FINAL DRAFT

TECHNICAL MEMORANDUM
ASSIMILATIVE CAPACITY STUDY
OF OWEN SOUND

SELECTION OF OWEN SOUND
WASTEWATER TREATMENT PLANT EFFLUENT LIMITS

Prepared For:
City of Owen Sound, Ontario

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ABBREVIATIONS

BOD_5	Biochemical Oxygen Demand (5-day, carbonaceous)
C of A	Certificate of Approval
cms	cubic metres per second (m^3/s)
CORMIX	Cornell Mixing Zone Expert System
CRA	Conestoga-Rovers & Associates
DO	Dissolved Oxygen
EA	Environmental Assessment
E. coli	Escherichia coli
GEMSS	Generalized Environmental Modelling System for Surface Waters
GIS	Geographic Information System
GLIS	Great Lakes Index Station
GLSP	Great Lakes Surveillance Program
GSCA	Grey Sauble Conservation Authority
IGLD	International Great Lakes Datum
IPZ	Intake Protection Zones
km	kilometre
LHOFS	Lake Huron Operational Forecast System
m	metre
m^3/s	cubic metres per second
m.a.s.l.	metres above sea level
m/s	metres/second
mg/L	milligrams per litre
MLD	Million litres per day
MNR	Ministry of Natural Resources (Ontario)
MOE	Ministry of the Environment (Ontario)
NH_3-N	Total ammonia-nitrogen ($NH_3 + NH_4^+$)
NOAA	U.S. National Oceanic and Atmospheric Administration
OCC	Ontario Climate Centre
ODWSP	Ontario Drinking Water Surveillance Program
PWQMN	Provincial Water Quality Monitoring Network
PWQO	Provincial Water Quality Objectives
SVCA	Saugeen Valley Conservation Authority
SWPP	Source Water Protection Program
SWPR	Municipality of Northern Bruce Peninsula Drinking Source Water Protection Region
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus

ABBREVIATIONS

TSS	Total Suspended Solids
UIA	Un-ionized Ammonia (NH_3)
UIA-N	Un-ionized Ammonia-Nitrogen (NH_3-N)
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
3-D	Three-Dimensional
7Q20	Minimum seven-day period flow with a return period of 20 years
°C	Degrees Celsius

1.0 INTRODUCTION

This desktop analysis of the assimilative capacity of Owen Sound was undertaken by Conestoga-Rovers & Associates (CRA) to determine appropriate effluent limits for the proposed upgrading of the Owen Sound Wastewater Treatment Plant (WWTP) from primary to secondary treatment. This assessment was one of the recommendations resulting from an Environmental Study Review (CRA, 2006) to identify the preferred secondary treatment upgrading alternative.

The Owen Sound WWTP, owned and operated by the City of Owen Sound, is currently a primary treatment facility with a current rated annual average flow capacity of 24.5 MLD. This assimilative capacity study assesses how the effluent discharge will change with the upgrading to secondary treatment (with no increase in rated plant capacity) and defines the impact of this change on the receiving water body. The Owen Sound WWTP discharges to Owen Sound, an inlet of Georgian Bay situated at the mouth of the Sydenham River.

1.1 OBJECTIVES

The objectives of this analysis are as follows:

- to review relevant aspects of hydrodynamic modelling completed in Owen Sound as part of the Source Water Protection Program;
- to determine representative background water quality for Owen Sound from available data;
- to define water quality impacts of the upgraded Owen Sound WWTP;
- to develop a preliminary design of a new discharge diffuser (if needed); and
- to formulate recommendations for effluent limits for the secondary treatment upgrade of the Owen Sound WWTP for review by the Ontario Ministry of the Environment (MOE).

1.2 APPROACH

The approach to the assimilative capacity analysis includes the following major phases of work:

1. ***Review Relevant Aspects of Previous Studies:*** Review data and reports from the Source Water Protection Program.
2. ***Define Background Water Quality of Owen Sound:*** Define representative background water quality from historical water quality information available from various sources. For analysis purposes, the 75th percentile data (25th percentile for dissolved oxygen) is used to characterize ambient conditions, as recommended under MOE Policy B-1-5, Determining Receiving-Water Based, Point-Source Effluent Requirements for Ontario Waters (MOEE, 1994b).
3. ***Assimilative Capacity Analysis:*** Determine water quality impacts for each conventional water quality parameter, especially with respect to eutrophication impacts associated with total phosphorus and nitrogen discharges. The water quality impacts are assessed using two water quality modelling packages, CORMIX (for delineating near-field mixing zone) and GEMSS (for far-field hydrodynamic modelling of plume dispersion). The assimilative capacity is conducted with respect to MOE Policy B-1-5 and Provincial Water Quality Objectives (PWQOs).
4. ***Formulation of Recommended Effluent Limits***: Develop effluent limit recommendations for the secondary treatment upgrade of the Owen Sound WWTP (with no increase in rated capacity) based on the assimilative capacity study.

1.3 ONTARIO MINISTRY OF THE ENVIRONMENT REGULATIONS AND DEFINITIONS

There are two key MOE documents that are applicable to the derivation of effluent requirements from WWTP outfalls and the delineation of the effluent plumes. Specifically, the ambient conditions and the new effluent discharge should be evaluated relative to the MOE's policies for surface water quality management (MOEE, 1994a) and the MOE guidelines for deriving effluent requirements (MOEE, 1994b).

The hydrodynamics of an effluent continuously discharging into a receiving water body can be conceptualized as a mixing process occurring in two separate regions. Thus, hydrodynamic dispersion modelling may be conveniently divided into "near-field" modelling and "far-field" modelling. This distinction is used in this Technical

Memorandum because of the difference in the required modelling techniques and background ambient considerations in Owen Sound.

In the first region, referred to as the "near-field", the initial jet characteristics of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing. The "near-field" mixing zone refers to the portion of the effluent plume between outfall/diffuser outlets (ports) to the location where the discharged plume has effectively completed its initial mixing with the ambient receiving water, as caused by effluent buoyancy and momentum fluxes. In the near-field region, outfall designers can usually affect the initial mixing characteristics through appropriate manipulation of design variables.

"Far-field" modelling involves the examination of plume dispersion beyond the near-field where mixing is controlled by buoyant spreading and passive diffusion due to ambient turbulence. Far-field mixing occurs at a greatly reduced rate in comparison to the initial mixing within the near-field zone.

A mixing zone can be considered as a limited area or volume where the initial mixing of the wastewater discharge occurs with the receiving water body. Numeric water quality criteria may be exceeded in a mixing zone. Under the MOE regulations, a mixing zone is defined as an area of water contiguous to a point source where the water quality does not comply with one or more of the Provincial Water Quality Objectives (PWQOs). PWQOs are numerical and narrative criteria which serve as chemical and physical surrogates of healthy populations of aquatic biota. They represent a satisfactory level of quality for surface waters (i.e. lakes, rivers and streams). The PWQOs are set at a level of water quality which is protective of all forms of aquatic life and all aspects of the aquatic life cycles during indefinite exposure to the water. Recreational uses of water are also protected by PWQOs based on public health and aesthetic considerations. The PWQOs are intended to provide guidance in making water quality management decisions and they are often used as the starting point in deriving wastewater effluent requirements to be included in effluent discharge regulations (i.e. Certificates of Approval).

The PWQOs for water quality parameters pertinent to municipal wastewater treatment discharges are presented in Table 1.1. The hydrodynamic modelling results are discussed in relation to these PWQOs and do not further address aquatic wildlife (i.e. fisheries, benthic invertebrates) and habitat conditions.

TABLE 1.1

PWQOS PERTINENT TO MUNICIPAL WASTEWATER TREATMENT DISCHARGES

Parameter	**PWQO**
Total Phosphorus	< 0.02 mg/L[1]
Ammonia (Un-ionized)	< 0.02 mg/L[2]
Biochemical Oxygen Demand	Refer to Dissolved Oxygen
Total Suspended Solids (Turbidity)	Not change Secchi disc reading by > 10%
Dissolved Oxygen	Values specified as a function of temperature[3]

Notes:
1. PWQO of 0.02 mg/L to avoid nuisance algae concentrations in lakes. PWQO of 0.03 mg/L for rivers/streams.
2. Percentage of un-ionized ammonia in aqueous ammonia solution is a function of pH and temperature conditions.
3. Refer to Table 4.4 in Section 4.3.4.4 for DO concentrations.

For the purposes of the modelling conducted for this assimilative capacity study, the near-field modelling results correspond to the initial mixing zone as defined by MOE policies. Conditions that are applicable to the (near-field) mixing zone and wastewater effluent discharges include the following:

- The Provincial Water Quality Objectives (PWQOs) should be met at the edge of the mixing zone;
- The mixing zone should not interfere with other water uses, such as water supply intakes, other effluent discharges, bathing beaches, fish spawning areas or fish migration routes;
- The effluent should not be acutely lethal to aquatic life;
- A discharge outlet should provide a minimum initial mixing ratio of 20:1 (the Owen Sound WWTP does not currently have a diffuser on the outfall discharge); and
- Discharges directly to a shoreline are not acceptable for new or expanded waste water discharges (Owen Sound WWTP does not discharge directly to a shoreline).

The MOE has specified surface water management policies that deal with situations where water quality is better than the PWQOs or where water quality does not meet the PWQOs. These water quality designations are made on a parameter by parameter basis and compliance with the PWQOs is to be determined from data that adequately reflect the spatial and temporal variations of the quality of the water body under consideration (MOEE, 1994a).

Under Policy 1, water quality shall be maintained at or above the PWQOs in areas which have water quality better than the PWQOs. Under Policy 2, water quality which presently does not meet the PWQOs shall not be degraded further and all practical measures shall be taken to upgrade the water quality to the PWQOs (MOEE, 1994a).

2.0 DATA SOURCES

2.1 CLIMATIC DATA

Climatic data was obtained from the Ontario Climate Centre (OCC). The data sets considered in this study included hourly climatic data from the following stations located in the greater Owen Sound Area:

- Collingwood 1994 - 2006 (OCC ID: 6111792)
- Wiarton 1953 - 2006 (OCC ID: 6119500)
- Beausoleil Island 1994 - 2006 (OCC ID: 6110617)
- Cove Island 1994 - 2006 (OCC ID: 61219J2)

Because of the geographic proximity of the Wiarton station (OCC ID 6119500), hourly wind speed, and direction data from this station was used in the modelling. Wind speed and direction data is also available from the Lake Huron Operational Forecast System (LHOFS), developed and maintained by U.S. National Oceanic and Atmospheric Administration (NOAA). Data from LHOFS was not used in this modelling because:

a) The model domain is small relative to the resolution of LHOFS data;
b) LHOFS data represents interpolated data and the priority here was given to real, observed data from a near-by weather station; and
c) Only a few years of LHOFS data are available as opposed to over 50 years of data observed at the Wiarton station, which provides significantly more information on climatic variability (extremes) in the study area.

Time series of hourly wind data was used as a direct input to the modelling. Hourly wind data was also used to calculate seasonal/extreme wind characteristics (extreme and seasonal average wind speed and direction). The breakdown of months to seasons used by the general scientific community was adopted for the calculation of seasonal averages:

- Winter – December, January, February
- Spring – March, April, May
- Summer – June, July, August
- Fall – September, October, November

The wind data set contained a number of missing hourly readings. Missing values were excluded from the calculation of both extremes and seasonal averages. Table A1 (Appendix A) summarizes the hourly wind data.

2.2 BATHYMETRY AND HYDRODYNAMIC DATA

Bathymetric data for Owen Sound was obtained from the Canadian Hydrographic Service navigational chart No. 2283, surveyed between 1964-1997, and published in 1999. Depths in the chart are reduced to Lake Huron's datum, which is 176.0 m above the 1985 International Great Lakes Datum (IGLD). A detailed, 1:12,000 chart was used to create GIS-based bathymetric surface of Owen Sound near the Harbour, and a 1:80,000 chart was used to create the bathymetric surface of the remaining areas of the Sound. Figure 1 shows a 3-dimensional representation of the bathymetric surface.

Lake Huron daily water level data was obtained from Environment Canada's Archived Hydrometric Database. Data from the Collingwood station was used in the modelling since no water level station exists in the Owen Sound area. Seasonal water level averages were calculated from daily water level data ranging from 1965-2005. No trends were factored into the calculation of seasonal water level averages. The calculation of seasonal averages therefore included all available data between 1965-2005. Most recent (2007) hourly water level data was obtained from the Canadian Hydrographic Service Archive. The hydrodynamic data is summarized in Table A2 (Appendix A). The table provides seasonal average values as well as extreme values recorded during the historical observation period at the Collingwood station. The typical seasonal data was used in the hydrodynamic modelling. The extreme data is identified for further subsequent modelling activities, if needed.

Information on current speed and direction in Owen Sound for various hydrodynamic and meteorological conditions was obtained from the Surface Water Source Protection Technical Studies (Baird, 2007). This information was compared to spatial patterns of currents generated in this study by a 3-dimensional (3-D) model, GEMSS. A discussion of the comparison is provided in Section 4.3.1.

Flows from tributaries discharging to a water body may have significant impacts on hydrodynamic circulation patterns. The main tributaries to Owen Sound are Sydenham River, Pottawatomi River, Indian Creek, Bothwell Creek, Waterton Creek, and Keefer Creek. Indian Creek was excluded from the analysis because no water quality data has been collected in this Creek.

Furthermore, the Creek's mouth is located far from the WWTP outfall location (approximately 4 kilometres (km)). Keefer Creek and Waterton Creek were not considered in the modelling because:

a) Their flow rates (less than 0.1 cm) have negligible effect on hydrodynamic circulation in the Sound;
b) They discharge to the Sound far from the WWTP location (approximately 8 km for Keefer Creek and approximately 18 km for Waterton Creek); and
c) They have only very limited flow data available.

Sydenham River average daily flow data was obtained from Environment Canada's Archived Hydrometric Database (Station ID 02FB007). Continuous data at this station was available from 1915-2005. However, due to missing data for the period 1927-1945, only data from 1946-2005 was analyzed. Limited flow data for Pottawatomi River (measured between 1973-2006) and Bothwell Creek (measured between 1972-2006) was obtained from the Grey Sauble Conservation Authority (GSCA).

Hydrodynamic data for the Owen Sound's main tributaries are summarized in Table A3 (Appendix A). Daily flows measured in these tributaries were used to calculate seasonal flow averages. No flow data was available for Spring and Winter seasons in the Pottawatomi River. Therefore, the seasonal average flow for the spring season was estimated by multiplying Pottawatomi River summer seasonal flow by a regional flow ratio of average seasonal spring flows to average seasonal summer flows. Similarly, the seasonal average flow for the winter season was estimated by multiplying Pottawatomi River fall seasonal flow by a regional flow ratio of average seasonal winter flow to average seasonal fall flows. The regional flow ratios were calculated as averages of simple flow ratios for Sydenham River and Bothwell Creek, where data for all seasons was available.

2.3 WATER QUALITY DATA

Water quality data for the assimilative capacity study was collected from the following sources:

- Owen Sound Richard H. Neath Water Treatment Plant (WTP) analytical reports;
- Great Lakes Index Station (GLIS) Network Monitoring Program (station ID 611 (Owen Sound));

- Water quality monitoring conducted by Environment Canada as part of the Canada-USA Great Lakes Water Quality Agreement (The Great Lakes Surveillance Program, Station ID 4); and
- Provincial Water Quality Monitoring Network (PWQMN) database.

Water quality data from the WTP was available for the period from 1998 to 2002 from the Ontario Drinking Water Surveillance Program (ODWSP) Summary Reports 1998-1999, 2000, 2001 and 2002. Some constituents in the ODWSP database, e.g. Total Phosphorus (TP), show elevated values that are not consistent with the values obtained from other sources. Our experience suggests that the likely cause of this is that the WTP intake pipe (which transports water *from* Owen Sound for treatment prior to distribution) is picking up bottom sediments, which then increases the concentration of some constituents. High values of filtered residue (in excess of 125 mg/L) measured at the WTP may support this explanation.

Another source of data representative of ambient conditions in Owen Sound is provided by the GLIS Network. Station 611 of the GLIS Network is located approximately 1.5 km) north from the WWTP outfall. Twenty measurements were available for summer and fall seasons during the two-year monitoring period 2002–2003. The constituents monitored included TP, Total Kjeldahl Nitrogen (TKN), and Total Suspended Solids (TSS). In addition, data on DO and temperature are available from a few vertical profiles. No BOD data was collected at this (or nearby GLIS) stations.

Water quality data are also collected under the Canada-USA Great Lakes Water Quality Agreement (The Great Lakes Surveillance Program, GLSP). The surveillance program involves open lake cruises with sampling in the spring, summer, and early fall. The closest GLSP sampling location is Station ID 1, located in Owen Sound approximately 17 km north-northeast from the WWTP outfall. Most data from this station are available for the period from 1984 to 2004. Only samples collected at the surface (temperature) and in 1 m depth (all other constituents) were analyzed and used in this study.

Tables A4 to A10 (Appendix A) summarize the water quality data extracted from the above described sources. The data analysis was limited to TP (Table A4), nitrogen (Table A5), TSS (Table A6), DO (Table A7), BOD (Table A8), temperature (Table A9) and pH (Table A10). 75th and 25th (DO) percentiles were calculated for the constituents to represent adverse ambient water quality conditions in the Sound. No trends were factored into the calculation of the 75th and 25th percentiles. The percentiles were then used as an input to the hydrodynamic mixing modelling.

Table A9 (Appendix A) shows large inconsistencies among the seasonal average temperatures calculated from the different data sources described above. These inconsistencies are caused by two main factors. The first factor is the small number of samples available from the data sources. The second factor is that most GLIS and GLSP field sampling is usually done from May to September, which means that only a few samples are collected during the Spring and Fall seasons and as such they represent more early/late summer conditions than average spring/fall conditions. The WTP Winter average temperature was calculated from only 2 measurements.

To accommodate this lack of data, temperature records from several stations in Georgian Bay were analyzed. The last row in Table A9 summarizes the results of this analysis. These adjusted temperatures were used in the modelling as they better represent the actual water temperature conditions in Owen Sound at depths similar to the outfall depth. It must be noted that the analysis was more qualitative than quantitative as the averages could not be calculated from samples obtained from different stations, depths, and sampling periods.

Water quality data for Sydenham River, Pottawatomi River and Bothwell Creek was obtained from the Provincial Water Quality Monitoring Network (PWQMN) and GSCA databases. Most constituents measured in Sydenham River (EC WSC Station 02FB007) were sampled between 1975 - 2006. Among the 23 different GSCA sampling locations available in Pottawatomi River only data from Station 7 (near Eddie Sargent Parkway) was used as this station was closest to the river mouth. At Station 7, 62 seasonal measurements were collected by GSCA, MOE, and the Ontario Ministry of Natural Resources (MNR) between 1973 and 2006. Water quality data for Bothwell Creek was obtained from GSCA sampling Station 3. A total of 25 seasonal measurements were collected at this station by GSCA, MOE, and MNR between 1972 and 2004.

Seasonal percentiles were calculated from the available data listed above. No trends were factored into the calculation of percentiles. The data is summarized in Tables A11, A12, and A13 in Appendix A.

2.4 OUTFALL DATA

The WWTP outfall is the place where the effluent pipe discharges the treated wastewater into the receiving waters of Owen Sound. The WWTP outfall system consists of a 42-inch outlet sewer that discharges approximately 200 m offshore in a depth of around 3 m (based on 2007 water levels). The outfall invert elevation is 172.97 m.a.s.l. The discharge angle is nearly horizontal (0.39 percent). This outfall data was obtained from the initial 1961 plant drawings (ON Water Res Commission Project 60-S-69: City of Owen Sound Sewage Treatment Plant by Gore & Storrie LTD). No modification of the outfall was shown on subsequent plant upgrade or expansion drawings. The location of the outfall is depicted on Figure 2.

Owen Sound near the WWTP outfall is characterized by relatively shallow areas of less than 2-3 metres (m) in depth extending from the shore for a distance of approximately 200 m. There is a deep (minimum 5 m) ship channel located in the middle of the Sound.

2.5 WWTP DATA

Existing water quality discharged by the Owen Sound WWTP was reviewed as part of the Environmental Study Review (CRA, 2006). Annual BOD_5, TSS, and TP effluent concentrations averaged 33 mg/L, 26 mg/L, and 0.43 mg/L, respectively, for the period reviewed (i.e. 2002-2004). It was noted that the current annual average effluent concentrations are close to or meeting the effluent quality typically associated with secondary treatment. The effluent quality typically associated with secondary treatment is 25 mg/L for BOD_5 and TSS and 1 mg/L for TP.

Compliance requirements for the Owen Sound WWTP are not specified in the current Certificate of Approval (C of A). Therefore, the effluent quality is currently subject to the criteria for primary sewage treatment plants specified in MOE Procedure F-5-1 as follows:

- 50 percent removal for $BOD_{5;}$
- 70 percent removal for TSS; and
- Total phosphorus less than 1 mg/L.

A review of the plant historical (i.e. 2002 – 2004) effluent quality completed as part of the Environmental Study Review (CRA, 2006) indicated that the plant is meeting the effluent guidelines on a yearly average basis. Yearly average removals for both BOD_5 and TSS have met the MOE Guideline, with BOD_5 and TSS removals averaging approximately 66 percent and 82 percent, respectively, for the period reviewed (i.e. 2002-2004). Yearly average concentrations of TP were less than 1.0 mg/L for the period reviewed.

Additional plant data was collected for the period 2005 to 2006 to update the data reviewed for the Environmental Study Review. Annual BOD_5, TSS, and TP effluent concentrations and BOD_5 and TSS removals for this period are presented in Table 2.1 in comparison to the MOE Procedure F-5-1 requirements. The plant is meeting the effluent removal guidelines for BOD_5 and TSS on a yearly average basis and yearly average concentrations of TP were less than 1.0 mg/L.

TABLE 2.1

ANNUAL EFFLUENT QUALITY FROM THE OWEN SOUND WWTP
2005-2006

Parameter	MOE Requirement	Removal (%)		Concentration (mg/L)	
		2005	**2006**	**2005**	**2006**
BOD_5	50% Removal	55	52	47	53
TSS	70% Removal	81	77	30	27
TP	< 1 mg/L	-	-	0.56	0.63

Influent temperature and effluent pH data for the period 2005 to 2006 was also collected for the Owen Sound WWTP. Effluent temperature and pH data is required as parameter inputs to the model and for the determination of the allowable total ammonia-nitrogen concentration (Section 4.3.4.2). Since the Owen Sound WWTP does not regularly measure the effluent temperature, data from a secondary treatment plant of similar size and in a similar geographic area was used to approximate the temperature change expected from influent to effluent at the Owen Sound WWTP with the upgrade to secondary treatment. The temperature change is impacted by various factors including the magnitude of the difference between the wastewater and air temperatures in different seasons, the surface area of treatment tanks and flow conditions. The influent and effluent temperature data (2004-2005) for a similar existing secondary treatment plant is summarized in Table 2.2 by season.

TABLE 2.2

TEMPERATURE CHANGE FROM INFLUENT TO EFFLUENT BY SEASONAL AVERAGE AT A SIMILAR LOCATION/SIZE OF SECONDARY TREATMENT FACILITY

Season [1]	Influent Temperature (°C)	Effluent Temperature (°C)	Temperature Difference (°C)
Winter	13.6	11.0	2.6
Spring	13.8	13.6	0.3
Summer	22.3	23.6	-1.3
Fall	21.9	21.4	0.5

Notes:

[1] Months assigned to seasons as described in Section 2.1.

The maximum cooling effect occurs in the winter with an average decrease in the influent temperature of 2.6°C. The warming effect that occurs in the summer months (with an average increase from the influent temperature of 1.3°C) is not as many degrees as the winter because wastewater and air temperatures are more similar in the summer months. These average seasonal temperature differences were applied to the Owen Sound WWTP influent temperatures to approximate the expected effluent temperature which is used as an input parameter to the hydrodynamic mixing zone models. The seasonal effluent temperature (adjusted influent temperatures as described above) and pH data for the Owen Sound WWTP is summarized in Table A14 (Appendix A).

3.0 REVIEW OF PREVIOUS STUDIES

3.1 SOURCE WATER PROTECTION PROGRAM

The Source Water Protection Program (SWPP) in Ontario was established by the Clean Water Act. The program uses scientific methods to assess threats to municipal drinking water systems. In the region of Bruce Peninsula, source water protection studies for eleven surface water intakes have been coordinated by the Saugeen Valley Conservation Authority (SVCA), Grey Sauble Conservation Authority (GSCA) and the Municipality of Northern Bruce Peninsula Drinking Source Water Protection Region (SWPR).

Stantec Consulting with Baird & Associates and Riggs Engineering were retained by SVCA to undertake source water protection studies for eleven intakes in the SWPR (Baird, 2007). Out of the eleven intakes, seven are located in Georgian Bay, including R.H. Neath intake located in Owen Sound. Hydrodynamic modelling was used for delineating intake protection zones (IPZ) for the seven intakes on Georgian Bay.

Wind data, currents, and water levels for the hydrodynamic modelling of the Georgian Bay intakes were obtained from the NOAA's Lake Huron Operational Forecast System (LHOFS). This data was also used to define open boundary conditions in the nested models of the intakes. The DELFT 3D computer package was used for the modelling.

The Owen Sound Nested model was built for the three intakes located at Owen Sound. The model grid size ranged from 7 m at the river mouth to 900 m offshore (Baird, 2007). The model was run for two three-week periods, from January 30, 2003 to February 20, 2003, and from November 10, 2003 to December 5, 2003. These two events were used to define the IPZs.

The Owen Sound nested model showed strong surface currents along the shoreline and weaker surface currents in the central deeper sections of the Sound. Bottom currents showed consistently opposite flow direction from the surface currents. The current speed near the WTP intake was observed in the range of 0.25 m/s and less, with predominant ENE-WSW direction. The delineated IPZ-2 (2-hour time of travel) was found to extend to the WWTP outfall. Review of Figure 4.31 (Baird, 2007) suggests that the WWTP outfall is at the southern edge of the IPZ-2.

According to Baird (2007), limitations of the modelling performed for delineating IPZs for the seven intakes on Georgian Bay include:

a) Use of an uncalibrated model;
b) Limited number of runs; and
c) No return period was associated with the events used in the analysis.

The hydrodynamic modelling results from the SWPP were used for the verification of spatial patterns of currents generated in this study. A discussion of the comparison is provided in Section 4.3.1.

4.0 ASSIMILATIVE CAPACITY STUDY

4.1 CORMIX AND GEMSS

The Cornell Mixing Zone Expert System (CORMIX) is a computer model for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies (Jirka et al., 1996). The major emphasis of the model is on the geometry and dilution characteristics of the initial mixing zone under steady ambient conditions. In this study, CORMIX1 and CORMIX2 subsystems were used for modelling of submerged single-port and multi-port discharges.

CORMIX1 was used for near-field mixing zone modelling of the existing WWTP effluent discharge. CORMIX2 was used to design a new outfall for the WWTP, and for near-field mixing zone modelling of the future WWTP effluent discharge. Both CORMIX models were used to determine the spatial extent (size) of the mixing zone; and to calculate initial mixing ratio at the edge of the near-field zone. Input parameters of the CORMIX models are provided for all modelling scenarios in Appendix B, Table B1 to Table B5.

The CORMIX model was built with an emphasis on the modelling of dispersion processes in the initial (near field) mixing zone. As such, the model is not an appropriate tool for far-field modelling, as it cannot simulate 3-D far-field circulation patterns. The far-field plume dispersion was modelled in this study by the model Generalized Environmental Modelling System for Surface Waters (GEMSS).

GEMSS is an integrated system of three-dimensional (3-D) hydrodynamic and transport models embedded in a geographic information and environmental data system (GIS) and set of pre- and post-processing tools to support 3-D modelling (ERM, 2006). GEMSS outputs include time-varying velocities, water surface elevations, and water quality constituent concentrations. The computations are done on a horizontal and vertical grid that represents the water body bounded by its water surface, shoreline, and bottom. Model boundary conditions include friction, wind shear, turbulence, inflow, outflow, surface heat exchange, and water quality kinetics. GEMSS has been peer reviewed and published (ERM, 2006).

In this assimilative capacity study, GEMSS was used to predict far-field plume mixing and movement in Owen Sound under various effluent-ambient scenarios. The salient parameters of the GEMSS model are provided in Table 4.1 below.

TABLE 4.1

PARAMETERS OF THE GEMSS MODEL

Parameter Group	Parameter Sub-Group/Scheme	Coefficient Value/Method
Hydrodynamic and Transport	Wind stress, scheme of Wu (1983)	A=0.8 B=0.065
	Bottom friction, Chezy	Czo=40
	Transport modelling scheme	Quickest with ULTIMATE
	Wetting (W) and drying (D) limiting thickness factors	W=0.8, D=0.8
	Density scheme	Nonlinear method
Dispersion	Vertical momentum dispersion	0-Equation method
		Mellor-Yamada method
		Von-Karman mixing length
		Prandtl number=10
	Momentum dispersion scheme, x-direction	Okubo (Ax0=0.00584, n=1.1)
	Momentum dispersion scheme, y-direction	Okubo (Ax0=0.00584, n=1.1)
	Transport diffusion scheme, x-direction	Prandtl
	Transport diffusion scheme, y-direction	Prandtl
Computation	Start-up time step	30 sec
	Maximum time step	60 sec
	Time step relaxation factor	0.75

4.2 MODELLING APPROACH

In the hydrodynamic mixing modelling, the near-field (CORMIX) and far-field (GEMSS) models were used together. The CORMIX model was used for initial near-field mixing zone modelling. Detailed information on effluent discharge and density, ambient density, depth at the outfall location, outfall configuration, and lake current velocities served as an input to the CORMIX model. The output from CORMIX then provided effluent loading input to the GEMSS model. GEMSS was used to predict effluent dispersion within the far-field plume under typical effluent-ambient conditions.

The GEMSS 3-dimensional model was setup for Owen Sound. The Sound stretches from the Town of Owen Sound and gradually widens in approximately north-east direction for about 25 km until it merges with Georgian Bay. In the vicinity of the WWTP outfall, the Sound is less than 1 km wide and its maximum depth does not exceed 10 m. Near its inlet to Georgian Bay, Owen Sound is more than 10 km wide with maximum depths close to 100 m.

Hydrodynamic conditions near the WWTP outfall are dictated by wind-driven currents from Owen Sound, main tributaries entering the Owen Sound (Sydenham and Pottawatomi Rivers), and bathymetric heterogeneity. Constant inflow from tributaries generates dominant current direction from the Sound to Georgian Bay. Stagnant hydrodynamic conditions can be observed in the Sound under calm weather patterns and low flow conditions in the main tributaries.

The GEMSS model was set up for the entire Owen Sound water body. A fine resolution grid was developed for the Sound (see Figure 3). The grid is curvilinear, with exponentially decreasing cell density toward the Georgian Bay. The grid has also nonlinear vertical density of cells (to handle the large depth differences between the southern portions of the inlet (depths in the range of 0-10 m) and the open waters toward Georgian Bay (depths of up to 100 m). This configuration provides high horizontal and vertical density of cells near the WWTP outfall (high output detail) and allows modelling of the entire Sound without sacrificing too much computational efficiency. The grid has variable number of vertical layers, ranging from 1 to a maximum of 30 layers. The smallest cell size is 25 m x 5 m x 0.7 m (deep) near the Sydenham River mouth. The largest cell size is 800 m x 250 m x 5 m at the model boundary with Georgian Bay. The total number of active cells used in the model was 2,492. The interaction between the Sound and Georgian Bay was modelled using a dynamic head boundary that allows mass exchange between the two connected water bodies.

Both CORMIX and GEMSS models were used for modelling of effluent-ambient scenarios. Two conditions were considered:

1. Typical, seasonal conditions, and
2. Worst-case conditions.

The typical conditions were developed for each season of the year (spring, summer, fall, winter). The typical conditions represented average seasonal climatic characteristics in the Sound, average seasonal water levels, seasonal tributary inflows, and average seasonal effluent and ambient water temperatures. Thermal stratification was not modelled as no data was available for developing a temperature gradient.

Since thermal stratification may have important implications on hydrodynamic patterns in the Sound, a theoretical stratification model was added to the model and tested. It was found that the theoretical stratification model has negligible impacts on hydrodynamic circulation in the shallow sections of the Sound near the WWTP outfall.

The seasonal climatic and hydro-dynamic characteristics were then coupled with water quality indices characterizing the background water quality of the receiver (Owen Sound). Water quality parameters of Owen Sound were expressed as the 75th percentile (or 25th percentile for DO) values.

The worst-case scenarios were defined by analyzing long-term historical hydro-climatic records available for the site and by examining the expected combinations of effluent and ambient conditions throughout the year. Two likely worst-case climatic conditions were identified:

1. Strong on-shore winds inducing current reversals over a period of a few days; and
2. Calm conditions inducing a stagnant situation characterized by minimal wind-induced hydro-dynamic turbulence/circulation in the Sound.

Actual wind speed and direction data selected from the climatic records was used to identify the worst-case condition. The strong and calm wind data periods selected represent the extreme worst-case climatic conditions that occurred in Owen Sound during the entire observation period 1953 to 2006.

For the strong winds scenario, data from the period November 19-24, 1957 was identified. The average and maximum wind speed during this 6-day period was 9.93 m/s and 17.77 m/s, respectively. The average wind direction during this period was south-west/north-west.

For the calm scenario, data from the period March 25-29, 1993 was identified. The average wind speed during this period was 0.44 m/s and all observations were in the category of breeze winds (0-3 m/s).

Low water levels in the Sound were also used in the definition of the worst-case scenarios. The current January 2007 average water level of 176.01 m.a.s.l. was identified for the worst-case condition. This water level is close to historical minimum levels and also represents the present situation in the Sound. Water depths of the model outputs are shown relative to a zero reference elevation, which does not represent the actual water surface.

Low-flow conditions in the tributaries were also assumed under the worst-case scenarios as high flows effectively improve mixing conditions. The 7Q20 (the minimum seven-day average flow with a return period of 20 years) low-flow statistics was calculated for Sydenham River from mean daily flows. The 7Q20 could not be calculated for Bothwell Creek and Pottawatomi River because of insufficient data available for these tributaries. A minimum flow was calculated for these tributaries as an alternative measure of low-flow conditions.

For both typical and worst-case summer conditions and for all parameters, ambient and effluent water temperatures of 18°C and 20.5°C, respectively, were used. These ambient/effluent temperatures generate weakly buoyant effluent conditions that are adverse for vertical mixing (strong buoyancy improves vertical mixing of the plume).

A steady-state model was used for running the typical condition scenarios. The rationale for the use of steady-state models, as opposed to dynamic models, was lack of continuous hydrodynamic and water quality data to perform complete dynamic simulation. Four seasonal steady-state models were therefore developed to account for different hydro-climatic conditions throughout the year.

All constituents were modelled as conservative, given the lack of hydrodynamic and water quality data. Ignoring decay rates of constituents is a more conservative way of modelling, as the concentrations of constituents are not allowed to decrease by radioactive decay, bacterial decomposition, or chemical reactions. Evaporation or sediment mixing effects were not evaluated. The lack of hydro-dynamic and water quality data in the Sound also prevented the calibration of the model.

The 3-D hydrodynamic model has several hydrodynamic, transport, and dispersion boundary conditions. Five open boundary conditions include a discharge condition that defines the flow of the three tributaries into Owen Sound, a discharge condition that defines effluent flow through the WWTP outfall, and a head boundary condition that defines mass exchange between the Sound and Georgian Bay. The head boundary was defined in such a way that the water (and the effluent) can leave/enter the Sound depending on current hydrodynamic circulation. Moreover, the concentration of the effluent at the boundary is not constant, but again can change dynamically depending on the inlet circulation. Thus, the dynamic definition of the head boundary adds a dynamic component into the steady-state model.

4.3 MODELLING RESULTS

4.3.1 COMPARISON OF HYDRODYNAMIC PATTERNS GENERATED BY GEMSS AND DELFT3D

As mentioned in Section 3.1, Baird (2007) used a nested modelling approach to simulate hydrodynamic patterns in Owen Sound. Baird used the DELFT 3D program for the modelling (this platform was purchased by the MOE in 2002, which provides benefits of sharing data and results). The DELFT 3D model was used with NOAA's spatially distributed and interpolated LHOFS wind data. The open boundary conditions were defined by LHOFS hydrodynamic outputs.

Baird (2007) provides in their report a series of figures depicting simulated surface and bottom currents in Owen Sound under southwest and northeast wind conditions. Figure 4 (Appendix A) shows the pattern of bottom layer currents generated by GEMSS under the prevailing southwest winds. It can be seen that the model results are markedly similar to those generated by the DELFT 3D model. Both models show stronger south-west wind-driven currents that follow the west and east shorelines, and a current reversal in the deeper central part of the Sound flowing from NE to SW. The models also show very similar bottom current patterns near the WWTP outfall.

In the more open areas of the Sound, GEMSS shows a homogeneous spatial distribution of surface and bottom currents. This is caused by the spatially homogeneous wind input data used in this modelling. Also, no horizontal and vertical temperature gradients were applied to the modelling because of lack of thermal stratification data.

4.3.2 EXISTING OUTFALL RESULTS

The CORMIX1 subsystem was used to estimate the dilution ratio at the edge of the mixing zone for the existing outfall configuration. Total phosphorous was used a constituent in the evaluation of the mixing efficiency of the existing outfall. The effluent concentration of TP was set to 0.8 mg/L and the model was run for typical summer conditions with an effluent rate of 24.5 MLD. The background concentration of TP in Owen Sound was set to 0.004 mg/L. The results are provided in Table B1, Appendix B.

The existing outfall configuration provides rather poor initial mixing in the near-field zone. The dilution ratio is 4.6:1, which leads to a TP concentration at the edge of the near-field zone of 0.173 mg/L in excess of the background TP concentration. The near-field zone is small because the plume spreading is dominated by strong buoyancy. The 20:1 dilution ratio is observed approximately 350 downstream from the outfall. The plume is of the H4-90A4 class. The description of the H4-90A4 class is provided in Table C1 (Appendix C).

The near-field mixing results from CORMIX1 were then used to set-up the outfall boundary condition in the GEMSS 3D model of the Sound. The model was run for all seasons. The model showed that dispersion of the plume in the far-field zone was worst during the summer season as compared to the other seasons of the year. This is the result of the specific combination of effluent-ambient water temperatures, wind direction, and low flow conditions in the tributaries that occur during the summer season. The summer season also presents the potential for the most significant algal growth conditions (as a result of warmer ambient water temperatures) and impacts on aquatic wildlife. Therefore, the following sections will summarize and show results for the summer season only.

Figures 5 and Figure 6 show GEMSS-generated surface and bottom layer TP levels under typical summer conditions. The surface area of the plume is very large, with areas that exceed the PWQO impacting the whole southern-most portion of the Sound. The plume extends for a couple of kilometres along the NE shore. Figure 7 shows the location of a vertical slice cut through the plume near the outfall location. The vertical slice is depicted on Figure 8. Water depths are shown on Figure 8 relative to a zero reference elevation. It can be seen that because of the relatively shallow water at the outfall, the positively-buoyant plume quickly rises to the surface. The figure also shows the effect of prevailing SW wind-induced currents that move the plume toward the NE shore.

4.3.3 NEW OUTFALL DESIGN

The existing single-pipe outfall does not provide effective near-field mixing resulting in a plume that is very large, and consequently the PWQOs are not met at the edge of the near-field mixing zone. To address these limitations, preliminary design parameters of a new outfall were developed that would comply with the MOE Policies.

According to MOE Policies, initial mixing for discharge diffusers must have a minimum near-field (initial mixing) ratio of 20:1. In addition, the outfall design should provide adequate mixing to meet PWQOs at the edge of the near-field mixing zone. Also, the outfall should be designed in such a way that the resulting mixing zone does not interfere with other water uses (e.g. water supply intakes, beaches, fish spawning areas, and migration routes).

A multi-port diffuser was designed for the new outfall. The technical parameters of the diffuser are as follows:

- Diffuser type: submerged, unidirectional, perpendicular multi-port diffuser;
- Outfall pipe: 206 m from the nearest shore;
- Diffuser length: 10 m;
- Number of ports: 6 single ports; spacing: 2.0 m; average diameter: 0.14 m;
- Height of the discharge port centers above Harbour floor: 0.5 m; and
- Vertical discharge angle: 15° (from horizontal plane).

These parameters were determined and optimized iteratively, using CORMIX2, to minimize the spatial extent of the mixing zone and to maximize the initial dilution ratio under various effluent-ambient conditions. The number of ports and their diameter was optimized to provide discharge velocities in the range from a minimum of 3.0 m/s (average effluent discharge) to 8 m/s (peak discharge).

4.3.4 PROPOSED OUTFALL RESULTS

4.3.4.1 TOTAL PHOSPHORUS

The simulation scenario of effluent TP concentration of 0.8 mg/L, effluent rate of 24.5 MLD, background TP concentration of 0.004 mg/L, and typical summer conditions was repeated with the new, proposed multi-port diffuser. Table B2 (Appendix B) provides the CORMIX2 output for this scenario. The near-field mixing zone extends

295 m downstream of the outfall location. The initial dilution ratio and the excess concentration of TP at the edge of this zone are 45:1 and 0.0177 mg/L, respectively. This concentration does not exceed the PWQOs. The plume is of the MU2 class. The description of the MU2 class is provided in Table C2 (Appendix C).

Figure 9 and Figure 10 show GEMSS-generated surface and bottom layer TP levels for this scenario. Figure 11 shows the concentrations of TP in a vertical slice cut through the plume near the outfall location. The TP concentrations are much lower than the concentrations obtained from the previous simulations which modelled the existing outfall. However, the extent of the area exceeding PWQO is still very large, affecting the southern portion of the Sound and stretching toward the NE shore for several kilometres. This difference between CORMIX and GEMSS outputs is caused by the high TP concentrations in Sydenham and Pottawatomi Rivers (0.03 mg/L) which are not considered in the CORMIX modelling.

To assess the adverse impacts of the tributaries on the ambient water quality in the harbour and near the outfall, a model simulation was performed that excluded the WWTP discharge and considered only the TP loading from the tributaries. Figures 12 and 3 depict the results. It can be seen that the plume from the tributaries is similar to the plume shown on Figures 9 and 10. The extent of surface and bottom areas with concentrations exceeding PWQO is smaller, impacting areas near the river mouths and the NE shore of the Sound. The bottom TP concentrations near the outfall location are around 0.015 mg/L.

The 75th percentile TP concentration in the tributaries equals or exceeds the PWQO limit for rivers/streams (0.03 mg/L) in the summer months for the Sydenham River and in the spring and winter months for the Pottawatomi River. As a consequence, the PWQO limit for lakes (0.02 mg/L) is also exceeded in the Sound in areas where the tributaries discharge to the Sound.

The next model simulation considered effluent TP concentration of 0.2 mg/L with a rate of 24.5 MLD, background TP concentration of 0.004 mg/L, and typical summer conditions. Table B3 (Appendix B) provides the CORMIX2 output for this scenario. The excess concentration of TP at the edge of the mixing zone is 0.004 mg/L, which is significantly lower than the PWQO limit. The plume is again of the MU2 class. GEMSS outputs for this scenario are provided on Figures 14 and 15, Appendix A. The mixing zone resulting from the interaction between the TP loadings from the tributaries and from the WWTP is much smaller; however, the model still shows significant areas with TP concentrations exceeding PWQO. This implies that even if the effluent concentration of TP is lowered to a value as low as 0.2 mg/L, effectively diluted by the diffuser to 0.004 mg/L at the edge of the mixing zone, the resulting concentrations can still be close to or even exceed the PWQO limit when the background concentration is elevated to 0.015 mg/L by degraded water from the tributaries.

The modelling of typical summer seasonal conditions for TP indicate large areas exceeding the PWQO despite the use of a discharge diffuser to achieve an initial mixing ratio of 45:1 and an effluent TP discharge concentration of 0.2 mg/L (as typical of *tertiary* treatment). Therefore, modelling of the extreme, worst-case conditions was not considered warranted.

4.3.4.2 AMMONIA

The un-ionized ammonia (NH_3) component of the in-stream total ammonia-nitrogen ($NH_3 + NH_4^+$) is a critical water quality parameter to be determined in assimilative capacity analysis. The PWQO for un-ionized ammonia (UIA) which must be met downstream of a WWTP discharge is 0.02 mg/L. The fraction of UIA that exists in aqueous equilibrium is a function of pH and temperature conditions.

Another UIA criterion applicable to wastewater treatment facilities is the requirement that the effluent be non-acutely lethal to aquatic life. Based on previous discussion with MOE on other projects, the anticipated future effluent total ammonia-nitrogen criteria that could be established will result in a maximum UIA-N concentration of 0.2 mg/L to prevent acute toxicity.

The PWQOs were written assuming that the concentrations of ammonia (un-ionized and total) were reported as simple ammonia. However, most laboratories report the ammonia concentrations as ammonia-nitrogen. The MOE Standards Development Branch has indicated that a conversion factor of 1.216 is appropriate to derive a concentration of ammonia-nitrogen from an ammonia concentration. For the purposes of this analysis, an un-ionized ammonia-nitrogen concentration of 0.2 mg/L (0.24 mg/L un-ionized ammonia concentration) was used as the basis to prevent acute toxicity with reference to the PWQOs un-ionized ammonia concentration of 0.02 mg/L (0.016 mg/L un-ionized ammonia-nitrogen).

There is currently no effluent compliance criteria limit for ammonia under the existing Owen Sound WWTP C of A. It is anticipated that the upgrade to secondary treatment will allow the biological conversion of ammonia-nitrogen to meet future compliance criteria for ammonia-nitrogen.

The historical effluent pH and adjusted influent temperatures of the Owen Sound WWTP (refer to Section 2.5) were reviewed to determine the end-of-pipe total ammonia-nitrogen concentration required to achieve an UIA-N concentration of 0.2 mg/L in the plant effluent. The two-year (2005 to 2006) average monthly influent temperatures (adjusted to effluent temperature with seasonal effect) were used with the 75th percentile of the daily pH to determine the allowable total ammonia-nitrogen limits in the effluent by month.

The results, shown in Table 4.2, indicate that nitrification to a minimum total ammonia-nitrogen concentration of 10 mg/L is required in the winter months and that nitrification to a minimum total ammonia-nitrogen concentration of 4 mg/L in the summer months will meet the 0.2 mg/L UIA-N criteria for end-of-pipe discharge in the warmer summer months. It is noted that the use of the 75th percentile value provides a conservative approach since higher pH drives the equilibrium to the UIA-N form. Monthly average pH values in the plant effluent (2005 to 2006) have been within the range of 7.1 to 8.3.

TABLE 4.2

EFFLUENT TOTAL AMMONIA-NITROGEN CONCENTRATION TO MEET 0.2 mg/L UN-IONIZED AMMONIA AT END-OF-PIPE

Month	Temperature (°C)		75th %ile pH	UIA-N[2] Factor	End-of-Pipe	
	Influent	Adjusted Effluent			UIA-N Concentration (mg/L)	Total NH_3-N Concentration (mg/L)
January	9	6	8.05	0.0149	0.2	13
February	8	5	8.05	0.0142	0.2	14
March	9	9	8.05	0.0185	0.2	11
April	10	10	8.05	0.0199	0.2	10
May	13	13	8.05	0.0250	0.2	8
June	17	18	8.05	0.0377	0.2	5
July	20	21	8.05	0.0466	0.2	4
August	21	22	8.05	0.0499	0.2	4
September	20	20	8.05	0.0411	0.2	5
October	18	18	8.05	0.0356	0.2	6
November	15	15	8.05	0.0286	0.2	7
December	12	9	8.05	0.0195	0.2	10

Notes:

1. Plant data based on 2-year (2005/2006) average of monthly influent temperatures adjusted for seasonal effect and 75th percentile of daily pH.
2. Fraction of un-ionized ammonia-nitrogen (UIA-N) is a function of temperature and pH conditions.

If a new diffuser achieves a 20:1 dilution as per the MOE Policy B-1-5 objective, the resulting concentration of UIA-N in the receiver at the edge of the mixing zone can be determined. The resulting concentrations of UIA-N in the receiver at the edge of the mixing zone can also be determined using the 45:1 dilution achieved by the proposed diffuser design. The seasonal temperatures and 75th percentile pH data was used to determine UIA-N in the receiving water of Owen Sound inlet. As shown in comparison of plant effluent (Table 4.2) and Owen Sound ambient (Table 4.3) conditions, the receiving waters of Owen Sound are generally at lower temperature and higher pH conditions than the wastewater effluent.

Using the effluent total ammonia-nitrogen concentrations derived to achieve the end-of-pipe UIA-N of 0.2 mg/L, the resulting in-Owen Sound UIA-N concentrations were determined (Table 4.3) with a minimum 20:1 dilution and the actual 45:1 dilution achieved by the proposed diffuser design. Background UIA-N concentrations were assumed to be negligible for the diffuser dilution.

TABLE 4.3

IN-HARBOUR UN-IONIZED AMMONIA-NITROGEN CONCENTRATION

Month	End-of-Pipe Total NH_3-N Conc. (mg/L)	In-Harbour		UIA-N[1] Factor	In-Harbour		
		Temp. (°C)	pH		UIA-N Conc. (mg/L)	20:1 Dilution UIA-N Conc. (mg/L)	45:1 Dilution UIA-N Conc. (mg/L)
Spring	10	7	8.2	0.0227	0.227	0.011	0.005
Summer	4	18	8.2	0.0514	0.206	0.010	0.005
Fall	6	12	8.2	0.0332	0.200	0.010	0.004
Winter	12	2	8.2	0.0152	0.182	0.009	0.004

Notes:
1. Fraction of un-ionized ammonia-nitrogen (UIA-N) is a function of temperature and pH conditions.

There is a trend in recent C of As issued for wastewater treatment facilities in Ontario to specify an UIA-N concentration requirement, rather than a total ammonia-nitrogen concentration. As shown, the requirement for an UIA-N concentration of 0.2 mg/L will also achieve the PWQO at the edge of the mixing zone, with a 45:1 dilution achieved by the proposed diffuser.

The 75th percentile ammonia concentration was 0.04 mg/L for the Sydenham River in the summer season. Using the in-Harbour temperature and pH of 18 °C and 8.2, respectively, the corresponding un-ionized ammonia concentration is 0.002 mg/L. This simple analysis indicates that PWQO for un-ionized ammonia (0.02 mg/L) will not be exceeded. There was no attempt to model the un-ionized ammonia concentration (as a function of temperature and pH as the tributaries discharge in the vicinity of the WWTP outfall) as the spatial and temporal data available is limited.

Since higher receiving water temperatures will drive the equilibrium to increase the un-ionized ammonia concentration and seasonal receiving water temperatures were set based on qualitative factors only (as discussed in Section 2.3), the impact of higher receiving water temperatures on the un-ionized ammonia concentration at the edge of the mixing zone was determined. With a summer total NH_3-N concentration of 4 mg/L at end-of-pipe and an assumed extreme high receiving water temperature of 25 °C (and pH of 8.2), the UIA-N concentration with a minimum 20:1 dilution is 0.017 mg/L (compared to a concentration of 0.010 mg/L for similar conditions but at a temperature of 18 °C as shown in Table 4.3). This does not exceed the PWQO for un-ionized ammonia (0.02 mg/L) even at the assumed extreme high temperature of 25 °C.

Based on previous discussions with MOE on other projects, the typical requirements for wastewater treatment discharge of total ammonia-nitrogen is 10 mg/L and 8 mg/L for winter and summer conditions, respectively. While this requirement is similar to the total ammonia-nitrogen concentration derived from this analysis for winter conditions, this analysis indicates the need to achieve a total ammonia-nitrogen concentration of 4 mg/L under summer conditions to meet the requirement for a non-acutely lethal effluent at the end-of-pipe.

Therefore, the following effluent nitrogen criteria are recommended for the Owen Sound WWTP to produce a non-acutely lethal effluent at the end-of-pipe and to meet the PWQO for UIA-N concentration at the edge of the mixing zone:

- 0.2 mg/L un-ionized ammonia-nitrogen (end-of-pipe temperature, pH, and total ammonia-nitrogen measurement required);
- 10 mg/L total ammonia-nitrogen (winter); and
- 4 mg/L total ammonia-nitrogen (summer).

4.3.4.3. SUSPENDED SOLIDS

The PWQOs do not contain any direct reference to suspended solids criteria. The 75th percentile suspended solids concentration of 0.5 mg/L from the GLIS sample data for summer season (Table A6, Appendix A) was used to define the background concentration in the model. Table B4 provides the CORMIX2 output for the typical summer conditions. With the effluent suspended solids concentration of 20 mg/L and a 45:1 dilution achieved by the proposed diffuser design, the excess suspended solids concentration at the edge of the mixing zone will be 0.435 mg/L. The plume is of the MU2 class.

Figures 16 and 17 present GEMSS-generated far-field model results for the typical summer conditions. The figures show significant impact of the tributaries on the levels and spatial distribution of TSS concentrations in the Sound near the WWTP outfall. The summer 75th percentile TSS concentration in Sydenham River is 8.6 mg/L and in Pottawatomi River 9.0 mg/L. The proposed diffuser effectively dilutes TSS in the Sound; however, the dilution of TSS coming from the tributaries is much less effective.

4.3.4.4 BIOCHEMICAL OXYGEN DEMAND AND DISSOLVED OXYGEN

A complex oxygen balance for a water body would include consideration of the following factors:

- Oxygen produced by aquatic vegetation during photosynthesis (during sunlight hours at the surface) and consumed during respiration and decomposition;
- Diffusion of oxygen into water at the air-water interface including wind impacts; and
- Stratification of the oxygen profile.

Wastewater treatment plant discharges may be expected to decrease the average DO concentration of the receiving water body either by contributing oxygen-demanding organic matter directly or nutrients (i.e. phosphorus) that stimulate growth of organic matter (i.e. algal growth). Total phosphorus concentrations relative to the PWQO of 0.02 mg/L for TP in lakes were discussed in Section 4.3.4.1. The impact of oxygen-demanding organic matter, conventionally measured as the 5-day carbonaceous BOD_5, is developed in this section. The modelling activities completed do not include consideration of oxygen diffusion at the air-water interface or stratification of the oxygen profile (i.e. concentrations at varying depths).

The PWQO for DO concentration is based on the oxygen needed to sustain aquatic life relative to oxygen saturation concentrations. The physical process that affects DO concentrations is the relationship between water temperature and gas saturation. In general, as the water temperature increases, the total amount of oxygen that it can contain decreases. As shown in Table 4.4, the required dissolved oxygen decreases with increases in water temperature relative to saturation for cold and warm water biota.

TABLE 4.4

PWQO FOR MINIMUM DISSOLVED OXYGEN CONCENTRATION

Temperature (°C)	Cold Water Biota		Warm Water Biota	
	% Saturation	DO (mg/L)	% Saturation	DO (mg/L)
0	54	8	47	7
5	54	7	47	6
10	54	6	47	5
15	54	6	47	5
20	57	5	47	4
25	63	5	48	4

As presented in Appendix A, the 25th percentile DO concentration obtained from the GLSP data is 9.2 mg/L for summer conditions. With an effluent BOD_5 concentration of 20 mg/L and a 45:1 dilution achieved by the proposed diffuser design, the oxygen demanding material in the plant discharge would decrease the dissolved oxygen concentration by approximately 0.44 mg/L at the edge of the mixing zone.

This reduction from the ambient DO concentration of 9.2 mg/L will not reduce the DO to less than the minimum DO concentrations specified for cold water (5 mg/L) or warm water (4 mg/L) biota as presented in Table 4.4 at a water temperature of 20°C.

Similarly, the 25th percentile dissolved oxygen concentration obtained from the GLSP data is 13.7 mg/L for spring conditions (fall and winter data is limited or not available). With an effluent BOD_5 concentration of 20 mg/L and a 45:1 dilution achieved by the proposed diffuser design, the oxygen demanding material in the plant discharge would decrease the dissolved oxygen concentration by approximately 0.44 mg/L at the edge of the mixing zone. This reduction from the ambient DO concentration of 13.7 mg/L will not reduce the DO to less than the minimum DO concentrations specified for cold water (8 mg/L) or warm water (7 mg/L) biota as presented in Table 4.4 at a water temperature of 0°C.

There are no BOD data systematically collected in Owen Sound under any program. Typically, oxygen demanding materials (i.e. organic matter) would act in the water body to decrease the oxygen concentration. To provide the most conservative model approach, a background ambient BOD concentration of 2 mg/L was assumed. Table B5 (Appendix B) provides the CORMIX2 output for this scenario, assuming typical summer conditions and the effluent concentration of 20 mg/L. The concentration of BOD at the edge of the mixing zone is 2.4 mg/L (0.4 mg/L + 2.0 mg/L). The plume is of the MU2 class.

Far-field model results for the typical summer conditions are presented on Figures 18 and 19. The impact of the tributaries on the concentration of BOD in the Sound is positive as the concentration of BOD in the tributaries is lower than the assumed background concentration in the Sound (1.0 mg/L in Sydenham River and 1.1 mg/L in Pottawatomi River). The higher effluent BOD levels impact the areas in the Sound near the WWTP outfall and along the NE shore.

4.3.4.5 BACTERIAL (*E. coli*)

The bacterial PWQO for *Escherichia coli* is 100 *E. coli* micro organisms per 100 mL, based on a geometric mean of at least 5 samples. This PWQO is based on a recreational water quality guideline published by the Ontario Ministry of Health in 1992 and was specifically intended for application to swimming and bathing beaches. *E. coli* was selected for the guideline because studies have determined that, among bacteria of the coliform group, *E. coli* is the most suitable and specific indicator of fecal contamination. As of May 1994, all new compliance, enforcement and water quality monitoring activities are to be based on the *E. coli* test.

Based on previous experience with bacterial requirements in recent Certificates of Approval for other municipal wastewater treatment facilities, it is anticipated that the *E. coli* effluent objective and compliance criteria for the Owen Sound WWTP will be 100/100 mL and 200/100 mL, respectively, based on a monthly geometric mean density.

5.0 RECOMMENDED EFFLUENT LIMITS AND CONCLUSIONS

Effluent design objectives relate to the design condition and performance objectives for the operation of the treatment facilities. Processes are designed and operated to achieve effluent concentrations less than the existing compliance criteria. Effluent compliance criteria are the legally enforceable concentrations required under the regulatory environmental legislation. The current (with primary treatment) and future expected (following upgrade to secondary treatment) compliance limits for the Owen Sound WWTP are presented in Table 5.1.

TABLE 5.1

EFFLUENT COMPLIANCE LIMITS

Parameter	**Compliance Limit**	
	Current (Primary Treatment)	**Future Expected (Following Upgrade to Secondary Treatment)**
Total Suspended Solids	70% Removal[1]	20 mg/L
Biochemical Oxygen Demand	50% Removal[1]	20 mg/L
Total Phosphorus	1 mg/L[1]	0.8 mg/L
Total Ammonia-Nitrogen		
Winter	No Limit	10 mg/L
Summer	No Limit	4 mg/L
E. coli	No Limit	200/100 mL
Chlorine	No Limit	N/A

Notes:

1. Compliance limits not currently specified in the Certificate of Approval. Therefore, current effluent is subject to the criteria for primary sewage treatment plants specified in MOE Procedure F-5-1.

N/A Not applicable. Ultraviolet irradiation to be used for effluent disinfection at the Owen Sound WWTP with upgrade to secondary treatment.

The future effluent compliance criteria (as shown in Table 5.1) may be achieved by upgrading to secondary treatment processes at the current rated capacity of the plant (24.5 MLD). The effluent requirements are within the possible range of conventional activated sludge plants, or equivalent secondary treatment. It is highlighted that the proposed effluent limits shown in Table 5.1 represent an improvement in effluent quality for all conventional parameters (TSS, BOD_5, TP, and Ammonia-Nitrogen) with the upgrade to secondary treatment. With no increase in flow capacity, it is noted that the contaminant loadings discharged from the Owen Sound WWTP will also decrease to the benefit of the receiving water conditions.

A new discharge diffuser will be required to improve the near-field mixing ratio from the current 4.5:1 (no diffuser) to a minimum of 20:1 as specified under MOE Policies. The preliminary discharge diffuser parameters provided in this Technical Memorandum will provide an initial mixing ratio of 45:1. Enforcement of MOE Policies with respect to discharge diffuser requirements may be decided on a case-by-case basis at the MOE's discretion.

Despite the provision of initial mixing conditions and an effluent TP discharge concentration of 0.8 mg/L, total phosphorus concentrations exceed the PWQO for significant areas of the Sound in the vicinity of the outfall and extending to the NE shore for several kilometres under summer conditions. It is predicted that the elevated TP and TSS concentrations in the two main tributaries have a deleterious impact on water quality conditions in the vicinity of the plant outfall.

The use of an effluent TP concentration of 0.8 mg/L will not result in any further degradation in this area as there is no increase in flow proposed with the upgrade to secondary treatment. Modelling results show that even if the effluent TP concentration is lowered to a value as low as 0.2 mg/L (as typically achieved by tertiary treatment methods), effectively diluted by the diffuser to 0.004 mg/L at the edge of the mixing zone, with the background concentration elevated to approximately 0.015 mg/L by the tributaries, the resulting concentrations can still be close to or exceed the PWQO limit.

CONCLUSIONS

The main conclusions of this study can be summarized as follows:

- The Intake Source Water Protection Modelling (Baird, 2007) has identified that the outfall is within the Intake Protection Zone (IPZ-2) designated by the 2-hour time of travel criteria. The potential impact of this designation on the outfall requirements has not been defined at this time.
- CORMIX and GEMSS were used together in this assimilative capacity study for near-field mixing zone modelling and to predict effluent dispersion within the far-field plume under typical effluent-ambient conditions. Surface and bottom layer currents generated by these models were in agreement with the model (DELFT3) results obtained by Baird (2007) in the vicinity of the Owen Sound WWTP outfall.
- The existing outfall (no diffuser) does not provide the minimum 20:1 initial mixing ratio indicated in MOE policies. A preliminary outfall design was developed to provide an initial mixing ratio of 45:1.

- Elevated TP and TSS concentrations in the two main tributaries (Sydenham and Pottawatomi Rivers) have a deleterious impact on water quality conditions in the vicinity of the plant outfall. Consequently, the model results show significant areas exceeding the PWQO with secondary treatment to an effluent TP concentration of 0.8 mg/L. However, the secondary treatment compliance criteria of 0.8 mg/L will not result in any further degradation in this area. The current compliance criterion for TP is 1.0 mg/L and there is no increase in rated flow capacity proposed with the upgrade to secondary treatment.
- The conclusions of this study are based on the modelling of predicted impacts under seasonal average conditions. Insufficient data is available to calibrate the model or to add a thermal stratification component to the model. However, use of a theoretical thermal stratification condition indicated that thermal stratification has negligible impact on hydrodynamic circulation in the shallow sections of the Sound near the WWTP outfall.

6.0 REFERENCES

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FIGURE 1

3D BATHYMETRIC SURFACE OF OWEN SOUND

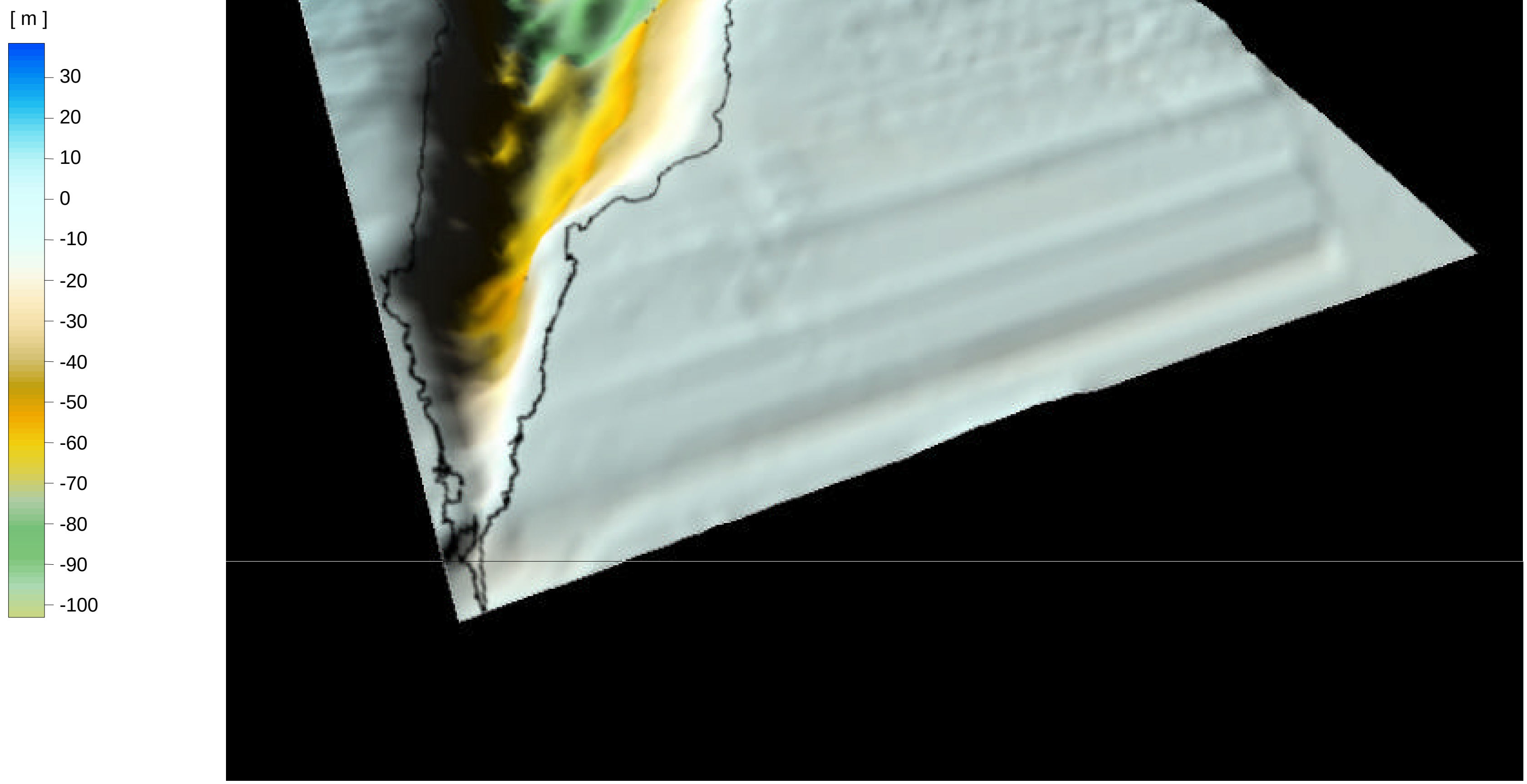


FIGURE 2

EXISTING OUTFALL LOCATION

(Background map: Canadian Hydrographic Service Navigational Chart No. 2283)

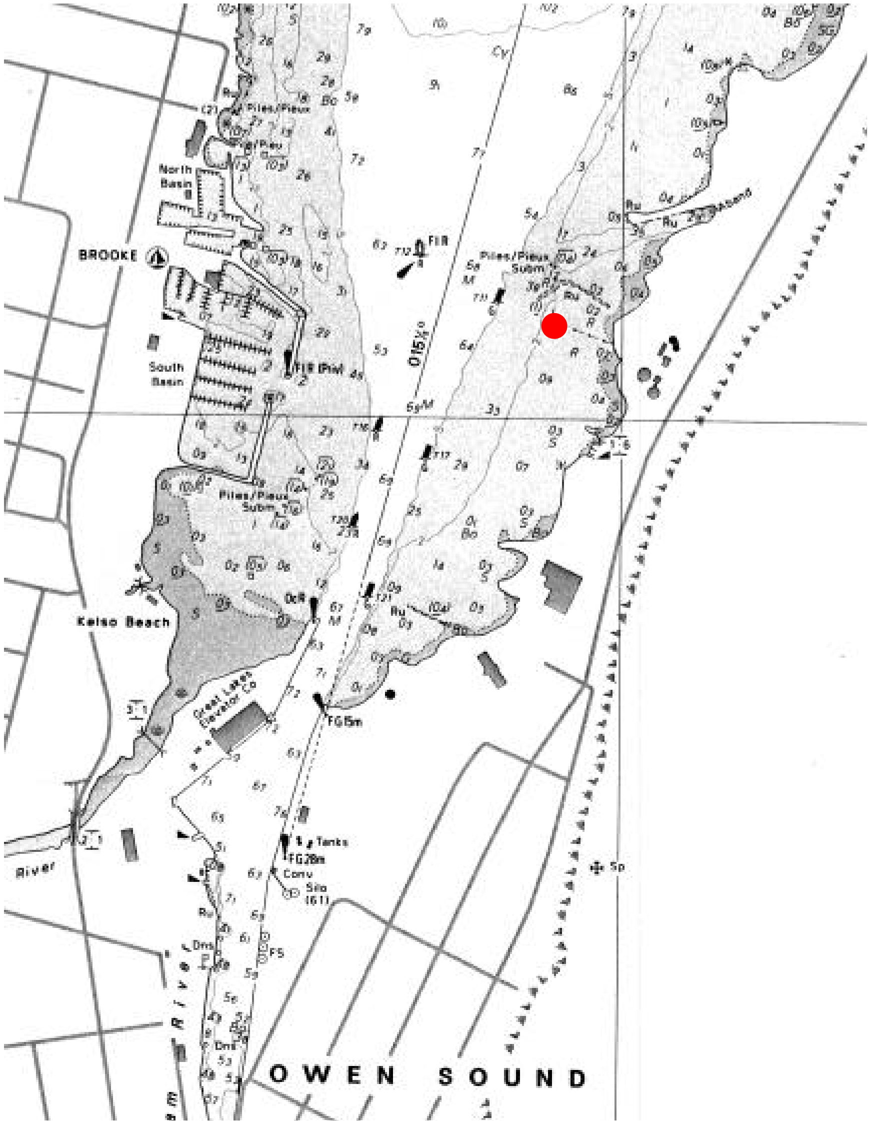


FIGURE 3

CURVILINEAR MODEL GRID OF OWEN SOUND

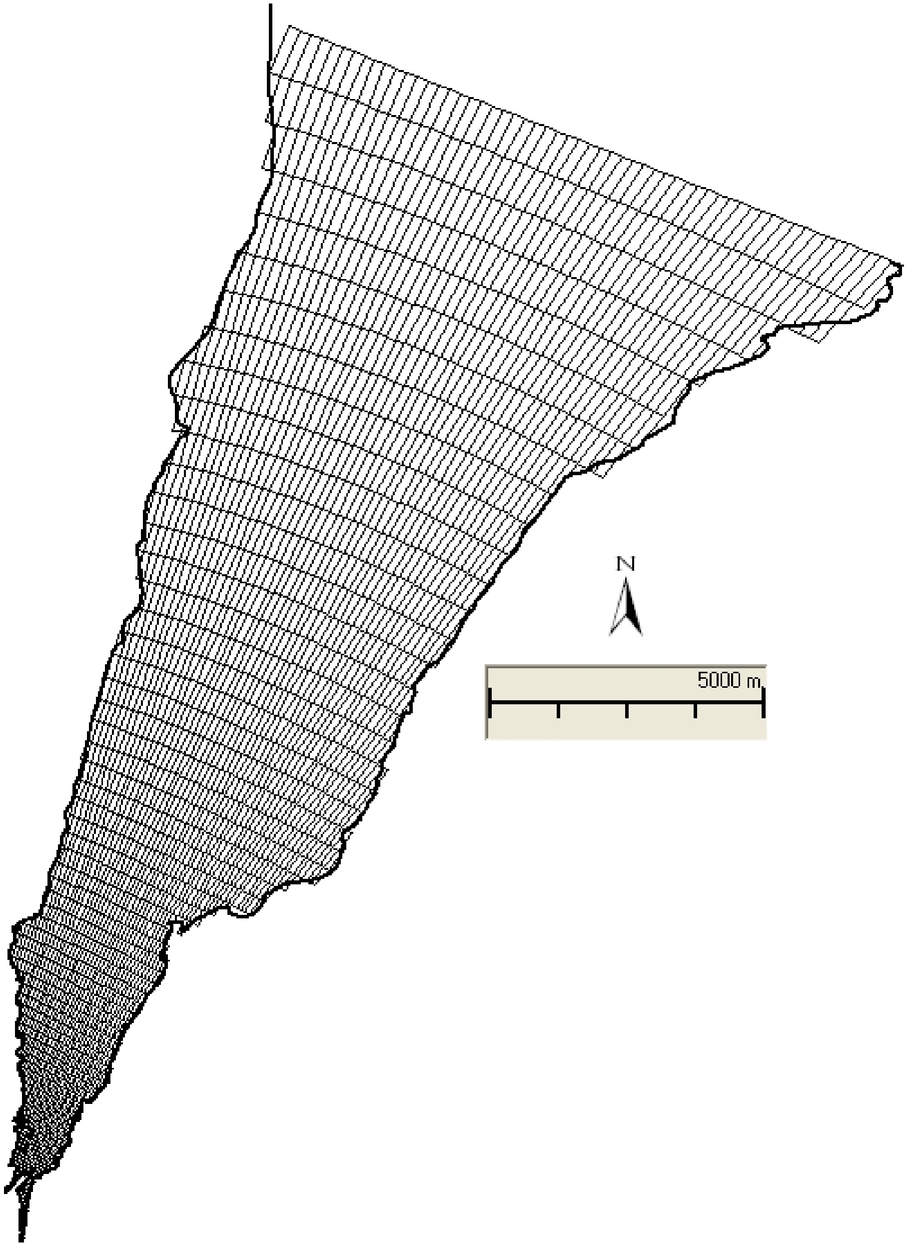


FIGURE 4

BOTTOM CURRENTS IN OWEN SOUND DURING WIND FROM THE SOUTHWEST AND 2-YEAR FLOOD FLOWS IN THE TRIBUTARIES

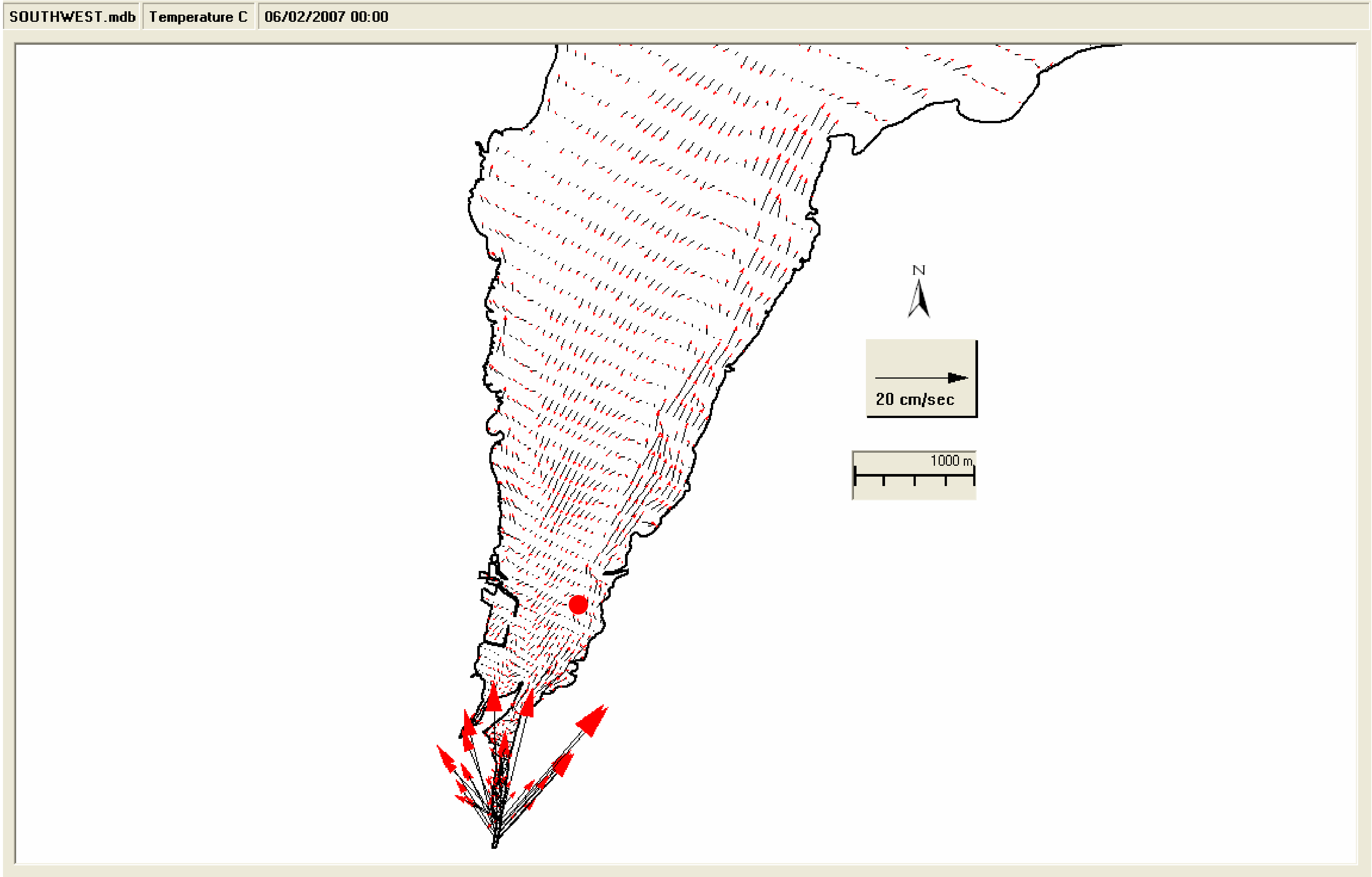


FIGURE 5

SURFACE LAYER TP LEVELS AT 24.5 MLD
0.8 MG/L END-OF-PIPE CONCENTRATION
EXISTING SINGLE-PIPE OUTFALL
SUMMER CONDITIONS

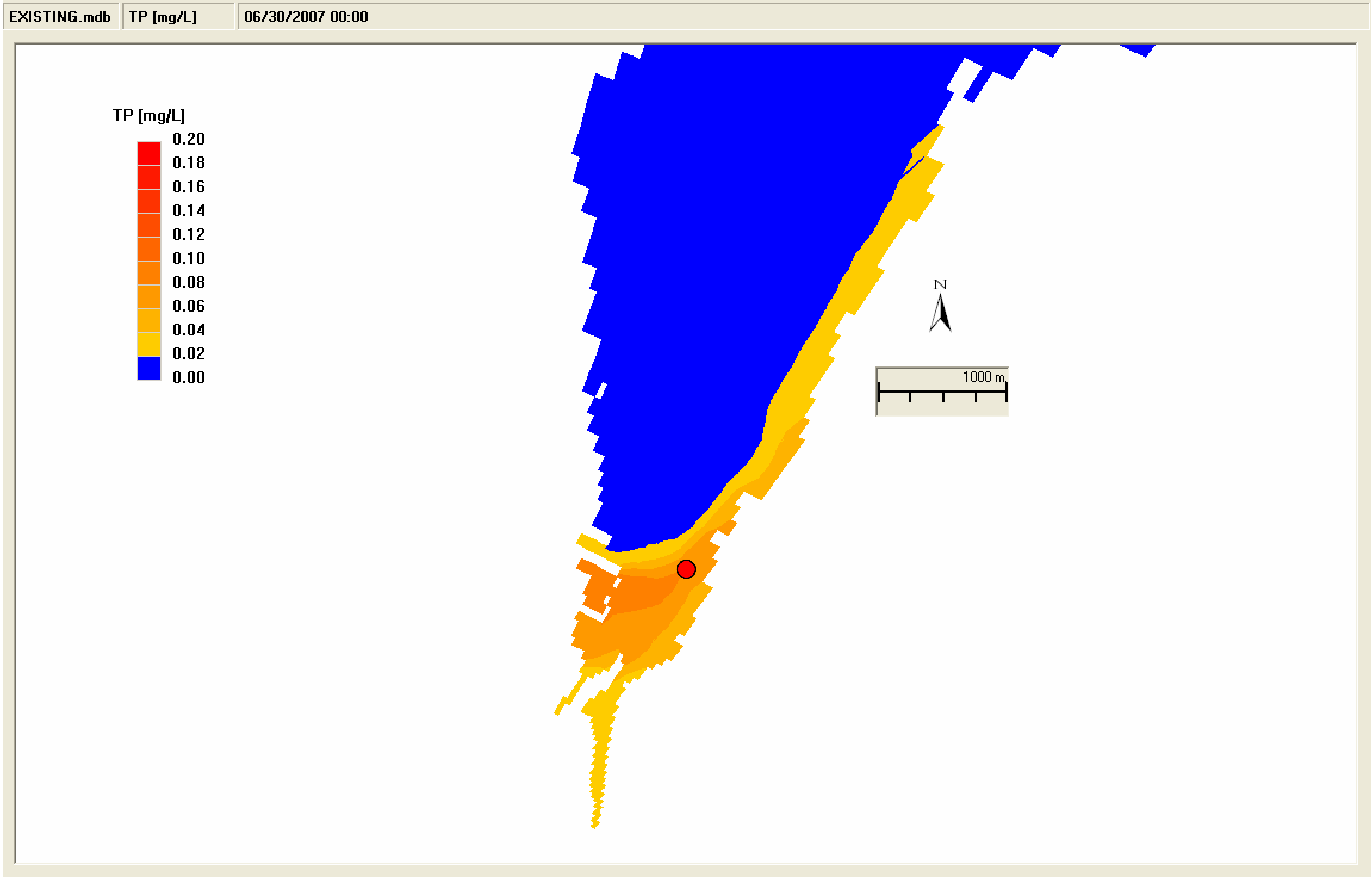


FIGURE 6

BOTTOM LAYER TP LEVELS AT 24.5 MLD
0.8 MG/L END-OF-PIPE CONCENTRATION
EXISTING SINGLE-PIPE OUTFALL
SUMMER CONDITIONS

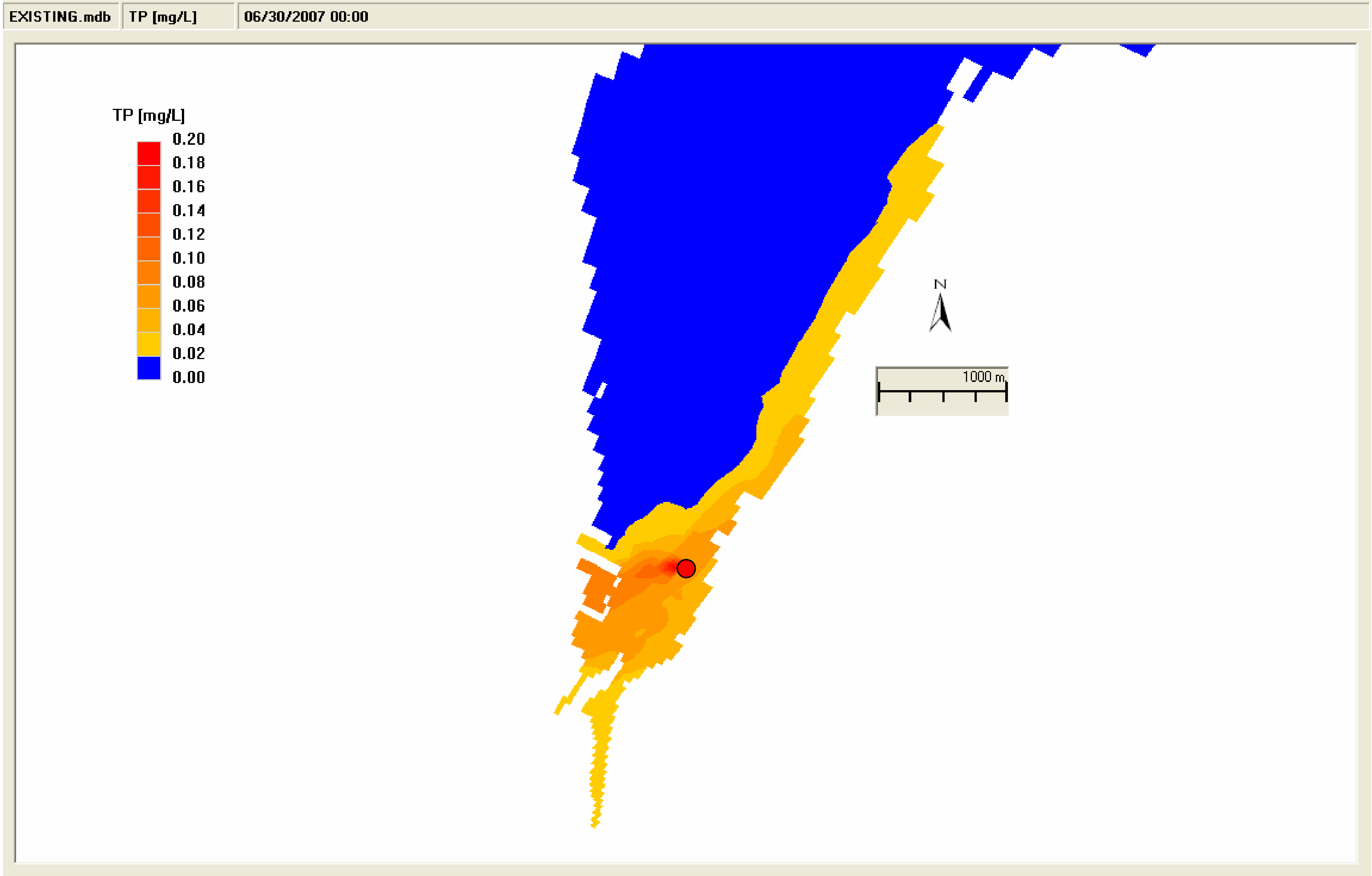


FIGURE 7

LOCATION OF VERTICAL SLICE NEAR THE OUTFALL LOCATION IN OWEN SOUND

FIGURE 8

VERTICAL SLICE FOR THE 24.5 MLD
0.8 MG/L TP END-OF-PIPE CONCENTRATION PLUME
EXISTING SINGLE-PIPE OUTFALL
SUMMER CONDITIONS

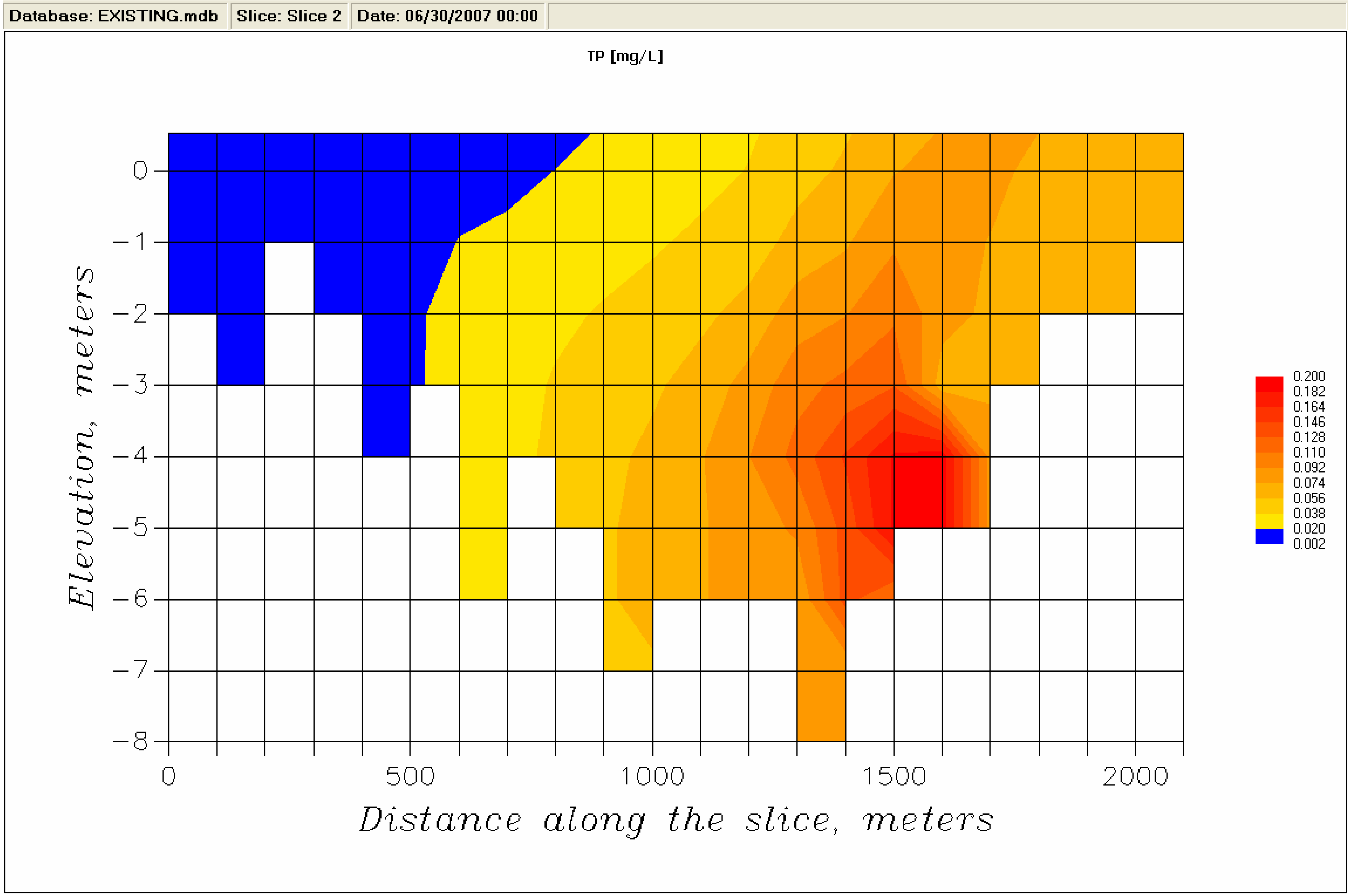


FIGURE 9

SURFACE LAYER TP LEVELS AT 24.5 MLD
0.8 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

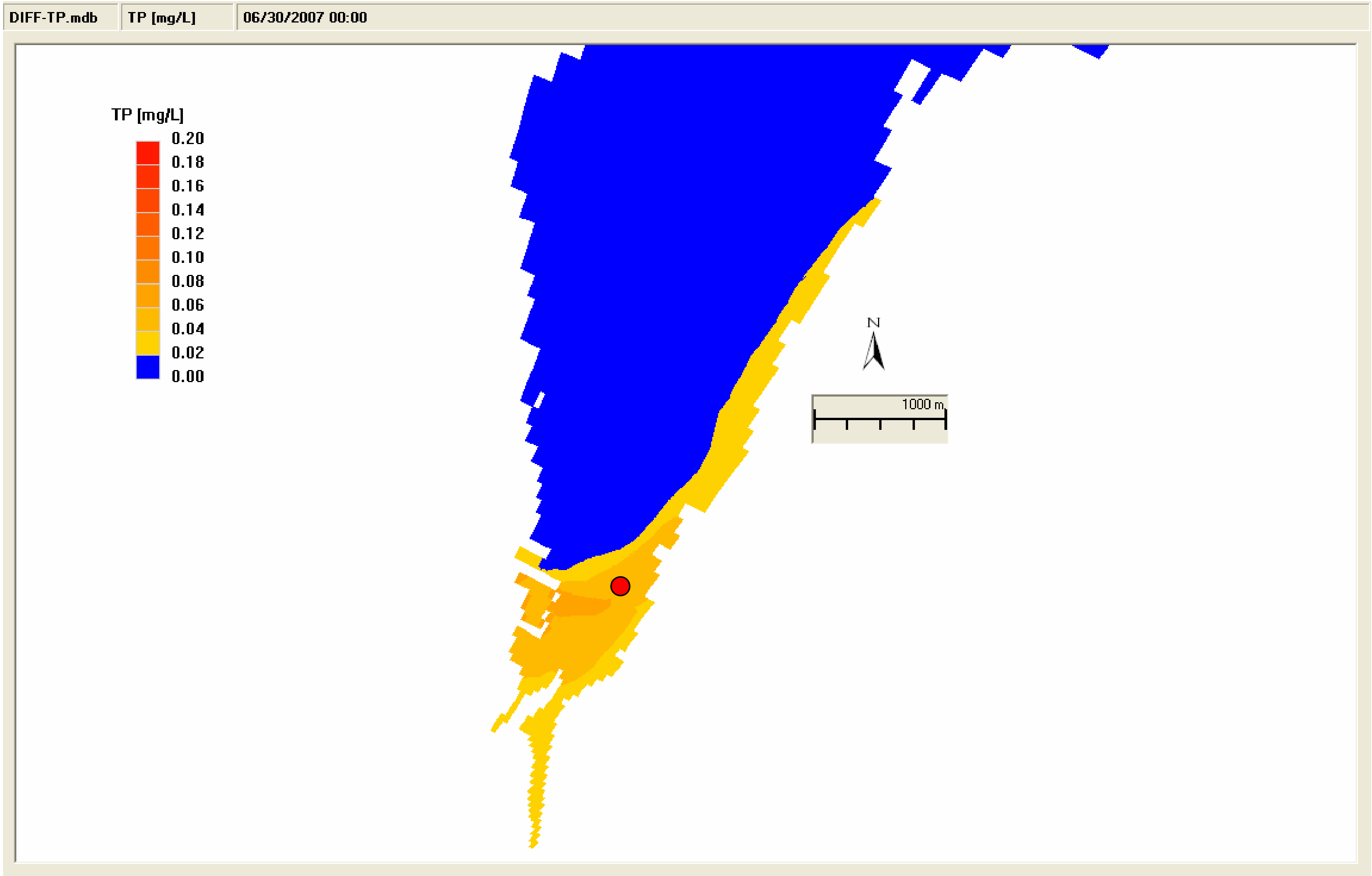


FIGURE 10

BOTTOM LAYER TP LEVELS AT 24.5 MLD
0.8 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

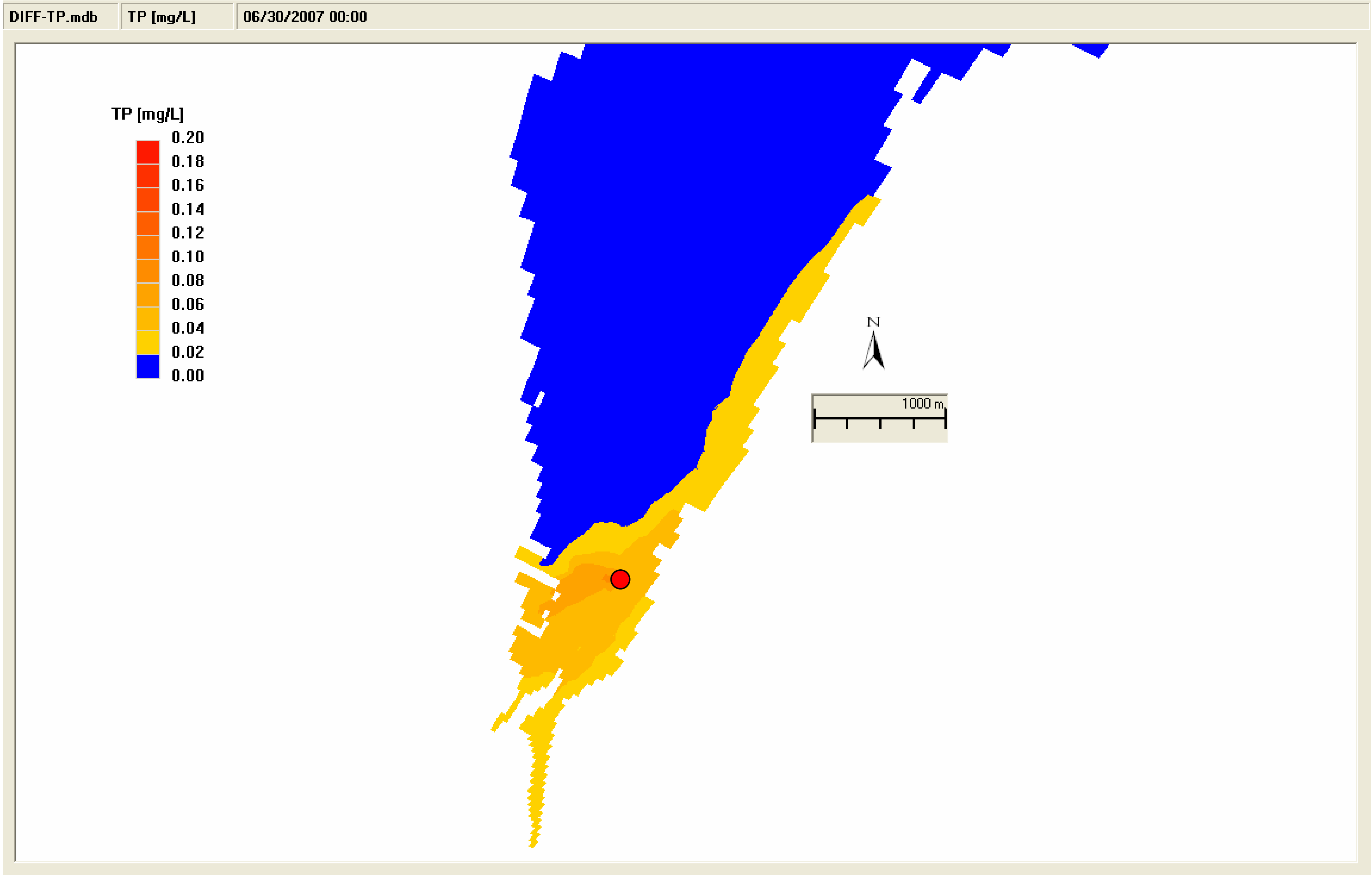
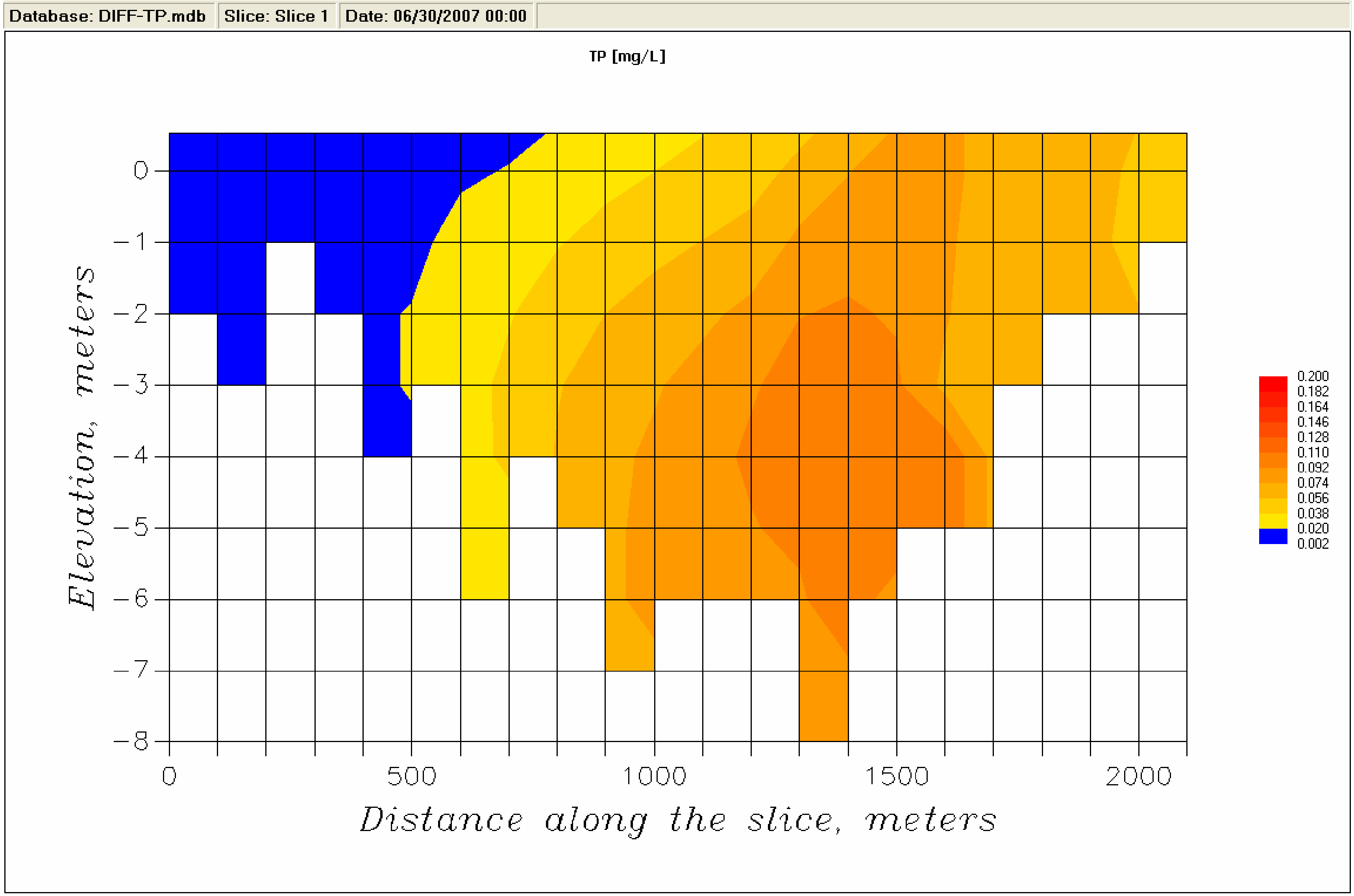


FIGURE 11

VERTICAL SLICE FOR THE 24.5 MLD
0.8 MG/L TP END-OF-PIPE CONCENTRATION PLUME
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS



Database: DIFF-TP.mdb | Slice: Slice 1 | Date: 06/30/2007 00:00

FIGURE 12

IMPACT OF TRIBUTARIES ON SURFACE LAYER TP LEVELS
NO WWTP DISCHARGE
SUMMER CONDITIONS

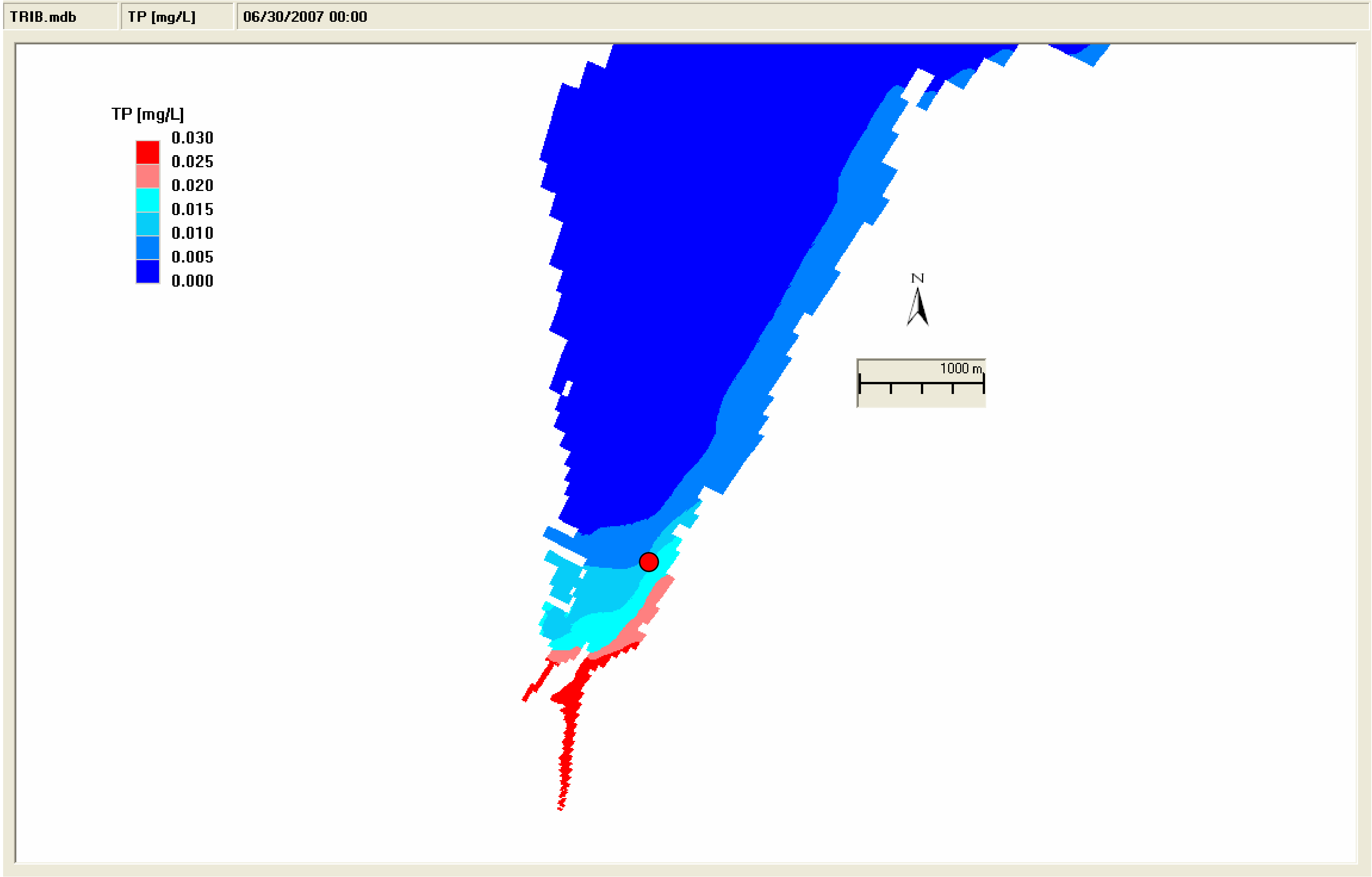


FIGURE 13

IMPACT OF TRIBUTARIES ON BOTTOM LAYER TP LEVELS
NO WWTP DISCHARGE
SUMMER CONDITIONS

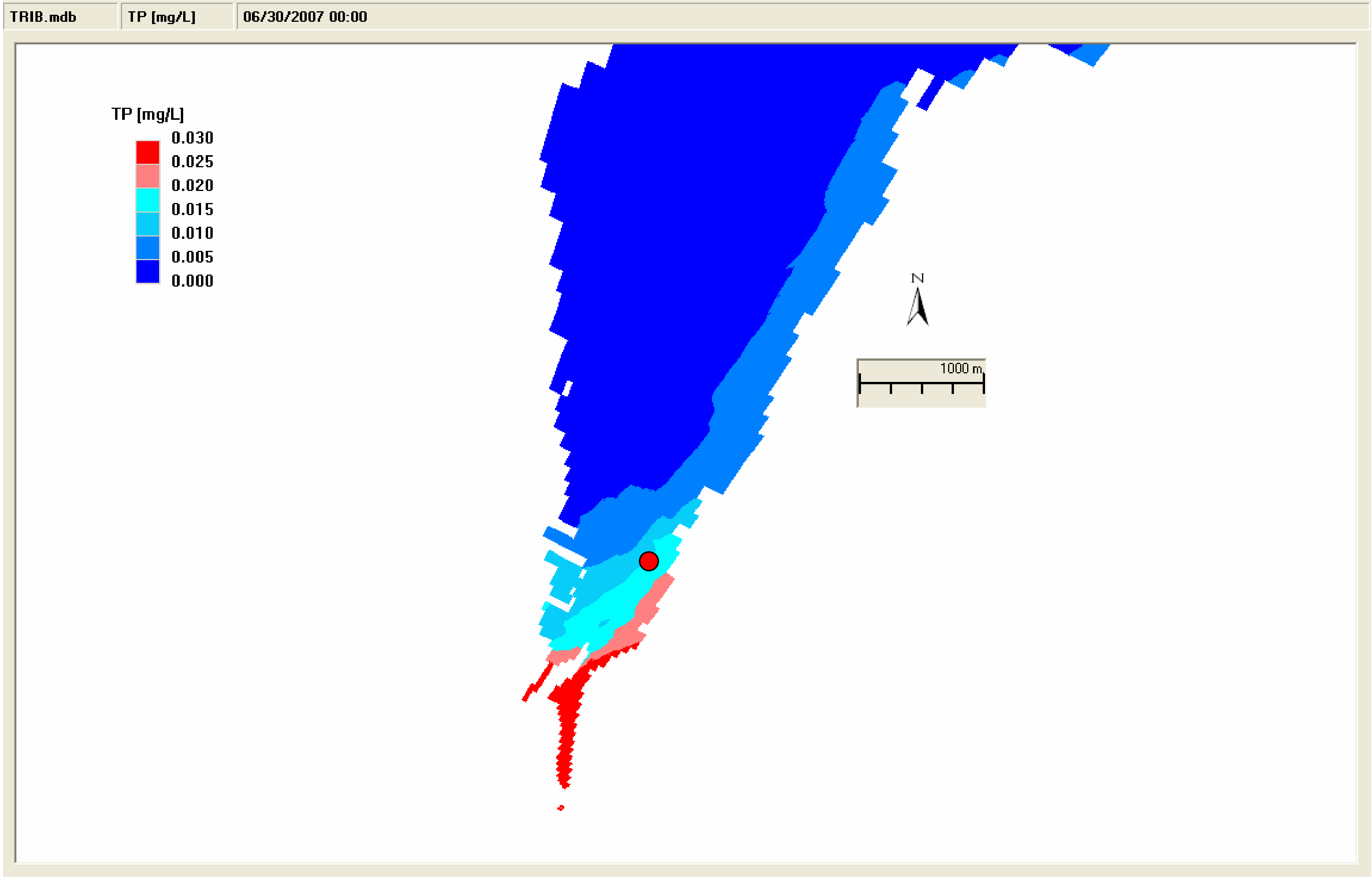


FIGURE 14

SURFACE LAYER TP LEVELS AT 24.5 MLD
0.2 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

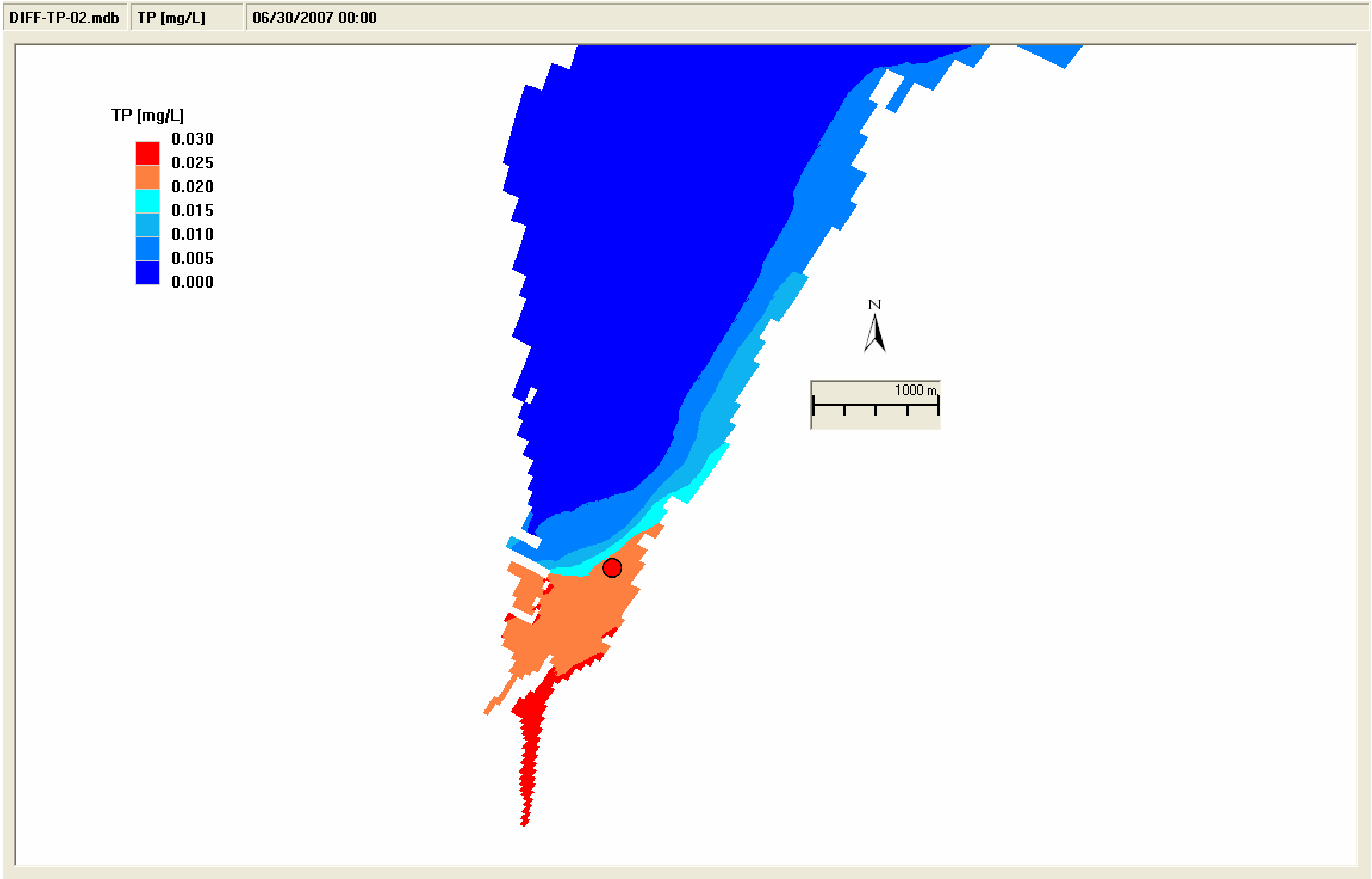


FIGURE 15

BOTTOM LAYER TP LEVELS AT 24.5 MLD
0.2 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

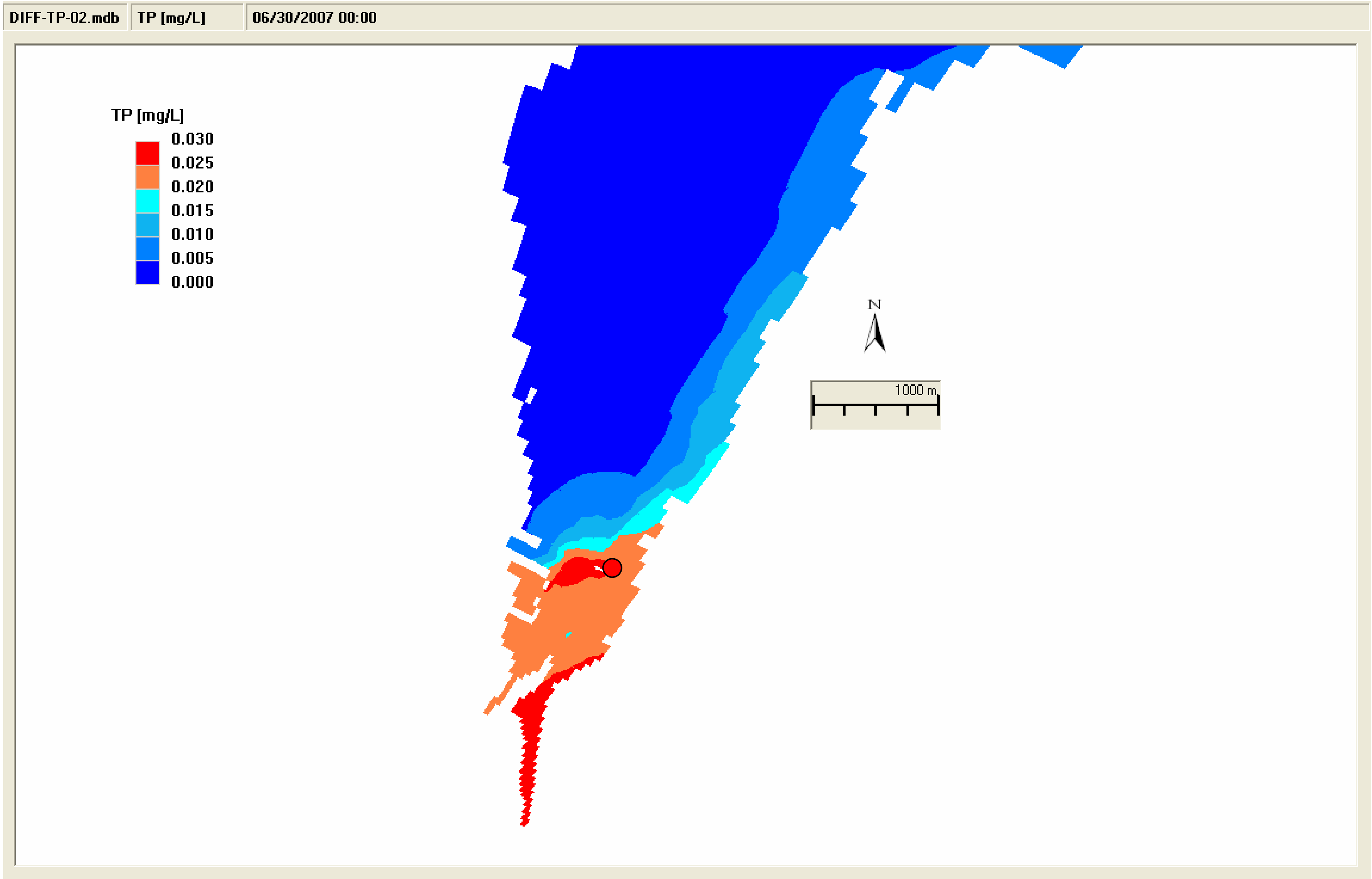


FIGURE 16

SURFACE LAYER TSS LEVELS AT 24.5 MLD
20 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

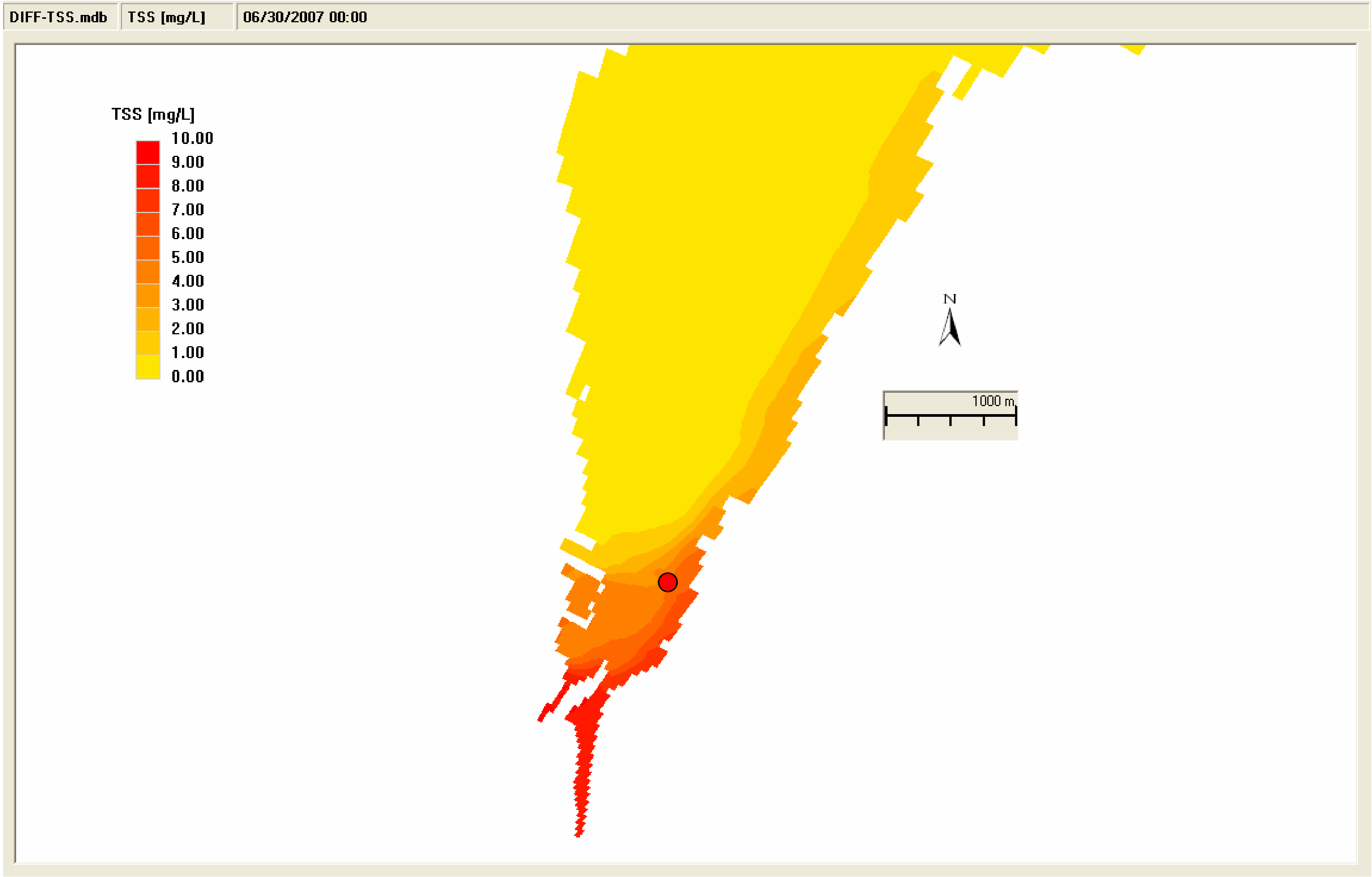


FIGURE 17

BOTTOM LAYER TSS LEVELS AT 24.5 MLD
20 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

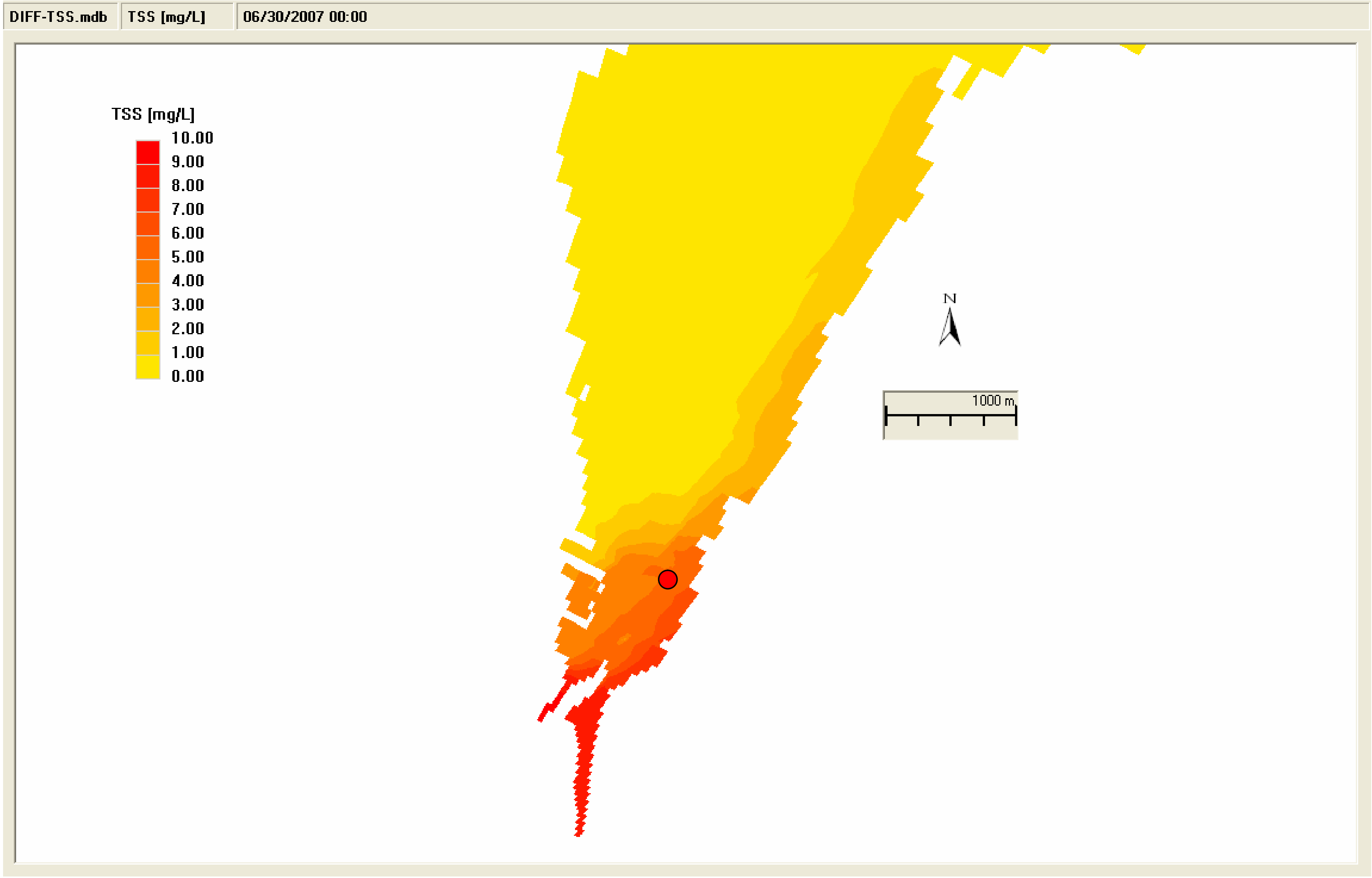


FIGURE 18

SURFACE LAYER BOD LEVELS AT 24.5 MLD
20 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS

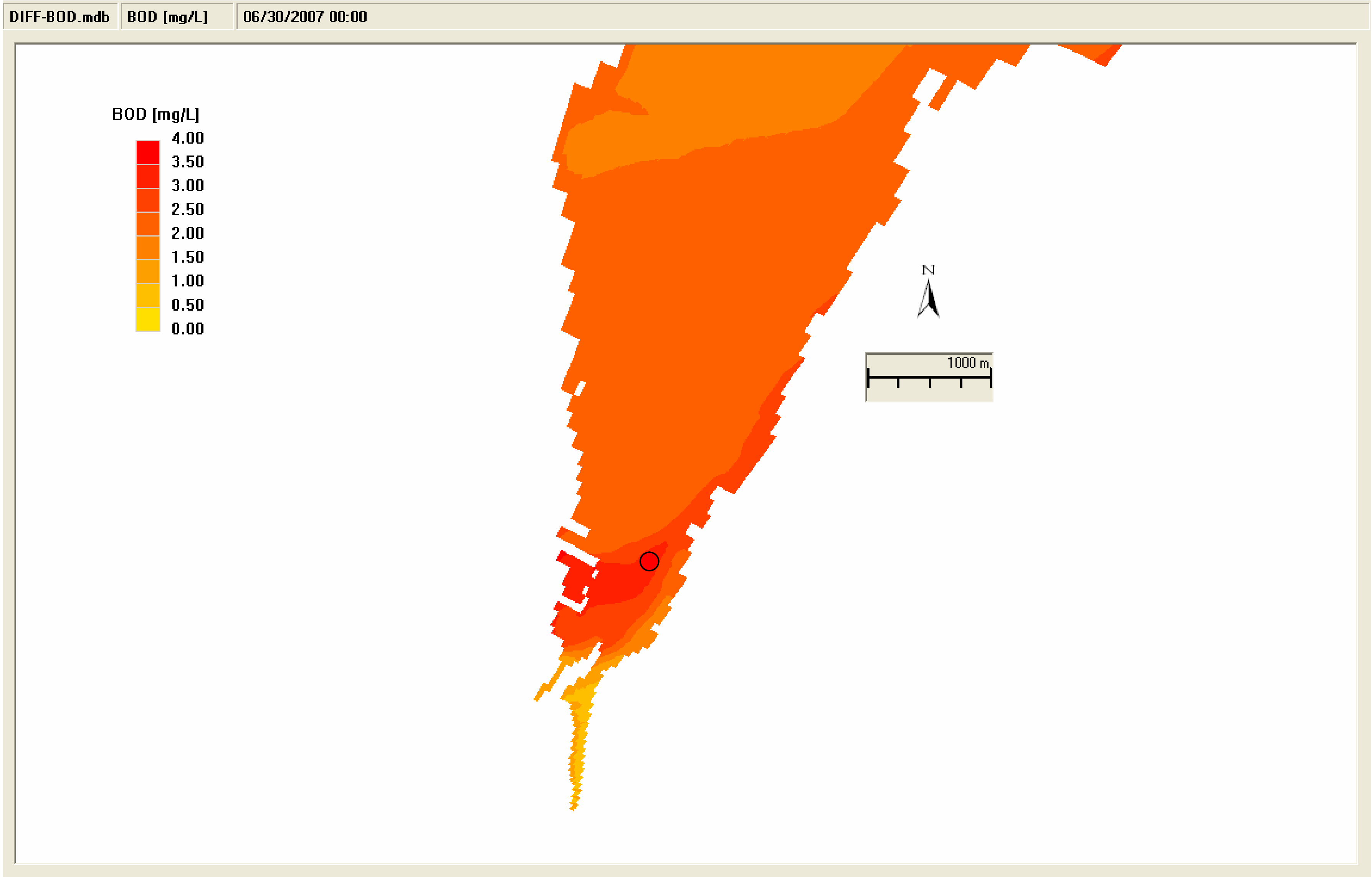


FIGURE 19

BOTTOM LAYER BOD LEVELS AT 24.5 MLD
20 MG/L END-OF-PIPE CONCENTRATION
PROPOSED DIFFUSER OUTFALL
SUMMER CONDITIONS