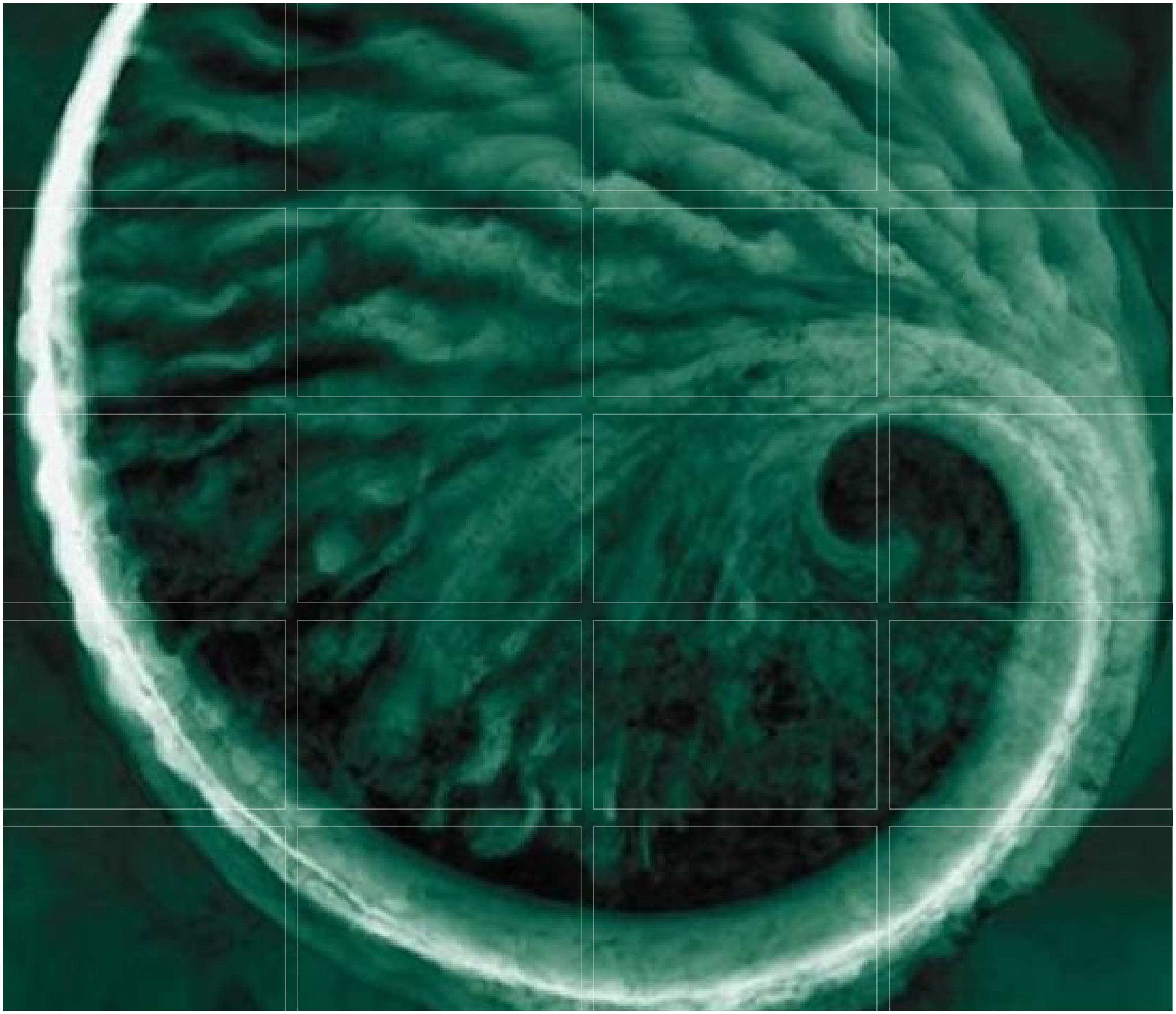
Appendix 8-F

Mixing Associated with Discharge of an Effluent to Murray River at Low Flow Conditions



Prepared for:

Mining

MURRAY RIVER COAL PROJECT

Mixing Associated with Discharge of an Effluent to Murray River at Low Flow Conditions

July 2014

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MURRAY RIVER COAL PROJECT

Mixing Associated with Discharge of an Effluent to Murray River at Low Flow Conditions

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1. INTRODUCTION

This document addresses the numerical simulation of effluent transport and mixing after discharge to Murray River for HD Mining's Murray River Coal Project. The MIKE3 hydrodynamics model was applied to simulate the pertinent processes. Various discharge locations were selected for evaluation and concentration distributions were simulated to assess mixing 100 m downstream of the discharge point. Results of the modelling are intended to support planning for the siting of discharge infrastructure and environmental assessment. More detailed analysis and simulations will be required to support permit applications associated with the Project.

2. NUMERICAL SIMULATION METHODS

2.1 SOFTWARE

The MIKE3 numerical model developed by Danish Hydraulic Institute (DHI) was used in the study. MIKE3 is three-dimensional numerical simulation software which solves Reynolds-averaged Navier-Stokes equations of motion and has been extensively used to study engineering and environmental problems related to marine and freshwater bodies. The model suite includes all the modules required to address advection / dispersion (transport/mixing) as well as sediment (cohesive or non-cohesive) transport phenomena.

MIKE3 includes the effects of environmental factors such as ice coverage, wind speed, air temperature, solar radiation, evaporation, precipitation and Coriolis forces (due to the earth rotation). It comprises two main flow models:

- Basic flow model with rectangular grid cells which uses finite-difference technique to solve the equations of motion. This model is more suitable for regular boundaries and can only be used for lake and coastal ocean studies; and
- Flexible Mesh model which applies finite-volume method and can be effectively used for irregular domains. Its sigma coordinate capability increases the vertical resolution with decreasing depth and also enables simulation of flows with sloping free surfaces as pertinent to rivers. On the horizontal plane one can apply triangular mesh, rectangular mesh or a combination of both. One can also locally increase grid resolution to capture smaller scale dynamics if needed.

We first applied the MIKE3 Flexible Mesh model to reproduce the Murray River flow fields then selected an optimal discharge location where mixing occurs most rapidly and thoroughly in the river.

2.2 HYDRODYNAMIC SIMULATIONS

The critical condition, corresponding to maximum effluent concentrations in the river, occurs at low winter flow of 5 m^3/s (7-day low flow with 10 year return period) under a rigid ice cover.

It was assumed that the effluent discharge flow rate is 100 L/s (0.1 m^3/s).

Numerical simulation of these conditions was undertaken by first calibrating the model using field data of depth and flow (stage and discharge data).

There are three sets of field data:

- Velocity measurements in summer 2012 at high flow of ~150 m^3/s. Velocity data were collected with a downward looking Acoustic Doppler Current Profiler (ADCP) across five river transects. The measurements provide three-dimensional velocity fields with 10 cm vertical resolution at each transect;

- Velocity and depth measurements across one section in April 2012 (53 m^3/s); and
- Velocity and depth measurements across three sections March 2014 (average 13 m^3/s).

By varying the turbulent closure mode and adjusting model parameters (e.g., bottom roughness) the model was calibrated to reproduce the velocity and depth values measured in the fields. The procedure is outlined below

2.2.1 Bathymetry and Mesh Generation

Over half of the time spent in industry on a computational fluid dynamics (CFD) project is devoted to grid generation (Versteeg & Malalasekera 1995). However MIKE3 has a user-friendly built-in mesh generator which makes it superior to the most of available models on the market. Over 100,000 bathymetry data points were collected over an approximately 5 km river reach from upstream of the Murray River FSR bridge downstream past M19 Creek to near the gas pipeline crossing (Figure 2.2-1). These data were imported via the mesh generator in UTM10 zone where the project is located. About 3,000 triangular grid cells were generated with about five to six grid points across the river width and 500 grid cells along the river banks (see Figure 3.1-1). Grid resolution is four times finer at the location of discharge, river bends as well as contracting sections (see Figure 3.1-2). When the bathymetry data were collected, discharge locations near the Decline Site were being considered; however, through further Project development, discussion with regulators regarding permitting requirements, and review of baseline data, focus changed to assess discharge locations near the Coal Processing Site (Figure 2.2-1).

2.2.2 Hydrodynamic Module Parameters

Time step: The time step (Δt) in numerical simulations is kept sufficiently small to satisfy the Courant-Friedrich-Lévy (CFL) condition and thereby ensure stability of the solution:

$$\mathrm{CFL} = \frac{u\,\Delta t}{\Delta x} + \frac{v\,\Delta t}{\Delta y} + \frac{w\,\Delta t}{\Delta z} < 1$$

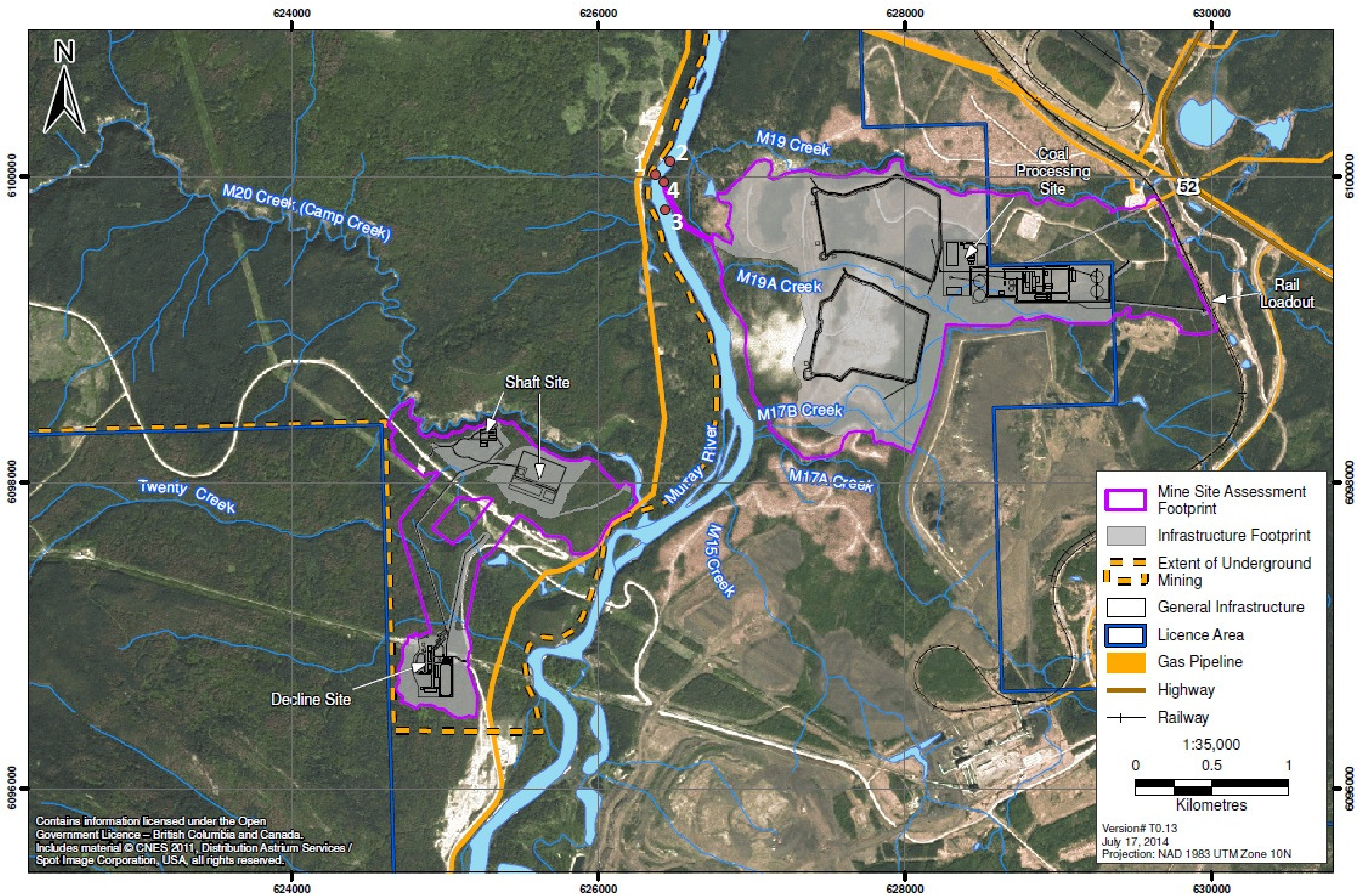
Here (u, v, w) are the orthogonal components of the three dimensional velocity field and (Δx, Δy, Δz) are the grid dimensions.

Eddy Viscosity: The Smagorinsky and Log law formulations were used for horizontal and vertical eddy viscosities respectively. These are known to produce more exact solutions in comparison with simpler formulations for turbulent closure.

Bed Resistance: is set by defining roughness height (ks) in meters. The ks value of 0.1 m leads to the best fit to measured velocity field values.

Ice Coverage: Selecting presence of an ice cover in the model introduces a no-slip boundary condition at the water surface and changes the vertical profile of velocity. A uniform ice layer of thickness 0.1 m was selected for the low flow winter case with a roughness height of 0.02 m applied at the ice / water interface.

Figure 2.2-1. Murray River Modelling Reach and Assessed Discharge Locations



Initial Condition: A constant initial surface elevation (horizontal plane) across the domain must be assumed. In practice the elevation of this plane is taken to be the approximate stage at the downstream section of the reach. [For calibration, field data were available for the high flow case.

Boundary Conditions: A no-slip boundary condition, i.e., zero velocity at solid boundaries, is applied at the stream bed / banks. There are two open boundaries: upstream and downstream sections. For the case of high flow in summer we have measurements of the stream bed elevation and the depth at those sections and use them as boundary conditions. However for the low flow situation, we know only the discharge value of approximately 5 m^3/s. In this case we estimate a downstream depth (resulting in a surface elevation) and use the 5 m^3/s discharge value as upstream boundary condition. We then run the model which adjusts the stream surface slope along the reach to maintain 5 m^3/s flow.

3. RESULTS OF THE NUMERICAL SIMULATIONS

A very low salt concentration was ascribed to the effluent to serve as a passive tracer in the model runs. The effluent salinity was selected as equal to 0.01 PSU, low enough to have a negligible effect on buoyancy in this regime. Values for dilution ratio are calculated by dividing 0.01 by the salinity calculated by the model. At a point where the effluent is fully mixed across the river section, the maximum physically possible dilution ratio is the river flow plus the effluent flow divided by the effluent flow rate:

$$D_{max} = \frac{5.1}{0.1} = 51.$$

Five sigma layers are used throughout the model regime with their thicknesses being proportional to the local river depth.

Below we summarize the model results where the concentration of the discharged substance is indicated by salinity.

It should be noted that:

- the colour scales are NOT uniform among the figures;
- at the locations downstream of the discharge point where the lateral mixing is not yet complete, dilution ratios can be higher than 51;
- a dilution ratio of 51 corresponds to a salinity of 0.0002; and
- sigma layer 1 is adjacent to the river bed and sigma layer 5 is adjacent to the surface.

3.1 DISCHARGE LOCATION 1

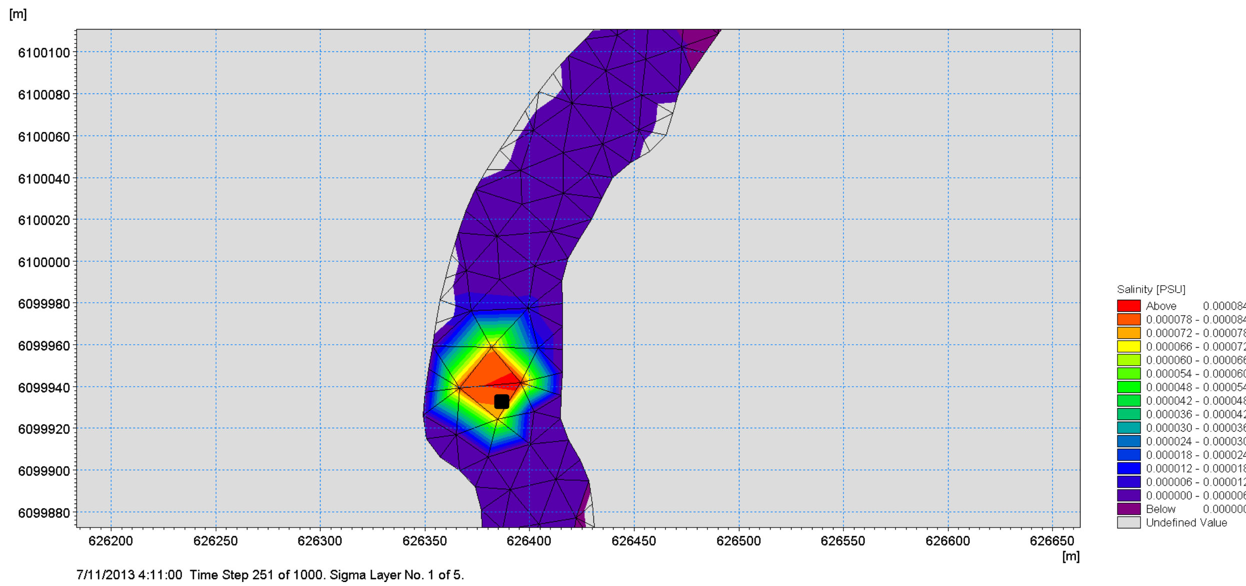
Discharge location 1 is located in the middle of the river at the bend. Figure 3.1-1 shows conditions in the bottom layer immediately after start of discharge as the model resolution requires homogeneity in each cell.

Figure 3.1-2 shows a cross section of the river looking upstream after equilibrium is achieved, that is after no further changes in concentration isopleths occur. The effluent moves toward the outside of the bend (toward the western bank) in response to centrifugal (or radial) acceleration.

Figure 3.1-3 shows the concentration isopleths in the surface layer and identifies the points at which time series of concentrations are plotted in Figure 3.1-3.

Figure 3.1-4 shows the evolution of concentrations and the final dilutions (indicated by values of D). At t1 adjacent to the outer bank, the concentration of effluent is highest and the final dilution achieved there is 28:1. At t4 adjacent to the inner bank, the final dilution is 83:1.

Figure 3.1-1. Salinity Map 1 s after Injection of the Effluent into the Model Domain.



Discharge location 1 is shown with a black rectangle.

Figure 3.1-2. Salinity Section 100 m Downstream the Discharge Location 1

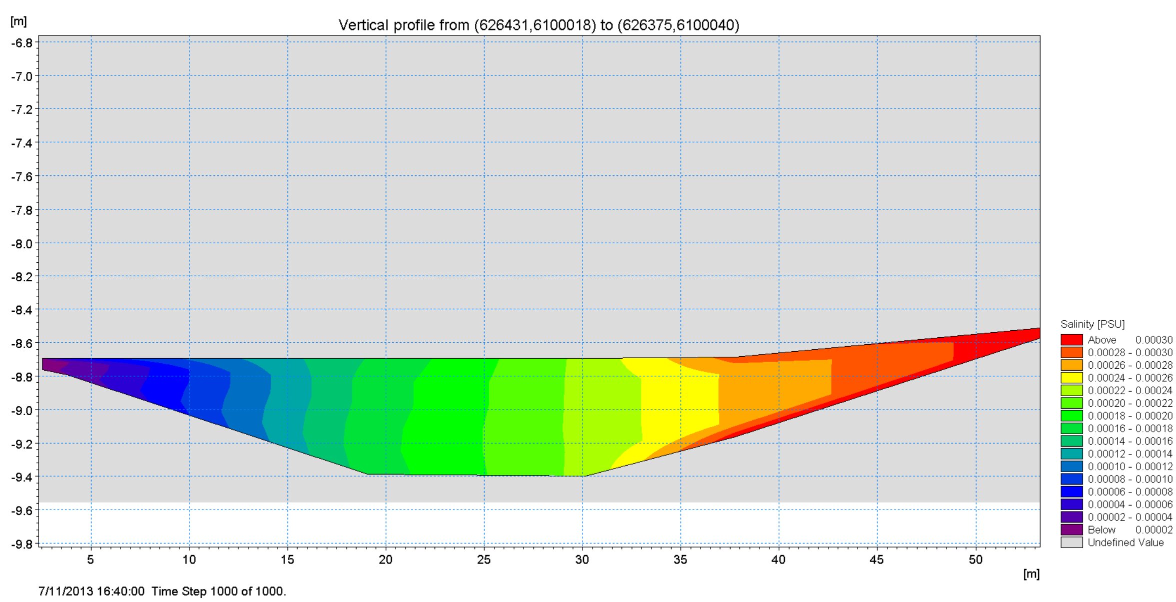
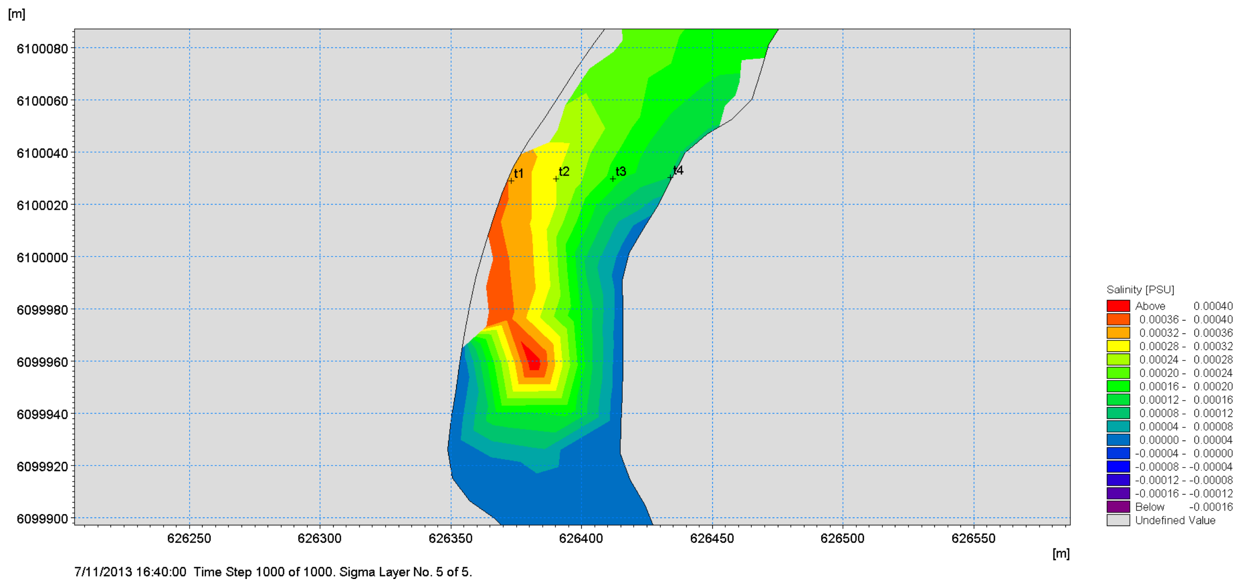
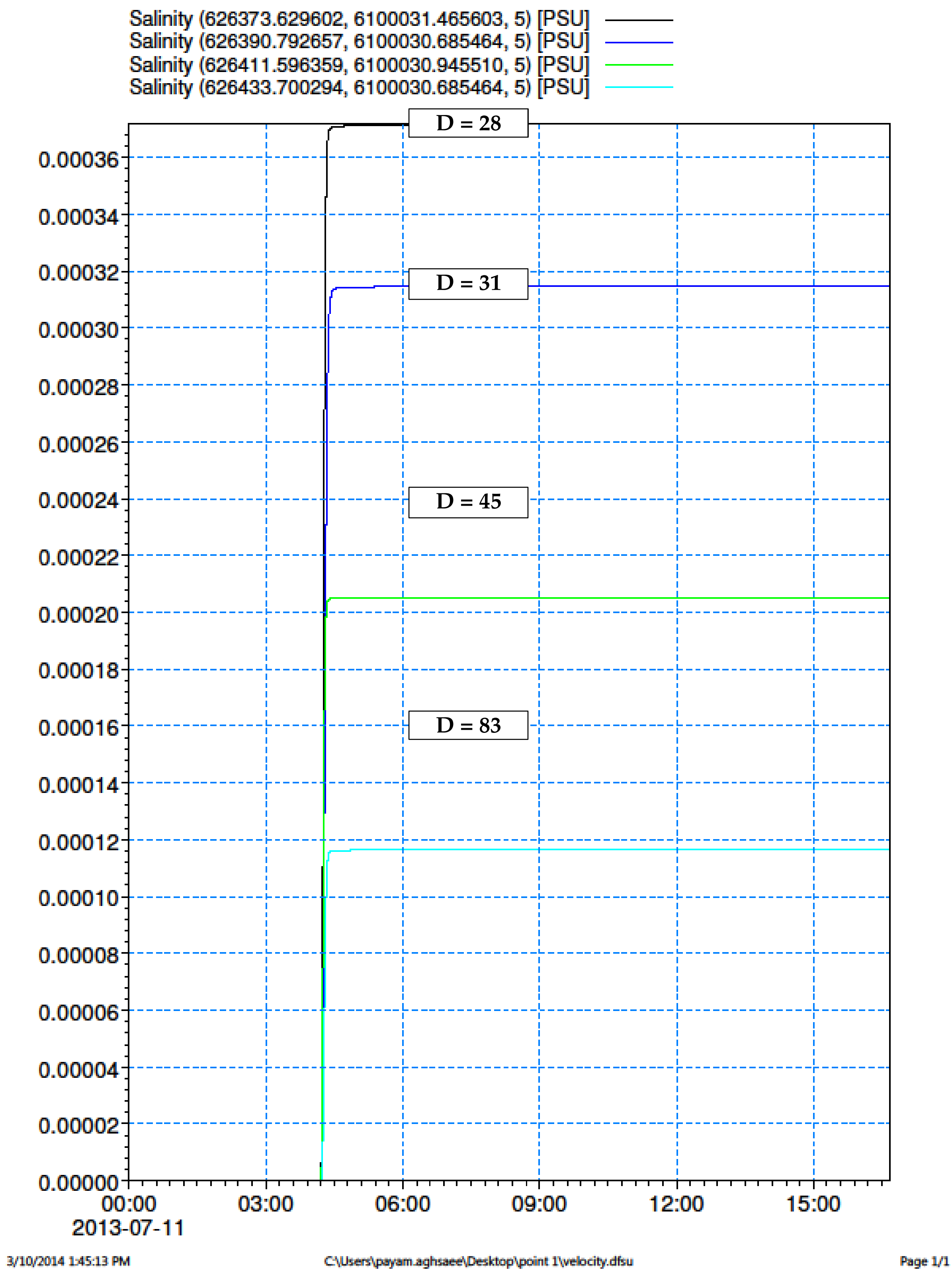


Figure 3.1-3. Salinity Map at the Surface



Time series of surface concentration are extracted at point t1-t4 across the section at 100 m downstream of the discharge location 1. Time series are shown in Figure 3.1-4.

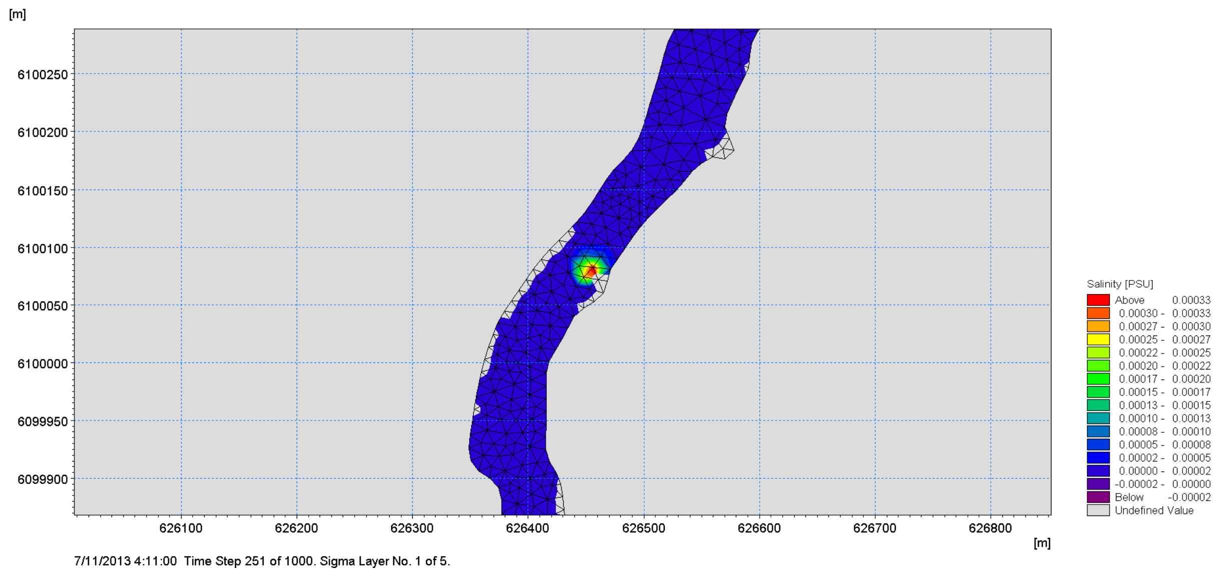
Figure 3.1-4. Times Series of Salinity Variations at Points t1-t4, 100 meters Downstream the Discharge Location 1



3.2 DISCHARGE LOCATION 2

Discharge location 2 is located near the right bank of the river approximately 100 m downstream of the bend. As for Figure 3.1-1, Figure 3.2-1 shows conditions in the bottom layer immediately after start of discharge as the model resolution requires homogeneity in each cell.

Figure 3.2-1. Salinity Map 1 s after Injection of the Effluent into the Model Domain



Discharge location 2 is shown in red.

Figure 3.2-2 shows a cross section of the river looking upstream after equilibrium is achieved, that is after no further changes in concentration isopleths occurs. The effluent plume tends to stay concentrated along the right (eastern) bank of the river. This is because, in the absence of stream curvature, there is no local radial acceleration (centrifugal acceleration).

Figure 3.2-3 shows the concentration isopleths in the surface layer and identifies the points at which time series of concentrations are plotted in Figure 3.2-4.

Figure 3.2-4 shows the evolution of concentrations and the final dilutions (indicated by values of D). At t1 adjacent to the left (western) bank, the concentration of effluent is lowest and the final dilution achieved there is 111:1. At t4 adjacent to the right bank, the final dilution is 36:1.

Figure 3.2-2. Salinity Section 100 m Downstream the Discharge Location 2

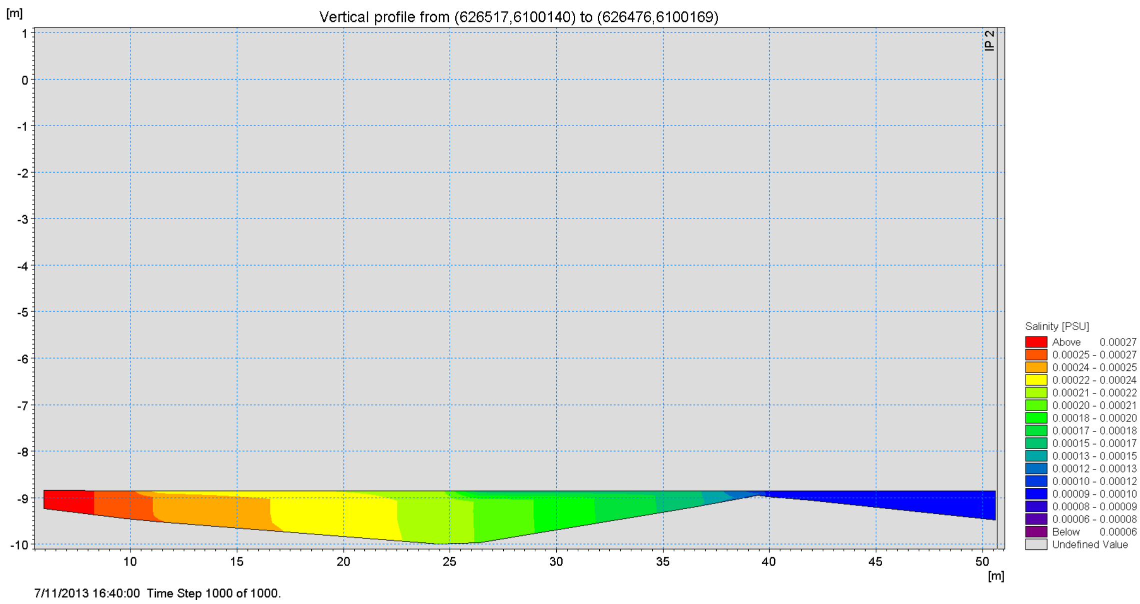
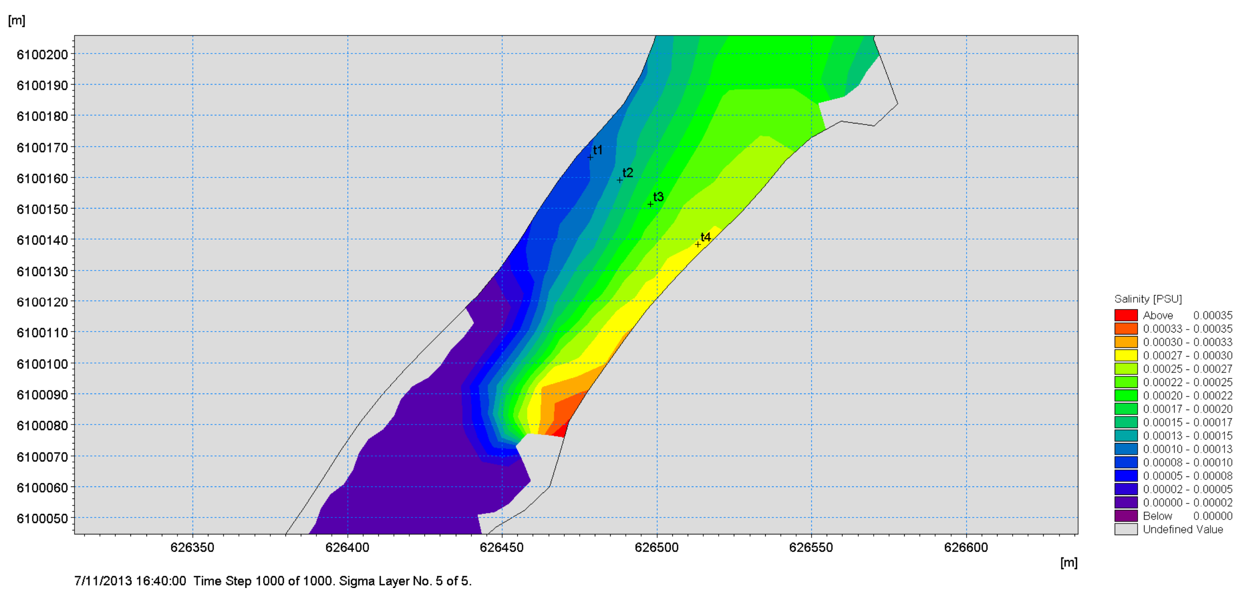
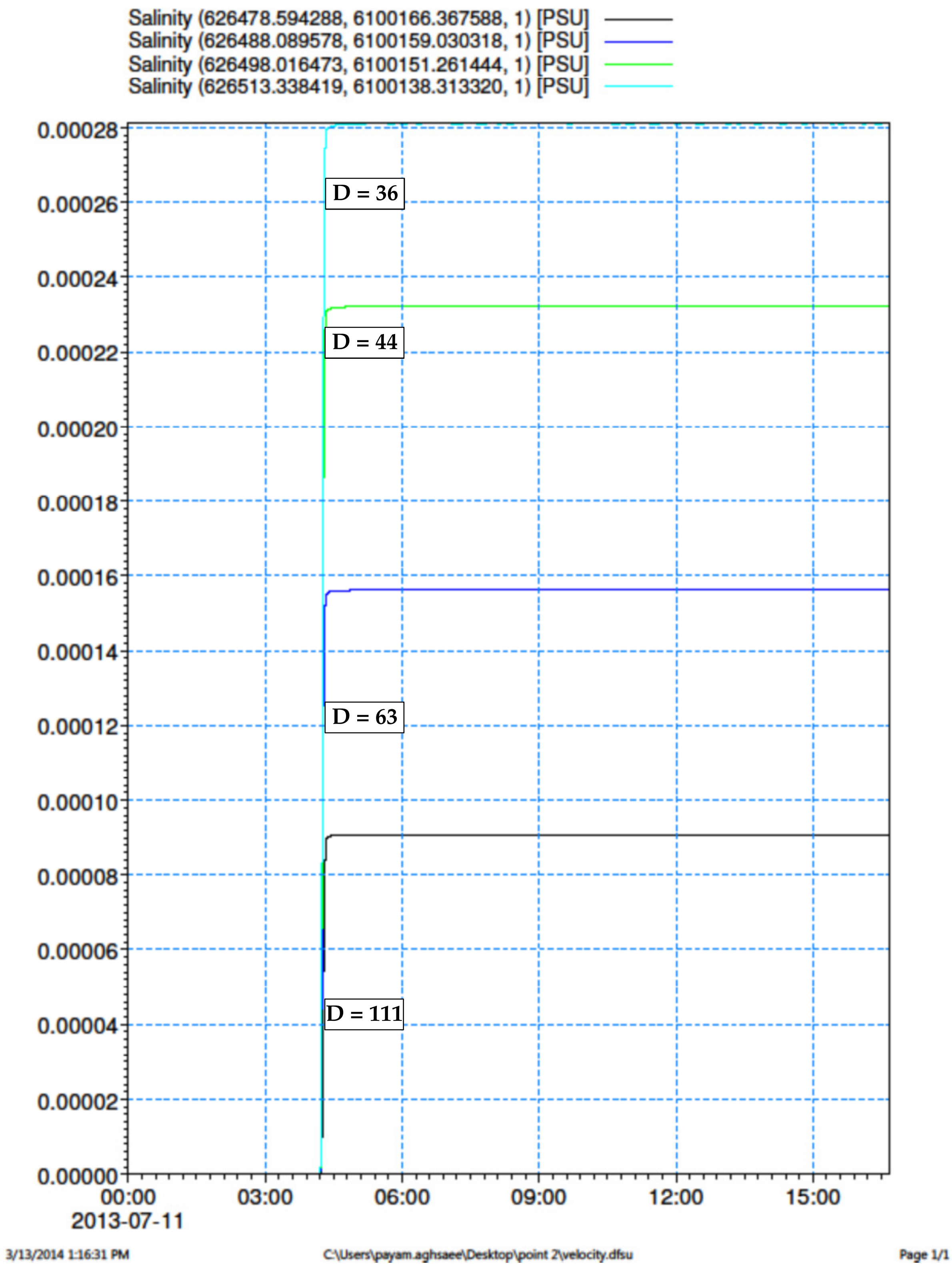


Figure 3.2-3. Salinity Map at the Surface



Time series of surface concentration are extracted at point t1-t4 across the section at 100 m downstream of the discharge location 2. Time series are shown in Figure 3.3-4.

Figure 3.2-4. Times Series of Salinity Variations at Points t1-t4 100 meters Downstream the Discharge Location 2



3.3 DISCHARGE LOCATION 3

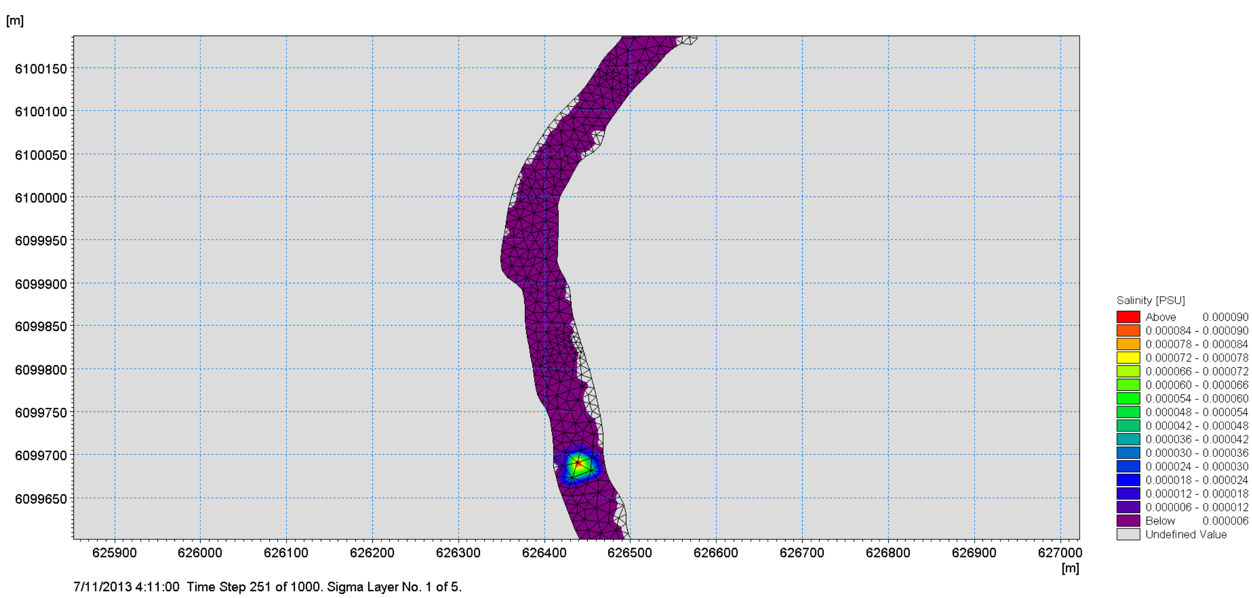
Discharge location 3 is upstream of the bend in the centre of the river. Figure 3.3-1 shows conditions in the bottom layer immediately after start of discharge as the model resolution requires homogeneity in each cell.

Figure 3.3-2 shows a cross section of the river looking upstream after equilibrium is achieved, that is after no further changes in concentration isopleths occur. The colour scale may be misleading in this figure: the difference between the red and blue regions is only 10%. The effluent plume tends to spread across the river with slightly higher concentrations toward the right (eastern) bank.

Figure 3.3-3 shows the concentration isopleths in the surface layer and identifies the points at which time series of concentrations are plotted in Figure 3.3-3.

Figure 3.3-4 shows the evolution of concentrations and the final dilutions (indicated by values of D). At t1 adjacent to the left bank, the concentration of effluent is slightly lower than along the right bank. Final dilutions are 53:1 along the left (western) bank and 48:1 along the right bank. 100 m downstream from this discharge point lateral homogeneity is nearly achieved although the colour scale of Figure 3.3-1 overemphasizes differences in concentration.

Figure 3.3-1. Salinity Map 1 s after Injection of the Effluent into the Model Domain



Discharge location 3 is shown in red.

Figure 3.3-2. Salinity Section 100 m Downstream the Discharge Location 3

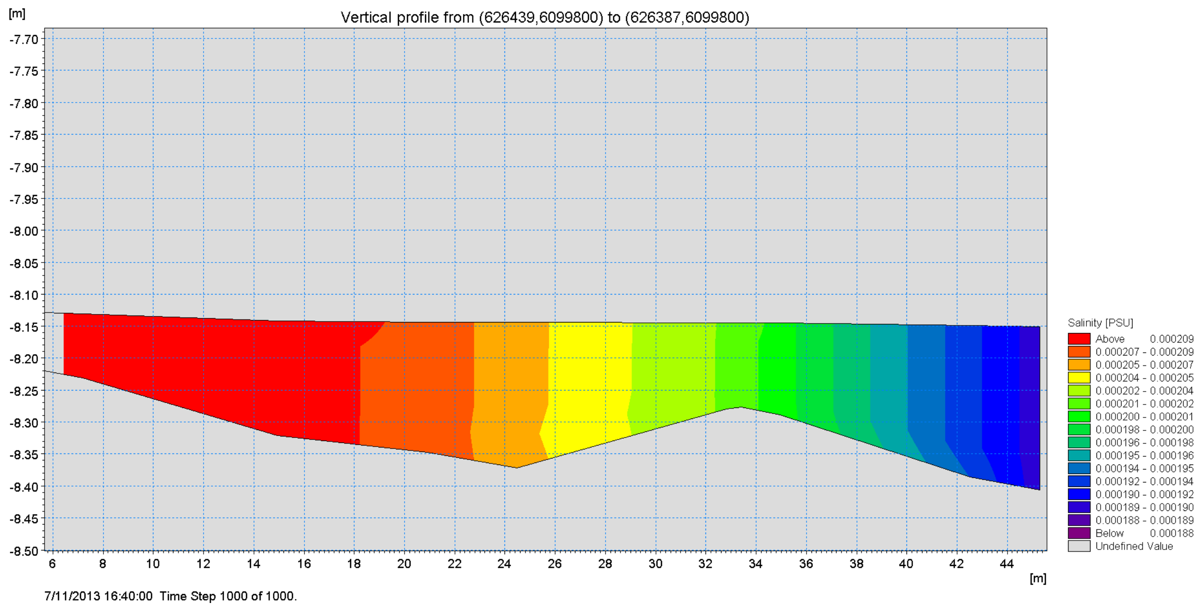
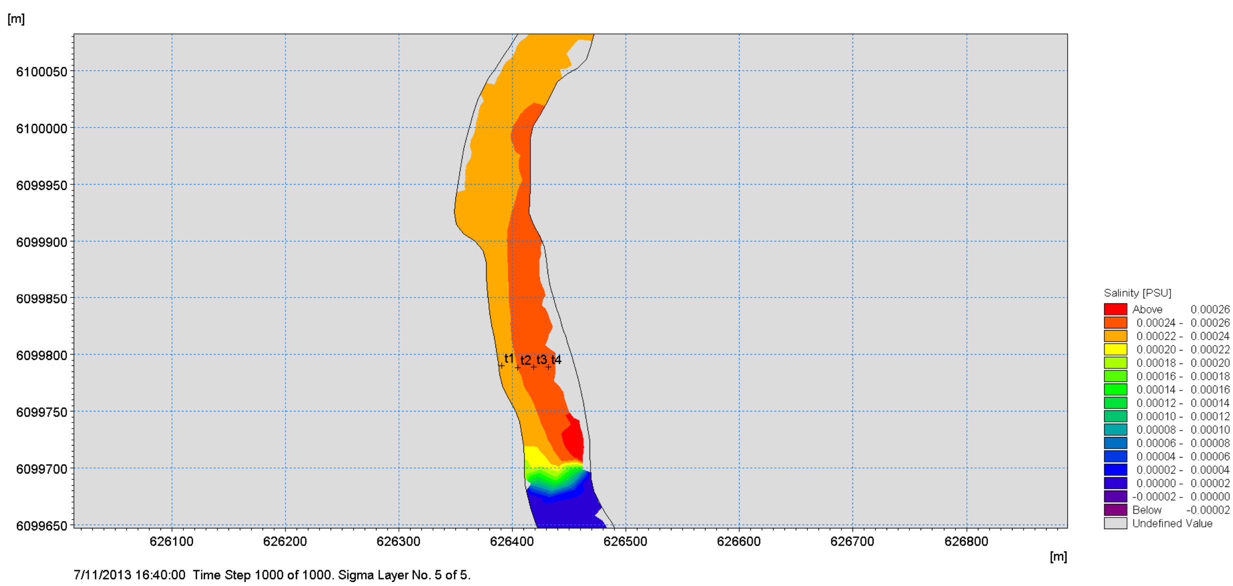
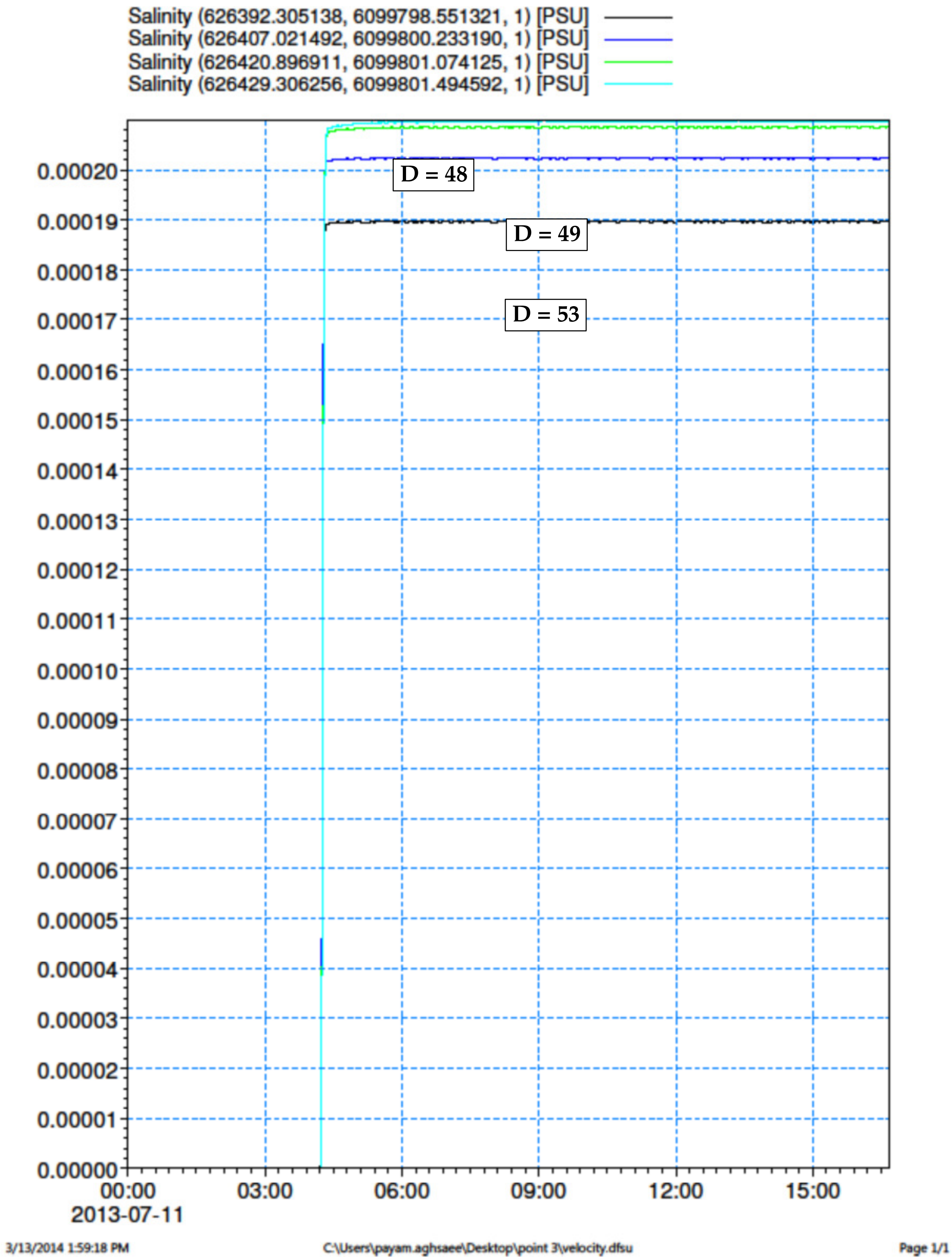


Figure 3.3-3. Salinity Map at the Surface



Time series of surface concentration are extracted at point t1-t4 across the section at 100 m downstream of the discharge location 3. Time series are shown in Figure 3.3-4.

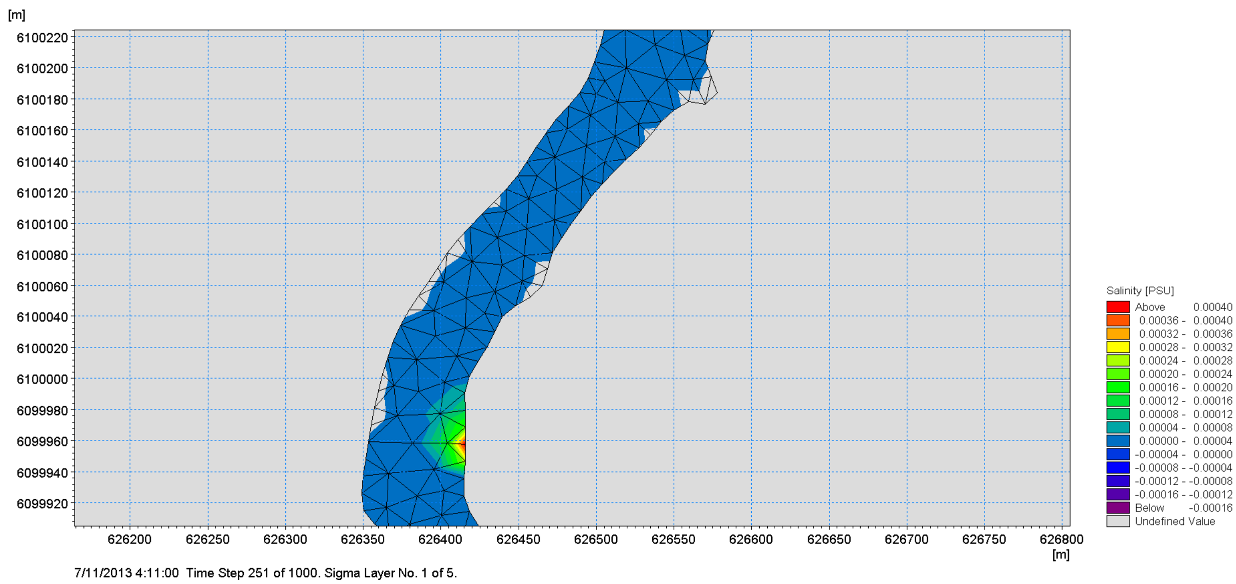
Figure 3.3-4. Times Series of Salinity Variations at Points t1-t4 100 meters Downstream the Discharge Location 3



3.4 DISCHARGE LOCATION 4

Discharge location 4 is at the inner bank of the bend. Figure 3.4-1 shows conditions in the bottom layer immediately after start of discharge as the model resolution requires homogeneity in each cell.

Figure 3.4-1. Salinity Map 1 s after Injection of the Effluent into the Model Domain



Discharge location 4 is shown in red.

Figure 3.4-2 shows a cross section of the river looking upstream after equilibrium is achieved, that is after no further changes in concentration isopleths occur. The effluent concentrations differ by a factor of 2 across the river. The effluent plume is slowly transported to the outside of the bend.

Figure 3.4-3 shows the concentration isopleths in the surface layer and identifies the points at which time series of concentrations are plotted in Figure 3.4-3.

Figure 3.4-4 shows the evolution of concentrations and the final dilutions (indicated by values of D). At t1 adjacent to the left bank, the concentration of effluent is about one half of that along the right bank. Final dilutions are 35:1 along the right bank and 67:1 along the left bank.

Figure 3.4-2. Salinity Section 100 m Downstream the Discharge Location 4

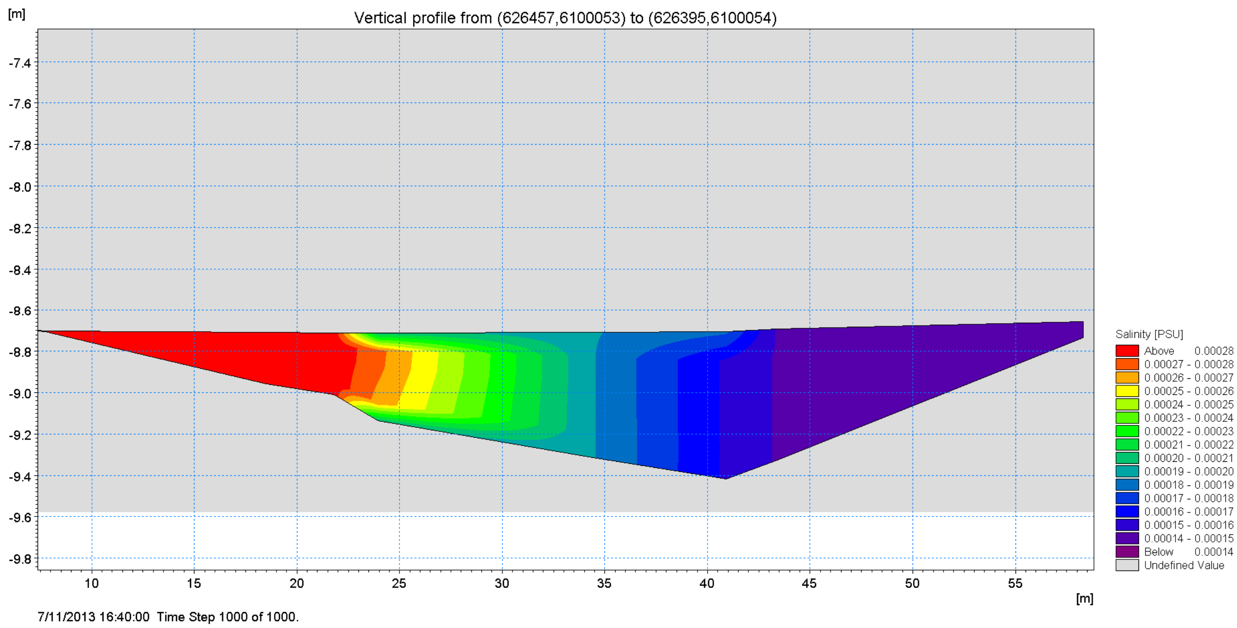
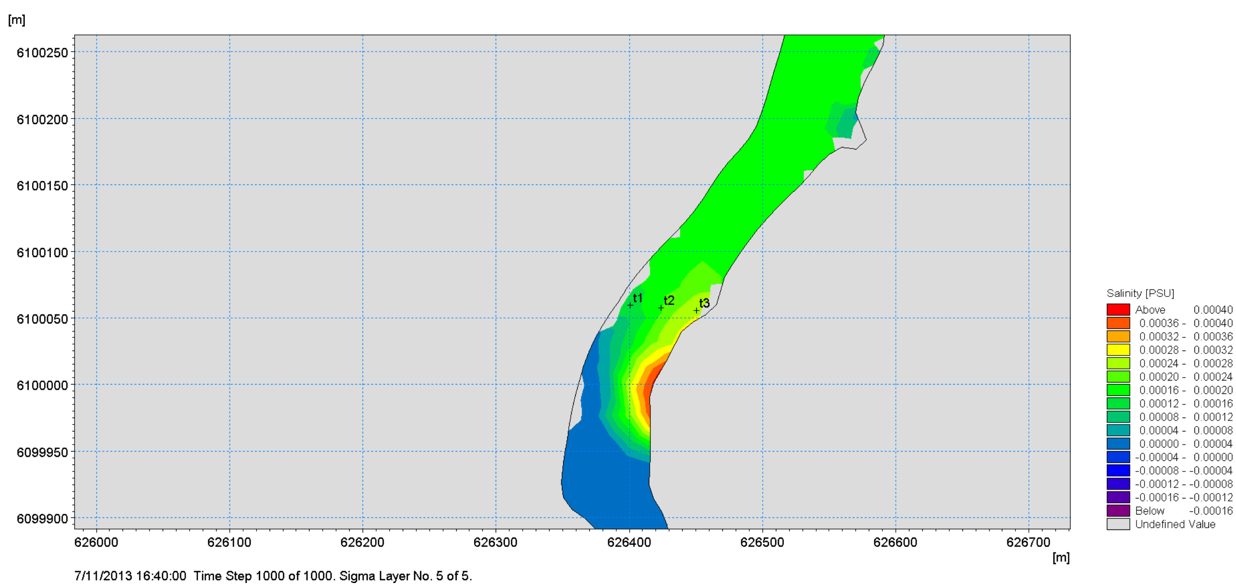
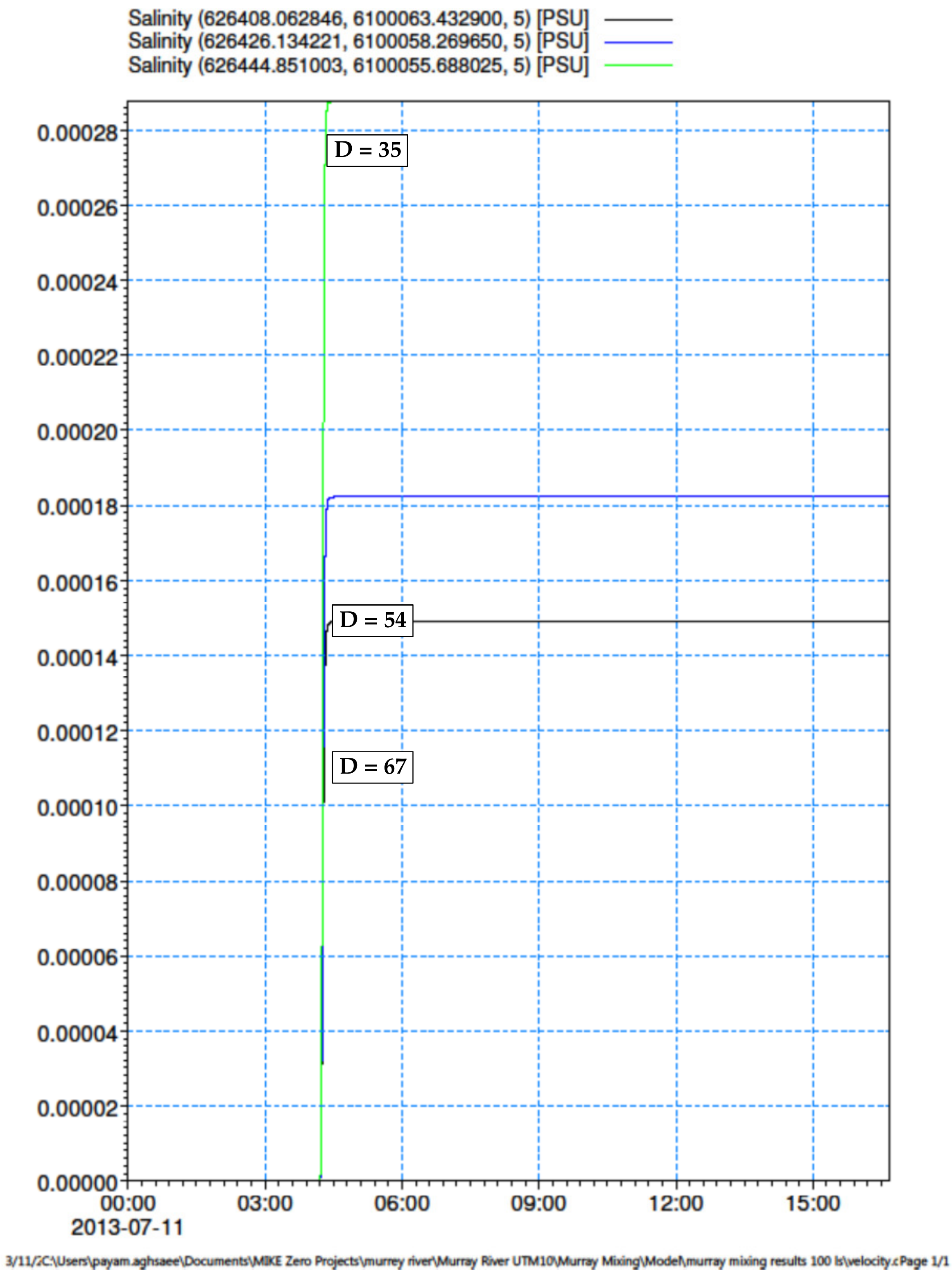


Figure 3.4-3. Salinity Map at the Surface



Time series of surface concentration are extracted at point t1-t4 across the section at 100 m downstream of the discharge location 4. Time series are shown in Figure 3.4-4.

Figure 3.4-4. Times Series of Salinity Variations at Points t1-t3 100 meters Downstream the Discharge Location 4



4. SUMMARY

The MIKE3 hydrodynamics model was applied to simulate effluent transport and mixing after discharge to Murray River. Modelling considered a single low flow condition in the river ($5m^3/s$), and a single discharge rage (100 L/s). Four discharge locations were selected for evaluation, and concentration distributions were simulated to assess mixing 100 m downstream of the discharge point.

Based on the results presented, the river has high dilution capacity, and mixing was achieved relatively quickly downstream at all locations. Location 4 is suggested as the most appropriate. It is located at the right bank, which would help minimize disturbance to the river during installation of outfall infrastructure, and good mixing is supported by the river bend.

Results of the modelling are intended to support planning for the siting of discharge infrastructure and environmental assessment. More detailed analysis and simulations may be required to support permit applications associated with the Project.