CorHyd User Manual

Internal Diffuser Hydraulics Model

MixZon Inc

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CorHyd is a mathematical model and as such may not be reliable under all conditions. The user is responsible for correctly implementing and interpreting the results of this model. MixZon recommends running sensitivity analysis to analyze varying ambient and discharge conditions. MixZon makes no warranties, express, implied in law or in fact, for the use and results of CorHyd for any particular purpose including diffuser design and hydraulic analysis.
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1 Introduction

CorHyd is a computer model that calculates the flow characteristics in multiport diffuser configurations. It includes loss calculations for complex geometries, as well as additional flow forcing due to density differences.

CorHyd was developed by Tobias Bleninger and Gerhard Jirka at the Institute for Hydromechanics, Karlsruhe Institute of Technology, Germany. The CorHyd algorithm (Chapter 4) has been developed into a Windows-based application coded in .Net C++. The application includes a graphical user interface for specifying input parameters, along with graphical output and analysis. The interface facilitates design modifications and iterations. The application is distributed within the CORMIX Mixing Zone System (www.mixzon.com), and includes this manual and several test cases. Publications from Bleninger et al., 2002, 2004, and 2005 describe the code development and demonstrate comparisons and validation.

2 Background

Multiport diffusers are efficient components of outfall infrastructure for river or submarine effluent disposal. They are utilized to avoid pollutant accumulation and provide rapid dispersion of the effluent. Multiport diffuser installations are increasingly applied for treated municipal or industrial wastewater discharges, cooling water discharges and concentrate discharges from desalination plants. They have considerable advantages compared to conventional bank or shoreline discharges through open channels due to two general principles:

i) the off-shore and submerged siting in less-sensitive and hydraulically more turbulent flow regions

ii) the hydraulically optimized discharge design, allowing for highly turbulent discharges resulting in strong initial mixing and effluent distribution.

Good outfall design must address both principles by studying the hydraulics outside and inside a diffuser. Mixing and transport models are generally used to analyze the external hydraulics affecting the effluent mixing with the ambient fluid. The internal hydraulics, which will be treated here, affect the flow partitioning and related pressure losses in the pipe manifold resulting in a discharge profile along the diffuser.

2.1 Multiport Diffusers

An outfall is a pipe system between the dry land and the receiving water. It consists of three components (Figure 1):
1. **Onshore headworks** (e.g. gravity or pumping basin)
2. **Feeder pipeline** which conveys the effluent to the discharge area
3. **Diffuser section**, where a set of openings releases and disperses the effluent into the environment to minimize the impacts on the quality of the receiving water body. The diffuser section can be a single branched or double branched system (T- or Y-shaped), buried, tunneled or laid on the seabed.

![Diagram of outfall configuration showing feeder pipe and diffuser](image)

Diffuser sections installed on the seabed usually consist of port orifices in the wall of the diffuser pipe (simple port configuration, Figure 2a). If diffusers are covered with ballast and protection layers, laid in a trench or even tunneled in the ocean floor, vertical risers (riser/port configuration, Figure 2c) are connected to the diffuser to convey the effluent to the water body. For deep-tunneled solutions often rosette-like port arrangements (Figure 2d) (similar to a gas burner device) are used to reduce the number of costly riser installations. In these cases, only a few, wide spaced risers are applied. In addition, ports may carry additional elements like elastic, variable area orifices (duckbill valves, Figure 2b), which change their effective open port area relative to the pressure difference between inside and outside the valve. Duckbill valves avoid debris and salt-water intrusion during low flow periods and allow high discharges during peak flow periods (Lee et al., 1998).
Recent monitoring of diffuser installations showed that inadequate attention to internal diffuser hydraulics often lead to hydraulic problems like partial blockage, high pressure losses, uneven flow distribution and salt water intrusion (Grace, 2005a, b; Bleninger et al., 2003; Domenichini et al., 2002, Neville-Jones and Chitty, 1996a, b). Consequences include higher energy demands, along with increased public health and environmental risks due to reduced effluent dilutions. For example, Faisst et al. (1990) suspected that non-uniform flow distributions along the Vancouver diffuser cause the observed parallel plume layers at different depths.

2.2 Multiport Diffuser Design Objectives

Multiport diffuser hydraulics design objectives are:
1. A uniform discharge distribution along the diffuser in order to meet dilution requirements and to prevent operational problems (e.g. intrusion of ambient water through ports with low flow). Exceptions should avoid near-shore impacts by keeping the seaward discharge higher.
2. **Minimized investment, operation and maintenance costs** using simple, flow optimized manifold geometries with small pressure losses.

3. **Prevention of off-design operational problems** like particle deposition or salt-water intrusion in the pipe system, requiring full flowing pipe sections and reasonably high velocities.

4. **Robustness to unsteady hydraulic conditions** in order to reach steady flow condition after short purging during start-up periods, optimized intermittent pumping cycles and considerations of wave induced circulations and transients.

Conflicting design objectives require compromises that are not sufficiently resolved in many cases (Bleninger et al., 2004). Existing diffuser hydraulic programs (Fischer et al., 1979, implemented in code PLUMEHYD; and Wood et al., 1993, implemented as DIFF) work well for simple diffusers with uniform geometries. However, they consider only short risers with negligible friction and local pressure losses. More complex designs may require long risers (like in deep-tunneled outfalls) with significant frictional and local pressure losses, Y-shaped diffusers, complex port/riser configurations including rosette-like arrangements, multiple ports on one riser, duckbill valves, or other port pressure losses. Available design rules regarding velocity ratios (Fischer et al., 1979) or loss ratios (Weitbrecht et al., 2002) for diffuser sections and downstream ports are only applicable for simple and uniform geometries (i.e. no geometrical changes along the diffuser). In some cases, unnecessarily conservative designs are produced, because in the actual diffuser installation, the velocities and pressure losses along the diffuser line may change in an irregular manner.

The CorHyd model is part of the CORMIX Mixing Zone System (Doneker and Jirka, 1996). CorHyd covers the internal diffuser hydraulics, computing velocities, pressures losses, and flow distribution for varying discharge and ambient conditions. This allows for evaluations of design alternatives regarding a cost effective internal hydraulics design, environmental sound solutions, and operational feasible systems.
3 Using the CorHyd Application

The graphical user interface (GUI) consists of several tab pages: ambient data, effluent data, diffuser/feeder pipe data, port/riser data, and output. The data can be input either by typing the data directly into the designated spaces or by importing an existing CorHyd case XML file. In addition, a help system is available.

3.1 Accessing Help

Help information can be accessed via one of the following methods:

1. Place the mouse pointer over any of the input items (entry boxes, push buttons, checkboxes, etc.). A small box with a "Tool Tip" will appear, with a brief hint about that input item’s use and meaning.

   Density of effluent (\( \rho_e \)) 998 kg/m\(^3\) Average density of the effluent

2. When the cursor is in a data entry field, press function key F1 to get a Help popup window.

3. Click on the More... button in the Help popup message to see more detailed online context sensitive help, including diagrams.
For example, for the angle beta from the Ports/Risers Configuration window, the following detailed information is shown:

**Gradual expansion or contraction (beta)**

*CORMIX UI Tooltip:*
Gradual expansion or contraction between pipe sections

**Input Data Range:** 0 - 180°

The angle of gradual expansion or contraction between pipe sections.

This refers to the connection between this pipe and the next upstream pipe (section numbers \( n \) and \( n+1 \)). For gradual diameter changes the angle beta (typically 0-180°) can be specified.

\[
\zeta = 3.2 \cdot \tan \frac{\beta}{2} \cdot \sqrt{\frac{\tan \frac{\beta}{2}}{1 - \frac{A_2}{A_1}}} \quad \text{with } \beta \text{ in rad}
\]

Gradual contraction [Idelchik 1986]

\[
\zeta = (-0.0125 \cdot n_y^4 + 0.0223 \cdot n_y^3 - 0.00723 \cdot n_y^2 + 0.0044 \cdot n_y - 0.00745) \cdot (1 - 2n\beta^2 - 10n\beta^4)
\]

with \( n_y = A_y/A_1 \leq 1.0 \) and \( \beta \) in rad

**Figure 3** Example online Help information for beta from the Ports/Risers configuration window


5. Select "Help -> CorHelp - Online User Guide" menu option, to access the user interface guide on the web site.

6. Click on the button in the tool strip. This brings up CorHelp - Online User Guide in your web browser.
3.2 Data Input

3.2.1 Using the Data Input Window Tabs

Select the window tabs shown below to input data. Generally you will want to start with the leftmost tab and proceed to the right.

Figure 4 CorHyd application main window
3.2.2 Getting Started

To get started, select the type of diffuser configuration (Single end vs. Y or T diffuser) and whether you’re solving for total head or the design flow rate.

- **Total head** $H_t$ given design flow $Q_d$. The total head is defined as the head (effluent water level elevation related to effluent density) above datum in the headworks, necessary to operate the system.
- **Flow rate** for a given total head in the headworks

Headwork buildings or treatment plant pumps are often limited and the outfall has to be designed for a maximum available total head in the headworks.
CorHyd uses a Cartesian coordinate system, in which the origin is user-defined. It is recommended to use a fixed datum for vertical coordinates, and to locate the $x$-coordinate close to parallel to the diffuser line for better visualization of the results.

Figure 5 Coordinate system used in CorHyd. Five pipe sections and two port/riser groups are shown in this example.
3.2.3 Effluent Data

Effluent data are entered by selecting the *Effluent* window tab.

![Figure 6 CorHyd effluent data window](image)
The design flow rate $Q_d$ shall be the maximum foreseen at the end of design life. Generally there is a headwork basin (or the treatment plant itself) with sufficient capacity to accept daily peaks and storm waters (or there may be an additional storm water outfall) resulting in an average flow rate for the outfall. In this case the design can be made based on the average daily maximum flow at life end.

Performance checks should explicitly done for the foreseen near future scenarios, often considering increasing flows in 5, 10 or 20 years.

Effluent density $\rho_e$ and viscosity $\nu$ generally do not change significantly. Typical values for municipal waste water are $\rho_e = 996-998$ kg/m³ and $\nu = 1.31 \times 10^{-6}$ m²/s (ATV-DVWK A110, 2001).

### 3.2.4 Ambient Data

Ambient data are entered by selecting the *Ambient* window tab.
The ambient water level elevation $H_d$ should be specified using the average water level elevation above datum at the discharge location.

The ambient density can be specified as a uniform average density $\rho_0$ or as stratified. Typical values for sea-water density are $\rho_0 = 1021-1026$ kg/m³. When specifying a stratified ambient density, both the surface density and the density gradient are entered. Performance checks should explicitly be done for the case of maximum average water level elevation ($H_{\text{max}} > H_d$) and maximum average ambient density ($\rho_{0,\text{max}} > \rho_0$). CorHyd computes the external pressure at a port orifice using the ambient density at the depth of the port.
Figure 8 CorHyd ambient data window showing stratified ambient density
3.2.5 Feeder and Diffuser Pipe Data

The main outfall pipe consists of:
- the feeder pipe, which conveys the effluent to the discharge location
- the diffuser pipe, which employs ports/risers to disperse the effluent into the ambient

CorHyd allows the user to select the orientation of the pipe configuration as shown in Figure 9. The default configuration shows the headworks on the left of the display, working out to the diffuser pipe on the right. Prior to version 4.0, CorHyd showed the diffuser pipe on the left of the display, working out to the headworks on the right.

Select the "Tools -> Options" menu option

![CorHyd Options](image)

*Figure 9 CorHyd user options window*
The input of both feeder and diffuser pipe sections is done via the start and end point coordinates $x_s$, $y_s$, $z_s$, the diameter $D_d$ and the roughness $k_{s,d}$. To reduce the input parameters the pipeline is schematized with pipe sections. Pipe section boundaries are locations where either bends or diameter changes or roughness changes occur. The fittings itself can be characterized by the radius $R$ (typical $R = 3D_d$) of a bend if bends between sections occur or an angle $\beta$ (typical $90 - 180^\circ$) for gradual diameter changes are applied.

The user should try to define as few sections as possible, but as many as necessary to represent the general configuration of the pipeline. The sections can be chosen independently of the port/riser configurations.

Note that pipes are not available in all sizes. Therefore, it is advisable to use pipe diameters using internal diameters found in catalogues of pipe producers.

Feeder pipe sections are configured in the *Feeder Config* window. The currently selected pipe section, the column where the cursor is currently located, is highlighted with a light “sand” color.

Start the input by inserting a feeder section that includes the headworks. Enter the onshore location of the headworks for the $x$, $y$, $z$ coordinates and fill in the related pipe section details. Then insert a new section (to the right) for every change of pipe diameter, direction, or other parameters. The resulting feeder section table shows, left to right, the pipe sections from the headworks to the offshore end.
Figure 10 CorHyd feeder configuration window (Pipe section 4 is selected)
Diffuser pipe sections are configured in the **Diffuser Config** window.

![CorHyd diffuser configuration window](image)

**Figure 11** CorHyd diffuser configuration window
3.2.6 Port / Riser Configuration Data

The concept of port/riser groups was conceived (Delft Hydraulics, 1995) to eliminate entering data for each individual port. All ports/risers within a group have the same characteristics. The user should try to use as few groups as possible, but as many as necessary to achieve optimized design.

For each port/riser group the number of risers ($Ngp$) in the group and the location on the diffuser pipe section must be specified. The spacing between each group ($Lf$) and the spacing between each riser in a group (often both are the same) are entered. Next the input of the port elevation ($Lr$) above the diffuser centerline is entered (This is used for calculating the external pressure at the outlets). If no risers are applied, the port elevation, riser diameter and roughness should be zero.

The number of ports per riser ($Np$) should be set to 1 or more. If ports consist of little attached pipes their length ($Lp$) and related roughness ($Ksd_p$) should be given. If there are no port pipes, the port diameter ($Dp$) should be set to the riser diameter ($Dr$) and the port length ($Lp$) should be set to 0.

If the number of ports per riser ($Np$) is 1, any bends or angles between the riser and the port must be specified by entering the bend ($bend_r$) and the radius of bend ($RO_r$). CorHyd calculates losses using the entered values. Alternatively, losses can be estimated and entered as additional known local losses ($zeta_r$ or $zeta_p$).

If the number of ports per riser ($Np$) is 2 or more, CorHyd assumes that there is a T-division (90° between the riser and the ports) with flow divided equally among the ports. The angle of 90° is assumed as a conservative estimate. CorHyd calculates the losses using the T-division equation (Idelchik 1986) in Appendix A.

For design discharges, a homogeneous distribution is desirable. Often only discharge due to gravity is allowed to drive the system. A homogeneous distribution can be achieved by either changing riser and/or port diameters along the diffuser or applying variable area orifices. The effective open area of variable area orifices (duckbill valves) changes with different discharges, while fixed port diameters do not. Variable area orifices are good for zero or low discharge scenarios, where intrusion must be prevented. They give almost homogeneous discharge profiles, due to the discharge dependent open area. Decreasing fixed riser and/or port diameters along a pipe leads to a more homogeneous discharge distribution, but also to increased losses and total head due to higher velocities.

Note that pipes are not available in all sizes. Therefore, it is advisable to use pipe diameters using internal diameters found in catalogues of pipe producers. Often a few centimeters difference in the port diameter makes considerable differences if applied all along the diffuser or in designated pipe sections. Furthermore changes of port diameters might be necessary during lifetime of the diffuser to adopt for changing boundary
conditions. This can be accomplished by utilizing flanges at the diffuser itself or by flanges at the riser pipe and attached port pipe, if risers are necessary. A tap with a hole of an intermediate size can then be fixed on these flanges and easily replaced by submarine work. Attention has to be paid to avoid abrupt diameter changes and sharp edges to reduce the additional losses caused by these constructional details.

Ports and risers are configured in the *Ports/Risers Configuration* window.

**Figure 12** CorHyd ports/risers configuration window

### 3.2.7 Duckbill Valves

CorHyd incorporates characteristic curves (headloss, jet velocity, effective open area) for a number of Tideflex duckbill valves. CorHyd generally supports 3 different Tideflex
duckbills for each pipe size (0.5 to 60 inch pipe diameter). Generally, this provides sufficient duckbill options for designing a diffuser.

In the Ports/Risers Configuration window in CorHyd, select Duckbill for Type of orifice. Then click on the button to configure duckbill valves. The Duckbill Valve Properties window (shown in Figure 13) allows the user to select a particular valve for the pipe size.

![Duckbill Valve Properties window]

Figure 13 Duckbill Valve Properties window
Each duckbill valve is denoted by a product code known as a Hydraulic Code. Each valve has a specified maximum reverse differential pressure. Duckbill check valves operate based on differential pressure. When the line pressure (at the valve inlet) exceeds the backpressure (at the valve outlet), the valve opens and flow is created. When the backpressure exceeds or overcomes the line pressure, the bill of the valve seals shut, thereby preventing any backflow from occurring. In general, the greater the maximum reverse differential pressure, the higher the jet velocity exiting the duckbill and the greater the port headloss.
3.3 Hints For Use

Feeder Config and Diffuser Config (Leg 1 and Leg 2) Windows

- The following buttons are available to insert and delete pipe sections.

![Insert or Delete Pipe Section](image)

An Insert pipe operation inserts a pipe to the left or right of the currently highlighted pipe section (the section where the cursor is). A delete pipe operation deletes the pipe section that is currently highlighted (the section where the cursor is).

- When the cursor is in a pipe section, right-click on the mouse to get these options:

![Insert Pipe Section](image)

Port / Risers Configuration Window

A Port/Riser Group is a group of one or more risers with ports that have the same attributes and are spaced evenly on the same diffuser pipe section.

- The following buttons are available to insert and port/riser groups.

![Insert or Delete Port/Riser Group](image)
An Insert operation inserts a port/riser group to the left or right of the currently highlighted port/riser group (the group where the cursor is). A delete operation deletes the port/riser group that is currently highlighted (the group where the cursor is).

➢ When the cursor is in a port/riser group, right-click on the mouse to get these options:

| Insert Port/Riser Group ——> |
| <——— Insert Port/Riser Group |
| Delete Port/Riser Group |
| Copy Group To... |
| Copy Group to Buffer |
| Paste Group from Buffer |

**Main Window Tool Strip Buttons**

The tool strip buttons provide shortcuts for performing important functions.

Here are some buttons that may be helpful.

| ![Video](play) | Perform validation and run simulation. |
| ![DiffuserViz](diffuser) | Visualize diffuser configuration. Starts up the DiffuserViz application. |
| ![Web](web) | View the CorHelp - Online User Guide in your web browser. |

*Table 1 CorHyd main window buttons*
3.4 Running the Simulation using the Output Window

Output options are selected in the Output window. The Run button validates the input data and, if the data are OK, runs the simulation. This window also provides for batch processing, which can also be used to run multiple simulations, varying certain parameters.

Output options include the following:

- **Text report**
- **Energy & Hydraulic Lines for locations along the diffuser centerline**

Graph of:

- Energy Line (EL) = \( \frac{p_d}{\gamma_e} + \frac{V_d^2}{2g} + z_d \)
- Pressure Line (PL) = \( \frac{p_d}{\gamma_e} + z_d \)
- **Discharge & Velocity Graphs**

  This option generates bar charts with a bar at every riser position plotted along the x-coordinate distance from the shore. The following charts are generated:
  - Discharge per Riser
  - Discharge Deviation
  - Port and Jet Velocities
  - Diffuser Velocities
3.5 CorHyd Text Report

A sample CorHyd text report is shown in Figure 15. This figure shows an excerpt from an actual report.

Note the table **OUTPUT Losses and Total Head**. The first part of the table can be used to evaluate where most of the losses occur (in the feeder, in the diffuser, in the ports, or due to high velocities). This information can be used to determine where to optimize the design.

Losses are usually related to losses along a streamline, i.e. the losses a fluid particle experiences going from the headworks to one of the outlets. In order to present an overall number, the average losses for all streamlines are reported in the table. Because averages are used, the sum of the average losses is not the same as the calculated total head; the percentages are not 100%.

To estimate the variation in the losses, the report presents the sum of all the lower values (streamline leaving the port closest to the headworks) and the sums all the upper values (streamline leaving the furthest port, which is port #1 in CorHyd).

The total energy head (energy in dimensions of length) is usually computed as the sum of the pipe elevation + pressure head + velocity head + losses. Thus, the minimum and maximum velocity head values are included in the minimum and maximum sums, respectively.

The report shows both the **relative total head** and the **absolute total head**. The calculated relative total head is the head required above the ambient water level $H_d$. The calculated absolute total head is the head required above the datum $z = 0$. If the water level elevation is the same as the datum, both of these total head values will be the same. The calculated head is the amount of head that is required at the headworks to operate the system. If the headworks already provides this head, then no additional pumping is necessary. If the calculated head is negative, this means that the ambient water level is greater than the effluent head in the pipe and no additional pumping is necessary.
OUTPUT Flowrates and Velocities:

- **Riser location**
  - \((x, y, z)\) Riser location
  - dist Riser distance from diffuser end (along pipe centerline)
  - q Individual riser discharge
  - Q Total discharge until this riser position
  - Vp Port velocity
  - D0 Effective port diameter (D0 in CORMIX)
  - Vj Jet velocity
  - Vr Riser velocity
  - Fr Densimetric Froude number
  - Vd Diffuser velocity
  - Dd Diffuser diameter
  - Vr/Vd Velocity ratio
  - Vp/Vd Velocity ratio
  - Intr Intrusion criteria \((Froude_{jet}>1)\) compliance \((1=ok, 0=Vj\ too\ slow)\)
  - Sed Diffuser sedimentation criteria compliance \((1=ok, 0=Vd\ too\ slow)\)

<table>
<thead>
<tr>
<th>Riser #</th>
<th>x [m]</th>
<th>y [m]</th>
<th>z [m]</th>
<th>dist [m]</th>
<th>q [m³/s]</th>
<th>Q [m³/s]</th>
<th>Vp [m/s]</th>
<th>D0 [m]</th>
<th>Vj [m/s]</th>
<th>Vr [m/s]</th>
<th>Fr [-]</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>-200.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>2.079E-02</td>
<td>2.079E-02</td>
<td>2.647</td>
<td>0.093</td>
<td>3.060</td>
<td>2.647</td>
<td>20.2</td>
</tr>
<tr>
<td>2</td>
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<td>0.0</td>
<td>0.0</td>
<td>14.0</td>
<td>2.058E-02</td>
<td>4.137E-02</td>
<td>2.620</td>
<td>0.093</td>
<td>3.043</td>
<td>2.620</td>
<td>20.1</td>
</tr>
<tr>
<td>3</td>
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<td>0.0</td>
<td>0.0</td>
<td>28.0</td>
<td>2.049E-02</td>
<td>6.186E-02</td>
<td>2.609</td>
<td>0.093</td>
<td>3.017</td>
<td>2.609</td>
<td>20.0</td>
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<tr>
<td>4</td>
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<td>0.0</td>
<td>42.0</td>
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<td>8.210E-02</td>
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<td>0.093</td>
<td>2.986</td>
<td>2.578</td>
<td>20.0</td>
</tr>
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<td>5</td>
<td>144.0</td>
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<td>0.0</td>
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<td>2.010E-02</td>
<td>1.022E-02</td>
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<td>0.092</td>
<td>2.953</td>
<td>2.559</td>
<td>20.0</td>
</tr>
<tr>
<td>6</td>
<td>130.0</td>
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<td>70.0</td>
<td>1.999E-02</td>
<td>1.222E-02</td>
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<td>0.092</td>
<td>2.921</td>
<td>2.546</td>
<td>19.9</td>
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<td>7</td>
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<td>0.0</td>
<td>84.0</td>
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<td>1.421E-02</td>
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<td>0.092</td>
<td>2.891</td>
<td>2.536</td>
<td>19.9</td>
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<tr>
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<td>0.0</td>
<td>0.0</td>
<td>98.0</td>
<td>1.985E-02</td>
<td>1.620E-02</td>
<td>2.528</td>
<td>0.092</td>
<td>2.868</td>
<td>2.528</td>
<td>19.9</td>
</tr>
<tr>
<td>9</td>
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<td>112.0</td>
<td>1.980E-02</td>
<td>1.818E-02</td>
<td>2.521</td>
<td>0.092</td>
<td>2.841</td>
<td>2.521</td>
<td>19.8</td>
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<tr>
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<td>1.976E-02</td>
<td>2.015E-02</td>
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<td>0.092</td>
<td>2.818</td>
<td>2.516</td>
<td>19.8</td>
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<td>0.0</td>
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<td>1.973E-02</td>
<td>2.133E-02</td>
<td>2.512</td>
<td>0.092</td>
<td>2.797</td>
<td>2.512</td>
<td>19.8</td>
</tr>
<tr>
<td>12</td>
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<td>0.0</td>
<td>154.0</td>
<td>1.971E-02</td>
<td>2.410E-02</td>
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<td>0.092</td>
<td>2.775</td>
<td>2.509</td>
<td>19.8</td>
</tr>
<tr>
<td>13</td>
<td>32.0</td>
<td>0.0</td>
<td>0.0</td>
<td>168.0</td>
<td>1.969E-02</td>
<td>2.607E-02</td>
<td>2.507</td>
<td>0.092</td>
<td>2.753</td>
<td>2.507</td>
<td>19.8</td>
</tr>
<tr>
<td>14</td>
<td>18.0</td>
<td>0.0</td>
<td>0.0</td>
<td>182.0</td>
<td>1.967E-02</td>
<td>2.803E-02</td>
<td>2.505</td>
<td>0.092</td>
<td>2.725</td>
<td>2.505</td>
<td>19.8</td>
</tr>
<tr>
<td>15</td>
<td>4.0</td>
<td>0.0</td>
<td>0.0</td>
<td>196.0</td>
<td>1.967E-02</td>
<td>3.000E-02</td>
<td>2.504</td>
<td>0.092</td>
<td>2.698</td>
<td>2.504</td>
<td>19.8</td>
</tr>
</tbody>
</table>

Mean: 2.000E-02  2.546 0.092  2.998  2.546

Feeder velocities \(V_f\) [m/s] from diffuser to headworks: 0.60

SIMULATION Data

- # of iterations = 3

OUTPUT Losses and Total Head:

<table>
<thead>
<tr>
<th>Type of loss</th>
<th>Loss [m]</th>
<th>% of the relative head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet head loss [m]</td>
<td>0.009</td>
<td>0.6 %</td>
</tr>
<tr>
<td>Feeder head loss [m]</td>
<td>0.036</td>
<td>2.4 %</td>
</tr>
<tr>
<td>Diffuser main pipe head loss [m]</td>
<td>0.025</td>
<td>1.7 %</td>
</tr>
<tr>
<td>Avg port/riser headloss [m]</td>
<td>0.756</td>
<td>50.3 %</td>
</tr>
<tr>
<td>Max port/riser headloss [m]</td>
<td>0.781</td>
<td>52.0 %</td>
</tr>
<tr>
<td>Min port/riser headloss [m]</td>
<td>0.730</td>
<td>48.6 %</td>
</tr>
<tr>
<td>Avg jet velocity head [m]</td>
<td>0.458</td>
<td>30.9 %</td>
</tr>
<tr>
<td>Max jet velocity head [m]</td>
<td>0.477</td>
<td>31.7 %</td>
</tr>
<tr>
<td>Min jet velocity head [m]</td>
<td>0.450</td>
<td>30.0 %</td>
</tr>
<tr>
<td>Avg density head difference [m effluent]</td>
<td>0.225</td>
<td>15.0 %</td>
</tr>
<tr>
<td>Max density head difference [m effluent]</td>
<td>0.225</td>
<td>15.0 %</td>
</tr>
<tr>
<td>Min density head difference [m effluent]</td>
<td>0.225</td>
<td>15.0 %</td>
</tr>
</tbody>
</table>

Sum of averages [m] 1.510 100.5 % of the relative head
Sum of all maximum losses [m] 1.554 103.4 % of the total head
Sum of all minimum losses [m] 1.476 98.2 % of the total head

Calculated relative total head [m] 1.503 above ambient water level \(H_d = 10.00\) m
Calculated absolute total head [m] 11.503 above datum \(z = 0\) m

Figure 15 Excerpt of sample CorHyd text report (abridged to fit page)
3.6 CorHyd Graphical Output

The following figures present examples the Graphical Output.

![Energy and Pressure Grade Lines for Feeder and Diffuser Pipes](image)

**Figure 16** CorHyd output: Energy and Pressure Grade Lines
Figure 17 CorHyd output graphs
3.7 **Diffuser Visualization**

3.7.1 Starting up Diffuser Visualization

Diffuser Visualization can be started in **CorHyd** by either:

1. Select "**Run -> Visualize Diffuser**" menu option.

![CorHyd menu](image1)

2. Click on the ![button](image2) button in the Main window tool strip to start the Diffuser Visualization application.

![Diffuser Visualization window](image3)

*Figure 18 Diffuser Visualization application window*
3.7.2 Diffuser Visualization Mouse Operations

Holding down the mouse buttons generates a stream of events that cause continuous actions (e.g., rotate, pan, zoom). For a mouse that has two buttons and a scroll wheel (which functions as the middle button), the mouse operations are:

<table>
<thead>
<tr>
<th>Mouse Button</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>Rotate the camera around its focal point</td>
</tr>
<tr>
<td>Middle</td>
<td>Pan the camera</td>
</tr>
<tr>
<td>Right</td>
<td>Zoom the camera</td>
</tr>
</tbody>
</table>

The left mouse button can also be configured to perform any one of these operations. For details, refer to the following section.

3.7.3 Diffuser Visualization Window Tool Strip Buttons

The tool strip buttons provide shortcuts for performing important functions.

Following are the operations of the buttons that are not standard.

<table>
<thead>
<tr>
<th>Button</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Copy" /></td>
<td>Copy the image to the Clipboard.</td>
</tr>
<tr>
<td><img src="image" alt="Rotate" /></td>
<td>Set the left mouse button to Rotate the view.</td>
</tr>
<tr>
<td><img src="image" alt="Pan" /></td>
<td>Set the left mouse button to Pan the view.</td>
</tr>
<tr>
<td><img src="image" alt="Zoom" /></td>
<td>Set the left mouse button to Zoom the view.</td>
</tr>
<tr>
<td><img src="image" alt="Zoom to Diffusers" /></td>
<td>Zoom to the diffusers, omitting the feeder pipes from view.</td>
</tr>
<tr>
<td><img src="image" alt="Zoom to Full Extent" /></td>
<td>Zoom to the full extent of the feeder/diffuser configuration.</td>
</tr>
<tr>
<td><img src="image" alt="Plan View" /></td>
<td>View the diffuser configuration in Plan view.</td>
</tr>
<tr>
<td><img src="image" alt="Z-X View" /></td>
<td>View the diffuser configuration in Z-X view.</td>
</tr>
<tr>
<td><img src="image" alt="Z-Y View" /></td>
<td>View the diffuser configuration in Z-Y view.</td>
</tr>
<tr>
<td><img src="image" alt="Enable/Disable Selection" /></td>
<td>Enable/disable selection of diffuser objects (pipes, risers, etc.)</td>
</tr>
<tr>
<td><img src="image" alt="CorHelp" /></td>
<td>View the CorHelp - Online User Guide in your web browser.</td>
</tr>
</tbody>
</table>
3.7.4 Diffuser Visualization Selection Mode

To enable selection of diffuser objects (pipes, risers, etc.), click on the Select tool button. The Select tool button is highlighted when Selection Mode is enabled. To disable Selection Mode, click again on the Select tool button.

In Selection Mode, position the mouse cursor over a diffuser object and left-click the mouse. The diffuser object will be highlighted as shown in Figure 19 and a message window will pop-up showing configuration data for that object.
4 CorHyd Simulation Model

The flow in multiport diffusers is a turbulent pipe flow controlled by two boundaries: first, the entrance boundary (flow rate or head), and, second, the ambient/discharge boundary, where the effluent properties differ from the ambient fluid. Both conditions vary in time due to discharge variations (diurnal changes, storm water events, process variations, and long-term changes due to increased sanitation coverage, production increase or extensions) and ambient pressure variations caused by density and/or water level variations (floods, droughts, tides or waves). However manifold flow time-scales are usually considerably smaller than the time-scales of boundary condition variations, for example for a 4 km long outfall the acceleration caused by a doubling of the feeder velocity due to a change in the headwork head would need approximately 2 min. Thus, a steady-state approach is applied for the regular diffuser design.


4.1 Governing equations

Several methodologies for the analysis of the diffuser internal hydraulics have been adopted by various authors. These include a 1-D pipe flow port-to-port analysis (Fischer et al., 1979, Wood et al., 1993). Fischer et al. (1979) define a bulk loss coefficient $C_d$ to estimate the loss from simple riser geometries for sharp-edged and bell-mouthed ports. These discharge coefficients are empirically based on discharge coefficient curves developed earlier (Rawn et al., 1960). While the discharge coefficients are useful for many diffuser applications, they do not consider diameter ratios and flow separation effects in detail.

Mort (1989) developed a one dimensional (1-D) finite difference model. Shannon (2002) utilized a 2-D or 3-D field Eulerian grid for every point of the diffuser. These methodologies have the advantage that unsteady, stratified flow (i.e. saltwater intrusion) calculations are easier to implement than the port-to-port analysis. However, they do not specify appropriate local loss formulations for common or complex diffuser and port geometries.

CorHyd focuses on a steady state pipe flow analysis without considerations of salt water purging or intrusion processes, which are covered elsewhere (Wilkinson, 1984, 1985; Wood et al. 1993, pp. 122, pp. 326; Wilkinson und Nittim, 1992; Burrows, 2001). However, considerations for off-design conditions for start-up or shut-down or extreme conditions will briefly be addressed later.

Manifold hydraulics is characterized by several flow separations, where local pressure losses not only depend on geometrical relations but also on the discharge ratios. For wastewater diffuser manifolds, discharge ratios are influenced by the pressure difference between the effluent and the ambient.

Figure 20 shows the definition diagram with the geometries defined as sets of diffuser pipe segment locations $x$, $y$, $z$, riser/port segment geometries (i.e. diameters $D$, cross-sections $A$, roughness $k_s$, and pipe section lengths $L$). Indices used are ‘d’ for diffuser pipe sections, ‘r’ for riser sections, ‘p’ for port sections and ‘j’ for jet properties at the vena contracta of the discharging jet. The ambient fluid is described by its density distribution $\rho_a(z)$ and the average water level elevation $H$ resulting in different external hydrostatic pressures $p_o,i$ at the vertical location of the jet centerline at the vena contracta at each $i$ position along the diffuser pipe, where risers or ports are attached. The effluent is described by its fluid density $\rho_e$ the internal pressures $p$, velocity $V$, and either the total flowrate $Q_o$ or the total available water level at the headworks (total head $H_t$).
Figure 20 Definition scheme for the port-to-port analysis: $p_{a,i}$ = ambient pressure, $H$ = average ambient water level elevation, $q_i$ = discharge through one riser/port configuration with velocity $v_i$ at elevation $z_{j,i}$. $p_{d,i}$ = internal diffuser pipe pressure upstream a flow division (node) with diffuser pipe centerline elevation $z_{d,i}$ and horizontal pipe location $x_{d,i}$.

The governing equations are continuity equations at each flow division

$$Q_1 = Q_2 \iff V_1 A_1 = V_2 A_2,$$

(1)

where $Q$ denotes the flowrate in one pipe section, and the work-energy equation along pipe segments with constant or known flowrate

$$\frac{V_1^2}{2g} + z_1 + \frac{p_1}{\gamma e} = \frac{V_2^2}{2g} + z_2 + \frac{p_2}{\gamma e} + h_e$$

(2)

The definition of $h_e$ can be seen as the turbulence closure for pipe flow hydraulics. The dissipation of turbulent kinetic energy causes heat losses in the system. This energy loss is compensated by decreasing pressure. Pressure losses in pipe flows are classified according the source of turbulence production in continuous pressure losses due to wall friction and local pressure losses due to geometrical changes. Wall friction causes cross-sectional flow non-uniformities, whereas geometrical changes cause streamwise flow non-uniformities.
Flows in pipe systems can be classified into laminar and turbulent flows by the pipe Reynolds number $Re = \frac{VD}{\nu_e}$ with the kinematic viscosity of the effluent $\nu_e$. Pipe flows with Reynolds numbers above a critical Reynolds number $Re_{cr} \approx 2000$, are considered as turbulent flows, which is essentially the case for wastewater pipe systems.

To calculate the individual riser discharge $q_i$ of such a system at the position $i$ (Figure 20) following considerations are in order:

1) The work energy equation (equation 2) is applied along a streamline following the diffuser pipe centerline. This results in equation (3). It equals the diffuser pressure $p_{d,i}$ directly upstream the port/riser branch with the known downstream diffuser pressure $p_{d,i-1}$ plus the known static pressure difference due to the elevation difference, plus the dynamic pressure difference plus the known pressure losses occurring in the main diffuser pipe. The pressure losses are divided into friction losses and local pressure losses like bends and diameter changes or the passage of a branch opening:

$$p_{d,i} = p_{d,i-1} + \rho_e g(z_{d,i-1} - z_{d,i}) + \frac{\rho_e}{2} v^2_{d,i-1} - \frac{\rho_e}{2} v^2_{d,i} + p_{e,d,i},$$

where pressure losses $p_{l,d,i} = \frac{\rho_e}{2} v^2_{d,i-1} \sum_{j=1}^{n_{d,i-1}} \left( \zeta_{d,i-1,j} + \lambda_{d,i-1,j}\frac{L_{d,i-1,j}}{D_{d,i-1,j}} \right)$, with loss coefficients related to the reference velocity $v_{d,i-1}$.

Optional input fields are foreseen in the computer model to allow specifying more detailed information on unusual local pressure losses $\zeta_i$, T- or Y-shaped diffuser configurations or the denomination of clogged or temporary closed ports. Implemented are all common local pressure losses, which are listed in 3.2.6. Therefore $\zeta_{p,i,j}$, $\zeta_{r,i,j}$, $\zeta_{d,i,j}$ denote the local loss coefficients for each $j$-component of the total number $n_{p,i}$ of pressure losses in a port, $n_{r,i}$ in a riser or $n_{d,i}$ in the diffuser pipe with pipe cross-sectional areas $A_{p,i,j}$, $A_{r,i,j}$ and $A_{d,i,j}$ respectively. $\lambda_{p,i,j}$, $\lambda_{r,i,j}$ and $\lambda_{d,i,j}$ denote the friction coefficients for related pipe components with length $L_{p,i,j}$, $L_{r,i,j}$ and $L_{d,i,j}$ diameter $D_{p,i,j}$, $D_{r,i,j}$ $D_{d,i,j}$ equivalent pipe roughness $k_{sp,i,j}$, $k_{sr,i,j}$, $k_{sd,i,j}$ respectively for either port, riser or diffuser component $j$. For each port or riser, the local and friction loss coefficients are determined iteratively, since they depend on the discharge.

2) The continuity equation (equation 1) between $i$ and $i-1$ allows specifying the velocities:

$$v^2_{d,i-1} = \frac{1}{A^2_{d,i-1}} \left( \sum_{k=1}^{i-1} q_k \right)^2$$
$$v_{d,i}^2 = \frac{1}{A_{d,i}^2} \left( \sum_{k=1}^{i} q_k \right)^2$$

3) The work energy equation (equation 2) applied along a streamline following the branch pipe and leaving the diffuser through the orifice results in equation (4). It equals the upstream diffuser pressure $p_{d,i}$ with the ambient pressure $p_{a,i}$ plus the static pressure difference due to the elevation difference between diffuser centerline and jet centerline, plus dynamic pressure difference between the diffuser and one single jet plus the pressure losses occurring in all pipe segments between these points:

$$p_{d,i} = p_{a,i} + \rho_e g (z_{jet,i} - z_{d,i}) + \frac{\rho_e}{2} v_{d,i}^2 - \frac{\rho_e}{2} v_d^2 + p_{e,d,i},$$

where pressure losses

$$p_{l,d,i} = \frac{\rho_e}{2} v_{p,i}^2 \left( \sum_{j=1}^{n_{p,i}} \left( q_{p,i,j} + \frac{\lambda_{p,i} L_{p,i,j}}{D_{p,i,j}} \right) \right) + \frac{\rho_e}{2} v_{r,i}^2 \left( \sum_{j=1}^{n_{r,i}} \left( q_{r,i,j} + \frac{\lambda_{r,i} L_{r,i,j}}{D_{r,i,j}} \right) \right),$$

with loss coefficients related to the reference velocity $v_{r,i-1}$.

4) The continuity equation (equation 1) between the diffuser and the port at position $i$ allows specifying the velocities:

$$v_{p,i}^2 = \frac{\rho_e}{2(C_{c,i} A_{p,i})} (\alpha_i q_i)^2$$

$$v_{r,i}^2 = q_i/A_{r,i},$$

where the individual jet discharge for more than one port at a riser is defined as $q_{jet,i} = \alpha_i q_i$ with $\alpha_i = 1/(\text{number of ports at a riser at position } i)$, thus assuming that the discharge through one specific riser with multiple ports is homogeneously distributed among these ports. This is valid for ports with similar geometry at this diffuser position that are mounted at the same elevation, what is common practice for multiport risers. Equation (4) therefore applies for multiple ports at one diffuser position or on the riser, but not for multiple risers at one location on the diffuser pipe, because constructional impractical. In addition $C_{c,i}$ defines the jet contraction coefficient either given by the user or calculated iteratively if Duckbill Valves are applied using $C_{c,i,DBV} = \alpha_i q_i/(V_{DBV,i} A_{p,i})$ with $V_{DBV,i}$ the duckbill jet velocity, which itself depends on the discharge individual port discharge $\alpha q_i$. 

38
For the calculation of the pressure outside the diffuser $p_a$, namely at the port orifice location, it is important to consider the exact elevation $z_{jet}$, a vertical density distribution $\rho_a = f(z)$ and the elevation of the water level $z_o = H$. 

\[
\int_{p_0}^{p_a} dp = - \int_{z_0}^{z_{jet}} \gamma_a(z) dz
\]

where $\gamma_a(z) = g \rho_a(z)$ and $p_o$ the reference pressure at the water surface, thus

\[
p_a = - \int_{z_0}^{z_{jet}} \gamma_a(z) dz + p_0
\]

The individual discharge $q_i$ is then given by solving equation (3) and (4) for $q_i$:

\[
q_i = \sqrt{\frac{2}{\rho_a} \left( p_{d,i-1} - p_{a,i} \right) + 2g \left( z_{d,i-1} - z_{jet,i} \right) + \left( \sum_{k=1}^{n_{r,i-1}} q_k \right)^2 \left( \frac{1}{A_{d,i-1}} \right) + \sum_{j=1}^{n_{p,i-1}} \left( \frac{1}{A_{p,i-1}} \right) \left( \frac{\zeta_{d,i-1,j} + \lambda_{d,i-1,j} \frac{L_{d,i-1,j}}{D_{d,i-1,j}}} {\zeta_{d,i-1,j} + \lambda_{d,i-1,j} \frac{L_{d,i-1,j}}{D_{d,i-1,j}}} \right) + \sum_{j=1}^{n_{r,i-1}} \left( \frac{1}{A_{r,i-1}} \right) \left( \frac{\zeta_{r,i-1,j} + \lambda_{r,i-1,j} \frac{L_{r,i-1,j}}{D_{r,i-1,j}}} {\zeta_{r,i-1,j} + \lambda_{r,i-1,j} \frac{L_{r,i-1,j}}{D_{r,i-1,j}}} \right) + \alpha_i \left( \frac{C_{\tau,i-1} A_{p,i-1}}{A_{p,i-1}} \right) \left( \frac{\zeta_{r,i-1,j} + \lambda_{r,i-1,j} \frac{L_{r,i-1,j}}{D_{r,i-1,j}}} {\zeta_{r,i-1,j} + \lambda_{r,i-1,j} \frac{L_{r,i-1,j}}{D_{r,i-1,j}}} \right) \right)}
\]

4.2 Friction losses - cross-sectional non-uniformities

The pipe flows are assumed to be axisymmetrical with a linear shear-stress distribution. Therefore, universal definitions for the velocity and shear-stress distributions apply. The velocity distribution can be approximated by a logarithmic profile, in practice often simplified with power laws in the form of $V/V_{max} = (y/r_o)^m$, where $V_{max}$ defines the maximum velocity, $y$ the transversal coordinate, $r_o$ the pipe radius and $m$ the power (e.g. $m = 1/7$ for $Re = 10^5$ (Jirka, 2001)).

Using a wall function a definition for the wall-shear stress $\tau_o$ results to

\[
\tau_o = \frac{\lambda V^2}{4 \rho_o^2}
\]

or in terms of a friction headloss in the so-called Darcy-Weisbach equation:

\[
h_{f,i} = \frac{\lambda V^2}{D 2g}
\]
where $L$ = the length of the considered pipe section and $\lambda$ = the friction coefficient defined by the Colebrook-White equation.

The friction coefficient $\lambda$ describes the relative influence of fluid viscosity and wall roughness by the dimensionless parameters $k_s/D$ with the equivalent sand roughness $k_s$ (after Nikuradse) and the Reynolds number $Re$. For laminar flows it is possible to derive $\lambda$ analytically to $\lambda = 64/Re$ (for $Re < 2000$). However, for turbulent flows only empirical values from experimental studies exist. For computer applications, an explicit formulation after Swamee and Jain (1976) is used $\lambda$:

$$\lambda = \frac{0.25}{\left(\log\left(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.5}}\right)\right)^2}, \quad \text{(10)}$$

which is valid for $10^{-6} < k_s/D < 10^{-2}$ and $10^{-3} < Re < 10^8$
Values of $k_s$ for different pipe materials and surface conditions of use are listed in Table 3. Further materials and conditions are listed in almost all hydraulics textbooks or are available from pipe manufacturers. A comprehensive summary is given in Idelchik (1986).

<table>
<thead>
<tr>
<th>material</th>
<th>condition</th>
<th>$k_s$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel</td>
<td>new</td>
<td>0.0015 - 0.0070</td>
</tr>
<tr>
<td></td>
<td>used</td>
<td>0.2 - 0.5</td>
</tr>
<tr>
<td>HDPE (high density polyethylene)</td>
<td>new</td>
<td>0.25 - 1</td>
</tr>
<tr>
<td></td>
<td>used (corroded)</td>
<td>1 - 1.5</td>
</tr>
<tr>
<td></td>
<td>old (heavily corroded)</td>
<td>3 - 4.5</td>
</tr>
<tr>
<td></td>
<td>with deposits</td>
<td>2 - 4</td>
</tr>
<tr>
<td>cast iron</td>
<td>new</td>
<td>0.3 - 0.8</td>
</tr>
<tr>
<td></td>
<td>new (average)</td>
<td>2 - 3</td>
</tr>
<tr>
<td></td>
<td>with joints</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3 - Outfall pipe materials and their related equivalent sand roughness values $k_s$ (Idelchik, 1986)

If only Manning’s $n$ values are known from literature or pipe manufacturers a conversion to $k_s$ can be done by:

$$k_s = (n 5.87 (2g)^{0.5})^6$$

(11)

4.2.1 Local losses - streamwise non-uniformities

Streamwise changes of the pipe system cause non-uniform streamwise velocities. Even gradual changes may hereby cause internal flow detachment processes, reverse currents in deadzones, locally increased accelerations or decelerations and overall increased turbulence. This increase is associated with additional energy, thus pressure losses. Typical geometrical differences occurring between one cross-sectional area and the adjacent one are inlets at the headworks or orifices at the outlet ports, pipe diameter expansions, contractions, bends, or combining and dividing flows.

Local pressure losses $h_{e,e}$ are generally parameterized as:

$$h_{e,e} = \zeta \frac{V^2}{2g}$$

(12)

where $\zeta$ denotes the dimensionless loss coefficient.

$\zeta$ depends on the geometrical configuration (diameter ratios, angles and radii of bends, gradual or immediate (rounded or sharp edged) changes), and the Reynolds number. For combining and dividing flows additional consideration of the flow ratios have to be included. Again mainly empirical values are available, which have been obtained in laboratory studies. There are numerous publications defining local loss coefficients $\zeta$ for a large number of different geometries under different flow conditions. Comparisons
between some of these publications showed considerable discrepancies even for simple geometries. The most accurate works stem from Idelchik (1986) and Miller (1990), which have been chosen for this study. The few analytical solutions (e.g. for sudden expansions) are also included.

The applied coefficients assume reasonably high Reynolds numbers (above $10^4$) and reasonable geometrical distance between the changes ($> 5D$) to avoid interaction of pressure losses. If needed, modification of the listed formulations can be found in Idelchik (1986). Furthermore, additional optional pressure losses, which are not considered here (e.g. obstructions due to valves or monitoring instruments), can be added manually.

Loss coefficients can be combined to reduce the amount of computation. The bulk loss coefficient is the sum of all coefficients, providing that the reference velocity is the same. Thus, all loss coefficients are being modified to refer to the same reference velocity $V_{ref}$. However, the velocity is an unknown quantity, but the flow rate $Q$ in one pipe section does not change. The modified loss coefficient $\zeta_{mod}$ is obtained by:

$$
\zeta_{mod} = \zeta \left( \frac{V^2}{V_{ref}^2} \right) = \zeta \left( \frac{Q/A}{Q/A_{ref}} \right)^2 = \zeta \left( \frac{A}{A_{ref}} \right)^2
$$

with $A_{ref}$ being the cross-sectional area of the reference section.

### 4.2.2 Simplifications and modeling assumption

The whole pipe system is assumed as flowing full under all conditions. A two-phase flow due to air entrance at the inlet or a stratified flow due to saltwater intrusion at the outlets will not be considered here. However, CorHyd allows specifying the hydraulic conditions down to which flowrate a full flowing system can be guaranteed. Air entrance at the inlet is avoided by keeping the top pipe invert under the minimum sea level or using backpressure valves or deaeration chambers. Saltwater intrusion can be avoided by keeping the port densimetric Froude number larger than unity (Wilkinson, 1988):

$$
F_p = \frac{V_p}{\sqrt{g\frac{\Delta \rho}{\rho}D_p}} > 1
$$

where $V_p$ and $D_p$ denote the port exit velocity and the port diameter respectively and $g\Delta \rho/\rho = g' \rho \frac{g \Delta \rho}{\rho}$ the reduced gravity with the density difference $\Delta \rho$ at the port orifice between the effluent and the ambient water. This condition can be achieved by designing either small enough port diameters or using variable area orifices.
4.3 Solving scheme

The pre-processor of CorHyd is used to calculate geometrical relations (i.e. lengths of pipe sections, horizontal and vertical angles between pipe axis and diameter ratios) and pre-defining necessary formulations for the calculation of loss coefficients according to the specified input data. CorHyd then solves for either the total head or the total flow together with the discharge distribution along the diffuser line. The post-processor allows for graphical visualization and saves the results additionally in an ASCII file for further coupling or external analysis. Additional program features allow for design optimization and off-design analysis.

To allow for an easy input procedure and fast calculations, CorHyd consists of different modules. Depending on the input details, CorHyd chooses automatically the applicable modules without user interaction. The CorHyd modules are:

1. One diffuser (simple setup)
2. Two diffusers (T or Y setup), where two diffuser calculations are coupled with one feeder pipe calculation
3. One of the following algorithms is used:
   a. Given total discharge, solve for the individual discharges and the total head.
   b. Given total head, solve for the individual discharges and the total discharge.

4.3.1 Algorithm given bulk discharge: solving for total head

The typical application is related to the problem where a total discharge \( Q_0 \) is given (e.g. treatment plant flow rate). For existing diffuser geometry and given boundary conditions (i.e. ambient pressure and/or ambient water level and density distribution), the governing equations can then be solved for the individual discharges and for the total head (bulk head) at the headworks necessary to drive the system.

The solving scheme starts with an estimate (initial condition) of the initial discharge \( q_1 \) at the first port/riser on the seaward side \((i = 1)\). CorHyd calculates this estimate using \( q_1 = \frac{Q_0}{N} \) with \( N \) = total number of risers. Equation (4) then gives the first internal pressure of the diffuser \( p_{d,1} \). Subsequent discharges \( q_2 \) until \( q_N \) are then calculated by equation (7). The total discharge is \( Q_{c(s)} = \sum_{k=1}^{N} q_k \). The error compared to the planned total discharge is \( e_{(s)} = Q_0 - Q_{c(s)} \). Further iterations (numbering \( s \)) are performed with modified initial conditions \( q_{1,m(s)} \) until sufficient accuracy is achieved (CorHyd uses the default stop condition \( e_{(s)} < Q_0/10,000 \)). To achieve fast convergence the algorithm in equation (15) has been implemented to calculate \( q_{1,m(s)} \):
\[ q_{1,m(1)} = q_1 \sqrt{\frac{Q_o}{Q_{c(1)}}}; \quad q_{1,m(2)} = q_1 e_2 - q_{1,m(1)} e_1; \quad \ldots \]

\[ q_{1,m(s)} = q_{1,m(s)} e_s - q_{1,m(s-1)} e_{s-1}; \quad \text{for } s > 2 \]  \hspace{1cm} (15)

A final application of equation (3) gives the total pressure \( p_{d,N+1} \) at the headworks. The total head \( H_t \) is defined as \( H_t = \frac{p_{d,N+1}}{\gamma} \) for example if the water level elevation of a gravity driven system or the necessary pump head has to be defined.

### 4.3.2 Algorithm for given total head: solving for total flow

The solution method changes for cases where the total head is limited, for example if gravity discharge is desired and treatment plant operation results in a given water level elevation \( H_t \). For existing diffuser geometry and given boundary conditions (i.e. ambient pressure and/or ambient water level and density distribution) the governing equations can be solved for the individual discharges and the total flow (bulk flow) which is possible for those conditions.

The solving scheme then starts with an estimate (initial condition) of the initial internal pressure \( p_{d,1} \) at the first port/riser location on the seaward side. CorHyd already implemented this estimate using \( p_{d,1} = \frac{H_t \gamma}{N} + p_{a,1} + \gamma (z_{jet,i} - z_{d,i}) \). Equation (4) then gives the first discharge \( q_1 \). Subsequent discharges \( q_2 \) until \( q_N \) are then calculated by equation. Equation (3) gives the total pressure \( p_{d,N+1} \) at the headworks. The total head is \( H_{t,c(s)} = \frac{p_{d,N+1}}{\gamma} \). The error compared to the planned total head is \( e(s) = H_t - H_{t,c(s)} \).

Further iterations (numbering \( s \)) are performed with modified initial conditions \( p_{d,1,m(s)} \) until sufficient accuracy is achieved (CorHyd uses the default stop condition \( e(s) < H_t/10,000 \)). To achieve faster convergence the algorithm in equation (16) has been implemented to calculate \( p_{d,1,m(s)} \):

\[ p_{d,1,m(1)} = p_{d,1} \frac{H_t}{H_{t,c(1)}}; \quad p_{d,1,m(2)} = p_{d,1,m(1)} e_2 - p_{d,1,m(2)} e_1; \quad \ldots \]

\[ p_{d,1,m(s)} = p_{d,1,m(s)} e_s - p_{d,1,m(s-1)} e_{s-1}; \quad \text{for } s > 2 \]  \hspace{1cm} (16)

The total discharge is \( Q_o = \sum_{k=1}^{N} q_k \).
5 Design and Optimization

The feeder diameter design is constrained by a maximum diameter to allow scouring of sediments during low flow periods. The near future design discharge $Q_{nf}$ (daily maximum) should therefore result in feeder velocities $v_{f,nf} > 0.5$ m/s (DIN EN 1671, ATV-DVWK-A 110 (2001) and ATV-DVWK-A 116 (2005)). This corresponds to a maximum feeder pipe diameter of $D_{d,max} = (Q_{nf} 8/\pi)^{0.5} \approx 1.6 Q_{nf}^{0.5}$. The feeder velocity for the far future design flowrate $Q_{ff}$ and the same diameter results then in $v_{f,ff} = v_{f,nf} Q_{ff}/Q_{nf}$. Generally, flow rates do not more than double or triple during the lifetime of an outfall, so far field feeder velocities are from 1 to 2 m/s, what is clearly acceptable in terms of operational viewpoints considering the related pressure losses.

The same considerations apply for the diffuser pipe, though that the flow decreases with every riser. Theoretically this would result in a continuously decreasing diffuser pipe diameter, but practical solutions include only very few of these tapers. This is because tapered diffusers are more expensive to install (about 20% more expensive than single diameter diffuser) and maintain (i.e. cleaning).

Port diameters are constrained by operational restrictions, where a 50 mm minimum port size for secondary- or tertiary-level treated effluent and storm water inflow to the sewage system was suggested by Wilkinson and Wareham (1996), to avoiding the risk of blockage. A minimum port size of 70 to 100 mm was specified for primary treatment plants (just screening and settling tank).

5.1 Design Methodology

The design of multiport diffusers depends on several interacting parameters. The general approach is schematized in Figure 21, which converges to an optimized system.
The first design flow rate should be the maximum foreseen at the end of design life. Generally there is a headworks basin (or the treatment plant itself) with sufficient capacity to accept daily peaks and storm waters. The ratio of the peak rate of flow to the average rate of flow might hereby range from 6 for small areas down to 1.5 for larger areas. For large ratios commonly additional storm water outfalls are foreseen. In the former cases, the design can be made on the average daily maximum flow at life end. For installations without storage facilities the design flowrate is the daily peak flow either including or excluding the stormwater peak discharges. The latter design discharge does not occur on a daily basis; therefore, optimization procedures for non-design discharges are even more important than for the other cases. The first internal hydraulics design step described in Table 4 uses the resulting geometries for a baseline calculation regarding the maximum design flow.
**Step 1: Baseline calculation - for far future design conditions**

- The data from the first successful mixing calculations is used as first design alternative for the internal hydraulics
  ⇒ run CorHyd with very few diffuser and port/riser sections and plot results

- Pipe velocities: Diffuser, riser and port velocities should be in between reasonable ranges, otherwise the diameters have to be increased or decreased generally for all sections and/or groups \( V_d < V_r < V_p < V_j \)
  ⇒ modify feeder/diffuser diameter to obtain operable velocities \( 0.5 \text{ m/s} < V_d < 5 \text{ m/s} \)
  ⇒ modify riser diameters to obtain operable velocities \( 0.5 \text{ m/s} < V_r < 5 \text{ m/s} \)
  ⇒ modify port diameters to obtain operable velocities \( 0.5 \text{ m/s} < V_p < 12 \text{ m/s} \) for at least a majority of port/riser configurations
  ⇒ port diameters should not be less than 100 mm to avoid possible problems of blockage

- Total head: The necessary total Head or the final flow should be in the desired order of magnitude, otherwise velocities and/or locations of high pressure losses should be reduced
  ⇒ simplify geometries and/or increase diameters to reduce the total head

- Flow distribution:
  ⇒ check whether the flow distribution lies in between reasonable limits \( |q_i - q_{mean}| \leq 0.1 \frac{Q}{N} \) for at least the majority of port/riser configurations
  ⇒ modify riser diameters for the whole diffuser to obtain a more homogeneous distribution of the riser inlet pressure losses
  ⇒ modify port diameters for the whole diffuser to obtain a more homogeneous distribution of the port pressure losses (i.e. if Duckbills are applied)

- Check external hydraulics with modified diffuser

- If either the external hydraulics or even the modified internal hydraulics does not fulfill the general requirements listed above, the user should try to do a re-design of the main diffuser characteristics. Else, proceed to the optimization in step 2.

**Table 4 Step 1: Baseline calculation - for far future design conditions**

However, diffusers are generally operated under varying flow conditions due to diurnal or seasonal changes. CorHyd includes a batch processing mode for diffuser analysis using varying effluent flows or varying total head values. Varying inflows can affect the discharge distribution for diffusers which are not horizontal.
Under low-discharge conditions, diffusers are confronted with issues of sediment deposition and/or intrusion of seawater. Seawater intrusion can seldom be avoided for all discharges. Duckbill valves and small diameter pipes prevent those problems, but lead to additional pumping costs or higher headworks storage buildings. Intrusion can be prevented if the port densimetric Froude number \((F)\) is bigger than one (Wilkinson, 1988). Particle deposition can be avoided by achieving pipe velocities bigger than critical velocity \((\approx 0.5 \text{ m/s})\) at least once a day. Thus, the second design step (Table 5) considers the diffuser performance for varying conditions and improves the design mainly by local changes along the diffuser line.

**Step 2: Diffuser characteristics - diffuser performance calculations**

- Analyze diffuser performance for intermediate flows
  ⇒ run CorHyd time-series for varying discharges and plot results

- Pipe velocities: time-series results allow to denote diffuser sections, where scouring velocities are too low for most of the flow rates and/or where port Froude numbers are below or near unity.
  ⇒ create additional diffuser sections at positions, where scouring velocities are not obtained for discharges which occur once a day
  ⇒ create additional port/riser groups for added diffuser sections (starting with the same geometry).
  ⇒ modify diffuser section diameters locally (tapering) to obtain scouring velocities

- Flow distribution: check whether the flow distribution lies in between reasonable limits \[\left(\frac{|q_i - q_{mean}|}{Q/N} \leq 0.1\right)\] for at least the majority of port/riser configurations
  ⇒ modify the riser group diameters locally
  ⇒ modify port group diameters locally
  ⇒ introduce additional port/riser groups if necessary and repeat local modifying

- Check external hydraulics with modified diffuser

- If either the external hydraulics or even the modified internal hydraulics do not fulfill the general requirements as listed above the user should try to do a re-design of the main diffuser characteristics. Else, proceed to the optimization in step 3.

**Table 5** Step 2: Diffuser characteristics - diffuser performance calculations

Additional analysis is needed, once the diffuser flows at startup differ considerably from those of the final design. A common technique to overcome the problem of initial malfunctions is “expanding diffusers” (Avanzini, 2003). These are designed to meet the initial and final requirements by either closing initially a certain number of ports (with fixed closures, welded duckbills or backpressure regulations, where former have to be removed manually and the latter open autonomous if enough discharge enters the
CorHyd User Manual

system) or modifying port diameters using replaceable flanged orifices (Bleninger et al., 2004). Furthermore, it is often easier and cheaper to operate the diffuser under these optimized conditions than operating the final diffuser with low flows.

CorHyd allows analyzing the diffuser performance for these scenarios by simply closing the ports or modifying the configurations. This routine may also be used for the analysis of accidents like port/riser ruptures due to anchor collisions, earthquakes, or structural failures. Step 3 (Table 6) thus considers off-design analysis and optimization.

<table>
<thead>
<tr>
<th>Step 3: Off-design calculation - near future design conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Near-future mixing calculations are used to figure out the number of necessary ports for low flow discharges.</td>
</tr>
<tr>
<td>- Analyze pipe velocities, and the flow distribution, if the final diffuser configuration with clogged ports allows discharging near-future flows under reasonable conditions.</td>
</tr>
<tr>
<td>- Check external hydraulics with modified diffuser</td>
</tr>
<tr>
<td>- If either the external hydraulics or even the modified internal hydraulics do not fulfill the general requirements as listed above the user should try to do a re-design of the main diffuser characteristics. Else, proceed to the optimization in step 4.</td>
</tr>
</tbody>
</table>

Table 6 Step 3: Off-design calculation - near future design conditions
5.2 Sensitivity Analysis

Multiport diffuser installations are complex and large constructions submerged in coastal waters. Besides the previously discussed varying environmental conditions, further uncertainties regarding constructional imprecision and deterioration have to be analyzed. In addition the governing equations are based on certain simplifications (i.e. empirical loss coefficients), which contain another source of inaccuracy. It is therefore strongly recommended to elaborate sensitivity analysis by varying critical parameters and comparing the consequences on the design parameters (total head and discharge distribution). This is especially important for the local loss coefficients and pipe roughness. Examples for that analysis are given in Wood et al. (1993, p. 133) and WRc (1990). Once considerable differences are obtained, it is recommended to perform laboratory studies for more accurate definitions of the coefficients.

<table>
<thead>
<tr>
<th>Step 4: Sensitivity analysis - prediction accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Final diffuser design under maximum discharge conditions</td>
</tr>
<tr>
<td>⇒ run CorHyd with additional port pressure losses to check influences of loss formulations on final result</td>
</tr>
<tr>
<td>⇒ vary geometrical details to check influences of construction imprecision on final result</td>
</tr>
<tr>
<td>⇒ add additional pressure losses on whole pipe-system to account for imprecision</td>
</tr>
<tr>
<td>⇒ vary material properties, roughness to check influences of deterioration</td>
</tr>
<tr>
<td>- Check external hydraulics with modified diffuser</td>
</tr>
</tbody>
</table>

Table 7 Step 4: Sensitivity analysis - prediction accuracy
Table 8 summarizes the results of a sensitivity analysis performed with CorHyd. It is hereby distinguished between horizontal and sloped diffusers where the port elevations are either at constant depth or varying along the diffuser.

<table>
<thead>
<tr>
<th>Increasing the ... :</th>
<th>leads to ... of the total head or the discharge distribution resp.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Head</td>
</tr>
<tr>
<td>Total discharge (no slope)</td>
<td>↑↑</td>
</tr>
<tr>
<td>- “ - (with slope)</td>
<td>↑↑</td>
</tr>
<tr>
<td>Ambient water depth (no slope)</td>
<td>↑↑</td>
</tr>
<tr>
<td>- “ - (with slope)</td>
<td>↑↑</td>
</tr>
<tr>
<td>Density difference (no slope)</td>
<td>↑</td>
</tr>
<tr>
<td>- “ - (with slope)</td>
<td>↑</td>
</tr>
<tr>
<td>Feeder length</td>
<td>↑</td>
</tr>
<tr>
<td>Diffuser length (constant total length)</td>
<td>↓↓</td>
</tr>
<tr>
<td>Diffuser pipe diameter</td>
<td>↓↓</td>
</tr>
<tr>
<td>Pipe roughness</td>
<td>↑</td>
</tr>
<tr>
<td>Number of risers (constant diffuser length)</td>
<td>↓</td>
</tr>
<tr>
<td>Riser spacing (variable diffuser length)</td>
<td>↓↓</td>
</tr>
<tr>
<td>Riser height</td>
<td>↑</td>
</tr>
<tr>
<td>Ports per riser</td>
<td>↓</td>
</tr>
<tr>
<td>Port diameter</td>
<td>↓</td>
</tr>
<tr>
<td>Flexible valves</td>
<td>↑↑</td>
</tr>
</tbody>
</table>

↑ / ↓ = moderate in-/ decrease
↑↑ / ↓↓ = strong in-/ decrease
0 = neutral or small changes

Table 8 Sensitivity of involved parameters on head loss, total head, and homogeneity of the discharge profile.

### 5.3 Design rules

A design rule that is often mentioned in literature (Grace 1978), recommends to keep the ratio between the cumulative port areas downstream a diffuser pipe $\Sigma_{k=1}^{N} A_{p,k}$ and the cross sectional area of the diffuser pipe $A_{d,N}$ smaller than one. This is explained by the justification that "it is impossible to make a diffuser flow full if the aggregate jet area exceeds the pipe cross-section area, since that would mean that the average velocity of discharge would have to be less than the velocity of flow in the pipe" (Fischer et al. 1979,
A further suggestion taken from Fischer et al. (1979, p.419) resumes that the best ratio “is usually between 1/3 and 2/3”, $1/3 < \sum_{k=1}^{i} (A_{p,k}/A_{d,i}) < 2/3$. These criteria work fine for simple and uniform geometries without risers and for horizontal laid diffusers or for first estimates. However, they can be unnecessarily conservative if no further optimization is done. For example, sloped diffusers (following the sloped bathymetry) may equalize the distortion of the discharge profile resulting from an area ratio bigger than one. First estimates for non-uniform riser systems can be done by replacing the port cross-sectional area in the mentioned criteria with the riser cross-sectional area and applying these criteria for each section separately.

Nevertheless, for changing geometries along the diffuser the previous criteria are not applicable in general. This, because 1) the diffuser velocities generally decrease along the diffuser or change considerably if tapering is applied, 2) the port/riser velocities may change if port/riser diameters are varied along the diffuser line causing a variation of $C_r$ and 3) the flow distribution depends also on the pressure losses along the diffuser, causing a variation of $\zeta_{dr}$. For example, pressure losses along the diffuser are considerably different for systems with same area ratio, but different number of openings.

Design rules regarding general loss ratios (Weitbrecht et al., 2002) for diffuser sections and downstream ports are also only applicable for simple geometries (no changes along the diffuser). For others, they are either unnecessarily conservative or not applicable, because pressure losses are changing drastically along actual diffuser installations and cannot be summarized for the whole diffuser construction.

Therefore a design rule for non-uniform systems or for uniform sections and groups of a non-uniform system has to come out of a combination of a loss ratio (buoyancy and riser inlet (or port outlet) and a velocity ratio (diffuser velocity and branch velocity (port or riser)). Furthermore, sections and groups of a non-uniform system have to be balanced in between each other to achieve an overall uniform diffuser performance. The optimal procedure to organize these modifications also under different flow conditions and further design criteria is described in the following chapters.

5.4 Off-design Conditions: Transients, saline intrusion and purging

Extraordinary conditions, like very short pumping cycles (order of minutes), full shutdown of flow, purging of a saline wedge during start-up or water-hammer issues cannot be analyzed with CorHyd due to its steady state assumption. Any of these conditions should be avoided by using duckbill valves, slowly closing valves, or pumps, sufficiently large headworks reservoirs allowing for long pumping cycles or flushing periods.

For the analysis of saline wedge purging usually laboratory or numerical studies are performed. Saline wedge purging can be guaranteed, for example, by using some velocity
criterion (Wilkinson, 1984) or a plug flow system, where one half of the outfall volume is accumulated in the headworks storage and then pumped at high velocities (e.g. 1.5 m/s proposed by Wood et al. (1993, pp. 122, pp. 326)). The time required to reach steady state once purging was initiated must also be determined (see Wilkinson und Nittim, 1992). Furthermore, flow accelerations during pump start-up could lead to oscillations (WRC 1990, p. 212). Wave-induced oscillations occur if large waves are passing over a diffuser section in shallow water (Grace, 1978, p. 302). Resonance effects and internal density-induced circulations are possible (Wilkinson, 1985).

Steady conditions should be achieved also by using sufficient storage capacities for extreme conditions during start-up or shutdown and by applying slowly changing valves and pumps. Otherwise, for example decreasing discharges may lead to a situation, where moving fluid in the outfall sucks the effluent from the headworks even beyond the equilibrium level, and swinging back once the flow is entirely shut down, sucking seawater in the outfall (Burrows, 2001). Besides the necessity of subsequent outfall purging the latter has critical impacts on valves mounted on discharge ports. Another critical situation might be related to wave motions in the ambient water, changing ambient pressure along the diffuser (wave crest above one riser and wave trough above other). These pressure differences can have effects on the flowrate distribution, if the fluid volume in the riser/port configuration is relatively small, compared to additional forcing (Mort, 1989).

However, the design should foresee steadily driven systems with add-on considerations of off-design conditions. Therefore, the calculator applies steady-state conditions only.

### 6 Case Study

The planned Berazategui outfall in Buenos Aires, Argentina has been chosen for that case study (Bleninger et al., 2005). The Berazategui outfall is planned to discharge the treated effluents of a wastewater treatment plant to be constructed for the city of Buenos Aires. The sewer-system is separated from the storm-water sewer and is designed for an average effluent flowrate of about 25 m³/s with a maximum peak discharge of 33.5 m³/s. The outfall starts at the pumping basin on the onshore headworks, from where a 4500 m long feeder tunnel conveys the effluent to the 3000 m long diffuser in the discharge area (Figure 22). The diffuser is composed of vertical risers carrying four ports in a rosette-like arrangement (Figure 23).
Figure 22  Schematic view of diffuser longitudinal section of Berazategui outfall

Figure 23  Side and top view of riser/port configuration of diffuser
The receiving water body is the Rio de la Plata estuary of the rivers Paraná and Uruguay (average annual fresh water discharge: 23,000 m³/s). The width of the estuary at the outfall location is about 50 km with a depth varying from 4 to 7 m (Figure 24). Tidal currents, including temporal density stratifications dominate the velocity field (average local velocity: \( u_a = 0.04 \) m/s, maximum velocities during tidal cycle \( u_{a,max} = 0.3 \) m/s).

![Figure 24](image)

**Figure 24** Top view of the Rio de la Plata delta showing the location of the Berazategui outfall and the ambient characteristics at its location (source: Nasa, 2005)

The calculated internal flow characteristics of the diffuser are summarized in Figure 25 and Figure 26 for maximum flow \( Q_{max} = 33.5 \) m³/s. A reasonably good discharge distribution along the diffuser (first bar-chart, Figure 25) with maximum deviations from the mean discharge of not more than 10% of the mean discharge (second bar-chart, Figure 25) could be obtained to an equal dilution requirement along the diffuser. Due to different pressure losses along the diffuser pipe and the port/riser configurations (line in second bar-chart, Figure 25) the discharge is decreasing typically to the seaward end, which can be prevented by modifying the geometries along the diffuser. In this case by reducing the main diffuser diameter to the seaward end, which also improves the diffuser velocities at the end sections (second bar-chart, Figure 26).

The use of duckbill valves with a nominal diameter of 150 mm provides a more homogeneous flow distribution especially for low flows (Figure 27). Without duckbills the flow distribution is unaffected by changing the total flow due to negligible density differences between the effluent and the ambient and the almost horizontal installation of the diffuser. However, the total head \( (H_t) \) necessary to drive the system is higher with
duckbill valves (Figure 27, legend). Larger duckbills (200 mm) reduce the total head almost to the level without duckbills, but decrease also the effects on the discharge distributions to negligible levels. Changes in the ambient water level do not have any effect on the flow characteristics but increase the total head.

To prevent intrusion of ambient water (including sediments), especially during low flow, the port densimetric Froude number should be bigger than unity. This gives a critical port velocity $V_{p,crit} = (\Delta \rho / \rho g D_p)^{0.5} = 0.041 \text{ m/s}$ for Berazategui. All port and jet exit velocities are considerably higher for all applied flow rates. Duckbill valves cause additionally a homogenization of the jet exit velocities.
Figure 25  Flow characteristics for final design at maximum flow: Individual riser flow distribution along diffuser, riser flow deviation from mean
Figure 26 Flow characteristics for final design at maximum flow: port and jet discharge velocities and diffuser pipe velocities, port and diffuser diameter (lines).
An increasing inflow or increasing ambient water level mainly increases the total head. Headworks storage tanks should be capable of managing these changes. For slowly increasing future flows, an extension of storage tanks can be done only when necessary, saving investment costs for the commissioning.
Figure 28 Changes in total head for varying discharges (fixed orifice ports)
Appendix A  Loss Coefficients in CorHyd

Local losses are due to geometrical differences between one cross-sectional area of a pipe and the adjacent one (i.e. expansions, contractions, or bends) or the inlet or end of a pipe (orifice). These changes may lead to flow detachment processes, reverse currents in deadzones, locally increased accelerations or decelerations, increased turbulence, which all cause energy losses, in closed pipe systems compensated by pressure losses.

Local pressure losses $p_1$ in a pipe system are generally calculated as:

$$p_1 = \zeta \frac{\rho_e V^2}{2}$$

or as headloss

$$p_1 / \gamma_e = \zeta \frac{V^2}{2g}$$

where $\zeta$ denotes the dimensionless loss coefficient, $\rho_e$ the effluent density and $V$ the reference velocity either upstream or downstream the geometrical change.

Table 9 gives an overview of implemented local loss coefficients $\zeta$. They are calculated automatically in CorHyd. These assume reasonable high Reynolds numbers (above $10^4$) and reasonable geometrical distance between the changes to avoid interaction of losses. Modification of the listed formulations can be found in Idelchik (1986) for special geometries and some limited ranges of Reynolds numbers, although those are not implemented in CorHyd. Furthermore additional optional losses can be added manually for risers and ports.
Table 9 Local Loss Formulations

<table>
<thead>
<tr>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>Sharp edged inlet (Idelchik, 1986)</td>
</tr>
<tr>
<td></td>
<td>(Reference velocity is $V$)</td>
</tr>
<tr>
<td></td>
<td>$\zeta = 0.5$</td>
</tr>
</tbody>
</table>

The value $\zeta = 0.5$ is automatically implemented in the code, if a feeder pipe exists. Although most of the constructions do have sharp edged inlets from the headworks into the feeder pipe other configurations may be applied by using the following graphs and changing the code in the mentioned files (zeta_entry = “new value”).
Rounded inlets (Idelchik, 1986, Miller, 1978)

The loss coefficient $\zeta$ for rounded (radius $r$) or edged inlets (angle $\Theta$ and edge width $t$) depends on either the relation of rounding radius $r$ and the pipe diameter $d$ or the edge width $t$ and the pipe diameter $d$ as well as the angle $\Theta$.

Expansion

(Reference velocity is $V_1$)

\[
\zeta_e = \left(1 - \frac{A_1}{A_2}\right)^2 = \left(1 - \left(\frac{d_1}{d_2}\right)^2\right)^2
\]

Sudden expansion (Idelchik, 1986)
Gradual expansion (Idelchik 1986)
\[
\zeta_e = 3.2 \cdot \tan \frac{\beta}{2} \cdot \left[ \tan \frac{\beta}{2} \left( 1 - \frac{A_1}{A_2} \right)^2 \right]
\]
with \( \beta \) in rad

Contraction
(Reference velocity is \( V_2 \))

Sudden contraction (Idelchik, 1986)
\[
\zeta_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right)^{3/4} = 0.5 \left( 1 - \left( \frac{d_2}{d_1} \right)^2 \right)^{3/4}
\]

Gradual contraction (Idelchik 1986)
\[
\zeta_c = \left( -0.0125 \cdot n_0^4 + 0.0224 \cdot n_0^3 - 0.00723 \cdot n_0^2 + 0.0044 \cdot n_0 - 0.00745 \right) \cdot (\beta^3 - 2\pi\beta^2 - 10\beta)
\]
with \( n_0 = \frac{A_2}{A_1} \leq 1.0 \) and \( \beta \) in rad

Bending
(reference velocity after bending)

Bend (Kalide 1980)
\[
\zeta_b = \left[ 0.131 + 0.159 \left( \frac{D}{R} \right)^{3.5} \right] \cdot \delta \left( \frac{180^\circ}{\delta} \right)
\]
where \( D \) is the pipe diameter and \( R \) the radius of the bend. Often applied as \( R = 3D \). Delta is the angle of the bend (e.g., rectangular bends).

Friction due to bend (Idelchik 1986)
\[
\zeta_{fr} = \lambda \cdot \frac{L}{D} \quad \text{with} \quad \frac{L}{D} = \pi \cdot \frac{\delta}{180^\circ} \cdot \frac{R}{D}
\]

Division of flow

T-division (Idelchik 1986)
\[
\zeta_t = 1 + 1.5(\alpha A/A_p)^2
\]
Flow is divided equally at an end of a pipe.
Unequal flow division (Idelchik 1986)

Branch (entering riser): \( \zeta_s = \frac{\zeta_{c,s}}{(V_r/V_d)^2} \)

Main pipe: \( \zeta_{st} = \frac{\zeta_{c,st}}{(V_r/V_d)^2} \)

with an angle between riser and diffuser axis assumed to be nearly 90°, and where \( \zeta_{c,st} \) from (Idelchik, 1986), \( \zeta_{c,s} = A \zeta_\zeta \zeta'_{c,s} \), with determination of \( A \) = 1.1 - 0.7 \( \frac{q_r}{q_d} \) when \( \frac{A_r}{A_d} \leq 0.35 \) and \( \frac{q_r}{q_d} \leq 0.4 \)

\[ A \zeta = 1.1 - 0.7 \frac{q_r}{q_d} \]

when \( \frac{A_r}{A_d} > 0.35 \) and \( \frac{q_r}{q_d} > 0.4 \)

\[ A \zeta = 0.85 \]

and determination of \( \zeta'_{c,s} \)

\[ \frac{D_r}{D_d} \leq 2/3 \quad \zeta'_{c,s} = 0.7956(\frac{V_r}{V_d})^2 + 0.2732(\frac{V_r}{V_d}) + 0.956 \]

\[ \frac{D_r}{D_d} = 1 \quad \zeta'_{c,s} = 0.3(\frac{V_r}{V_d})^2 + 1 \]

\[ 2/3 < \frac{D_r}{D_d} < 1 \quad \zeta'_{c,s} = 0.3(\frac{V_r}{V_d})^2 + 1 + (1-\frac{D_r}{D_d}(1-2/3))(0.7956(\frac{V_r}{V_d})^2 + 0.2732(\frac{V_r}{V_d}) + 0.956) - (0.3(\frac{V_r}{V_d})^2 + 1) \]

Orifices

Straight orifice

\[ \zeta = 1 \]

In addition, especially for straight orifices covered with perforated plates further losses can be added.

Side branching orifice (Fischer et al. 1979)

For sharp-edged and rounded orifices see eq. Error! Reference source not found. and Error! Reference source not found.

Flexible orifices (duckbills)


\[ \zeta_{duck} = \frac{H \cdot (\rho \cdot g)}{\rho \cdot \frac{V_{duck}}{2}} = \frac{2 \cdot H \cdot g}{V_{duck}^2} \]

Where \( H \) denotes the headloss, \( V_{duck} \) the discharge velocity which depends on the effective open area \( A_{duck} \) which depends on the flow through the valve. All these parameters are also dependent on the used stiffness of the rubber material.
### Inaccuracies in pipe siting

\( \zeta = n \zeta_s \), where \( n \) is the number of fittings (ATV-DVWK A110, 2001)

<table>
<thead>
<tr>
<th>( D ) [mm]</th>
<th>( \zeta_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.017</td>
</tr>
<tr>
<td>300</td>
<td>0.014</td>
</tr>
<tr>
<td>400</td>
<td>0.012</td>
</tr>
<tr>
<td>500</td>
<td>0.010</td>
</tr>
<tr>
<td>600 - 1000</td>
<td>0.005</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>0</td>
</tr>
</tbody>
</table>

### Inaccuracies in pipe fittings

\( \zeta = n \zeta_f \), where \( n \) is the number of fittings (ATV-DVWK A110, 2001)

<table>
<thead>
<tr>
<th>( D ) [mm]</th>
<th>( \zeta_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
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</tr>
<tr>
<td>300</td>
<td>0.006</td>
</tr>
<tr>
<td>400</td>
<td>0.004</td>
</tr>
<tr>
<td>500</td>
<td>0.003</td>
</tr>
<tr>
<td>600 - 1000</td>
<td>0.0015</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Diverging wye of the type $F_c + F_{st} > F_{st}$; $F_{st} = F_c$.

$\alpha = 0\text{–}90^\circ$, Side branching. [10]

Diagram

1. $0 < \alpha < 60^\circ$ and $\alpha = 90^\circ$ at $h_y/h_C < 2/3$:

$$s_{ct} = \frac{\Delta P_2}{\rho w^2_{2}/2} = A' \left[ 1 + \left( \frac{w_x}{w_C} \right)^2 - 2 \frac{w_x}{w_C} \cos \alpha \right] = A' s_{ct, s}$$

2. $\alpha = 90^\circ$ and $h_y/h_C = 1.0$ (up to $w_y/w_C = 2.0$):

$$s_{ct} = \frac{\Delta P_2}{\rho w^2_{2}/2} = A' \left[ 1 + 0.3 \left( \frac{w_x}{w_C} \right) \right] = A' s_{ct, s}$$

$h_y$ is the height of the cross section of the side branch;
$h_C$ is the height of the cross section of the common straight channel.

Values of $s_{ct, s}$

<table>
<thead>
<tr>
<th>$w_x/w_C$</th>
<th>$\alpha, ^\circ$</th>
<th>$\frac{h_y}{h_C} &lt; 2/3$</th>
<th>$\frac{h_y}{h_C} = 1.0$</th>
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</thead>
<tbody>
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<td></td>
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<td>45</td>
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<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
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<td>0.82</td>
<td>0.84</td>
<td>0.87</td>
</tr>
<tr>
<td>0.2</td>
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<td>0.75</td>
</tr>
<tr>
<td>0.4</td>
<td>0.38</td>
<td>0.46</td>
<td>0.60</td>
</tr>
<tr>
<td>0.6</td>
<td>0.20</td>
<td>0.31</td>
<td>0.50</td>
</tr>
<tr>
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<td>0.09</td>
<td>0.25</td>
<td>0.51</td>
</tr>
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<td>0.07</td>
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<tr>
<td>1.2</td>
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<td>0.74</td>
</tr>
<tr>
<td>1.4</td>
<td>0.24</td>
<td>0.70</td>
<td>0.98</td>
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<tr>
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<td>0.46</td>
<td>0.80</td>
<td>1.30</td>
</tr>
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<td>2.16</td>
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<td>2.75</td>
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<tr>
<td>10</td>
<td>98.0</td>
<td>98.3</td>
<td>98.6</td>
</tr>
</tbody>
</table>

Figure 29 Diagram for the coefficients to compute the loss coefficient for a flow division (reproduced from Idelchik, 1986)

A-7
Figure 30 Diagram for the coefficients to compute the loss coefficient for a flow division (reproduced from Idelchik, 1986)
Threaded wyes of the type \( F_s + F_c > F_c \cdot F_{st} = F_c \) made of malleable iron; \( \alpha = 90^\circ \) [2]

### Diagram 7-18

**Side branch**

\[
\zeta_{c,s} = \frac{\Delta p_s}{\rho w_2^2/2}, \text{ see the curves } \zeta_{c,s} = f(Q_s/Q_c) \text{ at different } F_s/F_{st};
\]

\[
\zeta_s = \frac{\Delta p_s}{\rho w_2^2/2} = \frac{\zeta_{c,s}}{(Q_s/Q_c)^2}.
\]

**Straight passage**

\[
\zeta_{c,ct} = \frac{\Delta p_{st}}{\rho w_2^2/2}, \text{ see the curve } \zeta_{c,ct} = f(Q_{st}/Q_c) \text{ at all } F_s/F_c;
\]

\[
\zeta_{st} = \frac{\Delta p_{st}}{\rho w_2^2/2} = \frac{\zeta_{c,ct}}{(1 - Q_s/Q_c)^2(F_s/F_{st})^3}.
\]

**Values of \( \zeta_{c,s} \) and \( \zeta_{c,ct} \)**

<table>
<thead>
<tr>
<th>( F_s/F_c )</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_s/Q_c )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( (Q_{st}/Q_c) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \zeta_{c,s} )</td>
<td>0.09</td>
<td>2.80</td>
<td>4.50</td>
<td>6.00</td>
<td>7.88</td>
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<td>1.00</td>
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<td>1.50</td>
<td>1.60</td>
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</table>

**Values of \( \zeta_{c,ct} \)**

<table>
<thead>
<tr>
<th>( F_s/F_c )</th>
<th>0.70</th>
<th>0.64</th>
<th>0.60</th>
<th>0.57</th>
<th>0.55</th>
<th>0.51</th>
<th>0.49</th>
<th>0.55</th>
<th>0.62</th>
<th>0.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{st}/Q_c )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( (Q_s/Q_c) )</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

Figure 31 Diagram for the coefficients to compute the loss coefficient for a flow division (reproduced from Idelchik, 1986)
Discharge from a straight tube through an orifice or a perforated plate (grid) with sharp-edged orifices (l/d_h = 0-0.015);
Re = \frac{w_0 d_h}{v} > 10^4 \quad [14-16]

\[
\zeta = \frac{\Delta p}{\rho w_0^2/2} = (1 + 0.707 \sqrt{1 - f^4}) \frac{1}{f^3}, \text{ see the graph}
\]

<table>
<thead>
<tr>
<th>\hat{f}</th>
<th>0.05</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
<th>0.25</th>
<th>0.30</th>
<th>0.35</th>
<th>0.40</th>
<th>0.45</th>
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<tr>
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<td>67</td>
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<td>11.5</td>
</tr>
<tr>
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<td>0.75</td>
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<td>3.30</td>
<td>2.70</td>
<td>2.22</td>
<td>1.80</td>
</tr>
</tbody>
</table>

Figure 32 Additional loss coefficients for orifices (reproduced from Idelchik, 1986)
Discharge from a straight tube through an orifice or a porous plate (grid) with differently shaped orifice edges; Re = \( w_{or} d_h / \nu > 10^4 \) [14-16]

**Scheme and graph**

\[
\xi = \frac{\Delta p}{\rho w_0^2 / 2}
\]

\[
\xi = \left\{ \left[ 1 + 0.5(1 - \tilde{f}) + \tau \sqrt{1 - \tilde{f}} \right] + \lambda \frac{l}{d_h} \right\} \frac{1}{\tilde{f}^2}
\]

\[
= \left( \xi_0 + \lambda \frac{l}{d_h} \right) \frac{1}{\tilde{f}^2}
\]

where \( \xi_0 = 1 + 0.5(1 - \tilde{f}) + \tau \sqrt{1 - \tilde{f}} \) ; for \( \lambda \), see Diagrams 2-1 through 2-6; \( \tau = f(l/d_h) \)

**Thick walled orifices**

\[
\begin{array}{cccccc}
\frac{l}{d_h} & 0 & 0.2 & 0.4 & 0.6 & 0.8 \\
\tau & 1.35 & 1.22 & 1.10 & 0.84 & 0.42 \\
\frac{l}{d_h} & 1.0 & 1.2 & 1.6 & 2.0 & 2.4 \\
\tau & 0.24 & 0.16 & 0.07 & 0.02 & 0 \\
\end{array}
\]

**Orifice edges beveled in the flow direction**

\[
\xi' = \left[ 1 + \sqrt{f'(1 - f')} \right] \frac{1}{f'^2}
\]

where \( \xi' = f(l/d_h) \)

\[
\begin{array}{cccccc}
\frac{l}{d_h} & 0.01 & 0.02 & 0.03 & 0.04 \\
\xi' & 0.46 & 0.42 & 0.38 & 0.35 \\
\frac{l}{d_h} & 0.06 & 0.08 & 0.12 & 0.16 \\
\xi' & 0.29 & 0.23 & 0.16 & 0.13 \\
\end{array}
\]

---

Figure 33 Additional loss coefficients for orifices (reproduced from Idelchik, 1986)
Discharge from a straight tube through an orifice or a perforated plate (grid) with differently shaped orifice edges; \( Re = \frac{w_{or} D_h}{\nu} > 10^4 \) \([14-16]\)  

**Diagram 11-19**

**Resistance coefficient**

\[
\zeta = \frac{\Delta p}{\rho w_{or}^2/2}
\]

\[
\zeta = \left[1 + \sqrt{\zeta'\left(1 - \frac{r}{d_h}\right)}\right]^2 \frac{1}{f^2}
\]

where \( \zeta' = f\left(\frac{r}{d_h}\right) \)

Orifice edges rounded in the flow direction

<table>
<thead>
<tr>
<th>( \frac{r}{d_h} )</th>
<th>0</th>
<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \zeta' )</td>
<td>0.50</td>
<td>0.44</td>
<td>0.37</td>
<td>0.31</td>
<td>0.26</td>
<td>0.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \frac{r}{d_h} )</th>
<th>0.06</th>
<th>0.08</th>
<th>0.12</th>
<th>0.16</th>
<th>0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \zeta' )</td>
<td>0.19</td>
<td>0.15</td>
<td>0.09</td>
<td>0.06</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Discharge from a tube through an orifice or a perforated plate (grid) with differently shaped orifice edges in transition and laminar regions (\( Re = \frac{w_{or} D_h}{\nu} < 10^4-10^5 \), tentatively) \([14-16]\)  

**Diagram 11-20**

1) \( 25 < Re < 10^4-10^5 \):

\[
\zeta = \frac{\Delta p}{\rho w_{or}^2/2} = \zeta_0 \frac{1}{f^2} + \varepsilon Re \zeta_{qu}
\]

2) \( 10 < Re < 25 \):

\[
\zeta = \frac{33}{Re} \frac{1}{f^2} + \varepsilon \zeta_{qu}
\]

3) \( Re < 10 \):

\[
\zeta = \frac{33}{Re} \frac{1}{f^2}
\]

where \( \varepsilon Re = f_0(Re) \) and \( \zeta_{qu} = f_1(Re, F_o/F_q) \), see Diagram 4-19 (it is assumed that \( f = F_{or}/F_o \) corresponds to \( F_q/F_q \); \( \zeta_{qu} \) is determined as at \( Re > 10^4-10^5 \) from Diagrams 11-18 and 11-19.

**Figure 34** Additional loss coefficients for orifices (reproduced from Idelchik, 1986)  

A-12
Appendix B  References


Neville-Jones, P.J.D., and Chitty, A.D., 1996b, “Sea outfalls - inspection and diver safety”, CIRIA, R158, UK


Avanzini, C., 2003, “Construction techniques, supervision, “As built report”, maintenance and monitoring planning as a key to a successful operation of submarine outfalls”, Proceedings Workshop: Submarine Outfalls: Design Considerations and Environmental Performance Monitoring, Sao Paulo, Brazil


Brooks, N.H., 1988, “Seawater intrusion and purging in tunneled outfall” *Schweizer Ingenieur und Architekt*, 106(6), 156-160 (I think this is a journal, oder?)

Burrows, R., 2001, “Outfalls I: Pipeline and diffuser manifold design and hydraulic performance”, *IAHR Short Course Environmental Fluid Mechanics*: Theory, Experiments and applications held at University Dundee


Kalide, W., 1980, “Technische Strömungslehre”, Carl Hanser Verlag, München Wien, 5th edition,


Williams, B.L., 1985 "Ocean Outfall Handbook", *National Water and Soil Conservation Authority*, Water&Soil Miscellaneous publication number 76, ISSN 0110-4705, Wellington
