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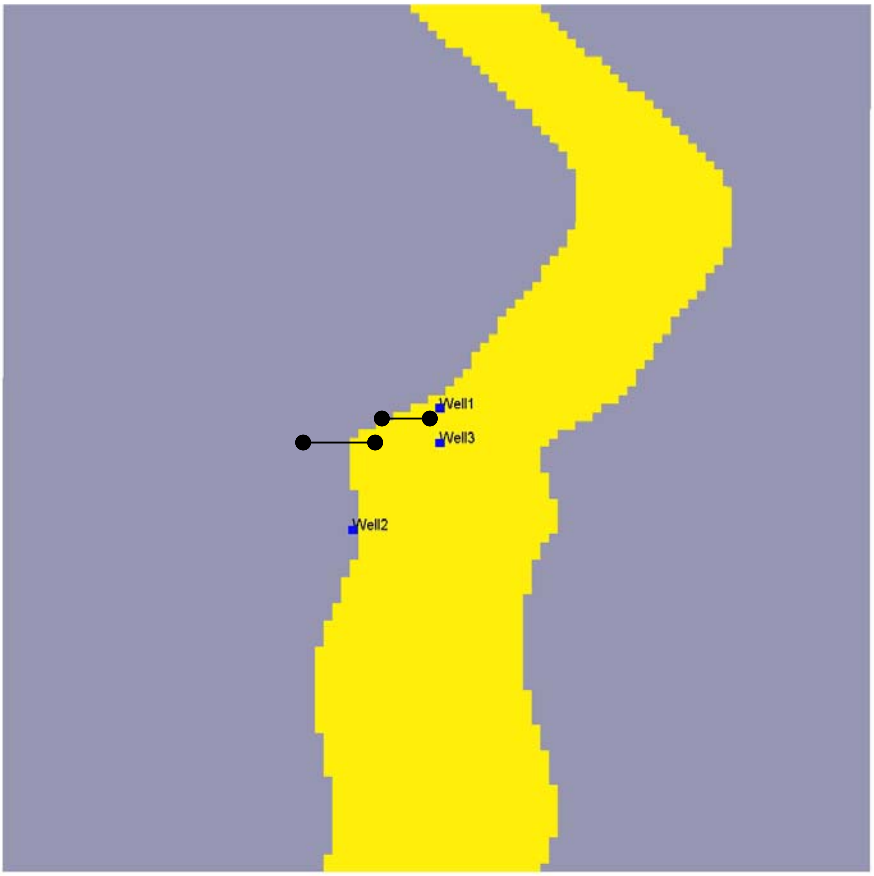
Note

Conditioning on distance from well to object edge



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Authors Frode Georgsen, Anne Randi Syversveen and Ragnar Hauge

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Norsk Regnesentral
Norwegian Computing Center
Postboks 114, Blindern
NO-0314 Oslo, Norway

Besøksadresse
Office address
Gaustadalléen 23
NO-0373 Oslo, Norway

Telefon · telephone
(+47) 22 85 25 00
Telefaks · telefax
(+47) 22 69 76 60

Internett · internet
www.nr.no
E-post · e-mail
nr@nr.no

Title	**Conditioning on distance to channel edge in Fluvial**
Authors	**Frode Georgsen, Anne Randi Syversveen and Ragnar Hauge**
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Abstract

The use of pressure tests in wells can give information about the lateral distance from the well in a sandstone object to a barrier for flow, typically the edge of the object. This gives more precise information on the location and width of objects and should be incorporated in the simulations from the geostatistical model.

This note gives a description on how such information is implemented in the existing stochastic facies models fluvial and gmpp, known in RMS as Facies:Channels and Facies:Composite.

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Contents

1 Introduction

Conditioning on well data in facies models is traditionally limited to ensuring that the correct facies is reproduced in the well. For object models, this means that an object of the correct facies must cover the observation, and not be eroded in the well by other objects.

In order to utilize information from well test data, this needs to be extended. Well test data give information about the horizontal distance from the well to the nearest flow barrier, typically an edge of the object. The second nearest flow barrier may also be detected, typically the opposite edge. This means that when conditioning a facies observation where a well test has been run, we should also condition the edges of the object to the well test data.

The method described in this paper opens up for the user to specify information about the distance from the well-location to one or both edges of the body in the lateral direction. Although this will typically be information achieved from well tests, it is irrelevant what the source of the information is, so distanced derived from e.g. geological indicators are also valid.

For the fluvial module, edge distance conditioning is implemented only for the channel facies, since this is the main reservoir facies where well tests will be run. Technically, it could be done also for crevasse facies. For the gmpp module, it is implemented only for objects of type axial, backbone and radial. The reason for this is that these are the only objects with flexible edges. Implementing edge conditioning for other object types is a serious challenge.

The additional input data is up to four parameters, specifying open or closed intervals for nearest and furthest edge. These parameters are passed through to the modules as well logs. Log information given for irrelevant facies will be ignored.

Details about the parameters and model are given in section 2. Section 3 outlines the conditioning algorithm used in fluvial, section 4 the one used in gmpp, and section 5 shows some examples.

2 Model specifications

Figure 1 shows a vertical cross-section with a segment of a (vertical) well with one channel observation and two intervals specifying the limits for the edge nearest to the well observation and the limits for the edge most far away. Note that it is not possible to specify on which side (left or right) of the observation the nearest edge is. This will be decided by the algorithm. This is in accordance with the fact that a well test will not be able to say anything about direction.

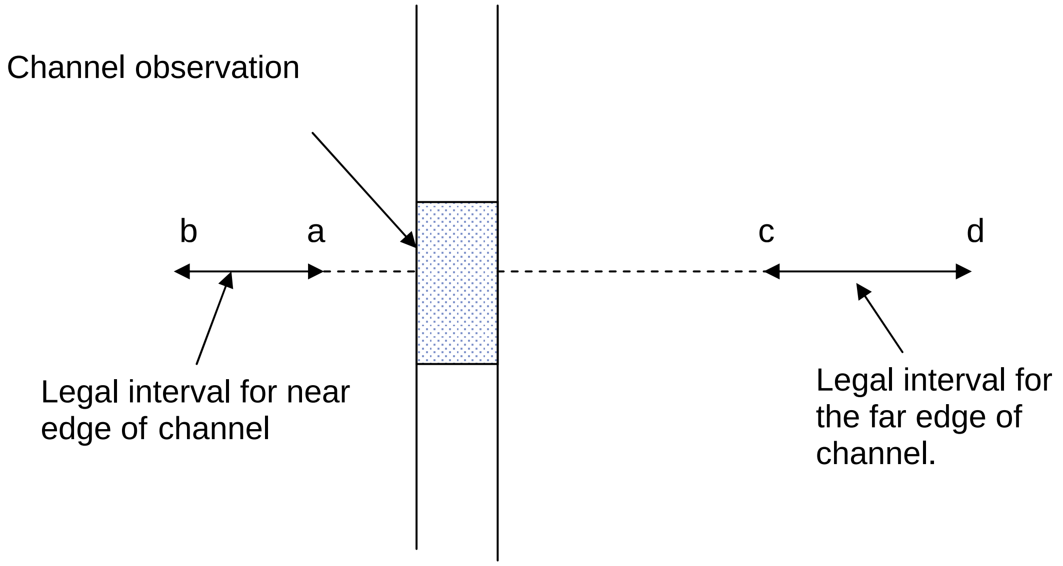

Figure 1: Vertical cross-section showing distance specifications for a channel observation

Referring to Figure 1 there are four input parameters. They are interpreted as follows:

a is the minimum distance from the well observation point to the near edge of the channel

b is the maximum distance from the well observation point to the near edge of the channel

c is the minimum distance from the well observation point to the far edge of the channel.

d is the maximum distance from the well observation point to the far edge of the channel.

The following restrictions apply to the parameters, and all three must be fulfilled:

i. a, b, c and d must be real numbers > 0 or have a code for missing value. Missing value means that no information on the parameter is available, and well conditioning is performed without distance information.

ii. In case a parameter is given a (non-missing) value, the previous parameters must have (non-missing) values.

iii. In case a parameter is given a (non-missing) value, the previous parameters must have smaller values.

Restriction (ii) implies for instance that if we have a value for the maximum distance to the nearest edge, **b**, we must also have a value for **a**, but not necessarily for **c** and **d**.

Restriction (iii) implies the obvious cases that **b** > **a** and **d** > **c**, but also that **c** > **b**. The latter implies the fact that the nearest edge always is closer to the well observation point than the other edge.

2.1 Assumptions in the model

Although well tests are typically done in vertical wells, we have designed the system to work for general wells. Since the well test gives only a single distance for the entire observation, we need to define our understanding of this distance. We use the following definition:

1. The distance restrictions must be honored for any point along the well path for the observation.

2. If data is given both for nearest and furthest edge, the same edge will be the nearest for all points.

3. If data is given only for nearest edge, the actual nearest edge may change along the observation, but the distance conditioning will always be honored for both edges.

Another important assumption is the direction we use when doing this conditioning. Guaranteeing the distance along any direction would be very difficult and time-consuming. Instead, we do the conditioning along the local y-axis for the object. This will give a good result as long as the edge rugosity is not too large, and fits nicely into the current parameterization and conditioning scheme, particularly for fluvial. The local y-direction for different objects is as follows:

- For channels in fluvial and axial objects in GMPP, the y-direction is perpendicular to the main axis of the object. This is described in Holden et. al. 1998 and illustrated in Figure 2.

- For backbone objects in GMPP, the y-direction is complicated, but essentially perpendicular to the local direction of the object. This is described in Hauge et. al. 2006.

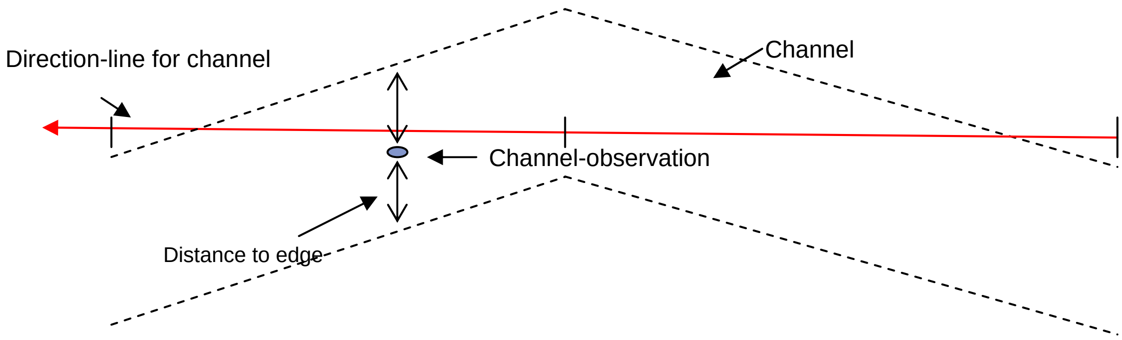

Figure 2: Distance to channel edge is measured perpendicular on the main direction line for channel

2.2 Limitations and possible problems

Due to erosion, the distance to a facies change may actually end up larger than what was specified for the observation. We ensure that the object actually conditioning the well observation also honors the distances, but other objects may erode or be eroded by the conditioning object near the well, increasing the distance. These objects may also erode the conditioning objects nearer than the minimum distance given, so actual distance to first seen object edge may be short. But the distance to first facies edge will always be greater than the minimum given.

The extra conditioning may also lead to illegal models. This can happen with an observation from a general well, and a narrow interval for the edge. In this case, there may not be any location for the edge that is legal for all well points in the observation.

Even in cases where there is a legal solution, narrow intervals combined with complex well patterns may lead to convergence problems, as it can be difficult to find a legal solution. Larger intervals increase the flexibility and makes convergence simpler.

Finally, the conditioning on distance to edges also influences the width of the object. This opens for a possible conflict with the object width parameter. If e.g. all four parameters **a**, **b**, **c** and **d** are given, the actual width of the channel near the well must be greater than **a** + **c** and smaller than **b** + **d**. If the parameters for the width in the input model prohibits this, or makes it very unlikely, the conditioning might not be fulfilled.

3 Conditioning algorithm for fluvial

The algorithm for the general well conditioning using the concept of quilts is thoroughly explained in Skorstad et. al. (1999). The conditioning on distance to channel edges is implemented to fit into this algorithm by updating the quilt with the additional information.

A quilt is built for each of the vertical cross-sections that discretizes the main channel direction-line. Originally a quilt is created by projection of the channel location in section i to section i+1 through the positive channel observation point. This projection, combined with negative observations (points the channel may not pass through, due to background observations) gives legal and forbidden areas for the channel edges.

In each section we consider the wells that may influence the channel location in this section. For each of these wells, the following procedure is performed:

a. For each positive channel observation point:

1. Decide if there is any information on distance to edges. If not, go to 5.

2. Find which side of the channel the nearest edge is (left, right or undecided)

3. Find the projection(s) of the possible intervals for the left and the right edge of the channel from section i to section i+1 through the observation point given the information found in 2.

4. Update the intervals for left and right edges by merging the intervals found in 3 with the intervals found for previous observation points in this well.

5. If the body end is not reached, find the next positive observation point for the body and go to 1, otherwise end loop.

b. Add the legal intervals for left/right edges to the list of possible combinations.

The reason why the side for the nearest edge might be pre-decided already at step 2., even if this is not given as input to the model, is one of the following:

i) An observed channel-body can go through several sections, so the nearest side might have been decided in a previous section. Then the nearest side must be the same also in this section.

ii) To make the conditioning algorithm more efficient the channel location is also conditioned on positive observations 'far' (i.e. several sections) away. In this 'far quilt' a side for the nearest edge is chosen and this must be kept also when this section is investigated later.

If the side is already decided when step 3 is performed, the observation point gives rise to one possible combination of intervals for left and right edges. If the side is undecided, two such combinations are possible. Nevertheless the outcome of the procedure is that the quilt has a list of none, one, or several different legal combinations of intervals for the left and the right edge of the channel in this section.

If there are no possible combinations it is not possible to condition this channel to the distance-limits given, and the channel is rejected. If there is only one candidate, it is chosen. In the case with more than one, we must draw one of them according to a (approximately) correct probability distribution.

3.1 Probability distribution for channel edge limits

Suppose we have a pair of possible intervals for the left edge **l** = (l_{min}, l_{max}) and the right edge **r** =(r_{min}, r_{max}) of the channel location in section i+1. This means that the left edge of the channel must be within **l** and the right side within **r.** This gives some limitations on the horizontal deviation from the channel's main axis (HD) and the width of the channel (HW). Figure 3 illustrates this setting for a given set of edge limits (**l,r)**. The smallest possible value for HD, HD_{min} is the midpoint between l_{min} and r_{min}. A smaller value means that if the width of the channel is so small that the left edge is to the right of l_{min}, the right edge will be to the left of r_{min} and vice versa. The same argument applies for the biggest possible value for HD, HD_{max}. For each given value (*hd* in the figure) for HD we will have some restrictions on the width to ensure that the channel edges are within the limits given by (**l,r**).

We give the combination (**l,r**) a probability P* proportional to the joint probability for the values of (HD,HW) that are legal given (**l,r**) in section i+1. This can be found by the formula

$$P^*(l,r) = \int\int P(HW,HD) I_{l,r}(HW,HD) \text{ dHWdHD.}$$

The indicator $I_{l,r}(HW,HD)$ is 1 if HD, HW gives edges that match (**l,r**), and 0 otherwise.

The double integral above is not trivial to solve analytically, and is for simplicity approximated through the following procedure which in essence solves the inner integral and approximates the outer integral with a sum taken over sampled values for HD.

1. Find the minimum value HD_{min} and the maximum value HD_{max} for HD given the restrictions **R** and **L**:

   $$HD_{min} = (l_{min} + r_{min}) / 2$$

   $$HD_{max} = (l_{max} + r_{max}) / 2$$

2. Let

   $$HD_{min} = \max\{ HD_{min}, E(HD) - 3 * sd(HD)\}$$

   $$HD_{max} = \min\{ HD_{max}, E(HD) + 3 * sd(HD)\}.$$

   We ignore HD values more than 3 standard deviations away from the expected value as they give very small contribution to the total sum.

3. Let the sample intervals for HD-values be of length sd(HD). This means that we sample at most 7 HD-values, but must ensure that we sample at least 2.

4. For each HD-value:

   Compute the (non-scaled) value of the probability density function for HD=hd:

   $$p(HD=hd) = \exp[-0.5 * \{(hd - E(HD)) / sd(HD)\}^2].$$

   Find the legal intervals for HW given hd. This might be one or several intervals.

   Compute $\int_W P(HW \mid HD = hd) hw$,

   which is found from the cumulative normal distribution since HW is normal distributed.

   Compute π (HW, HD=hd) = p*(HD=hd) $\int_W P(HW \mid HD = hd) hw$.

5. $\hat{P}$ *(l,r) = ($\sum_{all\ hd} \pi(HW, HD = hd)$ * Length of interval) / # of intervals

   where $\hat{P}$ * is an approximation for *P**

This gives an unscaled probability for this combination (**l,r**) of edge limits. Performing this procedure on all combination gives a total probability distribution to draw the edge limits from.

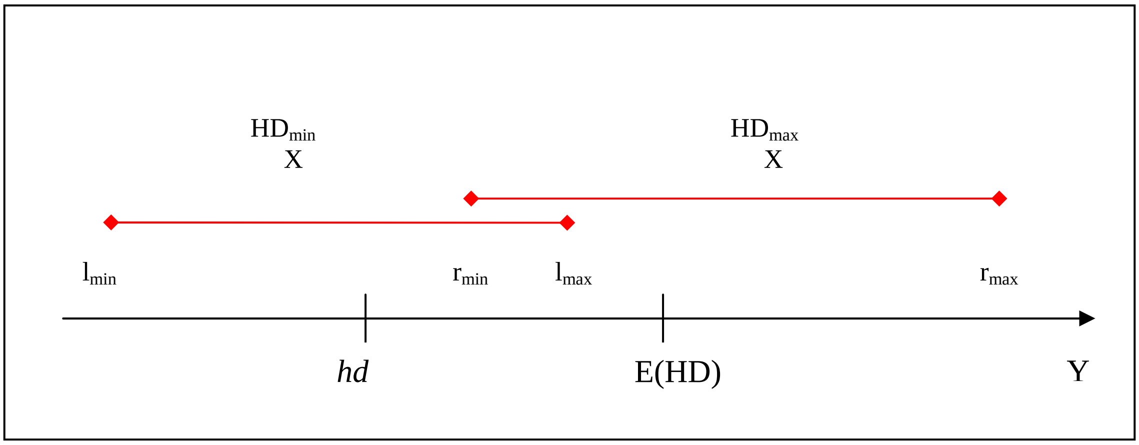

Figure 3: Example of a combination of legal intervals for left and right edge in the horizontal plane.

4 Conditioning in GMPP

The conditioning in GMPP is very similar to what is used in fluvial. Since GMPP does not traditionally have a quilting system, this was implemented for the occasion. The same approach is also used to find legal intervals, and choose between them.

5 Examples

5.1 Fluvial

To illustrate the methodology described above, five examples are shown and commented in the following. They are taken from simulation on a synthetic example design to illustrate the method. They all show a horizontal cross section of one channel in a reservoir box that is 5000 x 5000 m. The expected direction for the channel is along the vertical side of the reservoir. The mean channel width is 1000 m, and the range for horizontal deviation from main direction line and for the width is 2000 m. The simulations are conditioned on two or three wells. In Well 1 there is a channel observation that should penetrate the channel. In Well 2 no channels are observed, so the channel should avoid this well. In the figures the intervals for the edges are indicated by lines. Arrow at the end means an open interval, while point bar means closed interval.

The first example (Figure 4) shows the channel with no conditioning on distance to the channel edges.

In the second example (Figure 5) the observation in Well 1 is conditioned on a distance to the nearest edge being at least 750 m and the other parameters being unspecified (i.e. **a** = 750, **b, c** and **d** having missing value). As we can see from the figure, this constraint forces the channel to increase the width near Well 1, since the smallest possible width at the conditioning point is 1500 m.

The next example (Figure 6) shows a channel where the nearest edge is forced to be between 100 and 200 m from Well 1 (i.e. **a** = 100, **b** = 200, **c** = **d** = missing value). In this case the algorithm has chosen the right edge to be the nearest.

Figure 7 shows an example where all four distance parameters are specified. The nearest edge must be between 100 and 200 m from Well 1, and the other edge between 1500 and 1700 m away (i.e. **a** = 100, **b** = 200, **c** = 1500, **d** = 1700). This time the near edge is drawn at the left side, and the width of the channel is increased near Well 1 according to a minimum of 1600 m (**a** + **c**).

In the last example (Figure 8), one more well (Well 3) is included and placed close to Well 1. This well also contains one channel observation. The algorithm chooses the channel to go through both wells and also fulfil the restriction on the distance to the edges. For Well 1 the nearest edge should be between 100 and 200 m (**a** = 100, **b** = 200) and for Well 3 between 400 and 600 (**a** = 400, **b** = 600). No limitations are specified for the other edge (missing value for **c** and **d** in both wells). The illustration shows that these requirements are also taken care of.

5.2 GMPP

Similar tests as described above are also done for GMPP. We have used Backbone objects with mean width of 600, and we condition on only one well.

In the first case, we set **a** = 400, and **b**, **c**, **d** are missing. See left of Figure 9. In this case, the object becomes wider around the well in order to fulfill the distance to edge conditioning. The range of the Gaussian field at the edges is 0.3 in this case, which means that about 60% of the edge is influenced by the distance to edge conditioning, that is, 30% on each side of the well.

In the second test, **a**=100 and **b**=200, while **c** and **d** are missing, see middle of Figure 9. We see that the well appears close to the edge of the object.

In the last test, we set **a**=100, **b**=200, **c**=250 and **d**=300. The maximum width at the well location will now be 500, and to the left in Figure 9 we see that the object is narrower around the well location.

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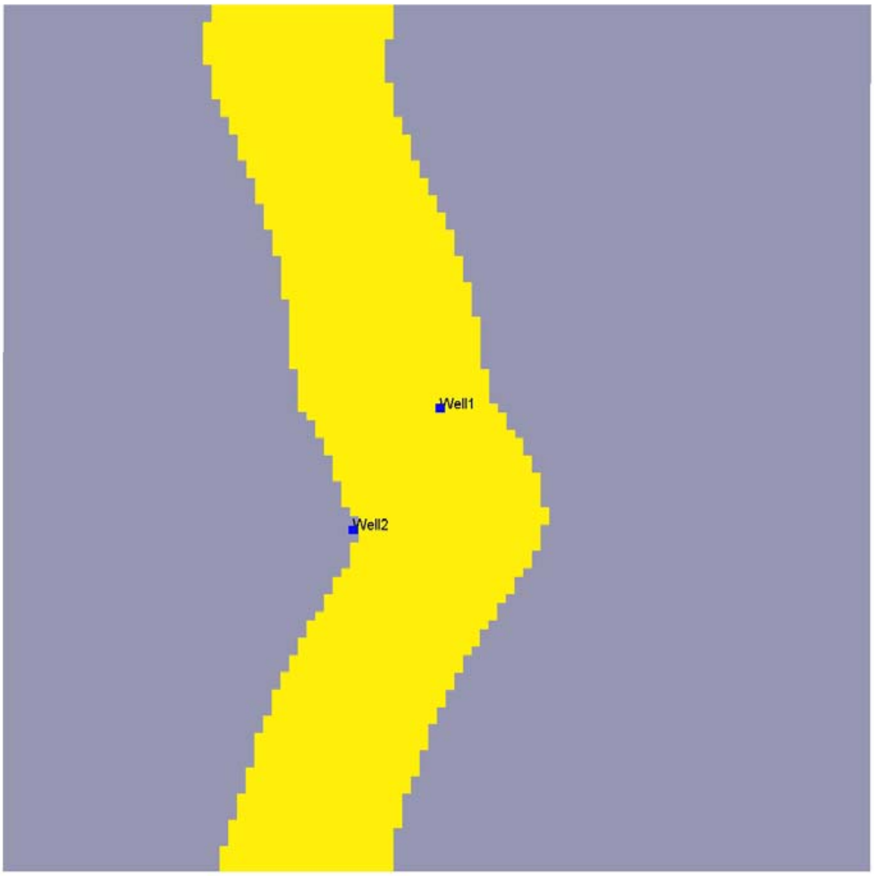

Figure 4: One channel positive conditioned on Well 1 and negative conditioned on Well 2 (No distance conditioning)

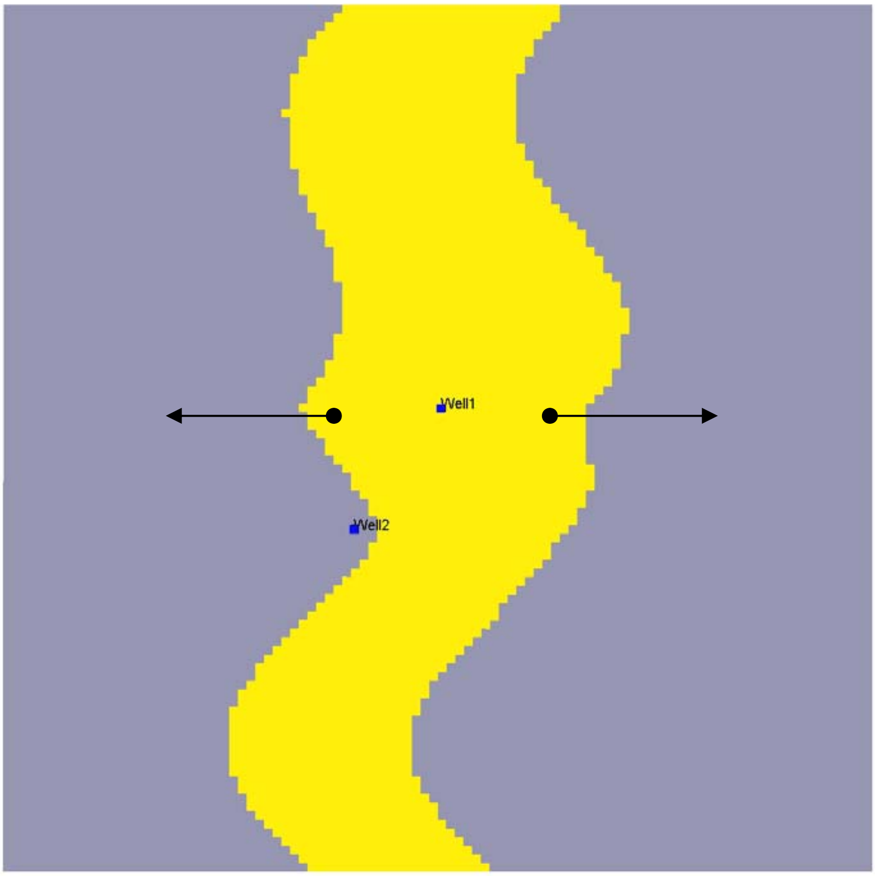

Figure 5: Channel conditioned on positive observation in Well 1 with distance limitation for nearest edge. Negative observation in Well 2

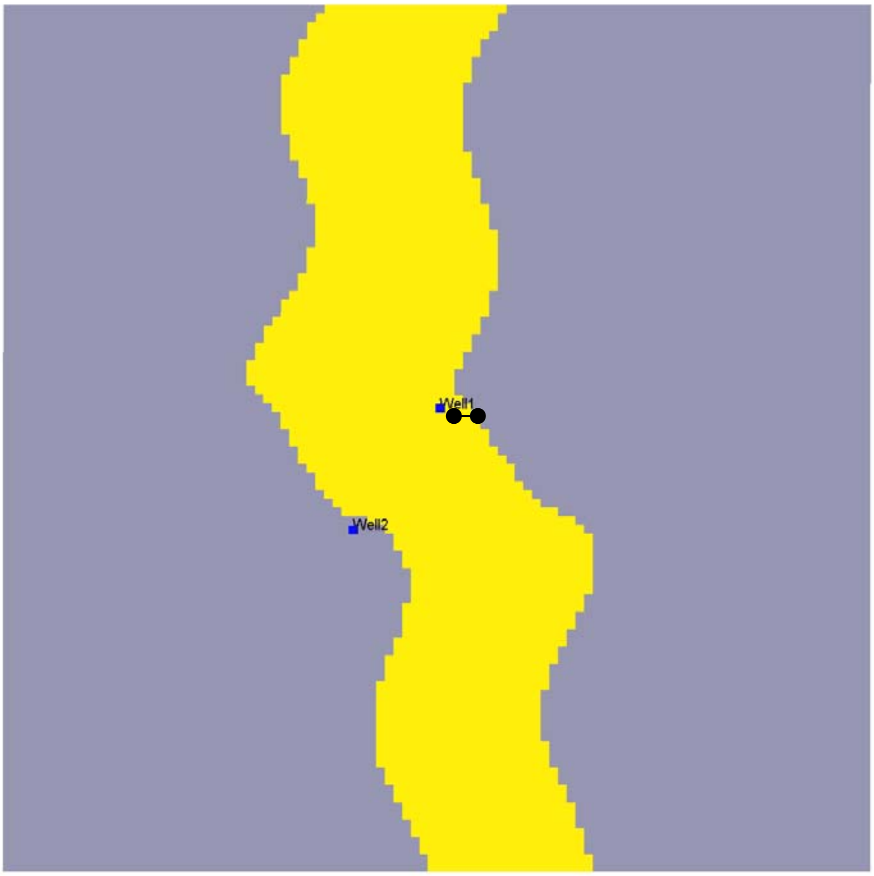

Figure 6: Channel conditioned on positive observation in Well 1 with distance limitations for nearest edge. Negative observation in Well 2

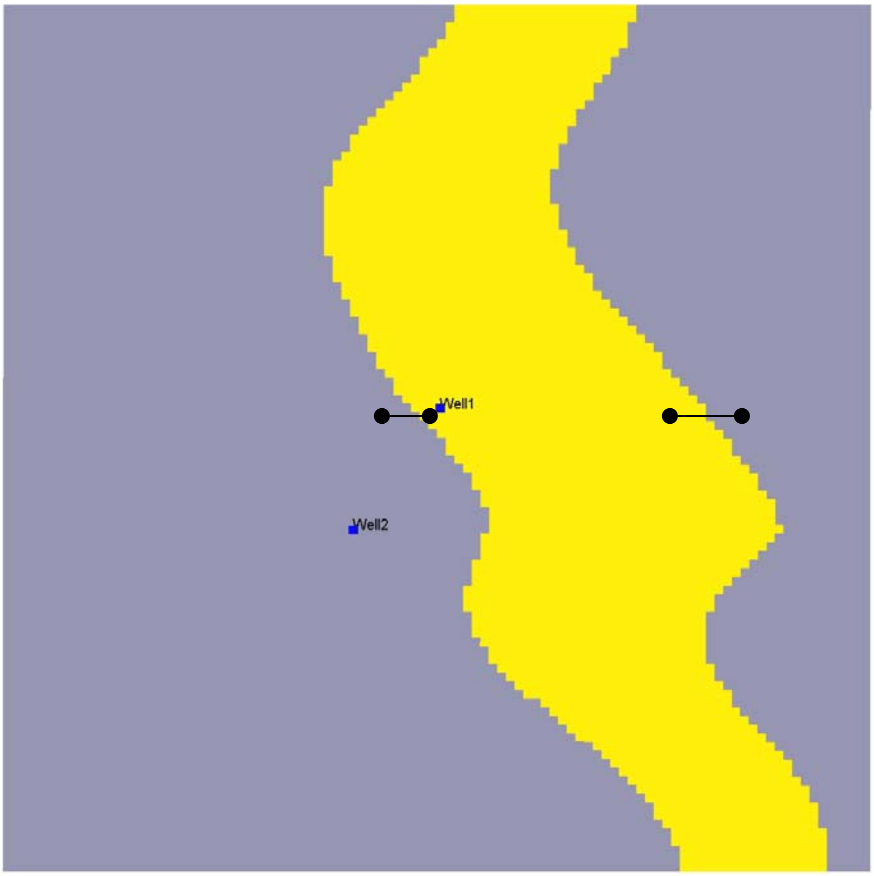

Figure 7: Channel conditioned on positive observation in Well 1 with distance limitations for both edges. Conditioned on negative observation in Well 2

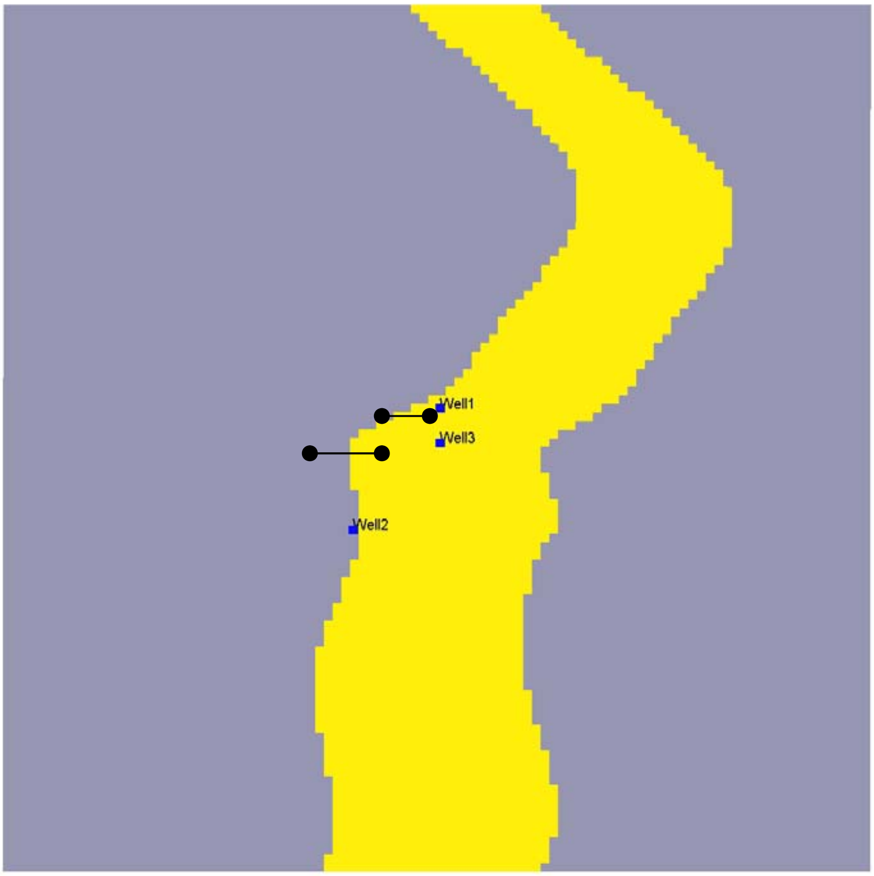

Figure 8: Channel conditioned on positive observation (distance limits) in Wells 1 and 3 and negative observation in Well 2

Figure 9: Backbone objects in GMPP conditioned on distance to well. Left: **a**=400, **b**,**c**,d are missing. Middle: a=100, b=200, c and d are missing. Right: a=100, b=200, c = 250, d=300. In all cases, the mean object width is 600.