USER'S MANUAL FOR CORMIX:
A HYDRODYNAMIC MIXING ZONE MODEL
AND DECISION SUPPORT SYSTEM
FOR POLLUTANT DISCHARGES INTO SURFACE WATERS

by

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Abstract

The Cornell Mixing Zone Expert System (CORMIX, Version 3.0 or higher) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone -- including compliance with regulatory constraints--, but the system also predicts the behavior of the discharge plume at larger distances. The highly user-interactive CORMIX system is implemented on microcomputers (IBM-PC, or compatible), and consists of three integrated subsystems:

---CORMIX1 for submerged single port discharges,
---CORMIX2 for submerged multiport diffuser discharges,
---CORMIX3 for buoyant surface discharges.

While CORMIX was originally developed under the assumption of steady ambient conditions, Version 3.0 also allows application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive description of the CORMIX system; it provides guidance for assembly and preparation of required input data for the three subsystems; it delineates ranges of applicability; it provides guidance for interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

Acknowledgments

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Glossary

Actual Water Depth (HD) - the actual water depth at the submerged discharge location. It is also called local water depth. For surface discharges it is the water depth at the channel entry location.

Alignment Angle (GAMMA) - the angle measured counterclockwise from the ambient current direction to the diffuser axis.

Allocated Impact Zone - see mixing zone.

Alternating Diffuser - a multi-port diffuser where the ports do not point in a nearly single horizontal direction.

Ambient Conditions - the geometric and dynamic characteristics of a receiving water body that impact mixing zone processes. These include plan shape, vertical cross sections, bathymetry, ambient velocity, and density distribution.

Ambient Currents - A velocity field within the receiving water which tends to deflect a buoyant jet into the current direction.

Ambient Discharge (QA) - the volumetric flow rate of the receiving water body.

Average Diameter (D0) - the average diameter of the discharge ports or nozzles for a multi-port diffuser.

Average Depth (HA) - the average depth of the receiving water body determined from the equivalent cross sectional area during schematization.

Bottom Slope (SLOPE) - the slope of the bottom that extends from a surface discharge into the receiving water body.

Buoyant Jet - a discharge where turbulent mixing is caused by a combination of initial momentum flux and buoyancy flux. It is also called a forced plume.

Buoyant Spreading Processes - far-field mixing processes which arise due to the buoyant forces caused by the density difference between the mixed flow and the ambient receiving water.

Buoyant Surface Discharge - the release of a positively or neutrally buoyant effluent into a receiving water through a canal, channel, or near-surface pipe.

Coanda Attachment - a dynamic interaction between the effluent plume and the water bottom that results from the entrainment demand of the effluent jet itself and is due to low pressure effects.

Cumulative Discharge - refers to the volumetric flow rate which occurs between the bank/shoreline and a given position within the water body.

Cumulative Discharge Method - an approach for representing transverse plume mixing in river or estuary flow by describing the plume centerline as being fixed on a line of constant cumulative discharge and by relating the plume width in terms of a cumulative discharge increment

Darcy-Weisbach Friction Factor - a measure of the roughness characteristics in a channel.

Deep Conditions - see near-field stability.

Density Stratification - the presence of a vertical density profile within the receiving water.

Diffuser Length (LD) - The distance between the first and last port of a multi-port diffuser line. See diffuser line.

Diffuser Line - a hypothetical line between the first and last ports of a multi-port diffuser.

Discharge Velocity (U0) - the average velocity of the effluent being discharged from the outfall structure.

Discharge from Shore (DISTB) - the average distance between the outfall location (or diffuser mid-point) and the shoreline. It is also specified as a cumulative ambient discharge divided by the product UA times HA.

Distance from Shore (YB1, YB2) - the distance from the shore line to the first and last ports of a multi-port diffuser.

Discharge Flow Rate (Q0) - the volumetric flow rate from the discharge structure.

Discharge Channel Width (B0) - the average width of a surface discharging channel.

Discharge Channel Depth (H0) - the average depth of a surface discharging channel.

Discharge Conditions - the geometric and flux characteristics of an outfall installation that effect mixing processes. These include port area, elevation above the bottom and orientation, effluent discharge flow rate, momentum flux, and buoyancy flux.

Far-field - the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.

Far-field Processes - physical mixing mechanisms that are dominated by the ambient receiving water conditions, particularly ambient current velocity and density differences between the mixed flow and the ambient receiving water.

FAST-CORMIX - a version of CORMIX data entry with short questions and without help sections; can be chosen in main menu; for advanced users.

Flow Classification - the process of identifying the most appropriate generic qualitative description of the discharge flow undergoing analysis. This is accomplished by examining known relationships between flow patterns and certain calculated physical parameters.

Flux Characteristics - the properties of effluent discharge flow rate, momentum flux and buoyancy flux for the effluent discharge.

Forced Plume - see buoyant jet.

Generic Flow Class - a qualitative description of a discharge flow situation that is based on known relationships between flow patterns and certain physical parameters.

Height of Port (H0) - the average distance between the bottom and the average nozzle centerline.

High Water Slack (HWS) - the time of tidal reversal nearest to MHW

Horizontal Angle (SIGMA) - the angle measured counterclockwise from the ambient current direction

to the plane projection of the port center line.

Hydrodynamic Mixing Processes - the physical processes that determine the fate and distribution of effluent once it is discharged.

Input Data Sequence - a group of questions from one of four topical areas.

Intermediate-field Affects - induced flows in shallow waters which extend beyond the strictly near-field region of a multi-port diffuser.

Iteration Menu - the last menu (red panel) the user can choose after completion of a design case; allows iteration with different ambient/discharge/regulatory conditions.

Jet - see pure jet.

Laterally Bounded - refers to a water body which is constrained on both sides by banks such as rivers, streams, estuaries and other narrow water courses.

Laterally Unbounded - a water body which for practical purposes is constrained on at most one side. This would include discharges into wide lakes, wide estuaries and coastal areas.

Legal Mixing Zone (LMZ) - see regulatory mixing zone.

Length Scale - a dynamic measure of the relative influence of certain hydrodynamic processes on effluent mixing.

Length Scale Analysis - an approach which uses calculated measures of the relative influence of certain hydrodynamic processes to identify key aspects of a discharge flow so that a generic flow class can be identified.

Local Water Depth (HD) - see actual water depth.

Low Water Slack (LWS) - the time of tidal reversal nearest to MLW

Main Menu - the first menu (red panel) the user can choose from when entering CORMIX.

Manning's n - a measure of the roughness characteristics in a channel.

Maximum Tidal Velocity (Uamax) - the maximum velocity occurring within the tidal cycle

Mean Ambient Velocity (UA) - the average velocity of the receiving water body's flow.

Mean High Water (MLW) - the highest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Mean Low Water (MLW) - the lowest water level (averaged over many tidal cycles) in estuarine or coastal flows.

Merging - the physical interaction of the discharge plumes from adjacent ports of a multi-port diffuser.

Mixing Zone - an administrative construct which defines a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur. In practice, it may occur within the near-field or far-field of a hydrodynamic mixing process and therefore depends on source, ambient, and regulatory

constraints.

Mixing Zone Regulations - The administrative construct that intends to prevent any harmful impact of a discharged effluent on the aquatic environment and its designated uses.

Momentum Jet - see pure jet.

Multi-port Diffuser - a structure with many closely spaced ports or nozzles that inject more than one buoyant jet into the ambient receiving water body.

Near-field - the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge.

Near-Field Region (NFR) - a term used in the CORMIX printout for describing the zone of strong initial mixing where the so called near-field processes occur. It is the region of the receiving water where outfall design conditions are most likely to have an impact on in-stream concentrations.

Near-field Stability - the amount of local recirculation and re-entrainment of already mixed water back into the buoyant jet region. Stable discharge conditions are associated with weak momentum and deep water and are also sometimes called deep water conditions. Unstable discharge conditions have localized recirculation patterns and are also called shallow water conditions.

Negative Buoyancy - the measure of the tendency of an effluent discharge to sink in a receiving water.

Non-buoyant Jet - see pure jet.

Open Format - data input which does not require precise placement of numerical values in fixed fields and which allows character strings to be entered in either upper or lower case letters.

Passive Ambient Diffusion Processes - far-field mixing processes which arise due to existing turbulence in the ambient receiving water flow.

Plume - see buoyant jet.

Positive Buoyancy - the measure of the tendency of an effluent discharge to rise in the receiving water.

Post-Processor - several options available within CORMIX (main menu or iteration menu) for additional computation or data display, including a graphics package, a near-field buoyant jet model, and a far-field plume delineator.

Pure Jet - a discharge where only the initial momentum flux in the form of a high velocity injection causes turbulent mixing. It is also called momentum jet or non-buoyant jet.

Pure Plume - a discharge where only the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing.

Pycnocline - a horizontal layer in the receiving water where a rapid density change occurs.

Pycnocline Height (HINT) - the average distance between the bottom and a horizontal layer in the receiving water body where a rapid density change occurs.

Region Of Interest (ROI) - a user defined region of the receiving water body where mixing conditions are to be analyzed.

Regulatory Mixing Zone (RMZ) - the region of the receiving water where mixing zone regulations are applied. It is sometimes referred to as the legal mixing zone.

Relative Orientation Angle (BETA) - the angle measured either clockwise or counterclockwise from the average plan projection of the port centerline to the nearest diffuser axis.

Schematization - the process of describing a receiving water body's actual geometry with a rectangular cross section.

Shallow Water Conditions - see near-field stability.

Stable Discharge - see near-field stability.

Staged Diffuser - a multi-port diffuser where all ports point in one direction, generally following the diffuser line.

Stagnant Conditions - the absence of ambient receiving water flow. A condition which rarely occurs in actual receiving water bodies.

Submerged Multi-port Diffuser - an effluent discharge structure with more than one efflux opening that is located substantially below the receiving water surface.

Submerged Single Port Discharge - an effluent discharge structure with a single efflux opening that is located substantially below the receiving water surface.

Surface Buoyant Jets - positively or neutrally buoyant effluent discharges occurring horizontally at the water surface from a latterly entering channel or pipe.

Surface Width (BS) - the equivalent average surface width of the receiving water body determined from the equivalent rectangular cross sectional area during schematization.

Tidal cycle - the variation of ambient water depth and velocity as a function of time occurring due to tidal (lunar and solar) influences.

Tidal period (PERIOD) - the duration of the tidal cycle (on average 12.4 hours).

Tidal reversal - the two instances in the tidal cycle when the ambient velocity reverses its direction.

Toxic Dilution Zone (TDZ) - the region of the receiving water where the concentration of a toxic chemical may exceed the acute effects concentration.

Unidirectional Diffuser - a multi-port diffuser with all ports pointing to one side of the diffuser line and all ports oriented more or less normally to the diffuser line.

Unstable Discharge - see near-field stability.

Vertical Angle (THETA) - the angle between the port centerline and the horizontal plane.

Wake Attachment - a dynamic interaction of the effluent plume with the bottom that is forced by the receiving water crossflow.

Zone of Initial Dilution - a term sometimes used to describe the mixing zone for the discharge of municipal wastewater into the coastal ocean, limited to the extent of near-field mixing processes.

Metric Conversion Factors
for Dimensions Used in CORMIX

Length: 1 m   = 3.281 ft
                                  = 39.37 in
                                  = 0.0006214 mile

Velocity: 1 m/s   = 3.281 ft/s (fps)
                                  = 2.237 miles/hr (mph)
                                  = 1.943 knots

Discharge: 1 m^3/s   = 35.31 ft^3/s (cfs)
                                  = 22.82 million-gal/day (mgd)

Density: 1000 kg/m^3 = 62.43 lb/ft^3

Temperature: ^{o}C   = (^{o}F - 32.0) * 0.5556

I Introduction

The Cornell Mixing Zone Expert System (CORMIX) is a software system for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. It was developed under several cooperative funding agreements between U.S. EPA and Cornell University during the period 1985-1995. It is a recommended analysis tool in key guidance documents (1,2,3) on the permitting of industrial, municipal, thermal, and other point source discharges to receiving waters. Although the system's major emphasis is on predicting the geometry and dilution characteristics of the initial mixing zone so that compliance with water quality regulatory constraints may be judged, the system also predicts the behavior of the discharge plume at larger distances.

The highly user-interactive CORMIX system is implemented on IBM-DOS compatible microcomputers, utilizes a rule-based systems approach to data input and processing, and consists of three subsystems. These are: (a) CORMIX1 for the analysis of submerged single port discharges, (b) CORMIX2 for the analysis of submerged multiport diffuser discharges and (c) CORMIX3 for the analysis of buoyant surface discharges. Without specialized training in hydrodynamics, users can make detailed predictions of mixing zone conditions, check compliance with regulations and readily investigate the performance of alternative outfall designs. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, several post-processing options are available. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments, and CMXGRAPH, a graphics package for plume plotting.

Several factors provided the original impetus for system development including: (a) the considerable complexity of mixing processes in the aquatic environment, resulting from the great diversity of discharge and site conditions and requiring advanced knowledge in a specialized field of hydrodynamics; (b) the failure of previously existing models (e.g. the U.S. EPA plume models (4) originally developed for municipal discharges in deep coastal waters) to adequately predict often routine discharge situations, especially for more shallow inland sites; (c) the issuance in 1985 by the U.S. EPA of additional guidelines (1) for the permitting of toxic aqueous discharges, placing yet another burden on both applicants and regulators in delineating special zones for the initial mixing of these substances; and (d) the availability of new computer methods, so-called expert systems, for making accessible to the user, within a simple personal computing environment, the expert's knowledge and experience in dealing with complex engineering problems.

Four separate publications (5,6,7,8) describe the scientific basis for the CORMIX system and demonstrate comparison and validation with field and laboratory data. The results of these works are summarized in the peer-reviewed literature (9,10,11,12,13,14,15, 16,17). The CORMIX systems approach and its performance relative to the earlier U.S. EPA plume models in the context of estuarine applications is also described in EPA's technical guidance manual for performing waste load allocations in estuaries (3).

EPA's established policy is to make the CORMIX system freely available to all potential users through its modeling software distribution facility at the U.S. EPA Center for Environmental Assessment Modeling (CEAM) in Athens, Georgia. Some of the CORMIX subsystems have been available to the industrial and regulatory user communities since December 1989 when distribution of CORMIX1 was commenced by Cornell University for the purpose of identifying subtle programming errors through application to actual mixing zone analysis problems by a

controlled users group. After this testing was deemed complete, CEAM commenced the distribution of CORMIX1 in November 1990. A similar approach was used to introduce CORMIX2 which began CEAM distribution in October 1991. In 1992, CORMIX1, CORMIX2, and CORMIX3 were integrated a single program and distributed by USEPA-CEAM as CORMIX Version 2.1 as of 1993.

Additional development of the post-processor modules, including plume graphics, the jet-integral model, and the far-field locator, were added to the system and distributed as CORMIX Version 3.0 as of 1994.

This manual describes the operation of a revised version, including a special routine for unsteady tidal applications, denoted as CORMIX Version 3.1 that has been distributed by Cornell as of June 1995. A slightly updated Version 3.2 will be distributed by USEPA-CEAM as of September 1996.

The objectives of this user's guide are as follows: (a) to provide a comprehensive description of the CORMIX system; (b) to provide guidance for assembly and preparation of required input data for all three subsystems as well as the post-processor models; (c) to delineate ranges of applicability of the subsystems; (d) to provide guidance for the interpretation and graphical display of system output; and (e) to illustrate practical system application through several case studies.

This manual is organized to meet the informational needs of two distinctly different groups of readers: 1) personnel in environmental management positions desiring an overview of the CORMIX systems capabilities, and 2) technical staff needing assistance in actual applications. Chapter II provides a summary of the physical processes of effluent mixing, as well as an overview of the regulatory background and practice on mixing zone applications. The general features of the CORMIX system are explained in Chapter III including summaries of: (a) predictive capabilities and limitations, (b) overall system structure and method of processing information, (c) user interaction, and (d) individual computational elements. Detailed guidance on the preparation and entry of input data, as required by the three CORMIX subsystems, is given in Chapter IV. Chapter V provides a description of system output, containing descriptive, quantitative, and graphical information on the predicted effluent flow. Chapter VI describes the background, input and output features of the CORJET jet integral model and the far-field plume locator program FFLOCATR. The closing remarks in Chapter VII contain information on system availability and user support, and on possible future developments and enhancements.

Appendices to this guide present four case studies on the application of all three CORMIX subsystems and its post-processor models. These are adapted from actual situations and illustrate the complete input requirements and output capabilities of the system. In addition, some of the assumptions on data schematization, problem simplification, and output interpretation, and construction graphical displays are discussed in a context typical of many mixing zone model applications.

II Background:
Mixing Processes and Mixing Zone Regulations

When performing design work and predictive studies on effluent discharge problems, it is important to clearly distinguish between the physical aspects of **hydrodynamic mixing processes** that determine the effluent fate and distribution, and the administrative construct of **mixing zone regulations** that intend to prevent any harmful impact of the effluent on the aquatic environment and associated uses.

2.1 Hydrodynamic Mixing Processes

The mixing behavior of any wastewater discharge is governed by the interplay of ambient conditions in the receiving water body and by the discharge characteristics.

The **ambient conditions** in the receiving water body, be it stream, river, lake, reservoir, estuary or coastal waters, are described by the water body's geometric and dynamic characteristics. Important geometric parameters include plan shape, vertical cross-sections, and bathymetry, especially in the discharge vicinity. Dynamic characteristics are given by the velocity and density distribution in the water body, again primarily in the discharge vicinity. In many cases, these conditions can be taken as steady-state with little variation because the time scale for the mixing processes is usually of the order of minutes up to perhaps one hour. In some cases, notably tidally influenced flows, the ambient conditions can be highly transient and the assumption of steady-state conditions may be inappropriate. In this case, the effective dilution of the discharge plume may be reduced relative to that under steady state conditions.

The **discharge conditions** relate to the geometric and flux characteristics of the submerged outfall installation. For a single port discharge the port diameter, its elevation above the bottom and its orientation provide the geometry; for multiport diffuser installations the arrangement of the individual ports along the diffuser line, the orientation of the diffuser line, and construction details represent additional geometric features; and for surface discharges the cross-section and orientation of the flow entering the ambient watercourse are important. The **flux characteristics** are given by the effluent discharge flow rate, by its momentum flux and by its buoyancy flux. The buoyancy flux represents the effect of the relative density difference between the effluent discharge and ambient conditions in combination with the gravitational acceleration. It is a measure of the tendency for the effluent flow to rise (i.e. **positive buoyancy**) or to fall (i.e. **negative buoyancy**).

The hydrodynamics of an effluent continuously discharging into a receiving water body can be conceptualized as a mixing process occurring in two separate regions. In the first region, the initial jet characteristics of momentum flux, buoyancy flux, and outfall geometry influence the jet trajectory and mixing. This region will be referred to as the "**near-field**", and encompasses the buoyant jet flow and any surface, bottom or terminal layer interaction. In this near-field region, outfall designers can usually affect the initial mixing characteristics through appropriate manipulation of design variables.

As the turbulent plume travels further away from the source, the source characteristics become less important. Conditions existing in the ambient environment will control trajectory and dilution of the turbulent plume through buoyant spreading motions and passive diffusion due to ambient turbulence. This region will be referred to here as the "**far-field**". It is stressed at this point that the distinction between near-field and far-field is made purely on hydrodynamic grounds. It is unrelated to any regulatory mixing zone definitions.

2.1.1 Near-Field Processes

Three important types of near-field processes are submerged buoyant jet mixing, boundary interactions and surface buoyant jet mixing as described in the following paragraphs.

Submerged Buoyant Jet Mixing: The effluent flow from a submerged discharge port provides a velocity discontinuity between the discharged fluid and the ambient fluid causing an intense shearing action. The shearing flow breaks rapidly down into a turbulent motion. The width of the zone of high turbulence intensity increases in the direction of the flow by incorporating ("entraining") more of the outside, less turbulent fluid into this zone. In this manner, any internal concentrations (e.g. fluid momentum or pollutants) of the discharge flow become diluted by the entrainment of ambient water. Inversely, one can speak of the fact that both fluid momentum and pollutants become gradually diffused into the ambient field.

The initial velocity discontinuity may arise in different fashions. In a "**pure jet**" (also called "momentum jet" or "non-buoyant jet"), the initial momentum flux in the form of a high-velocity injection causes the turbulent mixing. In a "**pure plume**," the initial buoyancy flux leads to local vertical accelerations which then lead to turbulent mixing. In the general case of a "**buoyant jet**" (also called a "forced plume"), a combination of initial momentum flux and buoyancy flux is responsible for turbulent mixing.

Thus, buoyant jets are characterized by a narrow turbulent fluid zone in which vigorous mixing takes place. Furthermore, depending on discharge orientation and direction of buoyant acceleration, curved trajectories are generally established in a stagnant uniform-density environment as illustrated in Figure 2.1a.

Buoyant jet mixing is further affected by ambient currents and density stratification. The role of **ambient currents** is to gradually deflect the buoyant jet into the current direction as illustrated in Figure 2.1b and thereby induce additional mixing. The role of ambient **density stratification** is to counteract the vertical acceleration within the buoyant jet leading ultimately to trapping of the flow at a certain level. Figure 2.1c shows a typical buoyant jet shape at the trapping or terminal level.

Finally, in case of multiport diffusers, the individual round buoyant jets behave independently until they interact, or merge, with each other at a certain distance from the efflux ports. After **merging**, a two-dimensional buoyant jet plane is formed as illustrated in Figure 2.1d. Such plane buoyant jets resulting from a multiport diffuser discharge in deep water can be further affected by ambient currents and by density stratification as discussed in the preceding paragraph.

Boundary Interaction Processes and Near-Field Stability: Ambient water bodies always have vertical boundaries. These include the water surface and the bottom, but in addition, "internal boundaries" may exist at pycnoclines. **Pycnoclines** are layers of rapid density change. Depending on the dynamic and geometric characteristics of the discharge flow, a variety of interaction phenomena can occur at such boundaries, particularly where flow trapping may occur.

In essence, boundary interaction processes provide a transition between the buoyant jet mixing process in the near-field, and between buoyant spreading and passive diffusion in the far-field. They can be gradual and mild, or abrupt leading to vigorous transition and mixing processes. They also can significantly influence the stability of the effluent discharge conditions.

The assessment of **near-field stability**, i.e. the distinction of stable or unstable conditions, is a key aspect of effluent dilution analyses. It is especially important for understanding the behavior of the two-dimensional plumes resulting from multiport diffusers, as shown by some examples in Figure 2.2. "**Stable discharge**" conditions, usually occurring for a combination of strong buoyancy, weak momentum and deep water, are often referred to as "**deep water**" conditions (Figures 2.2a,c). "**Unstable discharge**" conditions, on the other hand, may be considered synonymous to "**shallow water**" conditions (Figure 2.2b,d). Technical discussions on discharge stability are presented elsewhere (18,19).

A few important examples of boundary interaction for a single round buoyant jet are illustrated in Figure 2.3. If a buoyant jet is bent-over by a cross-flow, it will gradually approach the surface, bottom or terminal level and will undergo a smooth transition with little additional mixing

impingement point can take on one of the following forms: (a) If the flow has sufficient buoyancy it will ultimately form a stable layer at the **surface** (Figure 2.3b). In the presence of **weak** ambient flow this will lead to an upstream intrusion against the ambient current. (b) If the buoyancy of the effluent flow is weak or its momentum very high, unstable recirculation phenomena can occur in the discharge vicinity (Figure 2.3c). This local recirculation leads to re-entrainment of already mixed water back into the buoyant jet region. (c) In the intermediate case, a combination of localized vertical mixing and upstream spreading may result (Figure 2.3d).

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. Two types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are wake attachment forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet periphery is close to the water bottom.

a) Buoyant Jet in Stagnant Uniform Ambient

c) Buoyant Jet in Stagnant Stratified Ambient

b) Buoyant Jet in Uniform Ambient Cross-Current

Side View   Tap View

d) Jet Merging for Unidirectional Multipart Diffuser Forming Plane Buoyant Jet
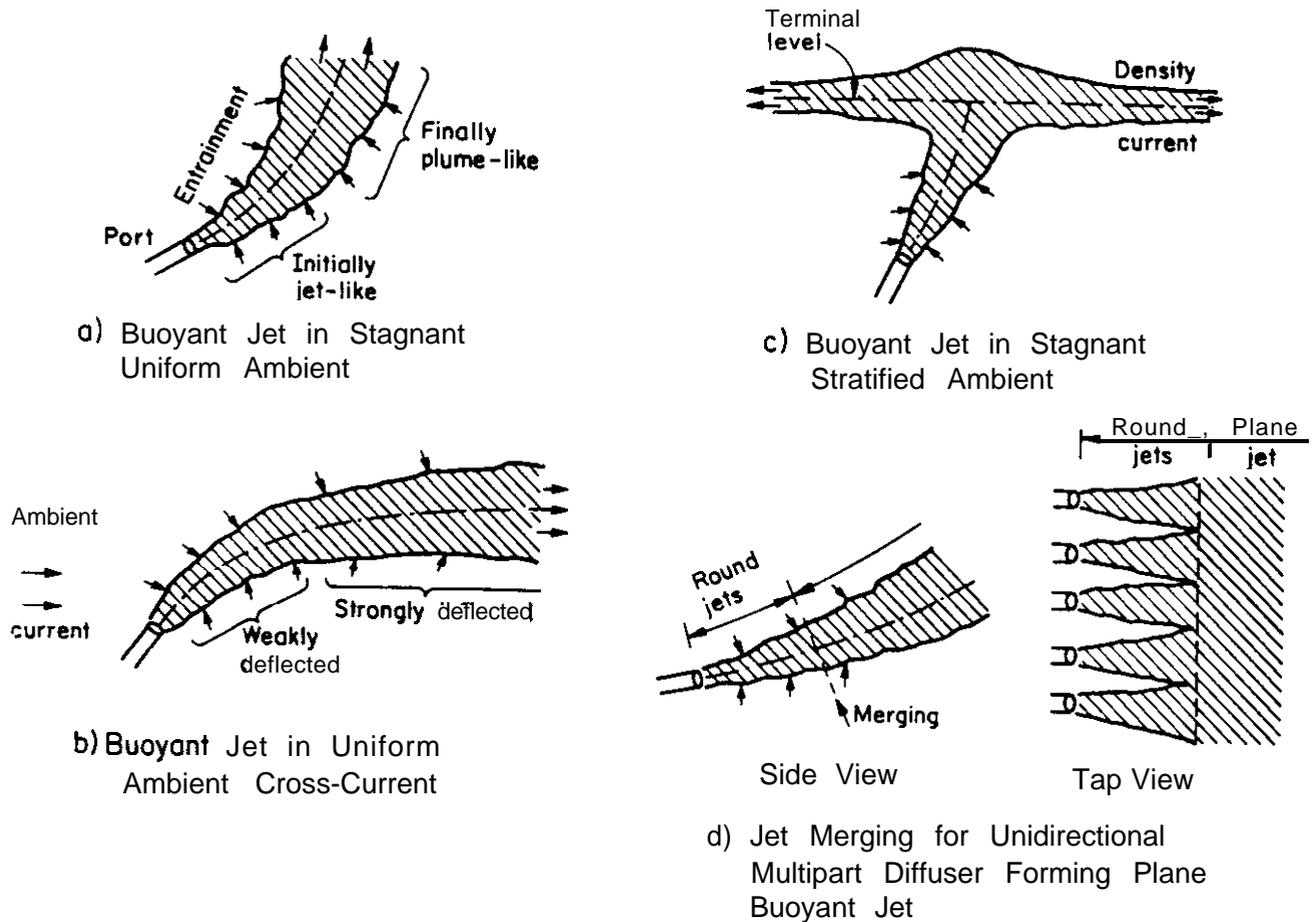
Figure 2.1:   Typical buoyant jet mixing flow patterns under different ambient conditions
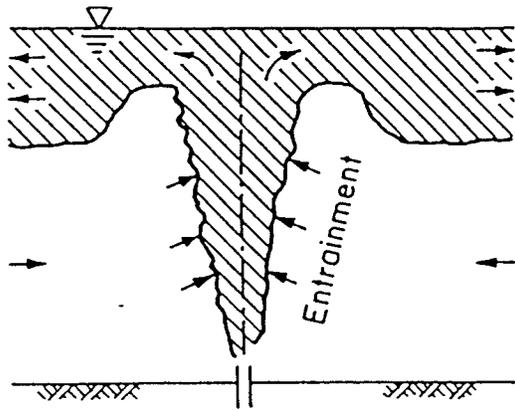
a) Deep Water, High Buoyancy,
   Vertical: Stable Near-Field
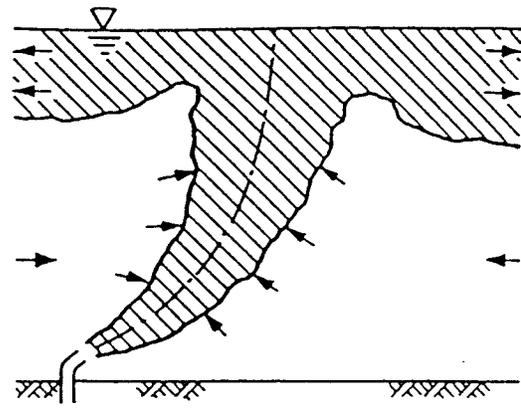
c) Deep Water, High Buoyancy,
   Near-Horizontal: Stable Near-Field
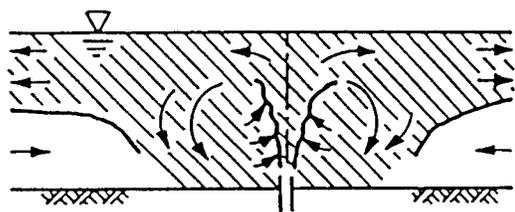
b) Shallow Water, Low Buoyancy,
   Vertical: Unstable Near-Field
   with Local Mixing and
   Restratification
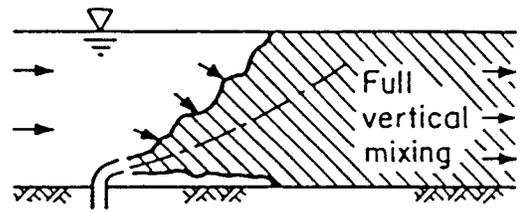
d) Shallow Water, Low Buoyancy,
   Near-Horizontal: Unstable Near-Field
   with Full Vertical Mixing

Figure 2.2: Examples of near-field stability and instability conditions for submerged discharges in limited water depth

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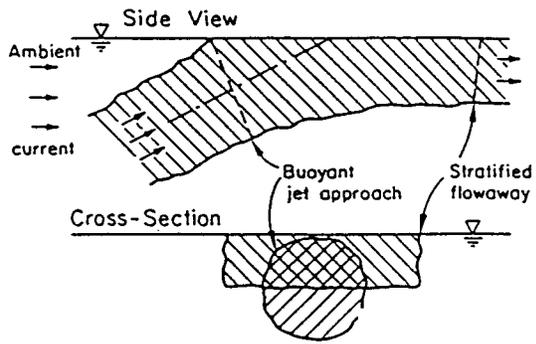
a) Gradual Surface Approach (Near-Horizontal)

b) Surface Impingement with Buoyant Upstream Spreading

c) Surface Impingement with Full Vertical Mixing in Shallow Water
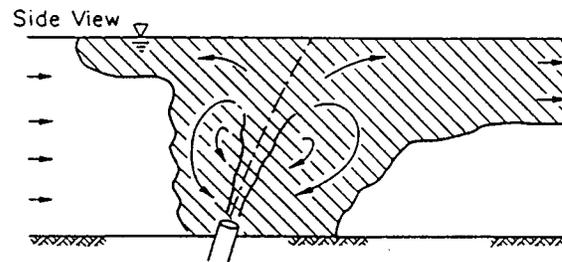
d) Surface Impingement with Local Vertical Mixing, Buoyant Upstream Spreading and Restratification

Figure 2.3: Examples of boundary interactions for submerged jets in finite depth

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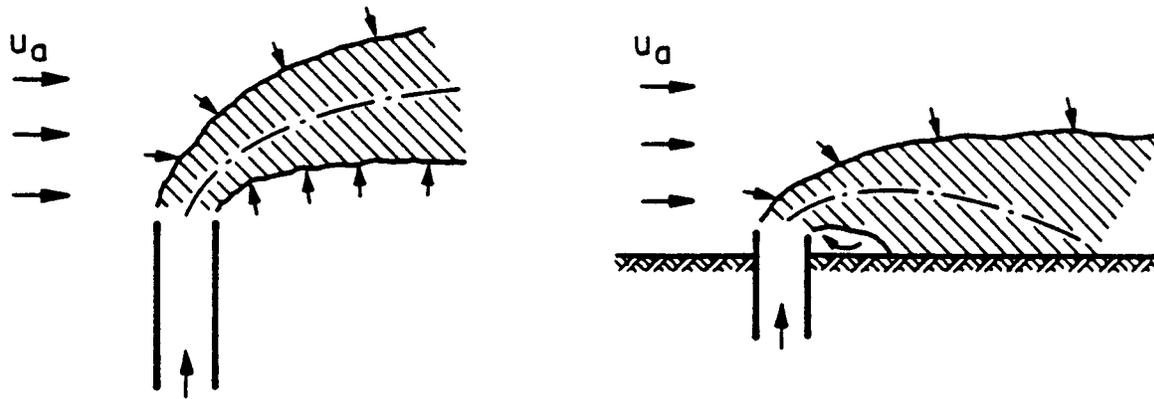
i) Free Deflected Jet/Plume
in Cross-flow

ii) Wake Attachment of
Jet/Plume

a) Wake Attachment
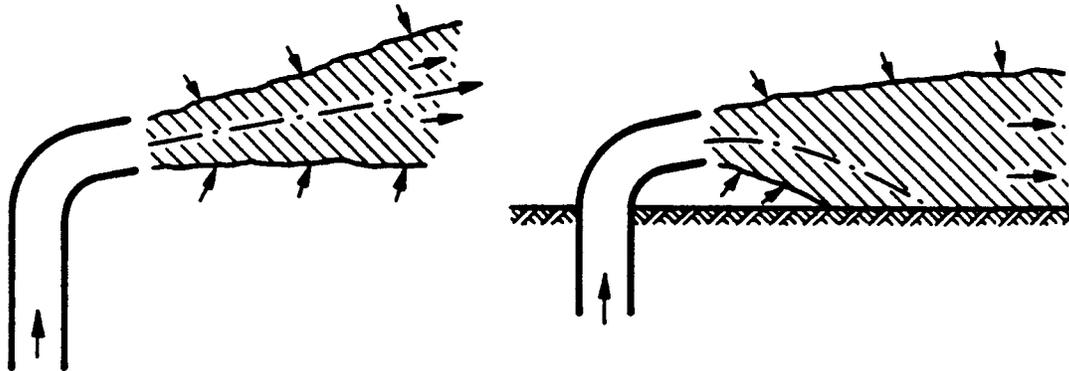
i) Free Jet

ii) Attached Jet

b) Coanda Attachment

Figure 2.4: Examples of wake (crossflow induced) attachment and Coanda attachment conditions for jets discharging near boundaries

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Surface Buoyant Jet Mixing: Positively buoyant jets discharged horizontally along the water surface from a laterally entering channel or pipe (Figure 2.5) bear some similarities to the more classical submerged buoyant jet. For a relatively short initial distance, the effluent behaves like a momentum jet spreading both laterally and vertically due to turbulent mixing.

After this stage, vertical entrainment becomes inhibited due to buoyant damping of the turbulent motions, and the jet experiences strong lateral spreading. During stagnant ambient conditions, ultimately a reasonably thin layer may be formed at the surface of the receiving water; that layer can undergo the transient buoyant spreading motions depicted in Figure2.5a.
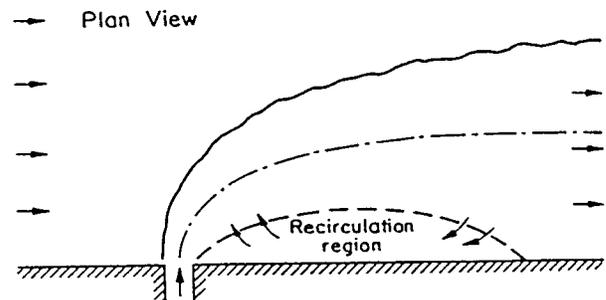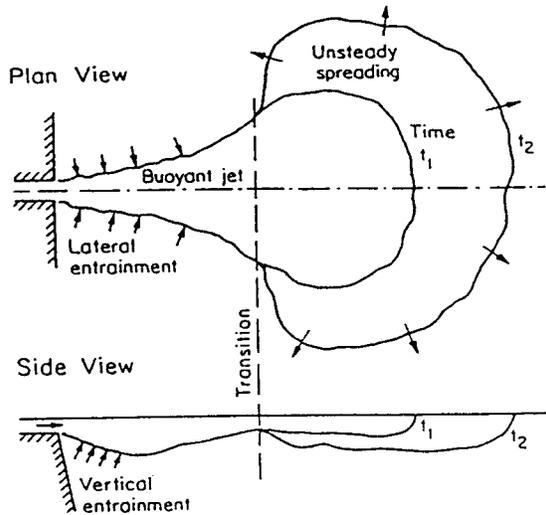
a) Buoyant Surface Jet in Stagnant Ambient

c) Shoreline-Attached Surface Jet in Strong Ambient Crossflow
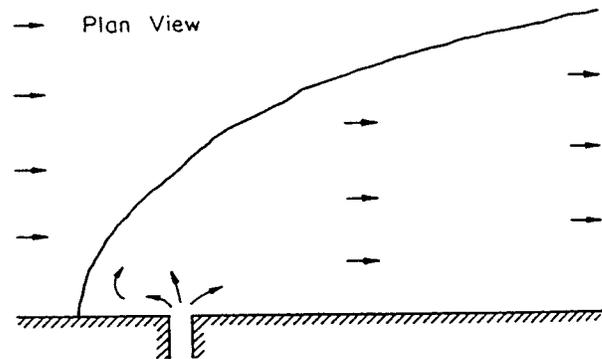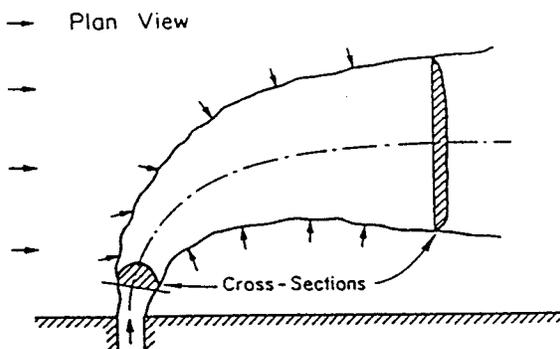
b) Buoyant Surface Jet in Ambient Crossflow

d) Upstream Intruding Plume in Weak Ambient Crossflow

2.5: Typical buoyant surface jet mixing flow patterns under stagnant or flowing ambient conditions

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In the presence of ambient crossflow, buoyant surface jets may exhibit any one of following three types of flow features: They may form a weakly deflected jet that does not interact with the shoreline (Figure 2.5b). When the crossflow is strong, they may attach to the downstream boundary forming a shore-hugging plume (Figure 2.5c). When a high discharge buoyancy flux combines with a weak crossflow, the buoyant spreading effects can be so strong that an upstream intruding plume is formed that also stays close to the shoreline (Figure 2.5d).

Intermediate-Field Effects for Multiport Diffuser Discharges: Some multiport diffuser installations induce flows in shallow water which extend beyond the strict near-field region. The resulting plumes are sometimes referred to as the "intermediate-field" (18) because they interact with the receiving water at distances that are substantially greater than the water depth; the order of magnitude of the water depth is typically used to define the dimensions of the near-field region. Intermediate fields may occur when a multiport diffuser represents a large source of momentum with a relatively weak buoyancy effect. Such a diffuser will have an unstable near-field with shallow water conditions. For certain diffuser geometries (e.g. unidirectional & staged diffuser types; see Section V) strong motions can be induced in the shallow water environment in the form of vertically mixed currents that laterally entrain ambient water and may extend over long distances before they re-stratify or dissipate their momentum.

Another type of interaction process concerns submerged buoyant jets discharging in the vicinity of the water bottom into a stagnant or flowing ambient. Two types of dynamic interaction processes can occur that lead to rapid attachment of the effluent plume to the water bottom as illustrated in Figure 2.4. These are **wake attachment** forced by the receiving water's crossflow or **Coanda attachment** forced by the entrainment demand of the effluent jet itself. The latter is due to low pressure effects as the jet periphery is close to the water bottom.

2.1.2 Far-Field Processes

Far-field mixing processes are characterized by the longitudinal advection of the mixed effluent by the ambient current velocity.

Buoyant Spreading Processes: These are defined as the horizontally transverse spreading of the mixed effluent flow while it is being advected downstream by the ambient current. Such spreading processes arise due to the buoyant forces caused by the density difference of the mixed flow relative to the ambient density. They can be effective transport mechanisms that can quickly spread a mixed effluent laterally over large distances in the transverse direction, particularly in cases of strong ambient stratification. In this situation, effluent of considerable vertical thickness at the terminal level can collapse into a thin but very wide layer unless this is prevented by lateral boundaries. If the discharge is non-buoyant, or weakly buoyant, and the ambient is unstratified, there is no buoyant spreading region in the far-field, only a passive diffusion region.

Depending on the type of near-field flow and ambient stratification, several types of buoyant spreading may occur. These include: (a) spreading at the water surface, (b) spreading at the bottom, (c) spreading at a sharp internal interface (pycnocline) with a density jump, or (d) spreading at the terminal level in continuously stratified ambient fluid. As an example, the definition diagram and structure of surface buoyant spreading processes somewhat downstream of the discharge in unstratified crossflow is shown in Figure 2.6.

The laterally spreading flow behaves like a density current and entrains some ambient fluid in the "head region" of the current. During this phase, the mixing rate is usually relatively small, the layer thickness may decrease, and a subsequent interaction with a shoreline or bank can impact the spreading and mixing processes.

Passive Ambient Diffusion Processes: The existing turbulence in the ambient environment becomes the dominating mixing mechanism at sufficiently large distances from the discharge point. In general, the passively diffusing flow grows in width and in thickness until it interacts

The strength of the ambient diffusion mechanism depends on a number of factors relating mainly to the geometry of the ambient shear flow and the amount of ambient stratification. In the context of classical diffusion theory (20), gradient diffusion processes in the bounded flows of rivers or narrow estuaries can be described by constant diffusivities in the vertical and horizontal direction that depend on turbulent intensity and on channel depth or width as the length scales. In contrast, wide "unbounded" channels or open coastal areas are characterized by plume size dependent diffusivities leading to accelerating plume growth described, for example, by the "4/3 law" of diffusion. In the presence of a stable ambient stratification, the vertical diffusive mixing is generally strongly damped.
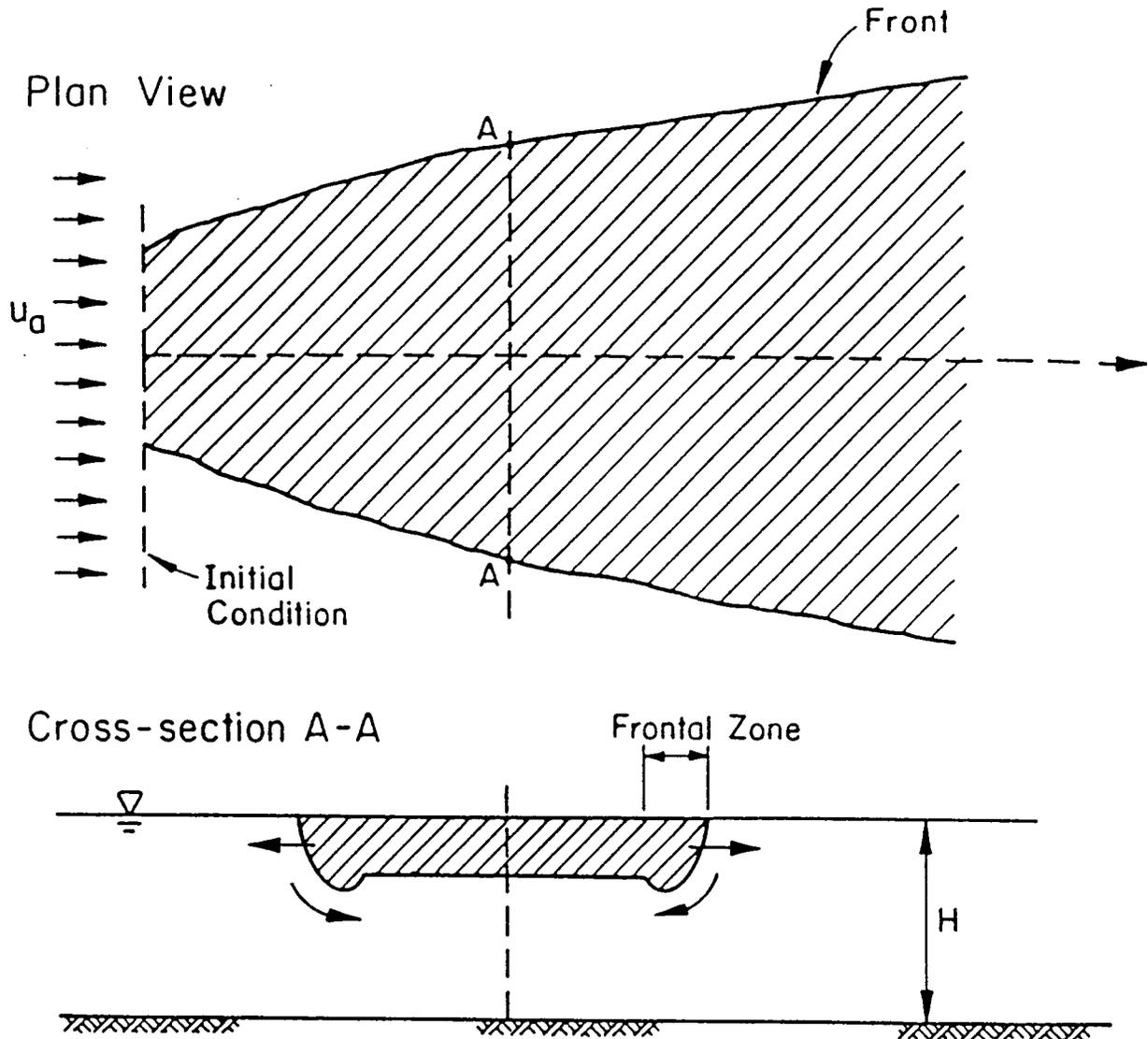
Figure 2.6: Buoyant spreading processes downstream of the near-field region (example of spreading along the water surface)

Plan View

Turbulent flow

u_a

Possible Bank Interaction

Plume Centerline

Initial Conditions

Side View

u_a

Possible Bottom Interaction
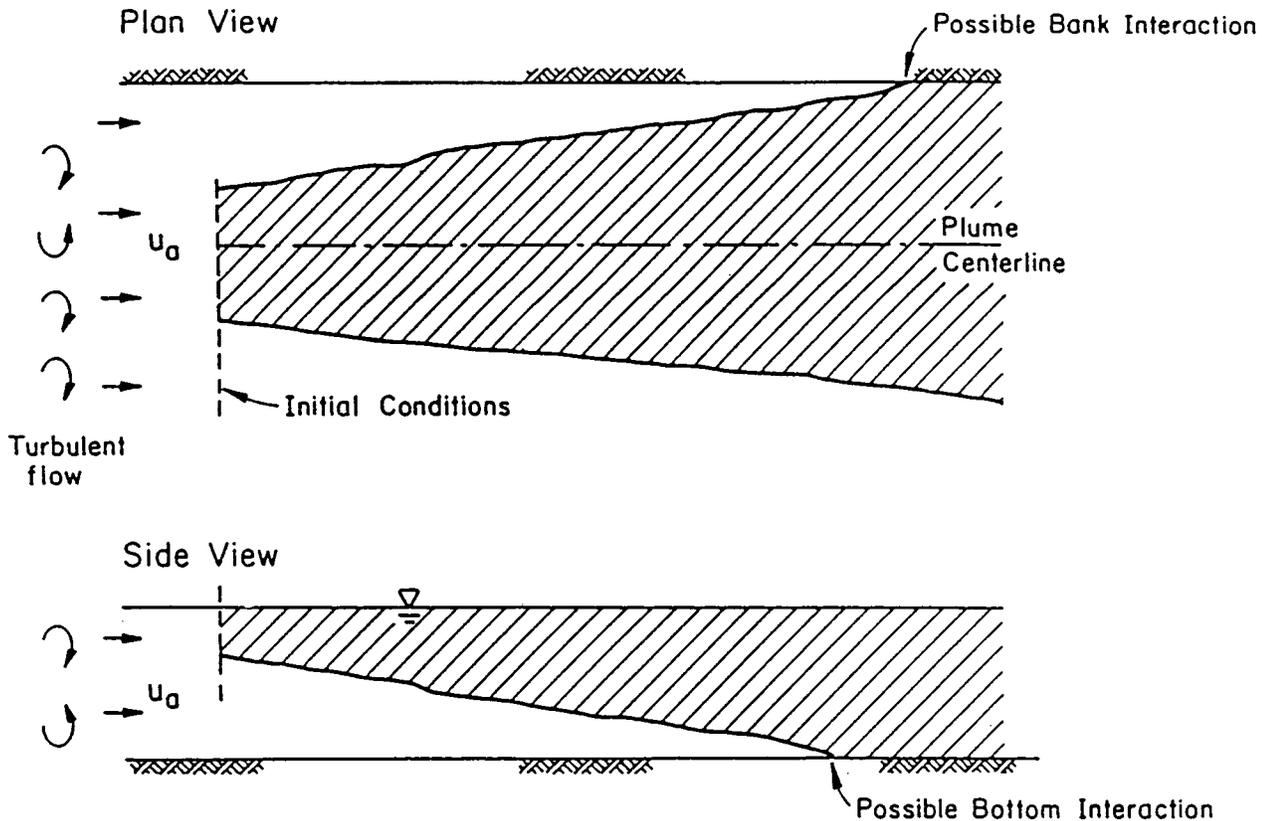
Figure 2.7: Passive ambient diffusion process with advection in the far-field

2.2 Mixing Zone Regulations

The discharge of waste water into a water body can be considered from two vantage points regarding its impact on ambient water quality. On a larger scale, seen over the entire receiving water body, care must be taken that water quality conditions that protect designated beneficial uses are achieved. This is the realm of the general waste load allocation (WLA) procedures and models.

On a local scale, or in the immediate discharge vicinity, additional precautions must be taken to insure that high initial pollutant concentrations are minimized and constrained to small zones, areas, or volumes. The generic definition of these zones, commonly referred to as "**mixing zones**", is embodied in federal water quality regulations and often cited in the regulations of permit granting authorities. As stated previously, mixing zones are administrative constructs that are independent of hydrodynamic mixing processes.

2.2.1 Legal Background

The Clean Water Act of 1977 defines five general categories of pollutants. These are: (a) conventional, (b) nonconventional, (c) toxics, (d) heat, and (e) dredge and fill spoil. The Act distinguishes between new and existing sources

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for setting effluent standards. Pollutants designated as "conventional" would be "generally those pollutants that are naturally occurring, biodegradable, oxygen demanding materials and solids. In addition, compounds which are not toxic and which are similar in characteristics to naturally occurring, biodegradable substances are to be designated as conventional pollutants for the purposes of the provision." Examples of conventional pollutants are: biochemical oxygen demand (BOD), total suspended solids, and fecal coliform bacteria. Pollutants designated as "nonconventional" would be "those which are not toxic or conventional", and some examples are: chemical oxygen demand (COD), fluoride, and ammonia. "Toxic" pollutants are those that cause harmful effects, either acute or chronic, at very low concentrations; examples of some designated toxic substances are: nickel, chloroform, or benzidine.

2.2.2 Mixing Zone Definitions

The mixing zone is defined as an "**allocated impact zone**" where numeric water quality criteria can be exceeded as long as acutely toxic conditions are prevented. A mixing zone can be thought of as a limited area or volume where the initial dilution of a discharge occurs (21). Water quality standards apply at the boundary of the mixing zone, not within the mixing zone itself. The U.S. EPA and its predecessor agencies have published numerous documents giving guidance for determining mixing zones. Guidance published by U.S. EPA in the 1984 Water Quality Standards Handbook (21) supersedes these sources.

In setting requirements for mixing zones, U.S. EPA (22) requires that "the area or volume of an individual zone or group of zones be limited to an area or volume as small as practicable that will not interfere with the designated uses or with the established community of aquatic life in the segment for which the uses are designated," and the shape be "a simple configuration that is easy to locate in the body of water and avoids impingement on biologically important areas," and "shore hugging plumes should be avoided."

The U.S. EPA rules for mixing zones recognize the State has discretion whether or not to adopt a mixing zone and to specify its dimensions. The U.S. EPA allows the use of a mixing zone in permit applications except where one is prohibited in State regulations. A previous review (5) of individual State mixing zone policies (1,22) found that 48 out of 50 States make use of a mixing zone in some form; the exceptions are Arizona and Pennsylvania. State regulations dealing with streams or rivers generally limit mixing zone widths or cross-sectional areas, and allow lengths to be determined on a case by case basis.

In the case of lakes, estuaries and coastal waters, some states specify the surface area that can be affected by the discharge. The surface area limitation usually applies to the underlying water column and benthic area. In the absence of specific mixing zone dimensions, the actual shape and size is determined on a case-by-case basis.

Special mixing zone definitions have been developed for the discharge of municipal wastewater into the coastal ocean, as regulated under Section 301(h) of the Clean Water Act (23). Frequently, these same definitions are used also for industrial and other discharges into coastal waters or large lakes, resulting in a plurality of terminology. For those discharges, the mixing zone was labeled as the "**zone of initial dilution**" in which rapid mixing of the waste stream (usually the rising buoyant fresh water plume within the ambient saline water) takes place. EPA requires that the "zone of initial dilution" be a regularly shaped area (e.g. circular or rectangular) surrounding the discharge structure (e.g. submerged pipe or diffuser line) that encompasses the regions of high (exceeding standards) pollutant concentrations under design conditions (23). In practice, limiting boundaries defined by dimensions equal to the water depth measured horizontally from any point of the discharge structure are accepted by the EPA provided they do not violate other mixing zone restrictions (23).

2.2.3 Special Mixing Zone Requirements for Toxic Substances

The U.S. EPA maintains two water quality criteria for the allowable concentration of toxic substances: a criterion maximum concentration

(CMC) to protect against acute or lethal effects; and a criterion continuous concentration (CCC) to protect against chronic effects (1). The CMC value is greater than or equal to the CCC value and is usually more restrictive. The CCC must be met at the edge of the same regulatory mixing zone specified for conventional and nonconventional discharges.

Lethality to passing organisms within the mixing zone can be prevented in one of four ways:

The first alternative is to meet the CMC criterion within the pipe itself.

The second alternative is to meet the CMC within a short distance from the outfall. If dilution of the toxic discharge in the ambient environment is allowed, a **toxic dilution zone (TDZ)**, which is usually more restrictive than the legal mixing zone for conventional and nonconventional pollutants, may be used. The revised 1991 Toxics TSD document (1) recommends for new discharges a minimum exit velocity of 3 meters per second (10 feet per second) in order to provide sufficiently rapid mixing that would minimize organism exposure time to toxic material. The TSD does not set a requirement in this regard, recognizing that the restrictions listed in the following paragraph can in many instances also be met by other designs, especially if the ambient velocity is large.

As the third alternative, the outfall design must meet the most restrictive of the following geometric restrictions for a TDZ:

---   The CMC must be met within 10% of the distance from the edge of the outfall structure to the edge of the regulatory mixing zone in any spatial direction.

---   The CMC must be met within a distance of 50 times the discharge length scale in any spatial direction. The discharge length scale is defined as the square-root of the cross-sectional area of any discharge outlet. This restriction is intended to ensure a dilution factor of at least 10 within this distance under all possible circumstances, including

situations of severe bottom interaction and surface interaction.

---   The CMC must be met within a distance of 5 times the local water depth in any horizontal direction. The local water depth is defined as the natural water depth (existing prior to the installation of the discharge outlet) prevailing under mixing zone design condition (e.g. low flow for rivers). This restriction will prevent locating the discharge in very shallow environments or very close to shore, which would result in significant surface and bottom concentrations (1).

A fourth alternative is to show that a drifting organism would not be exposed more than 1-hour to average concentrations exceeding the CMC.

2.2.4   Current Permitting Practice on Mixing Zones

It is difficult to generalize the actual practice in implementing the mixing zone regulations, given the large number and diverse types of jurisdictions and permit-granting authorities involved. By and large, however, current procedure falls into one of the following approaches, or may involve a combination thereof.

(i) The mixing zone is defined by some numerical dimension, as discussed above. The applicant must then demonstrate that the existing or proposed discharge meets all applicable standards for conventional pollutants or for the CCC of toxic pollutants at the edge of the specified mixing zone.

(ii) No numerical definition for a mixing zone may apply. In this case a mixing zone dimension may be proposed by the applicant. To do so the applicant generally uses actual concentration measurements for existing discharges, dye dispersion tests or model predictions to show at what plume distance, width, or region, the applicable standard will be met. The applicant may then use further ecological or water use-oriented arguments to demonstrate that

the size of that predicted region provides reasonable protection. The permitting authority may evaluate that proposal, or sometimes pursue its own independent proposal for a mixing zone.

This approach resembles a negotiating process with the objective of providing optimal protection of the aquatic environment consistent with other uses.

As regards the acute, or CMC, criterion for toxic pollutants, the spatial restrictions embodied in the Toxics TSD document (1) call for very specific demonstrations of how the CMC criterion is met at the edge of the "toxic dilution zone". Again, field tests for existing discharges or predictive models may be used.

2.2.5 Relationship Between Actual Hydrodynamic Processes and Mixing Zone Dimensions

The spatial requirements in mixing zone regulations are not always correlated with the actual hydrodynamic processes of mixing. With few exceptions, the toxic dilution criteria apply to the near-field of most discharges since the TDZ criteria (2) are spatially highly restrictive. The regular mixing zone boundaries, however, may be located in the near-field or the far-field of the actual effluent discharge flow since they are administratively determined by the permit-granting authority. Thus, the analyst must have tools at his disposal with the capability to address both the near and far-field situations.

III General Features of the CORMIX System

This section provides a general description of common features of CORMIX. CORMIX Version 3.1 has three different subsystem modules for diverse discharge conditions. The subsystems are CORMIX1, CORMIX2, and CORMIX3 for the analysis of submerged single port, submerged multiport, and buoyant surface outfall configurations, respectively. Furthermore, two post-processor models CORJET, a near-field jet integral model, and FFLOCATR, a far-field plume locator in non-uniform channels, are included. The following two sections give a detailed guidance for developing the required input data and for understanding program output. Reference is made throughout this document to CORMIX Version 3.1 dated June 1995 or Version 3.2 dated September 1996; other versions may differ somewhat.

3.1 Overview

The CORMIX system represents a robust and versatile computerized methodology for predicting both the qualitative features (e.g. flow classification) and the quantitative aspects (e.g. dilution ratio, plume trajectory) of the hydrodynamic mixing processes resulting from different discharge configurations and in all types of ambient water bodies, including small streams, large rivers, lakes, reservoirs, estuaries, and coastal waters. The methodology: (a) has been extensively verified by the developers through comparison of simulation results to available field and laboratory data on mixing processes (5,6,7,8), (b) has undergone independent peer review in journal proceedings (9,10,11,12,13, 14,15,16,17) and (c) is equally applicable to a wide range of problems from a simple single submerged pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in a deeply stratified coastal water.

System experience suggests that CORMIX1 applies to better than 95% of submerged single-port designs, CORMIX2 to better than 80% of multiport diffusers, and CORMIX3 to better than 90% of surface discharges. Lack of applicability is usually given by highly non-uniform ambient flow conditions that are prone to locally recirculating flows. Other non-applicable cases may arise to complicated discharge geometries in which case CORMIX advises the user not to proceed with the analysis. Whenever the model is applicable extensive comparison with available field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations, with associated plume geometries, are accurate to within ± 50 % (standard deviation).

The methodology provides answers to questions that typically arise during the application of mixing zone regulations for both conventional and toxic discharges. More importantly, this is accomplished by utilizing the customary approaches often used in evaluating and implementing mixing zones, thereby providing a common framework for both applicants and regulatory personnel to arrive at a consensus view of the available dilution and plume trajectory for the site and effluent discharge characteristics.

The methodology also provides a way for personnel with little or no training in hydrodynamics to investigate improved design solutions for aquatic discharge structures. To limit misuse, the system contains limits of applicability that prevent the simulation of situations for which no safe predictive methodology exists, or for discharge geometries that are undesirable from a hydrodynamic viewpoint. Furthermore, warning labels, data screening mechanisms, and alternative design recommendations are furnished by the system. The system is not fool proof, however, and final results should always be examined for reasonableness.

Finally, CORMIX is an educational tool that intends to make the user more knowledgeable and appreciative about effluent discharge and mixing processes. The system is not simply a black box that produces a final numerical or graphical output, but contains an interactive menu of user guidance, help options, and explanatory material of the relevant physical processes. These assist users in understanding model predictions and exploring the sensitivity of model predictions to assumptions.

3.2 Capabilities and Major Assumptions of the Three Subsystems and the Post-Processor Models

3.2.1 CORMIX Subsystems

CORMIX1 predicts the geometry and dilution characteristics of the effluent flow resulting from a **submerged single port diffuser discharge**, of arbitrary density (positively, neutrally, or negatively buoyant) and arbitrary location and geometry, into an ambient receiving water body that may be stagnant or flowing and have ambient density stratification of different types.

CORMIX2 applies to three commonly used types of **submerged multiport diffuser discharges** under the same general effluent and ambient conditions as CORMIX1. It analyzes unidirectional, staged, and alternating designs of multiport diffusers and allows for arbitrary alignment of the diffuser structure within the ambient water body, and for arbitrary arrangement and orientation of the individual ports. For complex hydrodynamic cases, CORMIX2 uses the "equivalent slot diffuser" concept and thus neglects the details of the individual jets issuing from each diffuser port and their merging process, but rather assumes that the flow arises from a long slot discharge with equivalent dynamic characteristics. Hence, if details of the effluent flow behavior in the immediate diffuser vicinity are needed, an additional CORMIX1 simulation for an equivalent partial effluent flow may be recommended.

CORMIX3 analyzes **buoyant surface discharges** that result when an effluent enters a larger water body laterally, through a canal, channel, or near-surface pipe. In contrast to CORMIX1 and 2, it is *limited to positively or neutrally buoyant effluents.* Different discharge geometries and orientations can be analyzed including flush or protruding channel mouths, and orientations normal, oblique, or parallel to the bank.

Additional major assumptions include the following:

--- All subsystems require that the actual cross-section of the water body be described as a rectangular straight uniform channel that may be bounded laterally or unbounded. The ambient velocity is assumed to be uniform within that cross-section.

--- In addition to a uniform ambient density possibility, CORMIX allows for three generic types of ambient stratification profiles to be used for the approximation of the actual vertical density distribution (see Section 4.3).

--- All CORMIX subsystems are in principle **steady-state models**, however recent developments (beginning with Version 3.1) allow the analysis of **unsteady mixing in tidal environments**.

--- All CORMIX systems can predict mixing for both conservative and first-order decay processes, and can simulate heat transfer from thermal plumes.

3.2.2 Post-Processor Models CORJET and FFLOCATR

CORJET, the Cornell Buoyant Jet Integral Model, is a **buoyant jet integral model** that predicts the jet trajectory and dilution characteristics of a single round jet or of a series of merging jets from a multiport diffuser with arbitrary discharge direction and positive, neutral or negative buoyancy in a general ambient environment. The ambient conditions can be highly non-uniform with both ambient current magnitude, current direction, and density a function of vertical distance. In general, CORJET can be used as an enhancement to the near-field predictions provided by CORMIX1 or 2 in order to investigate local details that have been simplified within the CORMIX representation. The major limitation of CORJET lies in the assumption of an *infinite receiving water body*, similar to all other available jet integral type models. Thus, CORJET should only be used after an initial CORMIX classification has shown that the single or multiple port discharge is indeed of the deep water type, i.e. hydrodynamically stable, without boundary interactions.

FFLOCATR, the Far-Field Plume Locator, uses the **cumulative discharge method** to delineate the CORMIX predicted far-field plume

within the actual irregular (meandering or winding) river or estuary channel geometry with uneven distribution of the ambient flow.

3.3 System Processing Sequence and Structure

The general CORMIX layout appears in Figure 3.1, which shows the overall structure and the execution sequence of the program elements. The system has overall common data input features for the three different discharge elements. During program execution, the elements are loaded automatically and sequentially by the system. Each element provides user interaction and prompting in response to displayed information. This may somewhat extend the total time required for a single CORMIX session, but has offsetting benefit of allowing the user to gain process knowledge and insight on design sensitivity.

The user has numerous options with the **Main Menu** at start-up. Option 1 is to start a new CORMIX session. Option 2 is to re-run and modify a former case. Option 3 is to simply re-display (without new computation) results of a former design case. Option 4 is to use the Post-Processor, which includes the CORJET near-field jet integral model, the FFLOCATR far-field locator, and the plume display graphics which will be discussed in Section V of this document. Option 5 is the file manager which lists all files from previous simulations. Option 6 is to set/change CORMIX system speed. Here the user can select REGULAR CORMIX, complete with detailed queries and user help, or FAST-CORMIX, which has terse questions and limited user help. Option 7 contains system information and reference material. Option 7 is to quit the CORMIX system and return to DOS.

The common program elements of CORMIX are composed of DATIN, PARAM, CLASS, HYDRO, and SUM (Figure 3.1). DATIN is the program element for the entry of data and initialization of other program elements. PARAM uses the input data to compute a number of important physical parameters and length scales, as precursor to CLASS which performs the hydrodynamic classification of the given discharge/ambient situation into one of many

possible generic flow configurations. HYDRO performs the actual detailed numerical prediction of the effluent plume characteristics. Finally, SUM summarizes the results from the classification and prediction, interprets them as regards mixing zone regulations, suggests design alternatives, and allows sensitivity analysis to be conveniently conducted using the current input data. At this point the **iteration menu** allows the user to perform an iteration with different ambient/discharge/regulatory conditions, or start a new design case, or make use of the post-processor options.

Due to its diverse programming requirements, CORMIX is written in two programming languages: VP-Expert, an "expert systems shell", and Fortran. The former is powerful in knowledge representation and logical reasoning, while the latter is adept at mathematical computations. Program elements DATIN, PARAM, CLASS, and SUM are written exclusively in VP-Expert. HYDRO is written in VP-Expert, but uses three Fortran executables HYDRO1, 2 and 3 for the actual detailed computation of plume characteristics. Finally, C++ is used in the specially developed graphics package CMXGRAPH.

3.4 CORMIX Data Input Features

All data is entered interactively in response to the CORMIX system prompts generated by the data input program element DATIN. DATIN queries the user for a complete specification of the physical environment of the discharge, as well as the applicable regulatory considerations for the situation undergoing analysis. A CORMIX session commences with questions on four topics which are asked sequentially in this order: site/case descriptions, ambient conditions, discharge characteristics, and regulatory mixing zone definitions. Data entry is entirely guided by the system and the available advice menu options provide expanded descriptions of the questions, if clarification is needed.

Chapter IV provides complete details on input specification for the three CORMIX discharge subsystems. Chapter VI deals with the input features of the post-processor models CORJET and FFLOCATR.
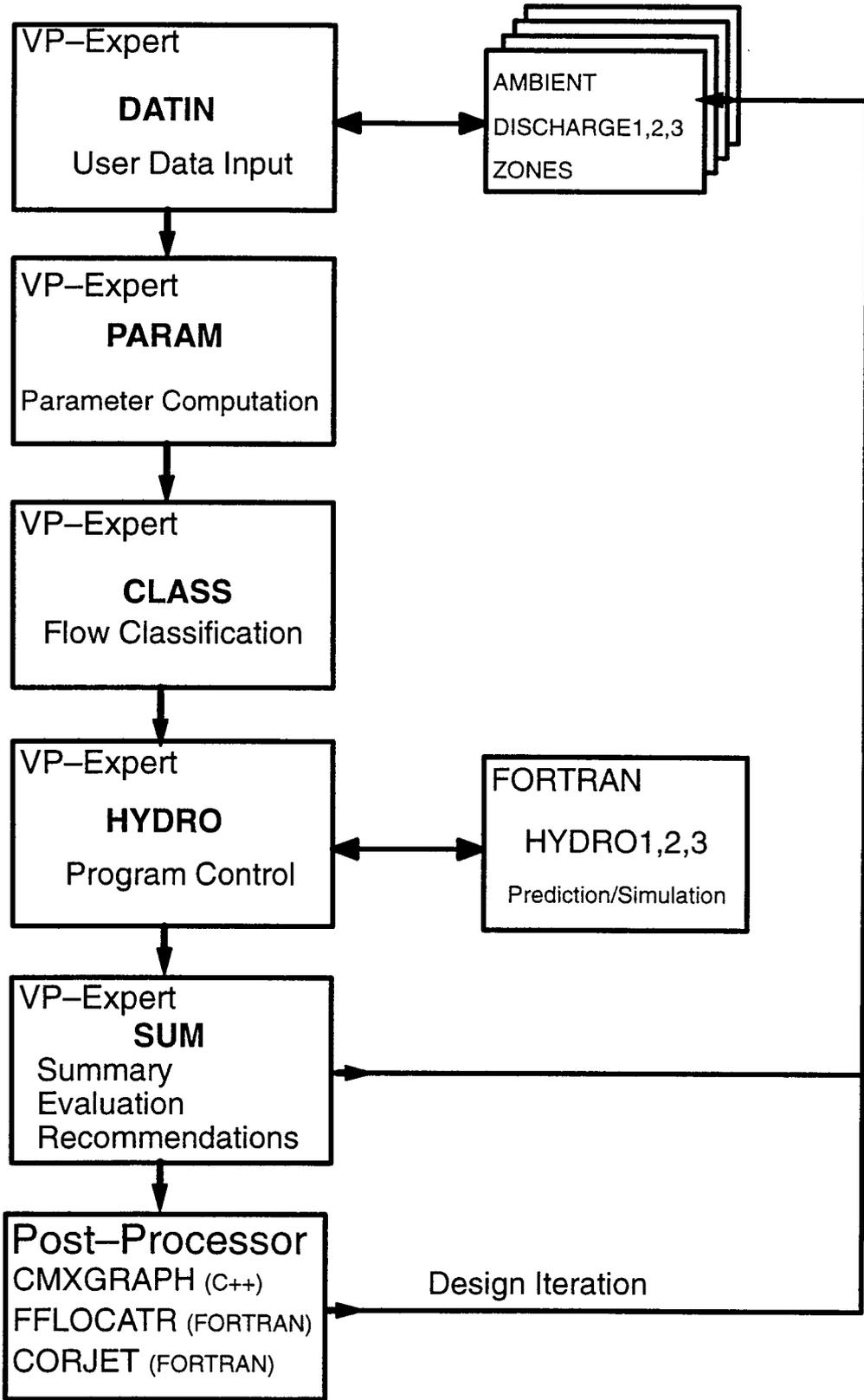
Figure 3.1: CORMIX system elements and processing sequence

3.5 Logic Elements of CORMIX: Flow Classification

To make predictions of an effluent discharge's dilution and plume trajectory, CORMIX typically combines the solutions of several simple flow patterns to provide a complete analysis from the efflux location all the way into the far-field.

The logic processing elements of CORMIX identify which solutions should be combined to provide the complete analysis. This process, called **flow classification**, develops a generic qualitative description of the discharge flow and is based on known relationships between flow patterns and certain calculated physical parameters.

PARAM is the program element that computes relevant physical parameters including: the various length scales, fluxes, and other values needed for the execution of other program elements. Length scales are calculated measures of the length of dynamic influence of various physical processes (see Chapters IV and V).

At the heart of CORMIX is a flow classification system contained in the program element CLASS. It provides a rigorous and robust expert knowledge base that carefully distinguishes among the many hydrodynamic flow patterns that a discharge may exhibit. As examples, these possibilities include discharge plumes attaching to the bottom, plumes vertically mixing due to instabilities in shallow water, plumes becoming trapped internally due to density stratification, and plumes intruding upstream against the ambient current due to buoyancy, and many others. Theoretically based hydrodynamic criteria using length scale analysis and empirical knowledge from laboratory and field experimentation, are applied in a systematic fashion to identify the most appropriate flow classification for a particular analysis situation. For all three subsystems, a total of about 80 generic flow configurations or classes can be distinguished.

The classification procedure of CORMIX is based on technical principles and has been verified by the developers through repeated testing and data comparison. It has also undergone independent peer review and the four documentation manuals (5,6,7,8) give the detailed scientific background for the classification scheme, in form of a number of criteria. The actual criteria constants are listed in the technical reports with comments on their sources and degree of reliability. Experienced users, especially those involved in research applications, may want to inspect these data values contained in the source code and occasionally vary some constant values within certain limits in order to examine improved prediction fits with available high-quality data. Extreme caution must be exercised when doing that as some values are interdependent; furthermore, if changes are made, they should be carefully documented.

When CLASS has executed, a description of the particular flow class is available to the user in the form of on-screen or hardcopy computer output; these description are also contained in the documentation reports (5,6,7). It is recommended that the novice or intermediate user review these to gain an appreciation of the involved hydrodynamic mixing processes.

3.6 Simulation Elements of CORMIX: Flow Prediction

Once a flow has been classified, CORMIX assembles and executes a sequence of appropriate hydrodynamic simulation modules in the program element HYDRO1, 2 or 3. HYDRO consists of: (a) control programs or "protocols" for each hydrodynamic flow classification and (b) a large number of subroutines or "simulation modules" corresponding to the particular flow processes, and their associated spatial regions, that occur within a given flow classification. The simulation modules are based on buoyant jet similarity theory, buoyant jet integral models, ambient diffusion theory, and stratified flow theory, and on simple dimensional analysis, as described elsewhere (5,6,7,8). The basic tenet of the simulation methodology is to arrange a sequence of relatively simple simulation modules which, when executed together, predict the trajectory and dilution characteristics of a complex flow. Each of the simulation models uses the final values of the previous module as "initial conditions".

3.7 CORMIX Output Features: Design Summary and Iterations

In addition to the narrative feedback during user input, the CORMIX system provides three types of output on-screen or in print: a) CORMIX Session Report that is a narrative summary, mostly for regulatory evaluation, of all discharge input data and global plume features, including compliance with mixing zone regulations, b) CORMIX1, 2 or 3 Prediction File that is a detailed listing of all plume properties as predicted by the Fortran program, and c) CMXGRAPH Plots representing plan, side, and trajectory views and concentration distribution of the predicted plume.

3.7.1 CORMIX Session Report

SUM is the final program element that summarizes the hydrodynamic simulation results for the case under consideration. The output in the CORMIX Session Report is arranged in four groups:

(1) Site summary gives the site identifier information, discharge and ambient environment data, and discharge length scales.

(2) Hydrodynamic simulation and mixing zone summary lists conditions at the end of the near-field region (NFR), regulatory mixing zone (RMZ) conditions, toxic dilution zone (TDZ) conditions, region of interest (ROI) conditions, upstream intrusion information, bank attachment locations, and a passive diffusion mixing summary. Users should be cognizant of the four major zone definitions, and associated acronyms, introduced above and defined as follows:

Near-Field Region (NFR): The NFR is simply the zone of strong initial mixing, corresponding to the "near-field" processes discussed in Chapter II. It has no regulatory implication whatsoever. However, the information on size and mixing conditions at the edge of the NFR is given as a useful guide to the discharge designer because mixing in the NFR is usually sensitive to design conditions, and therefore somewhat controllable. A notable exception is the effluent discharge into very shallow flow-limited streams where the actual discharge port design detail may have little bearing on instream concentrations.

Regulatory Mixing Zone (RMZ): The RMZ corresponds to either: (1) the applicable mixing zone regulation with specified size dimensions, or (2) a preliminary proposal for a mixing zone (see Section 2.2.4 (ii)).

Toxic Dilution Zone (TDZ): The TDZ corresponds to the EPA's definition of where toxic chemical concentrations may exceed the CMC value (see Section 2.2.3).

Region of Interest (ROI): The ROI is a user defined region of the receiving water body where mixing conditions are to be analyzed. It is specified as the maximum analysis distance in the direction of mixed effluent flow and is particularly important when legal mixing zone restrictions do not exist or when information over a larger area is of interest.

(3) Data analysis section presents further details on toxic dilution zone criteria, regulatory mixing zone criteria, stagnant ambient environment information, and region of interest criteria.

(4) Design recommendations section contains design suggestions in three general areas for improving initial dilution. These include: (a) geometry variations in discharge port design, (b) sensitivity to ambient conditions, and (c) process variations in discharge flow characteristics. The user is given guidance on the potential changes in mixing conditions from varying parameter values within these groups.

Finally, SUM is also used as an interactive loop to guide the user back to DATIN to alter design variables and perform sensitivity studies. Different options for iteration exist on the **iteration menu** depending on what input data changes are to be made. The importance of performing an ample number of CORMIX iterations cannot be sufficiently stressed. To obtain a design that

adequately meets water quality and engineering construction objectives, it is necessary to get a feel for the physical situation and its sensitivity to design changes through repeated system use.

3.7.2 CORMIX1, 2 or 3 Prediction File

The CORMIX1, 2 or 3 Prediction File is a detailed listing of all simulation input data as well as the predicted plume properties (plume shapes and concentration distributions) arranged by the individual flow modules that form part of the simulation. Additional information, such as encounter of local mixing zone regulations, plume contact with bottom or shoreline, etc., are listed in the output. Detailed output features are discussed in Chapter V.

3.7.3 CMXGRAPH Plots

The post-processing graphics package CMXGRAPH can be exercised flexibly by the user at different stages: directly after a CORMIX case prediction for an initial evaluation of the design case, or later to inspect or prepare plots for an earlier design case, or outside the CORMIX system to plot any plume predicted by CORMIX or CORJET. The user can view different views of the plume, with scaling and zooming possibilities. Finally, hardcopy printouts can be prepared through a direct print-screen option or by writing to a Postscript file. Details of the graphics feature are discussed in Chapter V.

3.8 Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The near-field jet integral model CORJET and the far-field plume locator model FFLOCATR can be exercised both within the CORMIX system, with guided input data assembly, or separately, with a simple Fortran input file. In both cases, only limited data are needed. Chapter VI provides a detailed discussion of the data requirements.

The output from these models is displayed on-screen or as a printed file. Furthermore, CORJET output can also be plotted with the CMXGRAPH program (see Section 5.3).

3.9 Equipment Requirements, System Installation and Run Times

The minimum recommended hardware configuration required for CORMIX is an IBM-DOS compatible microcomputer with: (a) a minimum of 550Kb of available RAM memory, (b) approximately 3Mb of hard disk space, (c) DOS 3.3 or higher operating system, and (d) a minimum 80386 with math co-processor to provide acceptable performance, especially with plume graphics display. The system will run on systems with less advanced processors, however simulation times can be long.

The RAM memory requirement of CORMIX may present an obstacle to many users because the configuration requirements of many commercial applications packages and the installation of memory resident software, or running DOS from windows, frequently reduce available RAM memory to less than 550Kb. The amount of available RAM memory can be determined with the DOS command CHKDSK. Although there are numerous approaches for increasing the size of a computer's available RAM memory, the simplest way is "boot" the computer from a floppy "system" disk that contains no AUTOEXEC.BAT or CONFIG.SYS files which consume additional memory. This should be done just prior to beginning an analysis session since it will temporary disable programs that consume RAM memory. The CONFIG.SYS file should allow the number of open files to be set to at least 20 by including the line statement "files=20". At the completion of the analysis session, the computer should be "booted" from the hard drive to restore normal operations. A bootable floppy system disk can be created with the DOS command FORMAT a:/S.

The CORMIX must be installed on a hard disk drive. The directory structure of CORMIX (Table 3.1) is fixed; it gets set up during the installation process; and it consists of a subsystem root directory, called "CORMIX", and six sub-directories. Complete installation instructions are available with the CORMIX distribution diskette.

Depending on computer configuration, a typical CORMIX session for one discharge/ambient condition may take less than 5

minutes for an Pentium-based computer to about 20 minutes for an 80286-based computer if all necessary input data is at hand. In some unusual cases (such as attached flow classes, e.g. H1A5) the numerical simulation routines in HYDROn may take up to 10 minutes to converge on Pentium-based systems.

Table 3.1
Directory Structure

CORMIX
Version 3.1 June 1995, Version 3.2 September 1996

Directory Name	Comments
CORMIX	system root directory; contains VP-Expert system files, the knowledge base program CORMIX.kmp or kbs (system driver), and the start-up batch file CMX.bat, and several other batch files to be used for starting up CORJET, CMXGRAPH, and FFLOCATR when used independently
CORMIX\DATA	contains cache "fact" files exported from knowledge base programs
CORMIX\EXE	contains Fortran hydrodynamic simulation programs HYDROn and file manipulation programs (*.exe)
CORMIX\KBS	contains all knowledge base programs (*.kmp or *.kbs)
CORMIX\POST	contains three post-processor programs CORJET, CMXGRAPH, and FFLOCATR
CORMIX\POST\CJ	contains CORJET numerical prediction files (fn.CJT) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\POST\FF	contains FFLOCATR cumulative discharge input data files (*.FFI) and prediction files (fn.FFX)
CORMIX\SIM	contains simulation results (Fortran files "fn.CXn", where n = 1,2,3, and fn = user designated filenames) and graphical postscript files (fn.Pvn, where v = view type, and n = 0 to 9)
CORMIX\SIM\CXn	contains simulation data files for each subsystem n (cache files "fn.CXC" and record keeping file "summary")
CORMIX\TEXT	contains all user-requested advice files and flow descriptions (*.txt)

IV CORMIX Data Input

4.1 General Aspects of Interactive Data Input

All CORMIX data input occurs interactively in response to system prompts and is entirely guided by the system. The user is automatically prompted for a complete specification of: site/case descriptions, ambient conditions, discharge characteristics, and regulatory definitions. The data for each of these four topical areas are called **input data sequences** herein. Questions are asked in plain English. Advice menu options within the program are available to provide help on how to prepare and enter data values when clarification of the system prompts is needed. The contents of these are also available in the documentation reports (5,6,7).

Regular CORMIX versus **FAST-CORMIX:** Upon in its initial installation the CORMIX system speed is set to "Regular CORMIX". In this mode the user will see detailed input questions with ample explanations for each variable. Also there will be opportunities to consult advice sections. It is recommended that the *novice user* employ this mode for about a dozen or so CORMIX sessions until he/she has become thoroughly familiar with the system. The *advanced user* can switch to the "FAST-CORMIX" mode in which only short questions are asked, thereby greatly accelerating data input and compacting it on screen. Certain advice section are not available. The differences are illustrated in the following:

Examples of three questions asked in **Regular CORMIX**:

```
1)    Do you want detailed ADVICE on how to specify the ambient density
      stratification?
            [no] [yes]

2)    Can the ambient density be considered 'UNIFORM' throughout the water column,
      or
      is there a 'NON-UNIFORM' vertical density stratification?
      As practical guideline, uniformity can be assumed if the vertical density
      variation between top and bottom is limited to 0.1 kg/m^3 or the  temperature
      variation to 1 degC.
            [uniform] [non-uniform]

3)    What is the WIDTH of the channel in the vicinity of the discharge (m)?
```

Corresponding questions in **FAST-CORMIX**:

```
1)    <Question not asked>

2)    AMBIENT DENSITY?
            [uniform] [non-uniform]

3)    Channel WIDTH (m)?
```

Data can be entered in an **open format** without concern for letter case or decimal placement.   The only constraint is that the following characters may not be entered in response to any question:
  + = { } , < > ' " / \ ;

The system checks data entries for consistency with question type (e.g. an alphabetic character for water depth), obvious physical errors (e.g. a negative length), possible inconsistencies with previous entries (e.g. an angular value implying that a port points directly back to the

shoreline) and situations outside the ranges of model applicability. Inconsistency with question type and obvious physical errors require immediate re-entry while possible inconsistencies with previous entries lead to a warning label and the opportunity for later correction. Entries specifying situations outside the ranges of model applicability usually require the re-entry of the entire data segment.

Warning: No attempt should be made to alter input data by manipulating any of the data files that are used by the HYDROn Fortran programs and execute these programs separately without using the VP-Expert segments DATIN, PARAM, and CLASS. Because of the inherent error and compatibility checking of input data within these program segments, unreliable prediction may result if they are by-passed!

As discussed in Chapter III, data input occurs in three or four program segments that load automatically. At the end of each data sequence (usually of the order of 5 to 20 items long) the entire sequence is displayed and the user is requested to accept or not accept the sequence. If it is not accepted, i.e. an error has been made, the user has another opportunity for entering the sequence. If an error is detected earlier there is no way of correcting immediately, it is best then to give a short answer (e.g. the value of 1) to all remaining questions and thus quickly move to the end of the sequence for the re-start opportunity.

Due to the similarity of data entry, a common description is given for all input data sequences, except discharge data to which a separate subsection for each CORMIXn subsystem is devoted below. Further guidance on data specification can be obtained from examining the case studies in the Appendices and from the documentation manuals (5,6,7). Following the discussion of input data sequences, units of measure conversion factors and checklists for input preparation are presented.

All the data input requirements of CORMIX are included in the **Checklist for Data Preparation** (see following page) that can be photocopied by the reader for future multiple use. The checklist aids in the assembly and preparation of this data prior to beginning an analysis to verify that all necessary data are available.

4.2 Site/Case Identifier Data

The first input data sequence determines basic information needed for the program to operate. These include: a two-part identifier for labeling output and a computer file name.

It is necessary to specify three site/case labels that facilitate the rapid identification of printed output and aid in good record-keeping. The system provides for one label called SITE NAME (e.g. Blue River), another called DESIGN CASE (e.g. 7Q10-low-flow, or High-velocity-port).

The user needs to supply a DOS-compatible FILE NAME, up to eight characters long, and without extension (e.g. sdif7q10). CORMIX will use that user-specified file name *fn*, and create, transfer, or store intermediate or final data files with that same file name, but with different extensions. The most important of these are the two output data files, SIM*fn*.CXn and SIM\\CXn*fn*.CXC, where n = 1, 2 or 3, which are discussed further in Chapter V.

4.3 Ambient Data

Ambient conditions are defined by the geometric and hydrographic conditions in the vicinity of the discharge. Due to the significant effect of boundary interactions on mixing processes, the ambient data requirements for the **laterally bounded** and **unbounded** analysis situations are presented separately in the discussions below. CORMIX analyses, as all mixing zone evaluations, are usually carried out under the assumption of **steady-state** ambient conditions. Even though the actual water environment is never in a true steady-state, this assumption is usually adequate since mixing processes are quite rapid relative to the time scale of hydrographic variations. In highly **unsteady tidal reversing flows** the assumption is no longer valid and significant concentration build-up can occur. CORMIX will assess this situation and compute some re-entrainment effects on plume behavior. The data requirements for that purpose are discussed in the Section 4.3.3. Following are discussions on ambient

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CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.00-3.20

SITE Name _____ Date: _____
Design **CASE** _____ Prepared by: _____
DOS **FILE NAME** _____ (w/o extension)

AMBIENT DATA: Water body is   bounded/unbounded
Water body depth _____ m   If bounded: Width _____ m
Depth at discharge _____ m   Appearance 1/2/3
If steady: Ambient flowrate _____ m³/s or: Ambient velocity _____ m/s

If tidal: Tidal period _____ hr Max. tidal velocity _____ m/s
     At time _____ hr before/at/after slack: Tidal velocity at this time _____ m/s

Manning's n _____ or: Darcy-Weisbach f _____
Wind speed _____ m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   fresh/salt water If fresh: Specify as density/temp. values
If uniform: Average density/temp. _____

If stratified: Density/temp. at surface _____
  Stratification type A/B/C Density/temp. at bottom _____
  If B/C: Pycnocline height _____ m If C: Density/temp. jump _____

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

> **SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1**
> Nearest bank is on left/right Distance to nearest bank _____ m
> Vertical angle THETA _____ ° Horizontal angle SIGMA _____ °
> Port diameter _____ m or: Port area _____ m²
> Port height _____ m

> **SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2**
> Nearest bank is on left/right Distance to one endpoint _____ m
> Diffuser length _____ m   to other endpoint _____ m
> Total number of openings _____ m Port height _____ m
> Port diameter _____ m with contraction ratio _____
> Diffuser arrangement/type unidirectional / staged / alternating or vertical
> Alignment angle GAMMA _____ ° Horizontal angle SIGMA _____ °
> Vertical angle THETA _____ ° Relative orientation BETA _____ °

> **BUOYANT SURFACE DISCHARGE -- CORMIX3**
> Discharge located on left/right bank Configuration flush/protruding/co-flowing
> Horizontal angle SIGMA _____ ° If protruding: Dist. from bank _____ m
> Depth at discharge _____ m Bottom slope _____ °
> If rectangular Width _____ m or: If circular Diameter _____ m
> discharge channel: Depth _____ m pipe: Bottom invert depth _____ m

Effluent: Flow rate _____ m³/s or: Effluent velocity _____ m/s
Effluent density _____ kg/m³ or: Effluent temperature _____ °C
Heated discharge? yes/no   If yes: Heat loss coefficient _____ W/m²,°C
Concentration units _____ Effluent concentration _____
Conservative substance? yes/no If no: Decay coefficient _____ /day

MIXING ZONE DATA:
Is effluent toxic? yes/no If yes: CMC _____ CCC _____
WQ stand./conventional poll.? yes/no If yes: value of standard _____
Any mixing zone specified? yes/no If yes: distance _____ m or width _____ % or m
        or area _____ % or m²

Region of interest _____ m Grid intervals for display _____

density specification and on wind effects.

CORMIX requires that the actual cross-section of the ambient water body be described by a rectangular channel that may be bounded laterally or unbounded. Furthermore, that channel is assumed to be uniform in the downstream direction, following the mean flow of the actual water body that may be non-uniform or meandering. The process of describing a receiving water body's geometry with a rectangular cross-section is herein called **schematization**.

Additional aids exist for the CORMIX user for interpreting plume behavior in the far-field of actual non-uniform (winding or meandering) flows in rivers or estuaries (see Section 6.2 for the post-processor option FFLOCATR).

The first step towards specifying the ambient conditions is to determine whether a receiving water body should be considered "bounded" or "unbounded." To do this, as well as answer other questions on the ambient geometry, it is usually necessary to have access to cross-sectional diagrams of the water body. These should show the area normal to the ambient flow direction at the discharge site and at locations further downstream. If the water body is constrained on both sides by banks such as in rivers, streams, narrow estuaries, and other narrow watercourses, then it should be considered "bounded." However, in some cases the discharge is located close to one bank or shore while the other bank is for practical purposes very far away. When interaction of the effluent plume with that other bank or shore is impossible or unlikely, then the situation should be considered "unbounded." This would include discharges into wide lakes, wide estuaries, and coastal areas.

4.3.1 Bounded Cross-Section

Both geometric (bathymetric) and hydrographic (ambient discharge) data should be used for defining the appropriate rectangular cross-section. This schematization may be quite evident for well-channeled and regular rivers or artificial channels. For highly irregular

cross-sections, it may require more judgment and perhaps several iterations of the analysis to get a better feel on the sensitivity of the results to the assumed cross-sectional shape.

In any case, the user is advised to consider the following comments:

a) Be aware that a particular flow condition such as a river discharge is usually associated with a certain water surface elevation or "stage." Data for a stage-discharge relationship is normally available from a USGS office; otherwise it can be obtained from a separate hydraulic analysis or from field measurements.

In the simplest case of a river flow, if river depth is known for a certain flow condition (subscript 1 in the following) corresponding perhaps to the situation at the time of a field study, then the depth for a given design (e.g. low) flow (subscript 2) can be predicted from Manning's equation

$$HA_2 = HA_1 \left[\frac{QA_2}{QA_1} \right]^{\frac{3}{5}}$$

in which QA is the ambient river flow and HA the mean ambient depth. This approach assumes that the both the ambient width and frictional characteristics of the channel (i.e. Manning's n) remain approximately the same during such a stage change.

b) For the given stage/river discharge combination to be analyzed, assemble plots showing the cross-sections at the discharge and several downstream locations. Examine these to determine an "equivalent rectangular cross-sectional area." Very shallow bank areas or shallow floodways may be neglected as unimportant for effluent transport. Also, more weight should be given to the cross-sections at, and close to, the discharge location since these will likely have the greatest effect on near-field processes. Figure 4.1a provides an example of the schematization process for a river or estuary cross-section.

"Nearest bank on the right"

Water level or tidal stage

BS

Actual cross-section (distorted scale)

Schematized bounded cross-section

HD

HA

DISTB
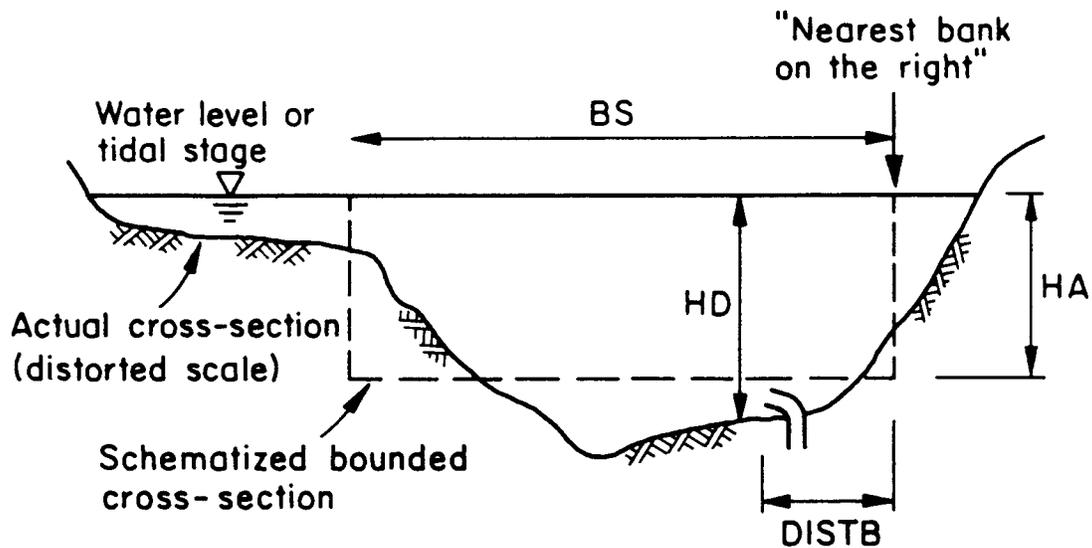
a) Example: Bounded Cross-Section Looking Downstream (River or Estuary)

"Nearest bank on the left"

DISTB

Design water level

HD

HA

Actual bathymetry (distorted scale)

Schematized unbounded cross-section
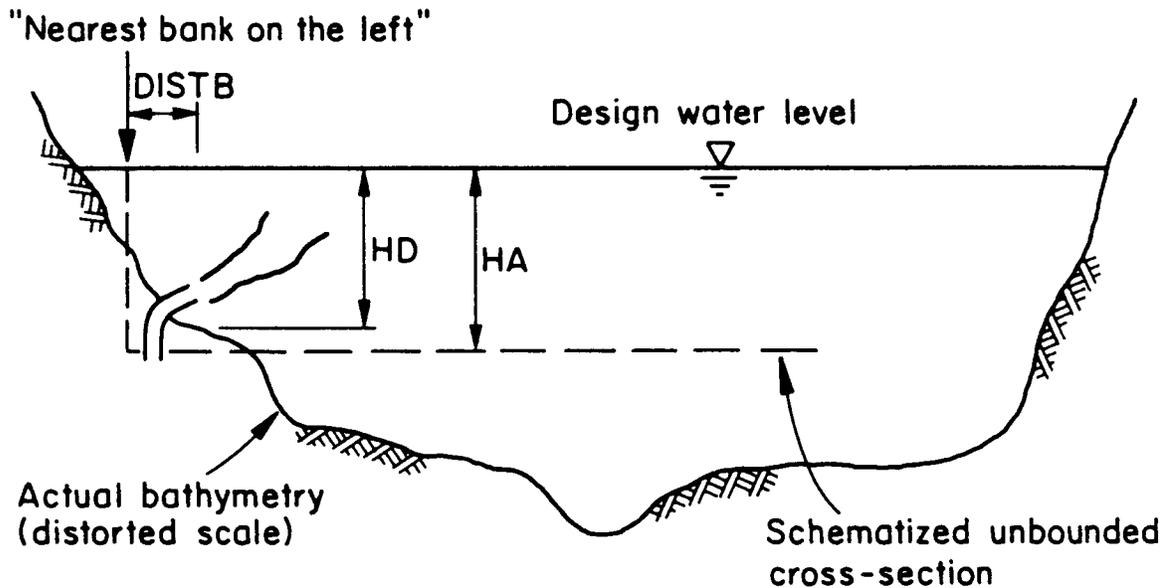
b) Example: Unbounded Cross-Section Looking Downstream (Small Buoyant Jet Discharge Into Large Lake or Reservoir)

Figure 4.1: Examples of the schematization process for preparing CORMIX input data on ambient cross-sectional conditions

c) The input data values for **surface width (BS)** and **(average) depth (HA)** should be determined from the equivalent rectangular cross-sectional area. When ambient discharge and ambient velocity data are available, the reasonableness of the schematization should be checked with the continuity relation. It specifies that ambient discharge equals velocity times cross-sectional area, where the area is given by the product of average width and depth.

The discussion of the cumulative discharge method (see Section 6.2 and Figure 6.2 for an illustration) will provide further perspective on the choice of these variables.

d) CORMIX also requires specification of the **actual water depth (HD)** in the general discharge location to describe local bathymetric features. A check is built in allowing the local depth HD not to differ from the schematized average depth HA by more than +/- 30%. This restriction is included to prevent CORMIX misuse in several discharge/ambient combinations involving strongly non-uniform channels. Alternative schematizations can be explored by the user to work around the restriction. The choice for these alternatives may be influenced somewhat by the expected plume pattern. As an example, Figure 4.1b illustrates a small buoyant discharge that is located on the side slope of a deep reservoir and that is rising upward. In this situation, the correct representation of the deeper mean reservoir depth is irrelevant for plume predictions. Although the illustration is for an unbounded example, the comments on choice of HA apply here, too.

When schematizing HA and HD in highly non-uniform conditions, HD is the variable that usually influences near-field mixing, while HA is important for far-field transport and never influences the near-field.

e) The **ambient discharge (QA)** or **mean ambient velocity (UA)** may be used to specify the ambient flow condition. Depending which is specified, the program will calculate and display the other. The displayed value should be checked to see whether it is consistent with schematizations and continuity principles discussed above.

The simulation of **stagnant conditions** should usually be avoided. If zero or a very small value for ambient velocity or discharge is entered, CORMIX will label the ambient environment as stagnant. In this case, CORMIX will predict only the near-field of the discharge, since steady-state far-field processes require a mean transport velocity. Although stagnant conditions often, but not necessarily always, represent the extreme limiting case for a dilution prediction, a real water body never is truly stagnant. Therefore, a more realistic assumption for natural water bodies would be to consider a small, but finite ambient crossflow.

f) As a measure of the roughness characteristics in the channel the value of **Manning's n**, or alternatively of the **Darcy-Weisbach friction factor f**, must be specified. Friction values are useful for applications in laboratory studies. If Manning's n is given, as is preferable for field cases, CORMIX internally converts it to an f friction value using the following equation

$$f = 8\,g\,\frac{n^2}{HA^{1/3}}$$

in which g = 9.81 m/s^2.

The friction parameters influence the mixing process only in the final far-field diffusion stage, and do not have a large impact on the predictions. Generally, if these values can be estimated within +/-30%, the far-field predictions will vary by +/-10% at the most. The following list is a brief guide for specification of Manning's n values; additional details are available in hydraulics textbooks (e.g. 24).

g) The **channel appearance** can have an effect on the far field mixing by increasing turbulent diffusivity for the passive mixing process, but will not significantly affect near-field mixing. Three channel appearance types are allowed in CORMIX. Type 1 are fairly straight and uniform channels. Type 2 have moderate downstream meander with a non-uniform channel. Type 3 are strongly winding and have highly irregular downstream cross-sections.

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Channel type	Manning's n
Smooth earth channel, no weeds	0.020
Earth channel, some stones and weeds	0.025
Clean and straight natural rivers	0.025 - 0.030
Winding channel, with pools and shoals	0.033 - 0.040
Very weedy streams, winding, overgrown	0.050 - 0.150
Clean straight alluvial channels	$0.031\ d^{1/6}$
(d = 75% sediment grain size in feet)	

4.3.2 Unbounded Cross-section

Both hydrographic and geometric information are closely linked in this case. The following comments apply:

a) From lake or reservoir elevation or tidal stage data, determine the water depth(s) for the receiving water condition to be analyzed.

b) For the given receiving water condition to be analyzed, assemble plots showing water depth as a function of distance from the shore for the discharge location and for several positions downstream along the ambient current direction.

c) If detailed hydrographic data from field surveys or from hydraulic numerical model calculations are available, determine the "**cumulative ambient discharge**" from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, determine the distance from the shore at which the same cumulative ambient discharge has been attained. Mark this position on all cross-sectional profiles. Examine the vertically averaged velocity and the depth at these positions to determine typical values for the **ambient depth (HA)** and **ambient velocity (UA)** input specifications. The conditions at, and close to, the discharge location should be given the most weight. The **distance from the shore (DISTB)** for the outfall location is typically specified as the cumulative ambient discharge divided by the product UA times HA.

When detailed hydrographic data are

unavailable, data or estimates of the vertically averaged velocity at the discharge location can be used to specify HA, UA, and DISTB. First, determine the cumulative cross-sectional area from the shore to the discharge location for the discharge cross-section. For each of the subsequent downstream cross-sections, mark the position where the cumulative cross-sectional area has the same value as at the discharge cross-section. Then proceed as discussed in the preceding paragraph.

d) The specification of the **actual water depth at the submerged discharge location (HD)** in CORMIX1 and 2 is governed by considerations that are similar to those discussed earlier for bounded flow situations discussed above. Figure 4.1b shows an illustration of the schematization for a small buoyant discharge located on the side slope of a deep reservoir. The plume is expected to rise upward and stay close to one shore, with bottom contact and vertical mixing not expected. In this situation, no emphasis on replicating the mean reservoir depth and the actual width is necessary. However, care must still be taken to specify an ambient mean velocity that is: (a) characteristic of the actual reservoir and (b) not determined using the reduced depth assumption.

The specification of HD for CORMIX3 is dictated by the depth condition some distance offshore from the discharge exit. It does not describe the conditions immediately in front of the discharge channel exit. When in doubt, set HD simply equal to HA in the CORMIX3 case.

e) Either **Manning's n** or the **Darcy-Weisbach friction factor f** can be specified for the ambient roughness characteristics as

described previously for the bounded case (see above). If the unbounded case represents a large lake or coastal area, it is often preferable to use the friction factor f. Typical f values for such open water bodies range from 0.020 to 0.030, with larger values for rougher conditions.

4.3.3 Tidal Reversing Ambient Conditions

When predictions are desired in an unsteady ambient flow field, information on the tidal cycle must be supplied. In general, estuaries or coastal waters can exhibit considerable complexity with variations in both velocity magnitude, direction and water depth. As an example, Figure 4.2 shows the time history of tidal velocities and tidal height for a mean tidal cycle at some site in Long Island Sound. The tidal height varies between mean Low Water (MLW) and Mean High water (MHW).

The tidal velocity changes its direction twice during the tidal cycle at times called slack tide. One of these times occurs near, but is not necessarily coincident with, the time MLW and is referred to as Low Water Slack (LWS). The slack period near MHW is referred to as High Water Slack (HWS). The rate reversal (time gradient of the tidal velocity) near these slack tides is of considerable importance for the concentration build-up in the transient discharge plume, as tidal reversals will reduce the effective dilution of a discharge by re-entraining the discharge plume remaining from the previous tidal cycle (8). Hence, CORMIX needs some information on the ambient design conditions relative to any of the two slack tides.
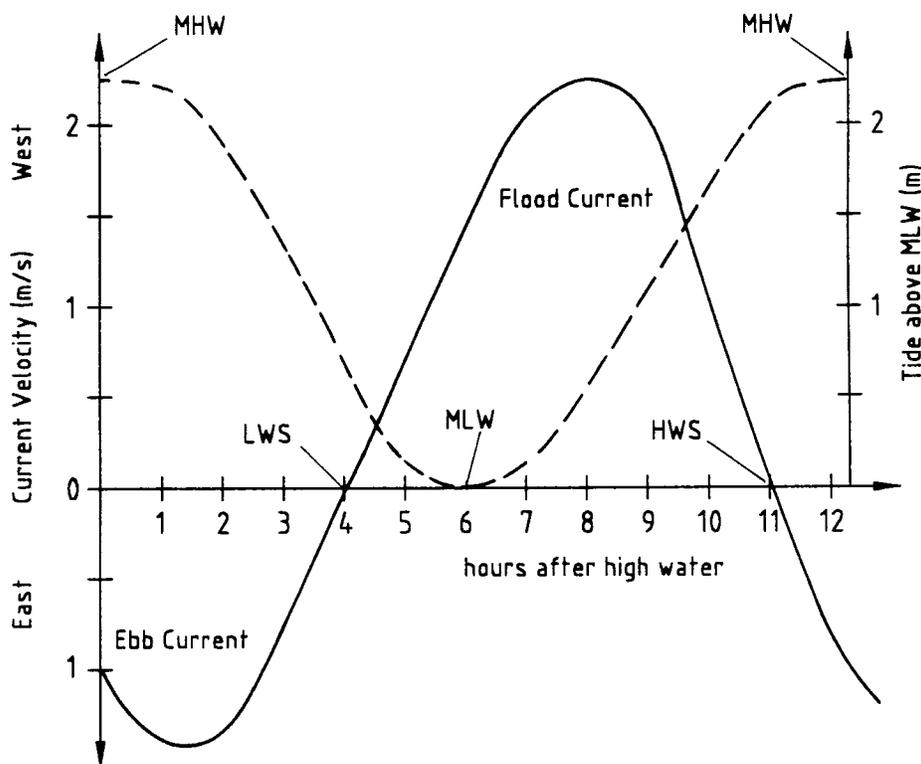
Figure 4.2: Example of tidal cycle, showing stage and velocity as a function of time after Mean High Water (MHW)

The **tidal period (PERIOD)** must be supplied; in most cases it is 12.4 hours, but in some locations it may vary slightly. The **maximum tidal velocity (UAmax)** for the location must be specified; this can usually be taken as the average of the absolute values of the two actual maxima, independent of their direction. A CORMIX design case consists then of an instantaneous ambient condition, before, at or after one of the two slack tides. Hence, the analyst must specify the **time** (in hours) **before, at, or after slack** that defines the design condition, followed by the actual **tidal ambient velocity (UA)** at that time. The ambient depth conditions are then those corresponding to that time.

In general, tidal simulations should be repeated for several time intervals (usually hourly or two-hourly intervals will suffice) before and after slack time to determine plume characteristics in unsteady ambient conditions.

Strongly unsteady conditions can also occur in other environments, such as in wind-induced current reversals in shallow lakes or coastal areas. In this case, any typical reversal period can be analyzed following an approach similar to the above.

4.3.4 Ambient Density Specification

Information about the density distribution in the ambient water body is very important for the correct prediction of effluent discharge plume behavior. CORMIX first inquires whether the ambient water is **fresh water** or **non-fresh** (i.e. brackish or saline). If the ambient water is fresh and above 4 $^{\circ}$C, the system provides the option of entering ambient temperature data so that the ambient density values can be internally computed from an equation of state. This is the recommended option for specifying the density of fresh water, even though ambient temperature per se is not needed for the analysis of mixing conditions. In the case of salt water conditions, Figure 4.3 is included as a practical guide for specifying the density if "salinity values" in parts-per-thousand (ppt) are available for the water body. Typical open ocean salinities are in the range 33 - 35 ppt.

The user then specifies whether the ambient density (or temperature) can be considered as **uniform** or as **non-uniform** within the water body, and in particular within the expected plume regions. As a practical guide, vertical variation in density of less than 0.1 kg/m^3 or in temperature of less than 1 $^{\circ}$C can be neglected. For uniform conditions, the **average ambient density** or **average temperature** must be specified.

When conditions are non-uniform, CORMIX requires that the actual measured vertical density distribution be approximated by one of three schematic stratification profile types illustrated in Figure 4.4. These are: Type A, linear density profile; Type B, two-layer system with constant densities and density jump; Type C, constant density surface layer with linear density profile in bottom layer separated by a density jump. Corresponding profile types exist for approximating a temperature distribution when it is used for specifying the density distribution.

Note: When in doubt about the specification of the ambient density values it is reasonable to first simplify as much as possible. The sensitivity of a given assumption can be explored in subsequent CORMIX simulations. Furthermore, if CORMIX indicates indeed a flow configuration (flow class) with near-field stability, additional studies with the post-processor option CORJET (see Section 6.1) can be performed to investigate *any arbitrary density distribution*.

After selecting the stratification approximation to be used, the user then enters all appropriate density (or temperature) values and **pycnocline heights (HINT)** to fully specify the profiles. The pycnocline is defined as zone or level of strong density change that separates the upper and lower layers of the water column. The program checks the density specification to insure that stable ambient stratification exists (i.e. the density at higher elevations must not exceed that at lower elevations).

Note that a dynamically correct approximation of the actua ldensity distribution should keep a balance between over-and under-estimationof the actual data similar to a best-fit in regression analysis. If simulation results indicate internal plume trapping, then it is

SEAWATER DENSITY (σ_t units)
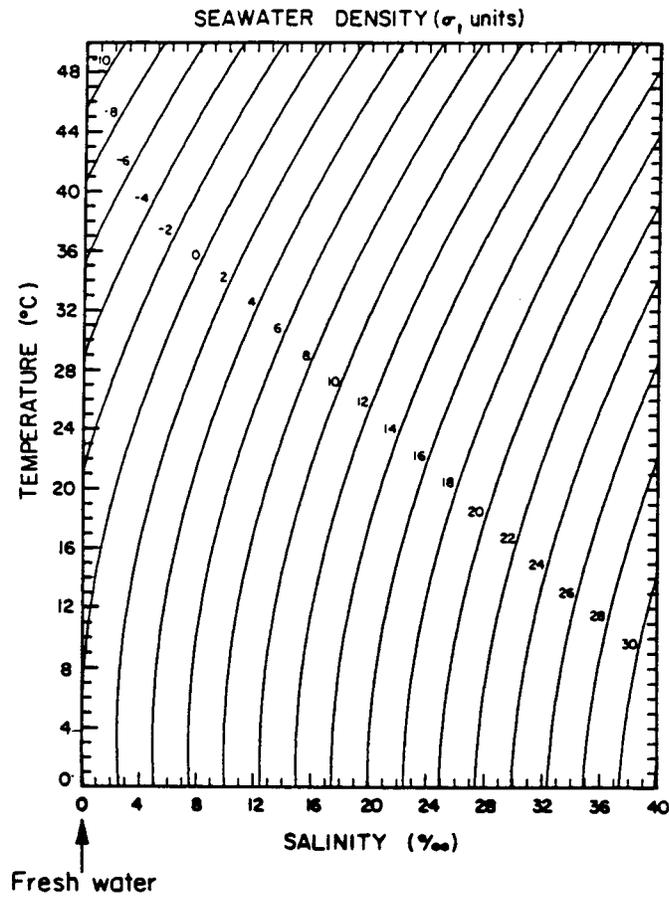
Density $[kg/m^3] = 1000.0 + \sigma_t$

Figure 4.3:   Diagram for density of seawater as a function of temperature and salinity
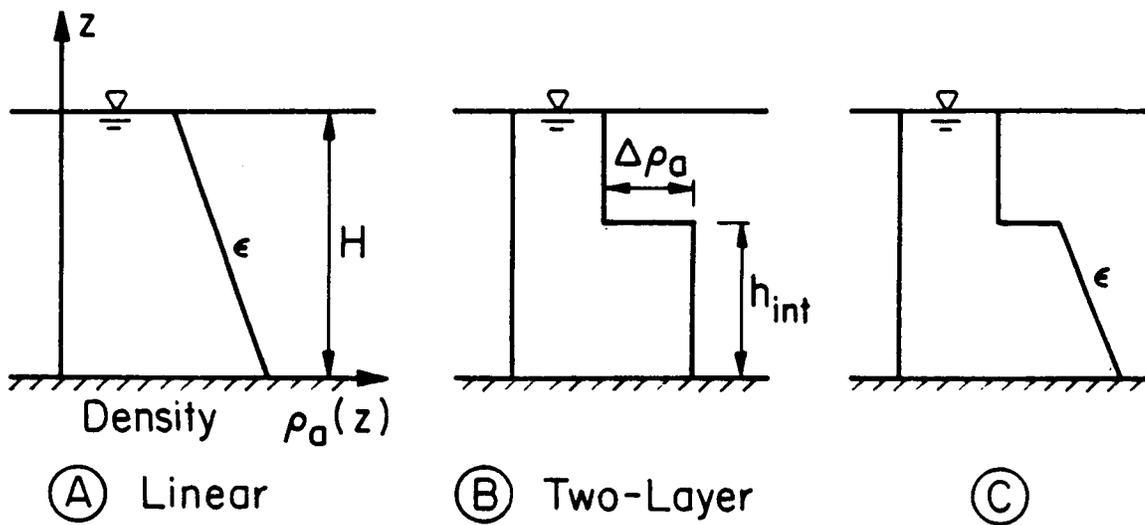
Figure 4.4:   Different approximations for representing the ambient density stratification

desirable to test --through repeated use of CORMIX-- different approximations (i.e. with different stratification types and/or parameter values) in order to evaluate the sensitivity of the resulting model predictions.

4.3.5 Wind speed

When specifying the **wind speed (UW)** at design conditions, it should be kept in mind that the wind is unimportant for near-field mixing, but may critically affect plume behavior in the far-field. This is especially important for heated discharges in the buoyant spreading regions. Wind speed data from adjacent meteorological stations is usually sufficient for that purpose.

The following guidelines are useful when actual measured data are not available.   The typical wind speed categories measured at the 10 m level are:

       ---   breeze (0-3 m/s)
       ---   light wind (3-15 m/s)
       ---   strong wind (15-30 m/s)

If field data are not available, consider using the recommended value of 2 m/s to represent conservative design conditions. An extreme low value of 0 m/s is usually unrealistic for field conditions, but useful when comparing to laboratory data. A wind speed of 15 m/s is the maximum value allowed in CORMIX.

4.4. Discharge Data: CORMIX1

Figure 4.5a is a definition sketch giving the geometry and flow characteristics for a submerged single port discharge within the schematized cross-section.

4.4.1 Discharge Geometry

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX1 requires the specification of 6 data entries. These specifications are illustrated in Figure 4.5a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **distance to the nearest bank (DISTB)**, (c) port **radius** (or **cross-sectional area**

for non-circular shaped ports) (*Note:* The specification of the port dimension should account for any contraction effects that the effluent jet may experience upon leaving the port/nozzle!) , (d) **height of the port (H0)** center above the bottom, (e) **vertical angle of discharge (THETA)** between the port centerline and a horizontal plane, and (f) **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerline. Angle THETA may range between -45° and 90°. As examples, the vertical angle is 90° for a discharge pointing vertically upward, and it is 0° for a horizontal discharge. Angle SIGMA may range between 0° and 360 $^{\circ}$. As examples, the horizontal angle is 0° (or 360 $^{\circ}$) when the port points downstream in the ambient flow direction, and it is 90°, when the port points to the left of the ambient flow direction.

In order to prevent an inappropriate system application, CORMIX1 checks the specified geometry for compliance with the three criteria illustrated in Figure 4.5b. These are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed HD's value for near-vertical designs, and one-third of HD's value for near-horizontal designs, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The port height restriction results from the fact that CORMIX1 only applies to submerged discharge applications.

In ordinary design practice, submerged implies a discharge close to the bottom, and not anywhere within the main water column or near the water surface. The port diameter restriction excludes very large discharge diameters relative to the actual water depth since these are unrealistic and/or undesirable.   The distance separating the upper and lower layers of the ambient density profile type B or C is restricted in order to prevent: (a) discharges into the upper layer or (b) an unrealistically thick plume relative to a thin upper layer. For those few extreme situations that would normally be limited by the above restrictions, Section 7.4 of Doneker and Jirka (5) contains a number of hints on how to conduct these difficult analyses; only advanced users should attempt these techniques.
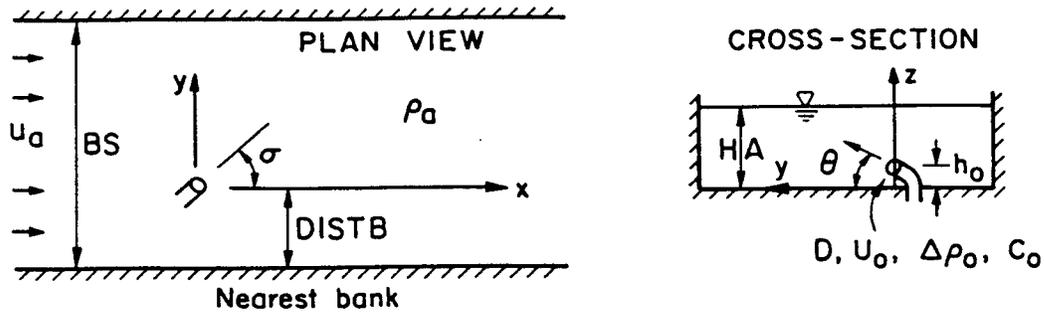
a) Definition Diagram CORMIX1 (Special case: HA = HD)
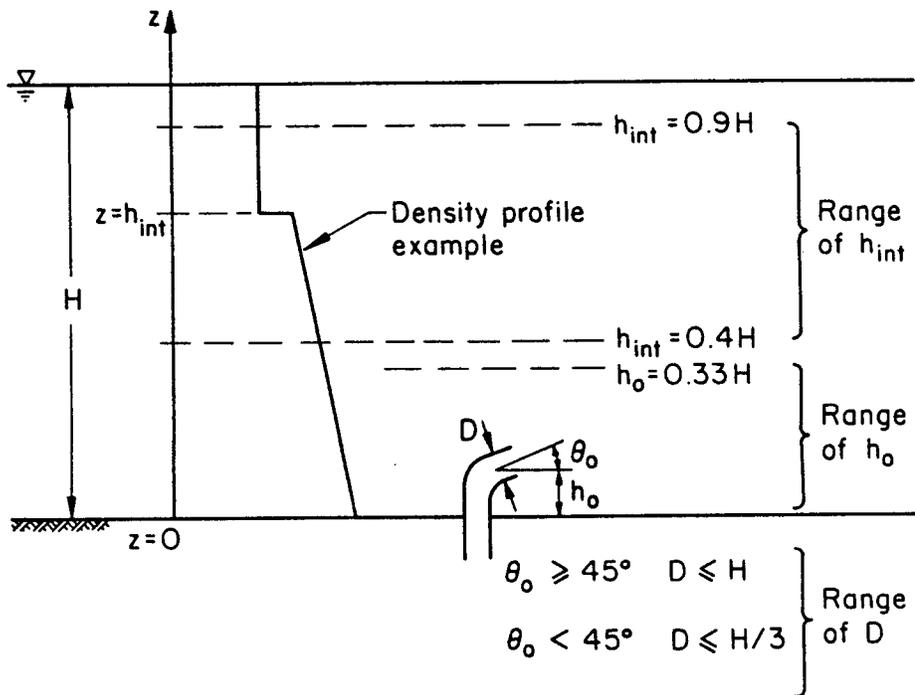
b) Limits of Applicability CORMIX1

Figure 4.5: CORMIX1 discharge geometry and restrictions

4.4.2 Port Discharge Flow

For discharge characteristics, CORMIX1 requires the specification of 3 data entries. These specifications include: (a) the **discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the port cross-sectional area and the program computes and displays the alternate value allowing for user inspection and verification. For a freshwater discharge, discharge density can be directly related to temperature via an equation of state since the addition of any pollutant or tracer has negligible effect on density.

The specification of the pollutant in the effluent is described in Section 4.7 below.

4.5 Discharge Data: CORMIX2

A generalized definition sketch showing the geometry and flow characteristics for a typical multiport diffuser installation is provided in Figure 4.6a. Due to the great number of complexities which may rise in describing an existing or proposed diffuser design, a few definitions are introduced prior to discussing actual data requirements of CORMIX2.

A **multiport diffuser** is a linear structure consisting of many more or less closely spaced ports or nozzles which inject a series of turbulent jets at high velocity into the ambient receiving water body. These ports or nozzles may be connected to vertical risers attached to an underground pipe or tunnel or they may simply be openings in a pipe lying on the bottom.

The **diffuser line** (or axis) is a line connecting the first port or nozzle and the last port or nozzle. Generally, the diffuser line will coincide with the connecting pipe or tunnel. CORMIX2 will assume a straight diffuser line. If the actual diffuser pipe has bends or directional changes it must be approximated by a straight diffuser line.

The **diffuser length** is the distance from the first to the last port or nozzle. The origin of the coordinate system used by CORMIX2 is located at the center (mid-point) of the diffuser line. The only exception is when the diffuser line starts at the shore; then the origin is located directly at the shore.

CORMIX2 can analyze discharges from the three major diffuser types used in common engineering practice. These are illustrated in Figure 4.7 and include: (a) the **unidirectional diffuser** where all ports (or nozzles) point to one side of the diffuser line and are oriented more or less normally to the diffuser line and more or less horizontally; (b) the **staged diffuser** where all ports point in one direction generally following the diffuser line with small deviations to either side of the diffuser line and are oriented more or less horizontally; and (c) the **alternating diffuser** where the ports do not point in a nearly single horizontal direction. In the latter case, the ports may point more or less horizontally in an alternating fashion to both sides of the diffuser line or they may point upward, more or less vertically.

4.5.1 Diffuser Geometry

CORMIX2 assumes uniform discharge conditions along the diffuser line. This includes the local ambient receiving water depth (HD) and discharge parameters such as port size, port spacing and discharge per port, etc. If the actual receiving water depth is variable (e.g. due to an offshore slope), it should be approximated by the mean depth along the diffuser line with a possible bias to the more shallow near-shore conditions. Similarly, mean values should be used to specify variable diffuser geometry when it occurs.

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX2 requires the specification of 13 data entries. These specifications are illustrated in Figure 4.6a and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) average **distance to the nearest bank (DISTB)**, (c) **average diameter (D0)** of the discharge ports or nozzles, (d) **contraction ratio** for the port/nozzle is required (This can range from 1 for well rounded ports --usual value-- down to 0.6 for sharp-edged orifices), (e) average
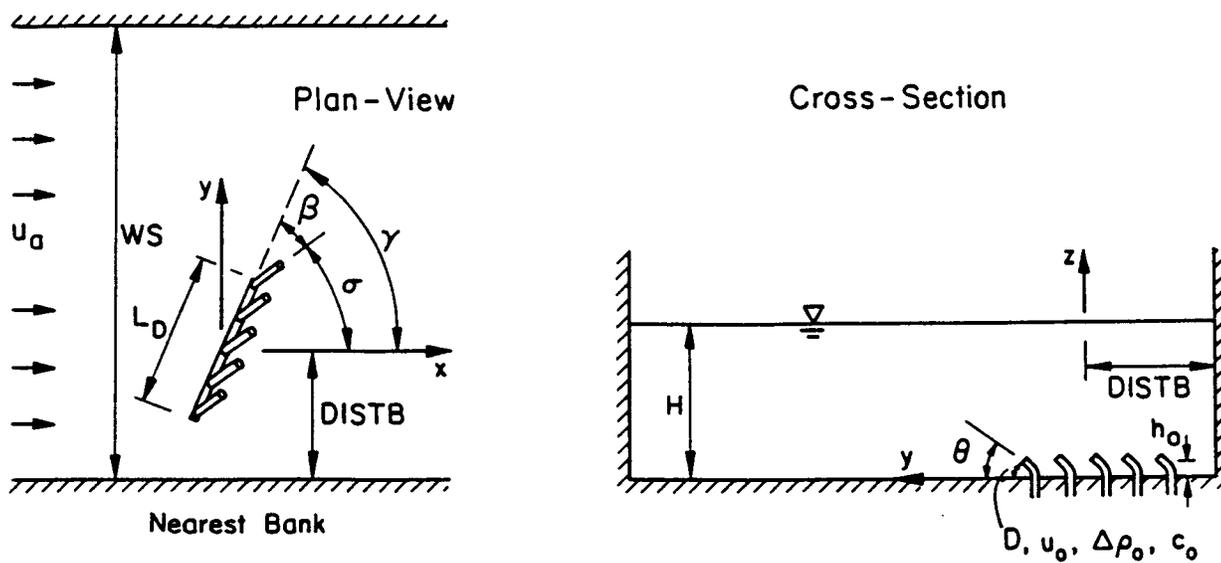
a) Definition Diagram CORMIX2
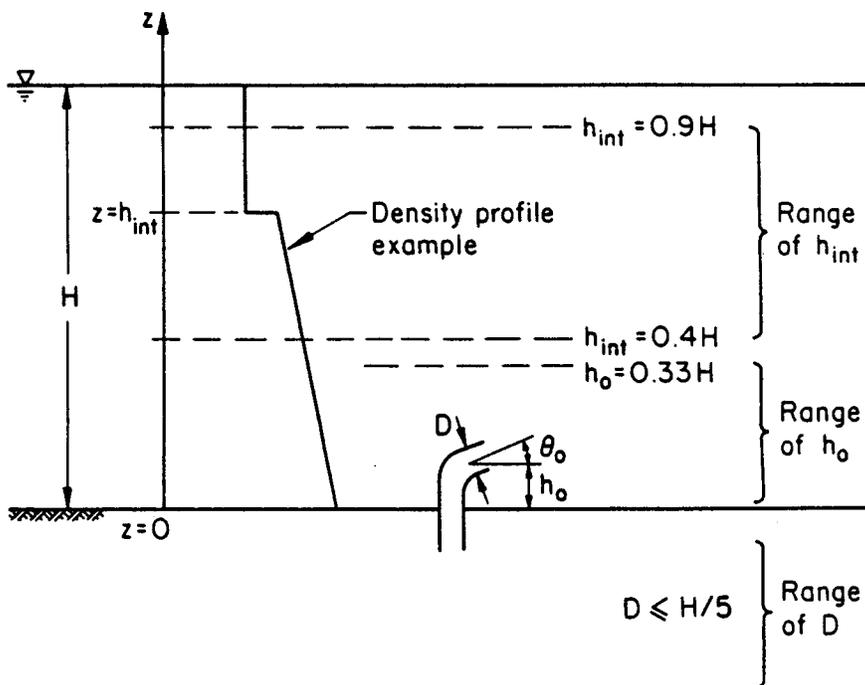
b) Limits of Applicability CORMIX2

Figure 4.6: CORMIX2 discharge geometry and restrictions
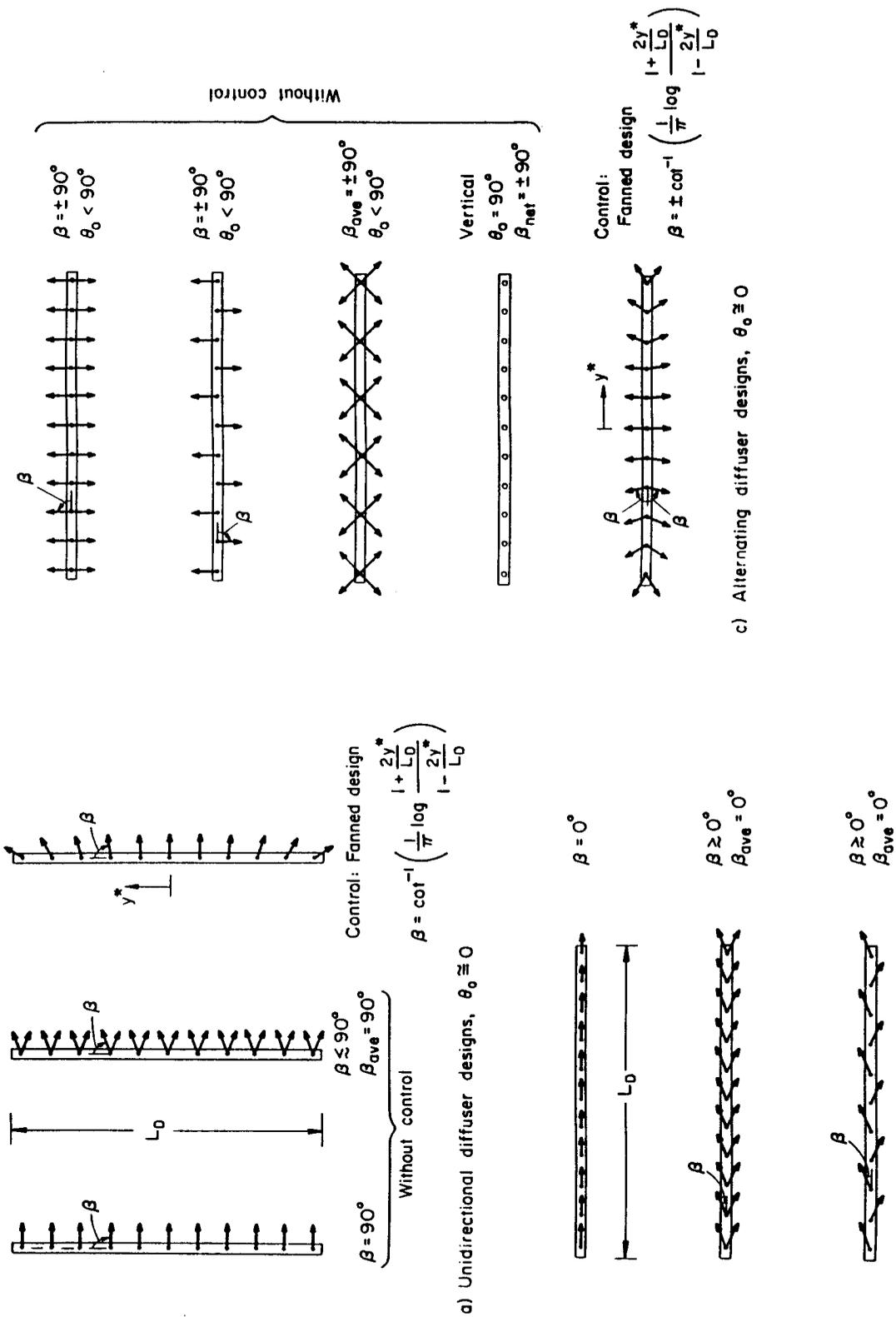
Figure 4.7: Configurations of common multiport diffuser types

height of the port centers (H0) above the bottom, (f) average **vertical angle of discharge (THETA)** between the port centerlines and a horizontal plane (-45 and 90°), (g)for the unidirectional and staged diffusers only, the average **horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to the plan projection of the port centerlines (0 to 360°), (h) approximate straight-line **diffuser length (LD)** between the first and last ports or risers, (I) **distance from the shore to the first and last ports or risers (YB1, YB2)** of the diffuser line, (j) number of ports or risers and the number of ports per riser if risers are present, (k) average **alignment angle (GAMMA)** measured counterclockwise from the ambient current direction (x-axis) to the diffuser axis (0 to 180 $^\circ$), and (l) for the unidirectional and staged diffusers only, **relative orientation angle (BETA)** measured either clockwise or counterclockwise from the average plan projection of the port centerlines to the nearest diffuser axis (0 to 90°). Note that CORMIX2 always assumes a uniform spacing between risers or between ports, and a round port cross-sectional shape.

As examples of angle specifications, THETA is 0 degrees for a horizontal discharge and it is +90 degrees for a vertically upward discharge, SIGMA is 0 degrees (or 360°) when the ports point downstream in the ambient flow direction and it is 90 degrees when the ports point to the left of the ambient flow direction, GAMMA is 0 degrees (or 180°) for a parallel diffuser and it is 90 degrees for a perpendicular diffuser, and BETA is 0 degrees for a staged diffuser and it is 90 degrees for a unidirectional diffuser.

CORMIX2 performs a number of consistency checks to ensure the user does not make arithmetical errors when preparing and entering the above data and it also checks the specified geometry for compliance with three criteria to prevent an inappropriate system application. Figure 4.6b shows the imposed limits of system application for CORMIX2 which are: (a) the port height (H0) value must not exceed one-third of the local water depth (HD) value, (b) the port diameter value must not exceed one-fifth of HD's value, and (c) the pycnocline value must be within the 40 to 90 percent range of HD's value. The restrictions are similar to those shown in

Figure 4.5b for CORMIX1 with the exception of the diameter limit for each port.

4.5.2 Diffuser Discharge Flow

For discharge characteristics, CORMIX2 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the total cross-sectional area of all diffuser ports and the program computes and displays the alternate value allowing for user inspection and verification.

The specification of the pollutant in the diffuser effluent is described in Section 4.7 below.

4.6 Discharge Data: CORMIX3

A definition sketch for the discharge geometry and flow characteristics for a buoyant surface discharge is provided in Figure 4.8. In general, CORMIX3 allows for different types of inflow structures, ranging from simple rectangular channels to horizontal round pipes that may be located at or near the water surface. In addition, three different configurations relative to the bank are allowed as illustrated in Figure 4.9. Discharge structures can be: (a) **flush** with the bank/shore, (b) **protruding** from the bank or (c) **co-flowing** along the bank.

4.6.1 Discharge Geometry

To allow the establishment of a reference coordinate system and orient the discharge to that reference, CORMIX3 requires the specification of up to 7 data entries. These specifications are illustrated in Figure 4.8 and include: (a) location of the **nearest bank** (i.e. left or right) as seen by an observer looking downstream in the direction of the flow, (b) **discharge channel width (B0)** of the **rectangular channel**, (c)**discharge channel depth (H0)**, (d) **actual receiving water depth at the channel entry (HD0)** and (e) **bottom slope (SLOPE)** in the receiving water body in the vicinity of the discharge channel, and (f)**horizontal angle of discharge (SIGMA)** measured counterclockwise from the ambient current direction (x-axis) to
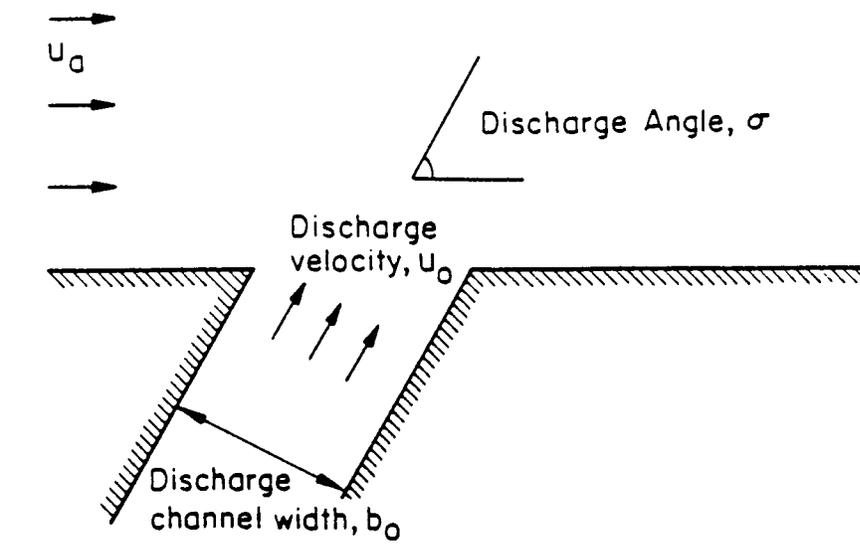
a) Plan View
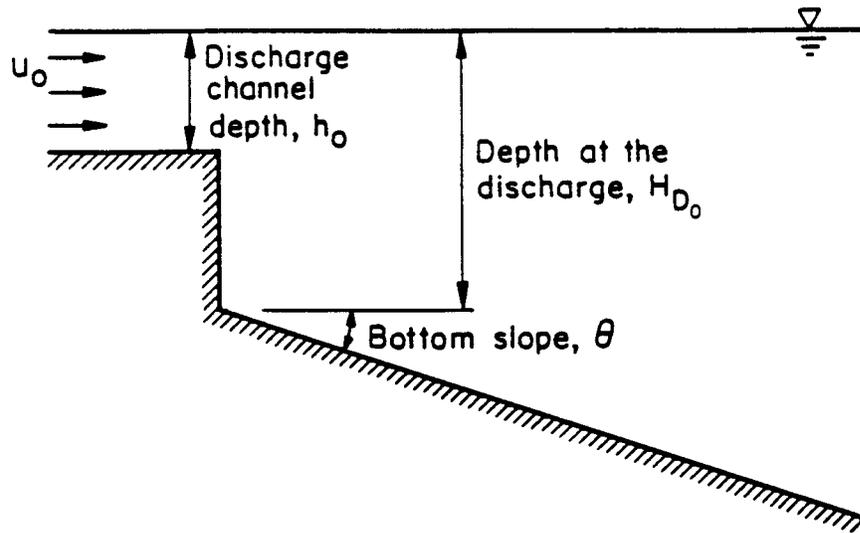
b) Cross-Section

Figure 4.8: CORMIX3 discharge channel geometry
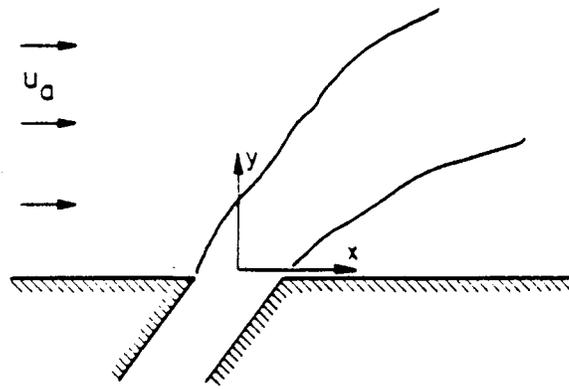
a) Discharge flush with bank
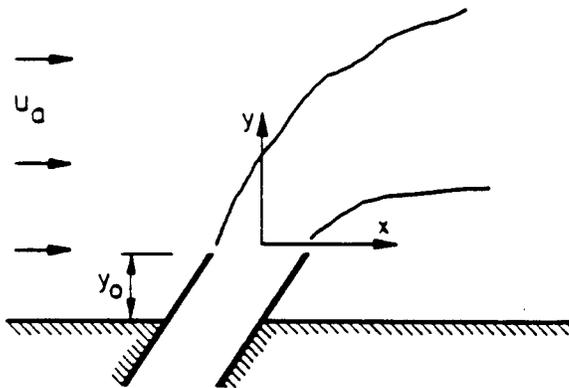
b) Protruding discharge
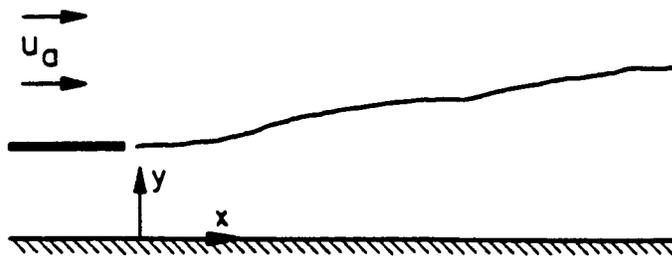
c) Coflowing along downstream bank

Figure 4.9: Possible CORMIX3 discharge configurations of discharge channel relative to bank/shoreline

the plan projection of the port centerline. In the case of a **circular discharge pipe**, the (b) **pipe diameter** and (c) **depth of bottom invert** below the water surface (water surface to bottom edge of pipe) must be specified, respectively. In all cases, CORMIX3 assumes the discharge is being issued horizontally.

CORMIX3 uses the variable HD0 for the actual water depth just in front of the channel exit and requires an additional specification for the receiving water bottom slope, again in front of the exit, extending into the receiving water body. These details are important for identifying cases where plume attachment to the bottom can occur.

In the case of a circular pipe discharge CORMIX3 assumes the outlet is flowing full and that it is not submerged under the water surface by more than ½ of the outlet diameter. If the discharge outlet has an odd cross-sectional shape (e.g. a pipe flowing partially full) then it should be represented schematically as a rectangular outlet of the same cross-sectional area and similar channel depth.

For open channel discharges, considerable care should be exercised when specifying discharge channel depth since this parameter is directly linked to the ambient receiving water depth (stage). This is especially important for tidal situations.

To prevent an inappropriate system application, CORMIX3 only allows for a discharge channel depth-to-width aspect ratio of 0.05 to 5. This prohibits the use of extremely oblong discharge geometry.

4.6.2 Discharge Flow

For discharge characteristics, CORMIX3 requires the specification of 3 data entries. These specifications include: (a) the **total discharge flow rate (Q0)** or **discharge velocity (U0)**, (b) the **discharge density** or **discharge temperature** for an essentially freshwater discharge, and (c) the **discharge concentration** of the material of interest. The Q0 and U0 variables are related through the channel cross-sectional area; the program computes and displays the alternate value allowing for user inspection and verification.

The discharge concentration of the material of interest (pollutant, tracer, or temperature) is defined as the excess concentration above any ambient concentration of that same material. The user can specify this quantity in any units. CORMIX1 predictions should be interpreted as computed excess concentrations in these same units. If no specific pollutant is under consideration, simply specify a discharge concentration of 100%.

4.7 Pollutant Data

CORMIX allows three types of pollutant discharges:

(a) Conservative Pollutant:
The pollutant does not undergo any decay/growth processes.

(b) Non-conservative Pollutant:
The pollutant undergoes a first order decay or growth process. One needs to specify the **coefficient of decay** (positive number) **or growth** (negative number) in units: /day (per day).

(c) Heated Discharge:
The discharge will experience heat loss to the atmosphere in cases where the plume contacts the water surface. It is necessary to specify the discharge condition in terms of *excess temperature ("delta T") above ambient in units degC*, and the **surface heat exchange coefficient** in units W/m^2,degC. Values of the heat exchange coefficient depend on ambient water temperature and wind speed. The following listing provides a guideline for the selection.

Typically, the near-field behavior is quite insensitive to the choice of these values, but it may affect the prediction results at greater distances in the far-field.

The **discharge concentration (C0)** of the material of interest (pollutant, tracer, or temperature) is defined as the *excess concentration above any ambient background concentration* of that same material. The user can specify this quantity in any **units of concentration** (e.g. mg/l, ppm, %, ^{o}C). CORMIX predictions should be interpreted as computed excess concentrations in these same units.

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SURFACE HEAT EXCHANGE COEFFICIENT (W/m^2,^{o}C)
Values for a lightly heated, natural water surface
(local excess temperatures 0 to 3 ^{o}C)

Ambient Water Temp. (^{o}C)	Wind Speed (m/s)					
	0	1	2	4	6	8
5	5	10	14	24	33	42
10	5	11	16	27	38	49
15	5	12	18	31	44	59
20	5	14	21	38	52	68
25	6	16	25	45	63	82
30	6	19	30	54	76	100

Ref: "Heat Disposal in the Water Environment", E.E. Adams, D.R.F. Harleman, G.H. Jirka, and K.D. Stolzenbach, Course Notes, R.M. Parsons Laboratory, Mass. Inst. of Techn., 1981.

If no pollutant data at all is available, it is most convenient to specify C0 = 100 %.

In case of an **ambient background concentration** it is important to treat all pollutant related data items in a consistent fashion. This includes the specification of any regulatory values as discussed in Section 4.8 below.

> *Example:* suppose the actual discharge concentration for a particular pollutant is 100 mg/l, and values of CMC and CCC for the pollutant are 20 mg/l and 10 mg/l, respectively. If the background ambient concentration for the same pollutant is 4 mg/l, the data entry to CORMIX would be for the discharge concentration = 96 mg/l, for CMC = 16 mg/l, and for CCC = 6 mg/l, respectively. All concentration values listed in the diverse CORMIX output (see Chapter V) must then be interpreted accordingly, and the actual concentration values are computed by adding the background concentration value. E.g. if the CORMIX predicted value for one particular point happens to be 13.6 mg/l, then the total concentration value at that point would be 17.6 mg/l. Also, all program mixing zone messages would occur at correct regulatory concentrations because they are interpreted as excess plume concentrations above ambient.

4.8 Mixing Zone Data

The user must indicate: (a) whether EPA's toxic dilution zone (TDZ) definitions apply, (b) whether an ambient water quality standard exists, (c) whether a regulatory mixing zone (RMZ) definition exists, (d) the spatial region of interest (ROI) over which information is desired, and (e) number of locations (i.e. "grid intervals") in the ROI to display output details. Depending on the responses to the above, several additional data entries may be necessary as described in the following paragraphs.

When TDZ definitions apply, the user must also indicate the criterion maximum concentration (CMC) and criterion continuous concentration (CCC) which are intended to protect aquatic life from acute and chronic effects, respectively. CORMIX will check for compliance with: (a) the CMC standard at the edge of the TDZ and (b) the CMC standard at the edge of the RMZ, proving a RMZ was defined. See Subsection 2.2.2 for additional discussion.

When a RMZ definition exists, it can be specified by: (a) a distance from the discharge location, (b) the cross-sectional area occupied by the plume, or (c) the width of the effluent plume.

The ROI, which is a user defined region where mixing conditions are to be analyzed, is specified as the maximum analysis distance in the direction of mixed effluent flow. The level of detail for the output data within the ROI and thus, for the entire hydraulic simulation, is established by specifying the number of grid intervals that will be displayed in the output files. This parameter's allowable range is 3 to 50 and the chosen value does not affect the accuracy of the CORMIX prediction, only the amount of output detail. A low value should be specified for initial calculations to minimize printout lengths while a large value might be desirable for final predictions to give enough resolution for plotting of plume dimensions.

4.9 Units of Measure

CORMIX uses the metric system of measurement. When data values are provided to the user in English units, these must be converted to equivalent metric measures. The list at the beginning of this manual gives the five metric dimensions used by CORMIX in the left column, and on the right, their equivalents in some common English units.

Pollutant concentrations can be entered in any conventional measure such as mg/L, ppb, bacteria-count, etc.

Considering the potential accuracy of CORMIX predictions, 3 to 4 significant digits are sufficiently accurate for most input data values as suggested in the above conversion list. The only exceptions are the ambient and effluent density values. These may require 5 significant digits, especially when simulating the discharge to an ambient density-stratified receiving water body.

V CORMIX Output Features

CORMIX is a highly interactive system and conveys information to the user through qualitative descriptions and detailed quantitative numerical predictions. This output can be viewed on-screen in text mode or graphics mode, can be directed to a printer, and is stored in subdirectory CORMIX\SIM and CORMIX\SIM\CXn files.   In this chapter the label n = 1, 2 or 3 designates the appropriate CORMIX subsystem.

5.1 Qualitative Output: Flow Descriptions

After completion of the input data entry sequences, the system proceeds through the program elements following the flow chart displayed in Figure 3.1. In addition to the routine operational messages provided during program execution, important qualitative information is displayed on-screen about the ongoing analysis of the given ambient/discharge case. The three general types of descriptive information provided are: (a) descriptive messages, (b) length scale

computation results and (c) flow class descriptions. The paragraphs within this Section aid in the interpretation of that information.

The program elements PARAM and CLASS, in particular, provide essential information on the expected dynamic behavior of the discharge. By actively participating in the interactive process, the novice and intermediate user can derive a substantial educational benefit and a technical appreciation of the physical aspects of initial mixing processes. Although advanced users may find some of the presented material somewhat repetitive, they should still consult the length scale computation results.

5.1.1 Descriptive Messages

These messages provide both physical information and insight into the logic reasoning employed by CORMIX.   Three example descriptive messages are:

```
"The effluent density (1004.5 kg/m^3) is greater than the surrounding
water density at the discharge level (997.2 kg/m^3).
Therefore, the effluent is negatively buoyant and will tend to sink
towards the bottom."

"STRONG BANK INTERACTION will occur for this perpendicular diffuser
type due to its proximity to the bank (shoreline).  The shoreline will
act as a symmetry line for the diffuser flow field.
The  diffuser  length  and  total  flow  variables  are  doubled  (or
approximately doubled, depending on the vicinity to the shoreline).
All of the following length scales are computed on that basis."

"The specified two layer ambient density stratification is dynamically
important. The discharge near field flow will be confined to the lower
layer by the ambient density stratification.
Furthermore, it may be trapped below the ambient density jump at the
pycnocline."
```

The preceding example output highlights several features of CORMIX's descriptive messages. These include: (a) conveying basic information about the involved mixing processes, (b) using a careful terminology (e.g. "..tend to sink.."), (c) describing key calculation assumptions, and (d) alerting the user to sensitive

analysis conditions. In some instances, the provided information may be obvious to the user, while in others it may not, particularly for situations involving linear ambient stratification. The use of a careful terminology is necessary because messages are presented as the analysis proceeds and subsequent tests may alter, or

amplify, initial results. For example, near-field instabilities, which are tested for late in the analysis, can prevent an otherwise sinking plume.

5.1.2   Length Scale Computations

The program element PARAM computes so-called "**length scales**" which represent important dynamic measures about the relative influence of certain hydrodynamic processes on effluent mixing. These calculated values are subsequently used in program element CLASS to identify the generic flow class upon which the hydraulic simulations will be based. This flow classification is accomplished through formal dynamic **length scale analysis**, which is a key aspect of the theoretical underpinnings for the CORMIX approach. The CORMIX documentation manuals (5,6,7) and related journal publications provide the theoretical background on length scale definitions and significance, their derivation from principles of dimensional analysis, and their use in the CORMIX flow classification approach.

Although flow classification is a formal process using criteria derived from theoretical studies and/or experimental data, a great deal can be deduced about the flow dynamics by comparing the calculated length scales to the actual physical measures of the ambient/discharge situation. Of greatest importance are comparison to such geometric measures as: the available water depth (HD), a pycnocline height (HINT) and the distance to the nearest bank (DISTB). The following discussion provides a brief explanation of the more important length scales and examples on how to make appropriate comparisons in a given application. Users are encouraged to make these comparisons.

a) Single port discharges: Some important length scales relating to submerged round buoyant jets (CORMIX1) are described in Table 5.1. All of these scales are defined from an interplay of the momentum and buoyancy flux quantities of the discharge with each other or with the current velocity and stratification gradient variables.

As an example, consider a vertically discharging buoyant jet into an unstratified ambient receiving water. When both calculated L_m and L_b values are substantially less than the local water depth (HD), this is an immediate indication to the user that the crossflow is very strong, leading to complete bending of the buoyant jet. If the reverse holds true, the crossflow may be so weak that its deflecting effect is negligible, and the buoyant jet will strongly interact (impinge) with the water surface. In the first instance, a situation as depicted in Figures 2.1b combined with Figure 2.1a will result, while in the second instance, a flow resembling Figures 2.2c or 2.2d may arise, depending on the relation of the two scales with each other.

As another example, consider a buoyant jet discharging into a linearly stratified ambient. If both L_m' and L_b' both larger than the pycnocline height (HINT) and even the water depth (HA), this would be an indication that the existing stratification is so weak that it will not lead to any trapping of the effluent plume within the available vertical space.

By making such comparisons, users will gradually get a good feel for the behavior of the buoyant jet, and other mixing processes within the space constraints of the ambient environment. Those interested in design can quickly gain an appreciation of the length scale measures and their sensitivity to design choices. However, there are limitations to these simplistic comparisons because the "length scales" are by no means precise measurements for the influence of the different processes. As their name implies they should be taken only as "scale" estimates. The actual CORMIX classification scheme uses formal criteria when comparing the length scale measures with the geometric constraints or each other.

b) Multiport diffusers: Some important length scales for multiport diffusers (CORMIX2) are described in Table 5.2.

To a large extent, these scales have a similar meaning for the behavior of the plane buoyant jet as the earlier ones discussed for the round buoyant jet (Table 5.1). However, they are calculated differently because the CORMIX2 system uses the "equivalent slot diffuser" concept to model the overall dynamics of the submerged multiport diffuser (Section 3.1). Except for the immediate close-up zone before the individual jets merge (Figure 2.1d) this concept is a dynamically valid and accurate representation of multiport diffuser flows (6).

Table 5.1
Length Scales for Single Port Submerged Discharges
(Used in CORMIX1 and CORMIX2)

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Plume/crossflow length scale $L_b = J_o / u_a^3$
interpretation: The vertically upward or downward flotation distance beyond which a plume becomes strongly advected by crossflow.

Jet/stratification length scale $L_m' = M_o^{1/4} / \epsilon^{1/4}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Plume/stratification length scale $L_b' = J_o^{1/4} / \epsilon^{3/8}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

_____

Notes: $M_o = U_o Q_o$, kinematic momentum flux
$J_o = g'_o Q_o$, kinematic buoyancy flux
$Q_o = U_o a_o$, source discharge volume flux
a_o = port area
u_a = ambient velocity
U_o = port discharge velocity
ϵ = ambient buoyancy gradient
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

However, there are some exceptions and additional complexities to interpreting the two-dimensional slot length scales measures described in Table 5.2. In addition to the predominately two-dimensional flow behavior, some of the large scale dynamics of multiport diffusers may also be influenced by other scales depending on the overall diffuser flow pattern. A notable example is circulating motions induced in shallow receiving waters due to intermediate-field effects (Section 2.1.1). The immediate close-up zone before the individual jets merge is also not addressed by the two-dimensional length scales. Additional discussion of these and other peculiarities can be found elsewhere (6,18).

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Table 5.2
Dynamic Length Scales for Multiport Diffuser (CORMIX2) in the
Two-Dimensional "Slot" Discharge Representation

Slot jet/plume transition length scale $\ell_M = m_o / j_o^{2/3}$

interpretation: For combined buoyant jet flow, the distance at which the transition from jet to plume behavior takes place in a stagnant uniform ambient.

Slot jet/crossflow length scale $\ell_m = m_o / u_a^2$

interpretation: In the presence of a crossflow, the distance of the transverse (i.e. across ambient flow) jet penetration beyond which the jet is strongly deflected (advected) by the cross flow. For a strictly co-flowing discharge ($\theta = 0$, $\sigma = 0$), the length of the region beyond which the flow is simply advected.

Slot jet/stratification length scale $\ell_m' = m_o^{1/3} / \epsilon^{1/3}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **jet** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Slot plume/stratification length scale $\ell_b' = j_o^{1/3} / \epsilon^{1/2}$
interpretation: In a stagnant linearly stratified ambient, the distance at which a **plume** becomes strongly affected by the stratification, leading to terminal layer formation with horizontally spreading flows.

Crossflow/stratification length scale $\ell_a = u_a / \epsilon^{1/2}$
interpretation: The vertically upward or downward floatation distance beyond which a plume becomes strongly advected by crossflow.

_____
Notes: $m_o = U_o q_o$, kinematic momentum flux per unit length
  $j_o = g'_o q_o$, kinematic buoyancy flux per unit length
  $q_o = U_o n a_o / L_D$, source discharge volume flux
  a_o = port area
  u_a = ambient velocity
  U_o = port discharge velocity
  ϵ = ambient buoyancy gradient
  g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$
  n = total number of nozzles
  L_D = overall diffuser length

c) Buoyant surface jets: Some important length scales that describe the near-field dynamics of buoyant surface jets discharging into unstratified receiving waters (CORMIX3) are listed in Table 5.3. These scales are defined in a similar manner to the submerged discharged cases but due to the discharge location at the surface, they have different interpretations. For example, L_m is compared to the channel width (BS) instead of the local water depth as it was in submerged case examples; if it exceeds BS, the discharge will quickly interact with the opposing bank.

Table 5.3
Dynamic Length Scales for Buoyant Surface Jets (CORMIX3)
Discharging into Unstratified Receiving Water

Jet/plume transition length scale $L_M = M_o^{3/4} / J_o^{1/2}$

interpretation: For stagnant ambient conditions, the extent of the initial jet region before mixing changes over into an unsteady surface spreading motion.

Jet/crossflow length scale $L_m = M_o^{1/2} / u_a$

interpretation: The distance over which a discharging jet intrudes into the ambient cross-flow before it gets strongly deflected.

Plume/crossflow length scale $L_b = J_o / u_a^3$

interpretation: A measure of the tendency for upstream intrusion for a strongly buoyant discharge.

Notes: $M_o = U_o Q_o$, kinematic momentum flux
$J_o = g'_o U_o$, kinematic buoyancy flux
$Q_o = U_o a_o$, source discharge volume flux
a_o = channel cross-sectional area
u_a = ambient velocity
U_o = channel discharge velocity
g'_o = discharge buoyancy = $g(\rho_a - \rho_o)/\rho_a$

---

d) Tidal reversing flows: Additional length and time scales can be defined for unsteady flows in which the scale of influence of oscillating plume depends on the rate of velocity reversal change at slack tide (8,17). CORMIX will take the actual steady-state predictions and adjust their concentration values according to the time after reversal relative to the time scale T_u and also limit their areal applicability relative to L_u.

5.1.3 Description of Flow Classes

Program element CLASS, performs a rigorous classification of the given discharge/ambient situation into one of many **generic flow classes** with distinct hydrodynamic features. In a way, this amounts to identifying a general pictorial description of the expected flow configuration.

Table 5.5 lists and describes the broad categories of flow classes available in CORMIX. CORMIX1, 2 and 3, consider 35, 31 and 11 distinct flow classifications, respectively. Each flow class identification consists of an alphanumeric label corresponding to the flow category and a number (e.g. MU2). Text descriptions of the flow classes are available on-screen during the analysis and can printed from the files stored within sub-directory CORMIX\TEXT (Table 3.1). Pictorial illustrations of the flow classes can be found in Appendix A. As an example, Figure 5.1 shows the pictorial illustration and text description for flow class S1, a case of an effluent that becomes trapped in ambient stratification. It is strongly recommended that novice or intermediate users scrutinize these materials to gain a qualitative understanding of the effluent flow's behavior.

Table 5.4
Dynamic Length and Time Scales for
Discharges into Unsteady Tidal Reversing Flows

Jet-to unsteady-crossflow length scale $L_u = \left(\dfrac{M_o}{|du_a/dt|} \right)^{1/3}$

interpretation: A measure of the distance of the forward propagation into the ambient flow of a discharge during the reversal episode.

Jet-to unsteady-crossflow time scale $T_u = \left(\dfrac{M_o}{|du_a/dt|^{1/4}} \right)^{1/6}$

interpretation: a measure of the duration over which an effluent may be considered as discharging into stagnant water while the velocity field is reversing.

_____

Notes: $M_o = U_o Q_o$, kinematic momentum flux
$|du_a/dt|$ = time rate of reversal of ambient velocity (absolute value)

Table 5.5
Flow Class Categories and Descriptions

CORMIX1:	35 flow classes
Classes S:	Flows trapped in a layer within linear stratification.
Classes V,H:	Positively buoyant flows in a uniform density layer.
Classes NV,NH:	Negatively buoyant flows in uniform density layer.
Classes A:	Flows affected by dynamic bottom attachment.
CORMIX2 :	31 flow classes
Classes MS:	Flows trapped in a layer within linear ambient stratification.
Classes MU:	Positively buoyant flows in a uniform density layer.
Classes MNU:	Negatively buoyant flows in uniform density layer.
CORMIX3	9 flow classes
Classes FJ:	Free jet flows without near-field shoreline interaction.
Classes SA:	Shoreline-attached discharges in crossflow.

Classes WJ: Wall jets/plumes from discharges parallel to shoreline.
Classes PL: Upstream intruding plumes.

```
FLOW CLASS S1

This flow configuration is profoundly affected by the linear
ambient density stratification. The predominantly jet-like flow
gets trapped at some terminal (equilibrium) level. The trapping
is also affected by the reasonably strong ambient crossflow.
Following the trapping zone, the discharge flow forms an internal
layer that is further influenced by buoyant spreading and passive
diffusion.

The following flow zones exist:

1) Weakly deflected jet in crossflow: The flow is initially
dominated by the effluent momentum (jet-like) and is weakly
deflected by the ambient current.

2) Strongly deflected jet in crossflow: The jet has become strongly
deflected by the ambient current and is slowly rising toward the
trapping level.

3) Terminal layer approach: The bent-over submerged jet/plume
approaches the terminal level. Within a short distance the
concentration distribution becomes relatively uniform across the
plume width and thickness.

***    The zones listed above constitute the NEAR-FIELD REGION
       in which strong initial mixing takes place. ***

4) Buoyant spreading in internal layer: The discharge flow within
the internal layer spreads laterally while it is being advected by
the ambient current. The plume thickness may decrease during this
phase. The mixing rate is relatively small. The plume may interact
with a nearby bank or shoreline.

5) Passive ambient mixing: After some distance the background
turbulence in the ambient shear flow becomes the dominating mixing
mechanism. The passive plume is growing in depth and in width. The
plume may interact with the upper layer boundary, channel bottom
and/or banks.

***    Predictions will be terminated in zone 4 or 5 depending on
       the definitions of the REGULATORY MIXING ZONE or the REGION OF
       INTEREST. ***
```

Figure 5.1:   Example of a Flow Class Description

5.2 Quantitative Output: Numerical Flow Predictions

After execution of the detailed flow prediction in program element HYDROn, the system provides two types of detailed numerical output on effluent plume trajectory and mixing and on compliance with regulations. A concise summary is available on-screen in the final system element SUM and a detailed numerical output file is also generated for inspecting and plotting the plume's behavior after the analysis.

5.2.1 Summary Output in SUM

The self-explanatory summary output which can be displayed on-screen includes: (a) the date and time of the analysis section, (b) a complete echo of the input data, (c) the calculated flux, length scale and non-dimensional parameter values, (d) the flow classification used for predicting plume trajectory and mixing, (e) the coordinate system used in the analysis, (f) a summary of the near-field region (NFR) conditions, (g) the far-field locations where the plume becomes essentially fully mixed (i.e. uniform concentration) in the horizontal and vertical directions, (h) a summary of the toxic dilution zone (TDZ) conditions, and (I) a summary of the regulatory mixing zone (RMZ) conditions. Although the raw data used to construct this summary output is permanently stored in file 'fn'.CXC within the output sub-directory CORMIX\SIM\CXn, a hard-copy printout should be requested during the analysis session because the raw data file is unformatted and does not contain the explanatory text that is available during program execution; 'fn' is the filename specified by the user during input data entry.

The **coordinate system conventions** pertain to the origin location and axis direction. In CORMIX1 analyses, the origin is located at the bottom of the receiving water just below the discharge port center and thus, at a depth HD below the water surface. In CORMIX2 analyses, the origin is located at the bottom of the receiving water, at the midpoint of the diffuser line and thus, at a depth HD below the water surface. In CORMIX3 analyses, the origin is located at the water surface where the discharge channel centerline and receiving water shoreline intersect. The x-axis lies in the horizontal plane and points

downstream in the direction following the ambient flow; the y-axis lies in the horizontal plane and points to the left as seen by an observer looking downstream along the x-axis; and the z-axis points vertically upward. Note that when the ambient current direction varies (e.g. due to reversing tidal flows), the interpretation of simulation results becomes more involved since the x-axis and the y-axis will change depending on flow direction.

In addition to the numerical predictions of the plume size, location and chemical concentration, the summary of the near-field region (NFR) conditions describes other relevant plume features such as bottom attachment, bank interaction and the degree of upstream intrusion. This information is useful for both engineering design and for determining whether important resource areas may be exposed to undesirable chemical concentrations.

In case of a toxic discharge, the summary toxic dilution zone (TDZ) conditions will indicate the location along the plume where the local concentration begins to fall below the specified CMC. CORMIX automatically checks compliance with the three geometric restrictions listed for mixing zones associated with toxics discharges under alternative 3 (see Subsection 2.3.3) and the results of these comparisons are displayed. The user can evaluate the fourth alternative by referring to travel times given at the end of each simulation module in the related output files.

When regulatory mixing zone (RMZ) criteria have been specified during input data entry, the geometric, dilution and concentration conditions at the edge of the specified or proposed RMZ are compared to these criteria and/or to the applicable CCC concentration following the practices discussed in Subsection 2.2.4. The results of these comparisons are displayed.

5.2.2 Detailed Prediction Output File *fn*'.CXn

The file 'fn'.CXn stored within sub-directory CORMIX\SIM contains the same kinds of information available in the summary output plus the detailed numerical predictions on plume geometry and mixing produced during the hydraulic simulation. Data in that file forms the

basis for further analysis, inspection, evaluation, and plotting of the plume shape and trajectory. The graphics package also uses the same data to plot on-screen, and print if desired, the plume properties as explained in Section 5.2.3.

During program execution, the user has several opportunities to display on-screen or print out this file. It can also be printed at a later date by using the DOS PRINT command or any word processor. CORMIX will not erase any of the files with .CXn (or .CXC) extension that get stored in the CORMIX\SIM sub-directory. Consequently, periodic directory maintenance is recommended to remove old and superfluous files. This is best accomplished with a built-in file manager (see Main Menu) that deletes the specified files from the hard disk, but also erases their entry from the record keeping file CORMIX\SIM\CXn\summary.

The 'fn'.CXn file is a FORTRAN output file generated by the HYDROn prediction program. As is typical of many FORTRAN outputs, its display features are terse with tight format control and data items labeled in symbolic form only (e.g. "Q0" for discharge flow rate). Complete output file examples can be inspected in Appendices B, C and D.

All three CORMIXn subsystems produce a 'fn'.CXn output file with common appearance and features as described in the following paragraphs.

a) Lead-in information: The output starts (and ends) with a "111...111", "222...222", or "333...333" banner line to accentuate which subsystem has been used. The date and time of the analysis session and all important input data are the next items in the file. These are subsequently followed by the calculated length scale values, non-dimensional numbers of interest to the specialist, the flow class identification, and the coordinate system is displayed.
b) Prediction results for each flow "module": As was mentioned previously in Subsection 3.6, the CORMIX prediction methodology utilizes a number of **simulation modules** that are executed sequentially and that correspond to the different flow processes and associated spatial regions which occur within a given flow class. The

'fn".CXn output reflects that sequence and is a arranged in output blocks for each module.

Each simulation module has a "MODnxx" label where "n" is 1, 2, or 3 corresponding to CORMIXn, and "xx" is a two-digit identification number. The two general types of modules are continuous flow and control volume.

The **continuous flow module** type describes the continuous evolution of a flow region along a trajectory. Depending on the number of grid intervals specified by the user, information on plume geometry, flow, and mixing information along the plume trajectory may be available for a few or many water body locations.

Figure 5.2 provides examples of typical output from continuous flow modules. The annotations along the right margin illustrate important features of the output format. Figure 5.2a was taken from a CORMIX1 simulation output file and shows an example of a submerged jet region module (MOD110, equivalent to CORJET). The output contains labeling information on the module, and explanatory notes on profile definitions. It also gives a numerical list on the predictions, first repeating the final values from the preceding flow module and then one line for each user-specified grid interval. This information gives the x-y-z position of the jet/plume centerline, the dilution (S) and concentration (C) at the centerline, and the jet width (B).

Dilution (S) is defined as the ratio of the initial concentration (at the discharge port) to the concentration at a given location, irrespective of any decay or growth effects if specified for a non-conservative pollutant. However, **concentration** (C) will include any first-order effects for non-conservative pollutants. Dilution (S) given by CORMIX for submerged jet or plume regions is the minimum centerline dilution for the jet/plume. The control volume and buoyant spreading modules give bulk dilutions, which are equivalent to flux-averaged dilutions for these regions. If a flux-averaged dilution S_f is desired for submerged jet or plume regions, the ratio of flux-average to minimum centerline dilution $S_f/S = 1.7$ and 1.3, for single-port round and multiport plane discharges, respectively.

```
------------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
Jet/plume transition motion in weak crossflow.
 Zone of flow establishment:             THETAE=     0.00  SIGMAE=     277.06
 LE    =     3.39  XE    =     0.21  YE    =    -3.38  ZE    =     1.00
 Profile definitions:
  B = Gaussian 1/e (37%) half-width, normal to trajectory
  S = hydrodynamic centerline dilution
  C = centerline concentration (includes reaction effects, if any)
       X        Y        Z        S        C        B
      0.00     0.00     1.00      1.0 0.100E+03    0.76
      0.21    -3.38     1.00      1.0 0.100E+03    0.76
      0.90    -7.41     4.11      1.8 0.562E+02    1.13
      1.55    -9.36     9.07      3.3 0.300E+02    1.59
      2.23   -10.55    14.27      5.4 0.186E+02    2.10
      2.95   -11.39    19.56      7.9 0.127E+02    2.63
      3.72   -12.02    24.85     10.8 0.928E+01    3.16
 Cumulative travel time =         18. sec
END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
------------------------------------------------------------------------------
```

a) Submerged buoyant jet module

```
------------------------------------------------------------------------------  BEGIN MOD341:
BUOYANT AMBIENT SPREADING                               Profile definitions:
  BV = top-hat thickness, measured vertically
  BH = top-hat half-width, measured horizontally from bank/shoreline
  S  = hydrodynamic average (bulk) dilution
  C  = average (bulk) concentration (includes reaction effects, if any)
 Plume Stage 1 (not bank attached):
       X        Y        Z        S        C        BV       BH
      1.93    -.82     0.00      8.4  .884E+00     .03      .58
      2.07    -.82     0.00      8.5  .869E+00     .03      .62
      2.20    -.82     0.00      8.6  .856E+00     .03      .65
 ** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
  or CCC value of  .850E+00 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
  standard or CCC value.
      2.34    -.82     0.00      8.8  .844E+00     .03      .68
      2.48    -.82     0.00      8.9  .833E+00     .03      .71
      2.62    -.82     0.00      9.0  .822E+00     .03      .74
      2.76    -.82     0.00      9.1  .811E+00     .03      .77
      2.89    -.82     0.00      9.2  .801E+00     .03      .80
      2.96    -.82     0.00      9.3  .796E+00     .03      .82
 Cumulative travel time =        95. sec
------------------------------------------------------------------------------  Plume is ATTACHED
to LEFT  bank/shore.
   Plume width is now determined from LEFT  bank/shore.
 Plume Stage 2 (bank attached):
       X        Y        Z        S        C        BV       BH
      2.96     .00     0.00      9.3  .796E+00     .03      .82
     16.05     .00     0.00     31.3  .237E+00     .03     2.59
     29.13     .00     0.00     96.8  .764E-01     .06     3.77
     42.22     .00     0.00    220.7  .335E-01     .10     4.76
     55.31     .00     0.00    411.4  .180E-01     .16     5.64
     68.39     .00     0.00    675.3  .110E-01     .23     6.45
     81.48     .00     0.00   1017.8  .727E-02     .31     7.20
     94.56     .00     0.00   1443.5  .513E-02     .40     7.91
    101.11     .00     0.00   1688.9  .438E-02     .45     8.26
 Cumulative travel time =      3367. sec
 END OF MOD341: BUOYANT AMBIENT SPREADING
------------------------------------------------------------------------------
```

b) Far-field flow module (example of buoyant spreading with bank contact)

Figure 5.2:   Examples of continuous flow modules within CORMIX

The **cumulative travel time** (T) is given at the end of each simulation module. The travel time can be used to assess the applicability of the steady-state predictions given by CORMIX to time scales appropriate for the particular application.

Another example of a continuous flow module output is shown in Figure 5.2b. It was abstracted from a CORMIX simulation output file and shows predictions for the far-field process of buoyant ambient spreading (Figure 2.6). Although it is terse, the output file values and commentary generally provide a complete picture of flow conditions. In this example output (Figure 5.2b), evidence of this completeness includes: (a) the prediction output is separated in two stages corresponding to before and after bank interaction, respectively; due to the typical oblong cross-section of the plume in this stage, width dimensions for the vertical and lateral extent are given and defined; the coordinates for the upper and lower boundaries of the plume are listed as a convenience for plotting; and the system searches for criteria that apply to mixing zone regulations and when a criterion is satisfied, a remark gets inserted in the output list at the appropriate spatial position. (Note: The length dimensions in Figure 5.2b are small as they relate to a laboratory simulation.)

Some mixing flow processes are so complicated that no mechanistically-based mathematical description of them is presently available in state-of-the-art science. Those processes are best analyzed with **control volume modules** as shown in Figure 5.3.

In the control volume modeling approach, the outflow values for a region are computed as a function of the inflow values and are based on conservation principles.

An output example for control volumes modules is illustrated in Figure 5.3. It is taken from a CORMIX1 simulation output file and gives predictions for a flow case corresponding to an unstable near-field (Figure 2.2c). Note that a separate listing of inflow variables and outflow variables is given with appropriate explanations. The tabular listing of plume shape is based on an interpolation routine using a generic plume shape for these upstream intruding motions, rather than

a detailed computation.

c) Numerous other supplementary messages on plume behavior (e.g. bottom attachment, bank contact, etc.) and on possible model restrictions (e.g. ambient dilution limitations in a flow-restricted river) are contained in the output as warranted; Figures 5.2 and 5.3 provide but a few examples of these user aids.

5.3 Graphical Output: Display and Plotting of Plume Features Using CMXGRAPH

5.3.1 Access to CMXGRAPH

CMXGRAPH is a specially developed graphics package, written in C++, for the display and plotting of CORMIX (and also CORJET, see Section 6.2) predicted effluent plumes. It uses the prediction files 'fn'.CXn that are stored in the directory CORMIX\SIM, and plots plume features based on the numerical and narrative information contained in these files.

The graphics system can be accessed in different ways:

(1) Use within CORMIX: Different access modes exist here.

(1a) The user can display the plume graphics immediately after the actual prediction and *before the file information is stored*. This is useful for an initial inspection and evaluation of results.
(1b) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.
(1c) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

(2) Use outside CORMIX:
The graphics system can be invoked directly by typing:

cmxgraph (or simply: cg) *filename*
where *filename* (including path and extension) is any prediction file generated by CORMIX or by CORJET.

```
--------------------------------------------------------------------------------
BEGIN MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING


  Vertical angle of layer/boundary impingement     =      79.65 deg
  Horizontal angle of layer/boundary impingement   =     324.93 deg


 UPSTREAM INTRUSION PROPERTIES:
        Upstream intrusion length                =      328.95 m
        X-position of upstream stagnation point  =     -325.23 m
        Thickness in intrusion region            =        0.55 m
        Half-width at downstream end             =      470.97 m
        Thickness at downstream end              =        0.70 m

 In this case, the upstream INTRUSION IS VERY LARGE, exceeding 10 times
   the local water depth.

 This may be caused by a very small ambient velocity, perhaps in
   combination with large discharge buoyancy.

  Control volume inflow:


       X        Y        Z        S        C        B
      3.72    -12.02    24.85     10.8 0.928E+01   3.16

 Profile definitions:

   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV       BH       ZU       ZL
  -325.23   -12.02    28.00   9999.9 0.000E+00   0.00      0.00    28.00    28.00
  -313.94   -12.02    28.00     46.5 0.215E+01   0.13     66.61    28.00    27.87
  -258.63   -12.02    28.00     19.3 0.519E+01   0.31    161.78    28.00    27.69
  -203.31   -12.02    28.00     14.5 0.688E+01   0.40    218.89    28.00    27.60
  -148.00   -12.02    28.00     12.5 0.802E+01   0.47    263.91    28.00    27.53
   -92.68   -12.02    28.00     11.4 0.878E+01   0.52    302.30    28.00    27.48
   -37.37   -12.02    28.00     10.9 0.919E+01   0.54    336.34    28.00    27.46
    17.95   -12.02    28.00     11.0 0.913E+01   0.55    367.24    28.00    27.45
    73.26   -12.02    28.00     14.4 0.694E+01   0.59    395.73    28.00    27.41
   128.58   -12.02    28.00     19.1 0.522E+01   0.65    422.30    28.00    27.35
   183.89   -12.02    28.00     22.0 0.455E+01   0.68    447.30    28.00    27.32
   239.21   -12.02    28.00     23.2 0.431E+01   0.70    470.97    28.00    27.30
 Cumulative travel time =        3037. sec

END OF MOD132: LAYER BOUNDARY IMPINGEMENT/UPSTREAM SPREADING
--------------------------------------------------------------------------------
```

Figure 5.3:   Example of control volume flow module

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As mentioned, numerous flow features (as evidenced by the different flow classes) can occur. It is difficult to develop a robust graphics package that operates safely for all of these possibilities. The CMXGRAPH system has been widely tested, but occasional crashes can occur for rare flow module combinations and then only for certain plot types. Should a crash occur and the direct access mode (1a), listed above, has been used then the current file information will be lost. In those cases, it is safer to *first save the current session file data* and then exercise the graphics system.

5.3.2 Use of CMXGRAPH

The graphics system has a self-explanatory screen interface as shown in Figure 5.4. The menu is controlled by the **keyboard** alone by typing the letters that appear in capital on the menu buttons, or by user the four cursor keys when in zoom mode.

The **GRAPHICS MENU COMMANDS** are as follows:

Help an advice section is available listing the same information as given here

Quit exits the graphics system

There exist FIVE PLOT TYPES:

Plan generates a plan view of plume (x-y), as seen from above *(entry option)*

Side generates a side view of plume (x-z), as seen by an observer looking from the bank/shore

Traj generates a side view along trajectory of plume. The view is stretched out along the actually curving centerline trajectory.

c-**X** generates a plot of concentration on the plume centerline plotted against downstream distance x

c-**D** generates a plot of concentration on the plume centerline plotted against distance along the plume trajectory

The user can CONTROL the plume VIEW:

Near displays the near-field region only ; useful for close-up details *(entry option)*

Full displays the complete near- and far-field regions (i.e. the entire prediction results)

SHOW/HIDE FEATURES can be exercised to display additional information:

Labels puts identifier labels (site/case information) on top of plot *(entry option)*

Wqual displays information on regulatory mixing regulations (TDZ, RMZ, ...) on the plot; this is

displayed by dotted lines where particular regulations are encountered.

Module   shows boundaries of prediction modules

ZOOM/SCALE CONTROL allows control of plot details:

Zoom   allows the user to enlarge any RECTANGULAR SECTION of the current plot; this is
                       accomplished by:
                       -- Use CURSOR Control keys to move cursor (up,down,left,right)

                       -- Cursor SPEED can be modified by typing any number: 1(slowest),2,.. to 0(fastest)
                       -- Press RETURN when first corner of desired rectangle has been reached
                       -- Move cursor to find opposite corner and press RETURN to fix opposite corner

s**K**ale   allows the user to FIX SCALE distortion of current plot. The current scale is displayed
                       in a window on the menu bottom (see Figure 5.4).
                       -- Type in desired distortion at the prompt: All subsequent versions of the plot (including
                       zooms will be fixed at this scale distortion.
                        -- Use the sKale button again, to release the scale distortion.

Bkup   back-up to earlier zoomed/scaled versions of current plot

Esc   exit from zoom/scale mode (also Quit or repeated Bkup can be used to exit)

Several PRINT OPTIONS are available:

pf**I**le   writes the current plot to a POSTSCRIPT FILE for later printing. The file can be edited
                       and/or printed later using any compatible software (including public domain software,
                       such as Ghostscript).

                       -- Each print file is stored as \"*filename*.Pvn\" where:

                       filename = CORMIX or CORJET assigned filename,
                       Pvn   = file extension indicating a Postscript file,
                       v   = P, S, T, X or D, for one of the five view types,
                       n   = 0 to 9, increasing file number.

                       -- If the total file number for a particular view type exceeds the maximum of ten (10), the
                       first file in the series will be erased and replaced by the new file.

ps**C**rn   allows a PRINT SCREEN action of the current plot

                        -- The plot is first recreated without the menu interface and plot border.

                        -- Then use the Shift-PrintScreen buttons, to print the plot on-line.
                       Important: The PRINTER must have been initialized for GRAPHICS MODE with the
                       DOS command: \"graphics [type] /r\"   where: [type] = type of printer (e.g.: color4,
                       laserjetii).
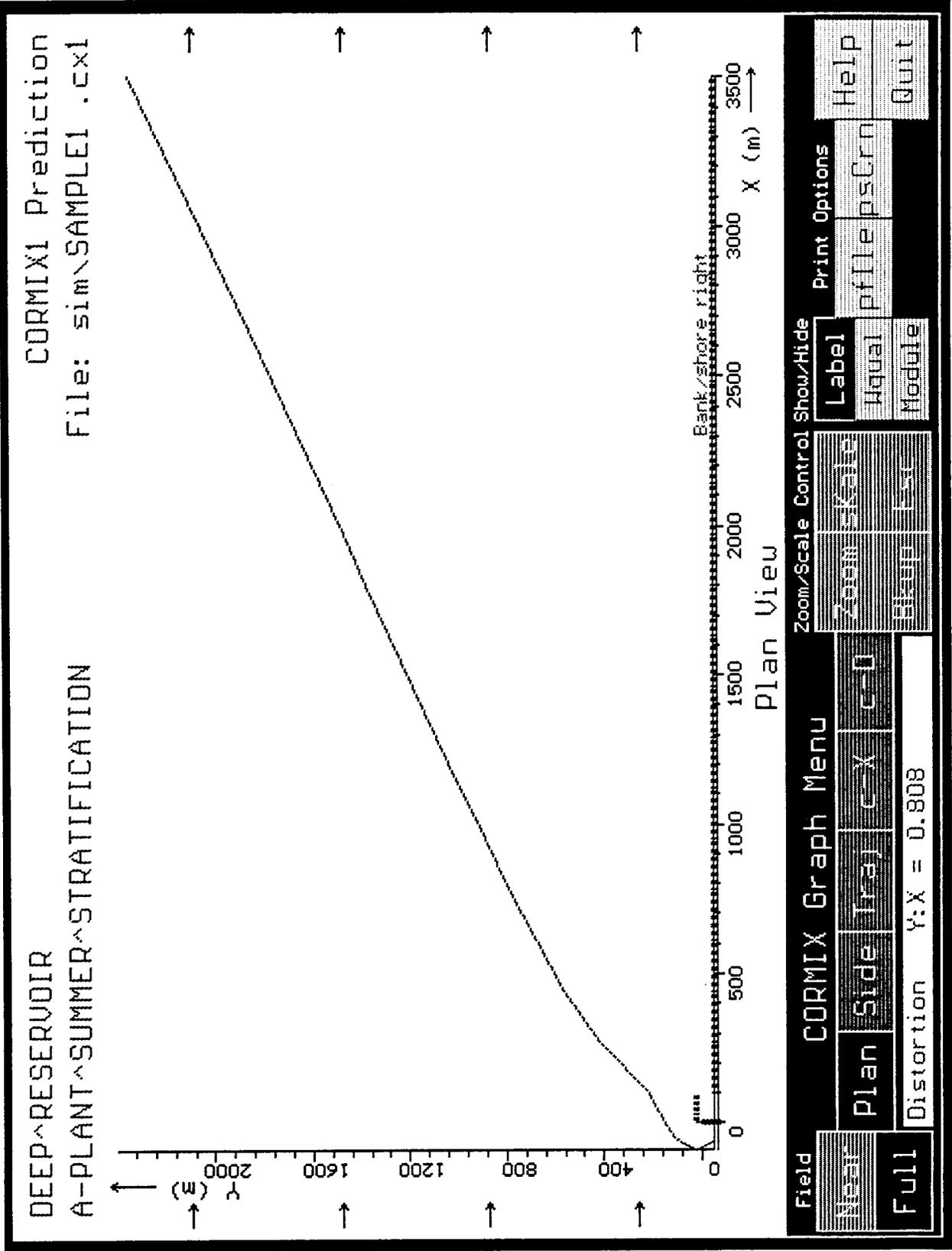
Figure 5.4 CMXGRAPH interface with menu options including example plot

The case study materials in the Appendices show some of the possibilities that can be exercised in the graphics display the plume features described in the *fn*.CXn output files. As shown above, the plume is characterized by its centerline trajectory, dilution, and width values. For understanding added detail in the plume cross-section, it is important to keep in mind the different concentration distributions and meanings of "plume width". These are explained in the supplemental statements at the beginning of each flow module (see Figures 5.2 and 5.3). Also, Figure 5.5 may be useful for further illustration. It gives the cross-sectional distribution of concentration for many of the commonly occurring plume cross-sections in the various regions predicted by the CORMIXn subsystems.

In some instances, users may desire to plot concentration isolines for the predicted plume shapes. The information contained in the HYDROn output file for each module and the definitions shown in Figure 5.5 are sufficient to construct such plots. In particular, in submerged plume or passive mixing regions having a Gaussian distribution, the following formula can be used

$$c(n) = c_c e^{-(\frac{n}{b})^2}$$

where c(n) is the lateral concentration, n is the coordinate position measured tranversely away from the centerline, c_c is the centerline concentration, e is the natural logarithm base, and b is the local plume half-width. However, this equation can not be used to plot concentration isolines in the control volume or buoyant spreading regions because they are defined with a top-hat or uniform concentration profile and not a Gaussian distribution.

By and large, all CORMIXn predictions are continuous from module to module satisfying the conservation of mass, momentum and energy principles. Occasionally, some *mismatches in plume width* can occur as a consequence of enforcing these principles. Most of these will be barely noticeable with the usual plotting resolution and they can usually be safely ignored. Some of the mismatches or discontinuities can be kept to a minimum by *specifying a large number for the grid intervals* (see Section 4.9) to increase the resolution of the CORMIX prediction. This is especially useful for the final simulations on a particular design case.

In addition, when bottom attachment or bank interaction occurs, the plume trajectory is assumed to (and simulation predictions do) shift suddenly to the boundary. In actuality, that shift would be much more gradual and this should be considered when interpreting the results of the CMXGRAPH plots or, alternatively, when plotting plume features by hand.

Submerged jet/plume

c_c = centerline concentration

0.37 c_c

Gaussian profile

B
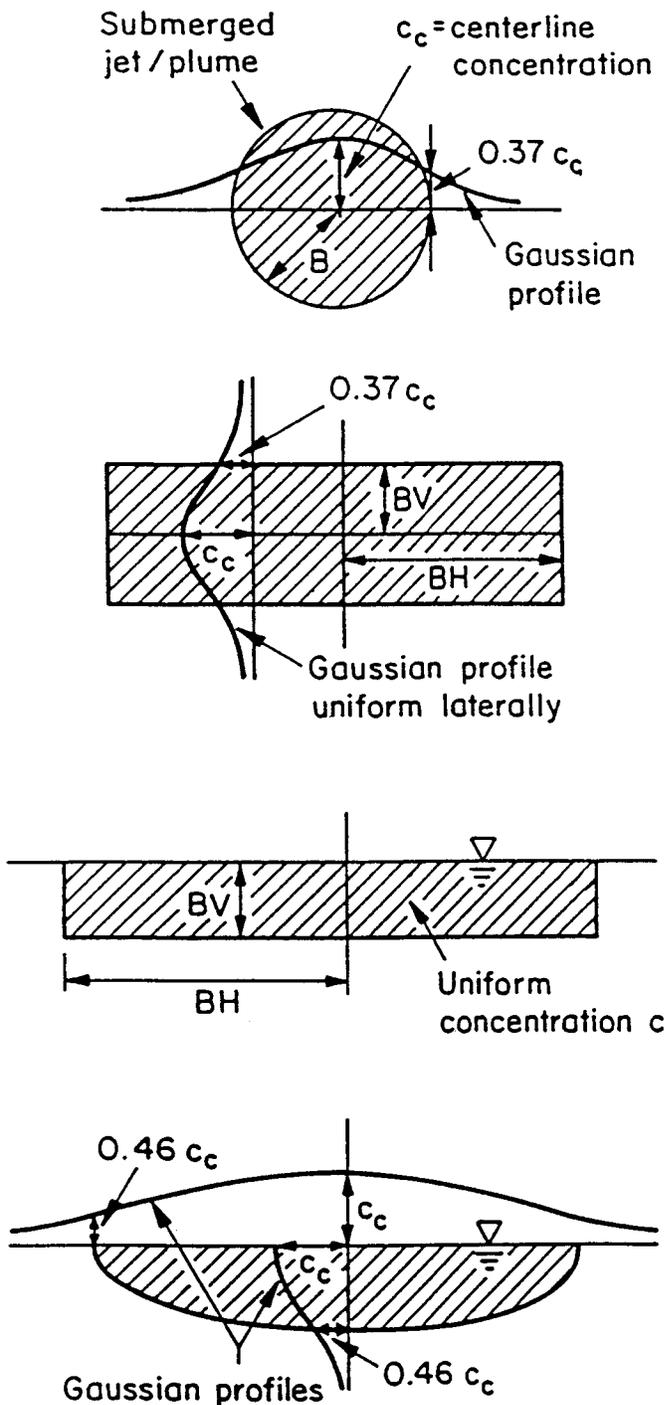
a) Submerged round jet/plume cross-section
B = radius
S = centerline dilution = $\dfrac{c_o}{c_c}$

0.37 c_c

BV

c_c

BH

Gaussian profile uniform laterally

b) Submerged plane jet/plume cross-section
BV = normal width
BH = lateral width
S = centerline dilution = $\dfrac{c_o}{c_c}$

BV

BH

Uniform concentration c

c) Cross-section during buoyant spreading along water surface
BV = vertical width
BH = lateral width
S = average dilution = $\dfrac{c_o}{c_c}$

0.46 c_c

c_c

c_c

Gaussian profiles

0.46 c_c

d) Cross-section during ambient diffusion process
BV = vertical width
BH = lateral width
S = centerline dilution = $\dfrac{c_o}{c_c}$

Figure 5.5: Cross-sectional distributions of CORMIX predicted jet/plume sections

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VI Post-Processor Models CORJET and FFLOCATR: Input and Output Features

The CORMIX system contains three post-processor options which be accessed directly from within the system or independently outside of CORMIX. In either case, the post-processor options provide additional enhancements to CORMIX in terms of plume display, and more detailed computation of near- and far-field plume features.

The first of the options, the graphics package CMXGRAPH, has already been described in Section 5.3. The second option is CORJET, the Cornell Buoyant Jet Integral Model, for the detailed analysis of the near-field behavior of buoyant jets. FFLOCATR, the Far-Field Plume Locator, for the far-field delineation of discharge plumes in non-uniform river or estuary environments is the third option. The latter two are described in this chapter.

6.1 CORJET: The Cornell Buoyant Jet Integral Model
6.1.1 General Features

CORJET is a Fortran model that solves the three-dimensional jet integral equations for submerged buoyant jets --either **a single round jet** or **interacting multiple jets in a multiport diffuser**-- in a highly arbitrary ambient environment. The ambient/discharge conditions include an arbitrary discharge direction, positive, neutral or negative discharge buoyancy, an arbitrary stable density distribution, and a non-uniform ambient velocity distribution with magnitude and direction as a function of vertical position.

Figure 6.1 displays these general characteristics for the case of a single port. In case of the multiport diffuser all the discharge port/nozzles point in the same direction (unidirectional or staged design) and the diffuser line can have an arbitrary alignment angle relative to the ambient current (for definitions see Section 4.5.1).

The detailed theoretical basis for CORJET can be found in the documentation report (8) on recent CORMIX system enhancements. CORJET is a type of a jet integral model whose original development in a two-dimensional framework and for a round jet only was first reported in the peer-reviewed literature by Jirka and Fong (25). Detailed verification studies with various experimental data sources have been reported (8,26).

In jet integral models the hydrodynamic equations governing the conservation of mass and momentum, and of other quantities as pollutant mass, density deficit, temperature and/or salinity, are solved step-wise along the general curved jet trajectory. The solution yields values of the trajectory position itself and of the centerline concentrations of these quantities, while the actual cross-sectional distribution is fixed a priori (mostly as a Gaussian distribution) in these models. Literally several dozen such model developments have been reported in the literature over the last thirty years or so of research on these mixing phenomena. Most of these developments differ (I) in the degree of simplifying assumptions on the ambient/discharge characteristics (e.g. two-dimensional trajectories or uniform ambient conditions only), and (ii) in the type of closure that is made to specify the turbulent growth and entrainment behavior in these jets under a variety of forcing conditions. Thus, some of these models can be demonstrated to be unduly limited for practical applications, and others to be clearly invalid in certain limiting regimes of plume behavior.

Whenever a jet integral model is reasonably general in its formulation and has been validated through experimental data comparison under a number of conditions it can be considered a useful prediction tool for near-field plume analysis. For practical purposes, all the models that meet the above conditions, in fact, differ little in their prediction results. The deviation among model results is usually less than the scatter in experimental data that is used for their verification. This holds true also for CORJET as well as another jet integral model,
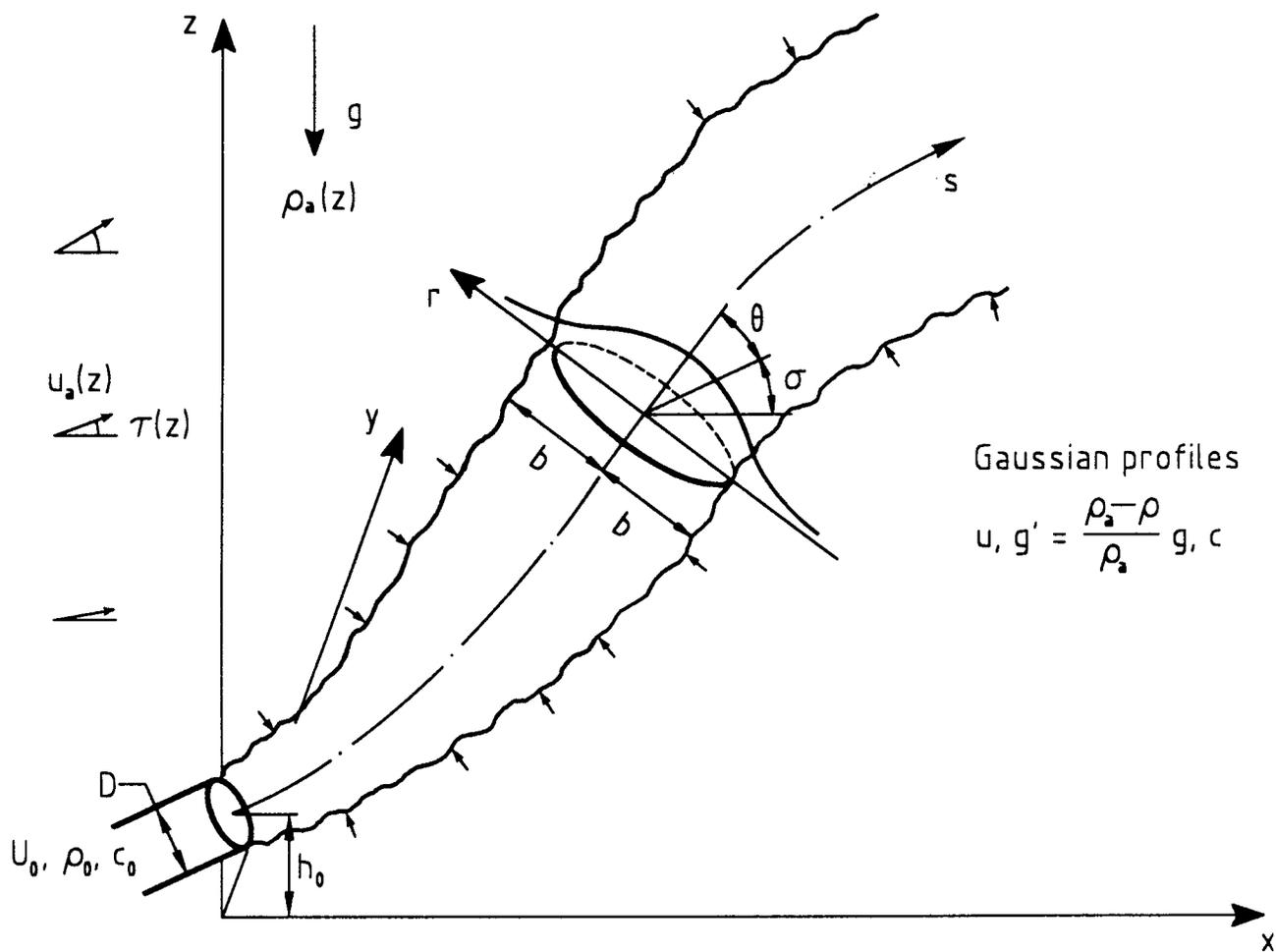
Figure 6.1: General three-dimensional trajectory of submerged buoyant jet in ambient flow with arbitrary density and velocity distribution: Case of a single round jet

(27), that has current USEPA support and distribution.

Both CORJET and PLUMES, although they differ in their internal formulation and closure assumptions, have a wide generality in discharge/ambient conditions and a reasonable verification base for a variety of conditions. They can deal with three-dimensional trajectories, with positive, neutral or negative discharge buoyancy, with conditions of reversible buoyancy (so-called nascent conditions in freshwater systems due to the density maximum at $4^{\circ}C$, requiring use of the full non-linear equation of state), with first-order pollutant decay, with variable stable ambient density, and with sheared non-uniform ambient currents, and with the merging of multiple port diffuser plumes. Three specialized features that the PLUMES model cannot deal with are a variable current direction at different levels, arbitrary diffuser alignments (with the extreme of a fully parallel alignment, $\gamma = 0^{\circ}$ in Figure 4.6), and applications to atmospheric plumes (using the concept of potential temperature and density).

Jet integral models, such as CORJET and

PLUMES, appear as useful and efficient tools for the rapid analysis of the near-field mixing of aqueous discharges. They require fairly little input data and are numerically efficient. However, their inherent limitations must be kept in mind.

All **jet integral models**, including CORJET, **assume an infinite receiving water body**, without any boundary effects due to limiting dimensions vertically (surface, bottom, or pycnocline) or laterally (banks or shore). Thus, they do not deal with such hydrodynamic effects as jet attachment and near-field instabilities that are so prevalent in many aqueous discharge plumes as emphasized in Section 2.1.1. Furthermore, they are **near-field models only** and do not give predictions on what happens to the entire mixing zone that may often cover larger distances (see Section 2.2.5).

In summary, jet integral models **if used alone** and by an inexperienced analyst are **not a safe methodology for mixing zone analysis**. They become safe only when used in conjunction with a more comprehensive analysis using the full CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries**.

In fact, the CORMIX system has built in several safeguards and warning statements to the user as explained below. When used in that context CORJET becomes a highly useful addition to the CORMIX system that can provide considerable additional detail and sensitivity analysis in the immediate near-field of the discharge plume.

6.1.2 Access to CORJET

CORJET, like the other post-processor options such as the graphics system (Section 5.3.1), can be accessed in different ways:
(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored,

by entering the Post-Processor option in the Iteration Menu.
(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the CORJET option is chosen the user must first specify whether a CORMIX1 or 2 simulation should be analyzed for the near-field with CORJET. Then the CORMIX1 or 2 filename in the CORMIX\SIM directory must be specified. CORJET will run automatically using the input data of the given CORMIX data file.

(2) Use outside CORMIX:
CORJET can be invoked directly by typing:
corjet (or simply: cj) *filename*
where *filename* (including path and extension) is any specially prepared input data file (see following section). Alternatively if one types:
corjet (or simply: cj)
the model will prompt the user for the input data filename.

6.1.3 CORJET Input Data File

This section for data preparation applies only if CORJET is run independently from the CORMIX system as discussed above. The **checklist** given on the following page is useful for data assembly prior to input data entry.

In this case, the Fortran model CORJET reads input data file with *filename* that is user-specified with arbitrary name, extension and directory. For user convenience it is recommended that all such files be kept in the special directory CORMIX\POST\CJ.

The input data file is a Fortran-readable file that is read in open format, that is all pertinent data values are arranged on a line and separated by one or more open spaces. The file consists of five data blocks, each of which must be lead in by two dummy lines that are not read. Table 6.1 gives an example of a data file in which the dummy lines are indicated by the # sign.

Table 6.1
Example of an input data file for CORJET

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):   Density option (½):   Ambient levels (1-10):
1             1                     3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA    TA     SA     RHOA   UA     TAUA
1      0.    12.    30.           0.5    0.
2      5.    15.    29.5          0.8    0.
3      15.   20.    28.           1.2    0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0    H0     U0     THETA0 SIGMA0 C0     KD     T0     S0     RHO0   LD    ALIGN
1      0.5   0.     3.0    45.    45.    100.   0.     30.    0.            0.    0.
#Program control:
#ZMAX  ZMIN  DISMAX NPRINT
30.    0.    200.   10
```

The **required input data values** (all in SI units) are discussed in the following. The definition of these values is entirely consistent with those for CORMIX (in particular, see Section 4.4 and 4.5 for discharge conditions).

Block 1: Identifier
LABEL: Any descriptive label/text (should not exceed 50 characters, so that it does not get truncated on the graphics plots)

Block 2: Fluid and density specification
IFLUID: 1 (water) or 2 (air, for atmospheric applications)
IDENOP: 1:   in case of water: Density will be calculated from specified temperature and/or salinity
                   In case of air: Potential density will be calculated from potential temperature assuming dry adiabatic conditions
             2: Density values will be specified directly
LEVAMB: Number of levels for which ambient conditions are given (1 to 10)

Block 3: Ambient Conditions (specify LEVAMB lines)
LEV: Level number (increasing from 1 to LEVAMB)
ZA: Specify vertical level (z-coordinate) (m)
TA :   if IFLUID=1(water): Temperature at ZA (degC) *(omit if IDENOP=2)*
             if IFLUID=2(air): Potential temperature at ZA (degC) *(omit if IDENOP=2)*
SALA: Salinity at ZA (ppt) *(omit if IDENOP=2 or if IFLUID=2)*
RHOA: if IFLUID=1: Density at ZA (kg/m^3) *(omit if IDENOP=1)*
             if IFLUID=2: Potential density at ZA (kg/m^3) *(omit if IDENOP=1)*
UA: Ambient velocity (speed) at ZA (m/s)
TAUA: Angle of ambient velocity vector measured CCW from x-axis (deg) (set = 0. unless velocity distribution in vertical is skewed, i.e. spiral-type)

Block 4: Discharge Conditions
NOPEN: 1: if SINGLE PORT DISCHARGE (i.e. 1 opening)
             >= 3: number of openings (ports) for MULTIPORT DIFFUSER
D0:   Port diameter (m) (should include contraction effects if any)
H0:   Port center height above x-y plane (m)
U0:   Jet exit velocity (m/s)
THETA0:   Vertical angle of discharge (deg)

CHECKLIST FOR DATA PREPARATION

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.10

| DOS File Name: | Date: |
| | Prepared by: |

Label:

Fluid/Density:

Fluid: 1 (water)   Density specificaton: 1 (via temp./sal.)   Number of ambient levels:
         2 (air)   2 (direct)   (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)	Velocity (m/s)	Angle of velocity (deg)

Discharge Conditions:

Number of openings: (=1 for single port s.p.)		Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m^3)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)

Program Control:

Max. vertical   Min. vertical   Max. distance along   Print intervals:
distance (m):   distance (m):   trajectory (m):   (best 5 to 10)

SIGMA0:   Horizontal angle of discharge axis measured CCW from x-axis (deg)
                         Examples: 0. = co-flow, 90. or 270. = cross-flow, 180. = counterflow
C0:   Discharge concentration (any units that need not be specified)
KD: Coefficient of substance decay [negative value if growth] (/s)
T0:   Discharge temperature (degC) *(omit if IDENOP=2)*
S0:   Discharge salinity (ppt) *(omit if IDENOP=2 OR IF IFLUID=2)*
RHO0:   Discharge density (kg/m^3) *(omit if IDENOP=1)*
LD: Diffuser length (m) (set = 0. [non-blank] if NOPEN=1)
ALIGN: Diffuser alignment angle (deg) measured CCW from x-axis (set = 0. if NOPEN=1)
                         Examples: 0. = parallel diffuser, 90. = perpendicular diffuser

Block 4: Program Control
ZMAX: Maximum vertical coordinate of interest (m)
ZMIN: Minimum vertical coordinate of interest (m)
                 ZMAX and ZMIN are cutoffs for + and - buoyancy, respectively!
DISMAX: Maximum distance of interest along trajectory (m)
NPRINT: Print intervals (any positive number less than 100; recommended value 5 to 10; does not affect
                 accuracy of computation!)

Note on density specification: It is important to note the mutual exclusivity for the indirect or direct density specification as listed above. Omit the values (i.e. leave blank spaces) depending on the value of the IDENOP parameter. This can be seen in the preceding example data file. Up to 10 ambient levels can be specified for density and velocity distribution. This is sufficient to replicate complicated observed ambient profiles. CORJET performs internal **consistency checks** to test whether the specified density distribution is statically stable.

The **coordinate system** in CORJET can, in principle be taken as consistent with the CORMIX1 and 2 conventions (Section 5.2.1), i.e. the origin at the bottom of the receiving water body. (In fact, this convention is exercised whenever CORJET is run from within CORMIX.) However, since CORJET does not recognize the dynamic effect of the presence of the actual bottom boundary it is often convenient to set the origin at the center of the discharge port. In that case the port height H0 must be entered as 0.0. x points horizontally in the downstream direction, y laterally across in the horizontal plane, and z vertically upward. In the rare case when the ambient velocity distribution is skewed in the vertical, the definition of the x direction is best made by the direction of the ambient velocity **at** the level of origin (then TAUA is 0.0 at that level!), but any other convention is possible, too, and can be implemented by the choice of the TAUA value

at the level of origin.

The CORMIX system contains upon its installation several **CORJET case studies** (see also Appendix E) that are installed as CORMIX\POST\CJ\case*.inp. It is recommended to copy one or more of these files and use the copy for constructing any future input data file.

6.1.4 CORJET Output Features

Regardless of the access mode (within or outside of CORMIX) CORJET has two output mechanisms, a numerical output file and a graphical display by means of CMXGRAPH.

(a) CORJET Output File:

(a.1) Use within CORMIX:

The output file gets stored as CORMIX\POST\CJ*fn*.CJX where *fn* is the CORMIX1 or 2 filename that has been specified during the data entry. This file can be viewed on-screen or printed within CORMIX.

A typical CORJET output file generated in this access mode is shown in Table 6.2 below corresponding to the input example presented above. The header information starts with the banner 'JJJ' and then echoes all the pertinent data that had been supplied to CORMIX and had been picked up for the CORJET simulation. The

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underlying CORMIX1 or 2 **flow class** is listed. If one of the **unstable or bottom-attaching** flow classes is encountered in this access mode, then **CORJET will not provide any predictions** since a pure jet integral model would not be **applicable**.

The tabular listing (see Table 6.2) gives the plume values along the trajectory. CORJET will cut off at a vertical level ZMAX that is equal to the water depth at discharge or ZMIN = 0.0 (for negatively buoyant cases) equal to the water body bottom. In neither case does it compute the actual boundary approach or impingement processes (as does the more complete CORMIX model in which some CORJET elements are, in fact, integrated, starting with Version 3.0). The interpretation of data values in this tabular listing is consistent with that for CORMIX1 or 2 (see Section 5.2.2).

Table 6.2
Example of CORJET output file when accessed within CORMIX

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNE ⊟ UOYANT JET INTEGRAL MODEL          Version 4.0, March 1995
-------------------------------------------------------------------------
FILE NAME:              cormix\post\cj\SAMPLE1.CJX
 Label/identifier:      A-PLANT^SUMMER^STRATIFICATION
 Time of CORJET run:      4/12/96--18:40:19
NEAR-FIELD DATA values for earlier CORMIX1  prediction (metric):
 Site name/label:       DEEP^RESERVOIR
 Design case:           A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:             cormix\sim\SAMPLE1 .CX1
 Time of CORMIX run:    06/24/95--22:29:54
 HD    =     30.50 UA    =      .01  CUNITS= PPM
 STRCND=  C      density stratified environment
 RHOAS =    996.21 RHOAB =    999.61  HINT  =     15.50  DRHOJ =    2.181
 FLOCLS=  S3
Corresponding CORJET ambient conditions:
   LEV    ZA     RHOA     UA    TAUA
    1     .00   999.61    .01    .00
    2   14.75   998.39    .01    .00
    3   16.25   996.21    .01    .00
    4   30.50   996.21    .01    .00
  Pycnocline thickness has been set to 1/10 of upper layer thickness.
Discharge conditions (metric):  SINGLE PORT
   D0     H0      U0  THETA0 SIGMA0   C0      KD     RHO0
  .254    .60    3.02  10.00  90.00 .35E+04 .00E+00  998.21
Program control:
  ZMAX    ZMIN   DISMAX  NPRINT
  30.50    .00  1525.00     10
Flux variables (based on ambient at discharge level):
  Q0  = .153E+00  M0  = .462E+00  J0  = .203E-02  GP0  = .133E-01
Length scales (m) and parameters:
  LQ  =      .23  LM  =     12.44  Lm  =    45.31  Lb  =    601.53
  Lmp =     4.88  Lbp =      3.06
  FR0 =    52.01  R   =    201.31
-------------------------------------------------------------------------
CORJET PREDICTION:            Stepsize =   .2251  Printout every  10 steps
 Single jet/plume:
   X     Y     Z    Sc     Cc      B |  DIST   Save    Gpc    Flc
  .00   .00   .60  1.0  .350E+04   .13|   .00   1.0  .13E-01 52.01
  .01  1.23   .82  1.0  .350E+04   .13|  1.25   1.4  .16E-01 95.03
  .04  3.45  1.22  2.5  .142E+04   .37|  3.50   4.2  .50E-02 33.42
  .11  5.65  1.65  4.1  .852E+03   .62|  5.75   7.0  .25E-02 21.98
  .22  7.85  2.13  5.8  .607E+03   .87|  8.00   9.8  .12E-02 19.01
  .35 10.04  2.65  7.4  .471E+03  1.12| 10.25  12.6  .32E-03 25.46
  .44 11.13  2.92  8.3  .423E+03  1.25| 11.38  14.0 -.59E-04 50.81
 Level of buoyancy reversal in stratified ambient.
  .53 12.22  3.19  9.1  .384E+03  1.37| 12.50  15.4 -.40E-03 16.80
  .74 14.40  3.68 10.8  .325E+03  1.63| 14.76  18.2 -.97E-03  8.35
  .99 16.61  4.06 12.4  .282E+03  1.88| 17.01  21.0 -.13E-02  5.70
 1.28 18.83  4.20 14.1  .248E+03  2.14| 19.26  23.8 -.13E-02  4.61
 1.31 19.05  4.20 14.3  .245E+03  2.17| 19.48  24.1 -.13E-02  4.56
 Maximum jet height has been reached.
 1.62 21.05  4.05 15.9  .220E+03  2.40| 21.51  26.8 -.99E-03  4.54
 1.99 23.23  3.63 17.8  .196E+03  2.66| 23.76  30.0 -.34E-03  6.68
 2.19 24.31  3.37 18.8  .187E+03  2.80| 24.89  31.6  .27E-04 22.15
 Terminal level in stratified ambient has been reached.    PROGRAM STOPS!
-------------------------------------------------------------------------
END OF CORJET PREDICTION:      Total number of integration steps =   106
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The main usefulness of CORJET when run in this mode lies in the short and separate display of the near-field buoyant jet only. In some cases, the pertinent regulatory constraints may be limited to that region.

(a.2) Use outside of CORMIX:
The output file gets stored as *filename*.OUT in the same directory for which the user had specified the input file (see Section 6.1.2(2)). This file can be viewed on-screen or printed using any text processor.

The CORJET output file corresponding to the input data file of Table 6.1 is listed in Table 6.3. The lead-in data provide an echo of the input data and then lists the calculated length scale and non-dimensional numbers controlling the mixing process.

Table 6.3
Example of CORJET output file

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.0, March 1995
-------------------------------------------------------------------------
FILE NAME:              post\cj\case2.OUT
 Label/identifier:      Case2: SINGLE PORT, STRATIFIED, VARIABLE CURRENT
 Time of CORJET run:     4/10/96--19:28: 6

Ambient conditions:     No. of levels: 3  Fluid: Water   Density option: 1
   LEV     ZA      TA      SA    RHOA      UA    TAUA
    1     .00   12.00   30.00 1022.71     .50     .00
    2    5.00   15.00   29.50 1021.74     .80     .00
    3   15.00   20.00   28.00 1019.43    1.20     .00
Discharge conditions (metric):  SINGLE PORT
   D0      H0      U0  THETA0 SIGMA0    C0      KD      T0      S0      RHO0
  .500     .00    3.00  45.00  45.00  .10E+03 .00E+0  30.0     .0   995.65
Program control:
   ZMAX    ZMIN   DISMAX  NPRINT
  30.00     .00  200.00      10
Flux variables (based on ambient at discharge level):
 Q0   =  .589E+00  M0   =  .177E+01  J0   =  .153E+00  GP0  =  .259E+00
 QT0  =  .106E+02  QS0  = -.177E+02
Length scales (m) and parameters:
 LQ   =      .44  LM   =      3.92  Lm   =     2.66  Lb   =     1.22
 Lmp  =     5.61  Lbp  =     6.71
 FR0  =     8.33  R    =     6.00
Zone of flow establishment (m):
 LE   =     1.30  XE   =      .75  YE   =     .62  ZE   =      .86
 THETAE=    38.34  SIGMAE=    34.00  GAMMAE=    49.43
-------------------------------------------------------------------------
CORJET PREDICTION:            Stepsize =   .2659  Printout every  10 steps
 Single jet/plume:
    X      Y      Z    Sc      Cc     B |  DIST    Save     Gpc   dTc dSALc
   .00    .00    .00   1.0  .100E+03   .25|    .00    1.0  .26E+00 18.0-30.0
   .75    .62    .86   1.0  .100E+03   .25|   1.30    1.4  .27E+00 20.8-34.7
  2.81   1.50   2.27   3.0  .334E+02   .64|   3.96    4.6  .83E-01  5.2 -9.9
  5.22   1.96   3.28   5.7  .176E+02   .94|   6.62    8.3  .42E-01  2.1 -5.1
  7.74   2.22   4.07   8.4  .118E+02  1.16|   9.27   12.1  .26E-01   .8 -3.3
 10.31   2.40   4.74  11.2  .890E+01  1.34|  11.93   15.8  .18E-01   .1 -2.4
 12.90   2.52   5.32  14.0  .716E+01  1.49|  14.59   19.5  .13E-01  -.3 -1.9
 15.51   2.61   5.84  16.6  .601E+01  1.62|  17.25   23.2  .96E-02  -.6 -1.5
 18.12   2.68   6.31  19.2  .520E+01  1.74|  19.91   26.7  .70E-02  -.8 -1.2
 20.75   2.73   6.74  21.7  .460E+01  1.84|  22.57   30.0  .50E-02 -1.0 -1.0
 23.38   2.78   7.13  24.1  .414E+01  1.93|  25.23   33.3  .34E-02 -1.1  -.8
 26.01   2.82   7.48  26.4  .379E+01  2.01|  27.89   36.3  .21E-02 -1.3  -.6
 28.65   2.85   7.80  28.5  .351E+01  2.08|  30.54   39.1  .10E-02 -1.4  -.5
 31.29   2.88   8.09  30.4  .329E+01  2.14|  33.20   41.6  .15E-03 -1.5  -.4
 31.82   2.89   8.14  30.8  .325E+01  2.15|  33.73   42.1 -.13E-04 -1.5  -.4
 Terminal level in stratified ambient has been reached.     PROGRAM STOPS!
-------------------------------------------------------------------------
END OF CORJET PREDICTION:      Total number of integration steps =   123
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

The actual tabular listing of the numerical output is divided in two halves by a vertical line. The left half lists data exactly in the same fashion as a CORMIX1 or 2 prediction file (see Section 5.2.2). The right half gives additional detailed information on the following variables:

DIST: distance (m) along the jet trajectory

Save: average (bulk) dilution, defined on the basis of total volume flux within the jet relative to the initial volume flux (discharge)

Gpc: centerline buoyant acceleration (m/s^2)

dTc: centerline temperature difference relative to local ambient temperature ($^{\circ}$C) *(if IDENOP = 1)*

dSALc: centerline salinity difference relative to local ambient salinity (ppt) *(if IDENOP = 1)*

Flc: local densimetric Froude number *(if IDENOP = 2)*

In this mode CORJET becomes an important engineering tool for **design sensitivity analysis** --and also for research purposes-- to evaluate the behavior of the near-field processes to some of the ambient/discharge details, some of which had to be simplified (schematized) within the CORMIX approach. The user can learn to understand through repeated use of CORJET that plume mixing can indeed often be represented by simple linear, or even uniform, approximations to the ambient density structure.

Again, it is emphasized that CORJET when used alone is not a safe prediction methodology because of the limiting assumption of infinite receiving water. For that reason an alert is printed at the end of each CORJET output file:

```
Note: CORJET has been used outside the
      CORMIX system, assuming unlimited
      receiving water.
      Carefully examine  all results for
      possible boundary effects due to
      surface,   bottom,   or   lateral
      boundaries.
```

Previous application of CORMIX assures a careful examination of the interaction of the discharge with boundaries has been accomplished.

(b) Graphics display and plotting of CORJET results:

The graphical display and plotting of the CORJET prediction results by means of CMXGRAPH is similar to that of CORMIX results as described in Section 5.3.

The graphics package can be invoked in either access mode (within or outside of CORMIX) immediately after the computation or independently on any existing CORJET output file that has been computed earlier. Thus, **CMXGRAPH has been configured to deal with both CORMIX prediction files and CORJET output files.**

6.2 FFLOCATR: The Far-Field Plume Locator

6.2.1 General Features

Although the main emphasis of CORMIX is on the near-field mixing behavior of discharges it can also be used for providing plume predictions at larger distances in the far-field provided the flow is not highly irregular with pronounced recirculating zones and eddies in the ambient flow.

The CORMIX predicted far-field always applies to a rectangular schematized cross-section with a straight uniform channel (see Sections 4.3.1 and 4.3.2). The FFLOCATR is a simple method for interpreting the schematized CORMIX far-field plumes within the actual flow patterns in natural rivers and estuaries. This procedure, based on the cumulative discharge method, is illustrated in Figure 6.2.

The **cumulative discharge method**, first proposed by Yotsukura and Sayre (28; see also 19,20), is a convenient approach of dealing with lateral mixing in natural irregular (but not highly irregular with recirculating zones!) channels. In such channel geometry the passive far-field plume that is vertically mixed, or approaches vertical mixing, will be positioned around the "streamline", or more precisely the "cumulative discharge line", that passes through the plume
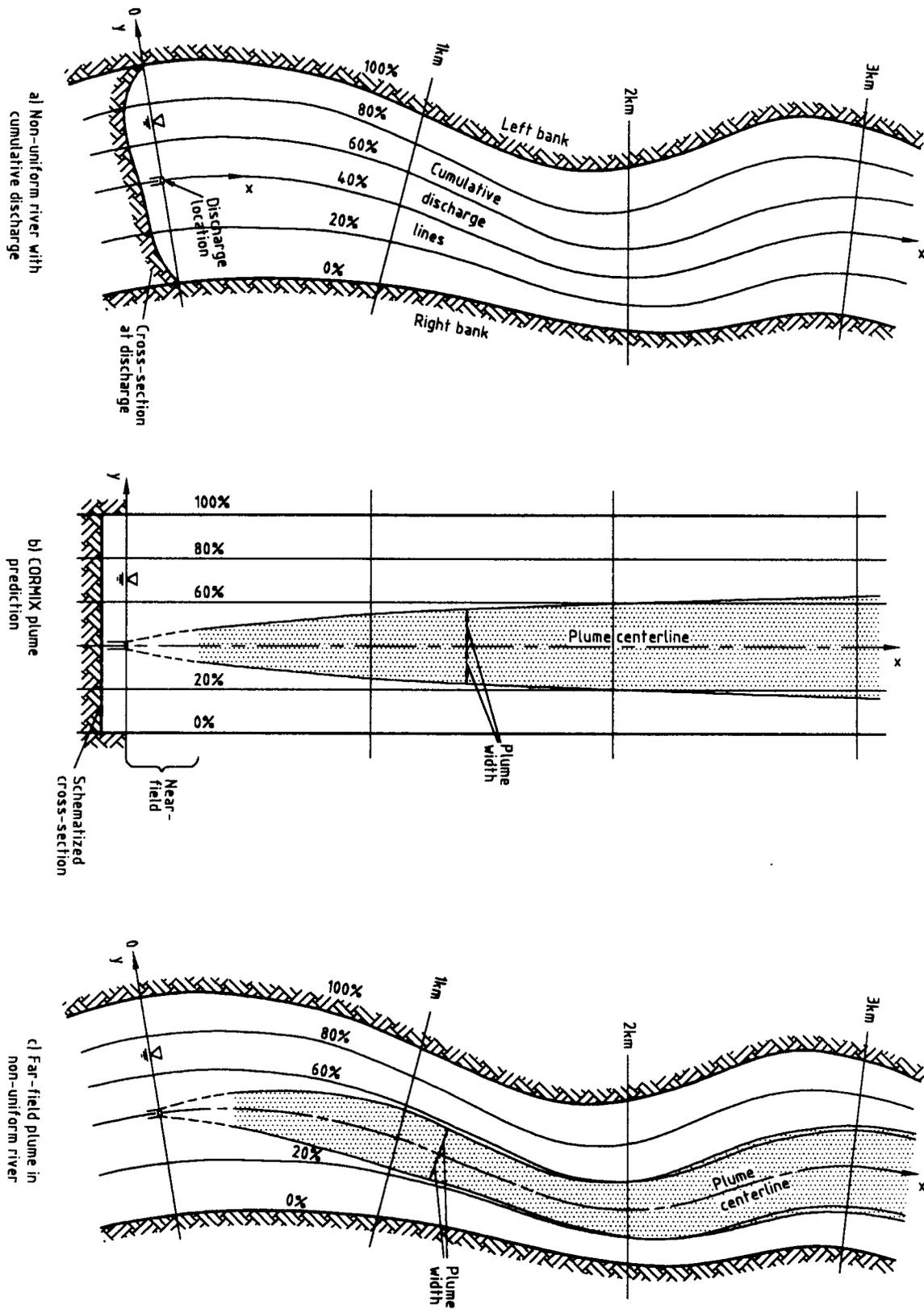
Figure 6.2: Illustration of the cumulative discharge method for translating the CORMIX predicted far field plume to the actual flow characteristics in winding irregular rivers or estuaries

center when it enters the far-field. Lateral spreading around this line occurs by lateral turbulent diffusion and can be enhanced buoyancy induced processes.

Looking downstream at a particular cross-section (see Figure 6.2a) the cumulative discharge $q(y)$ is defined as

$$q(y') = \int_0^{y'} \overline{u_a}(y') \, H(y') \, dy'$$

in which y' is the lateral coordinate pointing from the right bank to the left across the flow (y' differs from y as defined in CORMIX whose origin is at the discharge location), H is the local depth, and $\overline{u_a}$ is the depth-averaged local velocity. When the above equation is integrated across the full channel width B_s then the total discharge will result $Q_a = q(B_s)$. Hence, if the local values $q(y')$ are divided by Q_a the results can be presented in normalized form as the cumulative discharge lines ranging from 0% at the right bank to 100% at the left bank. The full distribution of such cumulative discharge lines in a river or estuary gives an appearance of the overall flow pattern that is important for pollutant transport. Closely spaced discharge lines are mostly indicative of areas of large depth and higher velocities as they occur in the outside portion of river bends or meanders (as sketched in Figure 6.2a).

In the CORMIX schematization of ambient flow characteristics and channel cross-section it is, in fact, useful to keep in mind the cumulative transport aspects of the ambient flow as remarked in Section 4.3.1 and 4.3.2. Thus, the uniform CORMIX flow field with the constant depth laterally is indeed conforming to a cumulative discharge distribution with equally spaced discharge lines, as indicated in Figure 6.2b. It is then conceptually straightforward to translate the CORMIX plume prediction back to the actual flow distribution by calculating and plotting the plume boundaries within the given cumulative discharge lines as shown in Figure 6.3c. The actual plume pattern may then show some surprising features such as strong "shifting back and forth" between opposing banks and an apparent "thinning' of the plume width. These realistic plume features are simply dictated by the non-uniform flow field.

Further technical details on the FFLOCATR model can be found in the report on CORMIX enhancements (8).

6.2.2 Access to FFLOCATR

FFLOCATR can also be accessed in different ways:

(1) Use within CORMIX:

(1a) It can be accessed at an end of the prediction after the file has been stored, by entering the Post-Processor option in the Iteration Menu.

(1b) It can be accessed on earlier existing files by directly choosing the Post-Processor option in the Main Menu.

In either case, once the FFLOCATR option is chosen the user must first specify whether a CORMIX1, 2 or 3 simulation should be interpreted for the far-field with FFLOCATR. Then the CORMIX filename in the CORMIX\SIM directory must be specified. Finally, the user must specify the name of the cumulative discharge input data file, or if that does not yet exist, the user can first create such file by entering data on the cumulative discharge distribution at several cross-sections.

(2) Use outside CORMIX:

FFLOCATR can be invoked directly by typing the command line with three arguments:

fflocatr CORMIXn *fn* POST\FF*cumdata*.FFI

(alternatively, ffl can be typed instead of fflocatr) where CORMIXn, n = 1, 2 or 3, specifies which earlier CORMIX simulation should be analyzed for the far-field, *fn* (without path and extension) is the name of the CORMIX prediction file in the CORMIX\SIM directory, and *cumdata* (with directory designation POST\FF and fixed extension FFI) is the cumulative discharge input data file (see following

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section) existing in directory CORMIX\POST\FF.

Alternatively if one types:

fflocatr (or simply: ffl)

without the three arguments, the model will prompt the user for the file information.

6.2.3 FFLOCATR Cumulative Discharge Input Data File

In general, it is more convenient to construct the *cumdata*.FFI file outside of CORMIX and store it in the CORMIX\POST\FF directory. This option is described first.

(a) Input Data File Prepared Outside of CORMIX:

FFLOCATR is a Fortran program and reads the *cumdata*.FFI file in open format. An example is shown in Table 6.4 (corresponding to the test case discussed in Appendix B).

Table 6.4
Example of a cumulative discharge input data file for FFLOCATR

```
SHALLOW RIVER CUMULATIVE DISCHARGE              (applies to Sample2)
Number of Cross-sections (XS):
3
XS 'Label-'  Dist.   10%   20%   30%   40%   50%   60%   70%   80%   90%  100%
<> <------> <----> <---> <---> <---> <---> <---> <---> <---> <---> <---> <--->
1  'STA1'    30.5    6.1  12.2  15.9  20.7  27.5  33.6  58.0  76.3  82.4  88.5
2  'STA2'   152.5    9.2  16.8  21.4  24.4  27.5  33.6  36.6  39.7  54.9  79.3
3  'STA3'   305.    18.3  33.6  39.3  45.8  48.8  51.9  54.0  56.4  61.0  67.1
```

The **required input data values** (SI units) are:

Line 1:   Any descriptive label.
Line 2:   <dummy line; not read>
Line 3:   NUMXS = Number of cross-sections (1 to 10) for which discharge data values will be entered
Line 4:   <dummy line useful for formatting subsequent data; not read>
Line 5:   <dummy line useful for formatting subsequent data; not read>
Lines 6ff: NUMXS lines must be entered, each containing the following data:
  XS =   number of cross-section, numbered sequentially beginning with 1
  STALAB =   arbitrary label for cross-section, bracketed by apostrophes ' with maximum total length of 10 characters (e.g. 'RM595' standing for river mile 595)
  YCD =   10 values, representing the position of the cumulative discharge line (m) measured from the right bank, beginning with the 10% line, incrementing by 10%, and ending with the 100% line. The 100% line is also equal to the channel width at that cross-section.

Consistency checks are performed on each data file to make sure that the entered values YCD are monotonically increasing. Essentially two methods can be used for obtaining the values for the cumulative discharge positions YCD in specific cases:

1) On the basis of detailed **stream-gaging surveys**, for example using the standard methods employed by the U.S. Geological Survey. This is the preferable approach for small to medium streams or rivers.

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2) Using the results of detailed **numerical models** for the flow distribution in open channel flow. This is preferable for larger rivers or estuaries.

The primary application for FFLOCATR is for **bounded channels** such as streams, rivers or estuaries. The model will not execute when it encounters a CORMIX file for a design case involving an unbounded ambient flow.

Nevertheless, it may sometimes be useful to provide a detailed far-field plume delineation also for **unbounded flow situations**, such as coastal areas or lakes. This can be done when detailed hydrographic data or numerical model predictions describing the flow distribution in the near-shore where the plume may be located are available. A CORMIX simulation can then be re-run specifying a "bounded channel" with a width equal to some arbitrary bounding offshore streamline. The YCD data can then be specified relative to the value of that chosen streamline. FFLOCATR will thus predict the far-field plume location in the irregular coastal zone (assuming recirculating eddies do not exist in the flow).

(b) Input Data File Prepared Within CORMIX:

The user can generate the data file with exactly the same data structure as discussed above also within CORMIX. The system will prompt the user for the individual data items (up to 10 cross-sections can be entered) and then for a *cumdata* filename. The file will then be stored automatically in directory CORMIX\POST\FF with extension FFI.

6.2.4 FFLOCATR Output Features

FFLOCATR generates an output file CORMIX\POST\FF*fn*.FFX indicating that the far-field plume prediction for the CORMIX design case *fn* has been interpreted under the actual far-field flow distribution. This file can be inspected on-screen when in CORMIX or externally with any text processor, and can be printed out. No graphics plotting option exists for this file.

As an example, Table 6.5 on the next page shows the output file that combines the cumulative discharge input data of Table 6.4 with the CORMIX2 plume predictions that are part of Appendix B. The output file preceded by the banner 'FFF' consists of three parts. The first part lists some of the underlying CORMIX data including file information. The second part echoes the complete cumulative discharge input data file.

The actual results of the FFLOCATR translation routine are given in the third part. For each of the specified cross-sections (stations) the output file lists the station label, the downstream distance, and the position of plume center, left edge and right edge, respectively, each measured from the right bank, and the local centerline dilution and concentration. Data of this kind can then readily be used to prepare plots of far-field plumes superimposed on maps of the actual flow field. This last step has been illustrated in Figure 6.2c.

It should be understood that the plume centerline in the far-field does not necessarily coincide with the cumulative discharge line that passes through the offshore discharge location (as has been illustrated in Figure 6.2 where a co-flowing discharge had been assumed). The plume centerline can shift because of near-field processes, as in case of a cross-flowing discharge, or if bank interaction occurs in the far-field, causing the centerline to shift to one bank/shore.

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Table 6.5
Example of FFLOCATR output file

```
FFLOCATR RESULTS FILE:
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
FFLOCATR:  FAR-FIELD PLUME LOCATOR                      Version 1.0, March 1994
-----------------------------------------------------------------------------
Output FILE NAME:        POST\FF\SAMPLE2.FFX
 Time of FFLOCATR run:   1995/ 6/ 2-- 8:54:38


-----------------------------------------------------------------------------
FAR-FIELD DATA values from earlier CORMIX2 prediction:
 FILE NAME:              SIM\SAMPLE2.cx2
 Site name/label:        B-PLANT^SHALLOW-RIVER
 Design case:            LOW-FLOW^7Q10
 Time of CORMIX2 run:    09/20/94--15:24:11

Channel characteristics (metric):
 BS    =     50.00  HA    =       .30  UA    =        .54
 BANK  =   right    DISTB =     20.00
 STRCND=   U        uniform density environment

Pollutant data:
 C0    =    100.00  CUNITS=    PERCENT


-----------------------------------------------------------------------------
CUMULATIVE DISCHARGE DATA (m):
 FILE NAME:              POST\FF\SH-RIVER.ffi
 Data label:            SHALLOW RIVER CUMULATIVE DISCHARGE
 Number of XS:           3
XS'Label-'  Dist. 10%   20%   30%   40%   50%   60%   70%   80%   90%  100%
1 'STA1  '   30.5  6.10 12.20 15.90 20.70 27.50 33.60 58.00 76.30 82.40 88.00
2 'STA2  '  152.5  9.20 16.80 21.40 24.40 27.50 33.60 36.60 39.70 54.90 79.00
3 'STA3  '  305.0 18.30 33.60 39.30 45.80 48.80 51.90 54.00 56.40 61.00 67.00


-----------------------------------------------------------------------------
FAR-FIELD PLUME PROPERTIES (m):
 XS   'Label-'  Distance      Left      Plume     Right     Dilution    Conc.
  #             downstream    edge    centerline   edge
  1   'STA1  '     30.50     27.50      20.70     13.28       30.1     .332E+01
  2   'STA2  '    152.50     27.50      24.40     17.80       31.4     .318E+01
  3   'STA3  '    305.00     48.80      45.80     34.32       33.0     .303E+01
-----------------------------------------------------------------------------
END OF FFLOCATR:  FAR-FIELD PLUME LOCATOR
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
```

VII Closure

7.1 Synopsis

The Cornell Mixing Zone Expert System (CORMIX) is a series of software subsystems for the analysis, prediction, and design of aqueous toxic or conventional pollutant discharges into diverse water bodies. The major emphasis is on the geometry and dilution characteristics of the initial mixing zone including compliance with regulatory constraints. The system also predicts the behavior of the discharge plume at larger distances in the far-field.

The highly user-interactive CORMIX system is implemented on IBM-PC compatible microcomputers and consists of three subsystems. These are: CORMIX1 for submerged single port discharges, CORMIX2 for submerged multiport diffuser discharges and CORMIX3 for buoyant surface discharges. The basic CORMIX methodology relies on the assumption of steady ambient conditions. However, recent versions also contain special routines for the application to highly unsteady environments, such as tidal reversal conditions, in which transient recirculation and pollutant build-up effects can occur.

In addition, two post-processing models are linked to the CORMIX system, but can also be used independently. These are CORJET (the Cornell Buoyant Jet Integral Model) for the detailed analysis of the near-field behavior of buoyant jets, and FFLOCATR (the Far-Field Plume Locator) for the far-field delineation of discharge plumes in non-uniform river or estuary environments.

This user's manual gives a comprehensive and uniform description of all three CORMIX subsystems; it provides advice for assembly and preparation of required input data; it delineates ranges of applicability of the three subsystems; it provides instruction for the interpretation and graphical display of system output; and it illustrates practical system application through several case studies.

7.2 System and Documentation Availability

The CORMIX system programs can be obtained from:

U.S. EPA - Center for Environmental
    Assessment Modeling (CEAM)
Environmental Research Laboratory
960 College Station Road
Athens, GA 30605-2700 USA
Tel. 706-546-3549 (or FTS 250-3590)
Fax:706-546-3402
E-mail: ceam@athens.ath.epa.gov

As of the release of this manual (late 1996) the following versions of CORMIX are available: CORMIX Version2.1 (1993, without graphics and post-processor features) and Version3.1 (August 1996, as described in this report). The models can be obtained by mail or over the electronic bulletin board operated by CEAM. Information on program installation and computer configuration are also provided by CEAM. The ftp address is:

ftp://ftp.epa.gov/epa_ceam/wwwhtml/ceamhome.htm

The distribution versions of CORMIX contain only the executable code of the FORTRAN programs HYDROn; they do not include the source code. The source code can be requested separately by writing to CEAM at U.S. EPA-ERL and giving the reason for code inspection and possible manipulation. The full code, while made up of simple individual modules, is complex with multiple interdependencies; only experienced research personnel should attempt this work when engaged in comparison of model predictions to new field or laboratory data.

The technical documentation reports(5,6,7,8) are available as U.S. EPA and NITS publications, and have also been issued as technical reports of the DeFrees Hydraulics Laboratory.

7.3 User Support

Technical and scientific support for CORMIX under contract from the USEPA is provided by:

Dr. Robert L. Doneker
Department of Environmental Science and
 Engineering
Oregon Graduate Institute
PO Box 91000
Portland, OR   97291-1000
Tel. 503-690-4053, Fax. 503-690-1273
 email: doneker@ese.ogi.edu

This includes assistance on problems of system installation and execution, and advice on the specification of input data as well as interpretation of CORMIX output.

Any high-quality field or laboratory data on effluent mixing processes is a valuable asset for any future development or updates on CORMIX. Transmittal of such data to the following address will be greatly appreciated:

Prof. Gerhard H. Jirka
Institute for Hydromechanics
University of Karlsruhe
PO Box 6380
D-76128 Karlsruhe, GERMANY
Tel. (49) 721/608-2200, Fax. (49) 721/66-16-86

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Appendix A

Flow Classification Diagrams for the Three CORMIX Subsystems
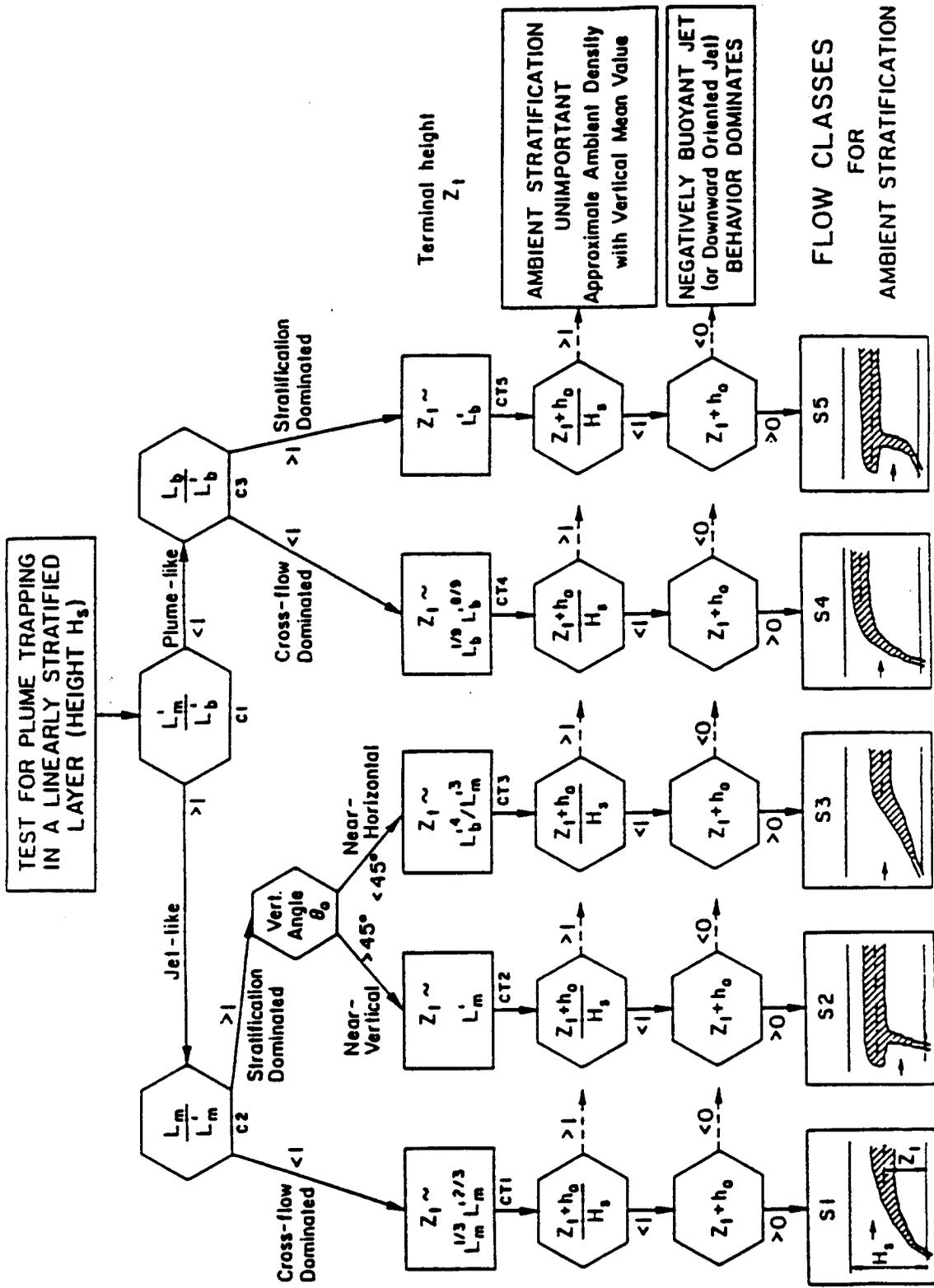
Figure A.1: CORMIX1 Classification: Assessment of ambient density stratification and different flow classes for internally trapped

FLOW CLASSIFICATION
BUOYANT SUBMERGED
DISCHARGES IN
UNIFORM DENSITY LAYER
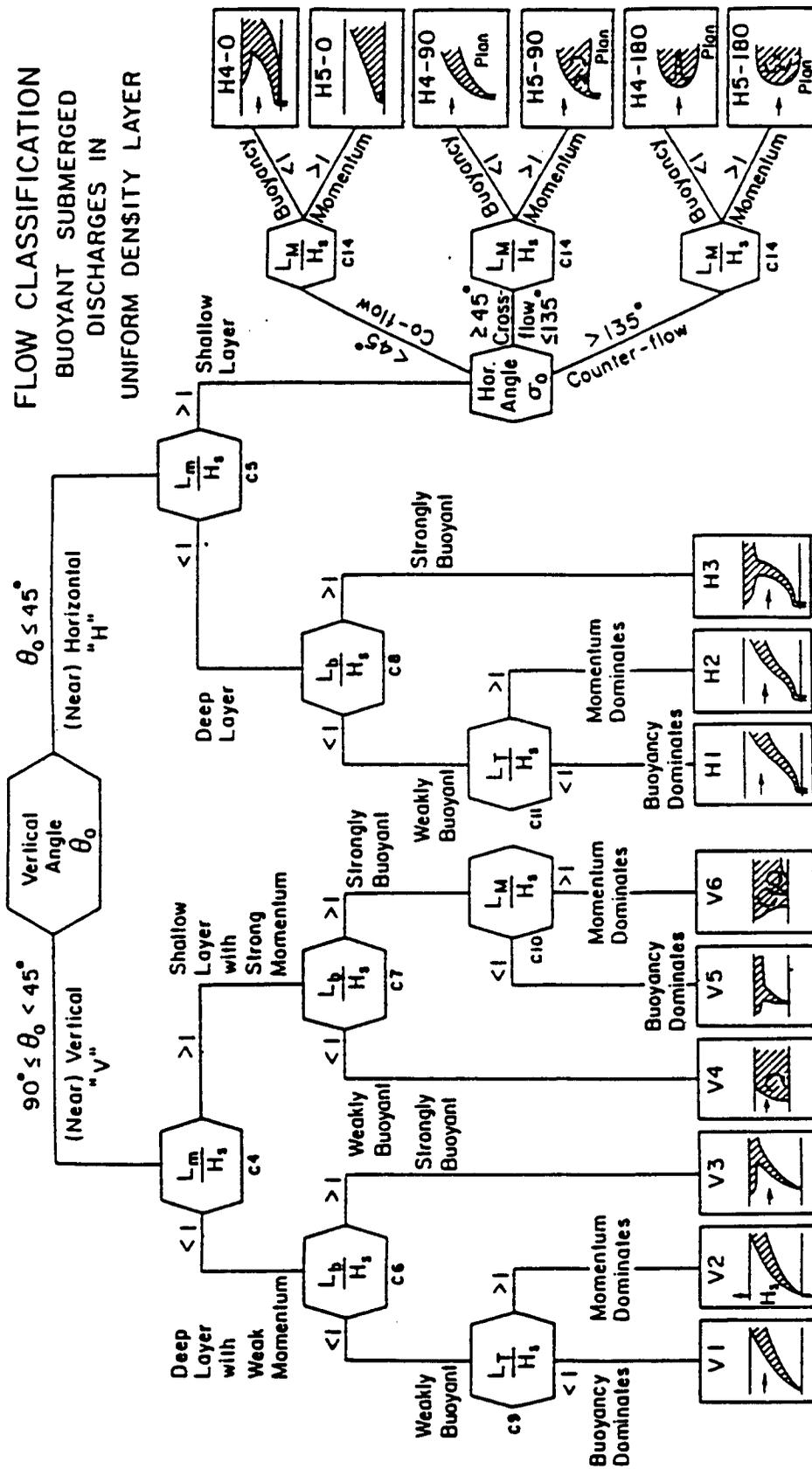
Figure A.2: CORMIX1 Classification: Behavior of positively buoyant discharges in uniform ambient layer flow
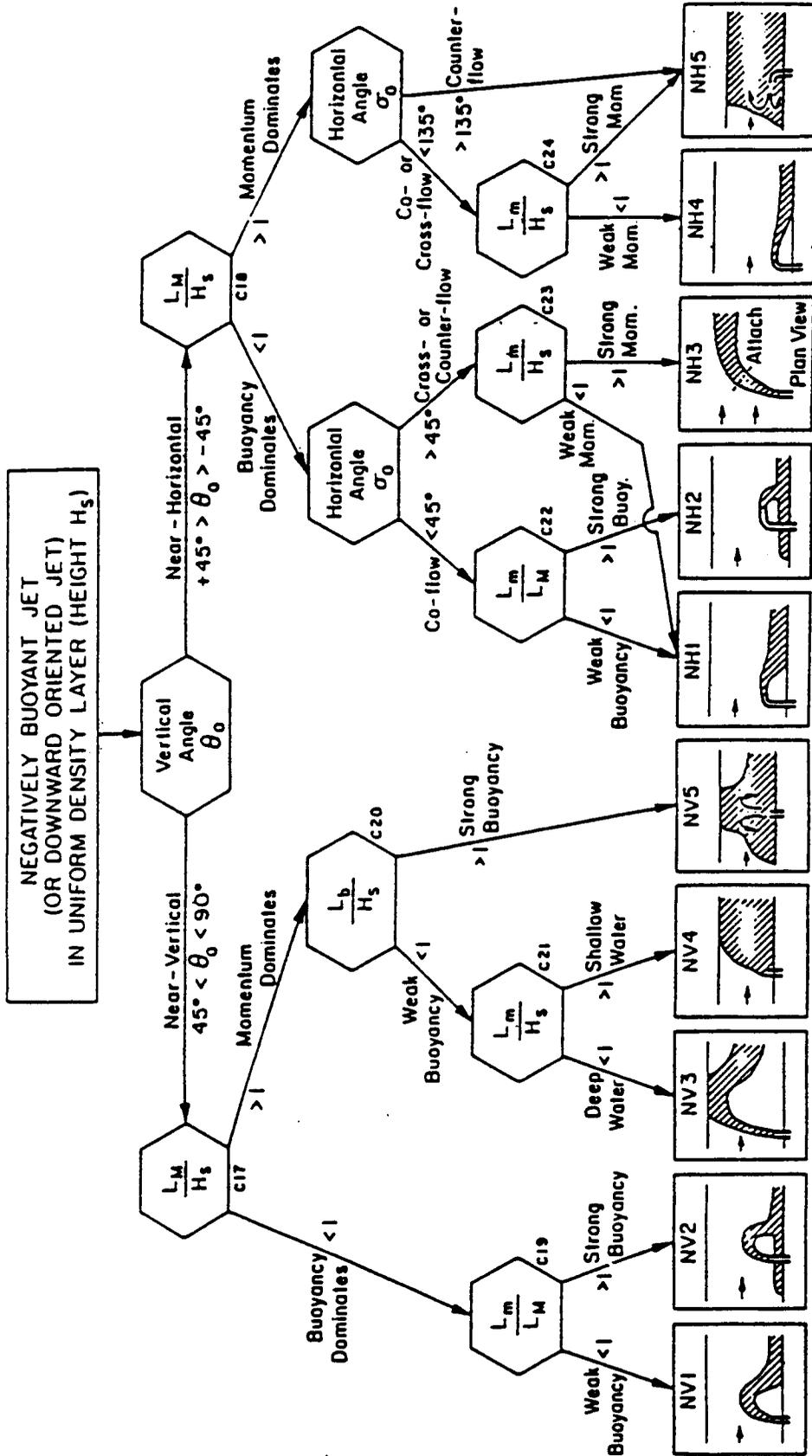
Figure A.3: CORMIX1 Classification: Behavior of negatively buoyant discharges in uniform layer flow (Flow Classes NV and NH)

CLASSIFICATION BOTTOM ATTACHMENT
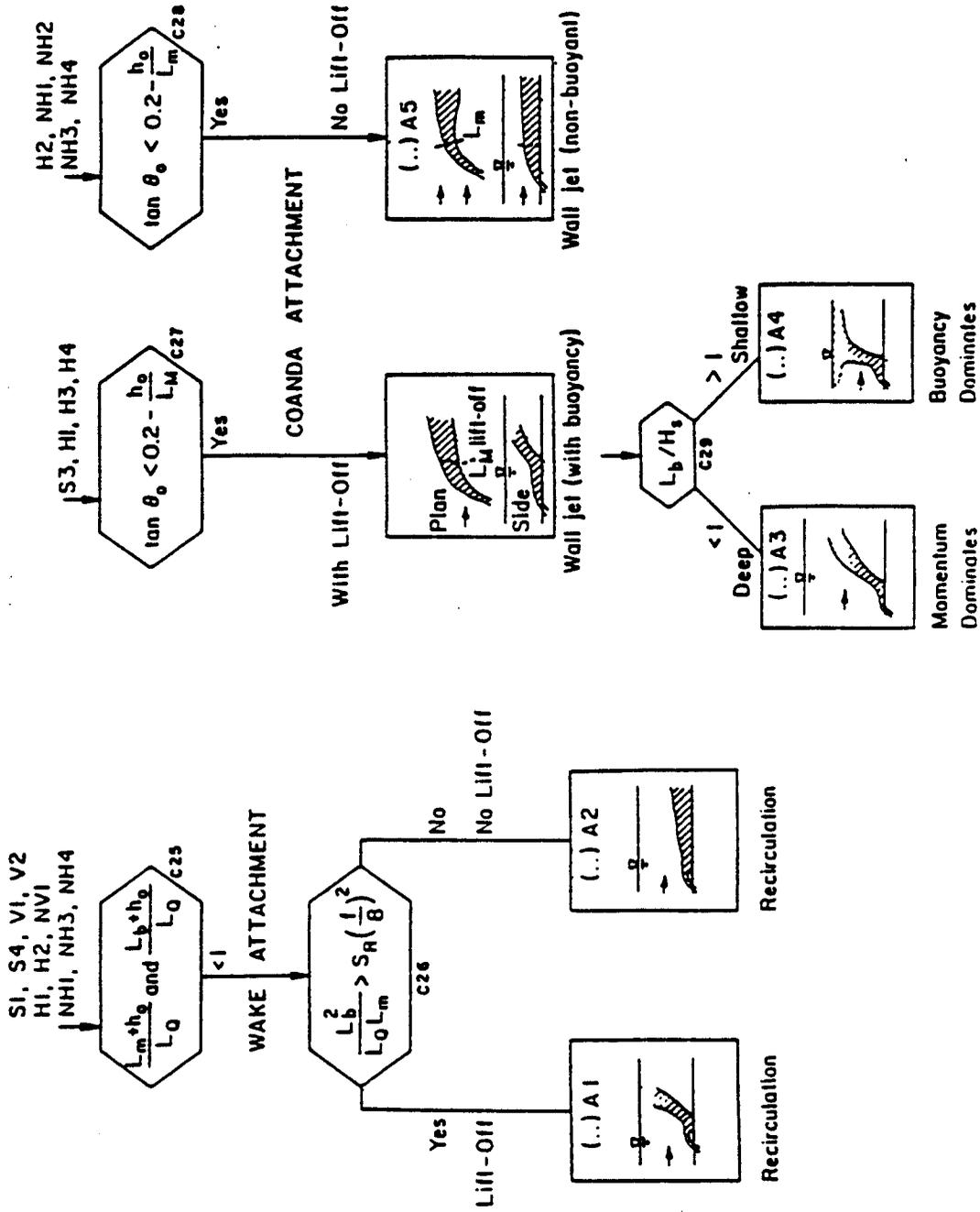
Figure A.4: CORMIX1 Classification: Dynamic bottom attachment of discharge due to wake or Coanda attachment
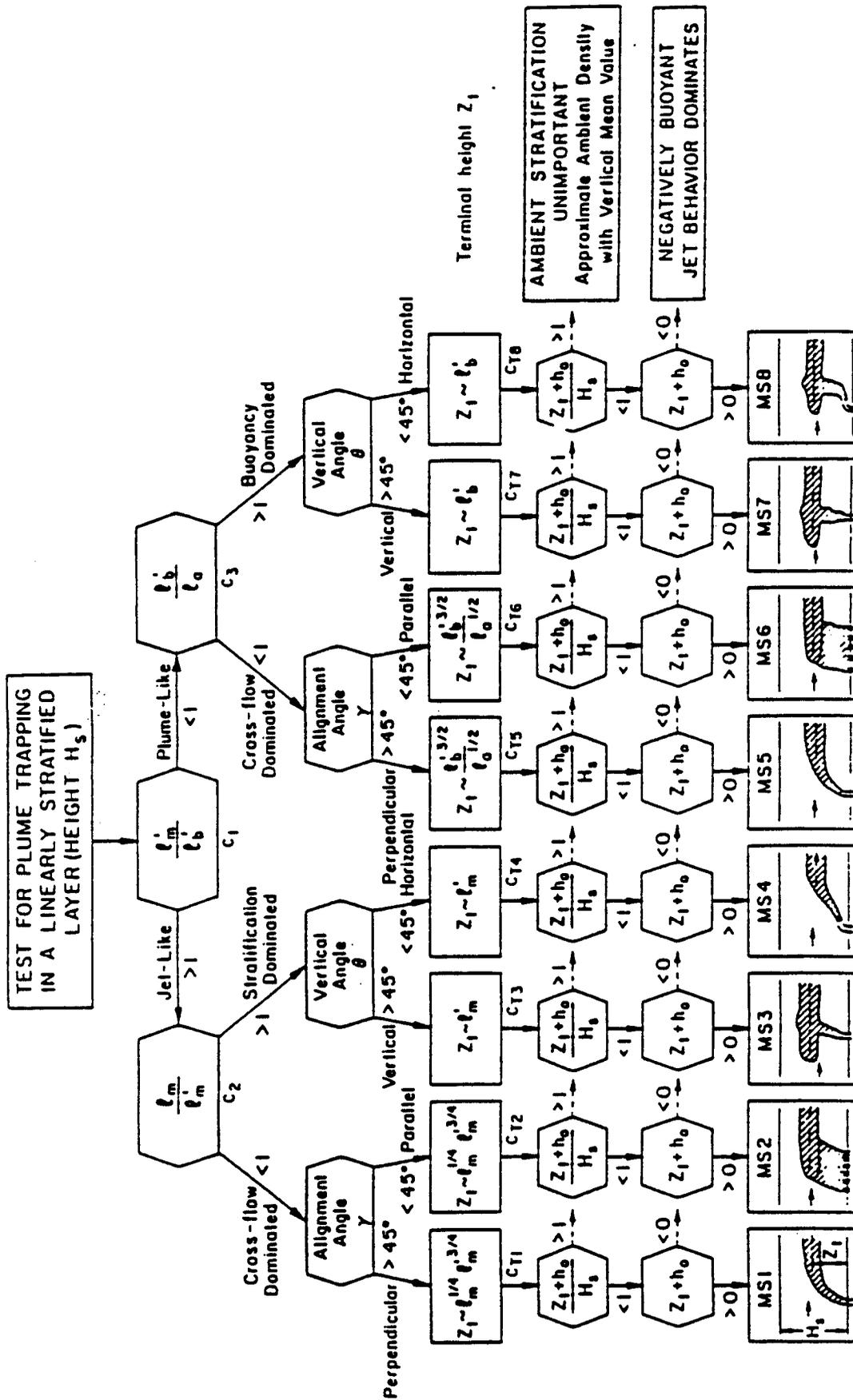
Figure A.5: CORMIX2 Classification: Assessment of ambient density stratification and different flow classes for internally trapped
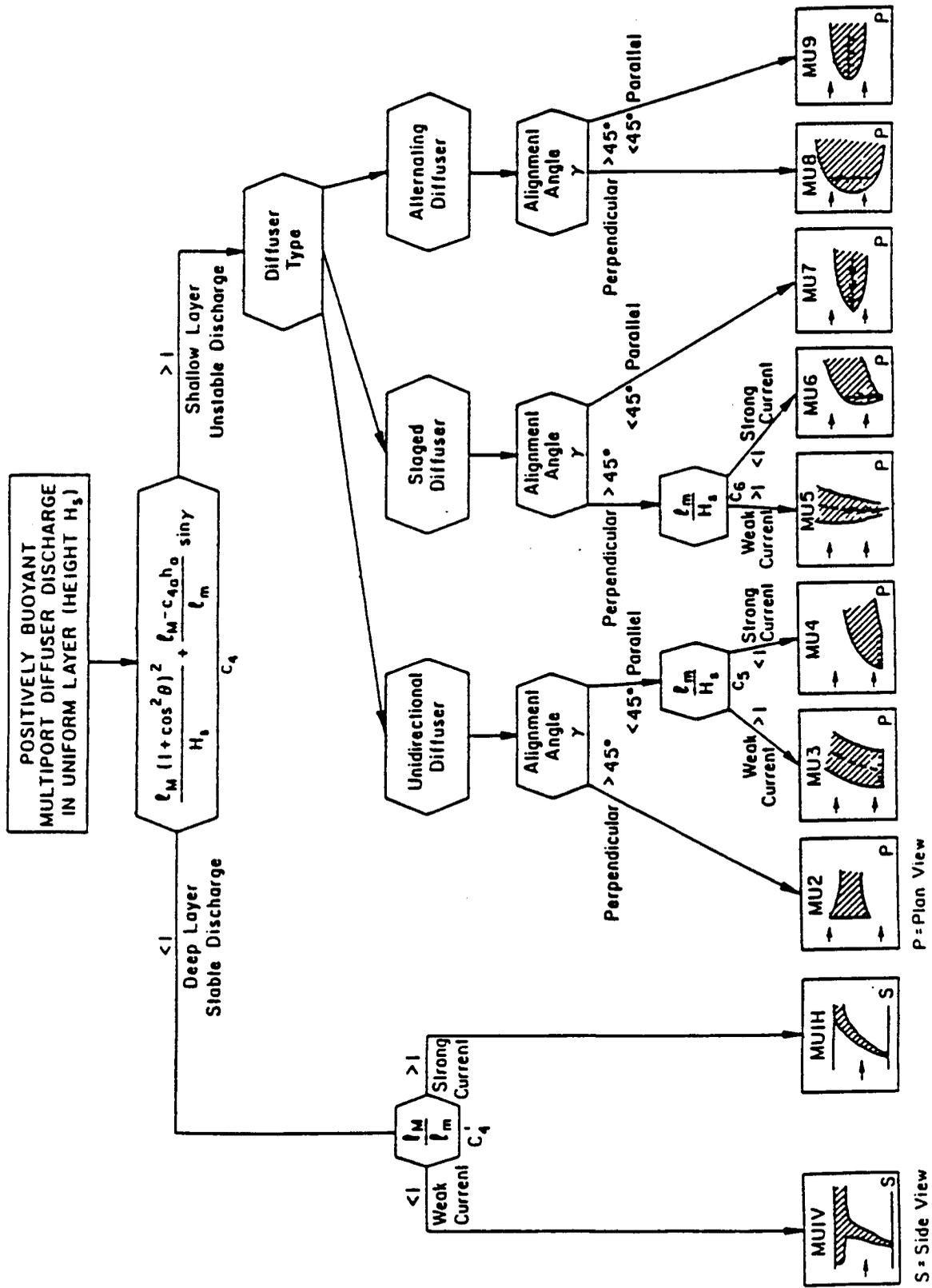
Figure A.6: CORMIX2 Classification: Behavior of positively buoyant multiport diffuser discharges in uniform ambient layer flow

Figure A.7: CORMIX2 Classification: Behavior of negatively buoyant multiport diffuser discharges in uniform ambient layer flow
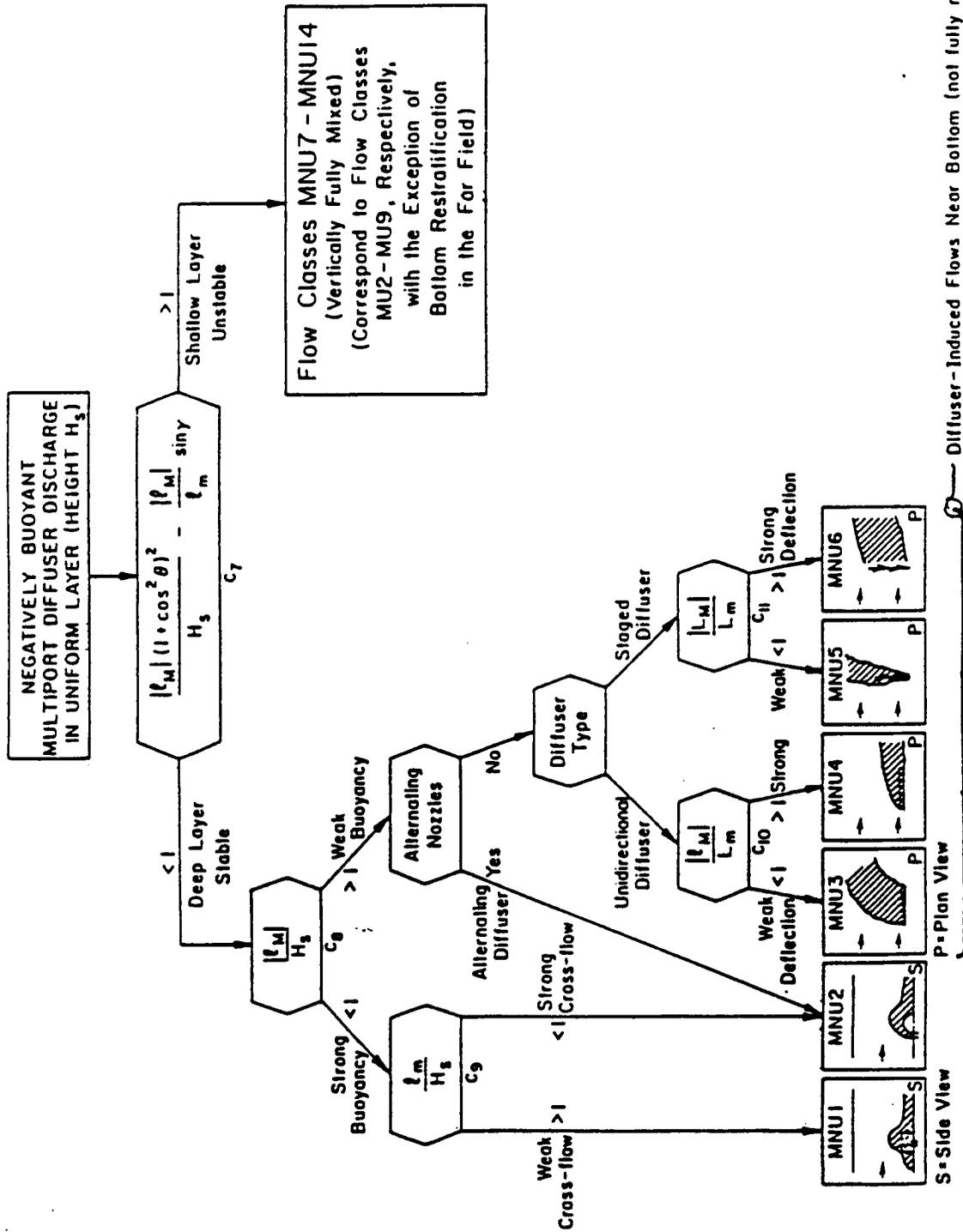
FLOW CLASSIFICATION FOR BUOYANT SURFACE DISCHARGES

$\dfrac{L_M}{L_Q A^{1/4}}$ C1

plume-like >1

jet-like <1

σ C2

PLUMES

$\dfrac{L_b A^{1/2}}{L_Q}$ C3

>1 S upstream intruding PL1

<1 shore-hugging PL2

<20° coflow

>20° crossflow

WALL JETS

$\dfrac{L_M}{H}$ C5

>1 shallow

$\dfrac{L_m}{H-h_o}$ C7

>1 S WJ2

<1 small source

<1 deep S WJ1

$(1+\cos\sigma)\dfrac{L_Q}{L_m}\left(\dfrac{L_M}{H}\right)^{3/2}$ C4

>1 SHORELINE ATTACHED JETS

$\dfrac{L_M}{H}$ C5

>1 shallow

$\dfrac{L_m}{H-h_o}$ C7

>1 SA2

<1 small source

<1 deep SA1

<1 FREE JETS

$\dfrac{L_M}{H}$ C5

>1 shallow

$\dfrac{L_m}{H-h_o}$ C7

>1 S FJ3

<1 small source

<1 deep

$\dfrac{L_M}{L_m}$ C6

>1 crossflow dominated FJ2

<1 buoyancy dominated S FJ1

S=possible classification for stagnant ambient

Plan View Side View

Plan View Cross-section

Figure A.8: CORMIX3 Classification: Assessment of buoyant surface discharges as free jets, shoreline-attached jets, wall jets, or

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Appendix B
CORMIX1: Submerged Single Port Discharge in a Deep Reservoir

This case study illustrates the application of CORMIX1 to the prediction of the effluent from a small manufacturing plant into a large and deep stratified reservoir.

B.1 Problem Statement

A manufacturing plant (A-Plant) is discharging its effluent into an adjacent deep reservoir. The plant design flowrate is 3.5 mgd ($\approx$ 0.15 m^3/s). The effluent contains heavy metal at a concentration of 3500 ppb, and is released at a temperature of 68 ^{o}F (= 20 ^{o}C). The density of the effluent at this low concentration can be considered equivalent to freshwater.

The existing reservoir has been formed by flooding a river valley. The reservoir length is about 60 miles. The water level in the reservoir is fluctuating depending on the release operation at the downstream dam with its hydropower installation. During summer conditions, the reservoir level is typically at an elevation of 710 ft above sea level. This results in a reservoir width of about 4000 ft ($\approx$ 1200 m) and a maximum depth of 310 ft ($\approx$ 95 m) at the discharge location. The mean river flow into the reservoir during the summer low-flow conditions is about 18,540 cfs ($\approx$ 525 m^3/s). The typical temperature of the inflowing river water is 55 ^{o}F ($\approx$ 13 ^{o}C).

Figure B.1 shows the local bathymetry (as obtained from a USGS map) in the vicinity of the proposed discharge. Since the discharge is very small relative to the reservoir size and the ambient flowrate, it is expected that mostly local conditions will be important, and not overall reservoir dimensions. (Note: Any such conjecture has to be verified against the final simulation results, and adjustments have to be made if needed.)

Temperature data as a function of depth obtained from field measurements in the center of the reservoir show a significant temperature stratification (see Figure B.2), as is typical for such deep reservoirs during summer conditions.

The stratification can be expected to be horizontally uniform and therefore similar conditions will hold at the discharge site. Also, the river inflow is colder than the surface layer of the stratified reservoir. The reservoir has a selective withdrawal structure at the dam, therefore it can be expected that the river water will flow predominantly in a vertically limited layer, that may extend from a depth of about 35 m to the surface. The velocity of that flow is estimated at about 1.5 cm/s ($\approx$ 0.015 m/s), given the 35 m thick layer and an about 1000 m width at that elevation. (Note: More detailed hydrodynamic investigations, using available models for stratified reservoir dynamics, can be used to obtain more precise estimates of the velocity field. Generally, however, it cannot be assumed that the velocity in stratified reservoirs is given by the simple average of the flowrate divided by the cross-sectional area.)

The proposed discharge location on the side slope of the cross-section is also shown in Figure B.1: a submerged single port discharge at an elevation of 610 ft above sea level, i.e. at a local depth of 100 ft ($\approx$ 30.5 m) below the surface, is proposed in the initial design phase. The port diameter is 10 in ($\approx$ 0.254 m) and is located 2 ft ($\approx$ 0.6 m) above the local bottom. The discharge is pointing offshore and is angled upward at 10 ^{o}.

The discharge is subject to State mixing zone regulations whereby the mixing zone width is less than 10% of the width of the water body. Furthermore, the heavy metal in the effluent is considered toxic with CMC and CCC limits of 1200 and 600 ppb, respectively.

B.2 Problem Schematization and Data Preparation

Figure B.3 is the data checklist that summarizes the CORMIX1 input for the present problem. The ambient water body has been characterized as unbounded in line with the expectation that the discharge plume will be small
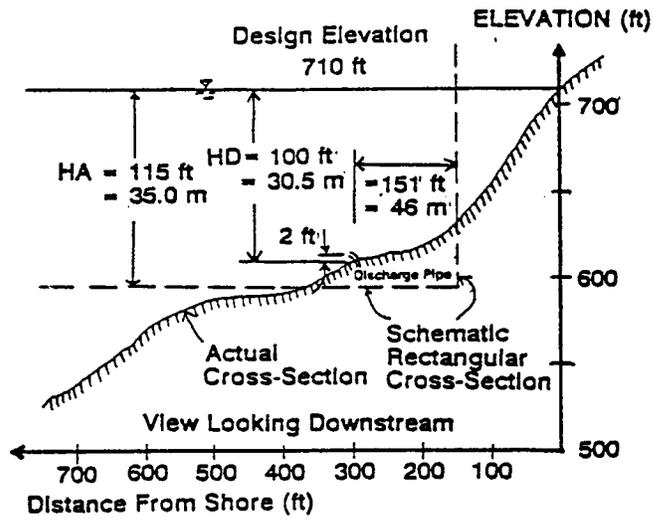
Figure B.1: Local details of Deep Reservoir cross-section and CORMIX1 schematization
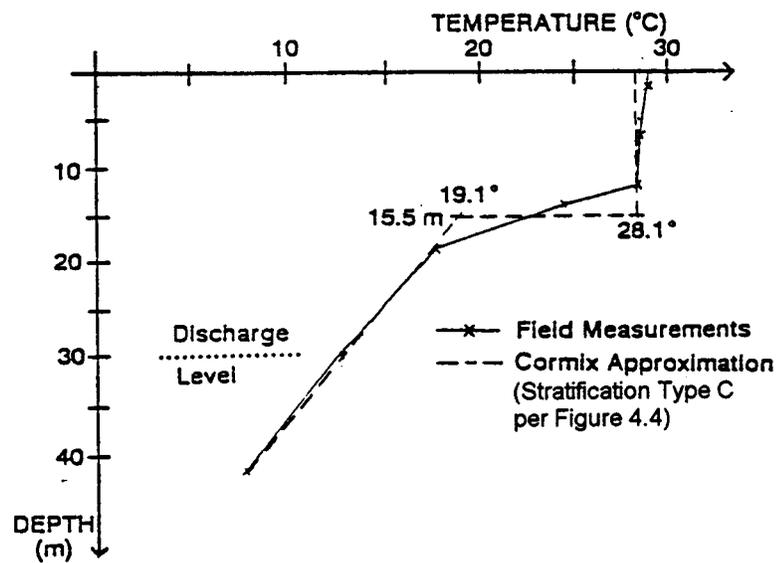
Figure B.2: Temperature field data as a function of depth and CORMIX1 representation of Type C temperature profile

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CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name   A-Plant Deep Reservoir   Date:
Design CASE   Summer Stratification   Prepared by: GHJ
DOS FILE NAME   Sample 1   (w/o extension)

AMBIENT DATA: Water body is   ~~bounded~~/unbounded
Water body depth   35.0   m   If bounded: Width   -   m
Depth at discharge   30.5   m   Appearance   1/2/3
If steady: Ambient flowrate   -   m³/s or: Ambient velocity   0.015   m/s

If tidal: Tidal period   hr   Max. tidal velocity   m/s
      At time _____ hr   before/at/after slack: Tidal velocity at this time   m/s

Manning's n   0.02   or: Darcy-Weisbach f   -
Wind speed   2   m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   fresh/~~salt~~ water   If fresh: Specify as   ~~density~~/temp. values
If uniform: Average density/temp.

If stratified: ~~Density~~/temp. at surface   28.1
   Stratification type   A/~~B~~/C   ~~Density~~/temp. at bottom   11.0
   If B/C: Pycnocline height   15.5   m   If C: ~~Density~~/temp. jump   9.0

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE – CORMIX1
Nearest bank is on   ~~left~~/right   Distance to nearest bank   46.0   m
Vertical angle THETA   10   °   Horizontal angle SIGMA   90   °
Port diameter   0.254 m or: Port area   -   m²
Port height   0.6   m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE – CORMIX2
Nearest bank is on   left/right   Distance to one endpoint   m
Diffuser length   m   to other endpoint   m
Total number of openings   m   Port height   m
Port diameter   m with   contraction ratio
Diffuser arrangement/type   unidirectional / staged / alternating or vertical
Alignment angle GAMMA   °   Horizontal angle SIGMA   °
Vertical angle THETA   °   Relative orientation BETA   °

BUOYANT SURFACE DISCHARGE – CORMIX3
Discharge located on   left/right bank   Configuration flush/protruding/co-flowing
Horizontal angle SIGMA   °   If protruding: Dist. from bank _____ m
Depth at discharge   m   Bottom slope   °
If rectangular   Width   m or: If circular   Diameter _____ m
discharge channel: Depth   m   pipe: Bottom invert depth _____ m

---

Effluent: Flow rate   0.153 m³/s or: Effluent velocity   -   m/s
Effluent density   -   kg/m³ or: Effluent temperature   20.0   °C
Heated discharge?   ~~yes~~/no   If yes: Heat loss coefficient   -   W/m²,°C
Concentration units   ppb   Effluent concentration   3500
Conservative substance?   yes/~~no~~   If no: Decay coefficient   -   /day

---

MIXING ZONE DATA:
Is effluent toxic?   yes/~~no~~   If yes: CMC   1200   CCC   600
WQ stand./conventional poll.?   ~~yes~~/no   If yes: value of standard   -
Any mixing zone specified?   yes/~~no~~   If yes: distance _____ - m   or width   120   % or m
                                or area   -   % or m²

Region of interest   3500   m   Grid intervals for display   20

Figure B.3:   Data preparation checklist for A-Plant Deep Reservoir design case study using CORMIX1

in size relative to the reservoir width. Furthermore, since (1) the discharge elevation is well above the lowest point of the reservoir and (2) the plume is expected to rise toward the surface, the ambient water depth is taken as 150 ft ($\approx$35.0 m) only.

The depth at the discharge corresponds to the local depth at the discharge location. Because of the sloping bank from the discharge to the near shoreline, the distance to bank (46 m) corresponds to one-half of the actual distance from the outlet to the shoreline at the water surface. The ambient velocity corresponds to the estimate made above for the stratified water body. A Manning's n of 0.02 describes the smooth bottom.

Density data is simply entered via the temperature values of the fresh water body. A Stratification Type C is chosen to describe the actual temperature profile.

The discharge data values summarize the discharge situation as described above. Finally, the mixing zone specifications include a width value of 120 m, corresponding to 10 % of the actual width of 1200 m. Information is desired over about one mile ($\approx$ 1600 m) which represents the region of interest (ROI) limitation.

B.3 CORMIX1 Session and Results

If desired by the user, CORMIX1 provides a summary of the data as they are entered, and then a full record of the simulation sequence and final results. This session summary report is shown in Table B.1. Of particular interest to the user are the evaluations in program element PARAM and CLASS. Note, that the computed length scales L_m' and $_bL'$ are quite small, indicating that the jet or plume will be trapped quickly by the ambient stratification; thus, this is the first numerical indication that the near-field jet/plume will indeed be small relative to the reservoir. The ambient flow related scales L_m and L_b are quite large, indicating that the ambient velocity is very weak. The resulting flow class S3 is dominated by the ambient stratification; the plume will be limited to the lower layer of the stratification. The user should also consult the description of flow class S3 that is available during the CORMIX1 session (not reproduced

here). The detailed plume properties are computed in program element HYDRO, and are displayed in the Fortran CORMIX1 prediction file (see Table B.2, discussed in more detail further below).

Many important features of the plume prediction are summarized in program element SUM of the session record (see Table B.1). Notably, all aspects pertaining to mixing zone regulations are contained in that summary. For example, it can be seen quickly from that summary that the present discharge configuration meets all three toxic dilution zone (TDZ) criteria and also the regulatory mixing zone (RMZ) limitation. Obviously, other ambient conditions and discharge variations should be considered in additional simulations before a design such as this should be deemed fully satisfactory.

B.4 Graphical Displays of Detailed Plume Predictions

As for most engineering studies it is desirable to produce graphical displays for visualization of the predicted results. The data contained in the CORMIX1 prediction file (Table B.2) form the basis for such plots. Unfortunately, it is often difficult to display all plume features in one single plot because the plume may contain a lot of near-field details while extending over large distances into the far-field. A short examination of Table B.2 proves that point: The plume gets quickly trapped within a very limited near-field but with considerable mixing (see MOD110 = CORJET of the CORMIX1 prediction). Yet after that the plume extends over large distances into the far-field forming a wide thin layer within the stratified reservoir (see MOD142).

Using the graphics package CMXGRAPH, two plots have been prepared to display the jet/plume side view in the near-field, using distorted and undistorted 1:1 scales, respectively, (Figure B.4) and the plan view in the near-field and larger scale far-field (Figure B.5) of the effluent plume. Figure B.4 shows the initial trajectory of the slightly upward curved jet that rises to maximum level of 4.29 m and then gets trapped at an elevation of 3.44 m above the local bottom. In the trapping stage the jet undergoes a complicated transition (MOD137) to the horizontally spreading layer. CORMIX1 predicts

Table B.1
CORMIX Session Report for A-Plant discharge into Deep Reservoir with summer stratification

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                   CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                   CORMIX v.3.10         June 1995
SITE NAME/LABEL:              Sample 1
  DESIGN CASE:                Summer Stratification
  FILE NAME:                  SAMPLE1
Using subsystem CORMIX1:      Submerged Single Port Discharges
  Start of session:          08/25/96--16:37:01
**********************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                         = unbounded
  Average depth               HA    =          35 m
  Depth at discharge          HD    =        30.5 m
  Ambient velocity            UA    =        .015 m/s
  Darcy-Weisbach friction factor F   =      0.0096
    Calculated from Manning's n      =         .02
  Wind velocity               UW    =           2 m/s
Stratification Type           STRCND = C
  Surface temperature               =        28.1 degC
  Bottom temperature                =        11.0 degC
  Temperature below thermocline     =       19.10 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density             RHOAS =    996.2053 kg/m^3
  Bottom density              RHOAB =    999.6071 kg/m^3
  Stratification height       HINT  =        15.5 m (pycnocline level)
  Density below pycnocline    RHOAP =    998.3866 kg/m^3
----------------------------------------------------------------------
DISCHARGE PARAMETERS:            Submerged Single Port Discharge
  Nearest bank                      = right
  Distance to bank            DISTB =         46. m
  Port diameter               DO    =        .254 m
  Port cross-sectional area   AO    =      0.0506 m^2
  Discharge velocity          UO    =        3.01 m/s
  Discharge flowrate          QO    =        .153 m^3/s
  Discharge port height       HO    =          .6 m
  Vertical discharge angle    THETA =          10 deg
  Horizontal discharge angle  SIGMA =          90. deg
  Discharge temperature (freshwater) =       20.0 degC
    Corresponding density     RHOO  =    998.2051 kg/m^3
  Density difference          DRHO  =      1.3548 kg/m^3
  Buoyant acceleration        GPO   =       .0133 m/s^2
  Discharge concentration     CO    =        3500 PPB
  Surface heat exchange coeff. KS   =           0 m/s
  Coefficient of decay        KD    =           0 /s
----------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ  =      0.22 m     Lm  =    45.31 m      Lb  =     602.57 m
  LM  =     12.42 m     Lm' =     4.94 m      Lb' =       3.11 m
----------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Port densimetric Froude number FRO  =       51.96
  Velocity ratio              R     =      201.30
----------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                   = yes
  CMC concentration           CMC   =        1200 PPB

  CCC concentration           CCC   =         600 PPB
  Water quality standard            = given by CCC value
  Regulatory mixing zone            = yes
  Regulatory mixing zone specification = width
  Regulatory mixing zone value      =         120 m (m^2 if area)
  Region of interest                =     3500.00 m
**********************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS  =    S3 |
  *------------------------*
  The specified ambient density stratification is important, the discharge
  near field flow is confined to the lower layer by the ambient density
  stratification.
  Applicable layer depth = lower layer depth =          15.5 m
**********************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
----------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
          46. m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
--------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
   implication.  However, this information may be useful for the discharge
   designer because the mixing in the NFR is usually sensitive to the
   discharge design conditions.
   Pollutant concentration at edge of NFR =         98.2267 PPB
   Dilution at edge of NFR               =         35.6
   NFR Location:                     x =         98.19 m
      (centerline coordinates)       y =         24.63 m
                                     z =          3.43 m
   NFR plume dimensions:     half-width =        191.86 m
                             thickness =           .94 m
--------------------------------------------------------------------------
Buoyancy assessment:
   The effluent density is less than the surrounding ambient water
   density at the discharge level.
   Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
   the surface.
--------------------------------------------------------------------------
Stratification assessment:
   The specified ambient density stratification is dynamically important.
   The discharge near field flow is trapped within the linearly stratified
   ambient density layer.
--------------------------------------------------------------------------
UPSTREAM INTRUSION SUMMARY:
Plume exhibits upstream intrusion due to low ambient velocity or strong
   discharge buoyancy.
   Intrusion length                   =          90.24 m
   Intrusion stagnation point         =         -87.98 m
   Intrusion thickness                =           1.29 m
   Intrusion half width at impingement  =        191.86 m
   Intrusion half thickness at impingement =        .94 m
************************* TOXIC DILUTION ZONE SUMMARY *************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
   Technical Support Document (TSD) for Water Quality-based Toxics Control,
   1991 (EPA/505/2-90-001).
   Criterion maximum concentration (CMC)  =           1200 PPB


   Corresponding dilution             =          2.9
The CMC was encountered at the following plume position:
   Plume location:                   x =           .05 m
      (centerline coordinates)       y =          3.93 m
                                     z =          1.31 m
   Plume dimensions:        half-width =           .10 m
                            thickness =            .10 m
   CRITERION 1: This location is within 50 times the discharge length scale of
            Lq =       0.22 m.
   +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

   CRITERION 2: This location is within 5 times the ambient water depth of
            HD =          30.5 m.
   ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.++++++++++++

   CRITERION 3: This location is within one tenth the distance of the extent
            of the Regulatory Mixing Zone of        98.19 m downstream.
   +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

   The diffuser discharge velocity is equal to        3.01 m/s.
      This exceeds the value of 3.0 m/s recommended in the TSD.

   *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY **********************
The plume conditions at the boundary of the specified RMZ are as follows:
   Pollutant concentration            =         98.226660 PPB
   Corresponding dilution             =         35.6
   Plume location:                   x =         98.19 m
      (centerline coordinates)       y =         24.63 m
                                     z =          3.43 m
   Plume dimensions:        half-width =        191.86 m
                            thickness =           .94 m
At this position, the plume is CONTACTING the RIGHT bank.
Furthermore, the CCC for the toxic pollutant has indeed been met
   within the RMZ. In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
   plume position:
   CCC                                =           600 PPB
   Corresponding dilution             =          5.8
   Plume location:                   x =           .21 m
      (centerline coordinates)       y =          7.82 m
                                     z =          2.12 m
   Plume dimensions:        half-width =           .10 m
                            thickness =            .10 m
********************** FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
   technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
   CORMIX predictions on dilutions and concentrations (with associated
   plume geometries) are reliable for the majority of cases and are accurate
   to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
   the design configuration as highly complex and uncertain for prediction.
****************************************************************************
DESIGN CASE:                  Summer Stratification
FILE NAME:                    SAMPLE1
Subsystem CORMIX1:            Submerged Single Port Discharges
END OF SESSION/ITERATION:     08/26/96--05:37:41
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

```
CORMIX1 PREDICTION FILE:
11111111111111111111111111111111111111111111111111111111111111111111111111111
                         CORNELL MIXING ZONE EXPERT SYSTEM
Subs⊟em CORMIX1:                                        Subsystem version:
 Sub⊟ed Single Port Discharges           CORMIX_v.3.1_____June_1995
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:       DEEP^RESERVOIR
 Design case:           A-PLANT^SUMMER^STRATIFICATION
 FILE NAME:             cormix\sim\SAMPLE1 .cx1
 Time of Fortran run:   06/24/95--22:29:54

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA    =     35.00  HD  =     30.50
 UA    =      .015 F     =      .010 USTAR = .5200E-03
 UW    =     2.000 UWSTAR= .2198E-02
 Density stratified environment
 STRCND= C          RHOAM = 997.6240
 RHOAS = 996.2053  RHOAB = 999.6072  RHOAH0= 999.5599  E    = .7730E-03
 DRHOJ =    2.1813  HINT  =     15.50  ES   = .2153E-02

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =     46.00
 D0    =       .254 A0    =       .051 H0   =       .60
 THETA =     10.00  SIGMA =     90.00
 U0    =      3.020 Q0    =       .153       = .1530E+00
 RHO0  = 998.2051  DRHO0 = .1355E+01  GP0  = .1329E-01
 C0    = .3500E+04  CUNITS=  PPB
 IPOLL = 1          KS    = .0000E+00  KD   = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .1530E+00  M0    = .4620E+00  J0   = .2034E-02  SIGNJ0=     1.0
 Associated length scales (meters)
 LQ    =       .23  LM    =      12.43  Lm   =      45.31  Lb   =     602.57
                                        Lmp  =       4.94  Lbp  =       3.12

NON-DIMENSIONAL PARAMETERS
 FR0   =     51.96  R   =     201.30

FLOW CLASSIFICATION
 11111111111111111111111111111111111111111111111111
 1  Flow class (CORMIX1)      =    S3     1
 1  Applicable layer depth HS =    15.50  1
 11111111111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .3500E+04  CUNITS=  PPM
 NTOX  = 1          CMC   = .1200E+04  CCC  = CSTD
 NSTD  = 1          CSTD  = .6000E+03
 REGMZ = 1
 REGSPC= 2          XREG  =       .00  WREG  =     120.00  AREG  =       .00
 XINT  =   3500.00  XMAX  =   3500.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and below the center of the port:
        46.00 m  from the RIGHT bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

        X        Y        Z        S        C        B
       .00      .00      .60      1.0   .350E+04     .13

END OF MOD101: DISCHARGE MODULE
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
```

```
     Jet-like motion in linear stratification with weak crossflow.

   Zone of flow establishment:              THETAE=    10.00  SIGMAE=     89.45
    LE   =     1.25  XE   =      .01  YE   =     1.23  ZE   =      .82

   Profile definitions:
     B = Gaussian 1/e (37%) half-width, normal to trajectory
     S = hydrodynamic centerline dilution
     C = centerline concentration (includes reaction effects, if any)

          X        Y        Z        S        C        B
         .00      .00      .60      1.0   .350E+04     .13
         .01     1.23      .82      1.0   .350E+04     .14
         .02     2.30     1.01      1.7   .205E+04     .26
         .04     3.48     1.23      2.6   .136E+04     .39
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .120E+04
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
         .08     4.67     1.45      3.5   .101E+04     .53
         .13     5.97     1.72      4.4   .790E+03     .67
         .18     7.14     1.97      5.3   .658E+03     .80
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .600E+03 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
         .24     8.32     2.24      6.2   .564E+03     .94
         .32     9.49     2.52      7.1   .493E+03    1.07
         .40    10.65     2.81      8.0   .437E+03    1.21
         .49    11.82     3.10      8.9   .393E+03    1.34
         .60    12.99     3.39      9.8   .357E+03    1.48
         .71    14.15     3.66     10.7   .328E+03    1.61
         .84    15.33     3.90     11.6   .303E+03    1.75
         .98    16.51     4.09     12.4   .281E+03    1.89
        1.13    17.70     4.23     13.3   .262E+03    2.03
        1.27    18.77     4.29     14.2   .247E+03    2.15
   Maximum jet height has been reached.
        1.45    19.96     4.27     15.1   .232E+03    2.29
        1.63    21.15     4.16     16.1   .218E+03    2.43
        1.83    22.32     3.97     17.1   .205E+03    2.57
        2.04    23.48     3.72     18.1   .193E+03    2.71
        2.26    24.63     3.44     19.1   .183E+03    2.85
    Terminal level in stratified ambient has been reached.
   Cumulative travel time =         63. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING

  UPSTREAM INTRUSION PROPERTIES:
          Maximum elevation of jet/plume rise      =       7.64 m
          Layer thickness in impingement region    =       1.29 m
          Upstream intrusion length                =      90.24 m
          X-position of upstream stagnation point  =     -87.99 m
          Thickness in intrusion region            =       1.29 m
          Half-width at downstream end             =     191.87 m
          Thickness at downstream end              =       .95 m

   Control volume inflow:
       X        Y        Z        S        C        B
      2.26    24.63     3.44     19.1   .183E+03    2.85

  Profile definitions:
     BV = top-hat thickness, measured vertically
     BH = top-hat half-width, measured horizontally in Y-direction
     ZU = upper plume boundary (Z-coordinate)
     ZL = lower plume boundary (Z-coordinate)
     S  = hydrodynamic average (bulk) dilution
     C  = average (bulk) concentration (includes reaction effects, if any)

        X        Y        Z        S        C        BV       BH       ZU       ZL
     -87.99    24.63     3.44   9999.9  .000E+00     .00      .00     3.44     3.44
     -84.26    24.63     3.44     75.2  .465E+02     .33    27.13     3.60     3.27
     -66.02    24.63     3.44     31.3  .112E+03     .79    65.91     3.83     3.04
```

```
    -47.77     24.63      3.44     23.8   .147E+03   1.04     89.17    3.96    2.92
    -29.53     24.63      3.44     20.8   .169E+03   1.19    107.51    4.03    2.84
    -11.28     24.63      3.44     19.4   .180E+03   1.28    123.15    4.07    2.80
      6.96     24.63      3.44     19.3   .181E+03   1.29    137.02    4.08    2.79
     25.21     24.63      3.44     22.5   .155E+03   1.22    149.61    4.05    2.82
     43.45     24.63      3.44     27.7   .126E+03   1.11    161.21    3.99    2.88
     61.70     24.63      3.44     32.1   .109E+03   1.02    172.04    3.95    2.93
     79.95     24.63      3.44     34.4   .102E+03    .97    182.22    3.92    2.95
     98.19     24.63      3.44     35.6   .982E+02    .95    191.87    3.91    2.96
 Cumulative travel time =        6459. sec

END OF MOD137: TERMINAL LAYER INJECTION/UPSTREAM SPREADING
-------------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 In this design case, the discharge is located CLOSE TO BANK/SHORE.
 Some boundary interaction occurs at end of near-field.
   This may be related to a design case with a very LOW AMBIENT VELOCITY.
   The dilution values in one or more of the preceding zones may be too high.
 Carefully evaluate results in near-field and check degree of interaction.

 Consider locating outfall further away from bank or shore.
 In the next prediction module, the plume centerline will be set
   to follow the bank/shore.
 ** REGULATORY MIXING ZONE BOUNDARY is within the Near-Field Region (NFR) **
-------------------------------------------------------------------------------
BEGIN MOD142: BUOYANT TERMINAL LAYER SPREADING

 Plume is ATTACHED to RIGHT bank/shore.
   Plume width is now determined from RIGHT bank/shore.

 Profile definitions:
   BV = top-hat thickness, measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

 Plume Stage 2 (bank attached):
       X         Y         Z         S        C        BV       BH      ZU       ZL
     98.19    -46.00      3.44     35.6   .982E+02   1.38    262.50    4.13    2.74
    268.28    -46.00      3.44     42.7   .820E+02    .93    468.27    3.90    2.97
    438.37    -46.00      3.44     48.4   .722E+02    .81    609.62    3.84    3.03
    608.46    -46.00      3.44     54.7   .640E+02    .77    728.17    3.82    3.05
    778.55    -46.00      3.44     61.7   .568E+02    .75    836.14    3.81    3.06
    948.64    -46.00      3.44     69.2   .505E+02    .75    938.66    3.81    3.06
   1118.73    -46.00      3.44     77.3   .453E+02    .76   1038.24    3.82    3.06
   1288.82    -46.00      3.44     85.9   .408E+02    .77   1136.20    3.82    3.05
   1458.91    -46.00      3.44     94.8   .369E+02    .78   1233.26    3.83    3.04
   1629.00    -46.00      3.44    104.0   .336E+02    .80   1329.86    3.84    3.04
   1799.10    -46.00      3.44    113.6   .308E+02    .81   1426.23    3.84    3.03
   1969.19    -46.00      3.44    123.4   .284E+02    .83   1522.53    3.85    3.02
   2139.28    -46.00      3.44    133.5   .262E+02    .84   1618.85    3.86    3.02
   2309.37    -46.00      3.44    143.8   .243E+02    .86   1715.24    3.86    3.01
   2479.46    -46.00      3.44    154.4   .227E+02    .87   1811.74    3.87    3.00
   2649.55    -46.00      3.44    165.2   .212E+02    .88   1908.37    3.88    2.99
   2819.64    -46.00      3.44    176.2   .199E+02    .90   2005.12    3.88    2.99
   2989.73    -46.00      3.44    187.4   .187E+02    .91   2102.02    3.89    2.98
   3159.82    -46.00      3.44    198.7   .176E+02    .92   2199.06    3.90    2.98
   3329.91    -46.00      3.44    210.3   .166E+02    .93   2296.24    3.90    2.97
   3500.00    -46.00      3.44    222.1   .158E+02    .95   2393.56    3.91    2.96
 Cumulative travel time =      233246. sec

 Simulation limit based on maximum specified distance =   3500.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD142: BUOYANT TERMINAL LAYER SPREADING
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CORMIX1: Submerged Single Port Discharges          End of Prediction File
11111111111111111111111111111111111111111111111111111111111111111111111111111
```

Figure B.4: Different side views of near-field jet/plume discharge in stratified reservoir. a) distorted unscaled view, b) view with fixed undistorted scale, and c) undistorted view along trajectory (in the x-y plane).

DEEP^RESERVOIR
A-PLANT^SUMMER^STRATIFICATION

CORMIX1 Prediction
File:sim\SAMPLE1 .cxl

Plan View
Distortion = 1.000

(a)

DEEP^RESERVOIR
A-PLANT^SUMMER^STRATIFICATION

CORMIX1 Prediction
File:sim\SAMPLE1 .cxl

Plan View
Distortion = 1.000
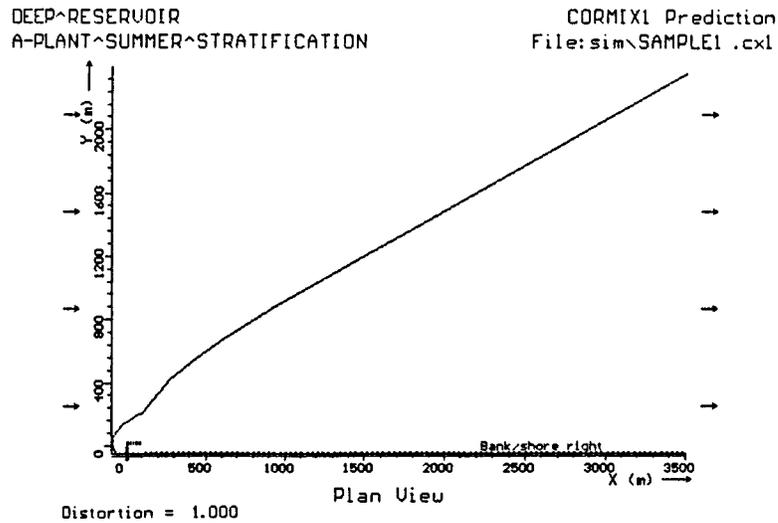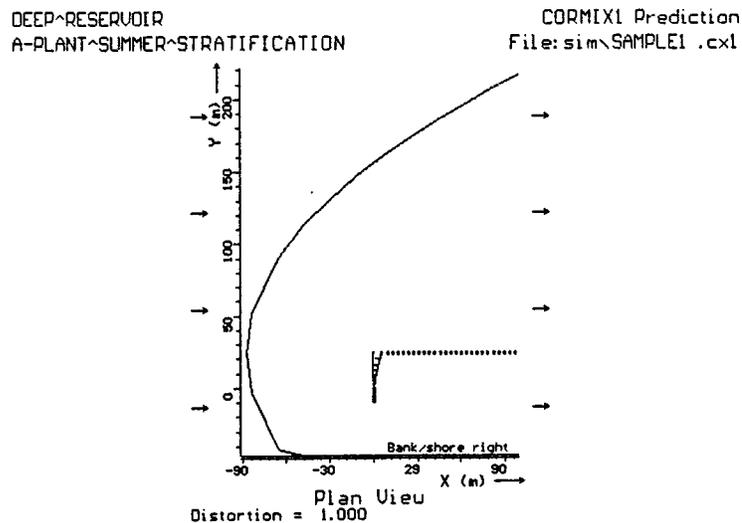
(b)

Figure B.5: Plan view of diffuser plume in a) complete field (near- and far), and b) near-field only. (Note: since in this simulation the discharge was schematized as an unbounded cross-section, the resulting plume would actually contact far shoreline when the plume width exceeds the actual cross-section width of 1000 m. This occurs when $BH \cong 1000$ m at $x \cong 1000$ m downstream as shown in view a). Thus, if plume concentration data were required after far shoreline contact, a bounded cross-section would need to be specified (BS = 1000) in a new simulation.

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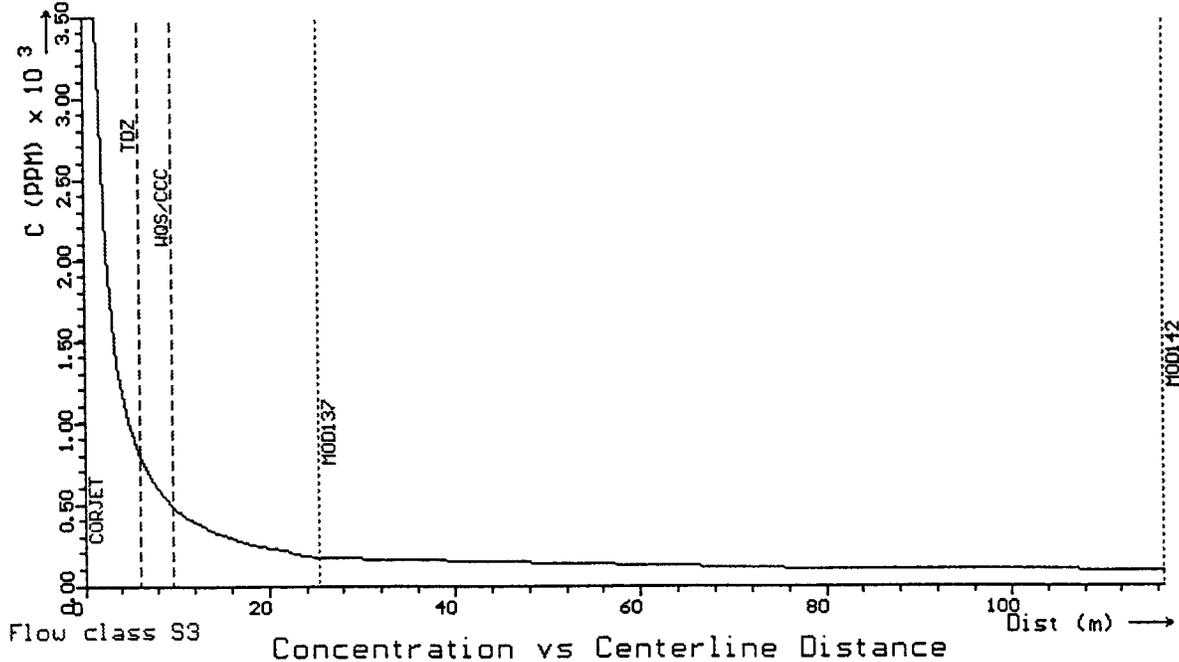
Figure B.6: Concentration distribution as a function of distance along plume centerline

a few parameters such as the upstream intrusion length, downstream width, and shape of the intrusion. As indicated in Figure B.5, reasonable transition boundaries can be assumed to provide smooth transitions to the far-field processes.

The side and plan views show the wide and thin layer that forms as the plume collapses laterally within the ambient stratification while it is advected by the weak ambient flow.

Some discontinuity in the predicted plume dimensions occurs in the transition from the control volume (MOD137) describing upstream spreading to the continuous prediction for ambient buoyant spreading (MOD142). The cause for this discontinuity is the simultaneous interaction of the plume with the channel boundary that occurs within MOD137. CORMIX1 detects such complicated simultaneous processes and warns the user who then can compensate by providing reasonable, mass-conserving transitions.

It is also possible to include concentration values, e.g. along the centerline, in plots of this type. This has not been done in these figures in order not to overload them. Alternatively, the concentration distribution following the centerline of the plume is plotted in Figure B.6. The rapid drop-off within the initial buoyant jet region is evident. Also, the thresholds for all water quality parameters and module boundaries have been exercised in the plot. Hence, the locations where the CMC (i.e. TDZ) and CCC values are met have been indicated.

B.5 Details of Buoyant Jet Near-field Mixing

The CORJET model option can be employed if further details within the very initial buoyant jet motion are desired. This option can be exercised internally at the conclusion of the CORMIX design case by choosing the post-processor. The CORJET output corresponding to this has already been shown as an example in

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Section 6.1, namely as Table 6.2. That output agrees well with that listed in Table B.2.

More importantly, CORJET could also be used separately to examine different approximations to the ambient density profile and/or velocity distribution. The reader is encouraged to explore this approach, following the procedures explained in Section 6.1 and illustrated in Appendix E.

Appendix C
CORMIX1 and 2: Submerged Single Port Discharge
and Multiport Diffuser in a Shallow River

The design modification of an existing (hypothetical situation) discharge from a plant into a shallow river is considered in this case study. This affords an opportunity to demonstrate the joint use of CORMIX and of a dye field study in order to analyze an existing effluent plume from a single port discharge and to suggest a design conversion to a multiport diffuser with improved mixing characteristics.

C.1 Problem Statement

An industrial plant (B-Plant) is currently discharging its effluent into an adjacent shallow river. The design flowrate is quite small at 2.1 mgd (≈ 0.092 m^3/s). The river is about 200 to 300 ft wide at the discharge location and the following downstream reach. Water depth is, of course, dependent on the river discharge that is seasonally variable. An examination of available streamflow records (USGS data) suggests a 7Q10 low flow discharge of 285 cfs (≈ 8.06 m^3/s).

Recent water quality studies in the discharge reach performed during low flow summer conditions have shown occasional coloration problems in the discharge plume that seem to be related to inadequate mixing characteristics of the present submerged single port discharge. For that reason the plant operator is considering an improvement of the discharge structure.

C.2 Existing Single Port Discharge: Dye Field Study and CORMIX1 Comparison

An initial field study was conducted in order (1) to measure the geometric and hydraulic characteristics of the discharge reach with special emphasis on the first 1000 ft downstream, and (2) to determine plume concentrations by means of a dye injection into the plant effluent.

Figure C.1 shows the plan geometry of the discharge reach. River cross-sections were determined by depth measurements at several stations as indicated. For example, Figure C.2 gives the cross-section at the discharge location. All cross-sections exhibit quite some non-uniformity as is typical for a gently meandering alluvial (gravel) river. The indicated water level corresponds to the river discharge of 840 cfs (≈ 23.7 m^3/s) that was measured during the field survey using the usual USGS stream-gaging methods. The ambient temperature at this flowrate was 20 $^\circ$C. The discharge pipe (diameter = 8 in ≈ 0.2 m) is located about 95 ft from the right bank, and is pointing in the downstream direction.

In order to obtain a detailed description of the flow field in the river, reach discharge measurements were conducted at several more downstream stations (200, 400, 750, and 1000 ft, respectively). Figure C.1 includes the cumulative discharge isolines, expressed in % of the total discharge as measured from the right bank, for the reach. These lines provide a useful indication of the mean flow pattern in such a winding river for subsequent interpretation of observed plume features (see also comments on cumulative discharge method in Section 6.2).

A dye test was carried out by continuously discharging a fluorescein dye solution into the plant effluent. The dye concentration exiting the discharge pipe was 560 ppb with a temperature of 22 $^\circ$C. Dye concentration were measured at the transects indicated in Figure C.1, and have been plotted in Figure C.3 as a function of distance from the right bank. The observed concentration profiles show decreasing peak (maximum) values with increasing downstream distances. Observations indicated a vertically mixed plume at all locations. In the display of Figure C.3 the plume centerline position is clearly shifting relative to the right bank, and the plume width occasionally appears to slightlycontract in width.

An initial CORMIX1 evaluation was carried out to ascertain its applicability in this somewhat
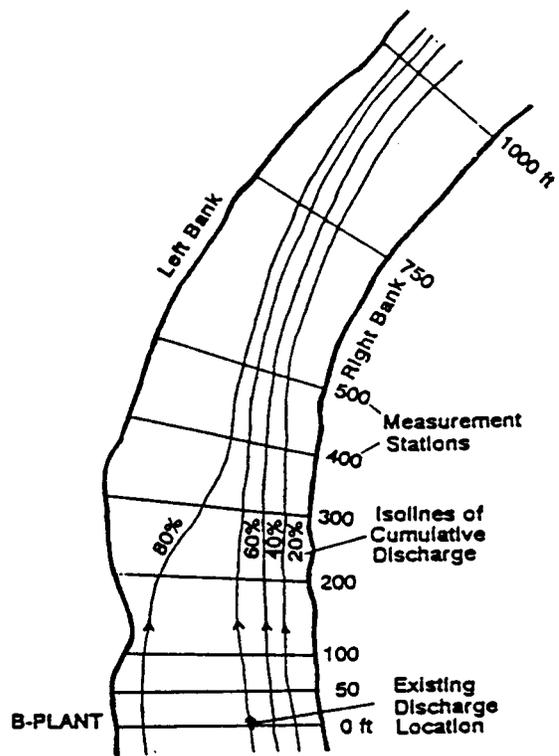
Figure C.1: Plan view of downstream reach of Shallow River with cumulative discharge measurement stations and distribution
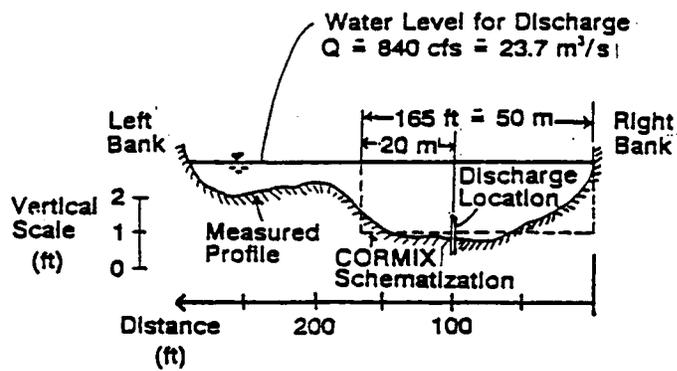
Figure C.2: River cross-section at discharge location
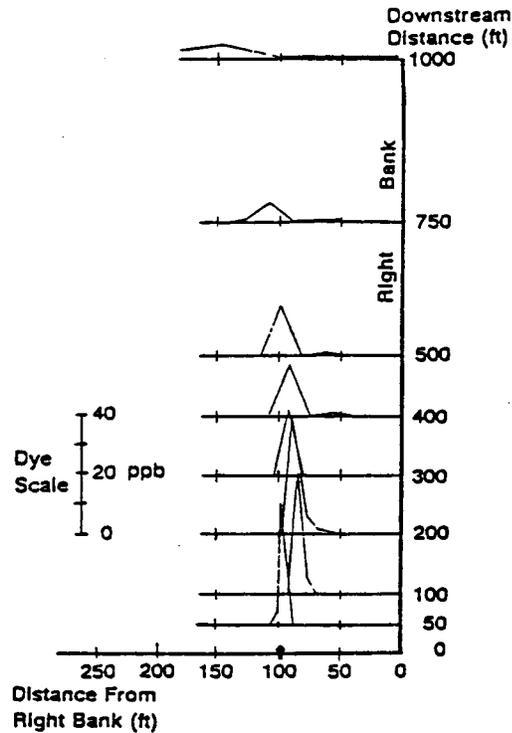
Figure C.3: Measured dye concentration plotted as a function of distance from right bank

irregular flow environment. For this purpose, the cross-section was schematized as a rectangular cross-section putting emphasis on the depth conditions around the discharge location. The average and local depths at this flow rate are both 1.9 ft or ($\gg$ 0.6 m).

Information from the cumulative discharge data was used. Note that the cumulative discharge data shows the discharge located at the 60 % line, i.e. it is hydraulically closer to the left bank, while it appears geographically closer to the right! This is reflected in the schematization: Within the 165 ft ($\gg$ 50 m) wide rectangular channel, the discharge is located 20 m from the left bank. The roughness of the slightly winding, but otherwise clean natural channel has been specified by a Manning's n value of 0.03.

Figure C.4 is the data checklist prepared for the CORMIX1 session, while Table C.1 represents the detailed CORMIX1 Prediction File (the session report is not given here). CORMIX1 predicts that the plume gets rapidly mixed over the shallow depth, and is primarily influenced by far-field mixing processes, a feature that is quite

consistent with observations. The dye concentration distribution predicted by CORMIX1 in the schematic rectangular channel are plotted in Figure C.5 and show a much more regular mixing pattern than the earlier Figure C.3. However, matters can be readily reconciled when both field data and CORMIX1 predictions are interpreted as a function of **cumulative discharge** (for example by means of the far-field post-processor FFLOCATR, although the details of the FFLOCATR application are not shown herein).

This has been done in Figure C.6 where both distributions are directly superposed on the cumulative discharge pattern. The agreement is excellent. This entire procedure points out the need for high-quality field data if detailed interpretations and predictions of discharge plumes are desired.

C.3 Proposed Multiport Diffuser Discharge Under 7Q10 flow Conditions: CORMIX2 Predictions

The following strategy is pursued in order

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CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name   Shallow River   Date:
Design CASE   ~~Dye Test~~   Prepared by: GHJ
DOS FILE NAME   Dye 1   (w/o extension)

AMBIENT DATA: Water body is   bounded/~~unbounded~~
Water body depth   __0.6__ m   If bounded: Width   __50__ m
Depth at discharge   __0.6__ m   Appearance   __1/2/3__
If steady: Ambient flowrate   __23.7__ m³/s or: Ambient velocity   __-__ m/s

If tidal: Tidal period   _____ hr   Max. tidal velocity   _____ m/s
     At time_____ hr   before/at/after slack: Tidal velocity at this time   _____ m/s

Manning's n   __0.03__ or: Darcy-Weisbach f   __-__
Wind speed   __2__ m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   fresh/~~salt~~ water   If fresh: Specify as   ~~density~~/temp. values
If uniform: Average ~~density~~/temp.   __20.0__

If stratified: Density/temp. at surface   _____
   Stratification type   __A/B/C__   Density/temp. at bottom   _____
   If B/C: Pycnocline height   m   If C: Density/temp. jump   _____

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1
Nearest bank is on   left/~~right~~   Distance to nearest bank   __20.0__ m
Vertical angle THETA   __0__ °   Horizontal angle SIGMA   __0__ °
Port diameter   __0.2__ m or: Port area   __-__ m²
Port height   __0.15__ m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on   left/right   Distance to one endpoint   _____ m
Diffuser length   m   to other endpoint   _____ m
Total number of openings   m   Port height   _____ m
Port diameter   m with contraction ratio   _____
Diffuser arrangement/type   unidirectional / staged / alternating or vertical
Alignment angle GAMMA   °   Horizontal angle SIGMA   °
Vertical angle THETA   °   Relative orientation BETA   °

BUOYANT SURFACE DISCHARGE -- CORMIX3
Discharge located on   left/right bank   Configuration flush/protruding/co-flowing
Horizontal angle SIGMA   °   If protruding: Dist. from bank_____ m
Depth at discharge   m   Bottom slope   °
If rectangular   Width   m or: If circular   Diameter_____ m
discharge channel: Depth   m   pipe: Bottom invert depth   m

Effluent: Flow rate   __0.092__ m³/s or: Effluent velocity   __-__ m/s
Effluent density   __-__ kg/m³ or: Effluent temperature   __22.0__ °C
Heated discharge?   ~~yes~~/no   If yes: Heat loss coefficient   __-__ W/m²,°C
Concentration units   __ppb__   Effluent concentration   __560__
Conservative substance?   yes/~~no~~   If no: Decay coefficient   __-__ /day

MIXING ZONE DATA:
Is effluent toxic?   ~~yes~~/no   If yes: CMC __-__ CCC __-__
WQ stand./conventional poll.?   ~~yes~~/no   If yes: value of standard   __-__
Any mixing zone specified?   ~~yes~~/no   If yes: distance __-__ m or width __-__ % or m
         or area __-__ % or m²

Region of interest   __1000__ m   Grid intervals for display   __20__

Figure C.4: Data preparation checklist for Shallow River dye test evaluation and verification using CORMIX1

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Table C.1
CORMIX1 Prediction File for dye test in Shallow River

```
CORMIX1 PREDICTION FILE:
111111111111111111111111111111111111111111111111111111111111111111111111111
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX1:                                    Subsystem version:
 Submerged Single Port Discharges        CORMIX_v.3.10_____June_1995
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:        Shallow^River
 Design case:            Dye^Test
 FILE NAME:              cormix\sim\dye1    .cx1
 Time of Fortran run:    04/14/96--11:03:24

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =     50.00  AS   =     30.00  QA   =     23.70  ICHREG= 2
 HA    =       .60  HD   =       .60
 UA    =       .790 F    =       .084 USTAR = .8081E-01
 UW    =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND= U          RHOAM =  998.2051

DISCHARGE PARAMETERS (metric units)
 BANK  = LEFT       DISTB =     20.00
 D0    =       .200 A0   =       .031 H0   =       .15
 THETA =       .00  SIGMA =      .00
 U0    =      2.929 Q0   =       .092       = .9200E-01
 RHO0  =  997.7714  DRHO0 = .4337E+00  GP0  = .4260E-02
 C0    = .5600E+03  CUNITS=  ppb
 IPOLL = 1          KS   = .0000E+00  KD   = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .9200E-01  M0   = .2694E+00  J0   = .3920E-03  SIGNJ0=     1.0
 Associated length scales (meters)
 LQ    =       .18  LM   =     18.89  Lm   =       .66  Lb   =      .00
                                      Lmp  =  99999.00  Lbp  =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0   =    100.31  R    =      3.70

FLOW CLASSIFICATION
 111111111111111111111111111111111111111111111
 1 Flow class (CORMIX1)      =     H5-0   1
 1 Applicable layer depth HS =      .60   1
 111111111111111111111111111111111111111111111

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .5600E+03  CUNITS=  ppb
 NTOX  = 0
 NSTD  = 0
 REGMZ = 0
 XINT  =   1000.00  XMAX  =   1000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and below the center of the port:
       20.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD101: DISCHARGE MODULE

 COANDA ATTACHMENT immediately following the discharge.

        X        Y        Z        S        C        B
       .00      .00      .00      1.0   .560E+03    .14

END OF MOD101: DISCHARGE MODULE
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION

 Bottom-attached jet motion.
```

```
  Profile definitions:
    B = Gaussian 1/e (37%) half-width, normal to trajectory
            Half wall jet, attached to bottom.
    S = hydrodynamic centerline dilution
    C = centerline concentration (includes reaction effects, if any)

        X         Y         Z         S         C         B
       .00       .00       .00      1.0   .560E+03       .10
      1.05       .00       .00      1.2   .483E+03       .16
      2.10       .00       .00      1.7   .337E+03       .21
      3.15       .00       .00      2.1   .263E+03       .26
      4.21       .00       .00      2.6   .216E+03       .29
      5.26       .00       .00      3.0   .185E+03       .32
      6.31       .00       .00      3.4   .163E+03       .35
      7.36       .00       .00      3.8   .146E+03       .38
      8.41       .00       .00      4.2   .132E+03       .40
      9.46       .00       .00      4.6   .121E+03       .42
     10.51       .00       .00      5.0   .112E+03       .44
     11.56       .00       .00      5.3   .105E+03       .46
     12.62       .00       .00      5.7   .983E+02       .48
     13.67       .00       .00      6.0   .927E+02       .50
     14.72       .00       .00      6.4   .878E+02       .51
     15.77       .00       .00      6.7   .834E+02       .53
     16.82       .00       .00      7.0   .795E+02       .55
     17.87       .00       .00      7.4   .761E+02       .56
     18.92       .00       .00      7.7   .729E+02       .57
     19.97       .00       .00      8.0   .701E+02       .59
     21.03       .00       .00      8.3   .675E+02       .60
 Cumulative travel time =         14. sec

END OF CORJET (MOD110): JET/PLUME NEAR-FIELD MIXING REGION
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING

  Control volume inflow:
        X         Y         Z         S         C         B
     21.03       .00       .00      8.3   .675E+02       .60

  Profile definitions:
    BV = layer depth (vertically mixed)
    BH = top-hat half-width, in horizontal plane normal to trajectory
    ZU = upper plume boundary (Z-coordinate)
    ZL = lower plume boundary (Z-coordinate)
    S  = hydrodynamic average (bulk) dilution
    C  = average (bulk) concentration (includes reaction effects, if any)

        X         Y         Z         S         C        BV        BH        ZU        ZL
     20.43       .00       .60      8.3   .675E+02       .00       .00       .60       .60
     20.55       .00       .60      8.3   .675E+02       .60       .11       .60       .00
     20.67       .00       .60      8.3   .675E+02       .60       .15       .60       .00
     20.79       .00       .60      8.3   .675E+02       .60       .19       .60       .00
     20.91       .00       .60      8.3   .675E+02       .60       .22       .60       .00
     21.03       .00       .60      8.3   .675E+02       .60       .24       .60       .00
     21.15       .00       .60      8.8   .637E+02       .60       .27       .60       .00
     21.27       .00       .60      9.9   .568E+02       .60       .29       .60       .00
     21.39       .00       .60     10.8   .517E+02       .60       .31       .60       .00
     21.51       .00       .60     11.4   .493E+02       .60       .33       .60       .00
     21.63       .00       .60     11.6   .482E+02       .60       .35       .60       .00
 Cumulative travel time =         15. sec

END OF MOD133: LAYER BOUNDARY IMPINGEMENT/FULL VERTICAL MIXING
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD153: VERTICALLY MIXED PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

 Phase 1: The plume is VERTICALLY FULLY MIXED over the entire layer depth.
 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

 -------------------------------------------------------------------------------
 Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.
```

```
END OF MOD153: VERTICALLY MIXED PLUME IN CO-FLOW
-------------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  3.25 to conserve the mass flux in the far-field!
 The correction factor is quite large because of the small ambient velocity
   relative to the strong mixing characteristics of the discharge!
   This indicates localized RECIRCULATION REGIONS and internal hydraulic JUMPS.
 Flow appears highly UNSTEADY and prediction results are UNRELIABLE!
-------------------------------------------------------------------------------
BEGIN MOD141: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD141: BUOYANT AMBIENT SPREADING
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   = .970E-02 m^2/s
  Horizontal diffusivity (initial value) = .242E-01 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
       X         Y        Z        S        C        BV        BH        ZU        ZL
      21.63      .00      .60     11.6   .482E+02     .60      1.12      .60       .00
      70.55      .00      .60     25.3   .222E+02     .60      2.44      .60       .00
     119.47      .00      .60     33.8   .166E+02     .60      3.26      .60       .00
     168.39      .00      .60     40.5   .138E+02     .60      3.92      .60       .00
     217.30      .00      .60     46.3   .121E+02     .60      4.48      .60       .00
     266.22      .00      .60     51.5   .109E+02     .60      4.98      .60       .00
     315.14      .00      .60     56.1   .998E+01     .60      5.43      .60       .00
     364.06      .00      .60     60.5   .926E+01     .60      5.84      .60       .00
     412.98      .00      .60     64.5   .869E+01     .60      6.23      .60       .00
     461.90      .00      .60     68.3   .820E+01     .60      6.60      .60       .00
     510.81      .00      .60     71.9   .779E+01     .60      6.95      .60       .00
     559.73      .00      .60     75.3   .744E+01     .60      7.28      .60       .00
     608.65      .00      .60     78.5   .713E+01     .60      7.59      .60       .00
     657.57      .00      .60     81.7   .686E+01     .60      7.90      .60       .00
     706.49      .00      .60     84.7   .661E+01     .60      8.19      .60       .00
     755.41      .00      .60     87.6   .639E+01     .60      8.47      .60       .00
     804.33      .00      .60     90.4   .619E+01     .60      8.74      .60       .00
     853.24      .00      .60     93.2   .601E+01     .60      9.01      .60       .00
     902.16      .00      .60     95.8   .584E+01     .60      9.27      .60       .00
     951.08      .00      .60     98.4   .569E+01     .60      9.52      .60       .00
    1000.00      .00      .60    101.0   .555E+01     .60      9.76      .60       .00
 Cumulative travel time =        1249. sec

 Simulation limit based on maximum specified distance =   1000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD161: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CORMIX1: Submerged Single Port Discharges            End of Prediction File
11111111111111111111111111111111111111111111111111111111111111111111111111111
```

Figure C.5: Dye concentrations predicted by CORMIX1 plotted as a function of distance from right bank in schematized channel

Figure C.6: Comparison of measured field dye distribution and CORMIX1 predictions within cumulative discharge pattern

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to improve the near-field mixing characteristics of the existing discharge: (1) Utilization of a multiport diffuser to increase the initial entrainment of ambient water into the multiple effluent jets, and (2) shifting of the discharge location toward the right bank to delay the contact with the left shoreline that -with the present installation- seems to occur at a downstream distance of 1000 ft.

The design study is carried out for the low flow ambient condition given by the 7Q10 discharge (285 cfs $\approx$ 8.1 m^3/s) as is typical for water quality studies on riverine sites. Temperatures of the discharge and ambient and channel roughness is assumed unchanged. The new local and average depth for this flowrate is calculated to be $\approx$ 0.3 m from the formula given in Section 4.3.1.

State water quality regulations call for a demonstration of plume concentrations at the edge of a mixing zone that is limited to one fourth (1/4) of the river width. With an average river width of 250 ft, this corresponds to a width limitation of 250/4 $\approx$ 62 ft ($\approx$ 19 m). (Note: The actual width limitation must be handled within the schematized cross-sections as specified. For the schematic channel width of 50 m this represents a 19/50 = 38% width limitation specification as used in CORIMX2.)

Obviously, a number of design solutions, with different diffuser configurations and locations, need to be investigated. One of several feasible solutions is presented in the following: A 15 m ($\approx$ 49 ft) long diffuser consisting of 7 nozzles is installed in perpendicular, co-flowing arrangement centered at the 40% cumulative discharge position. (Note: In the actual coordinate position, this corresponds to a distance of about 70 ft from the right bank; see Figure C.1.) The nozzle diameter is 2.5 in ($\approx$ 0.0635 m).

The CORMIX2 simulation is summarized in Figure C.7 (data preparation checklist), Table C.2 (session report), and Table C.3 (prediction file).

Inspection of the session record and prediction file shows that the plume becomes rapidly mixed over the very shallow water depth.

Furthermore, a high initial dilution of 29.8 is attained in a short region (labeled the "acceleration zone", MOD271) following the high velocity multiport discharge. These results are plotted in Figure C.8 using the graphics package CMXGRAPH. In order to illustrate the capabilities of the graphics program these plots include (a) the un-scaled plan view as it first appears on screen, (b) a re-scaled plan view that is undistorted (1:1) to show the actual long and narrow plume shape and river stretch, and (c) a side view of the near-field only with 1:2 vertical distortion. The user should explore the manifold features of the graphics package.

Obviously, predicted plan plume shapes should be interpreted with the **cumulative discharge method**. The far-field plume locator FFLOCATR (Section 6.2) is designed for exactly that purpose. The two data files examples in Section 6.2 (input: Table 6.4, output: Table 6.5) are, in fact, applications for the present design case. Hence, the results of Table 6.5 when plotted on the river plan view with the cumulative discharge isolines are shown in Figure C.9 and exhibit realistic plume shapes. After the rapid initial mixing in the near-field the plume is growing only very slowly in the far-field (MOD261). At the 1000 ft transect, the plume stays clear of the left bank.

The concentration distribution along the plume centerline is plotted in Figure C.10 for the near-field only, as very slow additional mixing occurs at larger distances (see Table C.3). As regards the **regulatory mixing zone (RMZ)** the prediction results indicate that it will be encountered at a considerable distance downstream, at about 354 m ($\approx$ 1200 ft), i.e. outside the region plotted in Figure C.10. The dilution at that location is 33.5, corresponding to a local centerline concentration value of 3.0 %.

Finally, it is illuminating to compare the performance of the proposed multiport diffuser design with the existing single port situation, both under 7Q10 low flow. This is also included in Figure C.10 by plotting the plume centerline concentrations. (Note: The data sheet, session record, and output file for this CORMIX1 application are omitted for space reasons.) Clearly, the multiport design achieves much more

rapid initial mixing by capturing more of the ambient entrainment flow as the diffuser is spread over portion of the river width. Figure C.10 also includes an additional CORMIX1 prediction for a single plume out of the 7-nozzle arrangement to provide more detail in the near-field; the user has been prompted by several messages within CORMIX2 to perform this additional prediction.

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name   B-Plant Shallow River   Date:
Design CASE   Low Flow 7Q10   Prepared by: GHJ
DOS FILE NAME   Sample 2   (w/o extension)

AMBIENT DATA: Water body is   bounded/~~unbounded~~
Water body depth   0.3   m   If bounded: Width   50   m
Depth at discharge   0.3   m   Appearance   ~~1~~/2/~~3~~
If steady: Ambient flowrate   8.1   m³/s or: Ambient velocity   -   m/s

If tidal: Tidal period   hr   Max. tidal velocity   m/s
     At time _____ hr   before/at/after slack: Tidal velocity at this time   m/s

Manning's n   0.03   or: Darcy-Weisbach f   -
Wind speed   2   m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   fresh/~~salt~~ water   If fresh: Specify as   ~~density~~/temp. values
If uniform: Average ~~density~~/temp.   20.0

If stratified: Density/temp. at surface
  Stratification type   A/B/C   Density/temp. at bottom
  If B/C: Pycnocline height   m   If C: Density/temp. jump

DISCHARGE DATA: Specify geometry for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1
Nearest bank is on   left/right   ~~Distance to nearest bank~~   m
Vertical angle THETA   °   Horizontal angle SIGMA   °
Port diameter   m or: Port area   m²
~~Port height~~   m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on   ~~left~~/right   Distance to one endpoint   12.5   m
Diffuser length   15   m   to other endpoint   27.5   m
Total number of openings   7   m   Port height   0.09   m
Port diameter   0.0635   m with contraction ratio   1.0
Diffuser arrangement/type   unidirectional /~~staged~~ /~~alternating~~ ~~convertical~~
Alignment angle GAMMA   90   °   Horizontal angle SIGMA   0   °
Vertical angle THETA   0   °   Relative orientation BETA   90   °

BUOYANT SURFACE DISCHARGE -- CORMIX3
Discharge located on   left/right bank   Configuration ~~flush~~/protruding/co-flowing
Horizontal angle SIGMA   °   ~~If protruding~~: Dist. from bank _____ m
Depth at discharge   m   Bottom slope   °
If rectangular   Width   m or: If circular   Diameter _____ m
~~discharge channel~~: Depth   m   pipe: Bottom invert depth _____ m

Effluent: Flow rate   0.092   m³/s or: Effluent velocity   -   m/s
Effluent density   -   kg/m³ or: Effluent temperature   22.0   °C
Heated discharge?   ~~yes~~/no   If yes: Heat loss coefficient   -   W/m²,°C
Concentration units   %   Effluent concentration   100
Conservative substance?   yes/~~no~~   If no: Decay coefficient   -   /day

MIXING ZONE DATA:
Is effluent toxic?   ~~yes~~/no   If yes: CMC   -   CCC   -
WQ stand./conventional poll.?   ~~yes~~/no   If yes: value of standard   -
Any mixing zone specified?   yes/~~no~~   If yes: distance ___ - ___ m or width   38   % ~~or x~~
               or area   -   % or m²

Region of interest   1000   m   Grid intervals for display   20

Figure C.7:   Data preparation checklist for Shallow River design case for multiport diffuser using CORMIX2

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                    CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                CORMIX v.3.10          June 1995
SITE NAME/LABEL:              B-PLANT SHALLOW-RIVER
  DESIGN CASE:                LOW-FLOW 7Q10
  FILE NAME:                  SAMPLE2
Using subsystem CORMIX2:      Submerged Multiport Diffuser Discharges
  Start of session:           06/24/95--22:35:06
**********************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                       = bounded
  Width                      BS        =        50.0 m
  Channel regularity         ICHREG   = 2
  Ambient flowrate           QA        =         8.1 m^3/s
  Average depth              HA        =        0.30 m
  Depth at discharge         HD        =        0.30 m
  Ambient velocity           UA        =      0.5400 m/s
  Darcy-Weisbach friction factor F     =      0.1054
    Calculated from Manning's n       =        0.03
  Wind velocity              UW        =           2 m/s
Stratification Type          STRCND   = U
  Surface temperature                  =        20.0 degC
  Bottom temperature                   =        20.0 degC
  Calculated FRESH-WATER DENSITY values:
  Surface density            RHOAS    =     998.2051 kg/m^3
  Bottom density             RHOAB    =     998.2051 kg/m^3
----------------------------------------------------------------------
DISCHARGE PARAMETERS:         Submerged Multiport Diffuser Discharge
  Diffuser type              DITYPE   = unidirectional perpendicular
  Diffuser length            LD       = 15.0 m
  Nearest bank                        = right
  Diffuser endpoints         YB1       =       12.5 m;    YB2 =      27.5 m
  Number of openings         NOPEN    =           7
  Spacing between risers/openings SPAC =        ~2.50 m
  Port/Nozzle diameter       D0       =      0.0635 m
  Equivalent slot width      B0       =      0.0014 m
  Total area of openings     A0       =      0.0031 m^2
  Discharge velocity         U0       =        4.14 m/s
  Total discharge flowrate   Q0       =       0.092 m^3/s
  Discharge port height      H0       =        0.09 m
  Nozzle arrangement         BETYPE   = unidirectional without fanning
  Diffuser alignment angle   GAMMA    =          90 deg
  Vertical discharge angle   THETA    =           0 deg
  Horizontal discharge angle SIGMA    =           0 deg
  Relative orientation angle BETA     =          90 deg
  Discharge temperature (freshwater)  =        22.0 degC
    Corresponding density    RHO0     =    997.7714 kg/m^3
  Density difference         DRHO     =      0.4336 kg/m^3
  Buoyant acceleration       GP0      =       .0043 m/s^2
  Discharge concentration    C0       =         100 PERCENT
  Surface heat exchange coeff. KS     =           0 m/s
  Coefficient of decay       KD       =           0 /s
----------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)      q0      =    0.006133 m^2/s
  Momentum flux                m0      =    0.025452 m^3/s^2
  Buoyancy flux                j0      =    0.000026 m^3/s^3
----------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m    lm  =      0.08 m       lM  =       28.80 m
  lm' =   99999.0 m     lb' =  99999.0 m        la  =    99999.0 m
  (These refer to the actual discharge/environment length scales.)
----------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number           FR0      =    1653.66
  Port/nozzle Froude number    FRD0     =     252.28
  Velocity ratio               R        =       7.68
----------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                     = no
  Water quality standard specified    = no
  Regulatory mixing zone              = yes
  Regulatory mixing zone specification = width
  Regulatory mixing zone value        =          19 m (m^2 if area)
  Region of interest                  =     1000.00 m
```

```
********************************************************************************
HYDRODYNAMIC CLASSIFICATION:
   *-------------------------*
   | FLOW CLASS    =    MU2 |
   *-------------------------*
   This flow configuration applies to a layer corresponding to the full water
   depth at the discharge site.
   Applicable layer depth = water depth =          0.30 m
********************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
--------------------------------------------------------------------------------
X-Y-Z Coordinate system:
   Origin is located at the bottom below the port center:
              20 m from the right bank/shore.
   Number of display steps NSTEP = 20 per module.
--------------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
   implication.  However, this information may be useful for the discharge
   designer because the mixing in the NFR is usually sensitive to the
   discharge design conditions.
   Pollutant concentration at edge of NFR =          3.3538 PERCENT

     (centerline coordinates)             y =         .00 m
                                          z =         .30 m
   NFR plume dimensions:       half-width =        6.73 m
                               thickness =         .30 m
--------------------------------------------------------------------------------
Buoyancy assessment:
   The effluent density is less than the surrounding ambient water
   density at the discharge level.
   Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
   the surface.
--------------------------------------------------------------------------------
Near-field instability behavior:
   The diffuser flow will experience instabilities with full vertical mixing
   in the near-field.
   There may be benthic impact of high pollutant concentrations.
--------------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
   Plume becomes vertically fully mixed ALREADY IN NEAR-FIELD at         7.50 m
   downstream and continues as vertically mixed into the far-field.
************************* TOXIC DILUTION ZONE SUMMARY ************************
No TDZ was specified for this simulation.
*********************** REGULATORY MIXING ZONE SUMMARY ************************
The plume conditions at the boundary of the specified RMZ are as follows:
   Pollutant concentration               =         2.955534 PERCENT
   Corresponding dilution                =          33.8
   Plume location:                   x =        384.55 m
     (centerline coordinates)         y =          .00 m
                                      z =          .30 m
   Plume dimensions:        half-width =          9.50 m
                            thickness =           .30 m
********************** FINAL DESIGN ADVICE AND COMMENTS **********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
   the actual three-dimensional diffuser geometry.  Thus, it approximates
   the details of the merging process of the individual jets from each
   port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
   (or riser assemblies) is somewhat greater (in the range between
   three times to ten times) the local water depth.  It is unlikely
   that sufficient lateral interaction of adjacent jets will
   occur in the near-field.  However, the individual jets/plumes may merge
   soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation.
   The results may be somewhat unrealistic in the near-field (minimum
   dilution may be overpredicted), but appear to be applicable for the
   intermediate- and far-field processes.
The user is advised to use a subsequent CORMIX1 (single port discharge)
   analysis, using discharge data for an individual diffuser jet/plume,
   in order to compare to the present near-field prediction.
--------------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
   technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
   CORMIX predictions on dilutions and concentrations (with associated
   plume geometries) are reliable for the majority of cases and are accurate
   to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
   the design configuration as highly complex and uncertain for prediction.
********************************************************************************
DESIGN CASE:               LOW-FLOW 7Q10
FILE NAME:                 SAMPLE2
Subsystem CORMIX2:         Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:  04/14/96--11:16:37
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

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Table C.3
CORMIX2 Prediction File for B-Plant discharge into Shallow River with multiport diffuser

```
CORMIX2 PREDICTION FILE:
2222222222222222222222222222222222222222222222222222222222222222222222222222
                    CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                      Subsystem version:
 Submerged Multiport Diffuser Discharges    CORMIX_v.3.00_____July_1994
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:        B-PLANT^SHALLOW-RIVER
 Design case:            LOW-FLOW^7Q10
 FILE NAME:              cormix\sim\SAMPLE2 .cx2
 Time of Fortran run:    06/24/95--22:36:15

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS   =     50.00 AS    =     15.00 QA    =      8.10 ICHREG= 2
 HA   =       .30 HD    =       .30
 UA   =      .540 F     =      .105 USTAR = .6199E-01
 UW   =     2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U         RHOAM =  998.2051

DIFFUSER DISCHARGE PARAMETERS (metric units)
 Diffuser type:      DITYPE= unidirectional_perpendicular
 BANK =  RIGHT      DISTB =     20.00 YB1  =    12.50 YB2  =     27.50
 LD   =     15.00 NOPEN =    7       SPAC  =     2.50
 D0   =       .064 A0    =      .003 H0    =       .09
 Nozzle/port arrangement:   unidirectional_without_fanning
 GAMMA =     90.00 THETA =       .00 SIGMA =       .00 BETA =     90.00
 U0   =      4.150 Q0    =            = .9200E-01
 RHO0 =   997.7714 DRHO0 = .4337E+00 GP0   = .4260E-02
 C0   = .1000E+03 CUNITS=   PERCENT
 IPOLL = 1          KS    = .0000E+00 KD    = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0   = .6133E-02 m0    = .2545E-01 j0    = .2613E-04 SIGNJ0=     1.0
 Associated 2-d length scales (meters)
 lQ=B =       .001 lM   =     28.81 lm   =       .09
 lmp  =  99999.00 lbp  =  99999.00 la   =  99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0   = .9200E-01 M0    = .3818E+00 J0    = .3920E-03
 Associated 3-d length scales (meters)
 LQ   =       .15 LM   =     24.53 Lm   =      1.14 Lb   =       .00
                                   Lmp  =  99999.00 Lbp  =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0  =   1653.66 FRD0 =    252.28 R    =      7.68
 (slot)          (port/nozzle)

FLOW CLASSIFICATION
 2222222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)    =    MU2    2
 2  Applicable layer depth HS =      .30  2
 2222222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0   = .1000E+03 CUNITS=   PERCENT
 NTOX = 0
 NSTD = 0
 REGMZ = 1
 REGSPC= 2         XREG =       .00 WREG =     19.00 AREG =       .00
 XINT =   1000.00 XMAX =   1000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
        20.00 m  from the RIGHT bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP = 20 display intervals per module
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE
```

```
   Due to complex near-field motions:  EQUIVALENT SLOT DIFFUSER (2-D) GEOMETRY

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV        BH
      .00      .00      .09      1.0    .100E+03    .00      7.50

END OF MOD201: DIFFUSER DISCHARGE MODULE
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =    .30m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

      X        Y        Z        S        C        BV        BH
      .00      .00      .09      1.0    .100E+03    .00      7.50
      .38      .00      .09     11.2    .894E+01    .08      7.39
      .75      .00      .10     15.4    .649E+01    .15      7.30
     1.13      .00      .10     18.6    .536E+01    .23      7.22
     1.50      .00      .10     21.4    .468E+01    .30      7.15
     1.88      .00      .11     23.8    .420E+01    .30      7.09
     2.25      .00      .11     26.0    .385E+01    .30      7.04
     2.63      .00      .11     28.0    .358E+01    .30      6.99
     3.00      .00      .11     29.8    .335E+01    .30      6.95
     3.38      .00      .12     29.8    .335E+01    .30      6.91
     3.75      .00      .12     29.8    .335E+01    .30      6.87
     4.13      .00      .12     29.8    .335E+01    .30      6.84
     4.50      .00      .13     29.8    .335E+01    .30      6.82
     4.88      .00      .13     29.8    .335E+01    .30      6.80
     5.25      .00      .13     29.8    .335E+01    .30      6.78
     5.63      .00      .14     29.8    .335E+01    .30      6.76
     6.00      .00      .14     29.8    .335E+01    .30      6.75
     6.38      .00      .14     29.8    .335E+01    .30      6.74
     6.75      .00      .14     29.8    .335E+01    .30      6.74
     7.13      .00      .15     29.8    .335E+01    .30      6.74
     7.50      .00      .15     29.8    .335E+01    .30      6.73
 Cumulative travel time =        11. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

 Phase 1: The diffuser plume is VERTICALLY FULLY MIXED over the
         entire layer depth.
 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.
-------------------------------------------------------------------------------
 Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW
-------------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor  1.24 to conserve the mass flux in the far-field!
-------------------------------------------------------------------------------
BEGIN MOD241: BUOYANT AMBIENT SPREADING

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.
```

```
END OF MOD241: BUOYANT AMBIENT SPREADING
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)   =  .372E-02 m^2/s
  Horizontal diffusivity (initial value) =  .930E-02 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 1 (not bank attached):
      X         Y         Z         S         C         BV        BH        ZU        ZL
      7.50      .00       .30       29.8      .335E+01  .30       8.37      .30       .00
     57.13      .00       .30       30.4      .329E+01  .30       8.53      .30       .00
    106.75      .00       .30       30.9      .323E+01  .30       8.68      .30       .00
    156.38      .00       .30       31.5      .318E+01  .30       8.83      .30       .00
    206.00      .00       .30       32.0      .313E+01  .30       8.98      .30       .00
    255.63      .00       .30       32.5      .308E+01  .30       9.13      .30       .00
    305.25      .00       .30       33.0      .303E+01  .30       9.27      .30       .00
    354.88      .00       .30       33.5      .298E+01  .30       9.42      .30       .00
** REGULATORY MIXING ZONE BOUNDARY **
In this prediction interval the TOTAL plume width meets or exceeds
   the regulatory value =    19.00 m.
This is the extent of the REGULATORY MIXING ZONE.
    404.50      .00       .30       34.0      .294E+01  .30       9.56      .30       .00
    454.13      .00       .30       34.5      .290E+01  .30       9.69      .30       .00
    503.75      .00       .30       35.0      .286E+01  .30       9.83      .30       .00
    553.38      .00       .30       35.5      .282E+01  .30       9.96      .30       .00
    603.00      .00       .30       36.0      .278E+01  .30      10.10      .30       .00
    652.63      .00       .30       36.4      .275E+01  .30      10.23      .30       .00
    702.25      .00       .30       36.9      .271E+01  .30      10.36      .30       .00
    751.88      .00       .30       37.3      .268E+01  .30      10.48      .30       .00
    801.50      .00       .30       37.8      .265E+01  .30      10.61      .30       .00
    851.13      .00       .30       38.2      .262E+01  .30      10.73      .30       .00
    900.75      .00       .30       38.7      .259E+01  .30      10.86      .30       .00
    950.38      .00       .30       39.1      .256E+01  .30      10.98      .30       .00
   1000.00      .00       .30       39.5      .253E+01  .30      11.10      .30       .00
 Cumulative travel time =       1828. sec


 Simulation limit based on maximum specified distance =   1000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports,
  the above results may be unreliable in the immediate near-field of
  the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
  for one of the individual jets/plumes in the initial region
before merging.
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
CORMIX2: Submerged Multiport Diffuser Discharges      End of Prediction File
22222222222222222222222222222222222222222222222222222222222222222222222222222222
```

Plan View

Distortion = 10.983

(a)

Plan View

Distortion = 1.00

(b)

Side View

Distortion = 2.000

(c)

Figure C.8:   CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River. Examples of different graphics plots: a) Plan view over entire reach, b) equivalent undistorted plan view, and c) side view of near-field only.
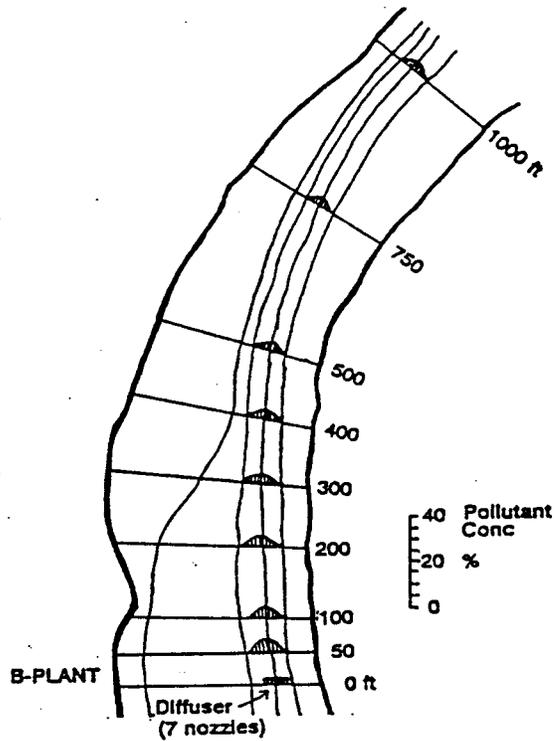
Figure C.9: Results of cumulative discharge interpretation of CORMIX2 prediction for B-Plant multiport diffuser discharge in Shallow River
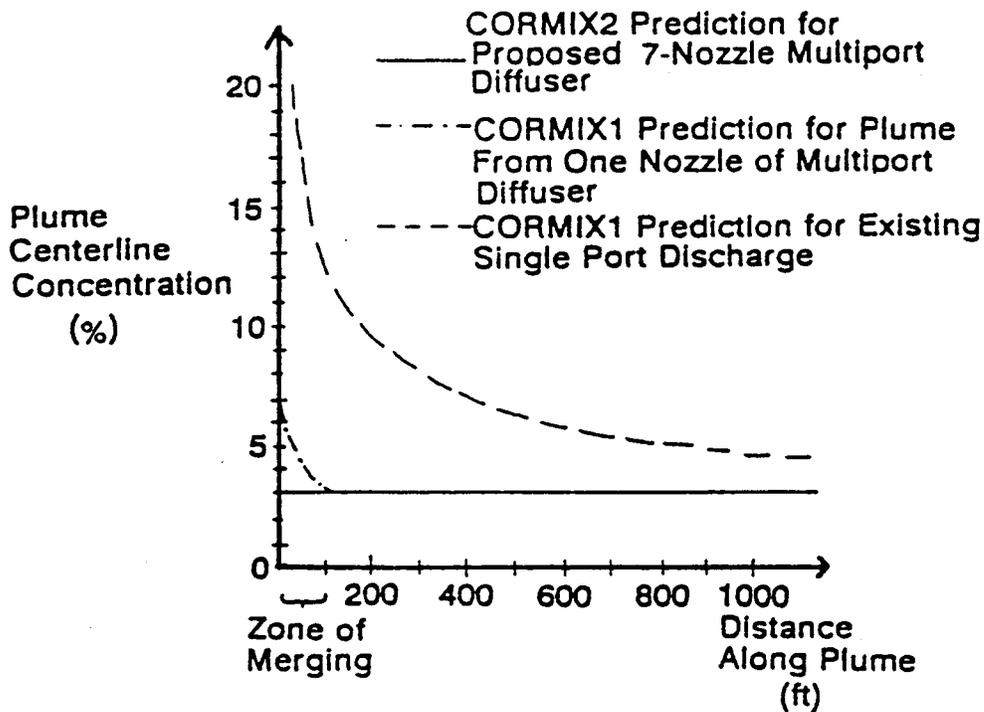
Figure C.10: Predicted plume centerline concentrations for multiport diffuser design (CORMIX1) in comparison to single port design (CORMIX2)

Appendix D
CORMIX3: Buoyant Surface Discharge In An Estuary

Estuarine conditions are characterized by highly variable ambient conditions during the tidal cycle. This case study provides a short application example for a buoyant surface discharge from a large manufacturing plant discharging its process water into an estuary.

D.1 Problem Statement

A manufacturing plant (C-Plant) is using process water at a capacity of 2.2 m³/s ($\approx$ 50 mgd). The process water is essentially fresh water with a discharge temperature of 20.0 °C and contains copper at a concentration of 80 µg/l.

The plant is located at the shore of an estuary. Figure D.1 shows the bottom bathymetry at the plant location; two transects have been measured and show a relatively rapid drop-off from the MSL line to a depth of about 5 m below MSL. It is proposed to build a discharge channel with a bottom elevation of about 1.0 m below MSL and a width of 2.0 m. Thus, given the tidal variation at the discharge location indicated in Figure D.1, the actual channel depth will vary from a maximum of about 1.8 m at MHW to a minimum of about 0.5 at MLW, with corresponding adjustments in the discharge velocity.

Figure D.2 shows data from oceanographic field surveys near the discharge site with ambient velocity variations from about +0.7 m/s for flood tide and to about -0.7 m/s for ebb tide. Figure D.2 also shows the tidal elevation variations from -.7 m above MLW at ebb to +1.1 m above MLW at flood. The estuary has brackish water with mean salinity of about 26 ppt, yielding a density of about 1018 kg/m³ (see Figure 4.3 as an aid).

State regulations specify a mixing zone of about 250 m extending in any direction from the discharge point. The CMC and CCC values for copper are 25 and 15 µg/l, respectively.

D.2 Steady State Simulation (for reference)

Although it is to be expected that the surface discharge plume for this situation will be quite variable in appearance and mixing characteristics due to the tidal reversal, a steady state simulation will be performed to illustrate the basic CORMIX3 application in a time invariant ambient receiving water. Furthermore, this simulation will be used as a basis for comparison in the next selection, where tidal CORMIX simulations are appropriately performed in order to determine the time evolution in this highly unsteady environment.

Assume that the conditions one hour after low water slack tide (t = 11.7 h) represent that in a large steady river (see condition (b), Figure D.2). This design condition is represented by a water level 0.35 m below MSL and an ambient velocity of 0.22 m/s. As shown in Figure D.1, the ambient water body is schematized as unbounded, with an average depth of 6 m at MSL, a local depth of 2.5 m at MSL (1.5 m below the discharge channel mouth), and a bottom slope of 11°.

Figure D.3 presents the input data checklist and Table D.1 shows the CORMIX3 prediction file (the session report is omitted here for brevity) for the steady state reference condition one hour after low water slack (LWS). The shallow discharge channel (depth of 0.65 m) produces a relatively weak free jet (flow class FJ1). After only 4.5 m offshore distance, the initial jet momentum is overwhelmed by the high discharge buoyancy, and forms a surface plume which is weakly deflected by the ambient crossflow (MOD313). In this region, buoyant forces rapidly thin and spread the plume horizontally. Both the CCC and CMC are met within this region, (and also within the regulatory mixing zone) as is displayed by CORMIX in the prediction file. The plume then becomes strongly deflected (MOD323) and finally contacts the shoreline some 1560 m downstream. The plume then becomes attached to the shoreline, and spreads through passive ambient diffusion and weak buoyant forces (MOD341), until the end of the region of interest (2000 m). Figure D.4 shows the above behavior.
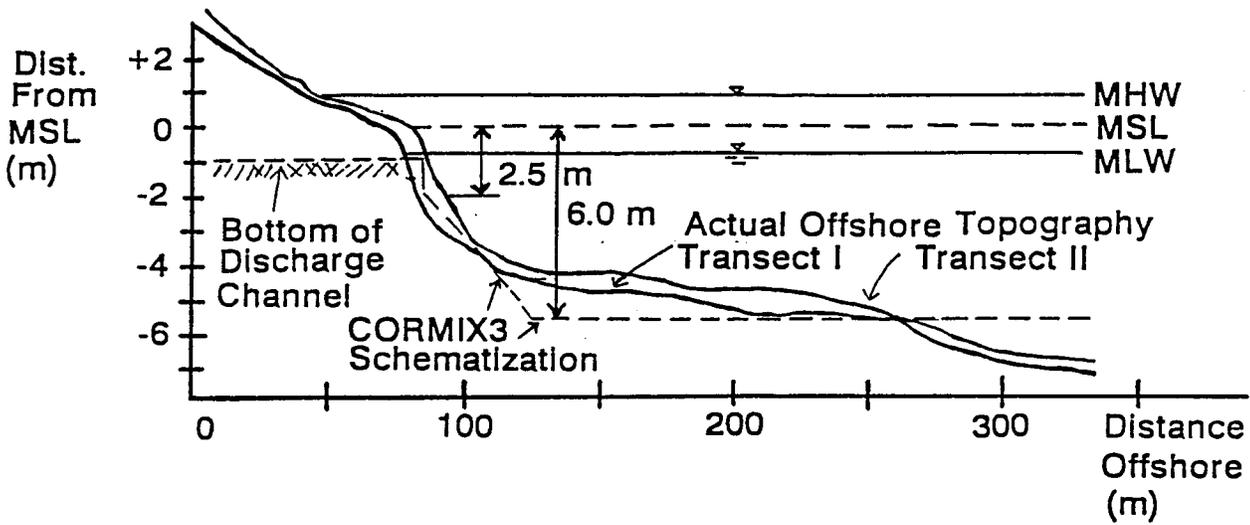
Figure D.1: Bathymetric conditions in Estuary in vicinity of C-Plant surface discharge
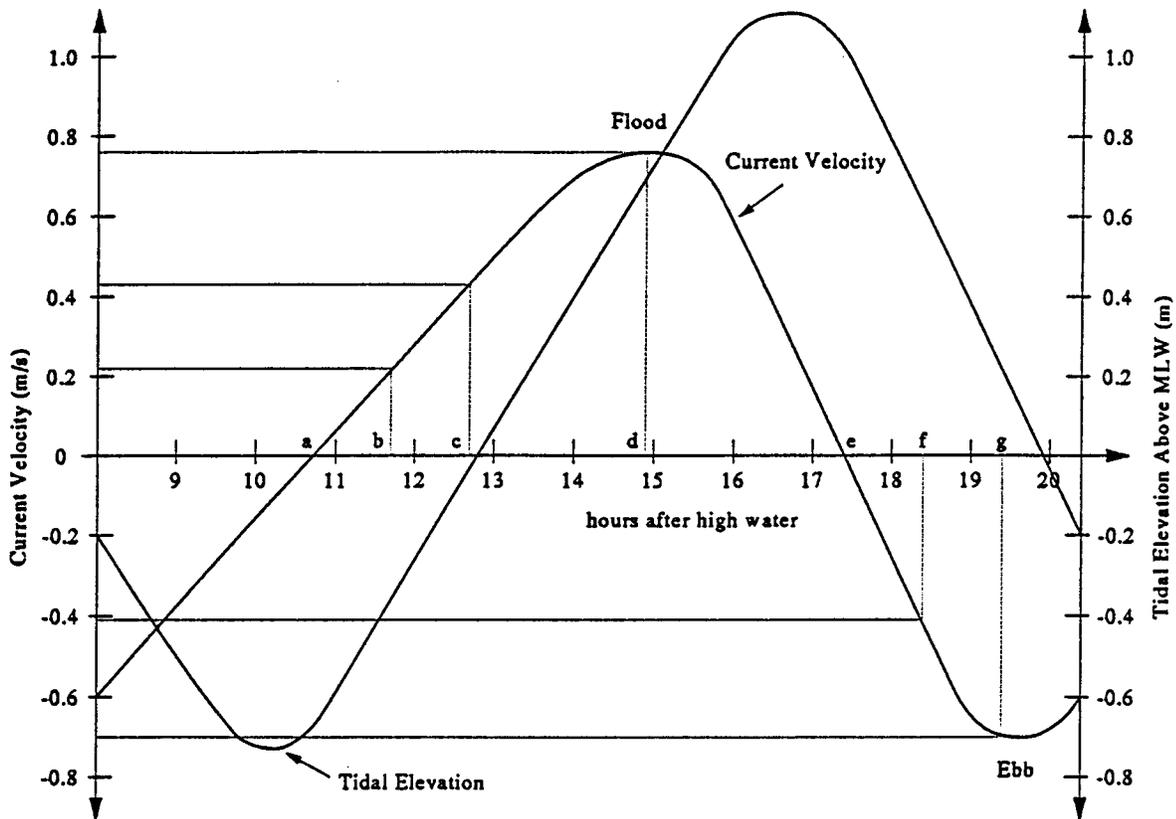
Figure D.2: Oceanographic data for Estuary showing tidal elevation and current. A complete tidal analysis might include simulations for all time instances labeled a to g.

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CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.10

SITE Name   C-Plant Estuary   Date:
Design CASE   Steady State - 1 hr. after slack   Prepared by: RLD
DOS FILE NAME   Sample1   (w/o extension)

AMBIENT DATA: Water body is   ~~bounded~~/unbounded
Water body depth   5.65   m   If bounded: Width   m
Depth at discharge   5.65   m   Appearance   ~~1~~/2/~~3~~
If steady: Ambient flowrate   m³/s or: Ambient velocity   0.22   m/s

If tidal: Tidal period   hr   Max. tidal velocity   m/s
     At time _____ hr before/at/after slack: Tidal velocity at this time   m/s

Manning's n   or: Darcy-Weisbach f   0.025
Wind speed   2   m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   fresh/salt water   If fresh: Specify as   density/~~temp. values~~
If uniform: Average density/temp.   1018.0

If stratified: Density/temp. at surface
  Stratification type   A/B/C   Density/temp. at bottom
  If B/C: Pycnocline height   m   If C: Density/temp. jump

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1
Nearest bank is on   left/right   Distance to nearest bank   m
Vertical angle THETA   °   Horizontal angle SIGMA   °
Port diameter   m or: Port area   m²
Port height   m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on   left/right   Distance to one endpoint   m
Diffuser length   m   to other endpoint   m
Total number of openings   m   Port height   m
Port diameter   m with contraction ratio
Diffuser arrangement/type   unidirectional / staged / alternating or vertical
Alignment angle GAMMA   °   Horizontal angle SIGMA   °
Vertical angle THETA   °   Relative orientation BETA   °

BUOYANT SURFACE DISCHARGE -- CORMIX3
Discharge located on   ~~left~~/right bank   Configuration flush/~~protruding/co-flowing~~
Horizontal angle SIGMA   90   °   If protruding: Dist. from bank _____ m
Depth at discharge   2.15   m   Bottom slope   11   °
If rectangular   Width   2   m or: If circular   Diameter _____ m
discharge channel: Depth   0.65   m   pipe: Bottom invert depth _____ m

Effluent: Flow rate   2.2   m³/s or: Effluent velocity   m/s
Effluent density   -   kg/m³ or: Effluent temperature   22   °C
Heated discharge?   ~~yes~~/no   If yes: Heat loss coefficient   -   W/m²,°C
Concentration units   mug-p-L   Effluent concentration   80
Conservative substance?   yes/~~no~~   If no: Decay coefficient   /day

MIXING ZONE DATA:
Is effluent toxic?   yes/~~no~~   If yes: CMC   25   CCC   15
WQ stand./conventional poll.?   yes/no   If yes: value of standard
Any mixing zone specified?   yes/~~no~~   If yes: distance   250   m or width   -   % or m
         or area   -   % or m²

Region of interest   2000   m   Grid intervals for display   20

Figure D.3:   Data preparation checklist for CORMIX3 steady-state simulation for C-Plant estuary discharge

```
CORMIX3 PREDICTION FILE:
333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                      Subsystem version:
 Buoyant Surface Discharges              CORMIX_v.3.10_____June_1995
--------------------------------------------------------------------------
--------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:        C-PLANT^ESTUARY
 Design case:            STEADY^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:              cormix\sim\SAMPLE3 .cx3
 Time of Fortran run:    06/24/95--22:32:20

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA   =      5.65  HD   =      5.65
 UA   =       .220 F    =       .025 USTAR = .1230E-01
 UW   =     2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U         RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =       .00  Configuration: flush_discharge
 SIGMA =     90.00  HD0  =      2.15  SLOPE =    11.00
 Rectangular channel geometry:
 B0   =     2.000 H0   =       .650  A0   = .1300E+01  AR    =       .325
 U0   =     1.692 Q0   =     2.200       = .2200E+01
 RHO0 =   998.2051 DRHO0 = .1979E+02  GP0  = .1907E+00
 C0   = .8000E+02  CUNITS=  MUG-P-L
 IPOLL = 1         KS   = .0000E+00  KD   = .0000E+00

FLUX VARIABLES (metric units)
 Q0   = .2200E+01  M0   = .3723E+01  J0   = .4195E+00
 Associated length scales (meters)
 LQ   =      1.14  LM   =      4.14  Lm   =      8.77  Lb   =     39.40

NON-DIMENSIONAL PARAMETERS
 FR0  =      3.62  FRCH =      4.80  R    =      7.69

FLOW CLASSIFICATION
 33333333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)   =    FJ1   3
 3  Applicable layer depth HS =    5.65  3
 33333333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0   = .8000E+02  CUNITS=  MUG-P-L
 NTOX = 1          CMC  = .2500E+02  CCC  = CSTD
 NSTD = 1          CSTD = .1500E+02
 REGMZ = 1
 REGSPC= 1         XREG =    250.00  WREG =       .00  AREG =       .00
 XINT =   2000.00  XMAX =   2000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
     channel/outlet:      .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
--------------------------------------------------------------------------
        TRJBUO    TRJATT    TRJBND    TRJNBY    TRJCOR    DILCOR
C       3.401     1.000     1.000     1.000     3.400     1.000
--------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
      X        Y        Z        S        C       BV       BH
      .00      .00     0.00     1.0  .800E+02      .65     1.00

END OF MOD301: DISCHARGE MODULE
```

```
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

  Control volume inflow:
        X        Y        Z        S        C       BV       BH
       .00      .00     0.00      1.0  .800E+02      .65     1.00

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

  Control volume outflow:
        X        Y        Z        S        C       BV       BH
       .13     4.11     0.00      1.4  .576E+02     1.09     1.41
 Cumulative travel time =            2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

 Surface JET into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

        X        Y        Z        S        C       BV       BH
       .13     4.11     0.00      1.4  .576E+02     1.28     1.65
       .13     4.14     0.00      1.4  .575E+02     1.28     1.66
       .13     4.16     0.00      1.4  .574E+02     1.28     1.66
       .13     4.18     0.00      1.4  .573E+02     1.28     1.66
       .13     4.20     0.00      1.4  .572E+02     1.29     1.66
       .14     4.23     0.00      1.4  .571E+02     1.29     1.67
       .14     4.25     0.00      1.4  .570E+02     1.29     1.67
       .14     4.27     0.00      1.4  .569E+02     1.29     1.67
       .14     4.29     0.00      1.4  .568E+02     1.30     1.67
       .15     4.32     0.00      1.4  .567E+02     1.30     1.68
       .15     4.34     0.00      1.4  .566E+02     1.30     1.68
       .15     4.36     0.00      1.4  .565E+02     1.30     1.68
       .15     4.38     0.00      1.4  .564E+02     1.30     1.68
       .15     4.41     0.00      1.4  .563E+02     1.31     1.69
       .16     4.43     0.00      1.4  .562E+02     1.31     1.69
       .16     4.45     0.00      1.4  .561E+02     1.31     1.69
       .16     4.47     0.00      1.4  .560E+02     1.31     1.69
       .16     4.50     0.00      1.4  .559E+02     1.32     1.70
       .17     4.52     0.00      1.4  .558E+02     1.32     1.70
       .17     4.54     0.00      1.4  .558E+02     1.32     1.70
       .17     4.56     0.00      1.4  .557E+02     1.32     1.70
 Cumulative travel time =            3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD313: WEAKLY DEFLECTED PLUME

 Surface PLUME into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

        X        Y        Z        S        C       BV       BH
       .17     4.56     0.00      1.4  .557E+02     1.32     1.70
       .41     6.86     0.00      2.3  .343E+02      .82     4.48
       .67     9.16     0.00      2.9  .279E+02      .66     6.76
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of   .250E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
```

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       .96     11.46     0.00     3.3   .244E+02    .58      8.88
      1.28     13.76     0.00     3.6   .220E+02    .52     10.93
      1.62     16.05     0.00     4.0   .202E+02    .48     12.95
      1.99     18.35     0.00     4.3   .188E+02    .45     14.94
      2.38     20.65     0.00     4.5   .177E+02    .42     16.93
      2.80     22.95     0.00     4.8   .167E+02    .40     18.92
      3.25     25.25     0.00     5.0   .159E+02    .38     20.91
      3.72     27.54     0.00     5.3   .152E+02    .36     22.90
 ** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .150E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
      4.22     29.84     0.00     5.5   .146E+02    .35     24.90
      4.75     32.14     0.00     5.7   .140E+02    .33     26.92
      5.30     34.44     0.00     5.9   .135E+02    .32     28.93
      5.87     36.74     0.00     6.1   .131E+02    .31     30.96
      6.48     39.03     0.00     6.3   .126E+02    .30     33.00
      7.11     41.33     0.00     6.5   .123E+02    .29     35.05
      7.76     43.63     0.00     6.7   .119E+02    .28     37.11
      8.44     45.93     0.00     6.9   .116E+02    .28     39.18
      9.15     48.23     0.00     7.1   .113E+02    .27     41.25
      9.88     50.52     0.00     7.2   .110E+02    .26     43.34
 Cumulative travel time =        248. sec

END OF MOD313: WEAKLY DEFLECTED PLUME
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD323: STRONGLY DEFLECTED PLUME

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally in Y-direction
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

        X         Y         Z         S         C        BV        BH
      9.88     50.52     0.00     7.2   .110E+02    .26     43.34
     84.15    123.86     0.00     7.5   .107E+02    .23     60.96
    158.42    154.39     0.00     7.8   .103E+02    .22     77.07
    232.69    176.11     0.00     8.1   .985E+01    .22     92.39
 ** REGULATORY MIXING ZONE BOUNDARY **
 In this prediction interval the plume distance meets or exceeds
   the regulatory value =   250.00 m.
 This is the extent of the REGULATORY MIXING ZONE.
    306.96    193.50     0.00     8.6   .934E+01    .22    107.24
    381.23    208.23     0.00     9.1   .876E+01    .23    121.77
    455.50    221.14     0.00     9.8   .815E+01    .25    136.02
    529.77    232.70     0.00    10.7   .750E+01    .26    150.02
    604.04    243.21     0.00    11.7   .685E+01    .28    163.77
    678.31    252.88     0.00    12.9   .621E+01    .30    177.26
    752.58    261.87     0.00    14.3   .560E+01    .32    190.49
    826.84    270.29     0.00    15.9   .504E+01    .34    203.46
    901.11    278.21     0.00    17.7   .452E+01    .36    216.17
    975.38    285.70     0.00    19.7   .406E+01    .39    228.65
   1049.65    292.82     0.00    21.9   .365E+01    .41    240.91
   1123.92    299.61     0.00    24.4   .328E+01    .44    252.95
   1198.18    306.11     0.00    27.1   .295E+01    .47    264.79
   1272.45    312.34     0.00    30.0   .267E+01    .50    276.45
   1346.72    318.34     0.00    33.1   .241E+01    .54    287.93
   1420.99    324.11     0.00    36.5   .219E+01    .57    299.25
   1495.25    329.69     0.00    40.1   .199E+01    .61    310.43
 Cumulative travel time =       7000. sec

END OF MOD323: STRONGLY DEFLECTED PLUME
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
BEGIN MOD341: BUOYANT AMBIENT SPREADING

 Profile definitions:
   BV = top-hat thickness,measured vertically
   BH = top-hat half-width, measured horizontally from bank/shoreline
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)
```

```
     Plume Stage 1 (not bank attached):
        X         Y         Z         S         C        BV        BH
     1495.25   329.69     0.00      40.1   .199E+01     .63     319.79
     1498.55   329.69     0.00      40.3   .199E+01     .63     320.29
     1501.84   329.69     0.00      40.5   .198E+01     .63     320.79
     1505.13   329.69     0.00      40.6   .197E+01     .63     321.29
     1508.42   329.69     0.00      40.8   .196E+01     .63     321.79
     1511.72   329.69     0.00      41.0   .195E+01     .64     322.29
     1515.01   329.69     0.00      41.1   .195E+01     .64     322.78
     1518.30   329.69     0.00      41.3   .194E+01     .64     323.28
     1521.59   329.69     0.00      41.5   .193E+01     .64     323.78
     1524.89   329.69     0.00      41.6   .192E+01     .64     324.27
     1528.18   329.69     0.00      41.8   .191E+01     .64     324.77
     1531.47   329.69     0.00      42.0   .191E+01     .65     325.27
     1534.77   329.69     0.00      42.1   .190E+01     .65     325.76
     1538.06   329.69     0.00      42.3   .189E+01     .65     326.26
     1541.35   329.69     0.00      42.5   .188E+01     .65     326.75
     1544.64   329.69     0.00      42.6   .188E+01     .65     327.25
     1547.94   329.69     0.00      42.8   .187E+01     .65     327.74
     1551.23   329.69     0.00      43.0   .186E+01     .65     328.23
     1554.52   329.69     0.00      43.2   .185E+01     .66     328.73
     1557.81   329.69     0.00      43.3   .185E+01     .66     329.22
     1561.11   329.69     0.00      43.5   .184E+01     .66     329.71
     Cumulative travel time =        7299. sec


     ------------------------------------------------------------------------
     Plume is ATTACHED to RIGHT bank/shore.
        Plume width is now determined from RIGHT bank/shore.

     Plume Stage 2 (bank attached):
        X         Y         Z         S         C        BV        BH
     1561.11     .00       0.00      43.5   .184E+01     .66     659.39
     1583.05     .00       0.00      44.6   .179E+01     .67     662.33
     1605.00     .00       0.00      45.7   .175E+01     .69     665.27
     1626.94     .00       0.00      46.8   .171E+01     .70     668.21
     1648.89     .00       0.00      48.0   .167E+01     .71     671.16
     1670.83     .00       0.00      49.1   .163E+01     .73     674.11
     1692.78     .00       0.00      50.3   .159E+01     .74     677.06
     1714.72     .00       0.00      51.4   .156E+01     .76     680.01
     1736.66     .00       0.00      52.6   .152E+01     .77     682.97
     1758.61     .00       0.00      53.8   .149E+01     .78     685.92
     1780.55     .00       0.00      55.0   .146E+01     .80     688.88
     1802.50     .00       0.00      56.2   .142E+01     .81     691.83
     1824.44     .00       0.00      57.4   .139E+01     .83     694.79
     1846.39     .00       0.00      58.6   .136E+01     .84     697.75
     1868.33     .00       0.00      59.9   .134E+01     .85     700.71
     1890.28     .00       0.00      61.1   .131E+01     .87     703.67
     1912.22     .00       0.00      62.4   .128E+01     .88     706.62
     1934.17     .00       0.00      63.6   .126E+01     .90     709.58
     1956.11     .00       0.00      64.9   .123E+01     .91     712.54
     1978.05     .00       0.00      66.2   .121E+01     .93     715.50
     2000.00     .00       0.00      67.5   .118E+01     .94     718.46
     Cumulative travel time =        9294. sec

     Simulation limit based on maximum specified distance =   2000.00 m.
        This is the REGION OF INTEREST limitation.

     END OF MOD341: BUOYANT AMBIENT SPREADING
     ------------------------------------------------------------------------
     ------------------------------------------------------------------------
     CORMIX3: Buoyant Surface Discharges                     End of Prediction File
     33333333333333333333333333333333333333333333333333333333333333333333333333333333
```

Figure D.4: CORMIX3 prediction of surface discharge from C-Plant into Estuary using a steady-state simulation. a) Plume shape in near- and far-field, and b) concentration along plume centerline.

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D.3 Detailed Tidal Simulations

A high variation in both ambient velocity and tidal elevation occurs during the tidal episode shown in Figure D.2. The changing water height produces a discharge velocity which varies from 0.61 m/s (at high water slack) to 2.2 m/s (at low water slack). When combined with the large buoyancy flux, this produces flows which change from momentum dominated jets to highly buoyant plumes in a short period of time. Simultaneously, the time-variant ambient velocity (which ranges from stagnant to 0.75 m/s) produces flows which are free and unattached at slack tide, yet become strongly shore-hugging at maximum flood or ebb currents.

In such highly time-variant ambient conditions, it is recommended that several CORMIX predictions be performed at **critical tidal conditions** throughout a reversal episode. These critical tidal conditions are identified as:

1) *Shortly after slack tide*: Effects of re-entrainment of discharge from the previous half-cycle are greatest. However, the flow is evolving rapidly in time, causing CORMIX tidal predictions to be limited in spatial extent. Several predictions should be made at hourly or half hourly intervals following the reversal.

2) *Maximum flood and ebb currents*: These represent extremes of along-shore extent and shoreline interaction. Re-entrainment will be less important at these times.

For the present scenario, it is suggested that up to seven simulations be performed at the times indicated on Figure D.2 by the letters a-g. In the following section, a detailed simulation is performed corresponding to time b, one hour after slack tide. The results are contrasted for that case to the steady-state assumption simulated in the preceding.

D.4 Tidal simulation one hour after slack tide

A detailed example of the tidal simulation capability of CORMIX is presented in this section, using conditions corresponding to those in Section D.2 (see Figure D.2, time b). To perform a CORMIX tidal simulation, four additional pieces of data are required:

1) the tidal period (usually 12.4 hours for a semi-diurnal tidal cycle)
2) the time of simulation (in hours relative to slack tide)
3) the ambient velocity at the time of simulation
4) the maximum velocity which occurs during the tidal cycle

From this data, CORMIX calculates the rate of reversal (du_a/dt) and related unsteady length scales (L_u, T_u, $[L_m]_{min}$, see Table 5.4), and determines the spatial extent of CORMIX applicability and the re-entrainment and build-up caused by the reversal of ambient current. (Note: If a simulation is performed at slack tide, then the time of simulation is $t = 0$ h, and the ambient velocity is set to $u_a = 0$ m/s.) However, in order to calculate the reversal rate, CORMIX requires input of the ambient velocity at an other time near reversal (for example, at one hour before or after slack tide). This information is only used to determine the limit of spatial applicability for the slack tide simulation.

For this application, the time of simulation is one hour after slack tide. The ambient velocity at this time is $u_a = 0.22$ m/s, and the ambient and discharge channel depths are the same as in Section D.2. The maximum ambient velocity during the tidal cycle is 0.75 m/s. For this simulation, the data preparation checklist is given in Figure D.5.

Table D.2 lists the CORMIX session report and Table D.3 the CORMIX3 prediction file for this tidal application. Two important consequences are evident when comparing Table D.3 and Table D.1 (corresponding steady-state simulation): 1) a concentration build-up in the near-field, and 2) the termination of the plume prediction after some distance. The latter distance is the region over which a reasonably steady-state plume can establish itself within the time-varying tidal environment. The theoretical background for these procedures is given in the report on recent CORMIX enhancements (8).

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- Version 3.1,3.2

SITE Name   C-Plant Estuary   Date:
Design CASE   Tidal simulation 1 hr after slack   Prepared by: GHJ
DOS FILE NAME   Sample 3T   (w/o extension)

AMBIENT DATA: Water body is   ~~bounded~~/unbounded
Water body depth   5.65 m   If bounded: Width   - m
Depth at discharge   5.65 m   Appearance   1/2/3
If steady: Ambient flowrate   - m³/s or: Ambient velocity   - m/s

If tidal: Tidal period   12.4 hr   Max. tidal velocity   0.75 m/s
    At time 1.0 hr ~~before/at~~/after slack: Tidal velocity at this time   0.22 m/s

Manning's n   -   or: Darcy-Weisbach f   0.025
Wind speed   2 m/s
Density data: UNITS: Density...kg/m³ / Temperature...°C
Water body is   ~~fresh~~/salt water   If fresh: Specify as   density/~~temp.~~ values
If uniform: Average density/~~temp~~.   1018.0

If stratified: Density/temp. at surface _____
    Stratification type   A/B/C   Density/temp. at bottom _____
    If B/C: Pycnocline height _____ m   If C: Density/temp. jump _____

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1
Nearest bank is on   left/right   Distance to nearest bank   _____ m
Vertical angle THETA   _____ °   Horizontal angle SIGMA   _____ °
Port diameter   _____ m or: Port area   _____ m²
Port height   _____ m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2
Nearest bank is on   left/right   Distance to one endpoint   _____ m
Diffuser length   _____ m   to other endpoint   _____ m
Total number of openings   _____ m   Port height   _____ m
Port diameter   _____ m with contraction ratio   _____
Diffuser arrangement/type   unidirectional / staged / alternating or vertical
Alignment angle GAMMA   _____ °   Horizontal angle SIGMA   _____ °
Vertical angle THETA   _____ °   Relative orientation BETA   _____ °

BUOYANT SURFACE DISCHARGE -- CORMIX3
Discharge located on   ~~left~~/right bank   Configuration flush/~~protruding/co-flowing~~
Horizontal angle SIGMA   90 °   If protruding: Dist. from bank   - m
Depth at discharge   2.15 m   Bottom slope   11 °
If rectangular Width   2.0 m or: If circular Diameter   - m
discharge channel: Depth   0.65 m   pipe: Bottom invert depth   - m

Effluent: Flow rate   2.20 m³/s or: Effluent velocity   - m/s
Effluent density   - kg/m³ or: Effluent temperature fresh 22.0 °C
Heated discharge?   ~~yes~~/no   If yes: Heat loss coefficient   - W/m²,°C
Concentration units   mug-p-L   Effluent concentration   80
Conservative substance?   yes/~~no~~   If no: Decay coefficient   - /day

MIXING ZONE DATA:
Is effluent toxic?   yes/~~no~~   If yes: CMC   25   CCC   15
WQ stand./conventional poll.?   ~~yes~~/no   If yes: value of standard   -
Any mixing zone specified?   yes/~~no~~   If yes: distance 250 m or width   - % or m
    or area   - % or m²

Region of interest   2000 m   Grid intervals for display   10

Figure D.5: Data preparation checklist for C-Plant discharge into Estuary design case for unsteady tidal conditions using CORMIX3

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM

SITE NAME/LABEL:            C-PLANT ESTUARY
  DESIGN CASE:              TIDAL SIMULATION ONE HOUR AFTER SLACK
  FILE NAME:                SAMPLE3T
Using subsystem CORMIX3:    Buoyant Surface Discharges
  Start of session:         06/24/95--22:33:33
****************************************************************************
SUMMARY OF INPUT DATA:
----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                      = unbounded
  Average depth             HA       =          5.65 m
  Depth at discharge        HD       =          5.65 m
  Darcy-Weisbach friction factor  F  =          .025
  Wind velocity             UW       =             2 m/s
TIDAL SIMULATION at time    Tsim     =             1 hours
  Instantaneous ambient velocity  UA =           .22 m/s
  Maximum tidal velocity    UaMAX    =           .75 m/s
  Rate of tidal reversal    dUA/dt   =        0.2200 (m/s)/hour
  Period of reversal        T        =          12.4 hours
Stratification Type         STRCND = U
  Surface density           RHOAS    =          1018 kg/m^3
  Bottom density            RHOAB    =          1018 kg/m^3
----------------------------------------------------------------------------
DISCHARGE PARAMETERS:        Buoyant Surface Discharge
  Discharge located on               = right bank/shoreline
  Discharge configuration            = flush discharge
  Distance from bank to outlet  DISTB =         0.0 m
  Discharge angle           SIGMA    =            90 deg
  Depth near discharge outlet  HD0   =          2.15 m
  Bottom slope at discharge SLOPE    =            11 deg
  Rectangular discharge:
    Discharge cross-section area  A0 =        1.3000 m^2
    Discharge channel width   B0     =             2 m
    Discharge channel depth   H0     =           .65 m
    Discharge aspect ratio    AR     =          0.32
  Discharge flowrate        Q0       =      2.199990 m^3/s
  Discharge velocity        U0       =          1.69 m/s
  Discharge temperature (freshwater) =            20 degC
    Corresponding density   RHO0     =      998.2051 kg/m^3
  Density difference        DRHO     =       19.7948 kg/m^3
  Buoyant acceleration      GP0      =         .1907 m/s^2
  Discharge concentration   C0       =            80 MUG-P-L
  Surface heat exchange coeff.  KS   =             0 m/s
  Coefficient of decay      KD       =             0 /s
----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES:
  LQ   =       1.14 m       Lm   =     8.77 m       Lb   =      39.39 m
  LM   =       4.13 m
UNSTEADY TIDAL SCALES:
  Tu   =     0.2228 hours   Lu   =    39.34 m       Lmin=       2.57 m
----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Densimetric Froude number    FR0   =       3.62 (based on LQ)
  Channel densimetric Froude no.  FRCH =     4.80 (based on H0)
  Velocity ratio               R     =       7.69
----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                    = yes
  CMC concentration         CMC      =            25 MUG-P-L
  CCC concentration         CCC      =            15 MUG-P-L
  Water quality standard             = given by CCC value
  Regulatory mixing zone             = yes
  Regulatory mixing zone specification  = distance
  Regulatory mixing zone value       =           250 m (m^2 if area)
  Region of interest                 =       3500.00 m
****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
    *------------------------*
    | FLOW CLASS   =    FJ1 |
    *------------------------*
****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at water surface and at centerline of discharge channel:
           0.0 m from the right bank/shore.
  Number of display steps NSTEP = 20 per module.
```

```
----------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          .0000 MUG-P-L
  Dilution at edge of NFR             =        .0
  NFR Location:                    x =        .00 m
    (centerline coordinates)       y =        .00 m
                                   z =        .00 m
  NFR plume dimensions:    half-width =        .00 m
                           thickness =        .00 m
----------------------------------------------------------------------
UNSTEADY TIDAL ASSESSMENT:
  Because of the unsteadiness of the ambient current during the tidal
  reversal, CORMIX predictions have been TERMINATED at:
                                   x =     282.05 m
                                   y =     187.66 m
                                   z =        .00 m
  For this condition AFTER TIDAL REVERSAL, mixed water from the previous
  half-cycle becomes re-entrained into the near field of the discharge,
  increasing pollutant concentrations compared to steady-state predictions.
  A pool of mixed water formed at slack tide will be advected downstream
  in this phase.
************************ TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC) =          25 MUG-P-L
  Corresponding dilution              =       3.2
The CMC was encountered at the following plume position:
  Plume location:                  x =       1.04 m
    (centerline coordinates)       y =      12.05 m
                                   z =        .00 m
  Plume dimensions:        half-width =       9.41 m
                           thickness =        .56 m
  CRITERION 1: This location is within 50 times the discharge length scale of
            Lq =      1.14 m.
  +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

  CRITERION 2: This location is within 5 times the ambient water depth of
            HD =        5.65 m.
  ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

  CRITERION 3: This location is within one tenth the distance of the extent
            of the Regulatory Mixing Zone of      250.00 m downstream.
  +++++ The Regulatory Mixing Zone TEST for the TDZ has been SATISFIED. ++++++

  The diffuser discharge velocity is equal to         1.69 m/s.
    This is below the value of 3.0 m/s recommended in the TSD.

  *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
************************ REGULATORY MIXING ZONE SUMMARY ************************
The plume conditions at the boundary of the specified RMZ are as follows:
  Pollutant concentration             =       17.960500 MUG-P-L
  Corresponding dilution              =       4.4
  Plume location:                  x =     250.00 m
    (centerline coordinates)       y =     176.10 m
                                   z =        .00 m
  Plume dimensions:        half-width =      95.88 m
                           thickness =        .21 m
At this position, the plume is NOT IN CONTACT with any bank.
However, the CCC for the toxic pollutant has not been met within the RMZ.
  In particular:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                 =          15 MUG-P-L
  Corresponding dilution              =       5.3
  Plume location:                  x =       6.02 m
    (centerline coordinates)       y =      37.32 m
                                   z =        .00 m
  Plume dimensions:        half-width =      31.48 m
                           thickness =        .30 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
  plume geometries) are reliable for the majority of cases and are accurate
  to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges
  the design configuration as highly complex and uncertain for prediction.
****************************************************************************
DESIGN CASE:                 TIDAL SIMULATION ONE HOUR AFTER SLACK
FILE NAME:                   SAMPLE3T
Subsystem CORMIX3:           Buoyant Surface Discharges
END OF SESSION/ITERATION:    04/14/96--11:24:13
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

Table D.3
CORMIX3 Prediction File for C-Plant discharge into Estuary with unsteady tidal conditions

```
CORMIX3 PREDICTION FILE:
3333333333333333333333333333333333333333333333333333333333333333333333333333333
                       CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                        Subsystem version:
 Buoyant Surface Discharges                   CORMIX_v.3.10_____June_1995
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         C-PLANT^ESTUARY
 Design case:             TIDAL^SIMULATION^ONE^HOUR^AFTER^SLACK
 FILE NAME:               cormix\sim\SAMPLE3T.cx3
 Time of Fortran run:     06/24/95--22:34:03

ENVIRONMENT PARAMETERS (metric units)
 Unbounded section
 HA    =      5.65  HD   =      5.65
 Tidal Simulation at TIME =      1.000 h
 PERIOD=   12.40 h UAmax =       .750 dUa/dt=       .220 (m/s)/h
 UA    =       .220 F     =       .025 USTAR = .1230E-01
 UW    =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND= U         RHOAM = 1018.0000

DISCHARGE PARAMETERS (metric units)
 BANK  = RIGHT     DISTB =      .00  Configuration: flush_discharge
 SIGMA =     90.00 HD0   =     2.15  SLOPE =    11.00
 Rectangular channel geometry:
 B0    =     2.000 H0    =      .650 A0   = .1300E+01  AR    =      .325
 U0    =     1.692 Q0    =     2.200      = .2200E+01
 RHO0  = 998.2051  DRHO0 = .1979E+02 GP0  = .1907E+00
 C0    = .8000E+02 CUNITS=  MUG-P-L
 IPOLL = 1         KS    = .0000E+00 KD   = .0000E+00

FLUX VARIABLES (metric units)
 Q0    = .2200E+01 M0    = .3723E+01 J0   = .4195E+00
 Associated length scales (meters)
 LQ    =      1.14 LM    =      4.14 Lm   =      8.77 Lb   =     39.40
 Tidal:            Tu    =    .2229 h Lu   =     39.347 Lmin =      2.573

NON-DIMENSIONAL PARAMETERS
 FR0   =      3.62 FRCH  =      4.80 R    =      7.69

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)     =    FJ1    3
 3  Applicable layer depth HS =     5.65  3
 333333333333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    = .8000E+02 CUNITS=  MUG-P-L
 NTOX  = 1         CMC   = .2500E+02 CCC  = CSTD
 NSTD  = 1         CSTD  = .1500E+02
 REGMZ = 1
 REGSPC= 1         XREG  =    250.00 WREG  =       .00 AREG =        .00
 XINT  =   2500.00 XMAX  =   3500.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:      .00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 20 display intervals per module
--------------------------------------------------------------------------------
      TRJBUO    TRJATT    TRJBND    TRJNBY    TRJCOR    DILCOR
C      3.401     1.000     1.000     1.000     3.400     1.000
--------------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE

 Efflux conditions:
      X         Y         Z         S         C        BV        BH
      .00       .00      0.00       1.0    .800E+02     .65      1.00
```

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```
END OF MOD301: DISCHARGE MODULE
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD302: ZONE OF FLOW ESTABLISHMENT

  Control volume inflow:
       X        Y        Z        S        C        BV       BH
      .00      .00     0.00      1.0   .800E+02     .65     1.00

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

  Control volume outflow:
       X        Y        Z        S        C        BV       BH
      .13     4.11     0.00      1.4   .586E+02    1.09     1.41
 Cumulative travel time =          2. sec

END OF MOD302: ZONE OF FLOW ESTABLISHMENT
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD311: WEAKLY DEFLECTED JET (3-D)

 Surface JET into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .13     4.11     0.00      1.4   .586E+02    1.28     1.65
      .13     4.14     0.00      1.4   .585E+02    1.28     1.66
      .13     4.16     0.00      1.4   .584E+02    1.28     1.66
      .13     4.18     0.00      1.4   .583E+02    1.28     1.66
      .13     4.20     0.00      1.4   .582E+02    1.29     1.66
      .14     4.23     0.00      1.4   .581E+02    1.29     1.67
      .14     4.25     0.00      1.4   .580E+02    1.29     1.67
      .14     4.27     0.00      1.4   .580E+02    1.29     1.67
      .14     4.29     0.00      1.4   .579E+02    1.30     1.67
      .15     4.32     0.00      1.4   .578E+02    1.30     1.68
      .15     4.34     0.00      1.4   .577E+02    1.30     1.68
      .15     4.36     0.00      1.4   .576E+02    1.30     1.68
      .15     4.38     0.00      1.4   .575E+02    1.30     1.68
      .15     4.41     0.00      1.4   .574E+02    1.31     1.69
      .16     4.43     0.00      1.4   .573E+02    1.31     1.69
      .16     4.45     0.00      1.4   .572E+02    1.31     1.69
      .16     4.47     0.00      1.4   .571E+02    1.31     1.69
      .16     4.50     0.00      1.4   .571E+02    1.32     1.70
      .17     4.52     0.00      1.4   .570E+02    1.32     1.70
      .17     4.54     0.00      1.4   .569E+02    1.32     1.70
      .17     4.56     0.00      1.4   .568E+02    1.32     1.70
 Cumulative travel time =          3. sec

END OF MOD311: WEAKLY DEFLECTED JET (3-D)
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
BEGIN MOD313: WEAKLY DEFLECTED PLUME

 Surface PLUME into a crossflow

 Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .17     4.56     0.00      1.4   .568E+02    1.32     1.70
      .41     6.86     0.00      2.3   .354E+02     .82     4.48
      .67     9.16     0.00      2.8   .291E+02     .66     6.76
      .96    11.46     0.00      3.1   .256E+02     .58     8.88
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .250E+02
```

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```
        in the current prediction interval.
     This is the extent of the TOXIC DILUTION ZONE.
         1.28    13.76    0.00     3.4  .233E+02    .52   10.93
         1.62    16.05    0.00     3.7  .216E+02    .48   12.95
         1.99    18.35    0.00     3.9  .203E+02    .45   14.94
         2.38    20.65    0.00     4.2  .192E+02    .42   16.93
         2.80    22.95    0.00     4.4  .184E+02    .40   18.92
         3.25    25.25    0.00     4.5  .176E+02    .38   20.91
         3.72    27.54    0.00     4.7  .170E+02    .36   22.90
         4.22    29.84    0.00     4.9  .164E+02    .35   24.90
         4.75    32.14    0.00     5.0  .159E+02    .33   26.92
         5.30    34.44    0.00     5.2  .155E+02    .32   28.93
         5.87    36.74    0.00     5.3  .151E+02    .31   30.96
     ** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
     The pollutant concentration in the plume falls below water quality standard
        or CCC value of  .150E+02 in the current prediction interval.
     This is the spatial extent of concentrations exceeding the water quality
        standard or CCC value.
         6.48    39.03    0.00     5.4  .147E+02    .30   33.00
         7.11    41.33    0.00     5.6  .144E+02    .29   35.05
         7.76    43.63    0.00     5.7  .141E+02    .28   37.11
         8.44    45.93    0.00     5.8  .138E+02    .28   39.18
         9.15    48.23    0.00     5.9  .136E+02    .27   41.25
         9.88    50.52    0.00     6.0  .134E+02    .26   43.34
     Cumulative travel time =        248. sec

     END OF MOD313: WEAKLY DEFLECTED PLUME
     -------------------------------------------------------------------------------
     -------------------------------------------------------------------------------
     BEGIN MOD323: STRONGLY DEFLECTED PLUME

      Profile definitions:
        BV = top-hat thickness,measured vertically
        BH = top-hat half-width, measured horizontally in Y-direction
        S  = hydrodynamic average (bulk) dilution
        C  = average (bulk) concentration (includes reaction effects, if any)

          X        Y        Z        S        C        BV       BH
         9.88    50.52    0.00     6.0  .134E+02    .26   43.34
        84.15   123.86    0.00     4.9  .163E+02    .23   60.96
       158.42   154.39    0.00     4.6  .174E+02    .22   77.07
       232.69   176.11    0.00     4.5  .178E+02    .22   92.39
     ** REGULATORY MIXING ZONE BOUNDARY **
     In this prediction interval the plume distance meets or exceeds
        the regulatory value =   250.00 m.
     This is the extent of the REGULATORY MIXING ZONE.
       282.05   187.67    0.00     4.5  .177E+02    .22  102.26
     Cumulative travel time =       1485. sec

      CORMIX prediction has been TERMINATED at last prediction interval.
        Limiting distance due to TIDAL REVERSAL has been reached.

     END OF MOD323: STRONGLY DEFLECTED PLUME
     -------------------------------------------------------------------------------
     -------------------------------------------------------------------------------
     CORMIX3: Buoyant Surface Discharges                  End of Prediction File
     33333333333333333333333333333333333333333333333333333333333333333333333333333
```

The results of the tidal simulations are shown graphically in Figure D.6. The most obvious difference in the tidal CORMIX prediction at this time is that the maximum predicted downstream distance is limited to 275 m in the x-direction. Furthermore, a significant increase in the pollutant concentration (copper) is observed at the edge of the RMZ (compare Figure D.4b and D.6b at a distance of 250 m downstream) in the tidal application as a result of tidal re-entrainment. As a result, the copper concentration at the RMZ is 18 μg/L as opposed to 10 μg/L for the steady state simulation, which exceeds the CCC at this distance.

Plan View

(a)

Concentration vs Centerline Distance

(b)

Figure D.6:   CORMIX3 prediction of surface discharge from C-Plant into Estuary using a unsteady tidal simulation. a) Plume shape in near-field only (prediction is terminated after this region), and b) concentration along plume centerline.

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Appendix E
Two Applications of CORJET

Two case studies are presented here illustrating the application of the post-processing model included within CORMIX, namely CORJET, the Cornell buoyant jet integral model. As discussed in Section 6.1 is an important tool for predicting additional details within the near-field of a submerged discharge. Both case studies are included in the normal CORMIX installation package.

It is repeated here that CORJET, as any jet integral model, if used alone and by an inexperienced analyst, is **not a safe methodology for mixing zone analysis**. It is advised to use it only in conjunction with the more comprehensive CORMIX system. Therefore, in case of engineering design applications, **CORJET should be employed after prior use of the expert system CORMIX has indicated that the buoyant jet will not experience any instabilities due to shallow water or due to attachment to boundaries**.

E.1 Submerged multiport diffuser in deep water

A short diffuser consisting of 11 ports and a total length of 20 m is discharging fresh water at a temperature of 30 $^{\circ}$C into the stratified coastal ocean. The diffuser ports are each 0.5 m in diameter and well-rounded in their internal hydraulic design so that no further exit flow contraction will occur. The nozzles are oriented with a vertical angle of 45 $^{\circ}$ upward and a horizontal angle of 45 $^{\circ}$ pointing into the ambient crossflow (see multiport diffuser definition diagram, Figures 4.6 and 4.7). The diffuser has an alignment of 60 $^{\circ}$ with respect to the ambient current. The discharge flow has a concentration of 100 % of some conservative substance.

Detailed measurements in the water column give the distribution of temperature, salinity and current velocity as a function of vertical distance. The current at each level flows in the same direction, i.e. along the coastline. The water depth at the discharge location is of the order of 30 m.

The CORJET data preparation checklist for this design case is given as Figure E.1. Density data is specified in this case via temperature and salinity. The program computes internally the actual density distribution using the full (UNESCO) equation of state. It should be noted that in case of multiple ambient levels CORJET assumes outside the specified range (e.g. above 15 m in this case) that the data are linearly continued from the last specified interval. If uniform ambient conditions exist only a single level must be specified.

The port height H0 in the input data specification is set to 0.0 m; thus, the coordinate system is conveniently set at the discharge height. Another value for the actual height above the water bottom could be used too, but remember that CORJET, as all integral models, does not compute actual bottom interaction effects (see Section 6.1.1). A maximum computation height of 30 m and distance of 200 m is specified to stop the computation. The number of print intervals is set to 10, in order to provide sufficient detail.

A prior application of CORMIX (using a linear density approximation Type A) has shown that a stable multiport diffuser flow class MS results for this case. The reader is encouraged to ascertain that! Thus, CORJET is indeed applicable for this case.

Table E.1 shows the input data file as prepared externally using a line editor. The CORJET prediction file is shown in Table E.2. The file echoes the input data, but also lists the computed density values, and all important parameters and non-dimensional numbers. Note that all parameters and scales are referenced to the values of ambient conditions <u>at the level of discharge</u>. The second half of the output table gives the predicted plume conditions.

CHECKLIST FOR DATA PREPARATION

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.1

DOS File Name: CASE5MPD.INP   **Date:** 4/12/96   **Prepared by:** GHJ

Label: Case 5: MULTIPORT DIFFUSER, STRATIFIED, VARIABLE CURRENT

Fluid/Density:

Fluid: 1 (water)   Density specification: 1 (via temp./sal.)   Number of ambient levels: 3
2 (air)   2 (direct)   (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m³)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	30.0	-	0.5	0
2	5	15.0	29.5	-	0.8	0
3	15	20.0	28.0	-	1.2	0

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
11	0.5	0.0	3.0	45.0	45.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m³)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0	30.0	0.0	-	20.0	60.

Program Control:

Max. vertical distance (m): 30.0   Min. vertical distance (m): 0.0   Max. distance along trajectory (m): 200.0   Print intervals: (best 5 to 10) 10

Figure E.1: Data preparation checklist for CORJET simulation of multiport diffuser discharge into stratified coastal waters with arbitrary velocity distribution

Table E.1
CORJET input data file for multiport diffuser discharge into stratified coastal waters

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case5: MUL  ▱  RT DIFFUSER: STRATIFIED, VARIABLE CURRENT
#Fluid (1=  ▱ r,2=air), Density option (1=calculate,2=specify directly):
#Fluid (½):   Density option (½):   Ambient levels (1-10):
1             1                      3
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA    TA    SA     RHOA    UA    TAUA
1      0.    12.   30.            0.5   0.
2      5.    15.   29.5           0.8   0.
3      15.   20.   28.            1.2   0.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0   H0    U0    THETA0 SIGMA0 C0    KD   T0    S0   RHO0   LD    ALIGN
11     0.5  0.    3.0   45.    45.    100.  0.   30.   0.          20.   60.
#Program control:
#ZMAX   ZMIN  DISMAX NPRINT
30.     0.    200.   10
```

Table E.2
CORJET prediction file for multiport diffuser discharge into stratified coastal waters

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL           Version 4.1, April 1996
---------------------------------------------------------------------------
FILE NAME:            post\cj\case5mpd.OUT
 Label/identifier:    Case5: MULTIPORT DIFFUSER: STRATIFIED, VARIABLE CU
 Time of CORJET run:   4/13/96--15:56:58

Ambient conditions:     No. of levels: 3   Fluid: Water   Density option: 1
   LEV     ZA      TA      SA    RHOA     UA    TAUA
    1      .00   12.00   30.00 1022.71    .50     .00
    2     5.00   15.00   29.50 1021.74    .80     .00
    3    15.00   20.00   28.00 1019.43   1.20     .00

Discharge conditions (metric): For each port:
   D0      H0      U0   THETA0 SIGMA0    C0       KD      T0     S0     RHO0
   .500    .00    3.00   45.00  45.00 .10E+03  .00E+0   30.0     .0   995.65
 MULTIPORT DIFFUSER conditions:
   NOPEN    LD     SPAC   ALIGN   Q0total
     11   20.00    2.00   60.00    6.480 = .6480E+01

Program control:
   ZMAX    ZMIN   DISMAX   NPRINT
   30.00    .00  200.00       10

Flux variables (based on ambient at discharge level):   For each port:
 Q0   = .589E+00  M0   = .177E+01  J0   = .153E+00  GP0  = .259E+00
 QT0  = .106E+02  QS0  = -.177E+02
 For multiport diffuser (per unit length):
 q0   = .324E+00  m0   = .972E+00  j0   = .841E-01

Length scales (m) and parameters:   For each port:
 LQ   =      .44  LM   =    3.92  Lm   =    2.66  Lb   =     1.22
 Lmp  =     5.61  Lbp  =    6.71
 For multiport diffuser (per unit length):
 lQ=B =     .108  lM   =    5.07  lm   =    3.89  lq*  =      .74
 lmp  =     8.16  lbp  =   10.37
 FR0  =     8.33  FR02 =   17.92  Fa   =    1.14  R    =     6.00
 (port)          (2-D slot)
Zone of flow establishment (m):
 LE   =     1.30  XE   =     .75  YE   =      .62  ZE   =      .86
 THETAE=    38.34 SIGMAE=   34.00 GAMMAE=    49.43


---------------------------------------------------------------------------
CORJET PREDICTION:              Stepsize =   .2659  Printout every  10 steps
 Individual jet/plumes before merging:
    X      Y      Z     Sc     Cc      B |  DIST   Save    Gpc  dTc dSALc
   .00    .00    .00   1.0  .100E+03   .25|   .00   1.0  .26E+00 18.0-30.0
   .75    .62    .86   1.0  .100E+03   .25|  1.30   1.4  .27E+00 20.8-34.7
  2.80   1.50   2.27   3.0  .333E+02   .64|  3.96   4.6  .83E-01  5.2 -9.9
 Merging of individual jet/plumes to form plane jet/plume:
```

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```
Horizontal jet/plume half-width BH = B +  10.00
  4.26  1.78  2.85   4.5  .223E+02   .82|   5.55   6.6  .54E-01   3.1 -6.5
  5.31  1.84  3.01   6.3  .159E+02   .90|   6.62   6.4  .38E-01   2.1 -4.7
  7.96  1.88  3.22   7.4  .136E+02  1.09|   9.27   7.5  .32E-01   1.6 -3.9
 10.61  1.89  3.41   8.4  .118E+02  1.27|  11.93   8.6  .28E-01   1.3 -3.4
 13.26  1.89  3.59   9.5  .105E+02  1.45|  14.59   9.7  .24E-01   1.1 -3.0
 15.91  1.89  3.77  10.6  .940E+01  1.63|  17.25  10.7  .21E-01    .8 -2.7
 18.57  1.89  3.94  11.7  .852E+01  1.81|  19.91  11.8  .19E-01    .6 -2.4
 21.22  1.89  4.11  12.8  .779E+01  1.99|  22.57  12.9  .17E-01    .5 -2.2
 23.88  1.89  4.27  13.9  .717E+01  2.17|  25.23  14.0  .15E-01    .3 -2.0
 26.53  1.89  4.43  15.1  .664E+01  2.34|  27.89  15.1  .14E-01    .2 -1.8
 29.18  1.89  4.58  16.2  .619E+01  2.51|  30.54  16.1  .13E-01    .1 -1.7
 31.84  1.89  4.73  17.2  .580E+01  2.68|  33.20  17.2  .12E-01    .0 -1.6
 34.49  1.89  4.87  18.3  .545E+01  2.85|  35.86  18.2  .11E-01   -.1 -1.5
 37.15  1.89  5.01  19.4  .515E+01  3.02|  38.52  19.3  .97E-02   -.2 -1.4
 39.80  1.89  5.15  20.5  .488E+01  3.18|  41.18  20.3  .89E-02   -.2 -1.3
 42.46  1.89  5.28  21.5  .464E+01  3.34|  43.84  21.4  .82E-02   -.3 -1.2
 45.11  1.89  5.41  22.6  .443E+01  3.49|  46.50  22.4  .75E-02   -.3 -1.1
 47.77  1.89  5.53  23.6  .424E+01  3.64|  49.15  23.4  .69E-02   -.4 -1.0
 50.43  1.89  5.65  24.6  .407E+01  3.79|  51.81  24.3  .63E-02   -.4 -1.0
 53.08  1.89  5.77  25.6  .391E+01  3.94|  54.47  25.3  .58E-02   -.5  -.9
 55.74  1.89  5.88  26.5  .377E+01  4.08|  57.13  26.2  .54E-02   -.5  -.9
 58.39  1.89  5.99  27.5  .364E+01  4.22|  59.79  27.1  .49E-02   -.6  -.8
 61.05  1.89  6.09  28.4  .352E+01  4.35|  62.45  28.0  .45E-02   -.6  -.8
 63.71  1.89  6.20  29.3  .342E+01  4.48|  65.11  28.9  .42E-02   -.6  -.7
 66.36  1.89  6.29  30.1  .332E+01  4.61|  67.77  29.7  .38E-02   -.7  -.7
 69.02  1.89  6.39  31.0  .323E+01  4.73|  70.42  30.5  .35E-02   -.7  -.7
 71.68  1.89  6.48  31.8  .315E+01  4.85|  73.08  31.3  .32E-02   -.7  -.6
 74.34  1.89  6.57  32.6  .307E+01  4.96|  75.74  32.1  .29E-02   -.8  -.6
 76.99  1.89  6.65  33.3  .300E+01  5.07|  78.40  32.8  .27E-02   -.8  -.6
 79.65  1.89  6.74  34.1  .293E+01  5.17|  81.06  33.5  .24E-02   -.8  -.6
 82.31  1.89  6.81  34.8  .287E+01  5.27|  83.72  34.2  .22E-02   -.9  -.5
 84.97  1.89  6.89  35.5  .282E+01  5.37|  86.38  34.9  .20E-02   -.9  -.5
 87.62  1.89  6.96  36.1  .277E+01  5.46|  89.03  35.5  .18E-02   -.9  -.5
 90.28  1.89  7.03  36.7  .272E+01  5.54|  91.69  36.1  .16E-02   -.9  -.5
 92.94  1.89  7.09  37.3  .268E+01  5.62|  94.35  36.6  .14E-02   -.9  -.5
 95.60  1.89  7.16  37.8  .264E+01  5.70|  97.01  37.1  .12E-02  -1.0  -.4
 98.26  1.89  7.22  38.3  .261E+01  5.77|  99.67  37.6  .11E-02  -1.0  -.4
100.91  1.89  7.27  38.8  .258E+01  5.83| 102.33  38.1  .93E-03  -1.0  -.4
103.57  1.89  7.33  39.2  .255E+01  5.89| 104.99  38.5  .80E-03  -1.0  -.4
106.23  1.89  7.38  39.6  .252E+01  5.95| 107.65  38.9  .67E-03  -1.0  -.4
108.89  1.89  7.43  40.0  .250E+01  6.00| 110.30  39.2  .56E-03  -1.1  -.4
111.55  1.89  7.47  40.3  .248E+01  6.04| 112.96  39.5  .45E-03  -1.1  -.4
114.20  1.89  7.51  40.6  .246E+01  6.08| 115.62  39.8  .35E-03  -1.1  -.4
116.86  1.89  7.55  40.8  .245E+01  6.11| 118.28  40.0  .26E-03  -1.1  -.3
119.52  1.89  7.59  41.0  .244E+01  6.13| 120.94  40.2  .17E-03  -1.1  -.3
122.18  1.89  7.62  41.1  .243E+01  6.15| 123.60  40.3  .94E-04  -1.1  -.3
124.84  1.89  7.65  41.2  .243E+01  6.16| 126.26  40.3  .23E-04  -1.1  -.3
125.90  1.89  7.66  41.2  .243E+01  6.15| 127.32  40.3 -.35E-05  -1.1  -.3
Terminal level in stratified ambient has been reached.    PROGRAM STOPS!
--------------------------------------------------------------------------
END OF CORJET PREDICTION:      Total number of integration steps =    475
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
Note: CORJET has been used outside the CORMIX system, assuming unlimited
      receiving water.  Carefully examine all results for possible boundary
      effects due to surface, bottom, or lateral boundaries!
```

The CORJET program when called within the normal CORMIX installation after its execution automatically links to the graphics package CMXGRAPH so the user can inspect the predicted plume, rather than looking at the output file. Many graphics options (see Section 5.3) exist to fully evaluate the plume geometry and concentration distributions. Three examples of graphics output are shown in Figures E.2 and E.3.

Figure E.2 shows the plan view, side view, and side view along the trajectory, respectively, of the plume, all with a plot scale fixed to 1:1, i.e. undistorted. All these figures have been produced with the Postscript-file print option (I) of CMXGRAPH (in contrast to all the figures in Appendices B to D that were made with the screen print (C) option). Such an undistorted is always preferable for the viewer of such plots in order to get an unbiased picture of the mixing pattern. Note the merging of the individual jets in the plan view. Figure E.3 gives the concentration distribution along the plume centerline trajectory, showing the rapid drop-off in this jet mixing process.

E.2 Smoke plume in stratified atmosphere with skewed wind velocity

As mentioned in Section 6.1 CORJET is also applicable for atmospheric conditions in which case the concept of potential density based on the perfect gas equation with adiabatic conditions is employed. Furthermore, the wind conditions in the lower atmospheric boundary layer with its greater freedom laterally often has a skewed velocity distribution with different wind directions at different levels above the ground. This is the topic of this case study.

An industrial chimney with a height of 40 m above ground discharges hot gases at a temperature of 200 ^{o}C into the atmosphere. The discharge has a diameter of 3 m and an exit velocity of 10 m/s. A discharge concentration of 100 % exists for a fairly rapidly decaying substance with a decay rate of 1 per 10 min or 0.0028 /s.

Typical measurements, for example using a tracked rising balloon, give the distribution of temperature and wind velocity as a function of height above the ground. This is shown in the CORJET data preparation checklist given as Figure E.4. Density data is specified in this case as air temperature, the program will convert density inputs internally to potential density as a function of temperature. The wind velocity vector with increasing height deviates increasingly from the direction at ground level. In this example the coordinate system has been set at ground level so that the chimney (i.e. "port") height is equal to 40 m.

Table E.3 shows the input data file for this case, while Table E.4 is the CORJET prediction file. The file echoes the input data, but also lists the potential density values, and all important parameters and non-dimensional numbers.

Predicted plume properties are shown graphically as Figures E.5 and E.6. Figure E.5 shows the plan view and the side view, respectively, of the plume, both with a plot scale fixed to 1:1, i.e. undistorted. The plan view shows that the plume follows the variable direction of the wind as it rises to higher levels.

Figure E.6 gives the concentration distribution along the plume centerline trajectory. The added effect of plume decay would be discernible only in the detailed output file (Table E.4) where the centerline concentration is not merely the inverse of the hydrodynamic centerline dilution (the effect of pure mixing) but lower because of the internal chemical decay effect.
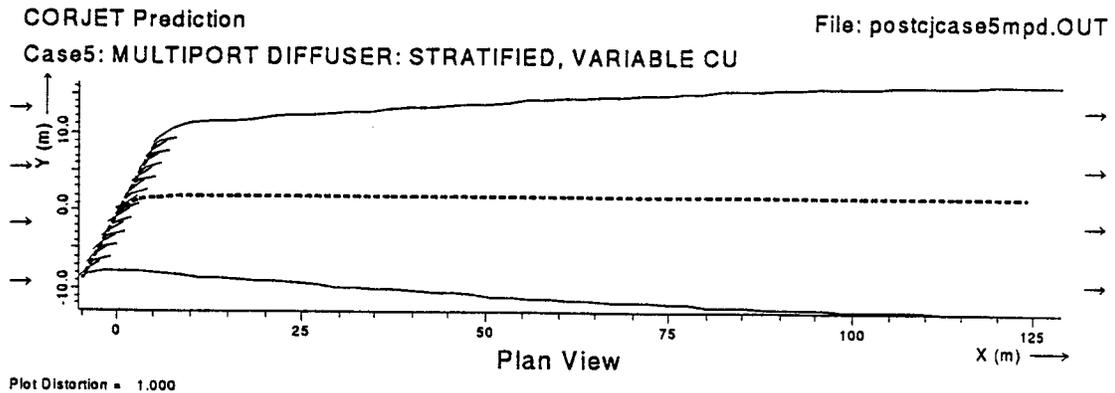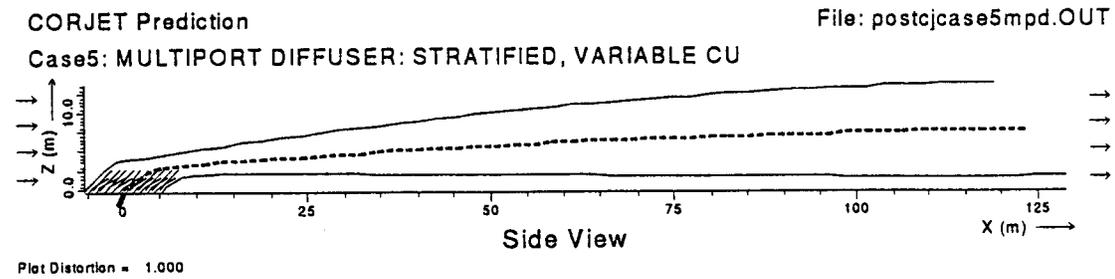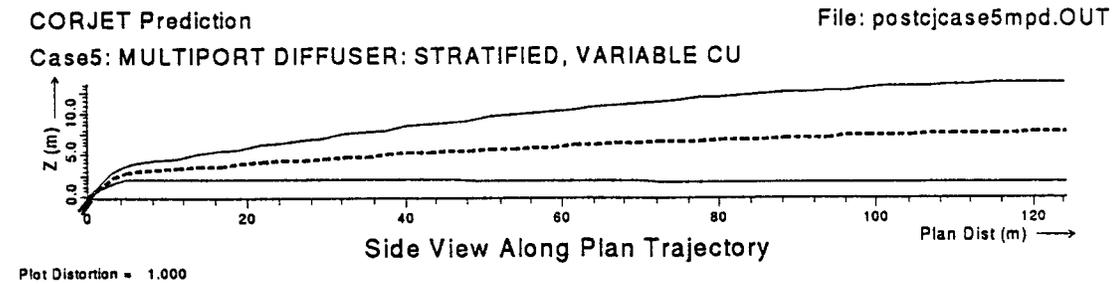
Figure E.2: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. a) Plan view, b) side view, and c) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

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Concentration vs Centerline Distance
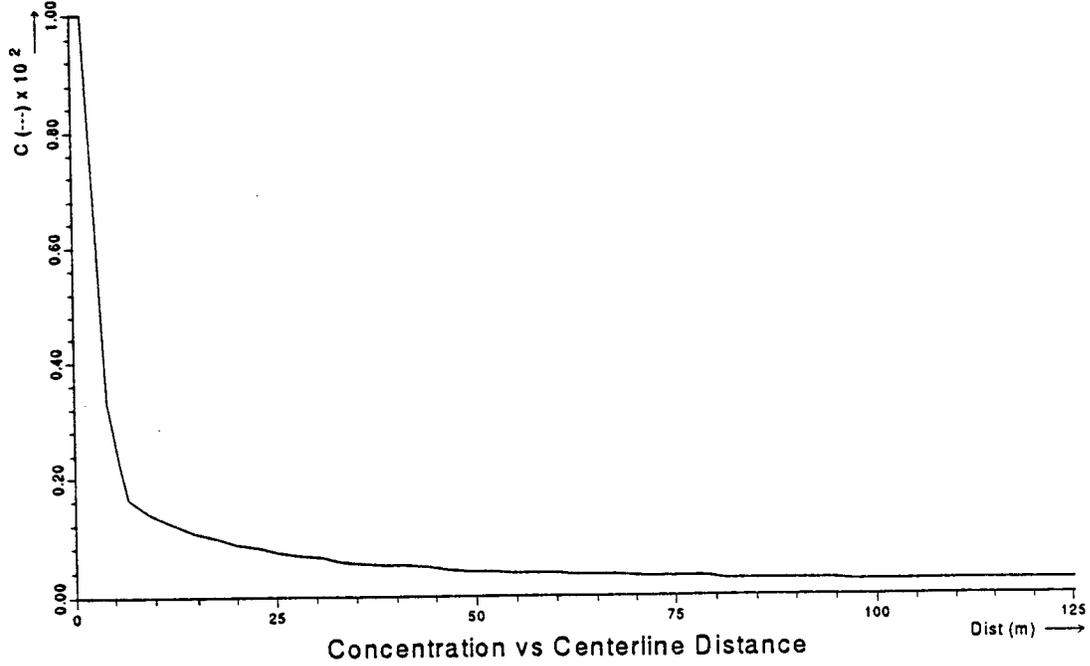
Figure E.3: CORJET prediction for multiport diffuser discharge into stratified coastal waters as plotted with graphics package. Concentration along centerline trajectory.

CORJET -- CORNELL BUOYANT JET INTEGRAL MODEL-- Version 4.1

DOS File Name: CASE3AIR.INP	Date: 4/12/96
	Prepared by: GHJ

Label: Case 3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND

Fluid/Density:

Fluid: xx(water)x   Density specification: 1 (via temp./sal.)   Number of ambient levels: 4
2 (air)   2x(direct)   (1 to 10)

Ambient Data:

Level No.	Elevation (m)	Temperature (°C)	Salinity (ppt)	Density (kg/m³)	Velocity (m/s)	Angle of velocity (deg)
1	0	12.0	-	-	2.0	0
2	50	12.0	-	-	5.0	15
3	100	12.5	-	-	6.0	25
4	200	13.0	-	-	6.5	30

Discharge Conditions:

Number of openings: (=1 for single port s.p.)	Port diameter (m)	Height above origin (m)	Exit velocity (m/s)	Vertical angle (deg)	Horizontal angle (deg)
1	3.0	40.0	10.0	90.0	0.0

Discharge conc. (any units)	Coefficient of decay (/s)	Discharge temp. (°C)	Discharge salinity (ppt)	Discharge density (kg/m³)	Diffuser length (m) (= 0. if s.p.)	Alignment angle (deg) (= 0. if s.p.)
100	0.0028	200.	-	-	0.0	0.0

Program Control:

Max. vertical distance (m): 200	Min. vertical distance (m): 0	Max. distance along trajectory (m): 1000	Print intervals: 30 (best 5 to 10)

Figure E.4: Data preparation checklist for CORJET simulation of chimney discharge into stratified atmosphere with skewed wind velocity distribution

Table E.3
CORJET input data file for chimney discharge into stratified atmosphere
with skewed wind

```
#CORJET INPUT FILE
#Title line (50 characters max.):
Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
#Fluid (1=water,2=air), Density option (1=calculate,2=specify directly):
#Fluid (1/2):   Density option (1/2):   Ambient levels (1-10):
2             1                       4
#Ambient conditions (if d.o.=1, fill in TA+SA; if 2, fill in RHOA):
#Level ZA     TA     SA    RHOA    UA    TAUA
1      0.     12.0                 2.0   0.
2      50.    12.0                 5.0   15.
3      100.   12.5                 6.0   25
4      200.   13.0                 6.5   30.
#Discharge conditions (T0+S0, or RHO0 as above; if NOPEN=1: set LD=0,ALIGN=0):
#NOPEN D0   H0   U0    THETA0 SIGMA0 C0    KD    T0    S0   RHO0   LD   ALIGN
1      3.0  40.  10.0  90.    0.     100.  .0028 200.            0.   0.
#Program control:
#ZMAX   ZMIN   DISMAX NPRINT
200.    0.     1000.  30
```

Table E.4
CORJET prediction file for chimney discharge into stratified atmosphere
with skewed wind

```
CORJET PREDICTION FILE:
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
CORJET:  CORNELL BUOYANT JET INTEGRAL MODEL          Version 4.1, April 1996
-------------------------------------------------------------------------------
FILE NAME:              post\cj\case3air.OUT
 Label/identifier:      Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND
 Time of CORJET run:      4/13/96--16:12:15

Ambient conditions:     No. of levels: 4   Fluid: Air    Density option: 1
   LEV      ZA        TA      SA     RHOA     UA     TAUA
    1      .00      12.00    .00     1.24    2.00     .00
    2     50.00     12.00    .00     1.24    5.00    15.00
    3    100.00     12.50    .00     1.24    6.00    25.00
    4    200.00     13.00    .00     1.23    6.50    30.00

Discharge conditions (metric):  SINGLE PORT
   D0      H0       U0   THETA0 SIGMA0   C0       KD      T0      S0      RHO0
  3.000   40.00   10.00  90.00    .00  .10E+03  .28E-0   200.0    .0      .75

Program control:
   ZMAX     ZMIN    DISMAX  NPRINT
  200.00     .00  1000.00      30

Flux variables (based on ambient at discharge level):
  Q0   = .707E+02  M0  = .707E+03  J0   = .275E+03  GP0  = .390E+01
  QT0  = .133E+05  QS0 = .000E+00

Length scales (m) and parameters:
  LQ   =      2.66  LM  =      8.26  Lm   =      6.04  Lb   =      3.23
  Lmp  =     11.97  Lbp =     14.42
  FR0  =      2.92  R   =      2.27
Zone of flow establishment (m):
  LE   =       .00  XE  =       .00  YE   =       .00  ZE   =     40.00
  THETAE=     41.69  SIGMAE=    12.00  GAMMAE=     41.69
-------------------------------------------------------------------------------
CORJET PREDICTION:               Stepsize =    .6042  Printout every  30 steps
 Single jet/plume:
    X      Y       Z      Sc      Cc      B  |  DIST   Save    Gpc   dTc dSALc
    .00    .00   40.00   1.0  .100E+03  1.50|   .00    1.0  .39E+01188.0   .0
    .00    .00   40.00   1.0  .100E+03  1.50|   .00    1.4  .41E+01204.4   .0
  15.18   3.42   49.21   4.5  .221E+02  3.53|  18.13   6.6  .12E+01 41.6   .0
  31.38   7.54   56.20   9.6  .104E+02  5.18|  36.25  13.8  .63E+00 19.5   .0
  47.86  12.09   62.22  15.8  .634E+01  6.64|  54.38  22.5  .39E+00 11.8   .0
  64.47  16.97   67.60  22.7  .440E+01  7.96|  72.51  32.2  .27E+00  8.1   .0
```

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 81.13  22.13  72.51  30.3  .330E+01  9.18|  90.64  42.8  .20E+00  6.0   .0
 97.83  27.54  77.06  38.4  .260E+01 10.30| 108.76  54.0  .16E+00  4.7   .0
114.52  33.18  81.30  47.0  .213E+01 11.36| 126.89  65.8  .13E+00  3.8   .0
131.21  39.03  85.29  55.9  .179E+01 12.35| 145.02  78.1  .11E+00  3.1   .0
147.88  45.08  89.05  65.1  .154E+01 13.29| 163.15  90.7  .90E-01  2.6   .0
164.52  51.31  92.63  74.5  .134E+01 14.18| 181.27 103.7  .77E-01  2.3   .0
181.14  57.72  96.03  84.2  .119E+01 15.02| 199.40 116.9  .67E-01  2.0   .0
197.71  64.29  99.27  94.0  .106E+01 15.83| 217.53 130.4  .58E-01  1.7   .0
214.26  71.02 102.38 103.9  .963E+00 16.60| 235.66 144.1  .52E-01  1.5   .0
230.77  77.88 105.37 113.8  .879E+00 17.35| 253.78 157.8  .47E-01  1.4   .0
247.25  84.85 108.25 123.7  .808E+00 18.06| 271.91 171.7  .42E-01  1.2   .0
263.71  91.92 111.04 133.8  .747E+00 18.75| 290.04 185.6  .39E-01  1.1   .0
280.14  99.07 113.75 143.9  .695E+00 19.42| 308.17 199.6  .35E-01  1.0   .0
296.56 106.30 116.39 154.1  .649E+00 20.07| 326.29 213.7  .32E-01   .9   .0
312.96 113.58 118.96 164.4  .608E+00 20.71| 344.42 228.0  .30E-01   .9   .0
329.34 120.93 121.47 174.7  .572E+00 21.33| 362.55 242.3  .27E-01   .8   .0
345.70 128.34 123.91 185.1  .540E+00 21.93| 380.67 256.7  .25E-01   .7   .0
362.05 135.79 126.30 195.6  .511E+00 22.52| 398.80 271.1  .23E-01   .7   .0
378.39 143.29 128.64 206.1  .485E+00 23.10| 416.93 285.7  .22E-01   .6   .0
394.72 150.83 130.92 216.6  .462E+00 23.66| 435.06 300.2  .20E-01   .6   .0
411.03 158.41 133.16 227.2  .440E+00 24.21| 453.18 314.8  .19E-01   .5   .0
427.33 166.03 135.35 237.8  .421E+00 24.75| 471.31 329.5  .17E-01   .5   .0
443.62 173.69 137.49 248.4  .403E+00 25.28| 489.44 344.1  .16E-01   .5   .0
459.90 181.39 139.58 259.0  .386E+00 25.80| 507.57 358.8  .15E-01   .4   .0
476.17 189.11 141.64 269.6  .371E+00 26.31| 525.69 373.5  .14E-01   .4   .0
492.43 196.87 143.65 280.3  .357E+00 26.80| 543.82 388.1  .13E-01   .4   .0
508.68 204.66 145.62 290.9  .344E+00 27.29| 561.95 402.7  .12E-01   .3   .0
524.92 212.48 147.54 301.4  .332E+00 27.76| 580.08 417.3  .11E-01   .3   .0
541.15 220.33 149.43 312.0  .321E+00 28.23| 598.20 431.9  .10E-01   .3   .0
557.37 228.20 151.28 322.5  .310E+00 28.68| 616.33 446.4  .95E-02   .3   .0
573.58 236.11 153.10 333.0  .300E+00 29.13| 634.46 460.9  .88E-02   .3   .0
589.79 244.03 154.87 343.5  .291E+00 29.57| 652.59 475.2  .81E-02   .2   .0
605.98 251.98 156.61 353.8  .283E+00 30.00| 670.71 489.6  .74E-02   .2   .0
622.17 259.96 158.31 364.2  .275E+00 30.42| 688.84 503.8  .68E-02   .2   .0
638.36 267.96 159.98 374.4  .267E+00 30.83| 706.97 517.9  .63E-02   .2   .0
654.53 275.98 161.61 384.6  .260E+00 31.23| 725.09 532.0  .57E-02   .2   .0
670.69 284.03 163.21 394.8  .253E+00 31.62| 743.22 545.9  .52E-02   .2   .0
686.85 292.09 164.77 404.8  .247E+00 32.01| 761.35 559.7  .47E-02   .1   .0
703.01 300.18 166.30 414.8  .241E+00 32.39| 779.48 573.4  .42E-02   .1   .0
719.15 308.28 167.79 424.6  .235E+00 32.76| 797.60 587.0  .38E-02   .1   .0
735.29 316.41 169.25 434.4  .230E+00 33.12| 815.73 600.4  .34E-02   .1   .0
751.42 324.56 170.68 444.1  .225E+00 33.47| 833.86 613.8  .30E-02   .1   .0
767.54 332.72 172.08 453.6  .220E+00 33.82| 851.99 626.9  .26E-02   .1   .0
783.66 340.90 173.44 463.1  .216E+00 34.16| 870.11 639.9  .22E-02   .1   .0
799.77 349.10 174.77 472.5  .212E+00 34.49| 888.24 652.8  .18E-02   .1   .0
815.88 357.32 176.07 481.7  .208E+00 34.81| 906.37 665.5  .15E-02   .0   .0
831.98 365.55 177.34 490.8  .204E+00 35.13| 924.50 678.0  .12E-02   .0   .0
848.07 373.80 178.57 499.8  .200E+00 35.43| 942.62 690.3  .87E-03   .0   .0
864.16 382.07 179.78 508.6  .197E+00 35.73| 960.75 702.5  .57E-03   .0   .0
880.24 390.35 180.95 517.4  .193E+00 36.03| 978.88 714.5  .29E-03   .0   .0
896.32 398.65 182.09 525.9  .190E+00 36.31| 997.01 726.2  .15E-04   .0   .0
897.39 399.20 182.17 526.5  .190E+00 36.33| 998.21 727.0 -.19E-05   .0   .0
Terminal level in stratified ambient has been reached.     PROGRAM STOPS!
--------------------------------------------------------------------------
END OF CORJET PREDICTION:      Total number of integration steps =  1653
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
```

(a)

(b)

Figure E.5: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. a) Plan view, and b) side view along trajectory both with plot scale fixed at 1:1 (undistorted).

CORJET Prediction   File: postcjcase3air.OUT

Case3: CHIMNEY, STRATIFIED AIR, VARIABLE WIND

Concentration vs Downstream Distance X

Figure E.6: CORJET prediction for chimney discharge into stratified atmosphere with skewed wind profile as plotted with graphics package. Concentration along centerline trajectory.