UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 457

Empire Wastewater Treatment Plant and Outfall

Outfall Mixing Zone Analysis

by

John R. Thene and Hong Wang

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1. Summary

1.1 Purpose

Metropolitan Council Environmental Services (MCES) in St Paul, Minnesota intends to relocate the Empire Wastewater Treatment Plant outfall from the Vermillion River to a location on the shipping channel in the Mississippi River, near the upstream end of Spring Lake (Figure 1.1). A study is being conducted to provide information on the mixing of the effluent with the flow of the Mississippi River, and to provide support for the siting and orientation of the outfall pipe. The results are based on an analysis using the "CORMIX expert system" for evaluation of mixing.

1.2 Objective

Generally, it is desirable to provide rapid mixing of effluents and thereby minimize the areas affected by the highest effluent concentrations. In this study, in addition to that general concern, the design objectives of the mixing analysis include:

- Avoidance of inflow to Spring Lake through the channels at the upstream end of the lake.
- Delivery of the plume to the center of the shipping channel so as to further reduce the possibility of entrainment of the plume into the channels leading to Spring Lake.
- Avoidance of upstream intrusion of the plume, which increases the probability of movement into Spring Lake.
- Low jet velocity to minimize affects on boat and barge traffic.
- Selection of outfall pipe diameter, location, depth of submergence, and vertical and horizontal angles to achieve these objectives.

1.3 Results

The study findings are summarized as follows:

- The Mississippi River discharge at the outfall location is reduced from the flow at St. Paul by flows to Baldwin and Spring Lakes. Available data on the flow split indicate that 57 percent of the river flow will be in the navigation channel at the outfall, with 21 percent entering Baldwin and 22 percent entering Spring Lake. This flow split is shown to occur for flows above 10,000 cfs, but is uncertain at the 7Q10 where there are no data available, and where wind will significantly change the distribution.
- The river flow used in the mixing calculations is 57 percent of the 7Q10.
- There are indications that the flow in the side channel to the right of the shipping channel and downstream of the outfall is in the downstream direction. Because it flows towards the shipping channel it is therefore not likely to entrain the plume into Spring Lake. Winter ice cover patterns suggest that the flow patterns around the islands are similar at low flow with an ice view (Fig. 1.2).
- The discharge temperature at the end of the 12-mile outfall is unknown. If it is assumed to be similar to current outfall temperatures, which are close to ground temperature, it is fairly certain that summer plumes will be negatively buoyant and winter plumes positively buoyant.
- Since in summer the plume will plunge to the bottom, wind action is less likely to divert the plume to Spring Lake. In winter, ice cover will likely prevent wind from redirecting the surface plume to Spring Lake.
- To best meet the objectives noted above, the outfall pipe, based on the evaluation of the 66-inch and 54-inch diameters, should enter the shipping channel flow in the direction defined by:

  Horizontal angle to flow direction: $0^\circ < \delta < 45^\circ$
  Vertical angles to horizontal direction: $12^\circ < \theta < 45^\circ$
- Alternative pipe diameters of 36, 42 and 48 inches were also evaluated for the preferred angles of:

  Horizontal angle to flow direction: $\delta = 45^\circ$
  Vertical angles to horizontal direction: $\theta = 0^\circ$

The 48-inch outfall pipe diameter has been selected as a result of the design studies completed during 2002. The mixing zone analyses indicate:

- Some upstream intrusion of the plume will occur for most winter conditions due to the buoyancy of the plume and the low channel velocities present. Discharge angles have little effect because buoyancy is controlling factor.
- Winter wind-induced currents may be restricted by ice cover and reduce chances of wind-induced transport of the treated wasterwater plume into Spring Lake.
- Summer conditions result in no upstream intrusion and plume is more likely to remain in navigation channel due to negatively buoyant (sinking) condition.
- Sinking condition makes summer discharge less subject to movement by wind-induced currents.
- Other studies have shown that mixing by barge tows is significant source of dispersion at flows below 5,000 cfs.
- In summer conditions, the plume will mix relatively rapidly, achieving a concentration of 10 percent of the starting concentration within 100 meters.
- In winter conditions mixing will occur more slowly.

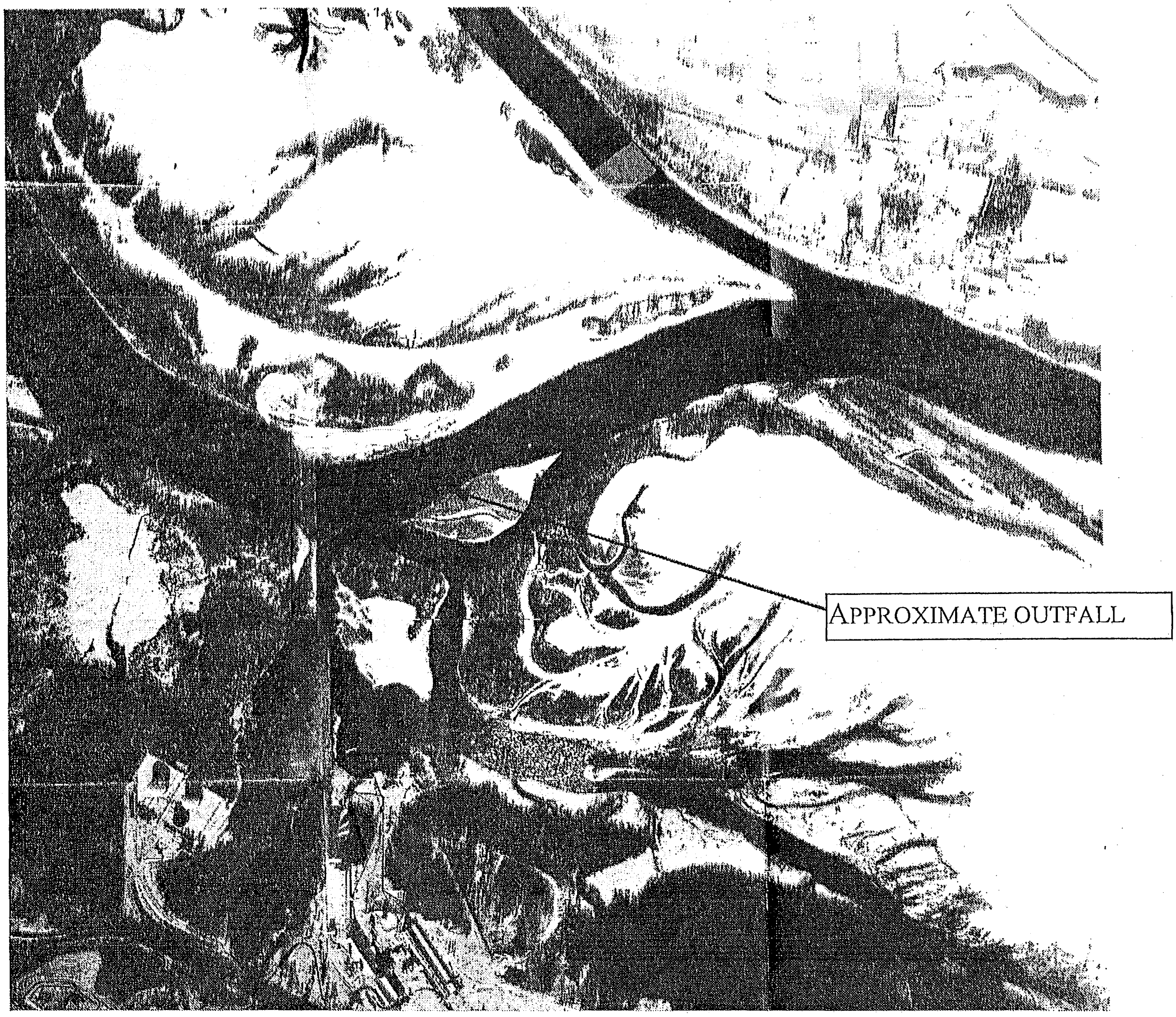


Fig. 1.2. Aerial view of outfall site in winter. Note ice cover and presence open water in active channels.

1.4 Recommendations

The results of the study indicate that:

- The outfall should be located on the shipping channel side of the island as indicated on Figure 1.1. This is the best location to avoid possible inflow to Spring Lake.
- The invert elevation of the outfall should be approximately El. 670 ft.
- The horizontal angle of the outfall should be about 45 degrees relative to river flow direction.

- The vertical angle of the discharge pipe may be set at 0 degrees (horizontal) as the angle has little influence on mixing predictions and is preferred to avoid sedimentation in the pipe.
- Air entrainment in the flow should be avoided as this may alter the mixing characteristics from those analyzed here.

2 Mixing Zone Concept

An "effluent mixing zone" can be thought of as a limited area or volume where the initial dilution of a discharge occurs. The discharge of treated wastewater into a river can be considered from two vantage points regarding its impact on ambient water quality. On a large scale, seen over the entire receiving water body, care must be taken that water quality conditions are achieved that protect designated beneficial uses. In the immediate discharge vicinity, additional precautions may be required to ensure that high initial pollutant concentrations are minimized and constrained to small zones, areas or volumes.

Hydrodynamic variability renders the arbitrary selection of some numerical dimension(s) to define a mixing zone impractical, it is more practical to use a numerical model to predict plume distance, width or region in which the applicable standard will be met.

The discharge concentration of the material of interest is defined as the excess concentration above any ambient background concentration of that same material. In this project the material of interest is not specified, and it is quantified by percentage of outfall concentration. It was assumed that at the outfall point some pollutants would be discharged into the river body at a concentration of 100 arbitrary units. Thus results can be interpreted as the percent of the initial concentration of a conservative solute.

3 Mixing Processes

In general, every shore located effluent source interacts with the river in several ways before the two become fully mixed. Therefore, the following mixing processes shall be considered:

1. Jet effects due to the momentum of the discharge.
2. Lateral displacement of river flow by the effluent input. Conservation of mass requires that the streamlines in the river be displaced towards the center to make room for the additional effluent flow rate added to the river.
3. Downstream advection by the river flow.
4. Transverse turbulent mixing and secondary flow in the river.
5. Buoyant spreading caused by the density difference between WWTP effluent and river water. The density depends on water temperature and total solids content.
6. Vertical turbulent mixing by the river due to bed shear.
7. Mixing by towboats and barge traffic.

Effluent models are usually subdivided into a **nearfield** and a **farfield.** In the nearfield, the mixing and dilution are influenced by effluent conditions, including jet effects, floating or plunging plumes, and lateral displacement of the river. In the farfield, the mixing is passive and imposed by the river geometry, roughness, advection and turbulence. Mixing by towboats and barges affects both nearfield and farfield mixing.

Previous studies related to Metro Waste Water Treatment Plants' outlets into the Mississippi River showed that effluent mixing zones exhibited strong seasonable variability. For much of the year the effluent is warmer than the river, resulting in a lower density, positively buoyant plume. During the summer, the situation reverses as the river warms up and the effluent enters the Mississippi River as an underflow. In both cases, the river develops a vertically stratified flow, which becomes fully mixed by discharge momentum flux, turbulence induced by bed shear, secondary currents, and towboat traffic. For low flow rates (less than 5000 cfs) towboat and barge passages were found to be the most significant source of the vertical mixing in previous studies.

The outfall mixing zone analysis is based on the low flow ambient condition given by the 7Q10 discharge. This condition is typically used for water quality studies on riverine sites but provides an infrequent critical condition. The 7Q10 discharge is the lowest mean discharge that can be expected to occur over a 7-day stretch in a 10-year period.

4 Cornell Mixing Zone Expert System (CORMIX)

4.1 Introduction

The Cornell Mixing Zone System (CORMIX) was selected for use in this study. CORMIX is a software system for the analysis and design of aqueous pollutant discharges into diverse water bodies. The major application of the program is in defining the geometry and dilution characteristics of the initial mixing zone, including compliance with regulatory constraints. However, CORMIX can also be used for prediction of the behavior of the discharge plume at larger distances.

The system consists of three integrated subsystems:

- CORMIX1 for the analysis of submerged single port discharges
- CORMIX2 for the analysis of submerged multiport diffuser discharges
- CORMIX3 for the analysis of buoyant surface discharges

Although basic CORMIX methodology relies on the assumption of steady ambient conditions, it offers routines for the application to highly unsteady environments, such as tidal reversal flow.

It also includes two post-processor models

- CORJET as a nearfield jet integral model and
- FFLOCART as a farfield plume locator in non-uniform channels

Today, CORMIX is the USEPA's officially recommended computerized methodology for predicting both the qualitative features (through flow classification) and quantitative aspects (e.g. dilution ratio, plume trajectory) of the mixing processes resulting from different discharge configurations and in all types of ambient water bodies - small rivers, large lakes, reservoirs, estuaries and coastal waters.

4.2 System Structure and Executive Procedure

CORMIX is composed of five basic program elements - DATIN, PARAM, CLASS, HYDRO and SUM.

DATIN is organized as a kind of query for collecting data about site/case under consideration, ambient conditions, discharge characteristics and regulatory mixing zone definitions.

PARAM is the program element that computes relevant physical parameters (length scales, fluxes) needed for the flow classification.

CLASS is the robust expert knowledge base, which carefully distinguishes among the many hydrodynamic flow patterns that a discharge may exhibit (e.g. discharge plumes attaching to the bottom, plumes vertically mixing due to instabilities in shallow water, plumes becoming trapped due to density stratification, plumes intruding upstream against the ambient current due to buoyancy).

Once the flow has been classified, CORMIX executes simulation modules in program element HYDRO, that gives the trajectory and dilution characteristics of considered flow.

SUM is the final program element that summarizes the hydrodynamic simulation results. CORMIX system provides three types of summary output files: Session Report, Cormix1, 2 or 3 Prediction File and CMXGRAPH plots.

The Session Report is a narrative summary, arranged in four groups:

- Site Summary gives the site information, discharge and ambient environment data and discharge length scales.
- Hydrodynamic Simulation and Mixing Zone Summary lists conditions at the end of the near-field region, regulatory mixing zone conditions, toxic dilution zone conditions, upstream intrusion information and bank

attachment location.

- Data Analysis Section presents further details on toxic dilution zone criteria, regulatory mixing zone criteria, stagnant ambient environment information and region of interest criteria.
- Design Recommendations Section, as most useful, contains design suggestions, including:
  a) geometry variations in discharge port design b) sensitivity to ambient conditions, and c) process variations in discharge flow characteristics.

To obtain a design that meets water quality and engineering construction objectives, CORMIX offers the possibility for returning to DATIN to alter design variables and repeat all procedures.

The Cormix1, 2 or 3 Prediction File is a detailed listing of all simulation input data as well as the predicted plume properties - plume shape and concentration distribution.

CMXGRAPH is a graphics package for the display and plotting of CORMIX and CORJET predicted effluent plumes, which can be accessed within or outside CORMIX.

4.3 CORMIX Data Input

Each CORMIX data input occurs interactively in response to system prompts and is entirely guided by the system.

All input data are divided into four groups:

1) Site/case description
2) Ambient conditions
3) Discharge characteristics
4) Regulatory definitions

Site/case data contain basic information needed for identification, such as site name and name of design case.

Ambient data are defined by geometric and hydrographic conditions in the vicinity of the discharge. To completely specify ambient conditions, the following have to be provided:

- plan view and a few cross sections at and close to the discharge location
- the ambient mean discharge Q, especially for summer low-flow condition
- roughness characteristic of the channel (as n or f)
- density specification - if the water body is non-uniform temperature data as a function of water depth are desired
- wind speed, if the receiving body is in the windy area

Specification of discharge conditions is based on the following necessary data:

- layout of the discharge - plan view and discharge cross section

- type and characteristics of the discharge (that also define the subsystem - CORMIX1, 2 or 3 which should be apply)
- discharge flow rate or velocity
- effluent temperature or density
- discharge concentration of the material of interest (pollutant, tracer or temperature)
- the type of material of interest (conservative or non-conservative)

In the input section, dealing with regulatory definitions, the user has to indicate:

- whether EPA's toxic dilution zone definitions apply (in which case the criterion maximum concentration - CMC and the criterion continuous concentration - CCC should be given)
- whether an ambient water quality standard exists
- whether a regulatory mixing zone - RMZ definition exists
- the spatial region of interest - ROI over which information is desired
- number of grid intervals within ROI, which will be displayed in the output files

4.4 Post-processor Options

Post-processor models - CORJET and FFLOCATR are developed to provide additional enhancements to CORMIX in terms of plume display and more detailed computation of nearfield and farfield plume features.

5 Cormix data input

5.1 *Hydrology of the Mississippi River*

Mississippi River flows vary seasonally and from year to year. In this project, the 7-day low flow with 10-year return period were used in the mixing zone analysis in order to cover extreme flow conditions. To derive a 7Q10 low flow, the lowest average flow in a seven consecutive day period is identified from daily discharge records at a continuous record gauging station for each year of record. The flow calculations completed by MPCA staff are listed in Table 5.1. The period of record for these calculations is 1936-1996.

Table 5.1. 7-day low flow with 10-year return period.

Season	7Q10 (cfs)	Cases for Analysis and Ambient Water Temperature	Discharge Temperature
Apr-Mar	1966	"Summer" Lowest flow based on whole year flow record, summer water temperature: 24°C.	18°C
Jun-Sep	2212	Not analyzed	
Oct-Nov	2602	Not analyzed	
Dec-Mar	2393	"Winter" with lowest water temperature: 6°C.	13°C
Apr-May	5685	Not analyzed	

The low flow estimates are based on the USGS gage #05331000 Mississippi River at St. Paul plus the design discharge from the MCES: Metro wastewater treatment facility (251 mgd). A 1978 agreement with Met Council, the Corps of Engineers, U.S. Geological Survey (USGS), and MPCA concluded that the appropriate period of record for assessing low stream flow records is 1936 to the present. This period of record reflects the consistent operation and presence of flow controlling structures on the river. Development of the input data is described in the following sections.

The climatic year (April 1 – March 31) is used for analysis because it does not usually separate the low flow seasons, as does the calendar year or water year. In order to assess critical conditions during warm weather, the annual low flow is analyzed in conjunction with the **summer** water temperatures. These low flow data are arrayed in order of magnitude and fit to a probability distribution. The probability distribution estimates the low flows that might recur, on the average, as an annual minimum. To understand the impact of buoyancy, the **winter** season 7Q10 from November to March is also used for study.

The discharge ratio through various channels in the Spring Lake area of the Mississippi River was estimated as 57% based on field measurements at the sites of MU 825.3 and SP823.2 (Figure 5.1 and Table 5.2). The resultant 7Q10 low flow is 1,120 cfs and 1,370 cfs for the annual from April to March and winter seasons from November to March, respectively.

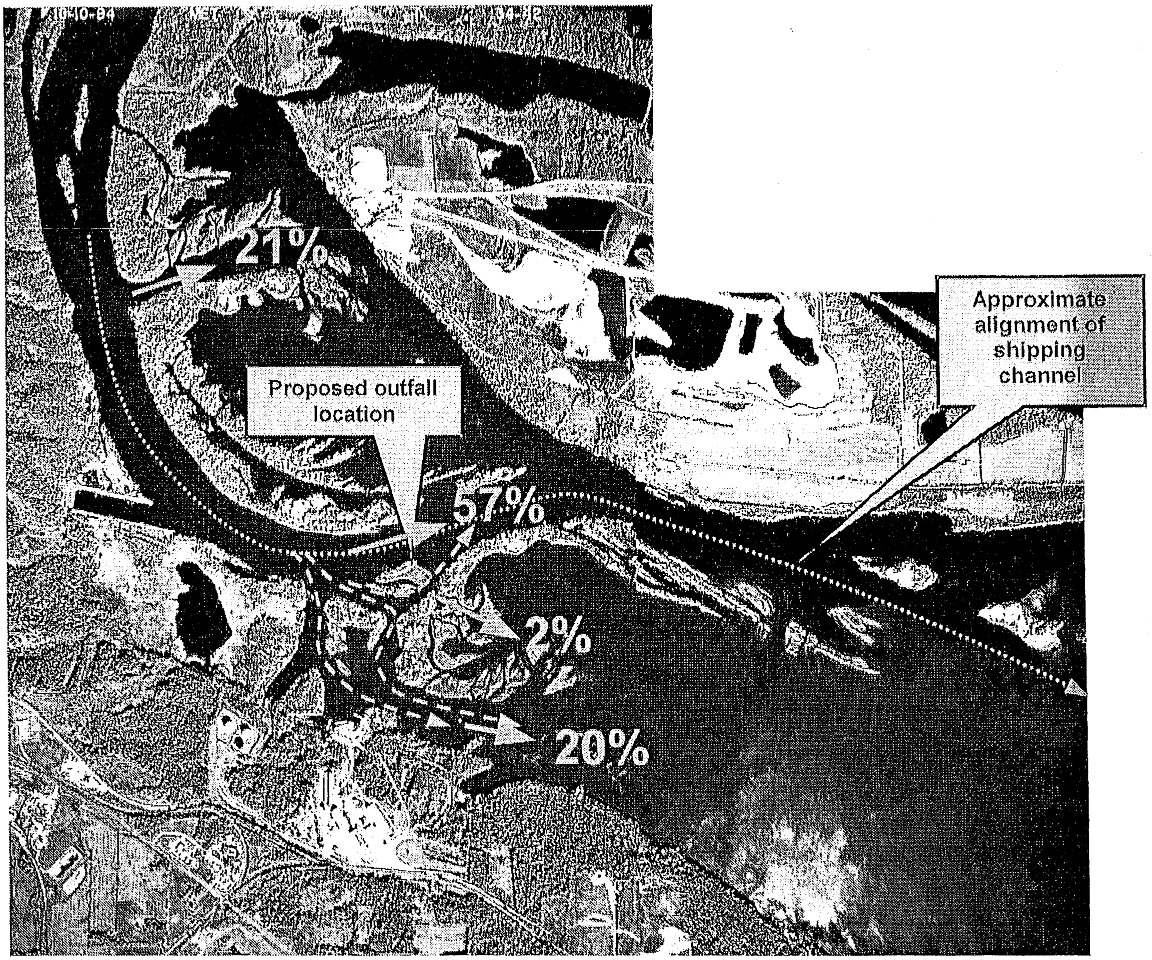


Fig. 5.1 Spring Lake aerial photo with proposed outfall location and flow pathways. Approximate flow proportions are based on nine sets of flow measurements taken in 1991, 1995 and 1996 with river discharge ranging from 10,000 to 30,000 cfs.

5.2 Mississippi River Elevation and Geometry

Water levels are required to define the depth of flow and velocity for a given discharge, which are controlled not only by river discharge but also by the water level control facilities at Lock and Dam No. 2. In this project, the water level of 687.2 ft for Pool 2 WS EL was used according to the Corps of Engineers' operation curve.

The river geometry is taken from a 1996 St. Paul Flood Control Project – Pool 2 HEC-2 model, conducted by the U.S. Army Corps of Engineers. Also a map covering river miles 817 to 825 from a 1972 floodplain mapping study (Minnesota Department of Natural Resources).

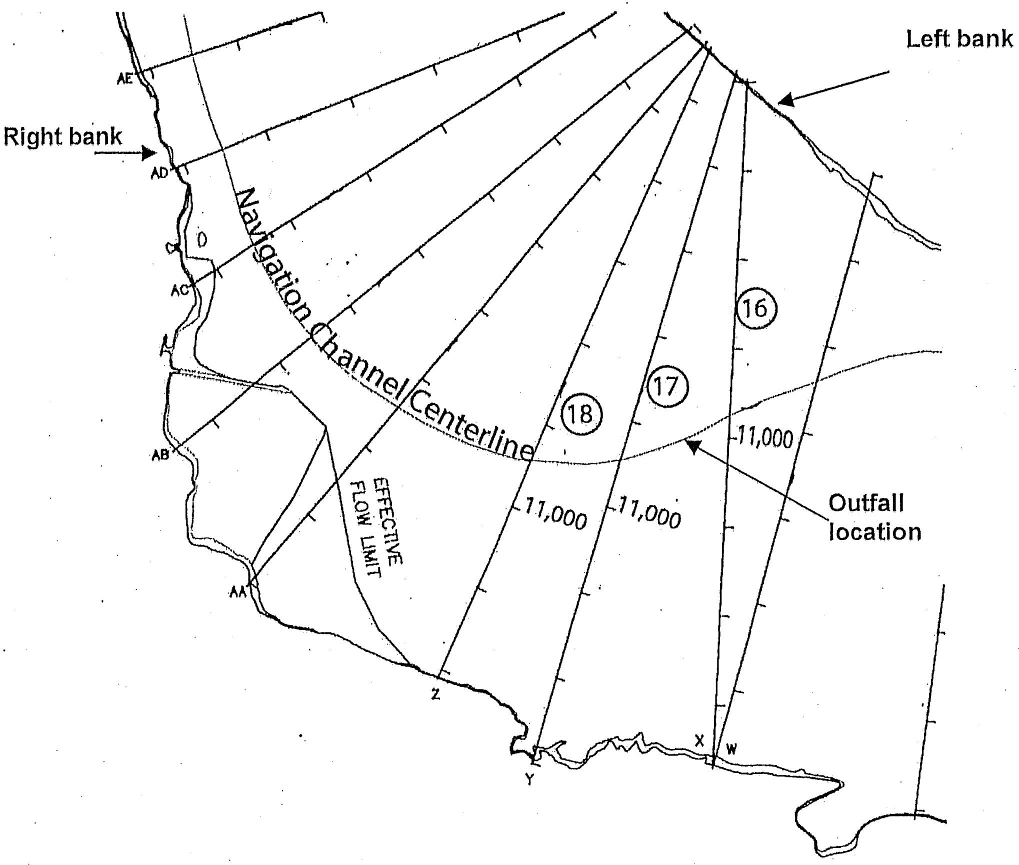


Fig. 5.2 Proposed outfall location on the navigation channel side of the island between cross sections 16 and 17.

The area of the proposed Empire Wastewater Treatment Plant outfall is located between cross sections 16 and 17 (Miles from 823 to 824). Cross Sections 16 and 17 (Fig 5.3 and 5.5) was taken from Pool 2 HEC-2 model. The main navigation channels were adjusted to a rectangular channel as required by the CORMIX model (Fig 5.4). The schematization was characterized in terms of water surface width (BS) and average depth (HA) based on the equivalent rectangular cross sectional area. The average vales based on cross sections 16 and 17 are: Base Width (BS) = 270 m; and Average Depth (HA) = 5.24 m. The roughness of the interested main channel is described by Manning's n from the Hec-2 model as: n = 0.035.

Table 5.2. Flow ratios in the Spring Lake area

MCES Data, 1995, 1996

Date	Total flow rate (upstream in channel) (cfs)	Flow to Baldwin Lake (cfs)	Fraction to Baldwin	Flow to Spring Lake (cfs)	Fraction to Spring Lake	Navigation channel (cfs)	Fraction in Navigation Channel (%)
14-Apr-95	25,293	5,655	22%	5,134	20%	14,504	57%
31-May-96	29,768	7,101	24%	6,272	21%	16,395	55%
14-Jun-96	23,859	5,822	24%	4,805	20%	13,232	55%
28-Jun-96	31,735	8,067	25%	6,780	21%	16,888	53%
17-Jul-96	12,732	2,844	22%	2,126	17%	7,762	61%
6-Aug-96	9,654	1,988	21%	1,767	18%	5,899	61%
Average:			23%		20%		57%

Corps of Engineers Data

Date	Total flow rate (L&D No. 2) (cfs)	Flow to Baldwin Lake (cfs)	Fraction to Baldwin	Main Channel to Spring Lake (cfs)	Fraction to Spring Lake	Smaller Channel to Spring Lake (cfs)	Fraction to Spring Lake	Navigation channel (cfs)	Fraction in Navigation Channel (%)
Site No.		5		1		2			
23-May-91	30,180			5,961	20%	613	2%		
20-Aug-91	14,450	3,235	22%	2,867	20%	125	1%	8,223	57%
7-Oct-91	10,300			2,283	22%	190	2%		
Average			22%		21%		2%		57%
Approximation including smaller channel to Spring Lake			21%		20%		2%		57%

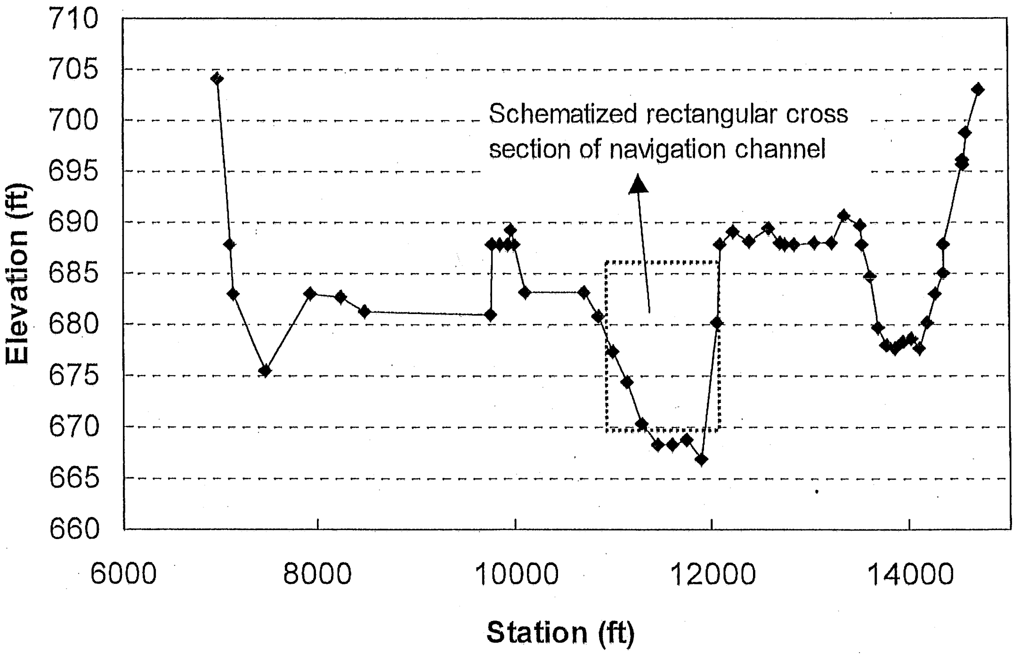


Fig 5.3. The geometry of Cross Section 16 (looking down steam) and schematized rectangular cross section. Outfall enters channel from the right.

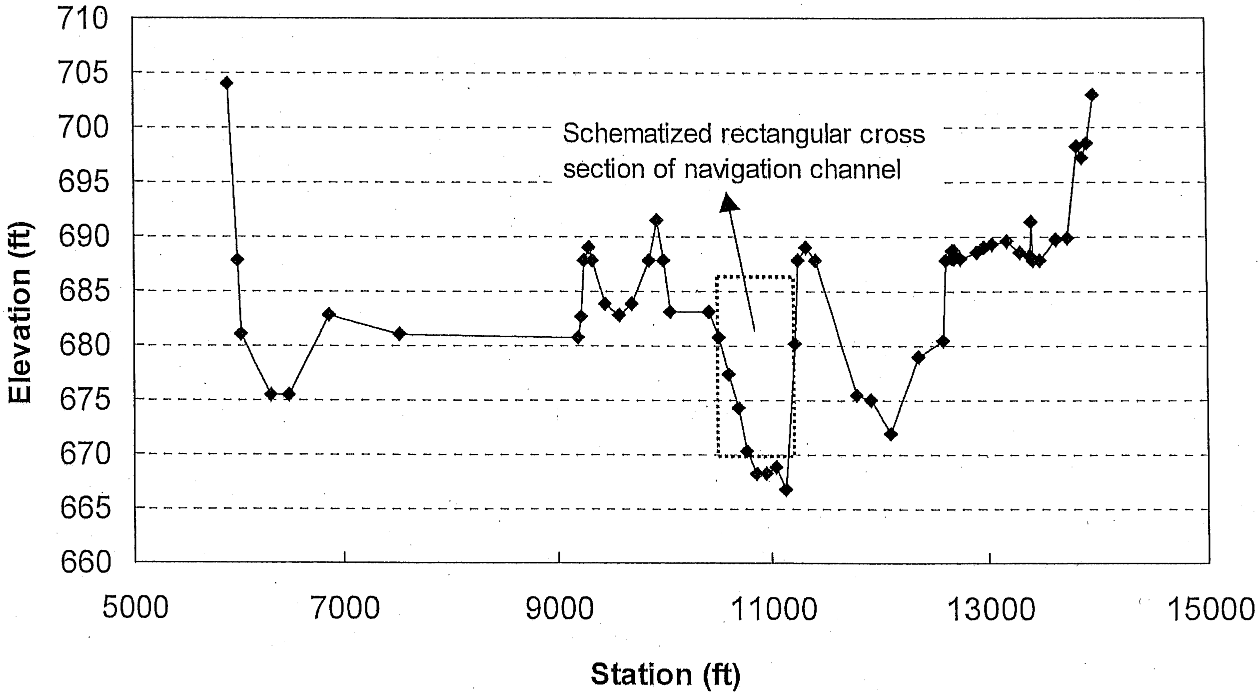
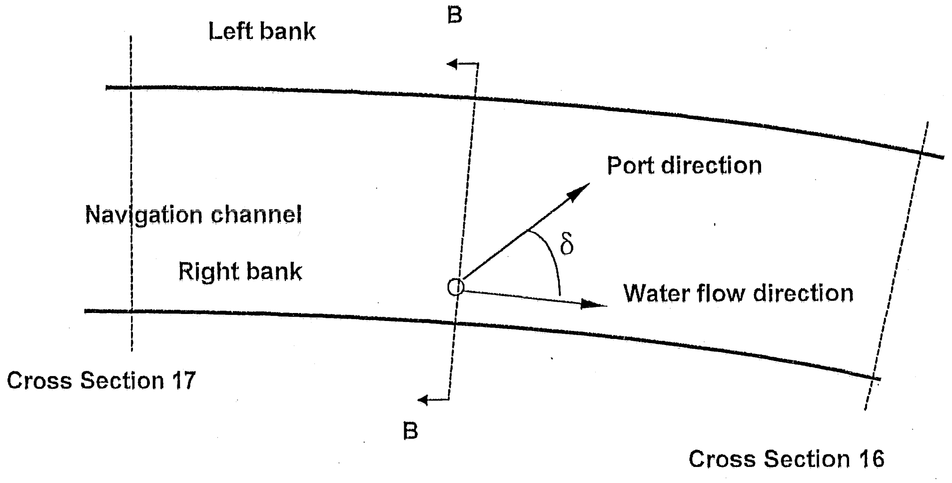
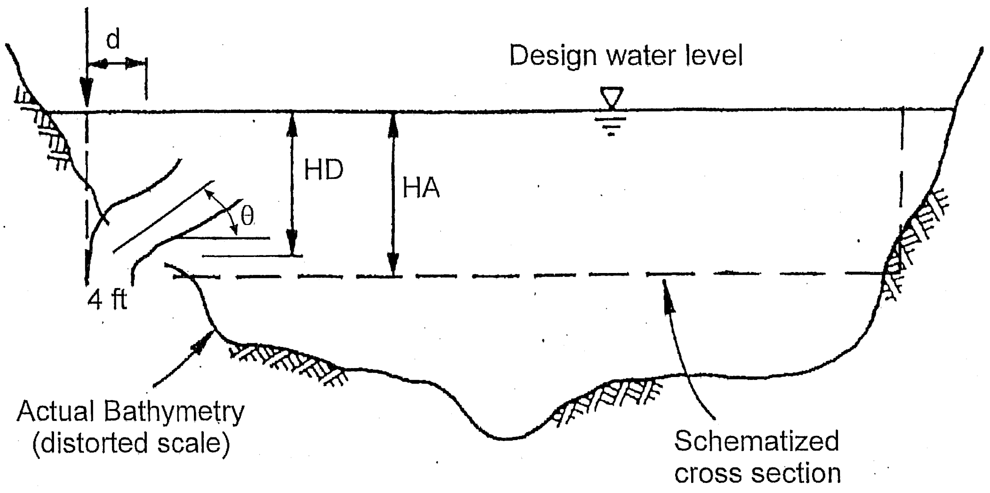


Fig 5.4. The geometry of Cross Section 17 (looking down steam) and schematized rectangular cross section.



A. Plan view (Outfall is near right bank in this study)



B. Cross Section (Looking upstream)

Fig. 5.5. Schematized cross section and plain view showing parameters required as CORMIX input data on ambient cross-section conditions (d = nearest bank distance, HD = discharge depth, HA = schematized cross section depth, δ = horizontal angle, θ = Vertical angle)

Three characteristics are used to describe river channel appearance in CORMIX:

1) fairly straight,
2) moderate downstream meander with a non-uniform channel, or
3) strongly winding and highly irregular downstream cross-section

The moderate downstream meander with a non-uniform channel was selected in the study.

5.3 Ambient and effluent water temperature

Mississippi River water temperature monitored at station 05331580 located at Hasting is available for 1990 and 1996 (Table 5.3). In the study, a temperature of 24°C in 1996 was used for April - March and 6 °C for average winter from November to March.

Table 5.3. Mississippi River mean monthly water temperature (°C)

Year	May	June	July	August	September
1990	12.3	17	21.2	19.1	16.1
1996	15	20	24	24.5	21.5

The effluent temperature was provided by the Metropolitan Council as shown in Fig. 5.6. 18°C was used for summer and 13 °C for winter in the study. Due to the lower temperature of the effluent than the ambient water, the effluent is negatively buoyant and will tend to sink toward the bottom in the summer. In the winter, the water will be warmer and lighter and tend to float over the ambient water.

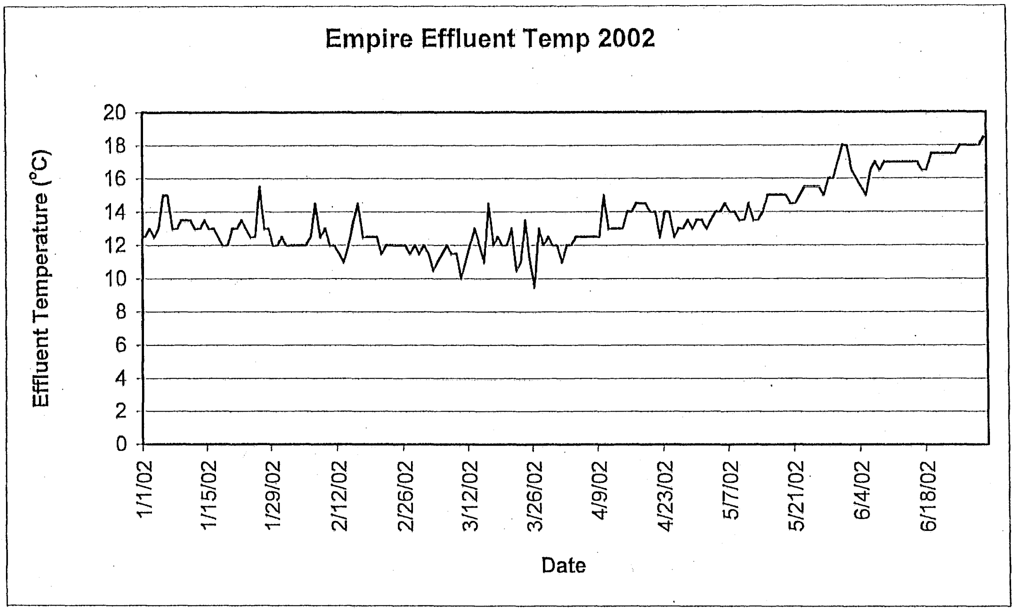


Fig. 5.6. Effluent temperatures of the Empire Wastewater Treatment Plant, January – June, 2002.

5.4 Effluent flow and water quality

The discharges of the Empire Wastewater Treatment Plant to be analyzed are listed in Table 5.4. Effluent concentration was taken as 100 (arbitrary unit), where ambient concentration is zero.

Table 5.4 Discharges of Empire Wastewater Treatment Plant used in mixing zone analysis:

Cases	Discharges (mgd)
25% of capacity	6
50% of capacity	12
Daily designed average	24
Peak discharge	60
150% of peak discharge	90

5.5 *Discharge port diameter*

Discharge port diameter affects near-field mixing remarkably. Typically, a high velocity discharge will have a high discharge momentum flux and maximize near-field mixing. However, a high velocity discharge may lead to unstable near-field flow configurations perhaps involving undesirable mixing patterns. Discharge velocities in typical engineering design may range from 3 m/s to 8 m/s. Very high velocities may lead to excessive pumping energy requirements. Very low velocities (less than 0.5 m/s) may lead to undesirable sediment accumulation within the discharge pipe. For actual conditions, however, many other factors are considered, such as engineering requirements, navigation impact, etc. Port diameters of 66 and 54 inches were analyzed initially to determine the best discharge angles. Subsequent analyses included diameters of 48, 42, and 36 inches.

5.6 *Discharge depth and near bank distance*

CORMIX 1 assumes that:

1) A deep submerged discharge should have an ambient depth of at least three times discharge port diameter. This will result in a discharge depth larger than 5 m if the discharge port diameter of 1.68 m (66 inch) is used.

2) The discharge depth should not differ from the schematized average depth by +-30%. This will result in a discharge depth from 3.7 to 6.8 m with the schematized average depth of 5.24 m.

3) The maximum water depth is 6 m according to the Corps of Engineers' operating curve for pool 2 WS EL =687.2 ft and cross sections 16 and 17.

In sum, the discharge depth should be within 3.7 to 6 m. The maximum discharge depth of 5 m, which meets above conditions, is used in the analysis. The estimated near bank distance at the water depth of 5 m is 16 m based on Cross sections 16 and 17.

6 Simulation results and recommendations for outfall design

6.1 Outlet design evaluations

The evaluation of outlet diameter, depth and orientation (vertical and horizontal angle) is reported here in terms of buoyancy, contact of the plume with the banks, upstream intrusion, and decrease in concentration with distance downstream. There are three main objectives here:

- Provide basis for engineering design,
- Avoidance of inflow to Spring Lake, and
- Rapid mixing to achieve lowest possible pollutant concentrations (though discharge is to meet water quality standards at the end of the pipe).

In order to avoid inflow to Spring Lake, the discharge must avoid situations where a portion of the flow could be entrained into the channels leading to Spring Lake. Treated wastewater inflows to Spring Lake would be avoided by keeping the plume moving downstream and by directing it into the center of the navigation channel. Ideally, that would mean that the plume would not experience any upstream intrusion, and would not reach the right bank until it is past the next downstream channel to Spring Lake.

In the case of upstream intrusion, the outfall location should be selected such that the intrusion should not reach to the next upstream channel. At the next downstream channel, flow is generally out of the channel and not towards Spring Lake; even with bank contact there should be no flow into Spring Lake.

The designer for the outfall also were interested in low jet velocity to avoid interferences with navigation. The owner's preference was for a single port minimize engineering and maintenance costs of the outfall.

6.2 Design Case I – Port diameter: 66"

6.2.1 66" Discharge flow – 6 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

According to the simulation criteria defined in Section 6.1, the preferable design angles for this case are horizontal angle δ = 0° to 90°, vertical angle θ = 0° to 45° (Table 6.1), providing good mixing conditions. There are no bank contacts both sides. When the vertical angle is larger than 45°, an upstream intrusion of the plume (about 5.9 m) occurs. The effluent concentrations are 24.3 % and 22.5 % of initial values at 5 and 50 m downstream respectively for two boundary angles. Due to lower temperature (18°C) of effluent than ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

Both horizontal and vertical angles are dependent variables. At the boundary angle conditions of δ = 90°, θ = 0° and δ = 0° and θ = 90°, there is an upstream intrusion of the plume of about 22 – 24 m and bank contacts are at about 17/18 m and 544/553 m from outfall respectively for right and left banks. However, the mixing will be fast for the angles of δ = 45° and θ = 45°. Due to the higher temperature (13 °C) of the effluent relative to the ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.2.2 66" Discharge flow – 12 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle δ = 0° to 90°, vertical angle θ = 0° to 45° (Table 6.1), providing good mixing conditions. There are no bank contacts both sides. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 22.0 % and 21.7 % at 10 and 50 m downstream respectively for two boundary angles. Due to lower temperature (18°C) of effluent than ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

Both horizontal and vertical angles are dependent variables. At the boundary angle conditions of δ = 90°, θ = 0° and δ = 0° and θ = 90°, there is an upstream intrusion of the plume about 23/24 m and bank contacts will be at about 32/30 m and 365/392 m respectively for right and left banks. However, the mixing will be fast for angles of δ = 45° and θ = 45°. Due to the higher temperature (13 °C) of effluent relative to the ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.2.3 66" Discharge flow – 24 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle δ = 0° to 90°, vertical angle θ = 0° to 45° (Table 6.1), providing good mixing conditions. At these boundary angle conditions of δ = 90°, θ = 0° and δ = 0° and θ = 45°, bank contacts will be at about

102/163 m and 451/538 m respectively for right and left banks. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 9.3 % and 7.1 % at 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The preferable design angles for this case are horizontal angle $\delta = 45^o$ to 90^o, vertical angle $\theta = 12^o$ to 83^o (Table 6.1), providing good mixing conditions. At the boundary angle conditions of Both horizontal and vertical angles are dependent variables. At the boundary angle conditions of $\delta = 90^o$, $\theta = 12^o$ and $\delta = 45^o$ and $\theta = 83^o$, bank contacts will be at about 140/222 m and 145/242 m respectively for right and left banks. When $\delta < 45^o$, there is a bank contact, and when $12^o > \theta > 83^o$, there is an intrusion of the plume occurs. The effluent concentrations are 8.8 % and 9.3 % at 500 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to the ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.2.4 66" Discharge flow – 60 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle $\delta = 0^o$ to 44^o, vertical angle $\theta = 0^o$ to 45^o (Table 6.1), providing good mixing conditions. At the boundary angle condition of $\delta = 44^o$, $\theta = 0^o$, there will be no right bank contact and left contact will be at about 350 m. At the boundary angle condition of $\delta = 0^o$, $\theta = 45^o$, however there will be no left bank contact and right contact will be at about 220 m. When horizontal angle is larger than 44°, there is an immediately left bank contact and model does not predict properly.

When vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 6.1 % and 5.3 % at 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The preferable design angles for this case are horizontal angle $\delta = 0^o$ to 56^o, vertical angle $\theta = 0^o$ to 45^o (Table 6.1), providing good mixing conditions. At the boundary angle condition of $\delta = 56^o$, $\theta = 0^o$, there will be no right bank contact and left contact will be at about 301 m. At the boundary angle condition of $\delta = 0^o$, $\theta = 45^o$, however there will be no left bank contact and right contact will be at about 178 m. When horizontal angle is larger than 56°, there is an immediately left bank contact and model does not predict properly. When vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 7.9 % and 5.3 % at 500 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.2.5 66" Discharge flow – 90 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle $\delta = 0^o$ to 29^o, vertical angle $\theta = 0^o$- 45^o (Table 6.1), providing good mixing conditions. At the boundary angle condition of $\delta = 29^o$, $\theta = 0^o$, there will be no right bank contact and left contact will be at about 620 m. At the boundary angle condition of $\delta = 0^o$, $\theta = 45^o$, however there will be no left bank contact and right contact will be at about 375 m. When horizontal angle is larger than 29°, there is an immediately left bank contact and model does not predict properly.

When vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 5.7 % and 5.3 % at 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to the ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

<u>Winter 7Q10 flow from November to March – 1,370 cfs</u>

The preferable design angles for this case are horizontal angle $\delta = 0^\circ$ to 37°, vertical angle $\theta = 0^\circ$ to 45° (Table 6.1), providing good mixing conditions. At the boundary angle condition of $\delta = 37^\circ$, $\theta = 0^\circ$, there will be no right bank contact and left contact will be at about 450 m. At the boundary angle condition of $\delta = 0^\circ$, $\theta = 45^\circ$, however there will be no left bank contact and right contact will be at about 320 m. When horizontal angle is larger than 37°, there is an immediately left bank contact and model does not predict properly. When vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 5.9 % and 5.3 % at 500 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to the ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.3 Design Case II – Port diameter: 54”

6.3.1 54” Discharge flow – 6 mgd

<u>Annual 7Q10 flow – 1,120 cfs, Summer Temperature</u>

The preferable design angles for this case are horizontal angle $\delta = 0^\circ$ to 90°, vertical angle $\theta = 0^\circ$ to 45° (Table 6.2), providing good mixing conditions. There are no bank contacts both sides. When the vertical angle is larger than 45°, an upstream intrusion of the plume about 6 m occurs. The effluent concentrations are 20.2 % and 18.3 % of initial values at 10 and 50 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The preferable design angles for this case are horizontal angle $\delta = 25^\circ$ to 90°, vertical angle $\theta = 12^\circ$- 61° (Table 6.2), providing good mixing conditions. At the boundary angle condition of $\delta = 90^\circ$, $\theta = 12^\circ$, there will be bank contacts at 45 and 380.8 m respectively for right and left banks. At the boundary angle condition of $\delta = 25^\circ$, $\theta = 61^\circ$, however there will be no left contact both bonks. When the horizontal angle is smaller than 35°, there is an immediately right bank contact. When the vertical angle is larger than 61° and smaller than 12°, an upstream intrusion of the plume occurs. The effluent concentrations are 4.2 % and 26.3 % at 500 m and 5 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.3.2 54" Discharge flow – 12 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle $\delta = 0^\circ$ to 90°, vertical angle $\theta = 0^\circ$- 45° (Table 6.2), providing good mixing conditions. At the boundary angle condition of $\delta = 90^\circ$, $\theta = 0^\circ$, there will be no left contacts both bonks. At the boundary angle condition of $\delta = 45^\circ$, $\theta = 0^\circ$, however there will be bank contacts at 70.6 and 823 m respectively for right and left banks. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 15.3 % and 6.7 % at 10 and 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

Both horizontal and vertical angles are dependent variables (Table 6.2). At the boundary angle conditions of $\delta = 90^\circ$, $\theta = 0^\circ$ and $\delta = 0^\circ$ and $\theta = 90^\circ$, there is an upstream intrusion of the plume about 48/49 m and bank contacts will be at about 37/34 m and 348/388.5 m respectively for right and left banks. However, the mixing will be fast for the angles of $\delta = 45^\circ$ and $\theta = 45^\circ$. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.3.3 54" Discharge flow – 24 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle $\delta = 0^\circ$ to 90°, vertical angle $\theta = 0^\circ$- 45° (Table 6.2), providing good mixing conditions. At the boundary angle condition, bank contacts will be at about 185 / 242 m and 237 / 521 m respectively for right and left banks. The effluent concentrations are 7.2 % and 5.2 % at 500 m downstream respectively for two boundary angles. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

Both horizontal and vertical angles are dependent variables (Table 6.2). At the boundary angle conditions of $\delta = 90^o$, $\theta = 0^o$ and $\delta = 0^o$ and $\theta = 90^o$, there is an upstream intrusion of plume about 85 - 99 m and bank contacts will be at about 72 / 62 m and 197 / 250 m respectively for right and left banks. However, the mixing will be fast for the angles of $\delta = 45^o$ and $\theta = 45^o$. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.3.4 54" Discharge flow – 60 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle $\delta = 0^o$ to 37^o, vertical angle $\theta = 0^o$ to 45^o (Table 6.2), providing good mixing conditions. At the boundary angle condition of $\delta = 37^o$, $\theta = 0^o$, there will be no right bank contact and left contact will be at about 550 m. At the boundary angle condition of $\delta = 0^o$, $\theta = 45^o$, however there will be no left bank contact and right contact will be at about 170 m. When the horizontal angle is larger than 37°, there is an immediately left bank contact and model does not predict properly. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 4.8 % and 4.4 % at 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The preferable design angles for this case are horizontal angle $\delta = 0^o$ to 45^o, vertical angle $\theta = 0^o$ to 45^o (Table 6.2), providing good mixing conditions. At the boundary angle condition of δ = 45°, θ = 0°, there will be no right bank contact and left contact will be at about 370 m. At the boundary angle condition of δ = 0°, θ = 45°, however there will be no left bank contact and right contact will be at about 160 m. When the horizontal angle is larger than 45°, there is an immediately left bank contact and model does not predict properly. When the vertical angle is larger than 45°, an upstream intrusion of plume occurs. The effluent concentrations are 5.0 % and 4.4 % at 500 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.3.5 54" Discharge flow – 90 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The preferable design angles for this case are horizontal angle δ = 0° to 23°, vertical angle θ = 0° to 45° (Table 6.2), providing good mixing conditions. At the boundary angle condition of δ = 29°, θ = 0°, there will be no right bank contact and left contact will be at about 750 m. At the boundary angle condition of δ = 0°, θ = 45°, however there will be no left bank contact and right contact will be at about 160 m. When the horizontal angle is larger than 23°, there is an immediately left bank contact and model does not predict properly. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 5.6 % and 4.4 % at 500 m downstream respectively for two boundary angles. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The preferable design angles for this case are horizontal angle δ = 0° to 28°, vertical angle θ = 0° to 45° (Table 6.2), providing good mixing conditions. At the boundary angle condition of $\delta = 28^{\circ}$, $\theta = 0^{\circ}$, there will be no right bank contact and left contact will be at about 700 m. At the boundary angle condition of $\delta = 0^{\circ}$, $\theta = 45^{\circ}$, however there will be no left bank contact and right contact will be at about 160 m. When the horizontal angle is larger than 28°, there is an immediately left bank contact and model does not predict properly. When the vertical angle is larger than 45°, an upstream intrusion of the plume occurs. The effluent concentrations are 4.6 % and 4.4 % at 500 m downstream respectively for two boundary angles. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.4 Summary of preferable mixing conditions for 66- and 54-inch outfalls

There is not a preferable angle covering all design cases. Based on the simulation, the following angles are recommended to best meet the design objectives in Section 1.2:

Horizontal angle:	$0^{\circ} < \delta < 45^{\circ}$
Vertical angles:	$12^{\circ} < \theta < 45^{\circ}$
Water depth:	5 m
Nearest bank distance:	16 m

Table 6.3 demonstrates the mixing conditions for a combination of the preferable angles: $\delta = 23^{\circ}$ and $\theta = 15^{\circ}$. Detailed simulation results and plots for the design cases with port diameter 66" are not presented since the design has been changed to a 48-inch outfall diameter.

6.5 *Additional Simulations for 36-, 42-, and 48-inch Outfalls*

Based on the above study results, recommendations and other engineering factors, Metropolitan Council Environmental Services selected the outfall design angles as

Horizontal angle:	$\delta = 45$ degrees
Vertical angles:	$\theta = 0$ degrees

The outfall port diameters to be studied include 36", 42" and 48". Further studies were conducted to understand the mixing conditions of effluent discharge from the Empire Wastewater Treatment Plant to the Mississippi River.

6.6 *Selected design cases for 36"*

6.6.1 36" Discharge flow – 6 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 55.2 % and 31.3 % of initial values at 5 and 10 m downstream respectively. The distance at 10% dilution of the effluent will be 30 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 108 and 214 m respectively for right and left banks and an upstream intrusion of the plume up to 108 m.

The effluent concentrations are 60.0 % and 9.2 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 120 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.6.2 36" Discharge flow – 12 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 58.2 % and 14.4 % of initial values at 10 and 25 m downstream respectively. The distance at 10% dilution of the effluent will be 30 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 55 and 350 m respectively for right and left banks and an upstream intrusion of the plume up to 48 m. The effluent concentrations are 57.7 % and 9.9 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 350 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.6.3 36" Discharge flow – 24 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 60.0 % and 5.9 % of initial values at 5 and 200 m downstream respectively. The distance at 10% dilution of the effluent will be 40 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

<u>Winter 7Q10 flow from November to March – 1,370 cfs</u>

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 28 and 530 m respectively for right and left banks and an upstream intrusion of the plume up to 20 m. The effluent concentrations are 53.4 % and 6.8 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 300 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positively buoyant and will tend to float towards the water surface.

6.6.4 36" Discharge flow – 60 mgd

<u>Annual 7Q10 flow – 1,120 cfs, Summer Temperature</u>

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1650 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 61.5 % and 3.8 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 40 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1230 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 61.5 % and 3.4 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 35 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.6.5 36" Discharge flow – 90 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 3760 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 62.0 % and 3.7 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 40 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 36" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1220 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 61.4 % and 3.5 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 40 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.7 *Selected design cases for 42"*

6.7.1 42" Discharge flow – 6 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 58.5 % and 13.9 % of initial values at 5 and 10 m downstream respectively. The distance at 10% dilution of the effluent will be 32 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 30 and 530 m respectively for right and left banks and an upstream intrusion of the plume up to 23 m. The effluent concentrations are 63.9 % and 7.6 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 380 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.7.2 42" Discharge flow – 12 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 63.0 % and 15.9 % of initial values at 10 and 25 m downstream respectively. The distance at 10% dilution of the effluent will be 32 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 50 and 360 m respectively for right and left banks and an upstream intrusion of the plume up to 46 m. The effluent concentrations are 62.0 % and 11.9 % at 5 m and 500 m downstream respectively. The Cormix prediction of the distance at 10% dilution of the effluent is not reliable. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.7.3 42" Discharge flow – 24 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 65.0 % and 8.7 % of initial values at 5 and 100 m downstream respectively. The distance at 10% dilution of the effluent will be 62 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 102 and 216 m respectively for right and left banks and an upstream intrusion of the plume up to 107 m. The intrusion is caused by the buoyancy and weak ambient flow velocity. The effluent concentrations are 65.0 % and 11.6 % at 5 m and 500 m downstream respectively. The Cormix prediction of the distance at 10% dilution of the effluent is not reliable. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.7.4 42" Discharge flow – 60 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1210 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 67.0 % and 4.5 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 65 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1120 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 67.0 % and 4.0 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 60 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.7.5 42" Discharge flow – 90 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 2770 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 68.0 % and 4.4 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 60 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 42" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1230 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 68.0 % and 0 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 65 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.8 Selected design cases for 48"

6.8.1 48" Discharge flow – 6 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 61.7 % and 15.2 % of initial values at 5 and 25 m downstream respectively. The distance at 10% dilution of the effluent will be 32 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 28 and 536 m respectively for right and left banks and an upstream intrusion of the plume up to 26 m. The effluent concentrations are 75.3 % and 8.2 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 415 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.8.2 48" Discharge flow – 12 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 63.3 % and 17.3 % of initial values at 10 and 25 m downstream respectively. The distance at 10% dilution of the effluent will be 40 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 47 and 360 m respectively for right and left banks and an upstream intrusion of the plume up to 43 m. The effluent concentrations are 66.0 % and 13.7 % at 5 m and 500 m downstream respectively. The Cormix prediction of the distance at 10% dilution of the effluent is not reliable. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.8.3 48" Discharge flow – 24 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there are no bank contacts both sides and no upstream intrusion. The effluent concentrations are 70.5 % and 9.9 % of initial values at 5 and 100 m downstream respectively. The distance at 10% dilution of the effluent will be 97 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 97 and 218 m respectively for right and left banks and an upstream intrusion of the plume up to 107 m. The effluent concentrations are 69.9 % and 13.8 % at 5 m and 500 m downstream respectively. The Cormix prediction of the distance at 10% dilution of the effluent is not reliable. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.8.4 48" Discharge flow – 60 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 930 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 72.0 % and 5.2 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 98 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will no bank contacts in the bounded section for right and left banks and no upstream intrusion. The effluent concentrations are 72.3 % and 4.5 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 82 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.8.5 48" Discharge flow – 90 mgd

Annual 7Q10 flow – 1,120 cfs, Summer Temperature

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 2770 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 68.0 % and 4.4 % of initial values at 5 and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 60 m. Due to the lower temperature (18°C) of the effluent relative to ambient water (24°C), the buoyancy is negative. There will be contact between the plume and the benthic layer.

Winter 7Q10 flow from November to March – 1,370 cfs

The simulation results using CORMIX for Port diameter of 48" at horizontal angle of 45° and vertical angle of 0° indicated that there will be bank contacts at 1230 m respectively for right and left banks and no upstream intrusion. The effluent concentrations are 68.0 % and 0 % at 5 m and 500 m downstream respectively. The distance at 10% dilution of the effluent will be 65 m. Due to the higher temperature (13 °C) of the effluent relative to ambient water (6 °C), the effluent is positive buoyant and will tend to float towards the water surface.

6.9 Summary of mixing conditions for 36-, 42- and 48-inch outfalls

The Cormix simulations for the three smaller diameters do not indicate important differences amongst the three diameters. Probably the most important difference may be in the exit velocity and its effect on boats. For the peak discharge condition, 60 mgd, discharge velocity is 4.0 m/s for the 36-inch outfall while it is 2.3 m/s for the 48-inch outfall.

Upstream intrusion of the plume, as would happen in winter conditions, is predicted to be practically the same for all three diameters. In fact, due to the buoyant plume conditions, and relatively low velocities for flows up to 24 mgd, the intrusion is determined by the river and wastewater flow rates, and is less dependent on diameter and orientation of the outfall.

Due to the low ambient velocities in the channel for the 7Q10 conditions, and the low velocity in the plume, there is relatively little turbulence to induce mixing. To achieve rapid mixing, a substantially higher jet velocity would be required.

7. Other Factors Affecting Vertical Mixing

Mixing by large tows is significant in the Mississippi River. A Mississippi River barge is typically 35 ft wide and 195 ft long. Unloaded, its draft may be only 1.5 to 2 ft, but when full, the draft is usually about 8 to 9 ft. Barge tows consist of 1 to 15 individual units and travel at speeds of up to 4 mph. A loaded 15 barge convoy displaces a water volume of 870,000 ft^3. At a river cross section of about 9000 ft^2, this corresponds to a longitudinal water displacement of 97 ft. The power output of a single tugboat is approximately 100 times the power loss of the river per mile at low flow.

Under low river flow conditions the lateral displacement of the water by a barge tow and the return flow after the passage will undoubtedly produce strong shear flows associated with almost immediate mixing. In this project, the contribution of barges and tugboats on mixing processes was not further explored

Table 6.1. Design case I (Port diameter: 66")

Discharge flow (mgd)		6				12				24			
Discharge Velocity (m/s)		0.12				0.24				0.47			
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Angle (Min/Max)	Vertical (θ)	0°	45°	0°	90°	0°	45°	0°	90°	0°	45°	12°	83°
	Horizontal (δ)	90°	0°	90°	0°	90°	0°	90°	0°	90°	0°	90°	45°
Bank contact	Right (m)	No	No	17	18	No	No	32	29.9	102	163	140	222
	Left (m)	No	No	544	553	No	No	365	391.5	451	538	145	242
Discharge depth (m)		5		5		5		5		5		5	
Near bank distance (m)		16		16		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive		Negative		Positive	
Near field region (NFR) (m)		21	86	17	18	17	60	32	30	42	163	113	221
Central line Conc. (%)	C_{NFR}	13	11	36	38	12	14	36	53	13	9	8	13
	5 m	38	98	50	54	34	99	65	90	27	100	20	27
	10 m	24	72	41	42	22	72	53	78	18	73	15	18
	25 m		39	35	36		39	38	56	15	39	11	15
	50 m		23	32	34		22	35	50	12	17	9	12
	100 m			28	29			32	45	11	12	9	11
	200 m			22	23			28	37	10	9	9	10
	300 m			17	17			23	30	10	8	9	10
	500 m			10	10			20	25	9	7	9	9
Note		Intrusion 6 m and bank contact when $\theta > 45^\circ$		Intrusion 22-24 at above boundary angles. Good at $\theta = 45^\circ$, $\delta = 45^\circ$		Intrusion occurs when $\theta > 45^\circ$		Intrusion 23-24 m at above boundary angles. Good at $\theta = 45^\circ$, $\delta = 45^\circ$		When $12^\circ > \theta > 83^\circ$, intrusion. When $\delta < 45^\circ$, bank contact			

Continued Table 6.1.

Discharge flow (mgd)		60				90			
Discharge Velocity (m/s)		1.19				1.78			
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Angle (Min/Max)	Vertical (θ)	0°	45°	0°	45°	0°	45°	0°	45°
	Horizontal (δ)	44°	0°	56°	0°	29°	0°	37°	0°
Bank contact	Right (m)	No	220	No	178	No	375	No	320
	Left (m)	350	No	301	No	620	No	450	No
Discharge depth (m)		5		5		5		5	
Near bank distance (m)		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive	
NFR distance (m)		679	982	302	648	1227	1227	1170	1227
Central line Conc.(%)	C_{NFR}	5	4	8	5	4	3	4	3
	5 m	86	99	75	100	95	100	90	100
	10 m	56	73	48	73	65	72	62	72
	25 m	28	39	19	39	34	38	31	37
	50 m	16	18	15	18	17	18	17	18
	100 m	13	12	12	12	12	13	12	12
	200 m	9	9	9	9	9	12	9	9
	300 m	8	7	8	7	7	7	8	7
	500 m	6	5	8	5	6	5	6	5
Note		1. There are intrusions and bank contacts beyond scope (δ: bank contact, θ: intrusion) 2. When δ > the given range, the model did not predict plume properly.							

Table 6.2. Design case II (Port diameter: 54")

Discharge flow (mgd)		6				12				24			
Discharge Velocity (m/s)		0.18				0.36				0.71			
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Angle (Min/Max)	Vertical (θ)	0°	45°	12°	61°	0°	45°	0°	90°	0°	45°	0°	90°
	Horizontal (δ)	90°	0°	90°	25°	90°	0°	90°	0°	90°	0°	90°	0°
Bank contact	Right (m)	No	No	45	No	No	70.6	36.7	33.8	184.5	242.3	71.6	62.2
	Left (m)	No	No	380.8	No	No	823	348	388.5	236.5	520.8	196.7	250
Discharge depth (m)		5		5		5		5		5		5	
Near bank distance (m)		16		16		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive		Negative		Positive	
NFR distance (m)		18.2	75.8	6.7	7.4	10.8	70.6	36.7	33.8	68.6	242.3	71.6	62.2
Central line Conc. (%)	C_{NFR}	11.4	9.6	44.6	18.5	14.8	10.9	28.3	54.6	8.6	6.1	21.4	57.9
	5 m	32	92	14.2	26.2	26.9	92	52	90	17.8	93.6	41.7	98
	10 m	20.2	64.2	10.2		15.3	63.4	42	81	14.4	64.7	35	90
	25 m		33	6.8			32.9	29.7	57.1	11.6	33	32	70
	50 m		18.3	6.6			18	27.6	52.2	9.4	14.3	22.5	60.3
	100 m			6.2			9.7	25	46.7	8.1	9.6	20.7	54.1
	200 m			5.5			8.3	21.6	38.4	7.3	6.7	18.7	47.2
	300 m			4.7			7.6	18.6	31.2	7.2	5.8	18.7	44.2
	500 m			4.2			6.7	17.3	26	7.2	5.2	18.7	44.2
Note		Intrusion 6 m and bank contact when $\theta>45^\circ$		Intrusions and bank contacts beyond scope .		Intrusion occurs when $\theta>45^\circ$		Intrusion 48.2-48.8 m at above boundary angles. Good at $\theta = 45^\circ$, $\delta=45^\circ$		Intrusions and bank contacts beyond scope.		Intrusion 99-85 m at boundary angles. Good at $\theta = 45^\circ$, $\delta=45^\circ$	

Continue Table 6.2.

Discharge flow (mgd)		60				90			
Discharge Velocity (m/s)		1.78				2.67			
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Angle (Min/Max)	Vertical (θ)	0°	45°	0°	45°	0°	45°	0°	45°
	Horizontal (δ)	37°	0°	45°	0°	23°	0°	28°	0°
Bank contact	Right (m)	No	170	No	160	No	160	No	160
	Left (m)	550	No	370	No	750	No	700	No
Discharge depth (m)		5		5		5		5	
Near bank distance (m)		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive	
NFR distance (m)		1159	1127	676.5	998.5	1227	1227	1227	1227
Central line Conc. (%)	C_{NFR}	3.2	2.8	4.4	3.1	2.9	2.8	3.0	2.8
	5 m	82	93.5	76	93	89.0	94	86.8	93.5
	10 m	54	64.7	49	64.1	60.5	64	58	65.0
	25 m	26	33.4	23	33.5	30.3	33.6	28.9	33.3
	50 m	13.5	15.0	13.3	14.7	14.2	14.0	14.0	13.0
	100 m	10.3	9.8	10.3	10.0	10.2	10.0	10.0	9.9
	200 m	7.4	7.0	7.7	7.0	7.1	7.1	7.1	7.0
	300 m	6.0	5.7	6.4	5.7	5.9	5.7	6.0	5.7
	500 m	4.8	4.4	5.0	4.4	5.6	4.4	4.6	4.4
Note		1. There are intrusions and bank contacts beyond scopes (δ: bank contact, θ: intrusion) 2. When δ > the given range, the model did not predict plume properly.							

Table 6.3. Mixing condition of the selected preferable angle ($\delta = 23^\circ$, $\theta = 15^\circ$)

Discharge flow (mgd)		6				12				24			
Discharge Velocity (m/s)		0.12		0.18		0.24		0.36		0.48		0.71	
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Diameter (in)		66”	54”	66”	54”	66”	54”	66”	54”	66”	54”	66”	54”
Bank contact	Right (m)	No	No	11.5	12.6	No	56.4	26.23	43.8	135.8	210.3	42	49.2
	Left (m)	No	No	520	524.8	No	934.6	358.2	No	512.3	477.3	No	No
Discharge depth (m)		5		5		5		5		5		5	
Near bank distance (m)		16		16		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive		Negative		Positive	
NFR distance (m)		50.7	47.4	11.5	12.6	40.4	47.3	26.3	20.8	135.8	210	42.0	49.2
Central line Conc. (%)	C_{NFR}	10.8	9.7	13.2	13.9	14.6	11.8	14.7	15.2	9.7	6.6	16.1	15.4
	5 m	82	78	50.2	65.6	90	84.6	96.7	100	94	86	100	100
	10 m	53.4	48.6	15.3	19.2	59.8	54	42.7	44.5	64.4	57.5	66.1	60.4
	25 m	25.6	22.4	12.4	13.0	28.4	25.1	14.7	12.0	31.8	33.4	19.4	18.1
	50 m	15.1	11.3	11.4	12.0		11.4	13.8		15.4	13.0	16.0	15.3
	100 m			10.3	10.8		9.7	12.5		11.2	9.5		
	200 m			8.8	9.1		8.7	10.9		9.1	6.8		
	300 m			7.5	7.8		8.1	9.8			6.2		
	500 m			5.4	5.6		7.2	9.2			5.7		
Note				Short right bank contact distance.				Short right bank contact distance in winter.					

Continue Table 6.3.

Discharge flow (mgd)		60				90			
Discharge Velocity (m/s)		1.19		1.78		1.79		2.67	
Period		April – Mar.		Nov. – Mar.		April – Mar.		Nov. – Mar.	
Diameter (in)		66”	54”	66”	54”	66”	54”	66”	54”
Bank contact	Right (m)	730	No	62.5	700	No	No	710	No
	Left (m)	520	No	No	500	930	740	700	910
Discharge depth (m)		5		5		5		5	
Near bank distance (m)		16		16		16		16	
7Q10 x 57.2% (cfs)		1,120		1,370		1,120		1,370	
Buoyancy		Negative		Positive		Negative		Positive	
NFR distance (m)		894	1227	63.6	909	1227	1227	1227	1227
Central line Conc. (%)	C_{NFR}	4.1	2.9	14.9	3.3	3.6	2.9	3.6	2.9
	5 m	96.2	88	100	88	97	89	97	88
	10 m	67.0	59	82	59	68	60.5	68	60
	25 m	34.5	29.8	25.9	29.5	35.3	30.3	35.1	30.2
	50 m	16.9	13.8	16.8	13.9	17.0	14.0	17.0	14.0
	100 m	12.2	10.1		9.9	12.08.7	9.6	12.2	10.1
	200 m	8.7	7.1		7.1	7.2	7.1	8.7	7.1
	300 m	7.1	5.8		5.8	5.6	5.9	7.2	5.9
	500 m	5.5	4.5		4.5		4.6	5.6	4.5
Note									

Table 6.4. Design case for selected design angles (Port diameter: 36")

Discharge flow (mgd)		6		12		24		60.		90	
Discharge Velocity (m/s)		0.40		0.80		1.60		4.0		6.0	
Period		April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.
Bank contact	Right (m)	No	108	No	55	No	28	1650	1230	3760	1220
	Left (m)	No	214	No	350	No	530	1650	1230	3760	1220
Discharge depth		5	5	5	5	5	5	5	5	5	5
Near bank distance (m)		16	16	16	16	16	16	16	16	16	16
7Q10 x 57.2% (cfs)		1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370
Buoyancy		Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
Near field region (NFR) (m)		33	108	30	54	230	29	1650	1230	3760	1220
Distance at 10% C (m)		30	120	30	350	40	300	40	35	40	40
Central line Conc. (%)	5 m	55.2	60.0	58.2	57.7	60.0	53.4	61.5	61.5	62.0	61.4
	10 m	31.3	36.0	34.3	33.7	36.0	48.1	37.3	37.3	38.0	37.3
	25 m	-	18.2	14.4	22.0	15.9	18.5	17.0	16.8	17.3	17.2
	50 m	-	15.0	-	15	9.2	16.4	9.3	8.9	9.5	9.2
	100 m	-	10.1	-	13.4	7.5	14.6	7.3	7.0	7.0	7.2
	200 m	-	9.3	-	11.8	5.9	12.2	5.6	5.3	5.5	5.3
	300 m	-	9.2	-	10.6	-	10.0	4.8	4.4	4.7	4.4
	500 m	-	9.2	-	9.9	-	6.8	3.8	3.4	3.7	3.5
Upstream intrusion (m)		No	- 20	No	- 48	No	- 108	No	No	No	No

Table 6.5. Design case for selected design angles (Port diameter: 42")

Discharge flow (mgd)		6		12		24		60		90	
Discharge Velocity (m/s)		0.29		0.59		1.18		2.95		4.42	
Period		April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.
Bank contact	Right (m)	No	30	No	50	No	102	1210	1120	2770	1230
	Left (m)	No	530	No	360	No	216	1210	1120	2770	1230
Discharge depth		5	5	5	5	5	5	5	5	5	5
Near bank distance (m)		16	16	16	16	16	16	16	16	16	16
7Q10 x 57.2% (cfs)		1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370
Buoyancy		Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
Near field region (NFR) (m)		33	30	31	50	160	102	1210	1120	2770	1230
Distance at 10% C (m)		32	380	32	*	62	*	65	60	60	65
Central line Conc. (%)	5 m	58.5	63.9	63.0	62.0	65.0	65.0	67.0	67.0	68.0	68.0
	10 m	13.9	40.5	37.8	42.3	39.8	39.7	42.3	41.5	42.2	42.2
	25 m	-	21.5	15.9	25.0	17.7	25.2	17.4	19.1	19.7	19.5
	50 m	-	19.9	-	18.0	10.5	23.9	10.9	10.5	10.8	11.0
	100 m	-	17.7	-	16.5	8.7	12.9	8.7	8.0	8.5	8.1
	200 m	-	14.5	-	14.4	-	11.7	6.6	6.0	6.5	6.1
	300 m	-	11.8	-	12.7	-	11.6	5.6	5.0	5.5	5.0
	500 m	-	7.6	-	11.9	-	11.6	4.5	4.0	4.4	4.0
Upstream intrusion (m)		No	- 23	No	- 46	No	- 107	No	No	No	No

* In these cases, Cormix prediction of distance to 10% dilution is not reliable.

Table 6.6. Design case for selected design angles (Port diameter: 48")

Discharge flow (mgd)		6		12		24		60.		90	
Discharge Velocity (m/s)		0.23		0.45		0.90		2.3		3.4	
Period		April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.	April – Mar.	Nov. – Mar.
Bank contact	Right (m)	No	28	No	47	No	97	930	No	1200	1200
	Left (m)	No	536	No	361	No	218	930	No	1200	1200
Discharge depth		5	5	5	5	5	5	5	5	5	5
Near bank distance (m)		16	16	16	16	16	16	16	16	16	16
7Q10 x 57.2% (cfs)		1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370	1,120	1,370
Buoyancy		Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive
Near field region (NFR) (m)		34	27	30	47	108	97	930	860	1200	1200
Distance at 10% C (m)		32	415	40	*	97	*	98	82	90	80
Central line Conc. (%)	5 m	61.7	75.3	63.3	66.0	70.5	69.9	72.0	72.3	73.0	73.0
	10 m	36.0	41.8	40.7	52.8	44.0	43.2	46.0	46.0	47.0	46.1
	25 m	15.2	2.0	17.3	30.0	19.5	29.9	21.4	21.2	22.0	21.7
	50 m	-	23.0	-	21.5	11.9	21.9	12.4	12.0	12.0	12.0
	100 m	-	20.3	-	19.5	9.9	15.6	9.7	9.3	9.9	9.3
	200 m	-	16.5	-	16.9	-	14.1	7.6	6.9	7.4	7.0
	300 m	-	13.2	-	14.9	-	13.9	6.4	5.7	6.3	5.7
	500 m	-	8.2	-	13.7	-	13.8	5.2	4.5	5.0	4.6
Upstream intrusion (m)		No	-26	No	- 43	No	- 107	No	No	No	No

* In these cases, Cormix prediction of distance to 10% dilution is not reliable.