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Effect of the infilling of Storavatnet (Bergen) on the hydrology

O17010/P5/B

Draft report

19-6-2017

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The lake "Storavatnet" (Bergen)

Name of document:	Effect of the infilling of Storavatnet (Bergen) on the hydrology
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Status:	Draft report
Date:	19-6-2017
Reference:	O17010-P5-B
Project name:	Storavatnet
Client:	Asplan Viak

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Sammendrag

P.M.

1 Introduction

1.1 General

For the construction of the new Rv555 road Statens Vegvesen is planning to partly fill in the north part of the Storavatnet lake near Bergen, see Figure 1.1.

Three alternatives have been proposed:

- Alternative A: Maximum infilling land and water
- Alternative B: Maximum infilling land
- Alternative C: Minimal infilling

In a later stage an extra alternative A was introduced in which the sill between the eastern infill area and the rest of the lake was lowered.

Dam Engineering was asked to simulate the effect of the partial infilling on the hydrodynamics in Storavatnet. Four scenarios will be investigated:

1) Extreme rainfall scenario with a return period of 1:200 year
2) Wind effect on currents
3) Temperature effect on currents
4) Spreading of salt water due to road salting

For the simulation a 3D hydrodynamic model of Storavatnet will be set-up that is capable of simulating rainfall (runoff), wind effects and temperature (density) effects on currents.

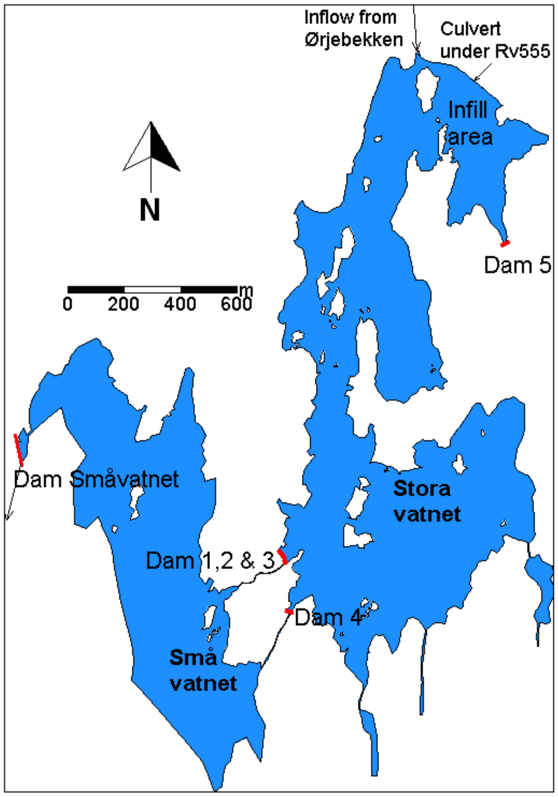


Figure 1.1: Overview of the project area (current situation)

1.2 Area description

Storavatnet is located 10 km west of the centre of Bergen. The lake has a surface area of approximately 1 km^2. The water level of the lake is regulated at 38.9m above the NN1954 reference level. The lake is feeded by runoff from a total catchment area of 3,3 km^2 (NEVINA). North of the lake the largest catchment area is located and is called Ørjebekken. The runoff from Ørjebekken into Storavatnet is now regulated with a culvert under the present road (Figure 1.2a). The water level of Storavatnet is controlled at 38.9m (NN1954) with a series of dams, see Figure 1.1. At Dam 2 and 4 water can be discharged into Småvatnet, see

Figure 1.2b and c. Dam 2 has a control mechanism and is only open during winter (Figure 1.2c and d). In the spring and summer no water is discharged here. The top level of the dams is circa 40.2m.

a) Present culvert of outflow Orjebekken into Storavatnet

b) Dam 4

c) Dam 2 and control mechanism

d) Outflow Dam 2

Figure 1.2: Photos of Storavatnet

In Småvatnet the water level is controlled by another dam (Figure 1.1). Here the industry takes in water with 15-22 m^3/minute (personal communication Hendrik Fasmer – Lilli Mjelde). Yearly an average water volume of 9 million m^3 is used. The water is discharged in the Alvøen fjord.

1.3 Report outline

This report consists of the following chapters: In Chapter 2 the 3D model is described. Chapter 3 deals with the outcomes of the extreme rainfall simulations. In Chapter 4 the outcomes of the wind simulations are described. A discussion about water the water circulation is given in Chapter 5. Finally in Chapter 6 conclusions and recommendations will be given.

2 Model set-up FINEL3D

2.1 Choice of model

The hydrodynamic model that will be used is the FINEL3d model. This is a 3D non-hydrostatic finite element model. The model is developed by the Technical University Delft and Svašek Hydraulics (Labeur, 2009, Labeur & Wells, 2007, 2009, 2010, Talstra, 2016). The model has been used around Bergen to model sediment spreading in Sørfjorden (Dam, 2017a) and to calculate the effect of floating breakwaters in Os harbour (Dam, 2017b)

2.2 Computational grid

The benefit of this finite-element model is that it uses triangular shaped meshes. Triangles are especially useful when following complicated geometries like fjords and lakes in Norway, since there is (almost) unlimited freedom in placement of the triangles. Another advantage of this model is that the coarseness of the grid is easily refined near the area of interest.

Figure 2.1 shows the computational grid. The horizontal resolution near the infill area is set at 3.5m. The rest of Storavatnet has a resolution of 7m. Småvatnet is outside the area of interest and has therefore a coarser resolution of 30m.

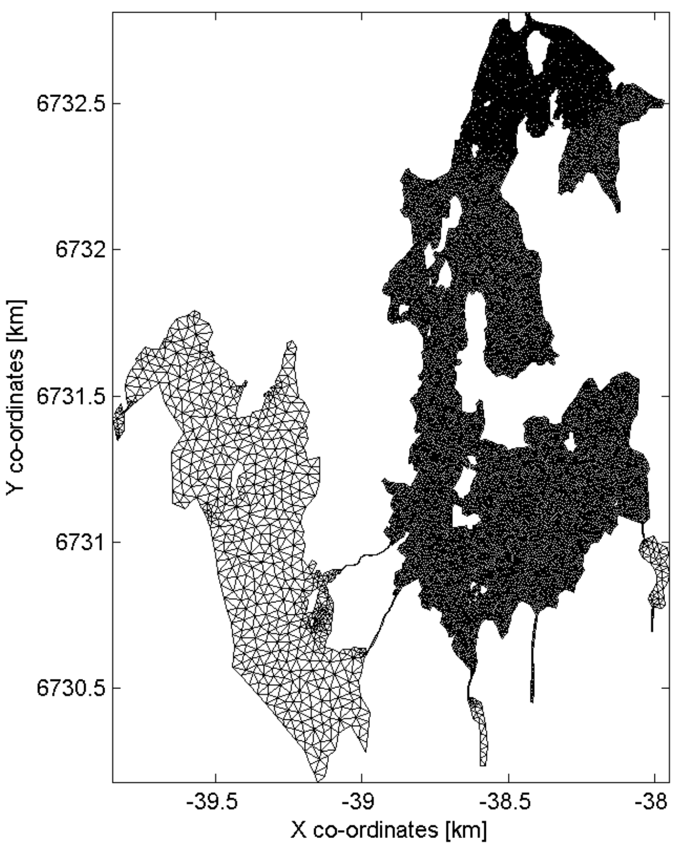


Figure 2.1: Computational grid of the FINEL3d model.

The opening in Dam 4 has a measured width of 2.3m (measured during a field trip). Dam 2 has an estimated opening of 1m. These widths are used as width of the dams in the model.

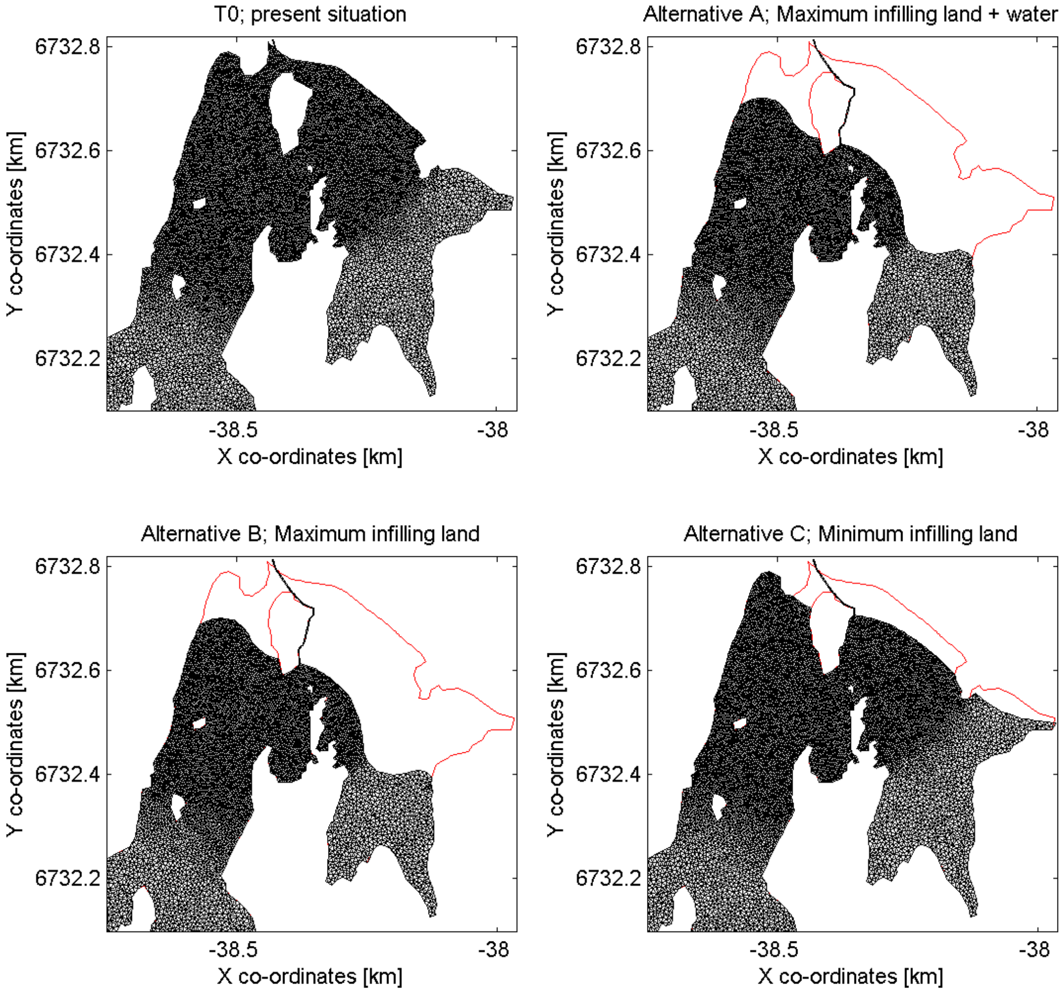


Figure 2.2: Detail of the grid of present situation and the 3 alternatives near the infill area

For each alternative the computational grid is adjusted because the land-water outline changes. Figure 2.2 shows the details of the grid near the infill area. Note that the grids of Alternative A and B are the same (Alternative A is equal to B, but with an extra infilling under water).

The extreme rainfall scenario uses 3 vertical layers, since vertical resolution is not important here. The wind scenario uses a high vertical resolution with a total of 10 vertical layers. Wind causes large vertical differences in velocities and therefore a high vertical resolution is required.

2.3 Bed level

Bed level data of the model consists of detailed measurements of the depth of Storavatnet. The bed level of the model is shown in Figure 2.3. Note that in Småvatnet no bed level data is present. Here a constant depth of 10m below the controlling water level is presumed. This is not important for the outcomes of the simulations. Some small streams are schematised in the model at the south side of Storavatnet. These streams discharge water during rain events into Storavatnet. The height in the model is taken from a 10x10m DTM model (downloaded from nve.no). The height of Dam 4 is set at 30 cm below the controlling water level of

38.9m (=38.6m). This water height of 30 cm was measured during a field trip. As an assumption the height of Dam 2 is also set at 38.6m.

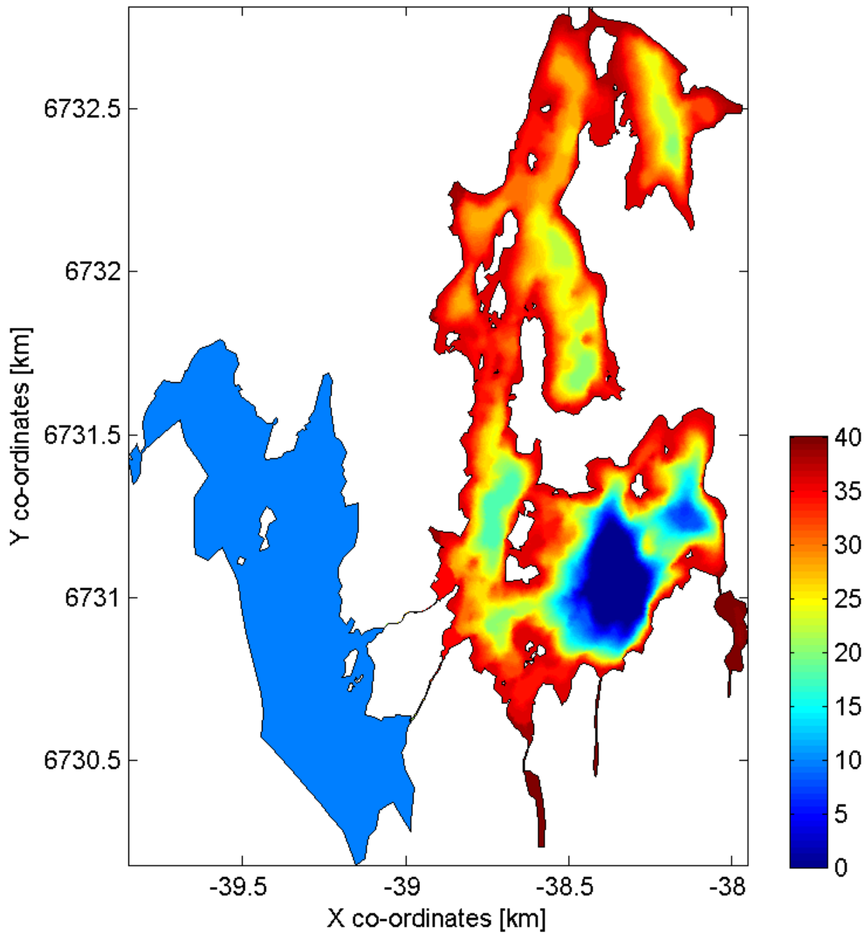


Figure 2.3: Bed level of the FINEL3d model (Bed level in m with reference to NN1954)

For each alternative the bed level is adjusted near the infill area and interpolated to the computational grid of each alternative (Figure 2.4).

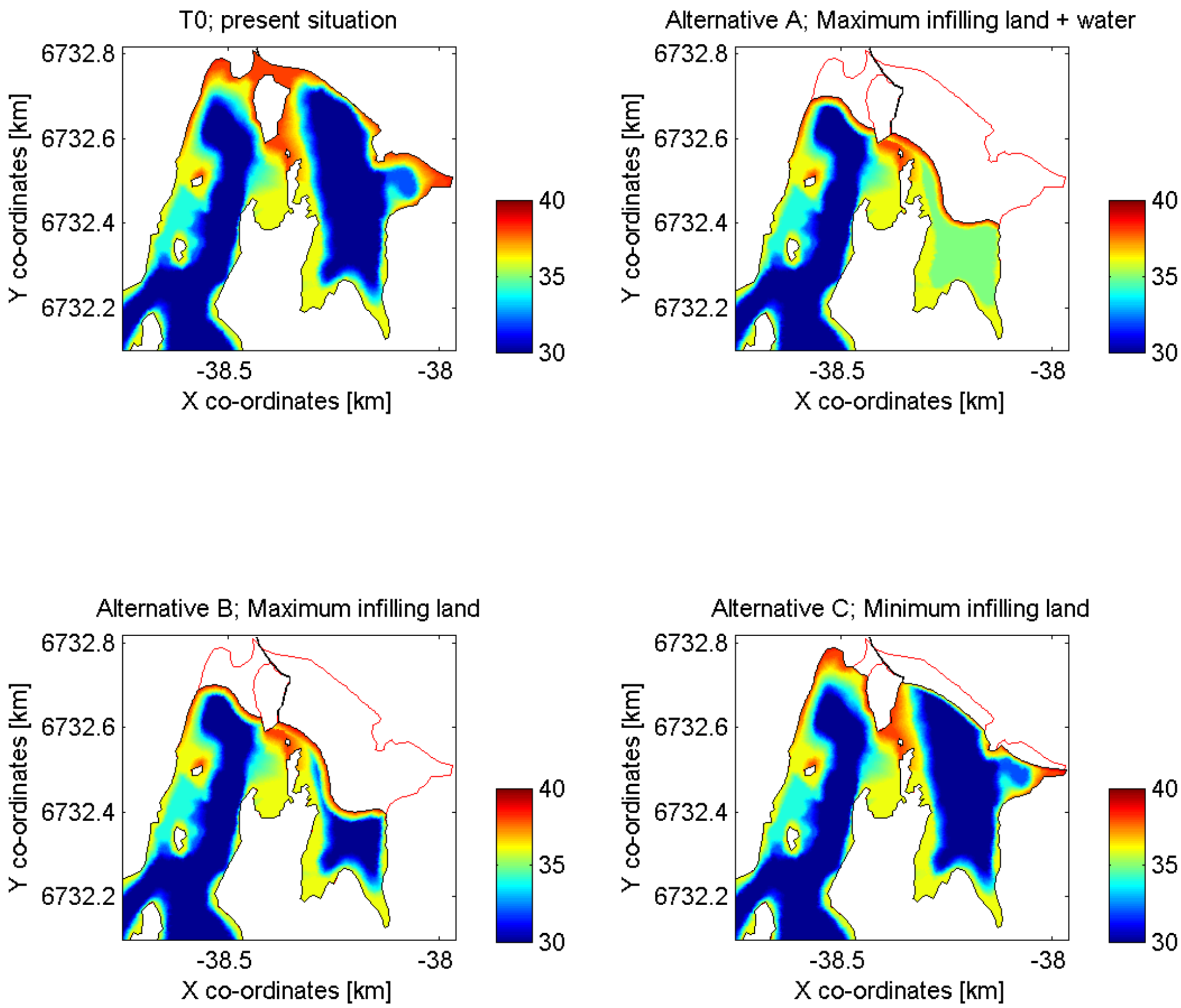


Figure 2.4: Detail of the bed level of the T0 situation and the 3 alternatives for the infill area (Bed level in m with reference to NN1954)

2.4 Boundary conditions

Boudary conditions for the extreme rainfall scenario consist of rainfall input and discharge of streams.

A constant (average) water intake is applied of 18.5 m^3/minute. Note that this is not important for the outcomes of the simulations.

2.5 Other settings

Other settings and assumptions that are applied are:

- The model uses a k-ε turbulence model.
- Bottom roughness is set at 5cm nikuradse roughness height in the lake and 1m at the (mountain) streams.

The outcomes are not sensitive for these parameter settings of the model.

3 Simulation of extreme rainfall scenario

3.1 Introduction

In this chapter the simulation of the extreme rainfall scenario is described. First the method to model the extreme rainfall scenario is described, followed by the outcomes of the model simulations.

3.2 Extreme rainfall/runoff scenario

3.2.1 IVF curve

In this report a rainfall scenario with a return period of 200 years is considered. The IVF curve of rainfall for Bergen-Sandsli is taken as basis for the calculation. A 1:200 year rainfall event has a total rainfall over one day of 123.6mm for Bergen-Sandsli (Figure 3.1). During this day the rainfall is not equally spread, but a peak occurs during a 5 minute interval with a rainfall of 9.9 mm (1.98 mm/minute), see Figure 3.2. All numbers are multiplied with a climate factor of 1.4.

This extreme rainfall day with a return period of 1:200 years will be simulated in the model. The simulation runs 24 hours from 00:00hr to 00:00hr the next day. The peak with the highest rainfall is set at 12:00 AM. The rest of the rainfall is equally spread before and after 12:00 AM, see Figure 3.2.

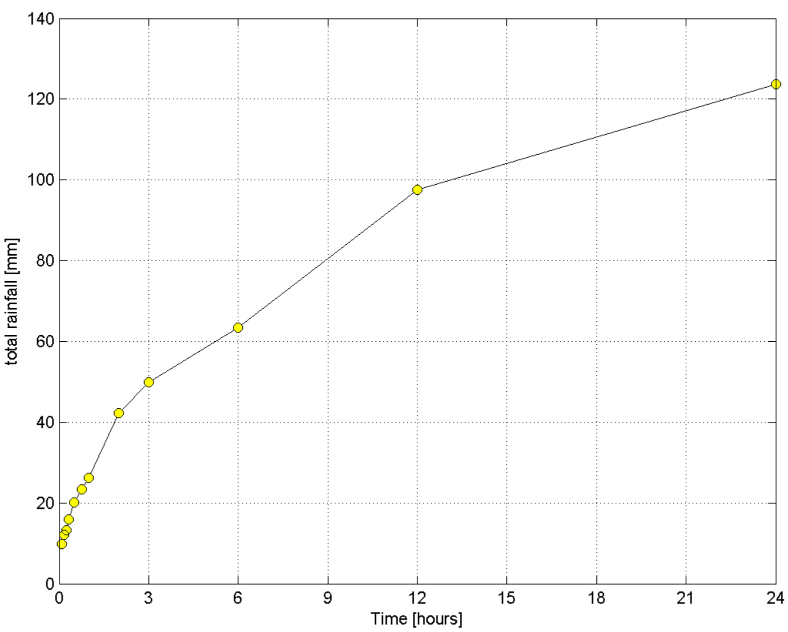


Figure 3.1: 1:200 year IVF curve of Bergen-Sandsli over period 1982-2014 (Meteorologisk Institut)

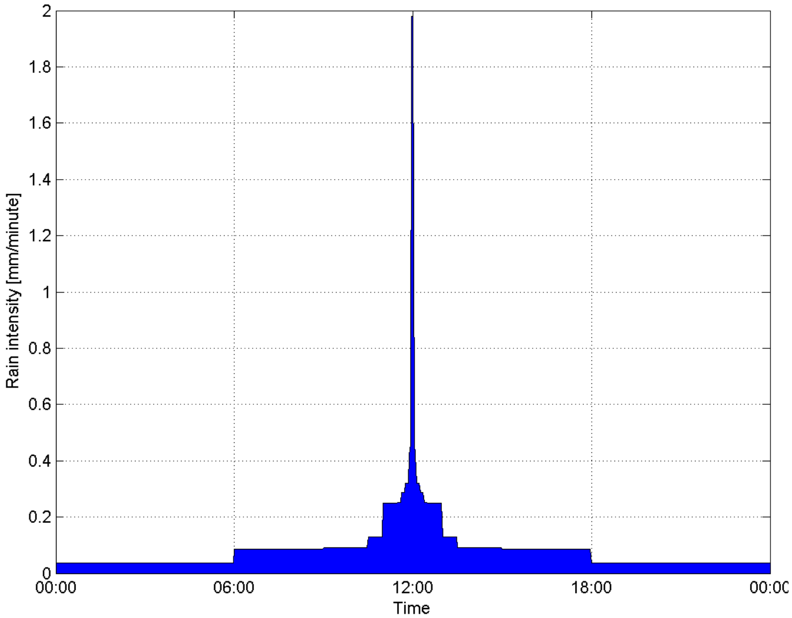


Figure 3.2: Rain intensity for a 1:200 rainfall event

3.2.2 Rainfall runoff

The model area only contains only Storavatnet, therefore the rainfall that falls directly into the lake immediately contributes to a water level increase. Since 2/3 of the total catchment area is from land a few assumptions should be made before this water is drained into the lake.

The catchment area of the island in Storavatnet and at the west-, south- and eastside of Storavatnet is determined per 10x10meter and is directly 'transported' to the nearest grid cell of the model. No time difference between the falling of the rain on the ground and the discharge into the lake is applied, since the distances in this catchment area are small. Note that it is assumed that all the rainfall discharges into the lake. In reality a portion of the rainfall will be retained. This assumption thus imposes an upper limit of the effect.

3.2.3 Ørjebekken and area northeast of Storavatnet

For Ørjebekken and the area northeast of Rv555 a slightly different approach is followed. Here again the rainfall is determined per 10x10m and a general runoff coefficient of 0.6 is applied. The runoff coefficient is taken from Rambøll (2016). For this area a time difference between the falling of the rain and the runoff into the lake is applied. Rambøll calculates a runoff time difference of 16 minutes. This number is used to calibrate the average time difference between the falling of the water and the discharging of the water into Storavatnet. Furthermore it is assumed that the existing and the new culvert of Ørjebekken has a capacity of 5,0 m^3/s. In this way a discharge timeseries can be reconstructed that is used as input for the model. Note that according to this method the capacity of 5,0 m^3/s is insufficient during the highest peaks of a 1:200 year rainfall event.

The area northeast of Storavatnet drains into Storavatnet through an existing culvert under Rv555 (Figure 1.1). The same approach is used as for the runoff from Ørjebekken. No capacity limit is used here.

3.2.4 Other assumptions

- It is assumed that both dam 2 and 4 are open, so that maximum water is discharged from Storavatnet to Småvatnet;

- In the simulation of the alternatives it is assumed that the runoff from Ørjebekken will be discharged east of the existing island in Storavatnet;
- The lake has a homogenous temperature; i.e. no velocities due to difference in temperature are generated;
- There is no wind; i.e. no wind driven currents are generated.

3.3 Outcomes extreme rainfall scenario on water levels

Figure 3.3 shows the water level in Storavatnet of the 4 simulations. At the start of all simulations the water level is 38.9m. The water level rises since rainfall and runoff is larger than the runoff over dam 2 and 4. The water level increase is maximum around 12 AM at the peak of the rainfall. After 12 AM the rainfall becomes less and the water level increase decreases. At 18:00 the water level reaches its peak of 39,21m, a rise of 31 cm. After 18:00 the discharge over dam 2 and 4 is larger than the runoff/rainfall into Storavatnet and the water level decreases. The discharge over dam 2 and 4 is regulated automatically by the model. This means that the discharge is dependent on the water level; the higher the water level the higher the discharge. At 06:00 and 18:00 the rainfall/runoff into Storavatnet is the same, but the discharge over dam2 and 4 is higher at 18:00 (since the water level is higher).

Alternative A and B show the largest effect on the water level (Figure 3.3), since the infill area is largest with these alternatives. Compared to the present situation the water level difference is maximum 3 cm at 18:00. Alternative A and B show an equal effect on the water level since the infill area is equal. Alternative C shows a maximum increase of the water level of ca. 1cm at 18:00.

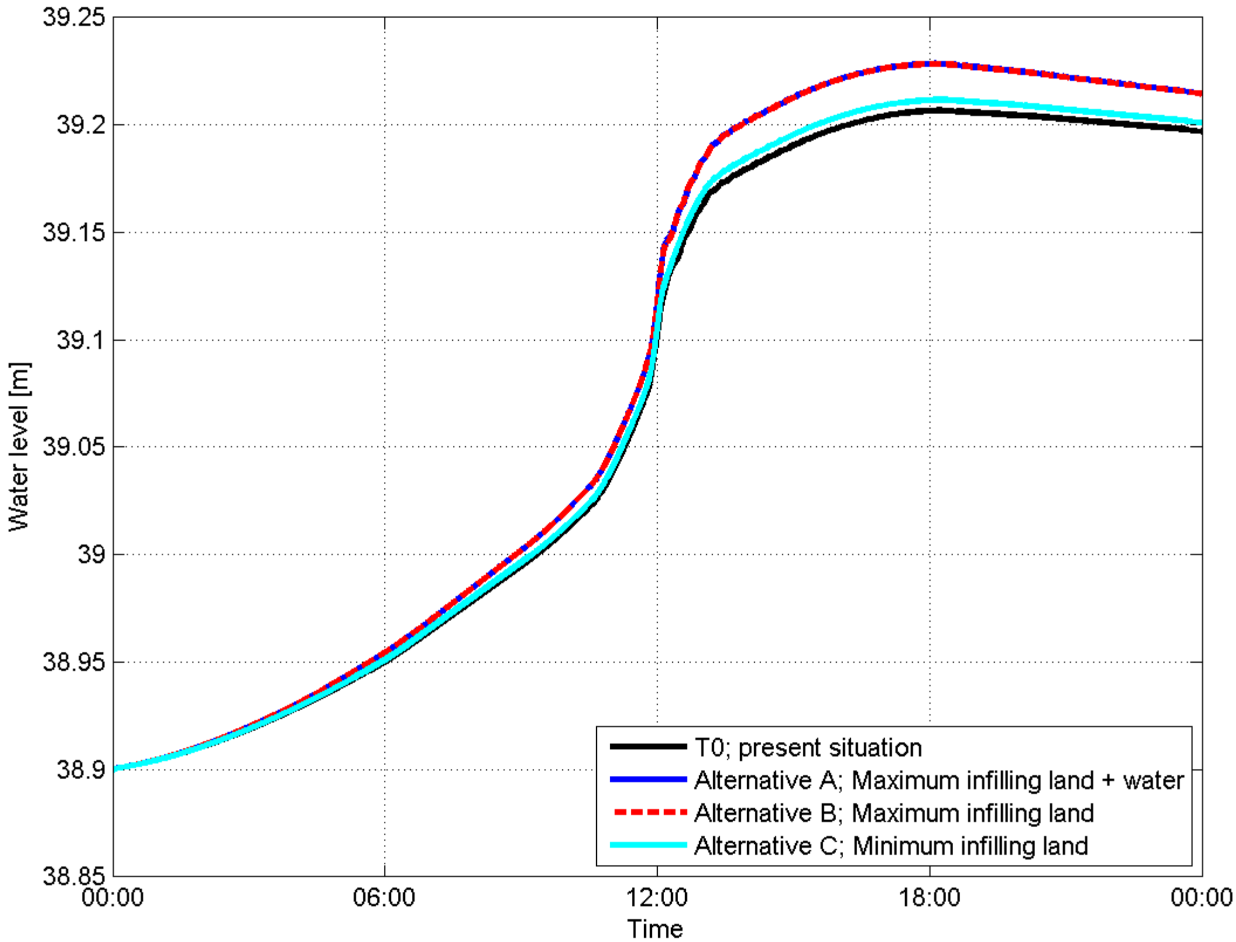


Figure 3.3: Water level in Storavatnet for a 1:200 year rainfall scenario for T0 and the 3 alternatives

3.4 Flow situation for Present situation (T0):

Figure 3.4 shows the velocities of the 1:200 year rainfall event at 12:00 AM in the area of interest. At this time the velocities are the largest. The outflow from Ørjebekken is clearly visible. According to the model this water is discharged in easterly direction. The outflow from the exising culvert is also present. The water is transported south over two small sills. The water depth here is small (~1m), so the velocities are increased to 15 cm/s. In the rest of Storavatnet no large velocities occur in the simulation at this time (not shown).

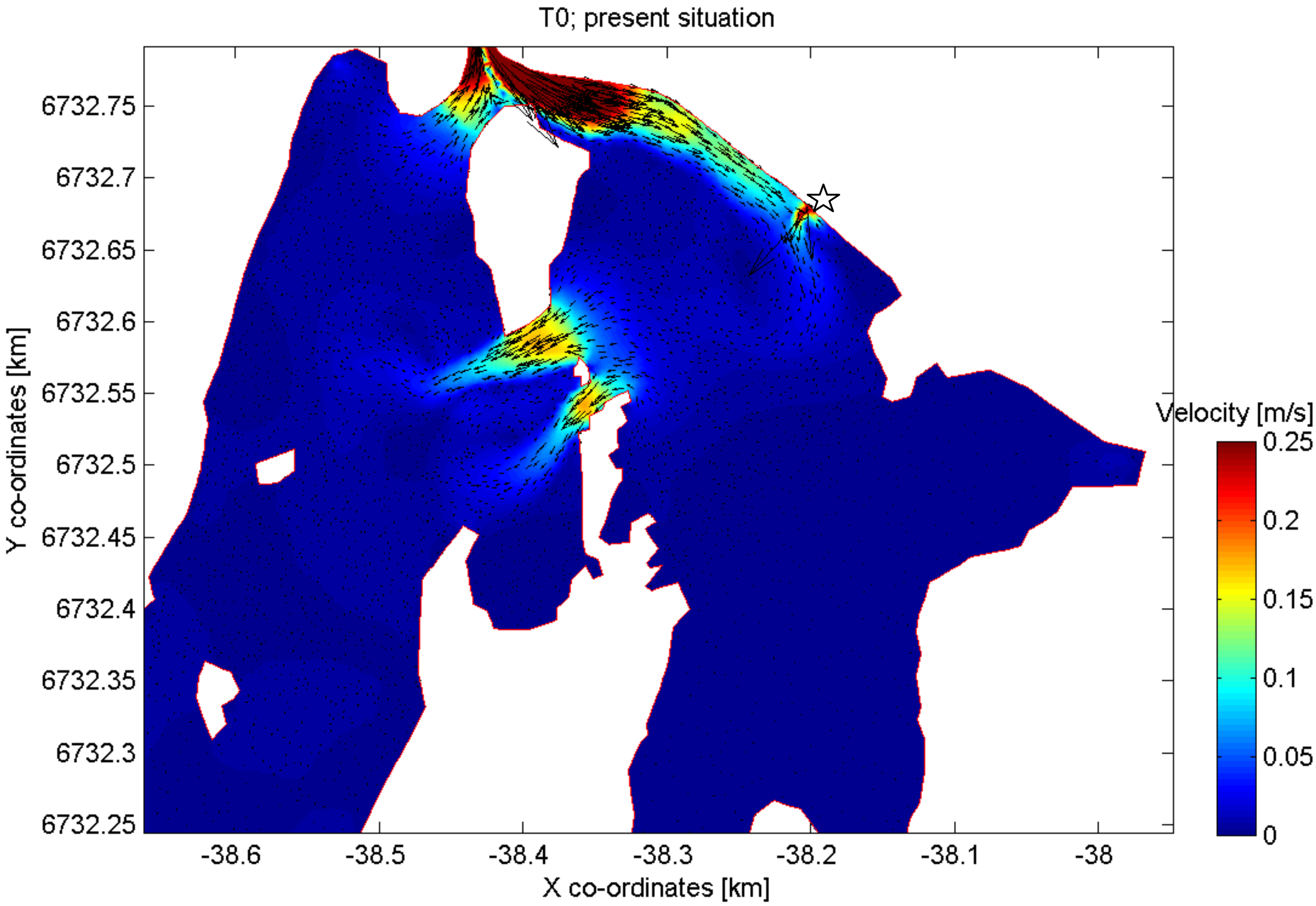


Figure 3.4: T0 present situation; velocities at 12:00 AM during extreme rainfall event.

3.5 Flow situation for Alternative A: Maximum infilling Land + water

Figure 3.5 shows the flow at 12:00 AM for Alternative A. The discharge from Ørjebekken is led around the island and discharged into Storavatnet just before the sills. The culvert with the discharge from the northeasterly catchment area is extended and released at the location as indicated by the star. The discharges occur just before the sills. This leads to (relative) large velocities in the area near and over the sills. Several horizontal circulation patterns occur as a consequence of the changed shape of the lake and discharge regime.

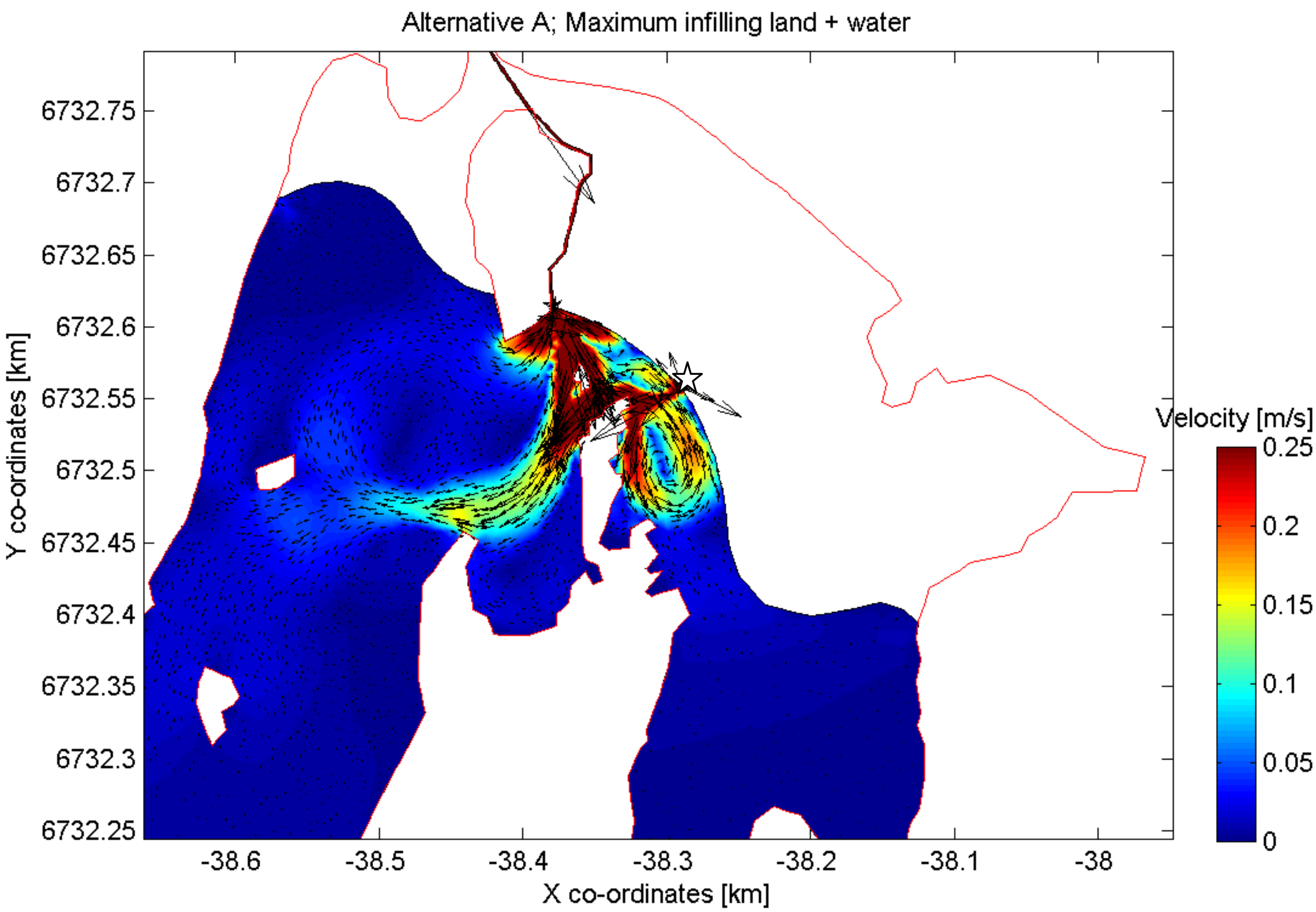


Figure 3.5: Alternative A; velocities at 12:00 AM during extreme rainfall event. The red line represents the present layout

3.6 Flow situation for Alternative B: Maximum infilling Land

Alterative B is equal to Alternative A, only an extra area in the lake is not filled in (Figure 2.4). This extra infill area is located south of the curlvert as indicated with the star. A small difference in flow velocity between Alternative A and B can be observed in the eddy that is present here. In Alternative A the flow velocity is slightly larger due to the shallower depth. In the rest of the area no differences in flow velocity can be observed between Alternative A and B.

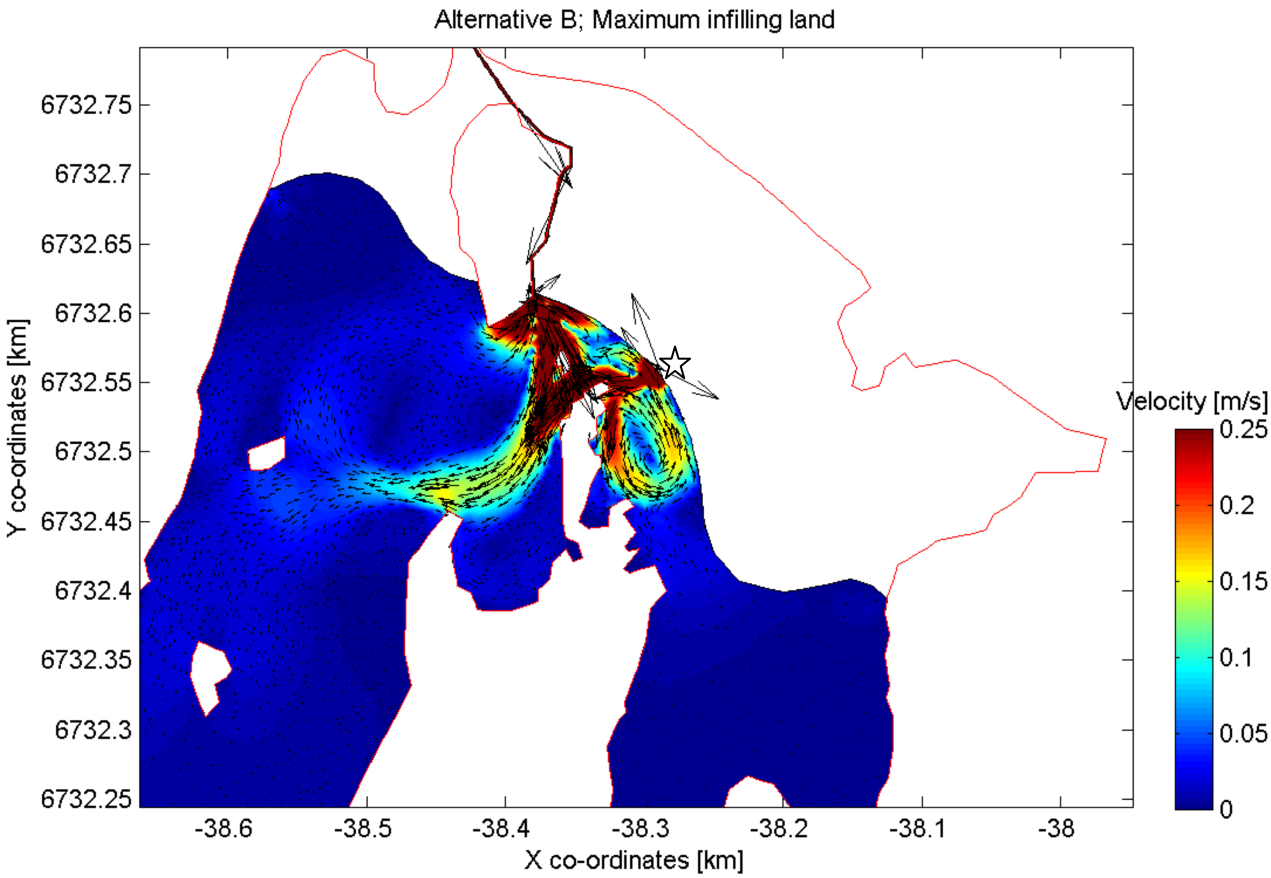


Figure 3.6: Alternative B; velocities at 12:00 AM during extreme rainfall event. The red line represents the present layout

3.7 Flow situation for Alternative C: Minimum infilling Land

Alternative C represents a minimum infilling of Storavatnet. The runoff from Ørjebekken is discharged again at the east side of the existing island. Runoff from the northeast area is discharged at the location as indicated by the star. The maximum flow situation indicates that most water from Ørjebekken is discharged in southerly direction. A part is deflected in easterly direction and creates an eddy. At the south side of the sills a smaller eddy is created.

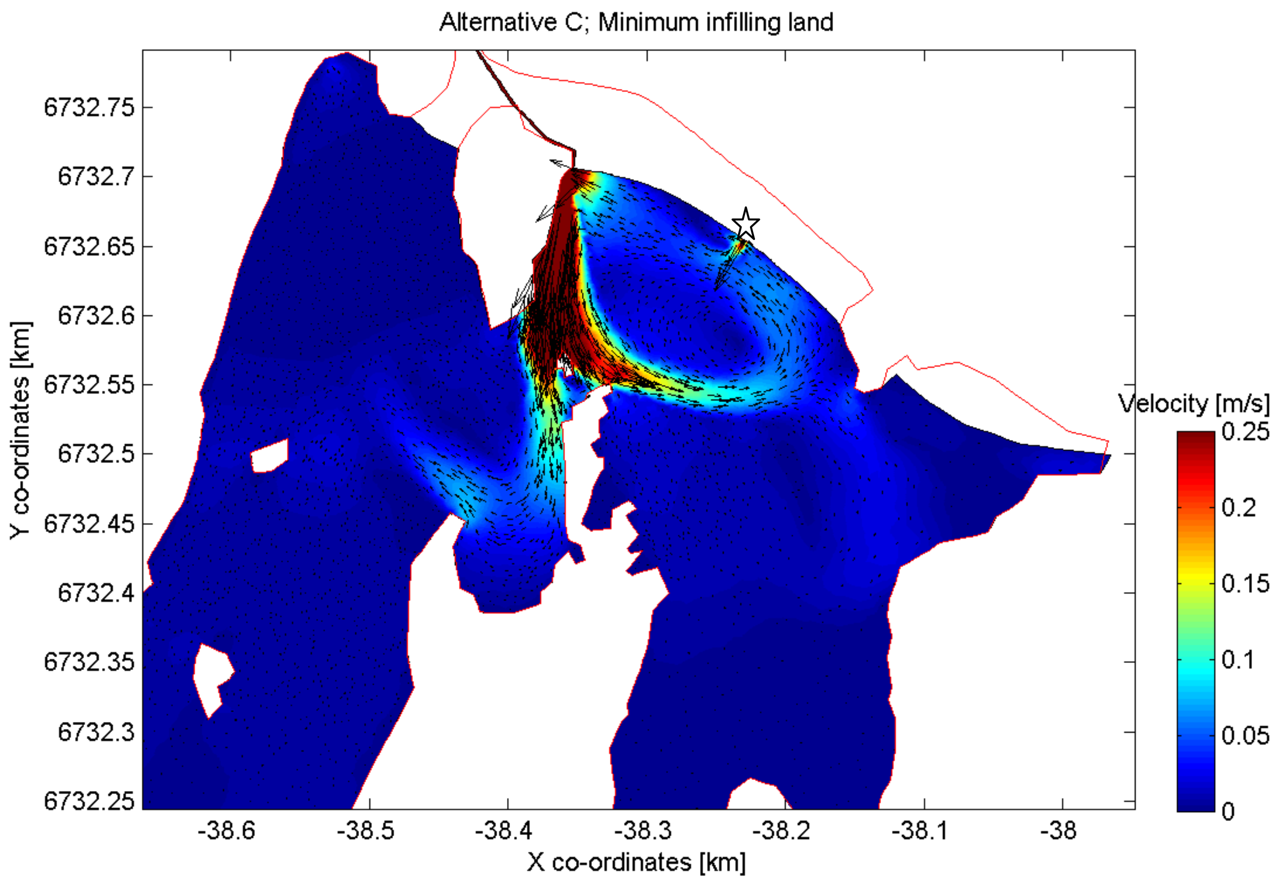


Figure 3.7: Alternative C; velocities at 12:00 AM during extreme rainfall event. The red line represents the present layout

4 Simulation of wind scenario: 15 m/s from 180°

4.1 Introduction

This chapter describes the outcomes of the simulations with a 15 m/s wind from a southerly direction. A 15 m/s wind is a (small) storm condition which occurs a few times a year.

In general wind generates surface currents in the direction of the wind. This is compensated by a opposite flow near the bottom. In this way vertical circulation cells are generated and these are dominant features in lake circulation. Wind generated currents are stronger in shallow areas.

A southerly wind is chosen here, since this generates the maximum fetch length over the lake (maximum length over open water) and the largest difference in water level over the lake (several cm). Also the effect of the alternatives

Other assumptions are:

- No temperature differences occur; a small sensitivity analysis reveals that velocities generated by wind are dominant over temperature difference generated velocities;
- There is no (rain)runoff to Storavatnet; also there is no runoff from Storavatnet to Småvatnet.
- A constant wind drag coefficient of 0.0026 is assumed in the model.

4.2 T0: Present situation

Figure 4.1 shows the wind generated velocities at the surface and at the bottom. The surface currents generally in the direction of the wind and are up to 0.5 m/s at shallow areas. In deep areas a return current is generated at the bottom in southerly direction. This current can be as large as 0.2 m/s. Wind thus generates large vertical cells in the water.

Compared to the velocities of the extreme rainfall scenario, the wind generated velocities are much larger.

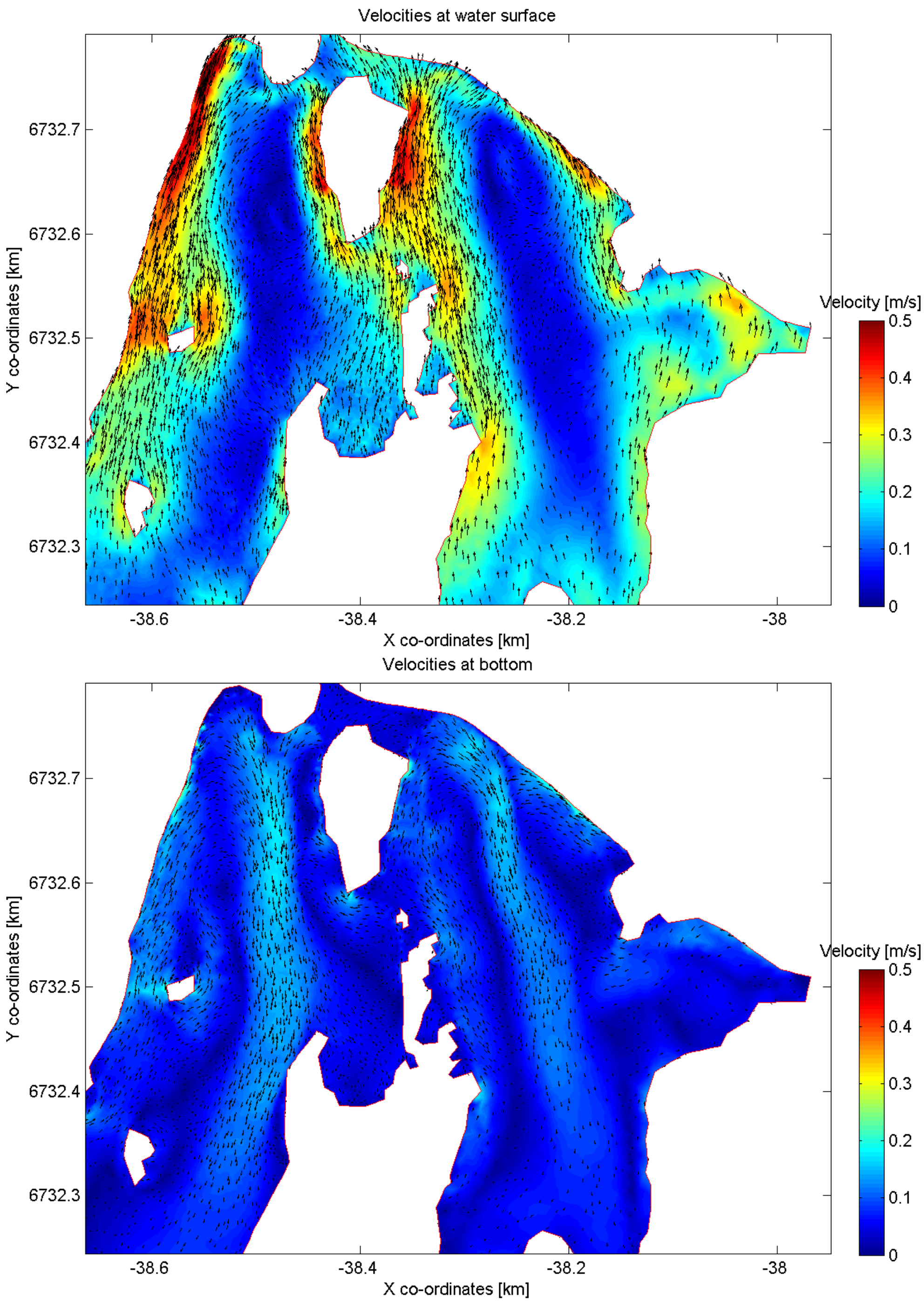


Figure 4.1: Present situation; wind scenario 15 m/s from 180°

4.3 Alternative A: Maximum infilling Land + Water

Alternative A consists of a maximum infilling of Storavatnet and on both land and water. The wind generated currents in the eastern part (where the infilling occurs) generally become less than the present situation (Figure 4.2). This is especially true for the bottom currents. This means that the wind circulation in this part of the lake becomes less. Near the western infill area the circulation pattern changes slightly, but the general circulation pattern is not affected.

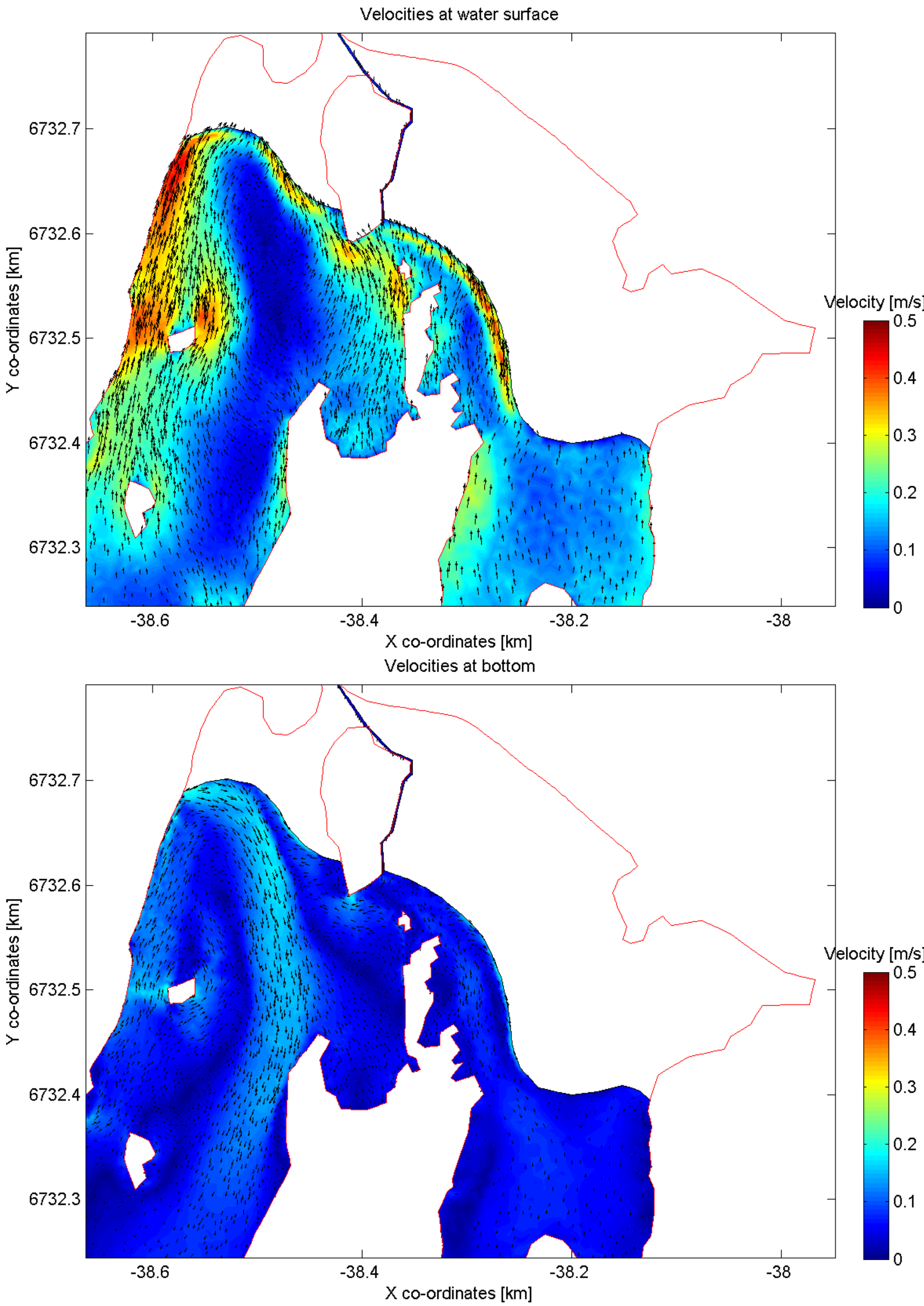


Figure 4.2: Alternative A; wind scenario 15 m/s from 180°

4.4 Alternative B: Maximum infilling land

The wind generated velocities of Alternative B (Figure 4.3) are generally comparable to Alternative A with exception of the eastern infill area. The velocities here are higher than Alternative A, especially the bottom generated return flow. This means that the infilling of Alternative A causes a reduction in circulation.

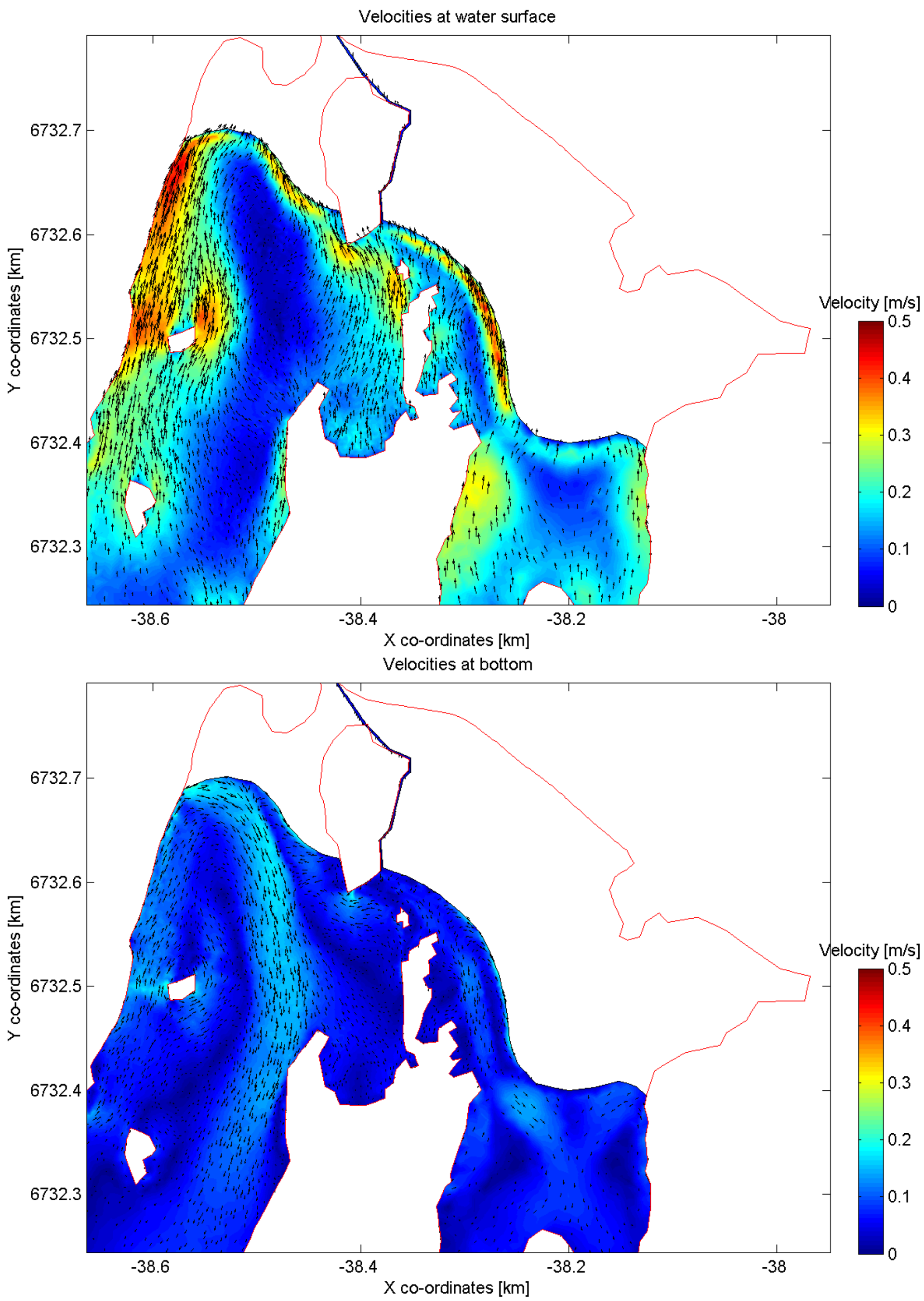


Figure 4.3: Alternative B; wind scenario 15 m/s from 180°

4.5 Alternative C: Minimum infilling land

The wind generated currents of Alternative C (Figure 4.4) are generally not largely affected by the infilling compared to the present situation. Both in the eastern and western part the circulation patterns are not largely affected.

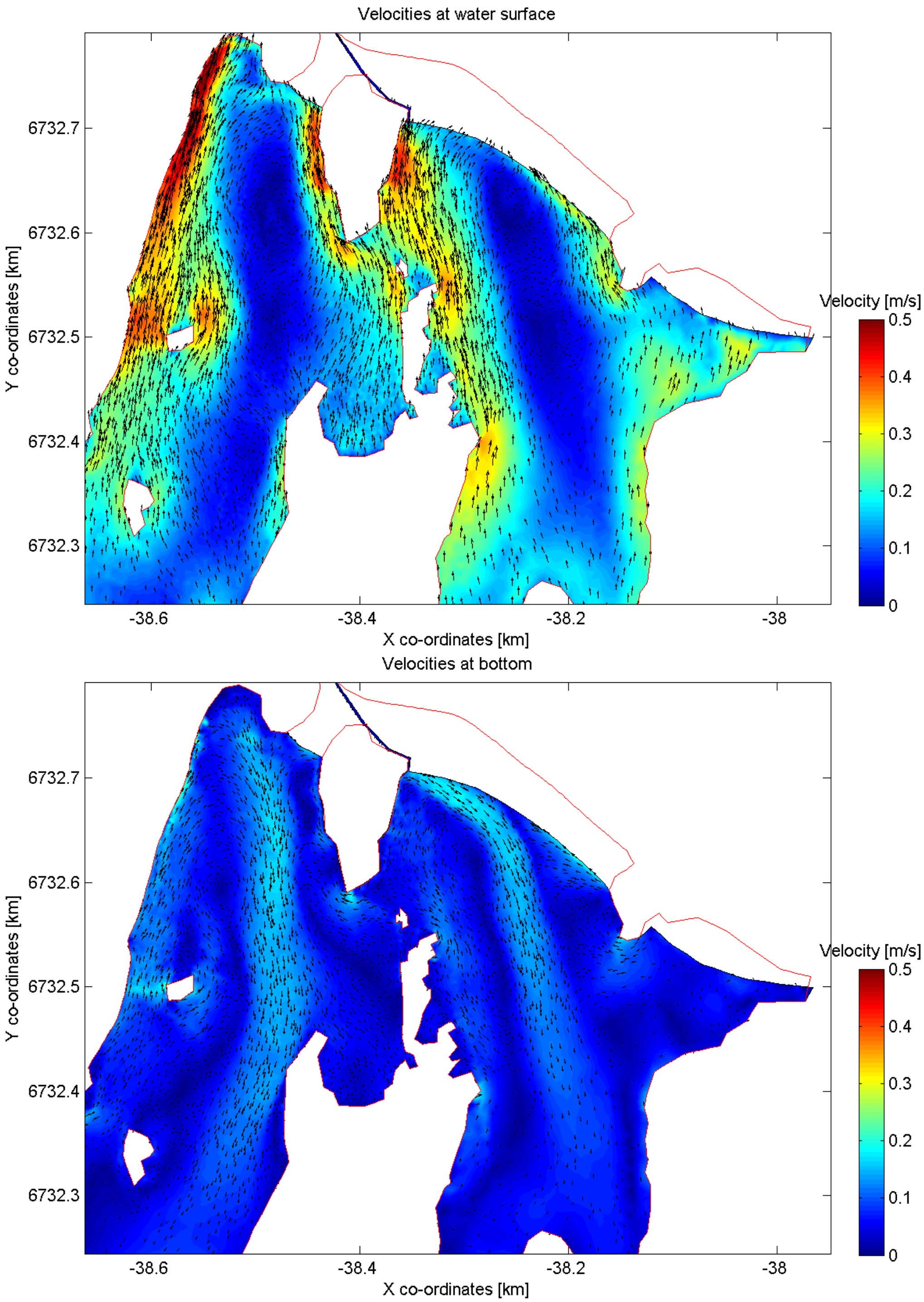


Figure 4.4: Alternative C; wind scenario 15 m/s from 180°

5 Extra simulations with a lowered sill for Alternative A

5.1 Introduction

As seen from the previous chapter the circulation pattern of the eastern infill area of Alternative A becomes less than the present circulation pattern. A consequence is that the water becomes more stagnant. During warm period this can lead to possible problems of algae blooms, see also the next chapter.

In order to improve water circulation in Storavatnet the sills between the eastern infill area and the western part of Storavatnet can be lowered to generate more water circulation (see Figure 5.1). The sills have a height of approximately 38m. This means that during normal circumstances only 90cm water is present op top of the sills. During hot periods the water level of the lake will be lower and the amount of water that exchanges between east and west is further limited. Lowering the sills would therefore enhance circulation and therefore the water quality. In this chapter the sills will be lowered to -4m in below the normal water level (38.9m) in the simulations. That is the same level as the infill height of Alternative A. Figure 6.3 shows the bed level of this alternative A with reduced sill height.

The next chapter deals with the temperature driven currents. In this chapter the results of Alternative A with a lower sill for the extreme rainfall and wind scenario will be discussed.

Figure 5.1: Location of sills in Storavatnet (photo: 1881.no)

5.2 Extreme rainfall scenario Alternative A with lowered sill

Figure 5.2 shows the maximum velocities of the extreme rainfall event for Alternative A with lowered sill (compare with Figure 3.5 for Alternative A with sill). The outflow from Ørjebekken remains the same in both simulations. The flow with a reduced sill height flows more over the eastern sill. The velocities over the western part of the sill are significantly reduced. The rest of the flow pattern shows some minor changes due to the lowering of the sill.

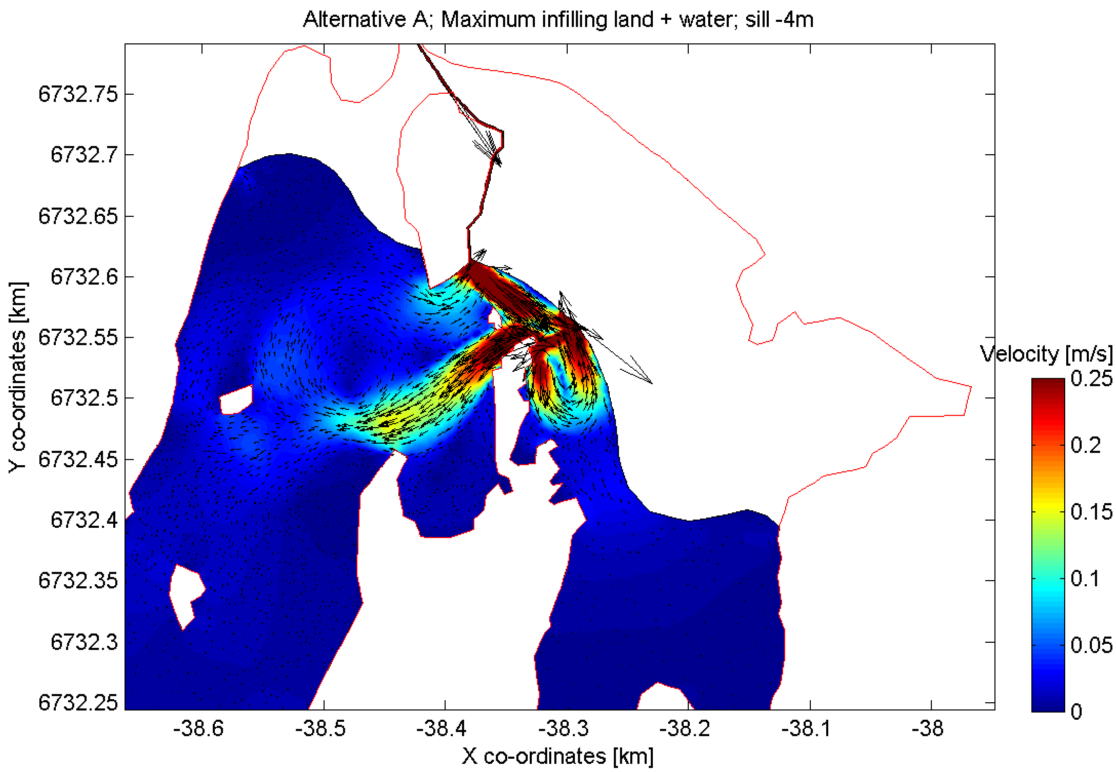


Figure 5.2: Alternative A with lowered sill; velocities at 12:00 AM during extreme rainfall event. The red line represents the present layout

5.3 Wind scenario Alternative A with lowered sill

Figure 5.3 shows the wind circulation velocities for Alternative A with the lowered sill (Compare with Figure 4.2 for Alternative A with present day sill). At the sill the velocities are reduced due to a lower sill height. In the rest of the area the flow velocities remain the same. This shows that wind driven currents are mainly locally generated.

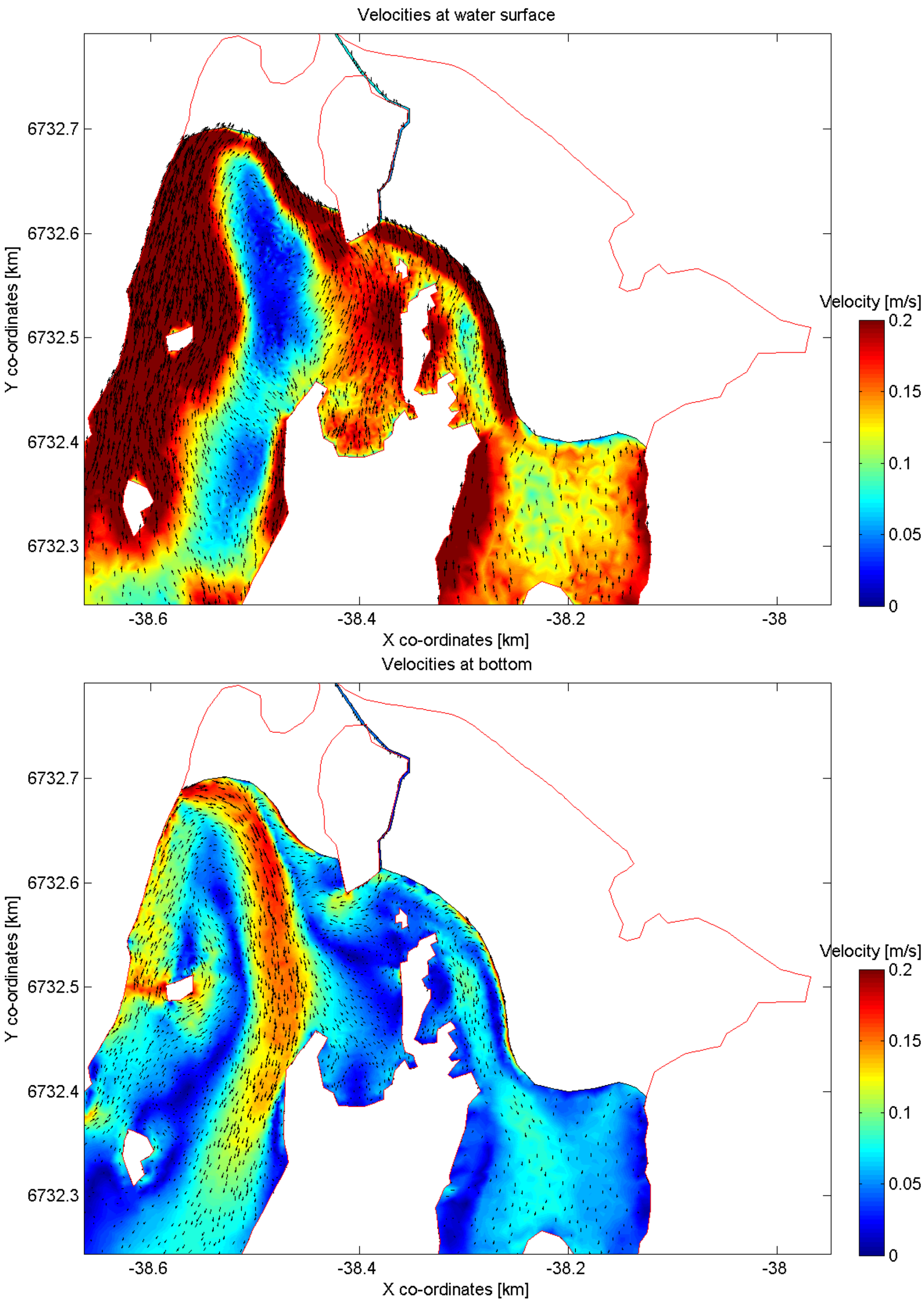


Figure 5.3: Alternative A with lowered sill; wind scenario 15 m/s from 180°

6 Simulation of water circulation due to water temperature differences

Temperature differences in lakes are one of the driving forces for water circulation. The temperature during the summer months can reach up to 20 degrees in the upper layer according to several measurements in Norway. This upper layer is called the epilimnion and is usually several meters thick up to 10-15m. Under this upper layer a sharp transition in temperature occurs, where the temperature drops to 4-6 degrees, this layer is called the thermoclime. Further down the lowest layer is called the hypolimnion and the temperature here is nearly constant at 4-6 degrees. Between the upper and lower layer there is (almost) no exchange of water and (suspended) matter.

When there is no water runoff and no wind, horizontal differences in water temperature is the only exchange mechanism that causes water circulation. When the air temperature is constant for a long time, the water temperature reaches a constant temperature and no horizontal difference in water temperature exists. At this point no water circulation takes place.

This is however a theoretical case, since for example day and night differences in air temperature causes cooling and warming of the top surface of the lake. A shallower part of the lake, like the infill area, warms quicker and cools quicker than a deeper part of the lake. This mechanism causes differences in water temperature in the upper part of the lake. Since warmer water has a different density than cooler water circulation tries to equal the horizontal differences in density.

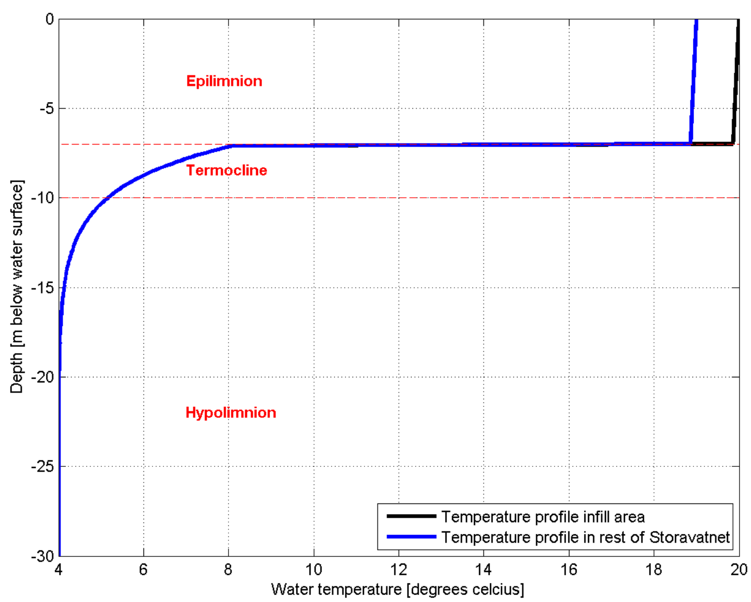


Figure 6.1: Initial assumed temperature profile that is used as input in the temperature simulations

In the temperature simulations an initial 3D temperature field is supplied to the model, see Figure 6.1. Here a typical summer temperature profile is assumed: the upper 7m contains warm water and below 7m a sharp transition in temperature is assumed up to 4 degrees in the lower levels. The upper part of the lake has a temperature of 19 degrees and the infill area has a temperature of 20 degrees in the upper part. This one degree difference occurs when the lake temperature is warming and the infill area warms quicker than the rest of the lake. This can be for example during a hot day, when the temperature warms in the morning. Temperature measurements of Storavatnet over a day period are not available; therefore we take measurements of another lake in Norway. Figure 6.2 shows the water temperature of Flaksvatn (South Norway) over the last 2 months. Note that the water temperature is warming from 4 degrees to 18 degrees over 2 months time, when the lake is warming towards the summer. The daily temperature difference between day and night can reach 2 degrees, so 1 degree difference between the shallow part and deeper part sounds reasonable.

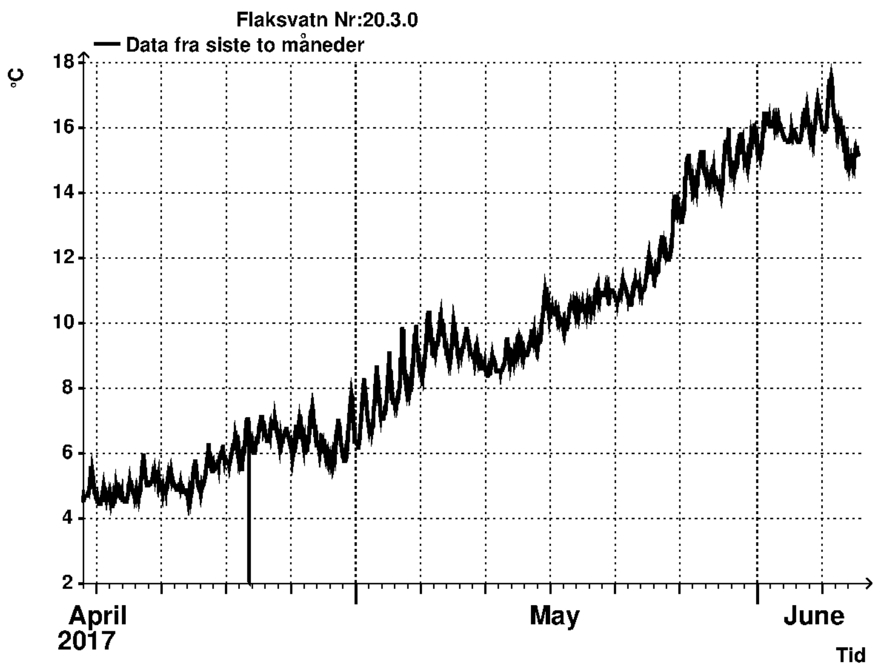


Figure 6.2: Lake temperature of Flaksvatn of the last 2 months (www.nve.no)

Four simulations are carried out to show the effect of reducing the height of the sill:

1. Alternative A (infilling to -4m); present day sill height; Temperature driven currents
2. Alternative A (infilling to -4m); sill height reduced to -4m; Temperature driven currents
3. Alternative A (infilling to -6m); present day sill height; Temperature driven currents
4. Alternative A (infilling to -6m); sill height reduced to -6m; Temperature driven currents

See Figure 6.3 for the bed levels of the 4 simulations.

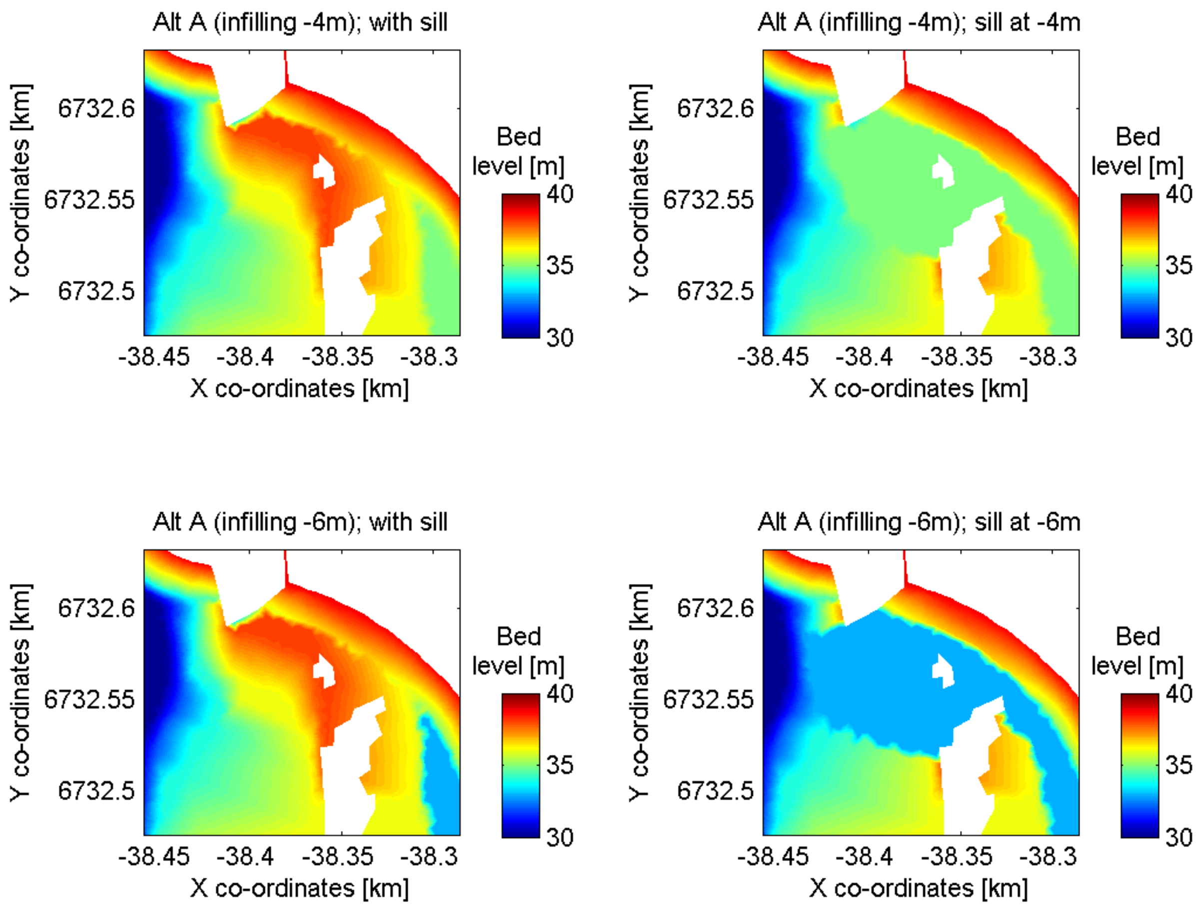


Figure 6.3: Bed level of the 4 temperature simulations

Figure 6.4 shows the currents at the water surface and Figure 6.5 after one hour of simulating. Note that the velocities at the surface are from east to west, while at the bottom the velocities are from west to east. The temperature of the lake tries to equal and that means that the warmer water of the eastern part is flowing to the western part. The cooler water in the western part is flowing to the eastern part to replace the water that has flowed out. This causes a water exchange between the western and eastern part. There is hardly any water exchange if the sill is present. It does not matter if the infilling is at -4m or -6m. If the sill is lowered the water circulation becomes much larger. The sill height at -4m gives velocities of several cm/s at the water surface. If the sill height (and infill height) is further lowered to -6m the water circulation is further enhanced. The water exchange is calculated over the sill during the one hour simulation, see Figure 6.6. The water exchance with a lowered sill at -4m becomes a factor 6 larger (0.4 m^3/s versus 2.5 m^3/s). When the sill is further lowered to -6m (and the infilling is also at -6m) the water exchange increases further to a factor 11 (0.4 m^3/s versus 4.5 m^3/s) according to the model results.

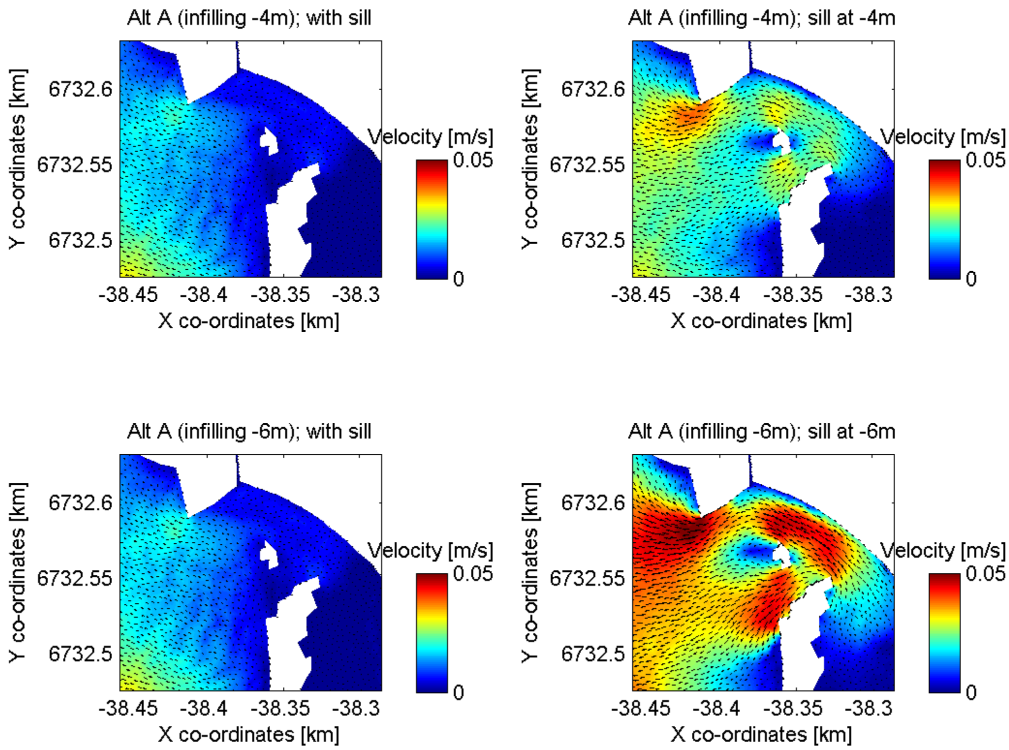


Figure 6.4: Flow velocity at the water surface after one hour; temperature simulations

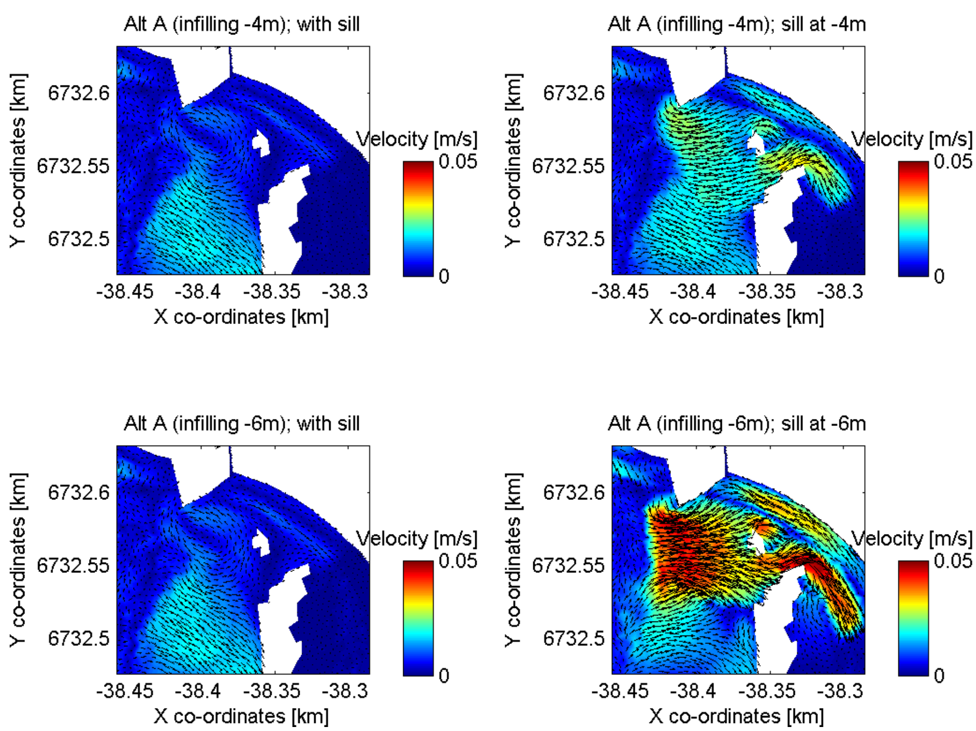


Figure 6.5: Flow velocity at the bottom after one hour; temperature simulations

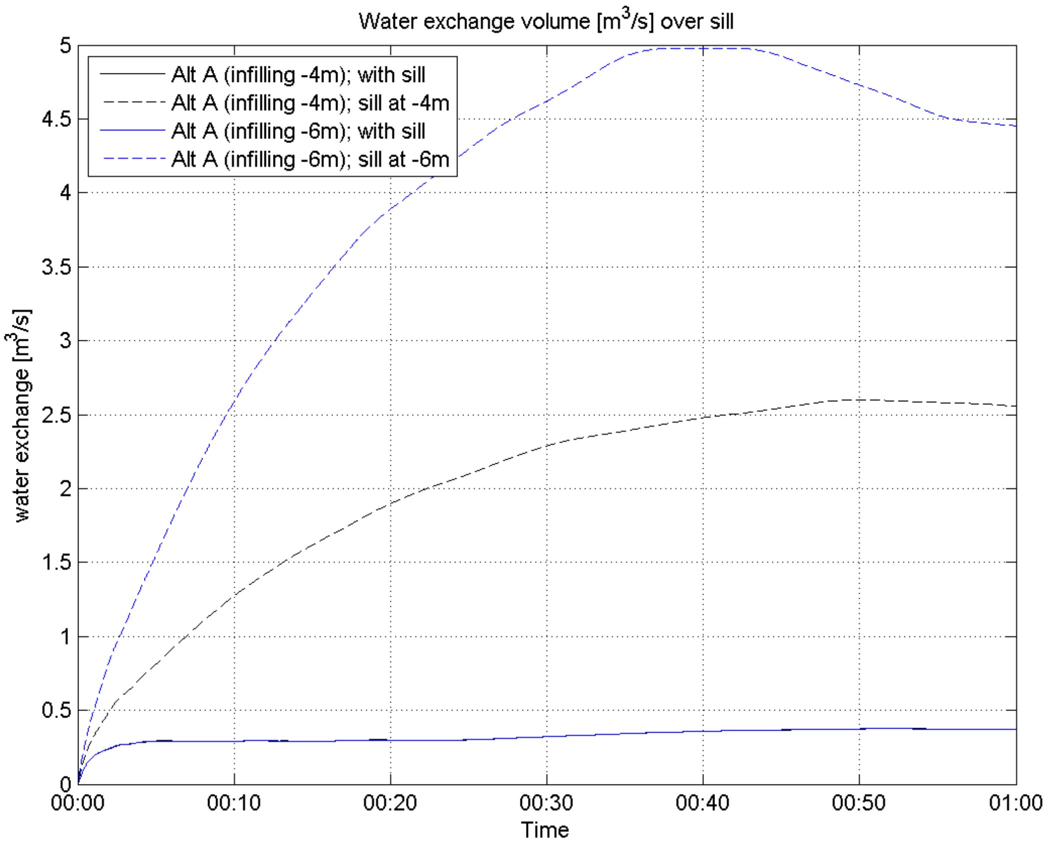


Figure 6.6: Exchange volume over the sill in m^3/s

Like water temperature residence time is another important factor for algae blooms. Table 6.1 shows the residence times of water for the four alternatives using the water exchange volumes of Figure 6.6. Here we assume further that the exchange of Figure 6.6 is maximum during morning. A similar (negative) exchange occurs in the evening when the lake is cooling. For the exchange volume over a day we assume a sinusoid.

The residence time of Alternative A with sill is then calculated at 6.3 days, while with the lowered sill this is 1.0 day. With an infill area at -6m the residence times of the situation with sill becomes 8.2 days and with the sill lowered this becomes 0.8 days.

Table 6.1: Residence time of water in eastern infill area for the 4 alternatives

Alternative	Residence time (days)
Alternative A; Infill -4m; present day sill	6.3
Alternative A; infill -4m; sill lowered to -4m	1.0
Alternative A; infill -6m; present day sill	8.2
Alternative A; infill -6m; sill lowered to -6m	0.8

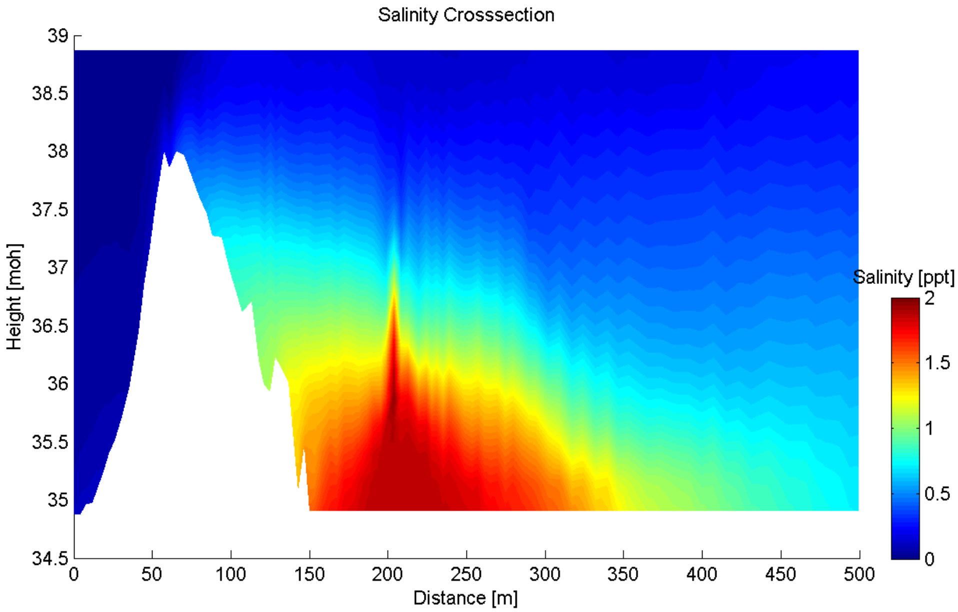
7 Simulation of salt water outflow in infill area

Road salt is used every winter to prevent roads to become slippery. The road water with dissolved salt runs to its discharge point in the sea or lake. At the moment of writing the report it was not certain that the planned road water discharge to sea could get permission. Therefore the consequence of a salt discharge into Storavatnet is investigated in this chapter.

To show the effect of discharging the road salt into the infill area of Storavatnet a simulation is carried out with a constant discharge of 0.5 m^3/s with a salinity of 2 g/l (2 ppt). A day with this constant discharging is simulated. Figure 7.1 shows the salinity after this day. The discharge point is located near 200m of the crosssection. The salt accumulates near the bottom of the infill area, because salt water is heavier than fresh water. Due to the presence of the sill the salt stays in the infill area and cannot spread further. Only a very small amount of salt comes over the sill.

By removing the sill the salt does get out of the infill area, but it will accumulate in the next deep point in Storavatnet, where it will be hard to get out.

Salt water in fresh water systems causes water quality problems and should be avoided as much as possible. It is therefore recommended to pursue the planned road water discharge into the sea.



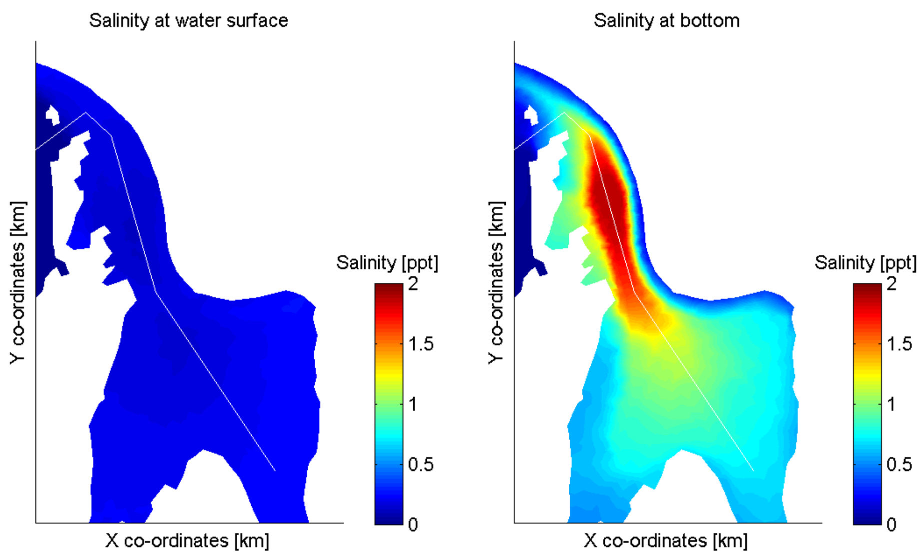


Figure 7.1: Salinity in water after one day discharging; Alternative A with present day sill; The crosssection of the top figure is shown as white lines in the bottom figures

8 Conclusions and recommendations

8.1 Conclusions

A 3D hydrodynamic model of Storavatnet called FINEL3d is set-up that can simulate the water levels and flow in Storavatnet.

Three infill scenarios are considered in the model

A) Alternative A: Maximum infilling Land + Water
B) Alternative B: Maximum infilling Land
C) Alternative C: Minimum infilling

In a later stage an extra Alternative A with a lowered sill height was investigated.

The effects of infilling are simulated with an extreme rainfall scenario, a southerly 15 m/s wind, temperature effects and a road water (salt) discharge

<u>Extreme rainfall scenario:</u>

An extreme rainfall scenario with a return period of 1:200 year shows that the infilling causes a raise in water levels of 3 cm for Alternative A and B and 1 cm for Alternative C.

The flow pattern for the extreme rainfall scenario changes mainly because of the location of the runoff of the Ørjebekken area. This generates large currents over the present sill and generates eddies that do not occur in the present situation. Reduction of the sill changes the flow pattern slightly.

<u>Wind generated currents:</u>

The wind generated currents are generally dominant over the currents generated by rainfall runoff. Wind generates vertical circulation patterns. Alternative A shows the most affected flow pattern compared to the present situation. The eastern part of the infill area does not generate a circulation pattern with the same magnitude. This means that there is a risk of stagnant water here. Alternative B, where the underwater infill does not occur, shows more circulation. Alternative C is minimally affected. Reduction of the sill height of Alternative A reduces the wind driven currents on the sill, but not in the rest of the area.

<u>Temperature effects:</u>

Reduction of the sill height improves water circulation between the eastern infill area and the western part of the lake. There is a calculated increase of water circulation of a factor 6 when the sills are lowered to -4m below the normal water surface. An infill area and a sill height at -6m enhances water circulation even more (factor 11) compared to the standard Alternative A (present day sill + infill at -4m). Residence time of water is 6 (infill -4m) and 8 days (infill -6m) with the present day sill, and become 1 (infill -4m) and 0.8 day (infill -6m) with a lowered sill.

<u>Road water (salt) discharge</u>

Releasing road water with salt into the infill area of Storavatnet will result in accumulation of salt near the bottom of the infill area. When the sills are lowered the salt can come out of the infill area, but accumulates in the next deep point of the lake. It is therefore recommended that the road water is not discharged into Storavatnet.

8.2 Recommendations

- In the simulations with a lowered sill the complete bed level near the sill is defined at -4m below the normal water level. In this way the maximum effect of the lowered sill is shown in the simulations. It is however probably not necessary to lower the complete area. The most important is to have sufficient water circulation. It is likely that lowering the southern sill of Figure 5.1, which is more directly connected to the rest of the eastern infill area, should be enough to have sufficient circulation.
- Measurements of waterlevel fluctuations over time in Storavatnet can help to improve the simulation of the runoff of the catchment area and the discharge to Småvatnet of the model.

9 References

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