Vertical Placement of Well Pairs in SAGD

Abhay Kumar and Clayton V. Deutsch

Drilling horizontal well pairs within bitumen deposit is a critical step for SAGD production. The production from well pair is highly affected by the surrounding rock types. This paper discusses a probabilistic approach to achieve a certain effective well length as function of depth. Methodology quantifies the probability of maintaining a cut-off effective well length for different elevation. A tool is developed to calculate and plot the effective well length over multiple realizations of base continuous bitumen. Inclined well pairs are also considered for effective well length calculation.

1. Introduction

Placement of SAGD well pair is very crucial and challenging for production. A large portion of well must pass through continuous bitumen body in order to be effective. A well portion passing through impermeable rocks like shell can cause serious production problem and even well failure. This portion of well does not contribute in heating and melting the bitumen and is ineffective well length. Steam injected in ineffective well portion is not used for bitumen production and therefore increases the steam to oil ratio of production. Because of this it is very important to make the well pairs as much effective as possible. Placing well pairs at higher elevation ensures the greater portion of well to be effective. But resource below producer cannot be accessed. Placing a well pair higher might result into loss of resource. An optimal vertical position of well can be achieved by ensuring the balance between loos of resource and loss of well length.

Uncertainty in the reservoir makes the well placement even more challenging. Balancing the effective well length and resource access can be easy if truth is known. A probabilistic approach is necessary to quantify the objective function in terms of uncertainty. The objective is to place the well pair deepest (maximum possible resource access) and ensure that a minimum probability threshold is maintained for a given length of well pair effective. The exact resource calculation is not presented here but can be found in [1].

2. BCB Surface

A continuous bitumen deposit can be defined within two boundary limits. The base of continuous bitumen deposit is BCB (base continuous bitumen) and top is TCB (top continuous bitumen). The definition of these boundaries can be used to define the limit of resource. For simplicity it is assumed that there is no SAGD recoverable resource below BCB surface and above TCB surface. Also, a well portion below the BCB surface is ineffective. Same way any well portion above the TCB is ineffective. In this paper only BCB is considered for effective length calculation. Generally well pairs are located in thick reservoirs and passing of a well pair through TCB limit is rare.

3. Problem Definition

Placement of horizontal well pair is more challenging because of uncertainty in BCB. Multiple geological realizations of BCB can be used in uncertainty analysis of well placement. A minimum portion of producer should be effective in order to be an efficient production from well. The problem can be expressed as determining the probability of effective well length as function of well elevation. Placing well at higher elevation increases effective well length but at the cost of loss of resource below. The objective is to achieve a certain level of confidence in well placement over effective well length. Mathematically this objective can be expressed as:

$$\text{Find } \min\ Z_{elev} \text{ of well such that: } prob(l_{eff} > x\%) > p_c \qquad (1)$$

Where $x\%$ effective well length is cut off and p_c is the minimum probability to achieve $x\%$ cut off length. For example $prob(l_{eff} > 80\%) > 0.9$ means that find the minimum elevation of well for which there is 0.9 probability that 80% of well length will be effective. To simplify the problem only straight line well trajectories are considered.

It is possible to have little curved well trajectories but it can be approximated by straight lines. Also, both flat and inclined wells are considered here and probabilistic calculations can be performed for both.

4. Methodology

A FORTRAN program `baseconfor` is developed to calculate the probability of effective well length as function of mean well elevation. Mean elevation of well is average of elevation of toe and heel. A well can be either flat or inclined but it has been assumed that well trajectory can be represented by straight line. **Figure-1** Illustrates the well position over BCB map. It also shows the BCB surface along the well. Surface shown in **Figure 1** is elevation of BCB surface as one move from heel of well (x1, y1) to toe of the well (x2, y2). Effective well length calculation is done by summing all effective well lengths over all cells. All cells along the well trajectory are determined and fraction of well length intercepted in each cell is calculated. Then effective well length is calculated by summing all fraction of well length in cells with lower BCB than well elevation at that cell. Considering inclined wells adds some interesting results. **Figure 1** shows flat well. **Figure 2** shows two possibilities of inclined wells: I, and II with equal mean well elevation. Well-I is inclined upwards and II is inclined downwards. But it is obvious for this case that case I is more favorable in terms of less ineffective well length. Calculation of effective well length in case of inclined well is little bit trickier. The correct effective well length calculation for a single cell is illustrated in **Figure 3**. In case of inclined well it is possible that some part of well inside a cell be below BCB value of cell and some well part above. The developed program takes care of this detailed calculation and produces a very precise effective well length calculation.

5. Calculating probability of effective well length

Uncertainty in BCB is quantified over horizontal well planning by means of probability distribution of effective well length calculated over multiple realizations. **Figure 5** shows all possible BCB surfaces along well, determined from 100 realizations. **Figure 4** shows one realization of BCB surface along with mean of BCB surface over 100 realizations. Planned well elevation is also shown in **Figure 5**. We are interested in the Probabilistic measure of effective well length over some cutoff. For this example we are calculating the probability of having effective well length more than 80%. A maximum of 5m elevation difference between heel and toe is allowed to provide inclined well. Well can be either inclined upward or downward. It is possible that upward inclined wells can be better at some elevations and downward inclined wells at different elevation. It depends on the trend of BCB surface for that elevation.

Effective well length is calculated for all 100 different realizations and for different well elevation with different well inclination. First effective length calculation is performed for flat well. Then small elevation difference between toe and heel of well are added in incremental manner and effective well length is calculated. The mean elevation of well is kept constant for this elevation calculation. The inclination of well is limited by some maximum allowable elevation difference between heel and toe of the well. An inclination which gives the maximum effective well length of this average well elevation calculation is selected. In case of equal effective well length for two different inclination (but same mean well elevation) is decided by one with minimum inclination. This way the distribution of effective well length is calculated for different elevation. **Figure 6** shows the plot of effective well length for all 100 realizations over different elevations. The two blue lines at bottom and top are P5 and P90 curves of effective well length. The middle red curve represents the P50 of effective well length for different elevation. The distribution of effective well length for 140m well elevation is also shown. **Figure 6** considers only flat wells. It also shows the probability o having 80% of effective well length for different elevations. This probability is calculated by CDF of effective well length. A 2m increase in well elevation increases the probability from 0.30 to almost 0.60.

Similar analysis is shown for inclined well case (**Figure 7**). A maximum elevation difference of 10m was allowed between heel and toe of well. **Figure 7(b)** shows the optimum inclination of well in terms of elevation difference between heel and toe of well. The probability of having at least 80% of well effective increased from 0.30 to 0.4. A positive elevation difference between toe and heel suggests that well is inclined upwards (**Figure 7(b)**). Increasing the well elevation by 2 meters gives probability of 1 having at least 80% of well length effective as compared to 0.6 in case of flat well.

6. Parameter file

Developed program calculates and plots BCB surfaces along well, distribution of effective well length for different well elevations and probability of having effective over provided cut off. The parameter file for **`baseconfor`** program is shown in **Figure 8**. The first line of parameter file has three inputs- name of BCB realization file, column number of BCB in file and total number of realizations to use in effective well length calculation. If single realization of BCB is provided then program calculates similar to multiple realization input but there is no distribution of effective well length over different elevations. Therefore the final plot of probability will be binary. Line 2 and line 3 of parameter file specifies the grid specification of BCB realizations. Line 4 specifies the well trajectory. The first four parameters are the co-ordinates of heel and toe. The first two values are x and y co-ordinates of heel and then the next two values are x and y co-ordinates of toe. The fifth parameter is the maximum allowable difference between the elevations of heel and toe. A 0 value of this parameter can be used for flat well calculations only. The sixth and last parameter in this line specifies the step size to increment the mean well elevation. Effective well length calculations are performed at all possible mean well elevations. Line 5 has two parameters. First parameter is flag to whether generate and ASCI output file with details of effective well length calculation. The next parameter is the name of output file. If flag is set to one then the output file contains the effective well length percentage for different realization, different mean well elevation and for different inclination of wells. Line 6 specifies the name of postscript output file to plot BCB map and surface along the well. This file contains two plots. First plot is the map of BCB along with well plotted over it. The second parameter specifies the realization number of BCB to plot as a map. A -1 value of second parameter will plot mean of BCB over all realizations. The last two parameters are the color limits of BCB for map. The same postscript file also plots all BCB surfaces along the well similar to as shown in **Figure 5**. The P5, P50, and P10 of BCB surfaces along the well are also plotted. Line 7 specifies the name of another postscript output file. This file plots effective well length plot for both flat and inclined wells. If inclined well is not specified then only plots corresponding to flat wells are shown. If inclined well is specified then plot contains results for both flat and inclined wells together in same file. All the plots shown in **Figure 6** and **Figure 7** are plotted in this file. The next parameter is the minimum cut off length for probability plot and calculation. The last parameter is planned well elevation. All plots with BCB surfaces, Effective well length, and probability reflects the planned well elevation.

References:

[1] Kumar, A; Deutsch, C.V;, 2010, Optimal Vertical Placement of Well Pairs in SAGD, CCG Report 201

[2] Mclennan, J.A;, Ren, W.;, Leuangthong, O;, and Deutsch, C.V; 2006, Optimization of SAGD well elevation, Natural Resource Research, 15(2), 120-121pp.

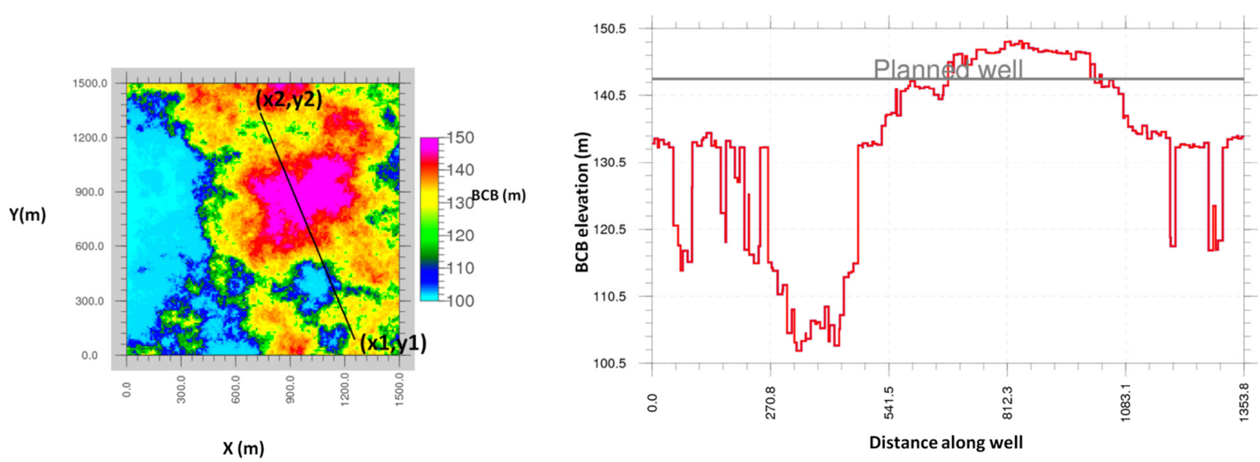

Figure 1- An Example of well position (left) and BCB surface along well (right) along the well, moving from (x1,y1) to (x2,y2).

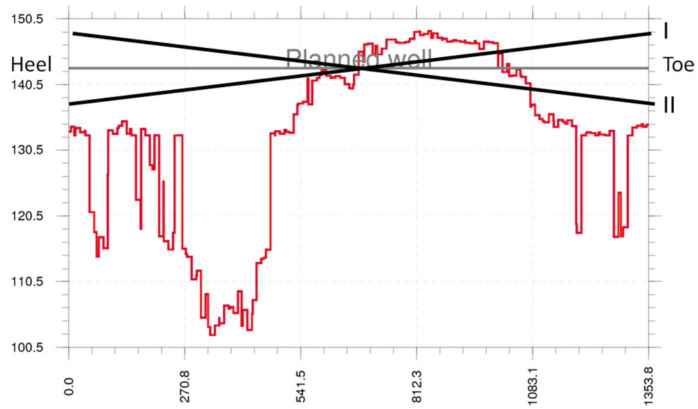

Figure 2- Two possibilities of inclined well.

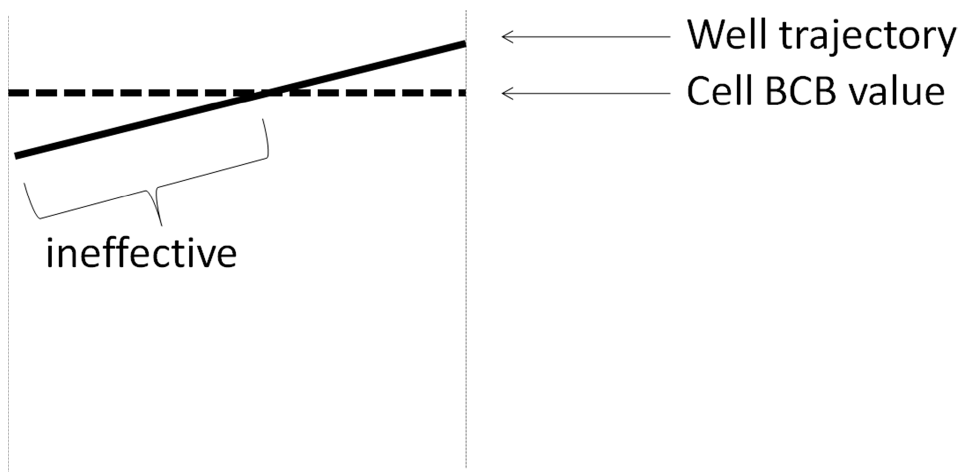

Figure 3- Effective well length calculation for a single cell.

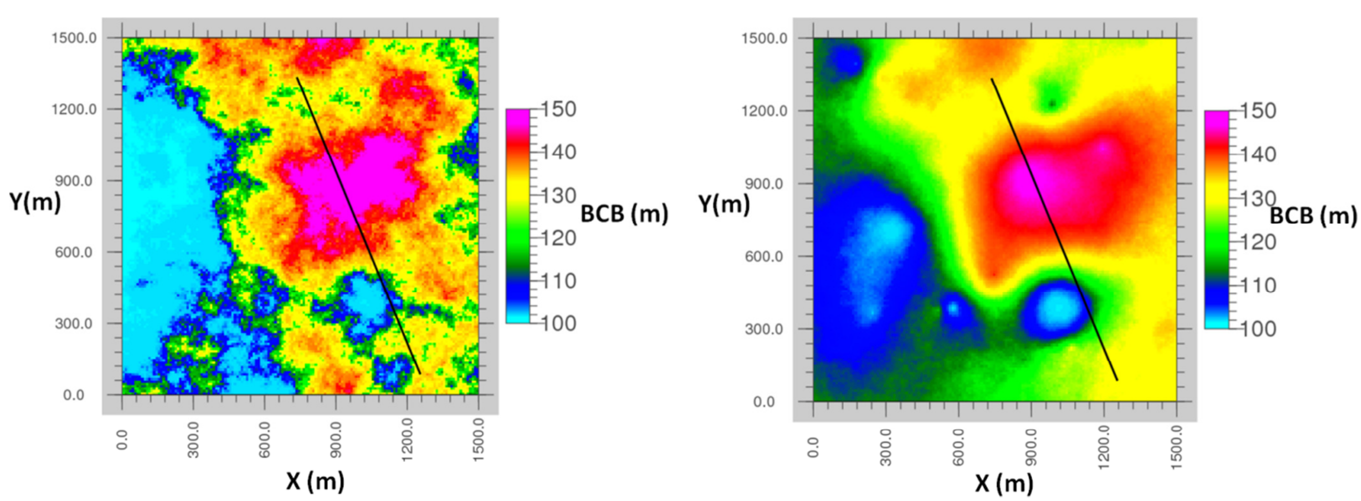

Figure 4- Well location over BCB realization 1 (left) and mean of BCB calculated from 100 realizations.

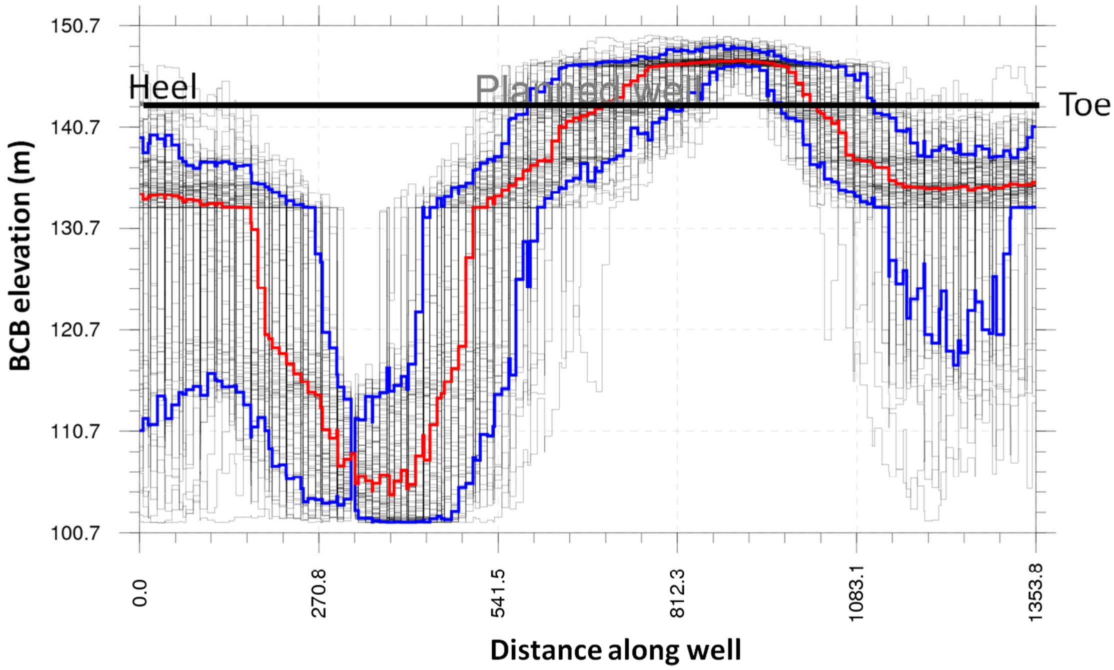

Figure 5- BCB surfaces along well determined from 100 realizations. Planned well elevation is also shown with dark horizontal line.

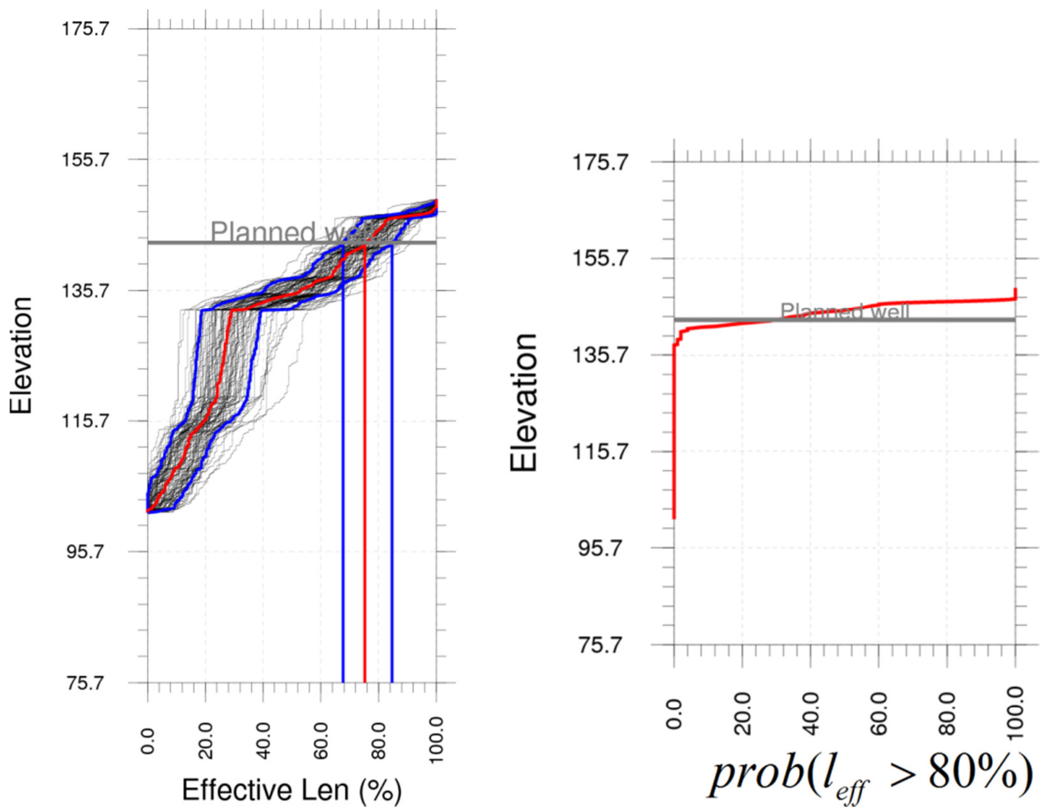

Figure 6- Effective well length in case of flat well trajectory. Distribution of effective well length over multiple realizations for different well elevation (left). Probability of having at least 80% of well effective (right)

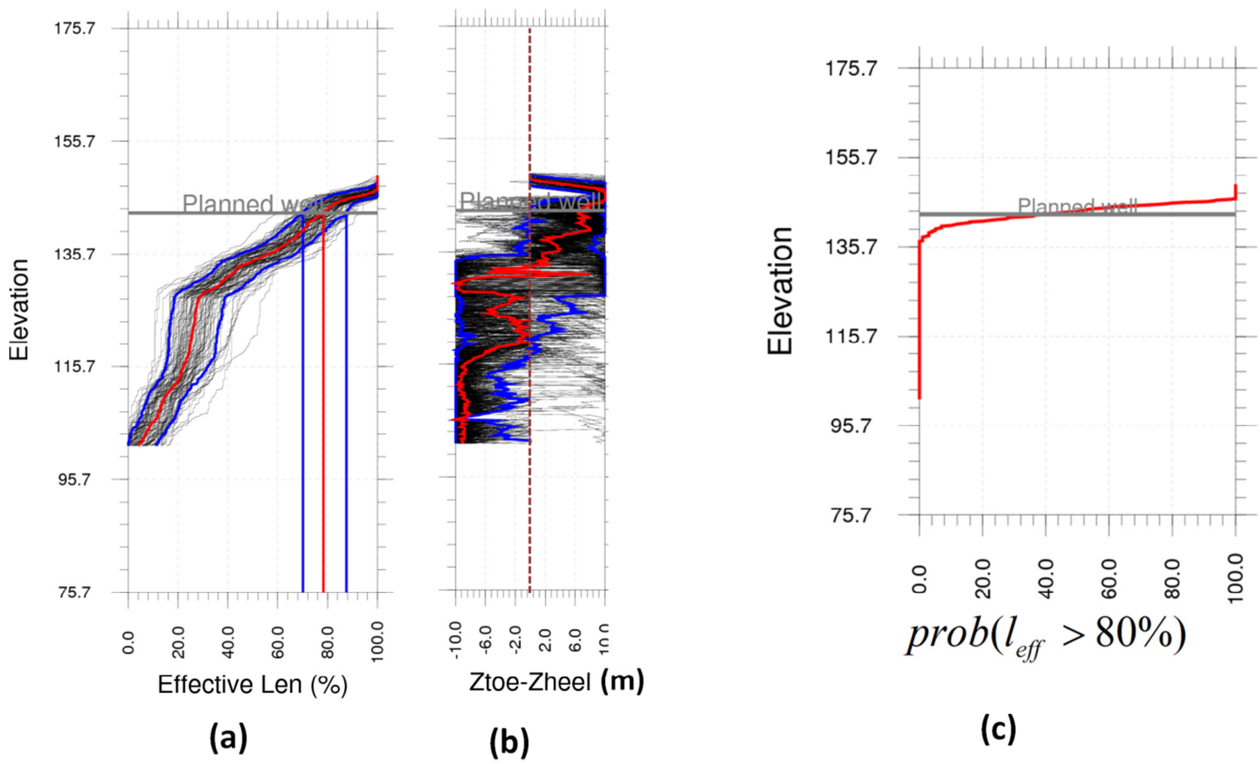

Figure 7- Effective well length in case of inclined well trajectory. (a) Probability of having at least 80% of well effective. (b) Optimum elevation difference between toe and heel of well. (c) Probability of effective well length being greater than 80% for different well elevation.

```
                   Parameters for BaseConfor
                   *************************

START OF PARAMETERS:
bcb100.out  1  100              -Input Data file, column number, number of realizations
150 5  10                       -input size: nx,xmn,xsiz
150 5  10                       -             ny,ymn,ysiz
1255 85 735 1335 10  0.2        -x1,y1,x2,y2,deltaz, stepz
1  baseconf.out                 -write result (1-yes), Result file
BCBwell.ps -1 100 150           -PS file for BCB surfaces along well, realz nbr to plot (-1 = mean), cmin, cmax
Probability.ps   80  143        -PS file for probability plot, min eff. well length, planned well elevation
```

Figure 8- Parameter file for effective well length calculation