all parameters on HIIP distribution for both layers had a slight change; where the uncertainty in structure surfaces became more effective on HIIP distribution than H2 layer thickness uncertainty.

Conclusion and Future Work

We would wish for the lowest uncertainty possible. However, too narrow uncertainty due to ignoring the uncertainty in the present geology leads to a false confidence in reserves and resources. Our aim is to obtain a realistic and fair measure of uncertainty. Decisions of stationarity and a modeling methodology are the most important factors in determining output uncertainty in any practical modeling study. In this preliminary study, a methodology for the assessment of uncertainty in the structure surfaces of a reservoir was developed and investigated. A more complete setup will have to be considered with accounting for parameter uncertainty in order to get a fairly global uncertainty. There is no question that uncertainty in the input histogram main parameter, such as the mean, must be considered for realistic global uncertainty characterization. There are several techniques for calculating parameter uncertainty in a required input histogram. These techniques include conventional bootstrap (BS), spatial-bootstrap (SBS), and Condition finite-Domain (CFD).

Any of the three techniques can be applied to quantify the uncertainty in the mean of each variable, whose uncertainty is of primary importance; Uncertainty in the mean of each parameter will be quantified with the three techniques mentioned above and will be compared to choose the optimum technique for quantifying full uncertainties in HIIP with parameter uncertainty. The results of uncertainty in HIIP distribution with/without parameter uncertainty will be analyzed and assessed to show the importance of accounting for parameter uncertainty in estimating HIIP in the presence of geology uncertainty.

References:

Babak, Olena and Deutsch, Clayton V., 2007; *Merging Multiple Secondary Data for Collocated Cokriging (recall of super secondary variable),* CCG Report 9.

Babak, Olena and Deutsch, Clayton V., 2006; *A Conditional Finite-Domain (CFD) Approach to Parameter Uncertainty,* CCG Report 8.

Deutsch, C.V., 2002, *Geostatistical Reservoir Modeling*. Oxford University Press, New York.

Deutsch, C.V. and Journel, A.G., 1998, *GSLIB: Geostatistical Software Library: and User's Guide*. Oxford University Press, New York, 2nd Ed.

	Minimum	Maximum	Cell Size	No. of Cells
X-Coordinate	0	5000	50	101
Y-Coordinate	0	6500	50	131

Table-1: Summary of Reservoir Grids

Well number	X-Coor.	Y-Coor.	Depth of Top H1	Depth of Top H2	Depth of Top H3	Thickness H1	Thickness H2
1	2618.6	6257.0	2044.2	2078.3	2110.8	34.1	32.5
2	2433.9	4679.5	1924.1	1958.3	1988.2	34.2	29.9
3	2021.5	2257.5	2012.3	2043.7	2073.5	31.4	29.8
4	4055.8	2759.5	2043.3	2075.9	2105.3	32.6	29.4
5	2667.0	4445.5	1986.7	2018.6	2046.3	31.9	27.7
6	2073.8	4630.0	1875.4	1897.4	1926.0	22.0	28.6
7	1197.0	4248.0	1889.7	1919.9	1943.3	30.2	23.4
9	3998.3	4748.0	2072.7	2103.5	2130.8	30.8	27.3
10	1747.9	3914.0	1890.5	1917.5	1943.8	27.0	26.3
11	2893.0	3733.0	2023.9	2060.9	2088.7	37.0	27.8
12	1223.8	2709.0	1928.2	1959.8	1983.3	31.6	23.5
13	2841.6	2387.5	1919.1	1954.9	1986.9	35.8	32.0
14	1797.3	1752.0	2006.4	2040.1	2067.6	33.7	27.5
15	4607.4	1990.0	2185.3	2214.2	2242.5	28.9	28.3
16	893.9	342.5	1953.0	1981.5	1987.7	28.5	6.2
17	841.8	1433.5	1957.7	1996.3	2023.6	38.6	27.3
18	2702.6	5165.0	1916.0	1950.1	1982.8	34.1	32.7
19	1583.1	4488.0	1821.6	1838.3	1862.6	16.7	24.3
20	2549.1	2889.5	2038.9	2070.9	2097.2	32.0	26.3

Table-2: Summary of Well Locations, Depth of Top Structure of Each Layer (H1, H2, and H3), and Thickness of The Two Layers (H1 and H2).

Well number	Thickness H1	Thickness H2	NP1	NP2	NTG for H1	NTG for H2	Av. Poro. H1	Av. Poro. H2	Std.Dev. Porosity-H1	Std.Dev. Porosity-H2
1	34.1	32.5	18.4	13.6	54.0	41.8	0.1898	0.1701	0.0523	0.0487
2	34.2	29.9	30.8	15.3	90.1	51.2	0.2214	0.2018	0.0637	0.0636
3	31.4	29.8	26.2	11.2	83.4	37.6	0.2032	0.2101	0.0662	0.0670
4	32.6	29.4	22.8	11.9	69.9	40.5	0.1987	0.1642	0.0613	0.0644
5	31.9	27.7	14.7	1.1	46.1	4.0	0.2381	0.1609	0.0521	0.0289
6	22.0	28.6	12.7	12.9	57.7	45.1	0.2142	0.2509	0.0686	0.0592
7	30.2	23.4	8.8	4.3	29.1	18.4	0.2116	0.1504	0.0579	0.0524
9	30.8	27.3	16.9	11.8	54.9	43.2	0.2266	0.2183	0.0614	0.0522
10	27.0	26.3	12.7	12.6	47.0	47.9	0.2625	0.1789	0.0857	0.0671
11	37.0	27.8	15.2	11.4	41.1	41.0	0.2248	0.2015	0.0587	0.0586
12	31.6	23.5	10.9	6.4	34.5	27.2	0.2074	0.2518	0.0751	0.0582
13	35.8	32.0	12.7	14.3	35.5	44.7	0.2245	0.2530	0.0855	0.0542
14	33.7	27.5	19.7	10.0	58.5	36.4	0.2558	0.2429	0.0789	0.0774
15	28.9	28.3	0.2	7.1	0.7	25.1	0.1116	0.1725	0.0066	0.0455
16	28.5	6.2	11.4	0.0	40.0	0.0	0.2546	0.0000	0.0596	NA
17	38.6	27.3	3.5	4.4	9.1	16.1	0.1914	0.1925	0.0682	0.0590
18	34.1	32.7	21.4	3.1	62.8	9.5	0.2596	0.1539	0.0528	0.0205
19	16.7	24.3	1.6	12.6	9.6	51.9	0.1308	0.1826	0.0236	0.0557
20	32.0	26.3	15.2	8.3	47.5	31.6	0.2542	0.1980	0.0586	0.0601
Minimum	16.7	6.2	0.2	0	0.7	0.0	0.1116	0.0000	0.0066	0.0205
Maximum	38.6	32.7	30.8	15.3	90.1	51.9	0.2625	0.2530	0.0857	0.0774
Mean	31.1105	26.8842	14.5158	9.0684	45.8607	32.2658	0.2148	0.1871	0.0598	0.0552
Std.Dev.	5.1155	5.6834	7.9049	4.6557	23.5292	15.9817	0.0404	0.0563	0.0189	0.0134

Table-3: Summary of Each Layer Thickness, Net Pay, Net-to-Gross, Average Porosity, and Porosity Standard Deviation in All 19 Wells Based on 10 % Porosity Cutoff.

Cases			HIIP for both layers							
			Base Case	Mean	Std. Dev.	P10	P90	95% P.I.	P10 - Mean	P90 - Mean
Uncertainty in Top Structure	OWC at 2050	Case 1-a	6.3508	6.3530	0.1016	6.2040	6.4758	0.3545	-0.1490	0.1229
	OWC at 2100	Case 1-b	8.1475	8.1407	0.0998	8.0325	8.2678	0.4028	-0.1082	0.1271
	OWC at 2150	Case 1-c	9.1869	9.1777	0.0769	9.0875	9.2880	0.3070	-0.0902	0.1104
Uncertainty in Thickness	H1 Layer	Case 2	9.1869	9.2133	0.0851	9.1151	9.3337	0.3024	-0.0982	0.1204
	H2 Layer	Case 3	9.1869	9.1928	0.0432	9.1418	9.2542	0.1539	-0.0510	0.0613
Uncertainty in OWC	Std.Dev.= 1	Case 4-a	9.1869	9.1868	0.0006	9.1861	9.1877	0.0025	-0.0007	0.0008
	Std.Dev.= 2	Case 4-b	9.1869	9.1867	0.0014	9.1847	9.1883	0.0053	-0.0020	0.0016
	Std.Dev.= 4	Case 4-c	9.1869	9.1866	0.0025	9.1836	9.1895	0.0099	-0.0030	0.0029
	Std.Dev.= 8	Case 4-d	9.1869	9.1836	0.0045	9.1777	9.1896	0.0161	-0.0059	0.0060
Uncertainty in NTG	H1 Layer	Case 5	9.1869	8.9908	0.0331	8.9537	9.0249	0.1003	-0.0372	0.0341
	H2 Layer	Case 6	9.1869	9.0328	0.0223	9.0093	9.0490	0.0600	-0.0234	0.0162
Uncertainty in Porosity	H1 Layer	Case 7	9.1869	8.9876	0.0220	8.9745	8.9971	0.0374	-0.0131	0.0094
	H2 Layer	Case 8	9.1869	9.0395	0.0159	9.0304	9.0454	0.0206	-0.0091	0.0059
Combined all	Combined all	Case 9	9.1869	9.2289	0.1129	9.0669	9.3637	0.4283	-0.1620	0.1348

Table-4: HIIP analysis for Both Layers; values are in million cubic meters.

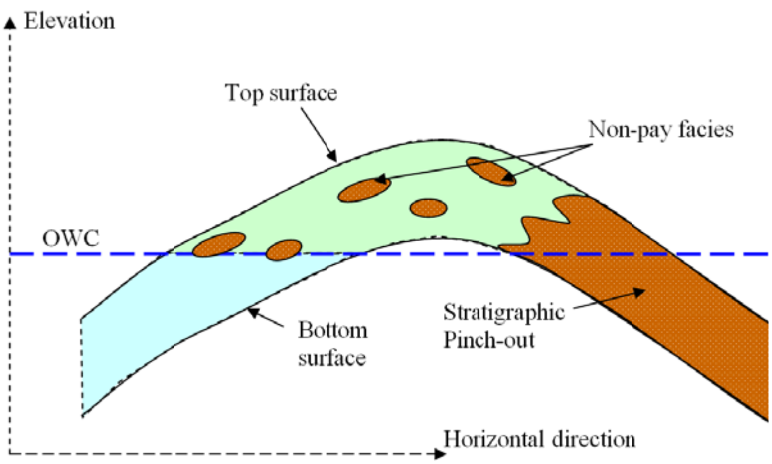

Figure 1: Reservoir Cross-section: The reservoir is bounded by the top and bottom structure surfaces and above the OWC level as shown in the green area above and excluding the non-pay facies.

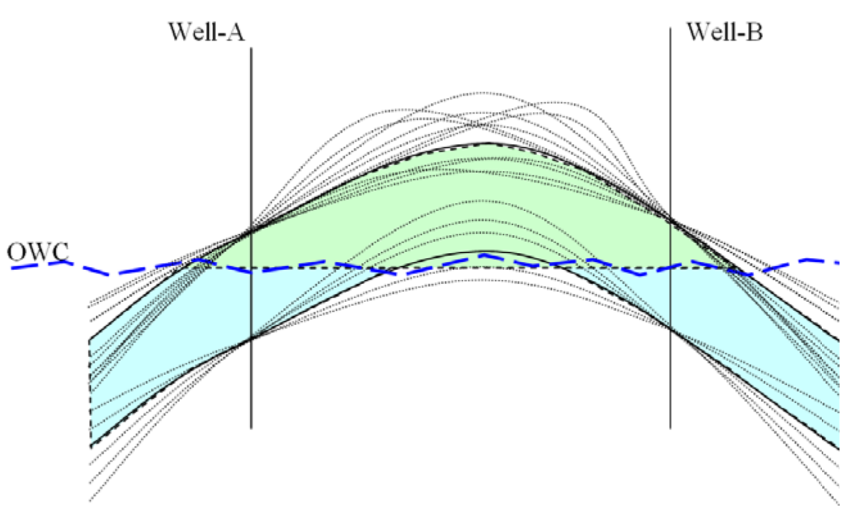

Figure 2: The uncertainty of the values of top/bottom surface structure and reservoir thickness increases as goes far from well locations.

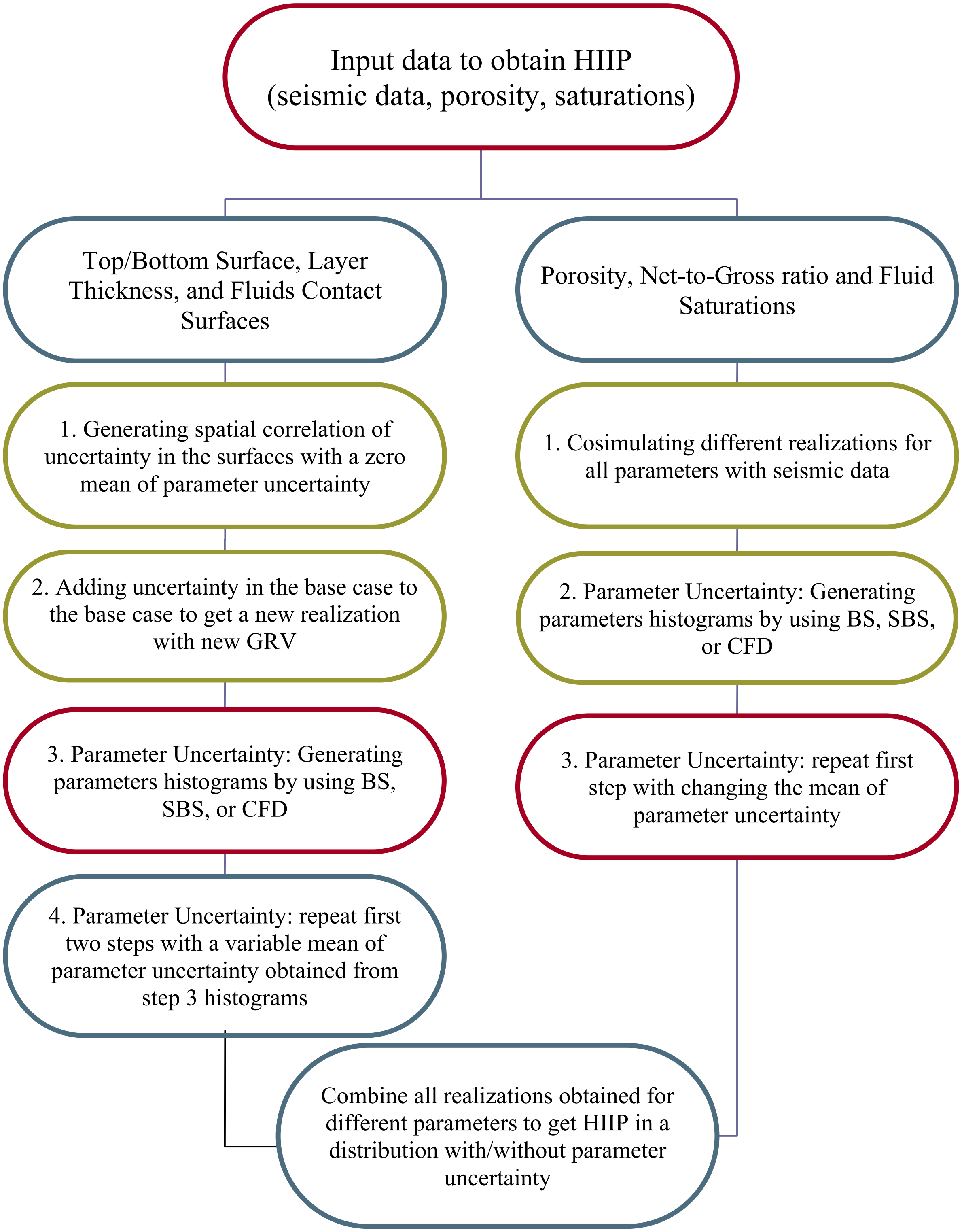

Figure 3: Flowchart of the proposed methodology.

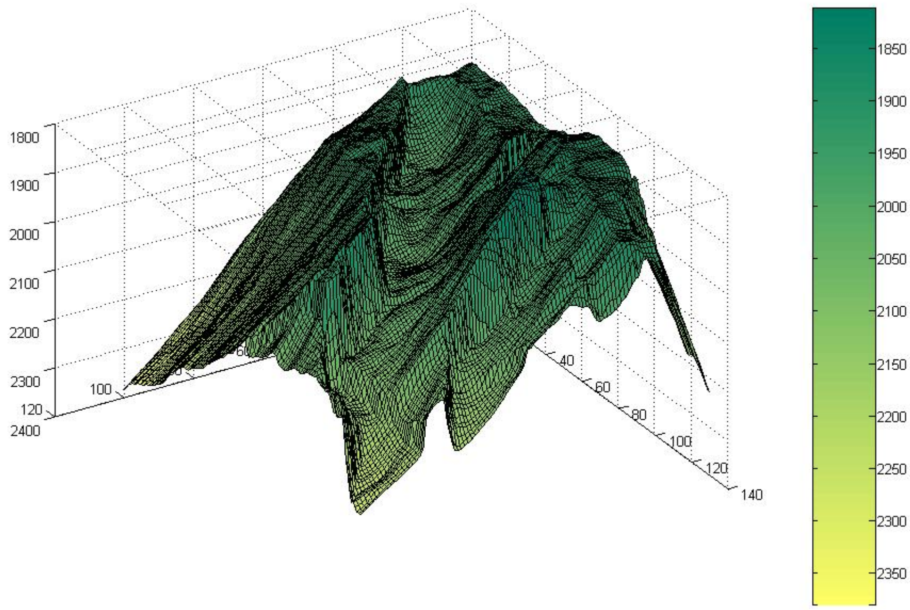

Figure 4: 3D view of Hekla field, top structure of H1 layer.

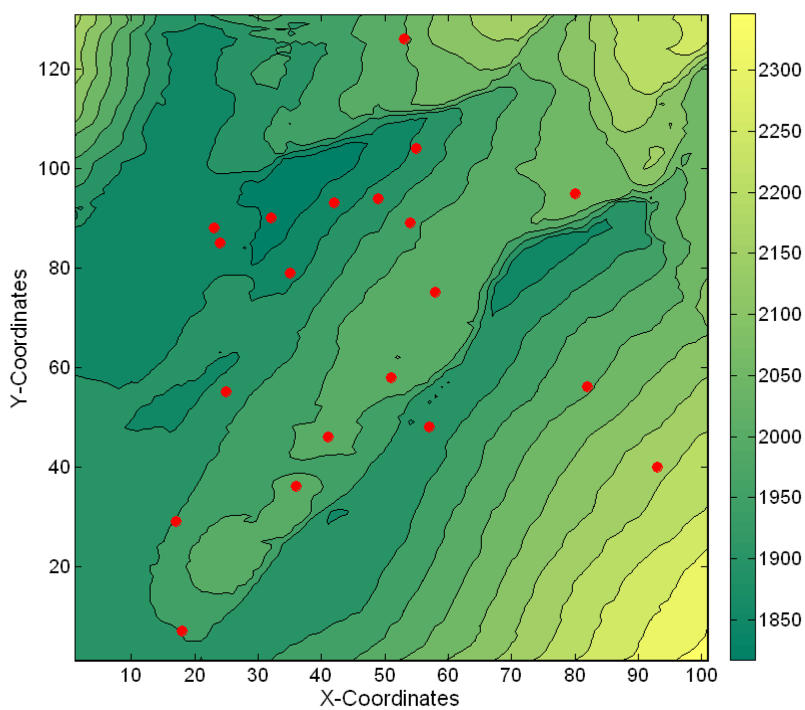

Figure-5: Contour map of H1 layer depth in Hekla field with showing the distribution of twenty well locations.

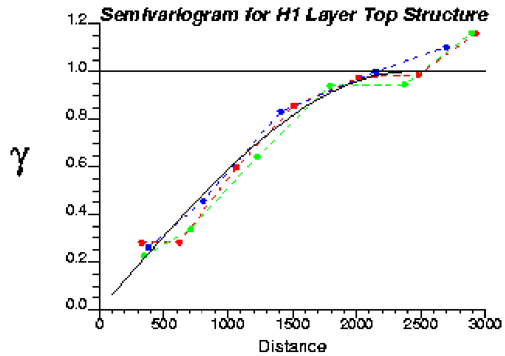

Figure 6: The variogram models fitting the experimental variograms for H1 Top Structure Depth.

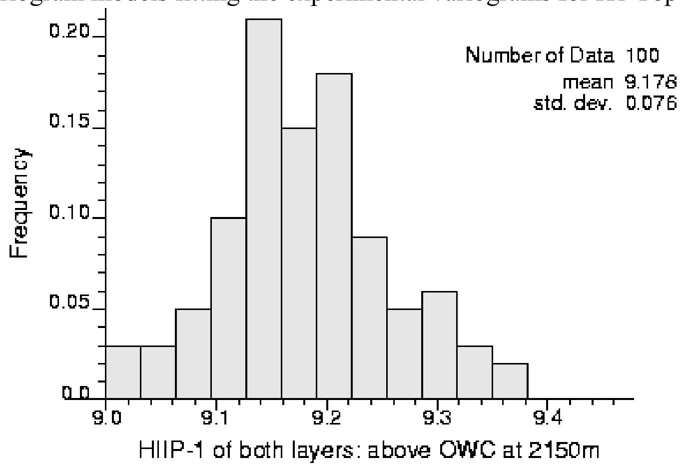

Figure 7: Case1-Histograms of HIIP for Both Layers above OWC of 2150m with uncertainty in Top/Bottom Surface Structure with a mean of zero and a standard deviation of 15m.

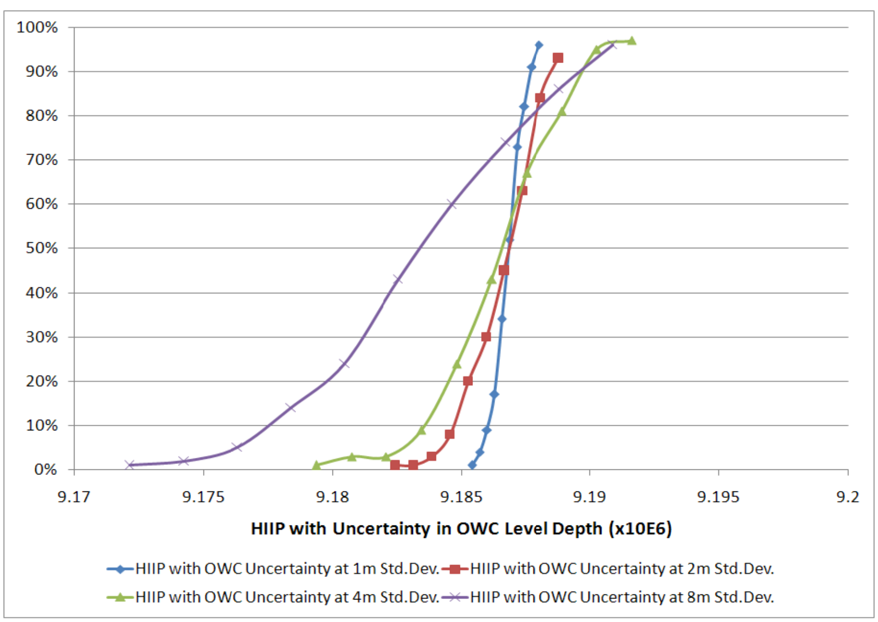

Figure 8: Case4-CDF's of HIIP for Both Layers above OWC of 2150m with uncertainty in OWC depth level with a mean of zero and a standard deviation of 1m, 2m, 4m, and 8m, respectively.

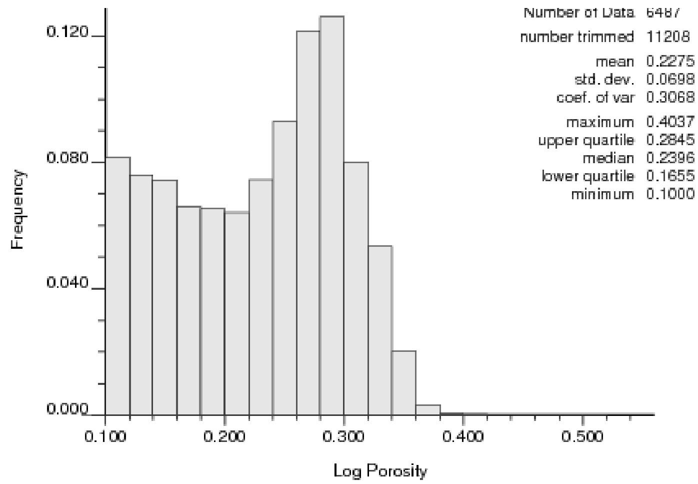

Figure 9: The histogram of porosity data obtained from logs over 10% porosity cutoff.

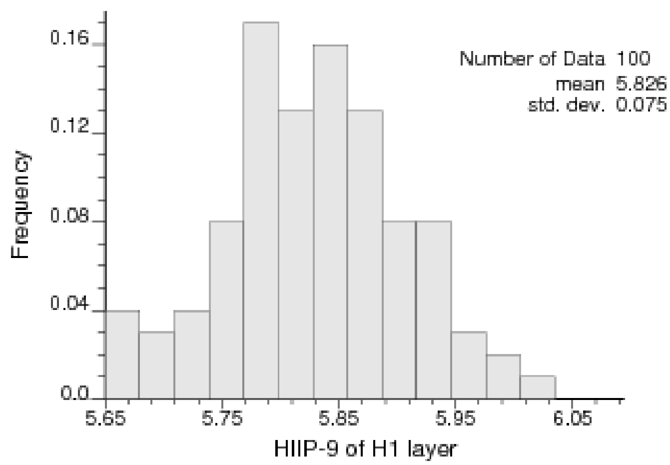

Figure 10: Case9-Histograms of HIIP for H1 Layer above OWC of 2150m with Full Uncertainty.

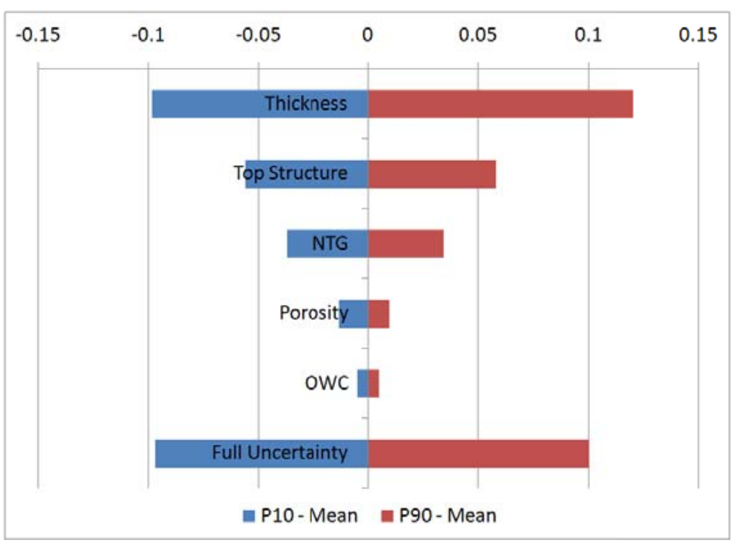

Figure 11: Tornado Chart for HIIP Distributions of H1 Layer.