U.S. Environmental Protection Agency

Visual Plumes 2005

Model Update Documentation

by

Walter Frick, U. S. Environmental Protection Agency
Donald Baumgartner, University of Arizona
Lorin Davis, CH2M-Hill
Zhongfu Ge, National Research Council
Kenwyn George, Alaska Department of Environmental Conservation
Phil Roberts, Georgia Institute of Technology

May 2005

U.S. Environmental Protection Agency

Visual Plumes 2005

- Modulating storm drain flows to reduce stream pollutant concentrations
- Empirical energy transfer function for dynamically collapsing plumes
- Non-empirical closure of the plume equations
- Visual Plumes mixing zone modeling software
- Plume profiles and peak-to-mean concentration ratios
- Simulation of soluble waste transport and buildup in surface waters using tracers

Foreword

Visual Plumes is software that attempts to enable the user to model a broad range of problems encountered by a large user community of both lay persons and professional scientists. Providing software to serve both the scientific and the user communities is a difficult assignment. The typical user wishes to obtain answers to specific questions without long-term commitments to mastering the fine points of the science while the scientists may seek maximum understanding, scope, and flexibility. The peer reviewer falls somewhere in this range, wishing to thoroughly review, understand, and master the work without also totally committing to the field.

Acknowledgements

The advice and assistance of the following individuals is gratefully acknowledged. This list is not complete and we owe a debt of gratitude to others as well.

Anise Ahmed
Maynard Brandsma
Roger Burke
Peter Howe
Candida West

Disclaimers

This is a draft document that should not be quoted or cited. Review comments are solicited. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1. Introduction

1.1 Rationale

This document supports the Visual Plumes update of 2005. It focuses on changes, refinements, and new product features. However, the user and reviewer, with limited time to devote to their tasks, may seek the briefest exposure to the application reasonable in the context of their involvement. To serve these disparate motivations, this document strives to identify absolutely essential elements in shaded text boxes, such as this one. Other material is offered to help the user better understand key issues and limitations associated with mixing zone and plume modeling. Further references are made to earlier documentation, particularly the Visual Plumes manual (Frick et al. 2003), the DOS Plumes manual (Baumgartner, Frick, and Roberts, 1994), and training material (PowerPoint presentations), all found on the Visual Plumes CD (and, subsequently, on the CEAM web site).

For the review version, there are also text boxes, like this one, that provide additional information and questions for the reviewer.

The original version of Visual Plumes was published and uploaded to the EPA Center for Environmental Assessment and Modeling (CEAM) web site in 2001 (Frick et al. 2001; Frick et al. 2003; Frick 2004). Since that time numerous changes have been made to the application to improve its performance and post-2001 compiles of the software have been made available to users on request. However, the web version has remained unchanged.

Recently substantial changes have been made to Visual Plumes that warrant a new release and web upload, called Visual Plumes 2005. Major changes to Visual Plumes include

- Contouring
- Far-field progressive vector diagram (PVD) plume tracking
- Improvements to the PDS surface discharge model (and other models)
- Plume morphology in small streams beyond the fully-mixed region
- Arbitrary source location

Contouring allows the analyst to input water quality criteria concentrations and other metrics (temperature, salinity, or velocity). Visual Plumes estimates and graphically displays the isopleths of these metrics. Combined with the ability to display mixing zone shapes, this capability makes it easier to determine whether or not elevated levels of contamination are likely to be confined to mixing zones.

The PVD approach depends on VP's time-series capability to estimate the movement of plumes in the far field. This is useful to approximate the impact of point sources on remote sites of interest, for example, beaches. The far-field plumes are also contoured. A primitive shore-deflection algorithm is offered to help prevent, tsunami fashion, overland plume transport.

Processing of the PDS model output has been significantly improved, supported by formatting changes to the PDS executable itself.

Many outfalls are in small streams that have limited overall mixing determined by the ratio of stream and effluent flow. VP 2005 includes an algorithm that estimates the continued homogenization of plume profiles beyond the full-stream mixing point. In some cases this allows the analyst to estimate the distance to the point at which a plume isopleth closes.

Finally, VP 2005 allows the user to specify the three-dimensional location of plume sources. This makes it possible to actually see the spatial relationship between different sources, for example, plumes from different ports along a diffuser. The merging algorithm remains unchanged, but it is easier to use the contouring capability to estimate the background concentration that an upstream plume generates in the vicinity of a downstream plume.

1.2 Organization

The VP manual (Frick et al. 2003) remains a primary source of general information for interface and model constructs. It may be downloaded from the web site (http://www.epa.gov/ceampubl/swater/vplume/index.htm) or found on the training compact disc. Changes are identified herein in the context of a mixing zone course tutorial, written from a technical assistance point of view. Technical assistance episodes help to define conceptual, theoretical, and coding problems. The solutions to these problems help to better understand the strengths and weaknesses of Visual Plumes. In cases of the latter, various approaches, practices, or a work-around can often overcome code deficiencies. Clearly, the resourcefulness and care of the user can significantly increase the quality and value of Visual Plumes analyses.

1.3 Visual Plumes installation and setup

The set up instructions found on p. 4.7 of the VP manual are no long fully up to date and are modified here. The VP CD has a subdirectory called "Visual Plumes (VP) Setup" that contains an executable program called *setup.exe* that installs VP. The default options, recommended, will establish the software in the target directory called c:\plumes5 (or other drive or directory). Of course, the default name, Walter Frick, and company, USEPA, should be replaced by the user's name and business. For technical assistance contact frick.walter@epa.gov.

After set up is complete, an examination of the plumes5 directory will reveal several applications programs including,
Plumes5.exe
Pdswin.exe
DKHw.exe
Rsbfor.exe
… to complete

Plumes5.exe may be renamed but the others should not be, as they may be called by VP.

There are also several prepared examples identified here by their project names,

Fan16
IdealCreek
… to complete

When run, VP creates a file called Vpsetup5 that stores the name of the last project. If the file is missing and VP is unable to establish a previous project, it creates one. When it does, its next action is to reveal the Select a model window (Fig. 1.1) which is used to define the target model, adjust the interface and set the components accordingly.
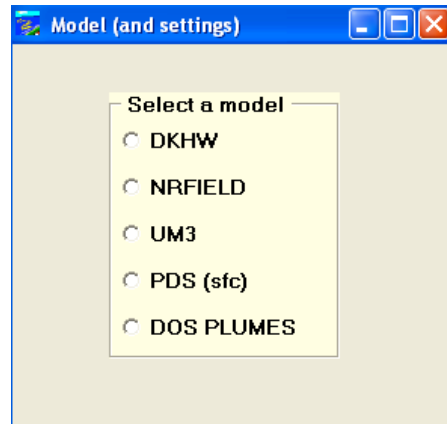
Figure 1.1. Starting Visual Plumes from scratch.

Were all the files listed above found after Visual Plumes was installed?

If there were problems during installation, what were they?

What changes would you suggest to the installation process?

1.4 Conventions

The default name for the executable file remains *Plumes.exe*, similar to its DOS predecessor, 3Plumesa.exe. The title line caption is "Visual Plumes 2005, PVD and Isopleth Version; U.S. EPA/ORD, Ecosystems Research Division, Athens."

Visual Plumes 2005 makes fundamental changes to the content of the diffuser tab and the corresponding project (*.vpp.db) file. These changes include the reduction of columns dedicated to mixing zone distance from two to one, now labeled "Mix zone distance", the removal of the port elevation column, the moving of the vertical and horizontal angle columns to new columns, and the reallocation of three other columns. The three new columns are labeled "Source x-coord", "Source y-coord", and "Isopleth value" respectively. The first two allow the source to be located anywhere in the horizontal plane and the latter specifies the concentration salinity, or temperature isopleths, or isotachs (isopleths of current speed).

As a result of the omitted and reallocated columns, earlier project files will not be read correctly in their entirety and some changes of input values will be necessary. If both versions of VP continue to be used, it is recommended that they and their project files reside in separate directories.

The Visual Plumes authors recommend installing Visual Plumes in a \Plumes directory, for example, c:\Plumes or e:\Plumes. But, see the previous paragraph. **Note:** the review package is intended to resemble a new user's introduction to VP.

Backup files: Visual Plumes maintains a minimum of two direct access database files, essentially the diffuser and ambient input tables, which have "db" extensions. (A project can reference multiple ambient db files.) All changes to these tables become permanent immediately. For that reason it is recommended that you maintain backup copies of the input files in a subdirectory of the main Plumes directory. When working with the files, copies can be made and pasted into the Plumes work directory. *In case unwanted changes are made to important files, you may choose to exit VP without saving. This option puts the original db files into backup files with a bak extension.* They must be renamed to be available to VP again.

Source of confusion: Experience shows that users have not found the Visual Plumes interface especially intuitive. Most confusing is the Settings tab. On the other hand, this tab helps to extend the functionality and flexibility of VP. Changes have been made to VP5 to help the situation, including the addition of informative messages and the hiding of components not required in selected models.

2. Mixing zone analyses and other applications

2.1 Historical context of mixing zones and other issues

2.2 What information goes into a mixing zone analysis?

In a mixing zone course setting, students are encouraged to bring their own problems to class where some time is set aside to work on and try to solve them. Student problems are a valuable counter-balance to instructor prepared problems. Among other benefits, they help to clarify problems and issues that are encountered by permit writers and other users. What information goes into a "typical" analysis? Here is a short list:.

- Site description, depth of discharge, outfall dimensions (especially number of ports, port diameter, spacing, vertical angle, and compass orientation), flow, and effluent concentration.
- Important ambient information includes stream dimensions and flow (Q), or currents in open or coastal waters.
- Beyond that are effluent salinity and temperature and ambient stratification: current, salinity, temperature, and concentration as functions of depth. Other information is often estimated, such as far-field currents and dispersion coefficient. Data obtained near the depth of the ports are usually most valuable as plumes are often discharged horizontally and experience considerable changes in properties at this depth.
- Diagrams and other tangible project information are very helpful.

Many projects lack for data; that is the way it is. If some information is unavailable we will do our best to fill it in. Data deficiencies sometimes afford a reason to discuss the sensitivity of the models to different parameters.

2.3 Beach bacteria and other far-field applications
In a mixing zone course setting, students are encouraged to bring their own problems to

3. Plumes, Jets, and Ideas

We are all familiar with plumes. The authors want to extend that familiarity to important plume properties, especially concentration. This section presents images and brief statements to introduce key ideas in a graphic way. Many of these ideas form the foundation of plume modeling and understanding.

3.1 Context for plumes and Visual Plumes

Here are some settings in which plumes are found. Fig. 3.1 shows the Amazon (below) merging with the Rio Negro (above). Both rivers form "plumes". For example, the Rio Negro may be considered to be a surface discharge into the Amazon, or conversely, although no one has ever attempted to use Visual Plumes on sources of this magnitude. Usually the meaning of a plume is unambiguous, generally being a jet or buoyant jet (plume) flowing into a typically larger ambient body of water

Figure 3.1 The confluence of the Amazon and the Rio Negro. Courtesy Roger Burke.

The boundary between the Amazon and the Rio Negro is irregular with water from each invading the other in scallop-like fashion. If one zoomed in on the edge this irregular pattern, the same pattern will be found at smaller scales, exhibiting fractal behavior. It is likely that the boundary between the two water masses is not vertical but that water from one, being less dense, spreads over the other, forming a lens. The mixing process between the water masses is often called entrainment or dispersion. Entrainment is the process by which ambient fluid is incorporated into a plume.

Good pictures of outfall plumes in water are hard to obtain because the phenomena are large in scale, often not very visible, and require special equipment to observe. Figure 3.2 shows plumes southwest of San Francisco observed from the air. They are only visible because the plumes rose to the surface during slack water and dye was injected into the effluent. Note that the low current conditions are transitory, some of the waste field in the upper portion of the photo deriving from when the plume first surfaced as the current velocity decreased prior to slack water.

Figure 3.2 Dyed plumes observed during the Southwest Ocean Outfall Project near San Francisco (Baumgartner and Frick 2002).

Due to the difficulties associated with measuring and observing plumes in the aquatic environment we tend to be dependent on atmospheric and experimental examples for our perceptions of plumes. Figure 3.3 shows two plumes issuing from power plant chimneys in Southern California. These plumes condense as they entrain ambient air before evaporating again as continued entrainment reduces the relative humidity in the plumes. Entrainment is explained in the next section.

Figure 3.3 Two power plant plumes under the influence of condensation and evaporation physics, leading to the concept of plume concentration contours. Inset: Bifurcating plume exhibiting complex plume symmetry.

The condensed portions of the plumes occur within volumes in which the water vapor pressure exceeds the saturation vapor pressure, thus the visible surfaces of the plumes are associated with a concentration contour. VP5 can represent such surfaces when the appropriate concentration is known, in other words, the updated software can depict not only the approximate physical outer boundaries of the plume associated with the mass flux, as with previous versions, but also inner plume contours relevant to special phenomena or regulations.

Determining approximate contour lines depends on knowing the distribution of properties in the plumes. An axisymmetric Gaussian profile or other comparable profile is often used to establish concentration levels as a function of radii. However, the inset of Fig. 3.3 shows that in wind (or current) axisymmetry is at best an assumption, the plume forming counter-rotating vortices.

Multi-port diffuser experimental plume observations are shown in Fig. 3.4. Note the effect current has on the plumes. While it may seem intuitive that entrainment, or dilution, would be directly proportional to the diameter of the plume, it is not a reliable indicator. In fact, the plume in the middle panel of Fig. 3.4 experiences the greatest dilution. However, the diameter remains comparatively small because the cross-sections that define the material plume element do not

converge as much and hence grow less laterally. A jelly sandwich effect.
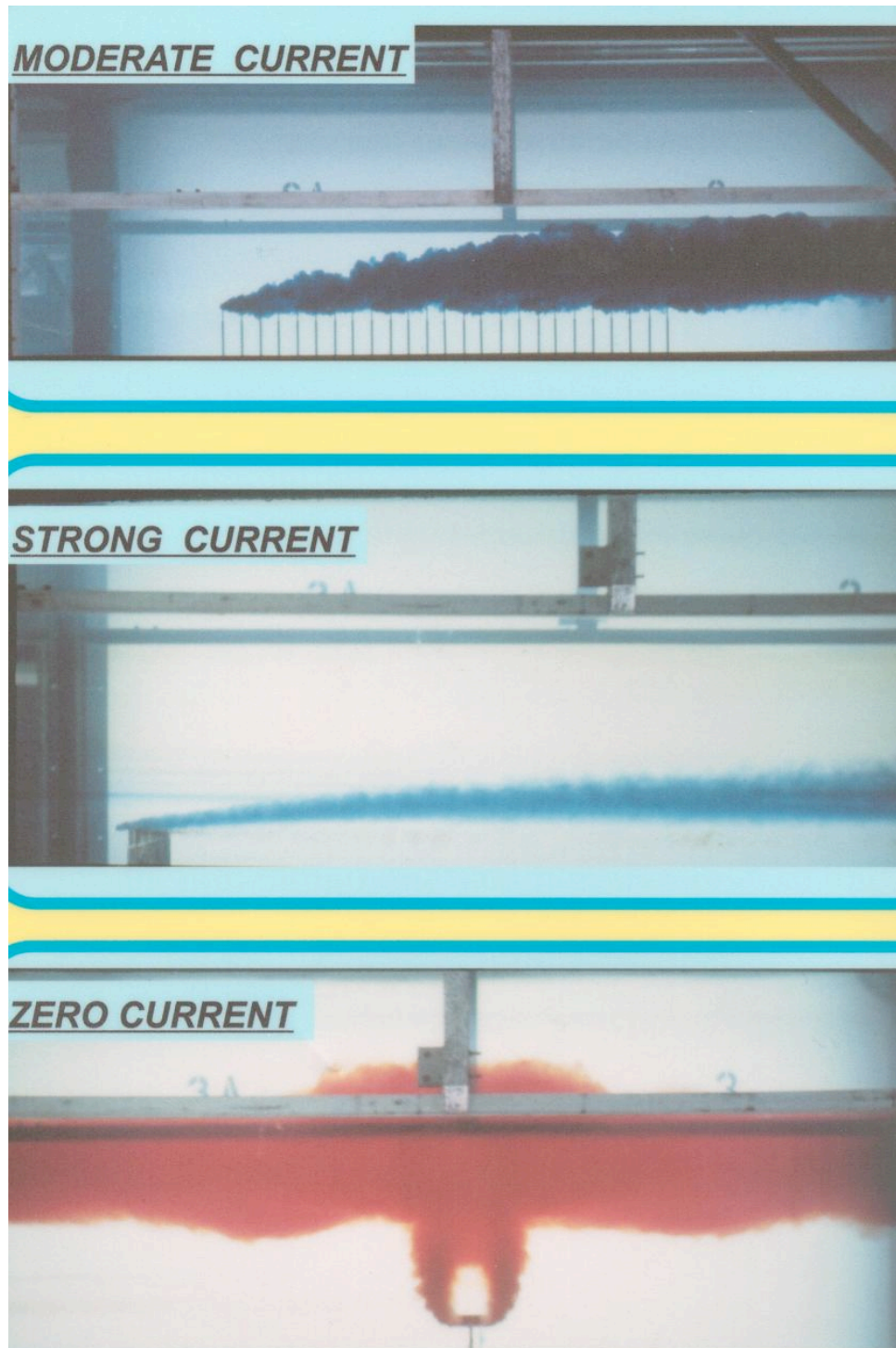
Figure 3.4 Experimental multi-port towed diffuser plumes in various orientations and current (Roberts, 20??; Baumgartner and Frick, 2002).

3.2 Entrainment and dilution

Details of plume theory are available in the DOS Plumes manual (Baumgartner, Frick, and Roberts 1994) and other sources. However, entrainment is such a key process for determining initial dilution and dispersion that a short discussion is appropriate here. Visual evidence of entrainment in nature is difficult to come by, Fig. 3.5 showing a rare and dramatic exception. It shows a cloud being entrained into the Mt. St. Helens volcano plume during the eruption in 1980 (Rosenfeld 1980). The intersection of the laminar cloud and turbulent volcano plume are striking. According to Frick (1981),

Figure 3.5 Entrainment made visible by a cloud being drawn into the Mt. St. Helens volcano plume in 1980. (Rosenfeld 1980)

"The smooth air around the plumes is due to the stabilizing effect of differential atmospheric subsidence. As plume modelers know, the mass flux in a plume increases with height: the plume effectively acts as a pump that carries entrained air upward. Conservation of mass requires air replenishment around the plumes, and the only possible source of replenishment is from above, thereby causing subsidence….

"When a cloud rides this subsiding air into the plume, it becomes smooth, much as stratus is smooth when embedded in stable air…. In addition, the increase in horizontal velocity near the plume boundary, due to plume aspiration, stretches the cloud out. Combined, these effects give an entrained cloud its smooth, slivery appearance."

Of course, this form of entrainment occurs all around the plume but is generally invisible. *Aspiration entrainment* may be attributed to the Bernoulli effect that is associated with the high velocity air in the core of the plume. High-velocity air (or water) is in turn associated with low

density and pressure (Frick 2005). The resulting radial pressure gradient sets up an inflowing circulation around the plume.

The other major form of entrainment is *forced entrainment* which becomes dominant as current increases above a small threshold level. The basic plume modeling hypothesis is that ambient flow impinging on a plume surface is entrained by the plume, thus forced entrainment is proportional to the area the instantaneous plume element projects to the oncoming current. The reason that this hypothesis appears to work as well as it does is that plumes are generally very turbulent in the initial dilution region, due to their initial momentum (jets) or buoyancy (plumes), or both. The high level of turbulence enables the plume to incorporate the oncoming flow (Baumgartner, Frick, and Roberts 1994). Another way of looking at this is that plume properties at the plume boundary are on the average the same as ambient properties, therefore pressure gradients cannot be supported that would deflect the oncoming flow. Of course, at some point turbulence collapses (Roberts 19??) and the argument loses its basis. In that region, referred to herein as the *far field*, another entrainment mechanism is implemented, called the Brooks or *far-field algorithm* (Frick et al. 1994). Far-field entrainment is as much due to ambient turbulence as to internal plume turbulence and generally acts more slowly.

3.3 Plume contours and plume averaging

Plume models, such as those found in VP5, are based on the assumption that the plumes are in steady state, in other words, their trajectories and overall shapes are constant with time, at least for short durations comparable to the time that it takes the effluent to traverse the distance between the point of discharge and maximum rise or some other end point. This implies that plumes are also uniform in composition at specific points. In fact, from a computational viewpoint, the physics of models such as UM3 assume that the basic control volume, or material plume element, is homogeneous in composition. In other words, the trajectory and mass growth of the plume element can be derived from its average properties and the lateral distribution of properties is not important. DKHW on the other hand assumes a lateral distribution and integrates across the plume to express plume properties in terms of centerline values and plume width.

But, in fact, plumes are not steady but undulate in time and exhibit patchiness. This unsteady behavior is apparent in Panel a. of Fig. 3.6. In contrast, Panel b. shows a time exposure of the same plume source. The visible portion of the time-averaged plume now corresponds to some pollutant concentration that one might attempt to contour in VP5.
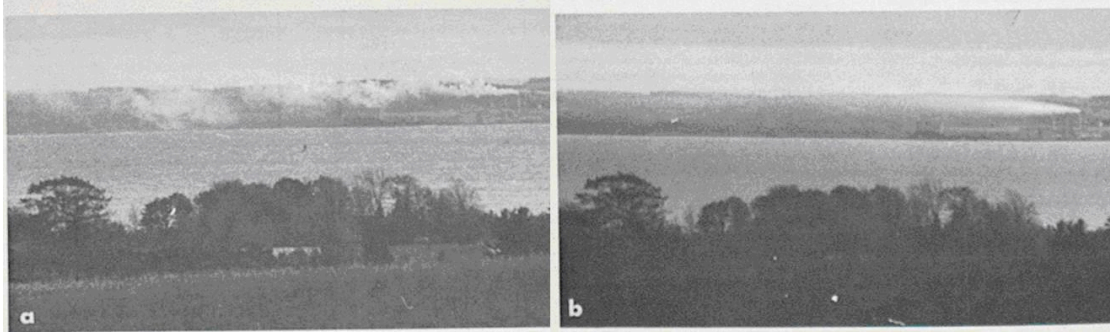
Figure 3.6 Instantaneous and time-averaged plumes (Slade 1968, after Calkowski 1961).

The advantage of contouring is that it is then easy to compare the plume to mixing zone boundaries to determine whether or not water quality criteria will be met. As criteria are generally established with respect to some time period, there is a good match between model outputs and regulatory needs. VP5 can assist in this determination by importing the coordinates of the mixing zone and displaying them graphically, together with the plume simulation. However, as is clear from Fig. 3.6, the user will wish to keep in mind that brief excursions in plume properties can occur outside the contoured region.

3.4 An idealized conceptual model of plumes

It should be clear from the foregoing discussion that plume models, such as those found in VP5, are based on the assumption that the plumes are in steady state. In essence, model conceptualizations of plumes are idealizations, like the one depicted in Fig. 3.7. Not only are they idealizations, but aspects of this ideal may not be explicitly modeled, even in rudimentary fashion. For example, Fig. 3.7, while depicting the merging of neighboring plumes, omits cross-diffuser merging from plumes discharged against the current and bending over and merging with the downstream plumes. Using the DKHW and UM3 models, cross-diffuser merging must be simulated by assuming half the spacing or by modeling the upstream plumes and using the results to define the effective background pollutant for the downstream plumes. However, RSB (or NRFIELD) implicitly includes cross-diffuser merging.
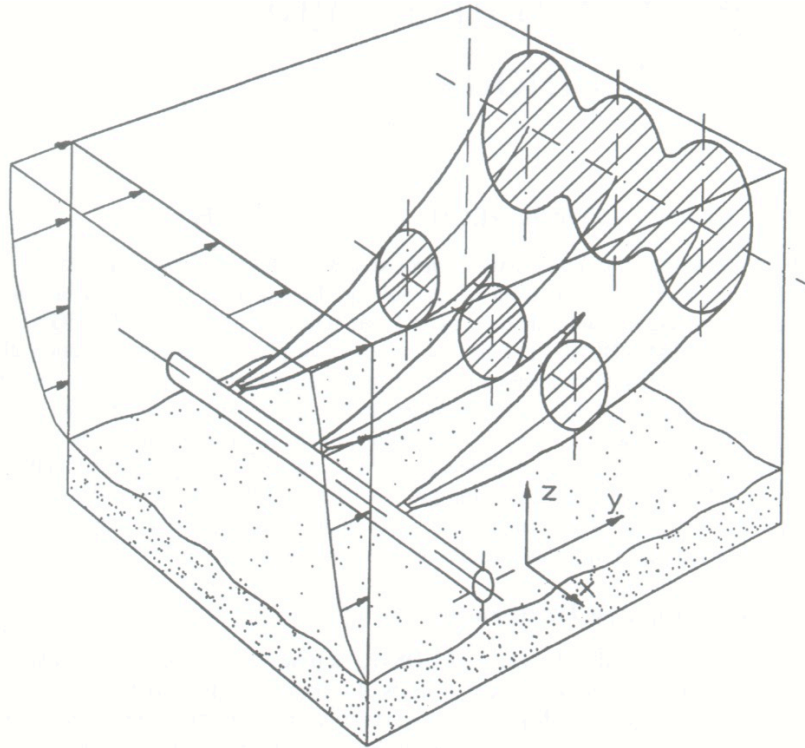
FIGURE 4.1   Three-dimensional plume with coordinate definitions.

Figure 3.7 A conceptualization of plume merging after Davis (1999).

4.0 Fundamentals of Visual Plumes; Project Fan-Run-16

4.1 Synopsis

This simple case is a good introductory application in that it exhibits some common features that also happens to have historical significance. Loh-Nien Fan was a student of Norman H. Brooks (of Visual Plumes' "Brooks" far-field algorithm fame) at the California Institute of Technology in the 1960s. His project thesis "Turbulent buoyant jets into stratified or flowing ambient fluids" (Fan 1967) provided the main high quality experimental measurements on which the Winiarski and Frick Lagrangian cooling tower plume model (Winiarski and Frick 1976) was first verified. The Lagrangian model is the ancestor of the UM3 model found in Visual Plumes. Fan's data were of sufficient quality to allow the important projected area entrainment hypothesis terms to be more rigorously defined and verified (Frick 1984). By identification of the growth and curvature terms of the projected area entrainment hypothesis, a coefficient of 1.0 (in other words no multiplying coefficient at all) appears to adequately "tune" the forced entrainment mechanism over a wide range of conditions. As a result, the UM3 model effectively functions with only a single tunable coefficient ─ the aspiration entrainment coefficient ─ required for the other entrainment mechanism.

This robustness is significant because it indicates that the solutions are less uncertain over a broad range of conditions than they would be if contributions from all three forced entrainment terms were represented by surrogate, tuned terms. This helps limit overall model uncertainty when other models, like the empirical Mancini bacteria decay model, themselves subject to uncertainty, are integrated with the plume model. The value of this characteristic has been recognized by others; the Lagrangian model has been adapted and verified further by Lee and Cheung (1990) and Cheung (1991).

Fan experimented with towed and flowing flume experiments. Figure 4.1 shows examples. At that time the effective equivalence of the two techniques was still under investigation.

F=80, k=16   (0.51cm ORIFICE)

A) STATIONARY JET (PHOTO NO. 7655.2)   B) TOWED JET (PHOTO NO. 7657.4)
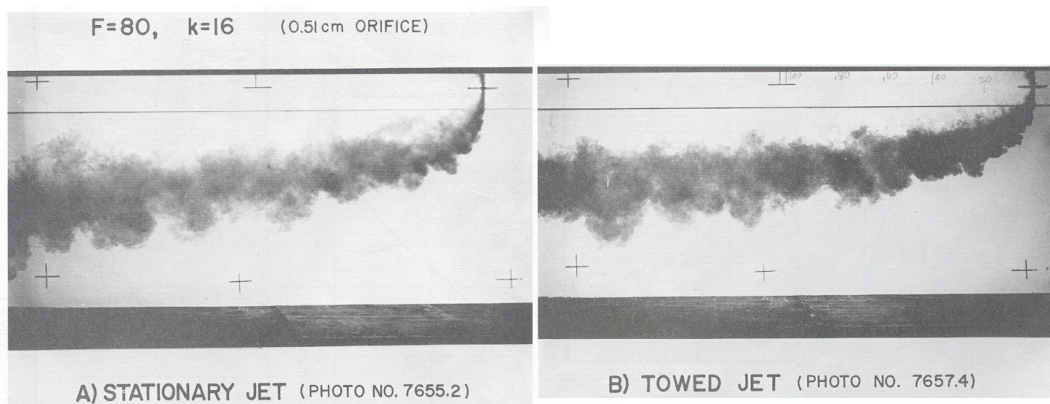
Fig. 55. Stationary and towed buoyant jets for the case
F = 80 and k = 16

Figure 4.1. A pump establishes a current in the flume (A) matching the towing speed in the towed jet experiment (B). (Fan 1967.)
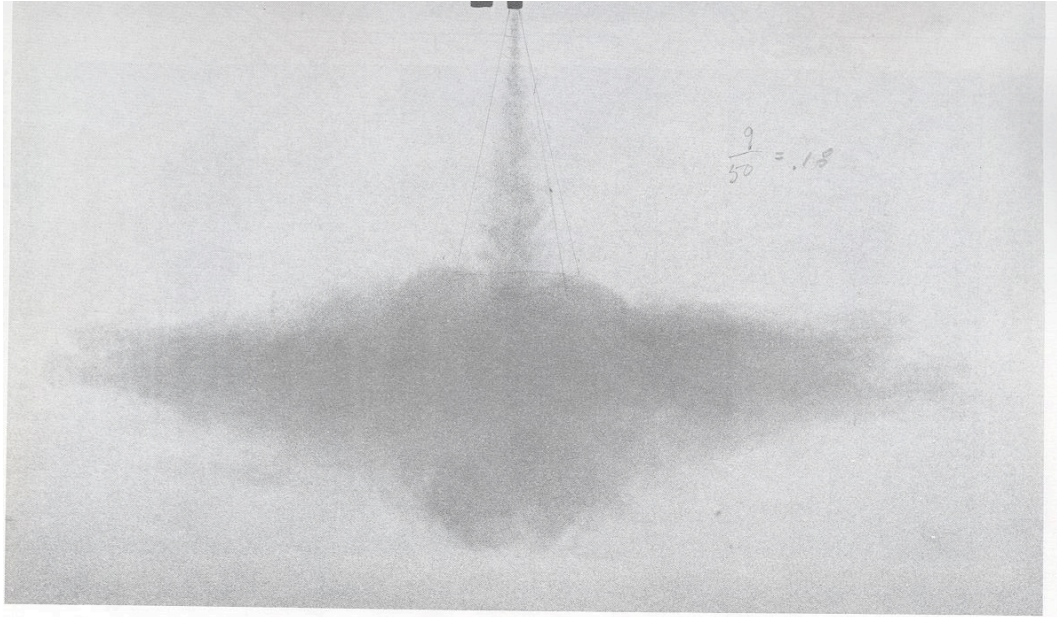
Fig. 22. A vertical buoyant jet in a stagnant, linearly stratified environment
(Jet No. 10, F = 18 and T = 100, Photo No. 7660)

Figure 4.2. A dense plume discharged into quiescent, stratified ambient fluid. (Fan 1967.)

Fan also worked with stratified stagnant ambient fluids. Figure 4.2 shows a plume overshooting its density equilibrium level and subsequently spreading horizontally at the plume's neutrally buoyant trapping level. Note that the experiment features a negatively buoyant plume, one where the effluent density is greater than the density of the receiving water. It is common practice in plume experiments to invert plume orientation to avoid having the source at the bottom of the water column where it is difficult to manipulate.

The examples depicted in Figs. 4.2 and 4.3 (Run 16) were obtained under stagnant, no current conditions. Such examples are not steady but change with time. Hence, the lateral penetration of plume in the upper spreading region will increase as effluent continues to be discharged. In contrast, in steady state a plume has an unchanging appearance on the average, the plume fluid moving through a plume envelope that does not change with time. This would be common in open ambient with current.
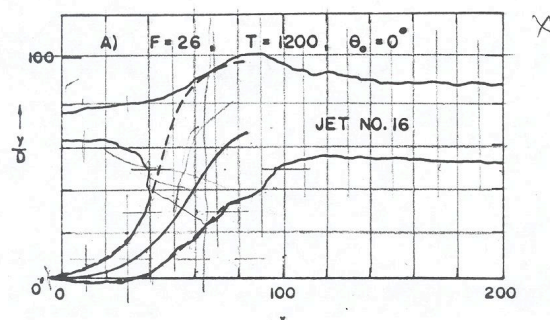
Figure 4.3. Fan Jet No. 16 with superimposed manual digitizing grid. Data in file Fan16.txt.

Fan's Jet No.16, inverted as described, is a buoyant jet, or plume (Fig. 4.3). The densimetric Froude number (*Fr*), defined in the DOS Plumes manual (Baumgartner, Frick, and Roberts 1994) is 26. The plume might be called a buoyant jet, neither dominated by momentum nor by buoyancy. Plumes with $|Fr| < 1$ possess such great buoyancy that vertical discharges may exhibit a region of decreasing radii, the plume element accelerated and stretched by buoyancy to briefly more than compensate for growth by entrainment. Discharged horizontally, the effluent may be

forced against the upper portion (invert) of the port with ambient water actually entering the outfall at the bottom of the port. Duck-billed rubber valves are sometimes used to prevent ambient water or seawater intrusion. *Fr > 100* act more like pure jets and may cause considerable head losses.

The plume in Fig. 4.3 is discharged to stratified stagnant ambient fluid and exhibits a counter-flowing intrusion, similar to the anvil of a thunderstorm cloud. As noted, in the absence of current this feature is unsteady and will expand with time. Depending on the size of the experimental tank, eventually the pollutant will be circulated into all parts of the tank.

When stagnant conditions are simulated in practice it is usually under the implicit assumption that this condition will not persist for long and that the model results are valid. The intrusion is associated with the overlap condition (Frick, Fox, and Baumgartner, 1994) sometimes reported in UM3 runs. It is a mathematical artifact and, if not explicitly addressed in theory, and can lead to entrainment being overestimated or to spurious overtuning of other coefficients.

The trace of the plume in Fig. 4.3 has been digitized for importation into Visual Plumes and is found in an ASCII file called Fan16.txt.

Other notable features include evidence of overshooting of the equilibrium depth (the boil under the "T") and a region of gravitational collapse to the right of maximum rise. Early plume models often were solved with reference to a point (or virtual) source, located at *O'*.

4.2 Exercise objectives

All of VP5's programs have a long verification history. Verification examples help to build confidence in the models and often exhibit considerable simplicity, making them good introductory problems.
For maximum understanding of the VP software and mixing zone modeling issues and constraints, reviewers are invited to execute VP5 and, from the File menu, open Project 5FanRun16 as they read through this section.
It is highly recommended that the VP manual is consulted, especially where specific sections are referred to herein.

The objective of the Fan Jet No. 16 case study is to become familiar with the basic input requirements of Visual Plumes and its most useful input features and options. While the project files may be found on the compact disc, you are encouraged to start with a new project. You will learn to set up a single scenario, the most common application and the basic building block for complex, multi-scenario analyses. Important skills include:

- Input and edit data in the diffuser and ambient database tables.
- Right-click the diffuser and ambient tables and become familiar with the options.
- Understand the significance of the base case.
- Appreciate the value of **not** entering redundant data in the database tables.
- Enter text in the memo box.

- Move from tab to tab.
- Become familiar with program options represented by the Model Configuration, Case selection, and other diffuser tab panels.
- Convert units.
- Recognize optional model components, especially on the settings tab.
- Understand the ambient table headers on the ambient tab.
- Learn the functions of interface buttons, radio buttons, checklists and other components.
- Navigate among and customizing the graphics screens.
- Understand and access the menus.
- Select the models from the Models menu.
- Understand the output on the text tab.
- Route text to files using the settings tab.
- Customize the output table.
- Understand project file naming conventions, the VPsetup file, and the project list file.
- Understand the differences between the native compiled UM3 model and legacy models, like the independently executable DKHW and PDSW models.

4.3 Preliminary inputs

Diffuser tab

Figure 4.4. Diffuser tab showing diffuser and effluent input. Part of the table has been cut to reduce the size of the image.
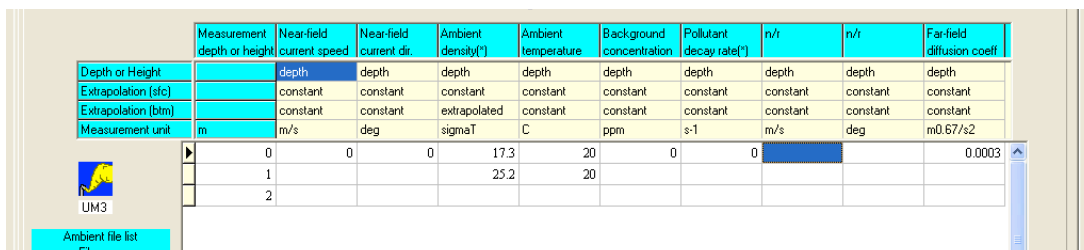
Figure 4.4 shows diffuser tab input for the Run-16 project, 5FanRun16.vpp.db, referencing the associated ambient file, 5FanRun16.001.db, on the Ambient file list. Setting up an example such as this uses the techniques and skills described in Sec. 4.2 of the manual: The One-port example.

The experienced VP user will discern differences with past versions. The diffuser table in the center now features columns for inputting the x-y coordinates of the source, as well as a column for inputting the isopleth value. The Model Configuration checklist has been simplified, no longer including the Average plume boundary option or the Same-levels time series option. The former is obviated by being able to specify contours and the latter is no longer needed to speed up execution as a simply visibility control on the ambient table results in a considerable speed up in execution.

The action of clicking the Parameters for selected row button, after ambient input was completed, yields the Froude number (cf. Fan's nominal value of 26), the effluent density, and the port velocity. To report flow in MLD and density in sigmaT units (see p. 6.4 of the manual) the user first changed the units by clicking on the unit and selecting the desired unit. The user wrote a long memo, part of which is not visible (one could scroll to see the rest). Clicking on the filename causes it to be echoed in the edit cell below the list, preparing it for editing. Otherwise, except for the data themselves, the tab has a largely default appearance.

Ambient tab

The ambient tab remains unchanged. Ambient input for Run 16 is shown in Fig. 4.5. Note that the user has clicked on the bottom Extrapolation (btm) row of the control array to toggle the "extrapolated" setting instructing VP to continue the density gradient below the depth of one meter.

		Measurement depth or height	Near-field current speed	Near-field current dir.	Ambient density(°)	Ambient temperature	Background concentration	Pollutant decay rate(°)	n/r	n/r	Far-field diffusion coeff
Depth or Height			depth	depth	depth	depth	depth	depth	depth	depth	depth
Extrapolation (sfc)			constant	constant	constant	constant	constant	constant	constant	constant	constant
Extrapolation (btm)			constant	constant	extrapolated	constant	constant	constant	constant	constant	constant
Measurement unit		m	m/s	deg	sigmaT	C	ppm	s-1	m/s	deg	m0.67/s2
	▶	0	0	0	17.3	20	0	0			0.0003
		1			25.2	20					
		2									

Figure 4.5. Ambient tab input.

The columns that show up as Effluent salinity (on the diffuser tab) or Ambient salinity are dual purpose columns. If you have density and not salinity, click on the units and select sigmaT from the pop-up list, you are then ready to enter density data. However, even though one has specified density, at least one temperature must be specified, even if it is just an estimate. Together, these inputs determine where on the density diagram the mixing lines end up (that can be significant in some cases). Taken in isolation, the end point densities are determined and would not need further reference to temperature. But, as the plume element changes its properties as it flow through the ambient, locating the end points of the mixing line along the proper isopycnal on the density surface in salinity-temperature space is important. (For more details see p. 7.1 of the Plumes manual.)

As the ambient temperature is constant, only one value needed to be specified, the other one could have been omitted.

Settings tab

Figure 4.6 shows the settings tab for UM3. A discussion of this tab begins on p. 2.11 of the VP manual. Due to its many settings and options (fewer for the other models) this tab presents a barrier to many users. (Note the screen capture was made when the cursor was on the UM3 aspiration coefficient edit box, hence the hint displayed at the bottom.)
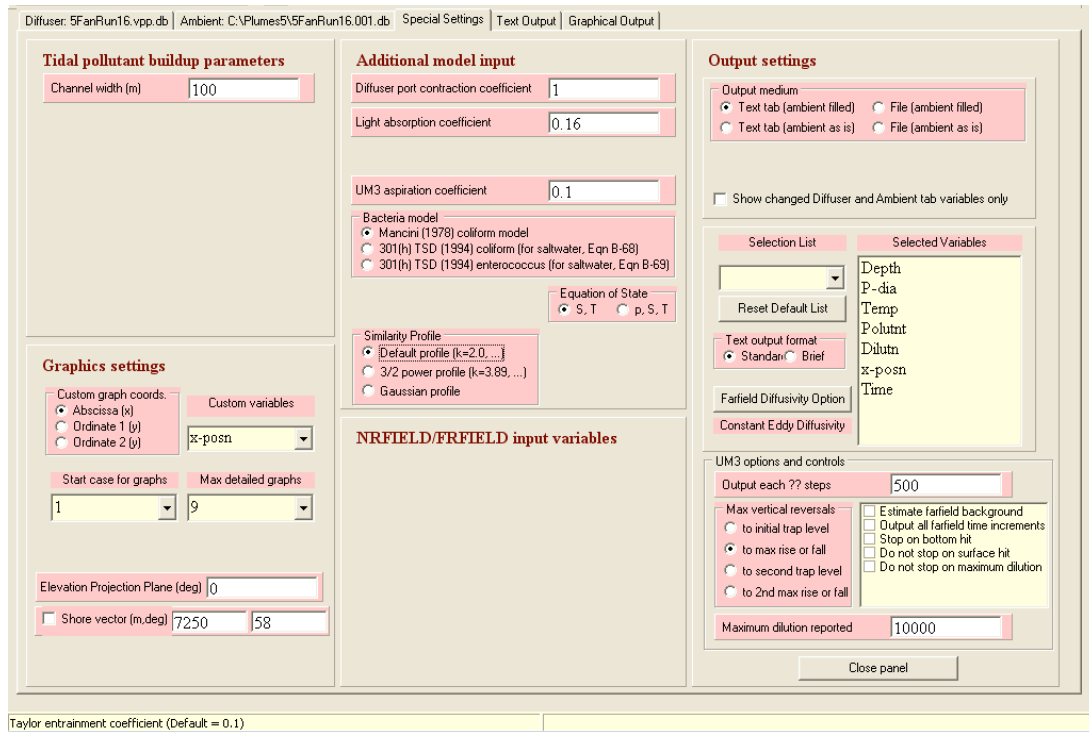
Figure 4.6. Special settings tab parameters and options (cropped for size).

The goal of this section is to make the settings tab less formidable. One rule is to leave default values as they are, unless there are reasons to change them.

The UM3 tidal pollutant buildup parameters panel is covered in detail on p. 2.13 of the VP manual. Most of its parameters are invisible unless the Tidal pollution buildup option is checked on the Model Configuration panel on the diffuser tab. This is an advanced option that requires time-series data input.

However, the Channel width edit box remains visible because it is used to issue the "stream limit reached" message, when applicable. In stream settings, the ultimate dilution that can be attained is often limited by the flow in the stream. A stream with flow nine times greater than the effluent flow will limit volume (or mass) dilution to 10:1. Beyond this limit VP may continue to distribute mass without actual further dilution. Hence, if this message is issued unexpectedly, the stream width value should be rechecked.

The Additional model input panel has fairly understandable parameters and options. They are described on p. 2.13 of the manual. New additions are the Bacteria model, Equation of state, and Similarity profile radio control boxes.

The similarity profile setting has considerable influence on the inner-core contours of the plume, resulting in longer or shorter concentrated plume regions. For details, see Appendix A.

The Output settings tab is explained on p. 2.14 of the VP manual. It affects the style of the ambient table reported on the text output tab and the routing of output to files, instead of to the text tab.

The Graphics settings panel is explained on p. 2.15 of the VP manual. It has settings for the custom graphics panel on the graphics tab as well as limits on the number of plume elevation plots, which can overwhelm the data buffers when they are too large, as in long time-series simulations.

New controls are the Elevation projection plane angle and the Shore vector parameters and control. The former prescribes the plane on which the plume contours are projected. For example, if effluent issues and current flows towards the northeast (45deg), a setting of 45 would assure that the projection plane is parallel to the axis of the plume. The shore vector is an estimate of the nearest (perpendicular) distance to shore. If shorelines are reasonably linear, it functions to deflect the plume as it encroaches on the beach. If it is activated (checked) and large (or not activated), the deflection is small or absent and unrealistic flow over the shoreline might be predicted (the "tsunami" effect).

The NRFIELD/FRFIELD panel remains unfinished.

Some parameters and options are specific to UM3 and have been moved to their own panel. This status is due to the fact that UM3 is coded into VP, whereas the other models are independent executables. Most parameters and options are described on p. 2.14 of the VP manual.

A new checklist describes new options, some of which are experimental. The significant options are "Stop on bottom hit" and "Do not stop on surface hit." The former will stop simulation when plumes are negatively buoyant and continued simulation is pointless. The other is sometimes useful where shallow water inhibits normal plume development but the internal energy of the plume is still substantial and more entrainment is probably occurring.

Model Selection
One of VP most outstanding features is its inclusion of independent models, DKHW, RSB (or NRFIELD), and PDS. Of course there are other models including Cormix (Jirka and Doneker 19??), OOC (Brandsma et al. 19??), Visjet (Lee et al. 19??), and graphical techniques (Economopoulos et al. 20??), to name a few. The philosophy is that plume modeling is still formative and different approaches should be encouraged. Various constraints prevent an even more collaborative and integrated modeling effort.

RSB is an empirical line source model based on experiments with "T" risers (Roberts 19??), thus it is not designed for single port discharge problems as this one. Attempting to run it will yield a message to that effect. The same holds for PDS, a surface discharge model (Davis 1999).

The two remaining models applicable to this single-port, submerged discharge are DKHW (Kannberg and Davis 1976) and UM3 (Baumgartner, Frick, and Roberts 1994). Their simulations are described below.

4.4 Fan-Run-16 Output

Figures 4.4 through 4.6 contain all the necessary input to run DKHW and UM3. They can now be run by making the appropriate selection from the Models menu or by using the corresponding model hotkeys, ^K and ^U respectively.
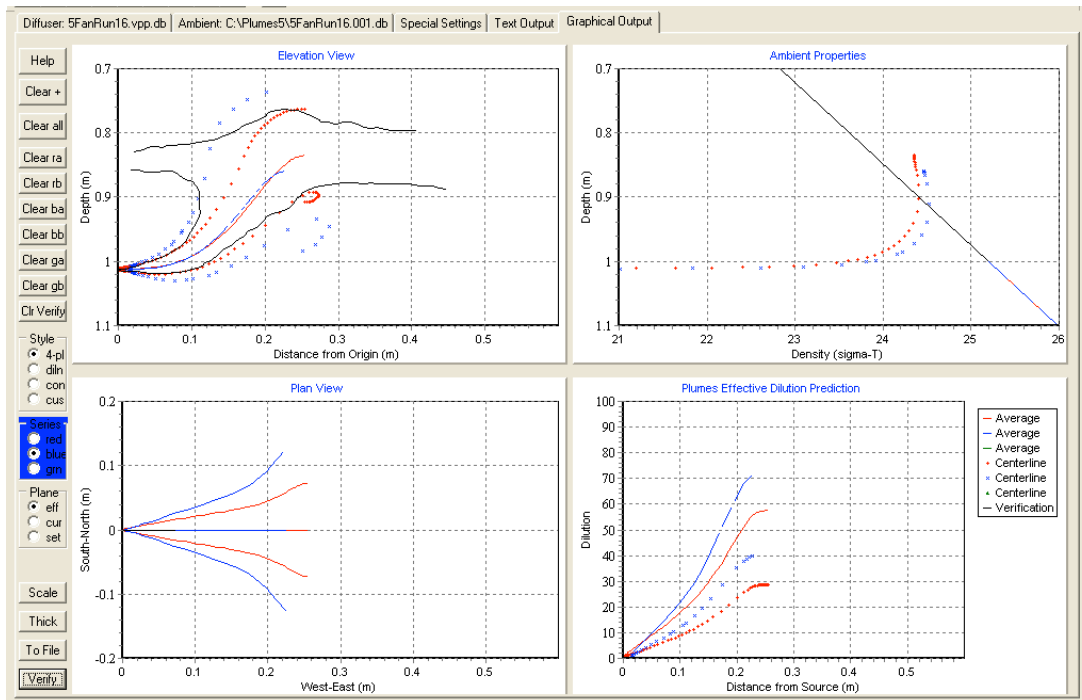
Figure 4.7. 4-panel graphics tab showing VP DKHW (blue) and UM3 (red) predictions for 5FanRun16. (Cropped to fit.)

Figure 4.7 shows DKHW and UM3 predictions after customizing the graphics settings by using the improved Scale button and by double-clicking in the graph margins (see p. 4.17 of the VP manual). Various options for rescaling, resizing and documenting are available. The black trace represents x-y coordinates imported from file Fan16.txt by clicking the Verify button and navigating the pop-up file dialog window.

As shown, the output in Figure 4.7 is very similar to the output of the original 2001 version of VP, that is the plume boundaries shown in the left panels represent the predicted physical boundaries of the plume, in this case the zero-concentration isopleth specified on first row (base case) of the diffuser table. Notice also that the predicted centerline trajectories fairly represent each other and the observed plume trajectory, an early verification test. On the other hand, physical radii vary substantially and the "peak-to-mean" ratio are also different (see Appendix A).

One of the primary differences between the original VP and this version is illustrated upon running the case represented by the second row of the diffuser table, in other words, the 5ppm isopleth case. (How blank cells are interpreted is explained on p. 2.5 of the VP manual, "The diffuser input table." Note that the case indicator triangle on the left must point to the desired case, selected by clicking on one of the cells in the row, see "Case selection on p. 2.6 of the VP manual.) Unlike the original version, VP5 graphically contours various parameters, including concentration. The results are shown in Fig. 4.8.
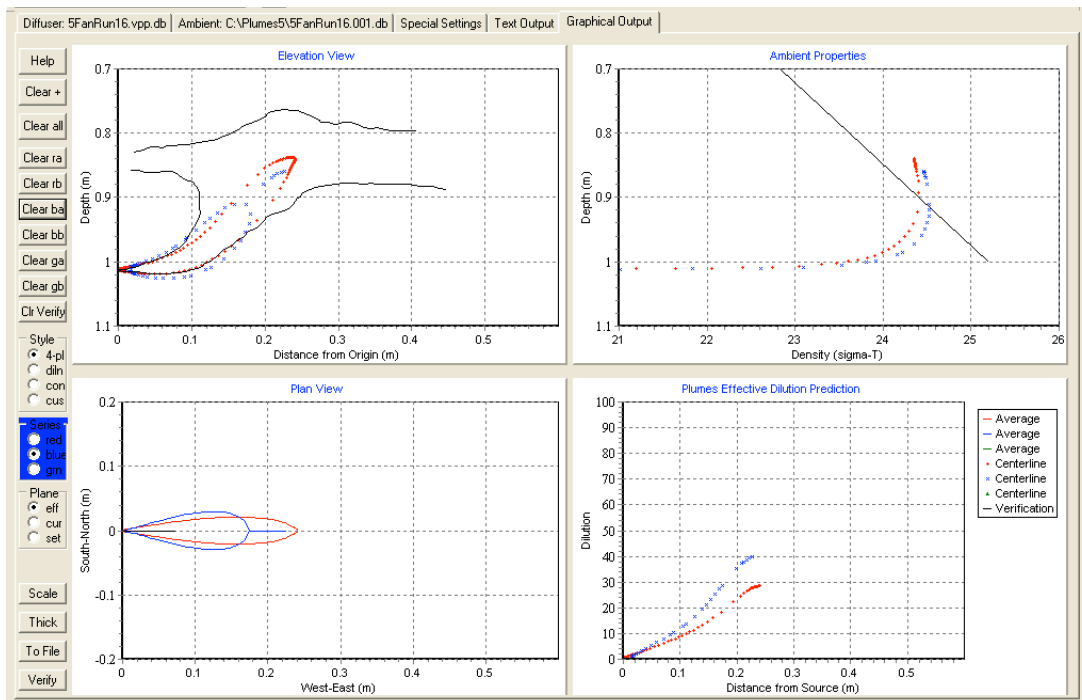
Figure 4.8. Like Fig. 4.7 but showing the 3.5ppm contours, dilution about 29:1. (The "a" traces have been cleared for clarity, thus centerline and other traces are not shown; see p. 2.19 of the VP manual.)

The value of contouring is that it facilitates comparing regions of elevated concentration to mixing zone dimensions that could be superimposed on the Plan View panel by preparing a file of the mixing zone x-y coordinates, as was done with Fan16.txt, and using the Verify button to import it into VP5.

The user is encouraged to experiment and change project parameters and settings. For example, they may consider the difference between dilution and effective dilution. The effective dilution is defined on p. 2.7 of the VP manual and elsewhere (notably Baumgartner, Frick, and Roberts 1994). For example, the user might simply change the ambient concentration from 0 to 10 on the ambient tab and run the models again. However, for the sake of exercise, a second ambient file might be created, as shown in the following section.

The consequence of changing the ambient concentration to 10ppm is a graphic prediction that appears identical to Fig. 4.7. The cause for this similarity can be understood by examining the text UM3 output for this project, Fig. 4.9.

```
/ UM3. 4/21/2005 9:16:19 AM
Case 1; ambient file C:\Plumes5\5FanRun16.001.db; Diffuser table record 2: --------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-den   Amb-tem   Amb-pol    Decay   Far-spd   Far-dir   Disprsn   Density
       m       m/s       deg       psu        C      kg/kg      s-1      m/s        deg     m0.67/s2   sigma-T
      0.0      0.0       0.0      25.13      20.0    0.00001     0.0       -          -      0.0003      17.3
      1.0      0.0       0.0      35.55      20.0    0.00001     0.0       -          -      0.0003      25.2
      2.0      0.0       0.0      45.86      20.0    0.00001     0.0       -          -      0.0003      33.1

Diffuser table:
    P-dia VertAng H-Angle SourceX SourceY   Ports  MZ-dis Isoplth P-depth Ttl-flo Eff-den    Temp Polutnt
     (m)   (deg)   (deg)    (m)     (m)       ()    (m)(concent)   (m)     (MLD)(sigmaT)      (C)   (ppm)
  2.50E-3   0.0     0.0     0.0     0.0      1.0    1.0    3.5    1.012 2.67E-4 1.00E-3      20.0   100.0

Simulation:
Froude number:      25.28; eff. density (sigma-T) 1.000000E-3; eff. velocity      0.63(m/s);
Current is very small, flow regime may be transient.
       Depth    P-dia     Temp  Polutnt   Dilutn   x-posn     Time   Iso dia
Step    (m)      (m)       (C)    (ppm)     ()       (m)       (s)     (m)
  0    1.012   0.0025     20.0    100.0     1.0      0.0       0.0     0.0;
Ambient species greater than plume isopleth value, physical boundary graphed
  1    1.012  0.00252     20.0    98.24    1.019   0.00012  0.000194  0.002524; bottom hit;
 280   0.892  0.0843      20.0    11.98    44.45    0.193    6.003    0.08425; trap level;
 313   0.851  0.116       20.0    11.6     55.06    0.225    8.602    0.1162; begin overlap;
 471   0.835  0.146       20.0    11.52    57.66    0.255   11.36     0.1459; local maximum rise or fall;
Rate sec-1           0.0 dy-1        0.0 kt:         0.0 Amb Sal      33.8307
  ;
9:16:19 AM. amb fills: 3
```

Figure 4.9. UM3 text output for ambient background concentration of 10ppm. Note the "physical boundary graphed" annotation. Also noteworthy are the pollutant concentration and dilution columns.

To understand graphic and text output consider the implications of attempting to reconcile the input with physical reality. In this hypothetical case, as the effluent concentration is 100ppm and the ambient is 10ppm, there can be no region with concentrations less than 10ppm, like 3.5ppm. VP5 responds by simply plotting the physical boundary of the plume that corresponds to the 10ppm isopleth and issuing the "physical boundary graphed" message. Users can satisfy themselves by running the case for a 10ppm concentration isopleth.

4.5 Effective dilution

The foregoing discussion surrounding the implications of background concentration brings into the focus of effective dilution, a concept that VP5 develops more thoroughly than ever before. Effective dilution was introduced more formally into EPA's modeling suite with the introduction of DOS Plumes (see p. 10 and p. 26 of the DOS Plumes manual).

In the original version of VP effective dilution could be calculated from the predicted plume concentration prediction. VP5 formalizes this process by reporting effective dilution directly when the Report effective dilution option is checked on the Model Configuration checklist on the diffuser tab, Fig. 4.10.

```
/ UM3. 4/21/2005 10:05:34 AM
Case 1; ambient file C:\Plumes5\5FanRun16.001.db; Diffuser table record 3: --------------------------------

Ambient Table:
     Depth   Amb-cur  Amb-dir  Amb-den  Amb-tem  Amb-pol    Decay   Far-spd  Far-dir  Disprsn   Density
        m       m/s      deg      psu        C    kg/kg      s-1       m/s      deg  m0.67/s2   sigma-T
      0.0       0.0      0.0    25.13     20.0  0.00001      0.0         -        -    0.0003      17.3
      1.0       0.0      0.0    35.55     20.0  0.00001      0.0         -        -    0.0003      25.2
      2.0       0.0      0.0    45.86     20.0  0.00001      0.0         -        -    0.0003      33.1

Diffuser table:
   P-dia  VertAng H-Angle SourceX SourceY   Ports  MZ-dis Isoplth P-depth Ttl-flo Eff-den    Temp Polutnt
     (m)    (deg)   (deg)     (m)     (m)     ()    (m)(concent)    (m)   (MLD)(sigmaT)    (C)   (ppm)
 2.50E-3     0.0     0.0     0.0     0.0     1.0    1.0    10.0   1.012 2.67E-4 1.00E-3    20.0   100.0

Simulation:
Froude number:      25.28; eff. density (sigma-T) 1.000000E-3; eff. velocity     0.63(m/s);
Current is very small, flow regime may be transient.
         Depth    P-dia    Temp Polutnt  net Dil   x-posn    Time   Iso dia
Step      (m)      (m)     (C)    (ppm)     ()      (m)      (s)      (m)
   0     1.012   0.0025   20.0   100.0     1.0      0.0      0.0    0.0025;
   1     1.012  0.00252   20.0   98.24    1.018  0.00012 0.000194  0.002524; bottom hit;
Ambient species greater than plume isopleth value, physical boundary graphed
 280     0.892   0.0843   20.0   11.98    8.35    0.193    6.003   0.08425; trap level;
 313     0.851    0.116   20.0    11.6   8.624    0.225    8.602   0.1162; begin overlap;
 471     0.835    0.146   20.0   11.52   8.678    0.255    11.36   0.1459; local maximum rise or fall;
Rate sec-1           0.0 dy-1         0.0 kt:          0.0 Amb Sal      33.8307
 ;
10:05:34 AM. amb fills: 3
```

Figure 4.10. UM3 output corresponding to Fig. 4.9 after the Report effective dilution option is checked and the model is rerun.

Note that the dilution column has been relabeled "net Dil" (effective dilution). The change is profound, compared to the volume (or mass) dilution of 57.7, the effective dilution is only 8.7. Obviously, the effective dilution better reflects the performance attributes of any given diffuser and illustrates the importance of ambient background on acting as an effective "source" of pollution that adds to the effluent burden.

4.6 Interfaces: flexibility vs. simplicity

The changes to the project discussed in the preceding sub-sections illustrate the flexibility of the VP5 interface, this even before changes to the settings tab have been proposed. The user can easily make changes that substantially change the performance characteristics of the VP5 models. It is this flexibility that makes the authors loath to adopt a more structured approach which constrains the options the user may exercise, even recognizing that such an approach would offer more simplicity, repeatability, and clarity.

That is not to say that VP5 could not be improved, to simplify its operating paradigm while maintaining its flexibility, a venture the authors hope to continue in the future. For example, a fingerprint facility is planned that would make it easy to repeat previous runs. As it is, VP5 output does not echo all possible parameters and settings. What is proposed is that a coded "fingerprint" be output that could be copied and pasted into an ongoing analysis and parsed, automatically changing all VP5 settings accordingly. This would overcome the limitations apparent in maintaining the project "Lst" file.

A corollary provides an opportunity to repeat the suggestion that the user peruse the VP5 examples and use one as a template, if appropriate. The alternative is to start from scratch and to risk specifying a parameter or setting that has unintended consequences.

4.7 Practice: creating importable coordinate files; showing mixing zones

A portion of the content of the Fan16.txt file is shown in Fig. 4.11. The construction of such files is explained on pp. 2.18 and A-5 of the VP manual. The related construction of the more complicated time-series files is explained beginning on p. 5.1.

To add a mixing boundary to the plan view graphics panel, the user could create another ASCII txt file or add to the Fan16.txt file. For example, in the 5Fan16 project the coordinates might represent the experimental tank walls.

The key words that VP5 uses to plot the data on the intended panel are repeated here, as their location in the VP manual is somewhat obscure, p. A-5. They are side, profile, path, dilution, effdilution, concentration, and generic. Their appearance in the txt file shifts plotting to the corresponding graphic panel, namely, the elevation, density profile, plan view, and dilution on the four-panel graphs, and dilution, concentration, and the generic custom panels. Units should correspond to the ones chosen in Visual Plumes. Blank lines will cause a space between data.

```
side view
  0.0001   1.0145
  0.0068   1.0157
  0.0149   1.0158
  0.0197   1.0161
  0.0264   1.0159
…
  0.4288   0.8831
  0.4373   0.8854
  0.4468   0.8878

  0.4047   0.7966
  0.3985   0.7965
  0.3920   0.7966
  0.3855   0.7961
…
  0.0338   0.8266
  0.0291   0.8284
  0.0199   0.8291

  0.0170   0.8577
  0.0212   0.8574
  0.0278   0.8569
…
  0.0168   1.0095
  0.0099   1.0114
  0.0042   1.0126
 -0.0001   1.0124
density profile
17.3 0.0
25.2 1.0
```

Figure 4.11. The abridged content of the Fan16.txt ASCII file.

For example, adding the key word and data to the Fan16.txt file

```
path view
0 0.1
0.2 0.1
0.2 -0.1
0 -0.1
0 0.1
```

will draw a rectangle on the plan view panel when the Verify button is used to import the revised Fan16.txt file. Very important, this must be done in an ASCII text editor, such as Delphi or Notepad.exe. The recommended delimiters are spaces.

4.8 Theory: changing the aspiration coefficient

This sub-section illustrates the importance of the aspiration entrainment hypothesis. It is the first change so far to the settings tab. The aspiration coefficient effectively determines the inflow velocity into the plume. An entrainment coefficient of 0.1 means that, at the boundary of the plume, the inflow velocity is one-tenth the average velocity in the plume element. For more information, see page 119 of the DOS Plumes manual (Baumgartner, Frick, and Roberts 1994).
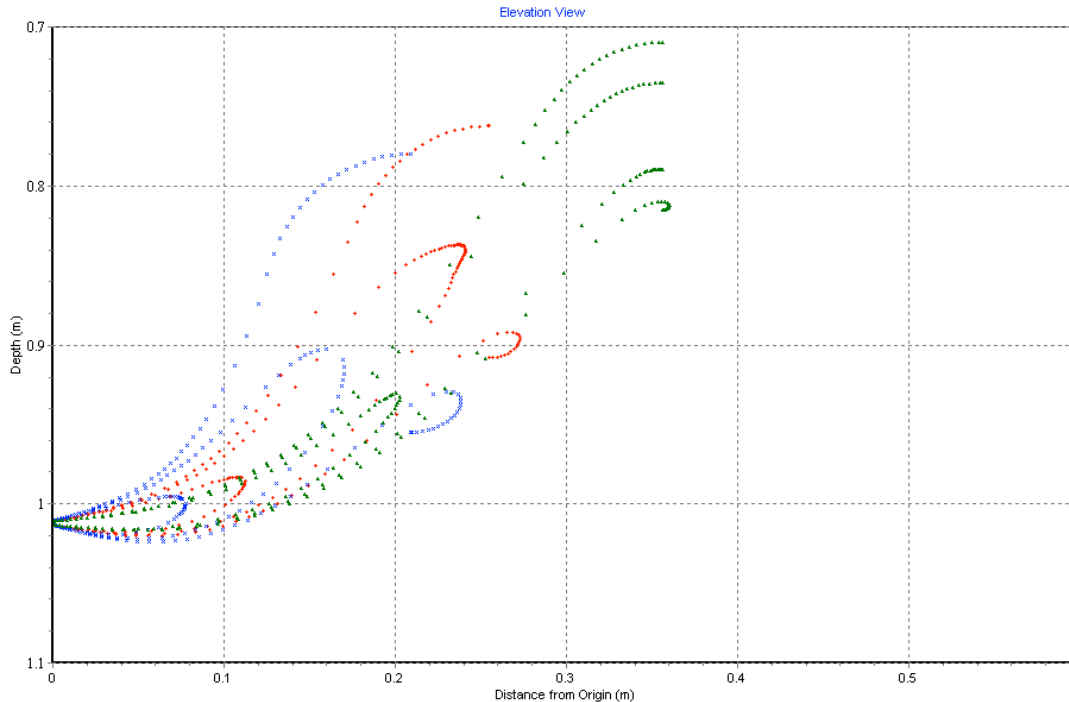
Figure 4.12. Like Fig. 4.7 but showing the 3.5ppm contours, dilution about 29:1. (The "a" traces have been cleared for clarity, thus centerline and other traces are not shown; see p. 2.19 of the VP manual.)

Figure 4.12 shows the predictions for aspiration coefficients of 0.05, 0.10, and 0.15 and isopleth concentrations of 0 (the physical boundary), 3.5, and 10ppm. This time the To File button has been clicked to save the graphics output as bitmap bmp files. This option creates a higher resolution image than is available in the normal VP5 4-panel graphic.

The To File button is described on p. 2.19 of the VP manual. All three contours can be run at once by first selecting the Sequential, all ambient list option on the Case selection radio panel on the diffuser tab (see p. 2.6 of the VP manual). Before using the To File button the user might change the font size of the labels for better legibility (p. 2.20 of the VP manual).

But to return to the theory, by studying this example the user may appreciate how the authors of UM3 selected a default value of 0.1 for the aspiration coefficient (Frick 1984). This value works well in many similar cases studied by Fan (1967) and others. This example also illustrates the experimental capability that VP5 attempts to retain and support. It is this kind of philosophy that leads the authors to offer different models and approaches to mixing zone problems.

4.9 Limitations, troubleshooting

- On the graphics tab you may wonder why initially there is no plume trajectory shown. Try pressing the Eff plane button on the graphics tab and re-run the example.

5. Data acquisition, quality, and current direction interpolation; Project Distillery

5.1 Synopsis:

A technical assistance client used VP 2001 to design a distillery outfall in the vicinity of a coral reef in the Caribbean. To provide ambient data they used an Acoustic Doppler Current Profiler (ADCP) to measure current speeds and directions at one-meter intervals in water approximately 60m in depth. One of the problems with this approach was the number of layers, 58, inputted into the VP ambient database table. In combination with an input error, the 2001 version incorrectly interpreted the data (it did not handle more than 20 layers correctly). As a result of this technical assistance, VP5 has been modified to handle up to 60 layers of ambient input. However, the first line of data in the ambient table must always correspond to the surface, i.e., the depth should be 0.0, its default value.

An analysis of the ADCP data concluded:

> "I have been thinking about your ADCP profile some more. Since I am using an ADCP myself, I wonder how best to program it, particularly with regard to the tradeoff between battery life and memory storage, and, ensemble averaging. My instrument is deployed in a self-contained mode at the bottom looking up. Too few ensembles [pings of sound] in an average leads to a great deal of spatial and temporal variability. As every ping draws power, with too many the instrument may run out of battery. If the data turn out to be too variable, fortunately they can be often post-processed to average them over longer time periods or more layers to smooth them.

> "Looking at the [Distillery.001.db] profile I think that would be a good idea. For example, for depths 52.5, 53.5 ... 57.5 current speeds are 26.36, 3.75, 21.9, 6.29, 37.73, and 11.94cm/sec respectively. It is doubtful these fluctuations are real. Even if they are, a model like UM3 responds too rapidly to these changes as the plume element rises through the water column. This is because UM3 assumes that at any moment in time the entrained water flow into the plume element has the properties of the ambient at the depth of the center of mass of the plume element, as opposed to water entering from a range of levels and thus in the aggregate representing an average that changes less drastically. The great variability in the noisy ADCP data set is the reason the modeled plume exhibits such a corkscrew trajectory. In reality, contributions to overall entrainment come from a range of depths because the plume element has finite dimensions that extend through several layers in the water column. If UM3 were smarter it would depth average the ambient properties in direct proportion to the area of the plume element surface exposed to different conditions as a result of its vertical extension through the water column."

To test the consequences of averaging, a spreadsheet was used to depth-average 5 1-m layers to obtain smoothly varying speeds and directions (as well as temperatures and salinities). It converts speed and direction data to vector components. It then averages 5-m layers, or 5 lines of data, to obtain 5-m layer average vector components. Finally, it converts those back into speed and direction measurements.

With VP 2001 it was not possible to copy and paste data from spreadsheets into the ambient db files, nor was that possible using the Delphi database function. (Delphi is the object-oriented programming language in which Visual Plumes is compiled.) Thus the averaged currents had to be manually input. Here the resulting ambient file is called Distillery.003.db.

Such copying and pasting is supported by VP5. However, at present only a block of one column at a time may be pasted into the diffuser or ambient tables. Copying columns of values from "db" files is only possible by opening the files in a database program

The averaging procedure does considerably smooth out the plume behavior, as is seen in the following sections, especially in the plan view simulations. Salinity and temperature data were also averaged to eliminate unrealistic unstable layers. The differences can be seen in the density profile plots.

5.2 Exercise objectives

In addition to emphasizing VP 5 input limits and the prohibition on non-zero depths in the first line of the ambient table, another objective of the distillery outfall design study is to become familiar with the creating and handling multiple ambient input files. The study also helps to understand the effect of data variability on simulated plume trajectories. It can be seen that higher data resolution does not always lead to better prediction and can significantly increase running time.

The user is encouraged to
- Create new ambient data files (Sec. 3.2.2, and p. 2.5)
- Understand flow direction conventions (Sec. 3.1.1)
- Learn the ambient data file naming convention (Sec. 3.4)
- Manipulate the Ambient file list on the diffuser and ambient tabs (p. 2.5)
- Add case ranges to the file names for subsequent parsing by VP (Sec. 2.2.1)
- Scale and customize graphics (Sec. 2.2.5, and p. 2.20)
- Understand the spreadsheet, vector-average-data.wb3, for averaging ADCP and similar data. (??)

Page and section references are to the VP manual.

5.3 Preliminary inputs

Diffuser tab
Figure 5.1 shows diffuser tab input values and the popup panel for manipulating the Ambient file list (obtained when right-clicking on the list). For example, with the third file selected as shown, the user could remove it from the list or add or insert files. The significance of each input file is briefly described in the project memo on the Project panel. As set up, a potential total of fifteen cases is possible, five flow and source x-coord values for each of the three ambient files. Although the same port is modeled in each case, different source coordinates are convenient for displaying the first three cases on the graphics tab. The 20000ppm effluent pollutant

concentration is arbitrary. The 25ppm isopleth value produces plumes of good lengths for illustrating various points.
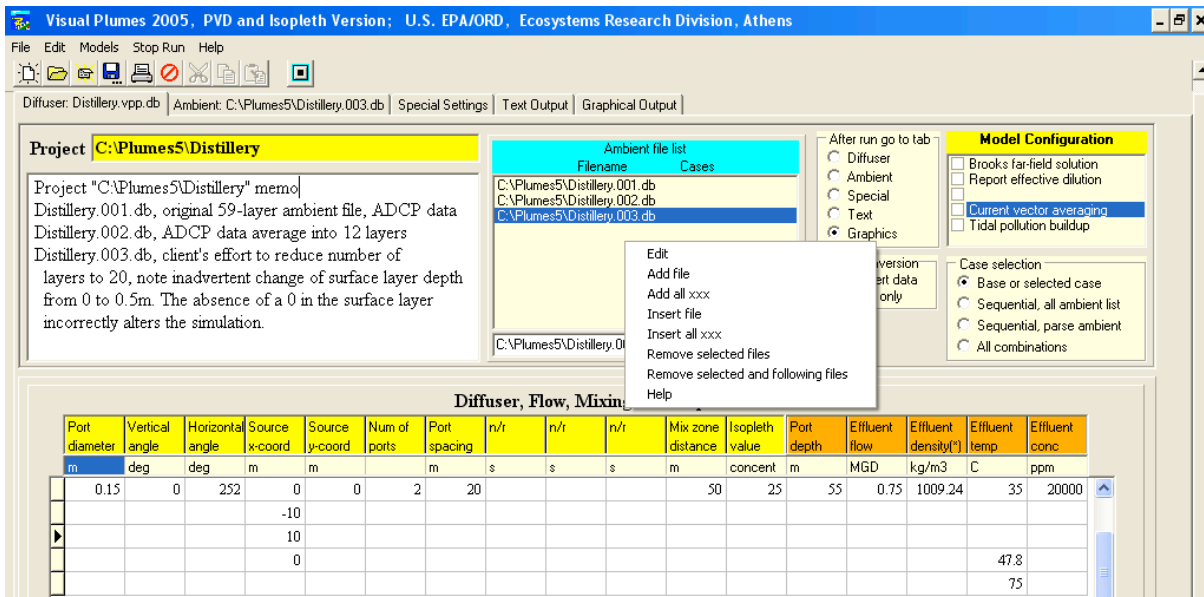
Figure 5.1 Part of the Distillery project diffuser tab. Right-clicking on the Ambient file list shows a popup of options for manipulating ambient input files.

Ambient tab

Part of the content of third of the three ambient files Distillery.003.db (featuring 58 rows of input data), is shown in Fig. 5.2. (The file is shown selected in the Ambient file list). Note the depth of the first row is 0.5m, not 0, the default value, as is recommended in Sec. 2.2.2 (p. 2.10) of the VP manual.
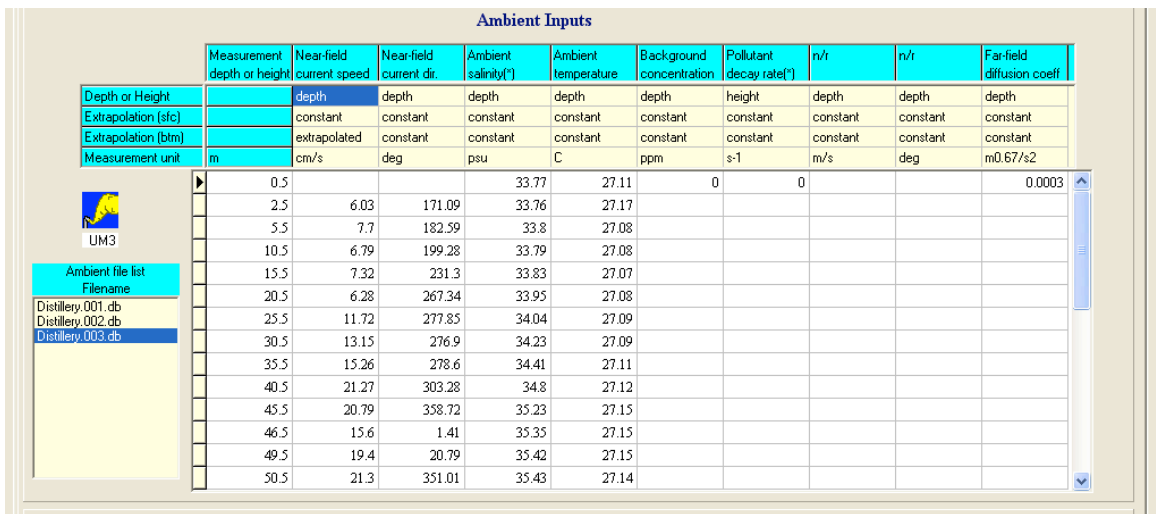
Figure 5.2 Part of the Distillery project ambient tab showing the client's efforts to reduce the number of layers to 20, the 2001 Visual Plumes graphics limit. Note the incorrect surface value of 0.5 (instead of 0) in Distillery.003.db. Also note the "Farfield dilution coeff" value.

Settings tab

The interesting part of the settings tab is shown in Fig. 5.3. The UM3 option "to 2nd max rise or fall" is selected to allow the isopleths for all cases to close without resorting to the far-field algorithm. In addition to outputting iterations that coincide with special events, like merging, as it normally does, UM3 is directed to output each 25th iteration. Finally, ambient current and direction, x and y coordinates, and time have been added to the Selected Variables list (controlling variables output on the text tab) by choosing them from the Selection list.
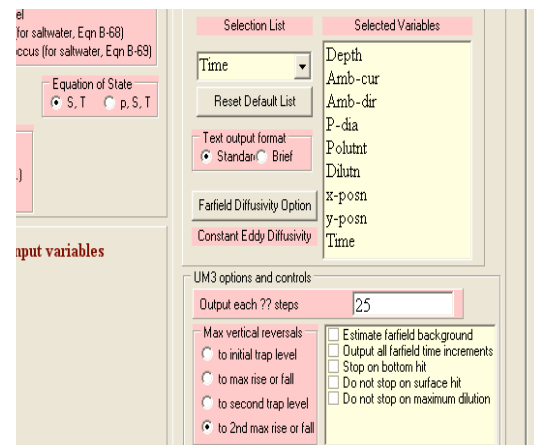
Figure 5.3. Settings tab options.

5.4 Consequences of spatial averaging

Entrainment is an extensive phenomenon that, in an ideal model, would affect plume element motion gradually, even as it moved through layers with extreme current shear. However, models such as UM3 assume that during each time step the properties of newly entrained fluid correspond to the ambient properties at the level of the center-of-mass of the plume element, making it much more sensitive to vertical changes in ambient properties than is justified, as illustrated by the middle trace in Fig. 5.4.
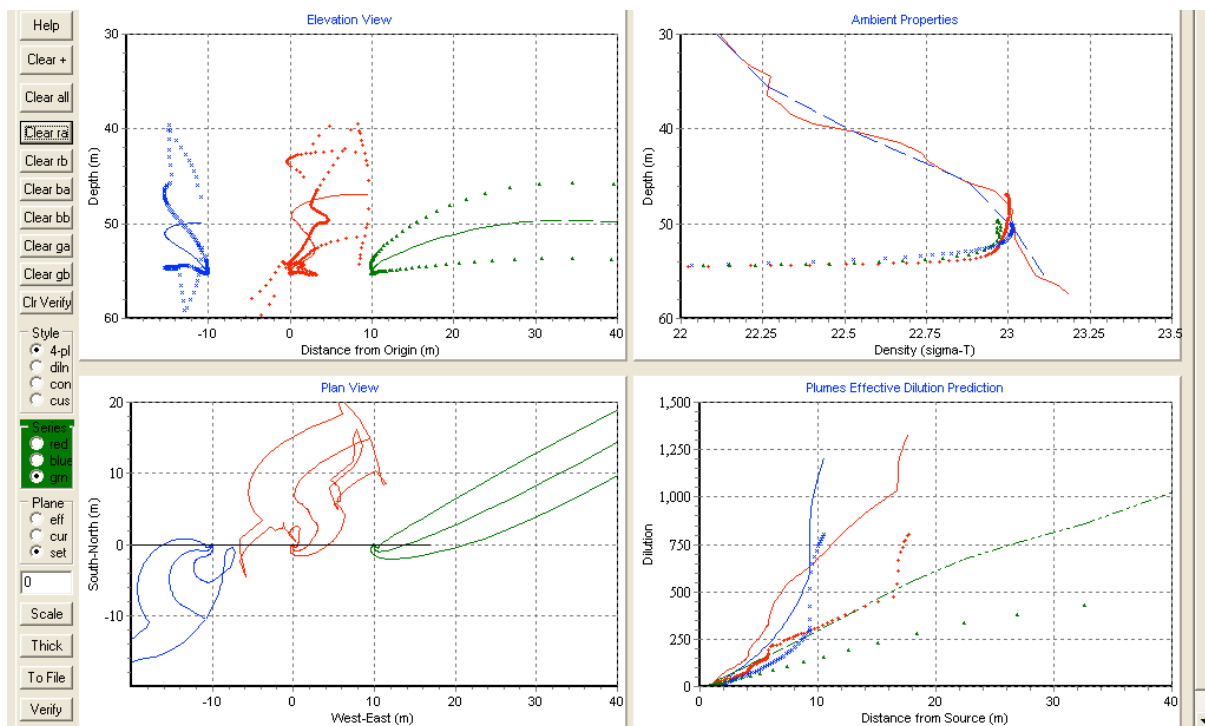
Figure 5.4 Graphics tab: ambient file Distillery.001.db (58 layers), red; Distillery.002.db (averaged, preferred), blue; and, Distillery.003.db, green (spurious because the "surface layer" was not specified to be at zero in the ambient table).

This sensitivity to ambient shear, especially in current speed and direction, is evident in the spiraling trajectories (red trace) in both the elevation and plan views in Fig. 5.4, that correspond to the 58-layer ambient data input in the ambient file Distillery.001.db. The erratic motion is evident both in the centerline and concentration contours. The elevation view is difficult to understand as the plume keeps changing directions (as is evident from the plan view). VP 5 must project three points (two plume element contour boundary points and the plume element center point) that are instantaneously in a vertical plane (defined by a vector normal to the plume element's velocity vector and the gravity vector) onto the vertical projection plane whose orientation is shown the black solid lines in the plan view. Imagine looking at a twist of ribbon held so that its cross-sectional line is everywhere vertical.

Never mind shears and sudden changes in direction, the alert student may wonder why the three plumes, that are sharing similar ambient input, are predicted to take off into widely different directions. The best explanation for this is deferred for Sec. 5.5, Vector interpolation.

The sideways protrusions at mid-trajectory are due to plume merging followed by the plume element entering an unstable layer. A treatment of plume merging is found on p. 126 of the DOS manual (Baumgartner, Frick, and Roberts 1994), Fig. 69 from that reference is reproduced in Fig. 5.5
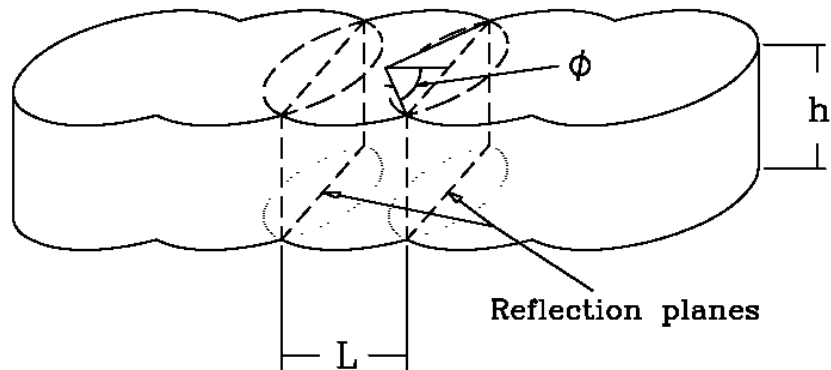
Figure 5.5 Merging geometry and reflection planes.

After the point of merging, growth of the plume element is limited to essentially one dimension, in Fig. 5.5, out of and into the plane of the page. Physically, the spreading of the plume becomes more pronounced. The question is: how well does the model describe the physics of this phase?

The merging algorithm found in UM3 works quite well over a broad range of conditions, especially in cases of moderate to strong currents that are fairly uniform in strength and direction. In such cases the plume element is well defined (as in Fig. 5.6.a) and the physical boundaries of the plume tend to grow steadily with a noticeable inflection at the point of merging. However, when currents are low the plume element will frequently exhibit overlap, as shown in Fig. 5.6.b. This mathematical condition is correlated with actual physical horizontal spreading of plumes and the upstream intrusion of plume material into the ambient fluid, as shown in Fig. 4.3.
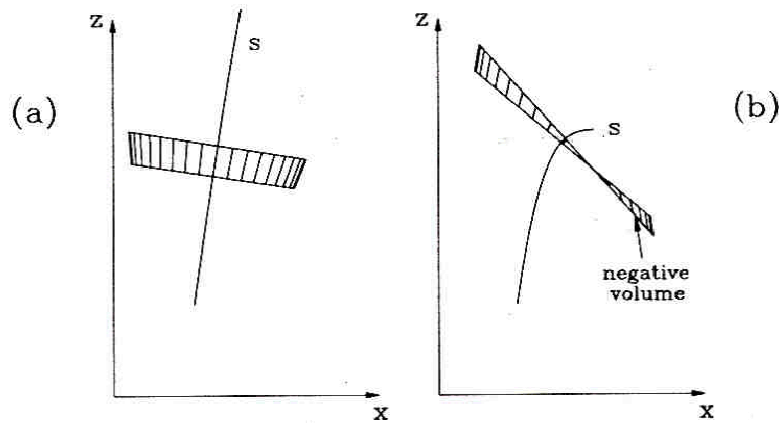
Figure 5.6 (a) A mathematically simple plume element in a region of weak trajectory curvature. (b) A severely overlapped plume element.

The UM3 model is based on the round-plume assumption. Furthermore, UM3 is a so-called "top hat" model, in other words, the plume element (or control volume) is assumed to have uniform properties at specific points along the trajectory. In this class of models the plume element must be geometrically and uniquely defined. In UM3 the defining end planes, or cross-sections, are defined to be perpendicular to the trajectory. As a consequence of this definition, if the plume element radius grows to be sufficiently large, as tends to happen in low currents, and the plume trajectory exhibits strong curvature, as tends to happen as the plume decelerates in a stable layer, the conditions for overlap are met (Fig. 5.6.b) and the mathematics of the plume element are greatly complicated. The complexities of overlap are analyzed by Frick, Baumgartner, and Fox (1994).

The version of UM3 found in VP5 includes an engineering solution to the overlap problem that attempts to mitigate the entrainment feedback mechanism described by Frick, Baumgartner, and Fox (1994). UM3 is a Lagrangian model; it traces the history of a material element (one that theoretically always contains all matter present in the element at the moment of conception at its source, plus entrained fluid). DKHW, and similar models, are Eulerian integral flux models. They are based on fixed control volumes, with end planes through which the plume material flows. The modeler has control over the design of the control volume and can explicitly avoid overlap. Nevertheless, as proven by Frick, Baumgartner, and Fox (1994), these models are subject to the same problem unless the ramifications of the angle of the flux vectors to the defining planes are explicitly formulated, something that is not generally done.

(DKHW does not run Case 1 (middle trace in Fig. 5.4) without alteration. As the plume rises only about 5m, the ambient table may be simplified by omitting all layers below the surface to a depth of about 45m, being sure to retain the surface row. However, even when that is done, the simulation stops without explanation before the merging point is reached.)

The corresponding text output for UM3 is given in Fig. 5.7, which has been edited for brevity, omitted lines indicated by four periods. Note that merging occurs in a region of overlap (indicated by the bracketing "begin overlap" and "end overlap" annotations). The user may safely conclude that the entrainment hypothesis is not well-defined in this region and that it is also likely that some horizontal spreading of the plume occurs in this region.

```
Simulation:
Froude number:      6.547; eff. density (sigma-T)      9.24; eff. velocity     0.93(m/s);
        Depth  Amb-cur  Amb-dir   P-dia  H-Angle  Polutnt  Dilutn   x-posn    y-posn   Iso dia
Step     (m)   (cm/s)    (deg)     (m)    (deg)    (ppm)     ()      (m)       (m)       (m)
   0    55.0    14.09    20.85    0.15   -108.0   20000.0    1.0      0.0       0.0      0.0;
   1    55.0    14.09    20.85    0.151  -107.9   19607.8    1.02  -0.00151  -0.00468   0.1514; bottom hit;
  25    55.0    14.13    20.88    0.25   -103.4   12190.6    1.632  -0.0393   -0.14     0.2498;
  50    54.99   14.26    21.02    0.381   -97.05   8288.9    2.394  -0.0648   -0.28     0.3803;
  75    54.98   14.45    21.23    0.497   -90.83   6492.2    3.052  -0.0718   -0.381    0.4968;
  98    54.96   14.66    21.45    0.595   -85.09   5496.9    3.603  -0.0692   -0.453    0.5943; begin overlap;
 100    54.96   14.67    21.47    0.603   -84.6    5427.9    3.648  -0.0687   -0.458    0.6023;
....
 450    54.32   18.61    46.28    1.695    20.23    900.0   21.93    0.825    -0.857    1.6831;
 474    54.24   17.24    53.36    1.895    27.06    717.9   27.5     1.003    -0.778    1.8789; end overlap;
....
 600    53.38    6.125  136.7     4.435    62.55    192.2  102.7     2.657     1.198    4.2906;
 607    53.31    7.846  146.4     4.65     64.64    182.2  108.3     2.735     1.355    4.4894; begin overlap;
 625    53.17   11.0    164.3     5.06     69.97    166.0  118.8     2.858     1.649    4.8687;
....
1058    50.59   21.59   318.4     9.411   134.0     67.63  291.8     1.448     5.192    8.5097; merging;
....
1275    48.07   22.01    15.73   13.53     51.93     30.47 647.6     1.193     9.436   10.704; trap level;
1300    47.78   21.06    14.9    13.43     45.24     28.3  697.3     1.869    10.19    10.378;
1325    47.47   20.04    13.88   13.41     38.94     25.7  767.7     2.886    11.1     10.003;
1330    47.41   19.76    13.1    13.42     37.73     25.13 785.3     3.144    11.31     9.9199; end overlap;
1350    47.16   18.64     9.949  13.56     33.09     22.77 866.5     4.51     12.27     9.5779;
1375    46.91   17.49     6.726  13.95     27.9      19.86 993.5     7.309    13.89     9.0728;
1384    46.88   17.33     6.278  24.99     25.97     18.7 1055.1     8.415    14.46    13.613; begin overlap;
1400    46.88   17.32     6.245  31.14     21.9      16.02 1231.7    8.786    14.61    10.123;
1403    46.88   17.32     6.238  32.44     20.93     15.32 1287.7    9.129    14.75     7.026; local maximum rise or fall;
1406    46.88   17.32     6.254  33.76     20.21     14.79 1334.1    9.514    14.89     0.0;
```

Figure 5.7 Edited UM3 output corresponding to middle plume in Fig. 5.4.

Before concluding this section some comments should also be made about the plume diameter decreasing after merging. This occurs partly because the plume element rises into an unstable layer in which the vertical velocity of the plume increases. This is evident in the Ambient properties panel of Fig. 5.4 (upper right). It is also evident from the text ambient table, as shown in Fig. 5.8. The density of 23.0119sigma-T at 49.5m is greater than 23.00932sigma-T at 50.5m. If possible, such density unstable layers should be removed from the data.

```
Ambient Table:
    Depth  Amb-cur  Amb-dir  Amb-sal  Amb-tem  Amb-pol   Decay  Far-spd  Far-dir  Disprsn   Density
     m      m/s      deg      psu      C       kg/kg     s-1     m/s      deg    m0.67/s2   sigma-T
    0.0    0.0603   171.1    33.77    27.11     0.0      0.0      -        -      0.0003    21.7796
....
   45.5    0.208    358.7    35.23    27.15     0.0      0.0      -        -      0.0003    22.86742
   46.5    0.156      1.41   35.35    27.15     0.0      0.0      -        -      0.0003    22.96018
   47.5    0.201     14.08   35.39    27.15     0.0      0.0      -        -      0.0003    22.98943
   48.5    0.234     16.89   35.42    27.15     0.0      0.0      -        -      0.0003    23.0119
   49.5    0.194     20.79   35.42    27.15     0.0      0.0      -        -      0.0003    23.00932
   50.5    0.213    351.0    35.43    27.14     0.0      0.0      -        -      0.0003    23.01877
   51.5    0.241     35.93   35.43    27.14     0.0      0.0      -        -      0.0003    23.0206
   52.5    0.264    251.2    35.45    27.14     0.0      0.0      -        -      0.0003    23.03317
   53.5    0.0375   123.2    35.47    27.12     0.0      0.0      -        -      0.0003    23.05228
   54.5    0.219     29.23   35.48    27.11     0.0      0.0      -        -      0.0003    23.06795
   55.5    0.0629    12.47   35.5     27.1      0.0      0.0      -        -      0.0003    23.08395
```

Figure 5.8 Edited UM3 output corresponding to middle plume in Fig. 5.4.

However, eliminating this layer does not dramatically change the simulated behavior of the plume around the region of exaggerated growth. The artifact must be attributed primarily to the limited ability of the engineering solution to the overlap condition.

The right trace, while having an appealing appearance, is least representative of actual conditions. Due to the absence of the 0.0m surface layer in the ambient file (Distillery.003.db) VP5 does not correctly process the input data, as is evident from the run-time ambient table output on the text tab (Fig. 5.9); there are no layers indicated below 0.5m. The far-field direction of the plume is not representative of currents found in the ambient table.

```
Case 1; ambient file C:\Plumes5\Distillery.003.db; Diffuser table record 1: ---------------------------------

Ambient Table:
    Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol    Decay   Far-spd   Far-dir   Disprsn   Density
      m       m/s       deg       psu        C       kg/kg     s-1       m/s       deg    m0.67/s2   sigma-T
     0.0     0.0603    171.1     33.77     27.11      0.0       0.0        -         -      0.0003   21.78206
     0.5     0.0603    171.1     33.77     27.11      0.0       0.0        -         -      0.0003   21.78206

Diffuser table:
```

Figure 5.9 The incorrectly processed ambient array formed from the ambient file Distillery.003.db, that does not possess data for the 0.0 surface layer.

Simply changing 0.5m to 0.0m in the first row of the ambient table (of file Distillery.003.db) results in a viable plume trajectory that is consistent with the input data.

The best of the three simulations corresponds to the ambient file Distillery.002.db (blue trace). This file represents the layer-averaged data that produce a smoothly varying centerline trajectory, followed by a short section that is comparable to the growth "spurt" seen in Fig. 5.4 for Case 1. This effect is further accentuated in the elevation view as the plume motion becomes almost normal to the projection plane.

5.5 Vector interpolation

The preceding section explains the consequences of spatial averaging and the importance of maintaining a surface layer (depth = 0.0). These consideration have important effects on plume simulations. This section explains how vector averaging can further influence the simulation. Vector averaging is turned on by checking the "Current vector averaging" box on the Model Configuration checklist on the diffuser tab.

The user may have noticed that the ambient array is shown filled out in the text output when a case is run, even if the cells are left empty on the ambient table on the ambient tab. (The array can be shown "as is" if this feature is turned of by selecting the "Text tab (ambient as is)" radio-button option on the Output settings panel on the settings tab.) In either case, when a model is run VP5 first prepares an internal array that has all cells filled in a similar fashion. This implies that the tables must be interpreted and missing values are either interpolated or extrapolated, held constant, or interpolated "linear-to-zero" as appropriate (partly determined by the ambient array settings above the ambient table).

If a direction cell is empty (null value) and is bracketed by defined depths and direction cells, then VP5 interpolates a value for that depth. Essentially, it does weighted averaging of the bracketing cells, treating the input as ordinary scalar values. It does not do vector interpolation or averaging.

For example, if the user inserts a 55m depth row to the file Distillery.002.db, they can force VP5 to output the ambient values on the text tab at this depth when the case is run. The result is shown in Fig. 5.10. The current speed is 0.095, the correctly weighted value for a level between the 50.5 and 55.5m levels spaced a tenth of the way from the 55.5m level. The corresponding weighted direction is 116deg, similarly spaced between 90deg at the 55.5m level and 350deg at the 50.5m level.

```
Case 1; ambient file C:\Plumes5\Distillery.002.db; Diffuser table record 1: ----------------------------------

Ambient Table:
    Depth   Amb-cur  Amb-dir  Amb-sal  Amb-tem  Amb-pol   Decay  Far-spd  Far-dir  Disprsn  Density
      m       m/s      deg      psu       C      kg/kg     s-1     m/s      deg    m0.67/s2  sigma-T
     0.0    0.0656   184.6    33.77    27.11      0.0      0.0      -        -      0.0003   21.7796
....
    50.5     0.14    350.0    35.43    27.15      0.0      0.0      -        -      0.0003   23.0176
    55.0    0.095    116.0    35.51    27.08      0.0      0.0      -        -      0.0003   23.10166
    55.5     0.09     90.0    35.52    27.07      0.0      0.0      -        -      0.0003   23.11099
```

Figure 5.10 Text output showing an interpolated layer at the 55m level.

However, 350deg is also -10deg. When this value is substituted for 350deg on the ambient tab the new interpolated value at 55m depth is 80deg (Fig. 5.11).

```
Case 1; ambient file C:\Plumes5\Distillery.002.db; Diffuser table record 1: ----------------------------------

Ambient Table:
    Depth   Amb-cur  Amb-dir  Amb-sal  Amb-tem  Amb-pol   Decay  Far-spd  Far-dir  Disprsn  Density
      m       m/s      deg      psu       C      kg/kg     s-1     m/s      deg    m0.67/s2  sigma-T
     0.0    0.0656   184.6    33.77    27.11      0.0      0.0      -        -      0.0003   21.7796
....
    50.5     0.14    -10.0    35.43    27.15      0.0      0.0      -        -      0.0003   23.0176
    55.0    0.095     80.0    35.51    27.08      0.0      0.0      -        -      0.0003   23.10166
    55.5     0.09     90.0    35.52    27.07      0.0      0.0      -        -      0.0003   23.11099
```

Figure 5.11 Text output showing an interpolated layer at the 55m level.

So which one is correct? The answer cannot be known with certainty but, more likely than not, the 80deg value is, as currents are more likely to turn 100deg in 5m than to turn 260deg in the same interval. The difference it makes to the simulation is shown in Fig. 5.12.
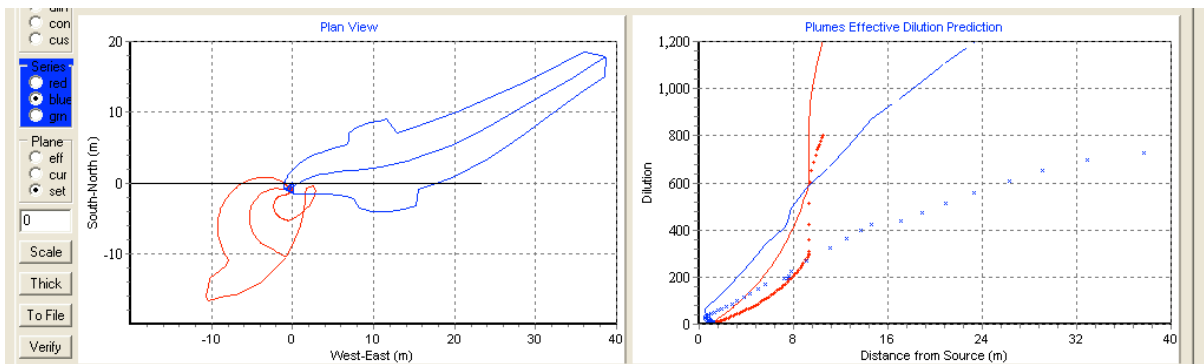
Figure 5.12 Changes in UM3 simulations due to the insertion of a 55m level into the ambient table. Red (lower trace), 50.5m direction 350deg; blue(upper trace), 50.5m direction -10deg.

Zooming reveals simulated plume behavior near the source (Fig. 5.13).
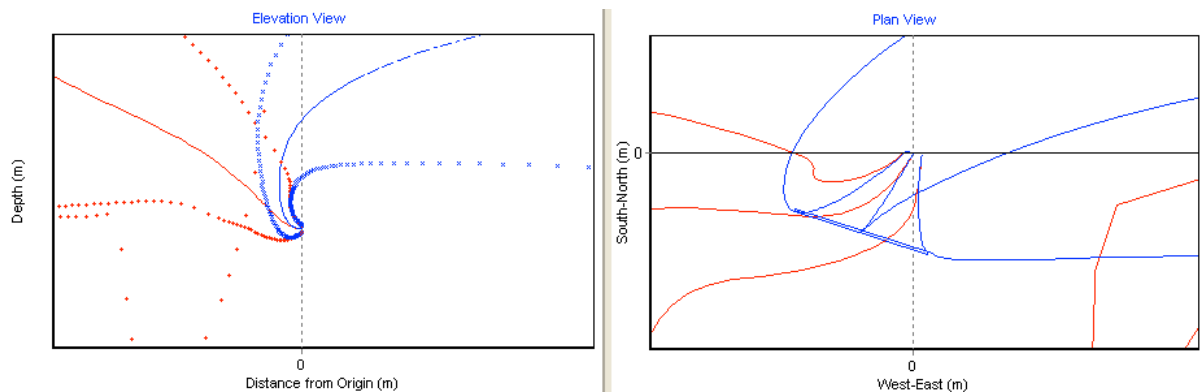
Figure 5.12 Near-source plume details, elevation view (left) and plan view (right).

Notice the plumes rotate in opposite directions and the right plume (with the -10deg direction at the 50.5m level) first flows against the current and then bends over into the current as it rises.

Up to this point now vector averaging (or interpolation) has been specified. Before checking this option on the diffuser tab the user should remove the 55m row and return the 50.5m direction value to 350deg. Then clear all graphics (the Clear + button on the graphics tab) and run the default option (no vector averaging). The results should look something like the red (left) trace in Fig. 5.13. On the graphics tab, check the blue series, return to the Current vector averaging option and run UM3 again. The results should look something like the blue (right) trace in Fig. 5.13. The latter is considered to be the best interpretation of the given input data.
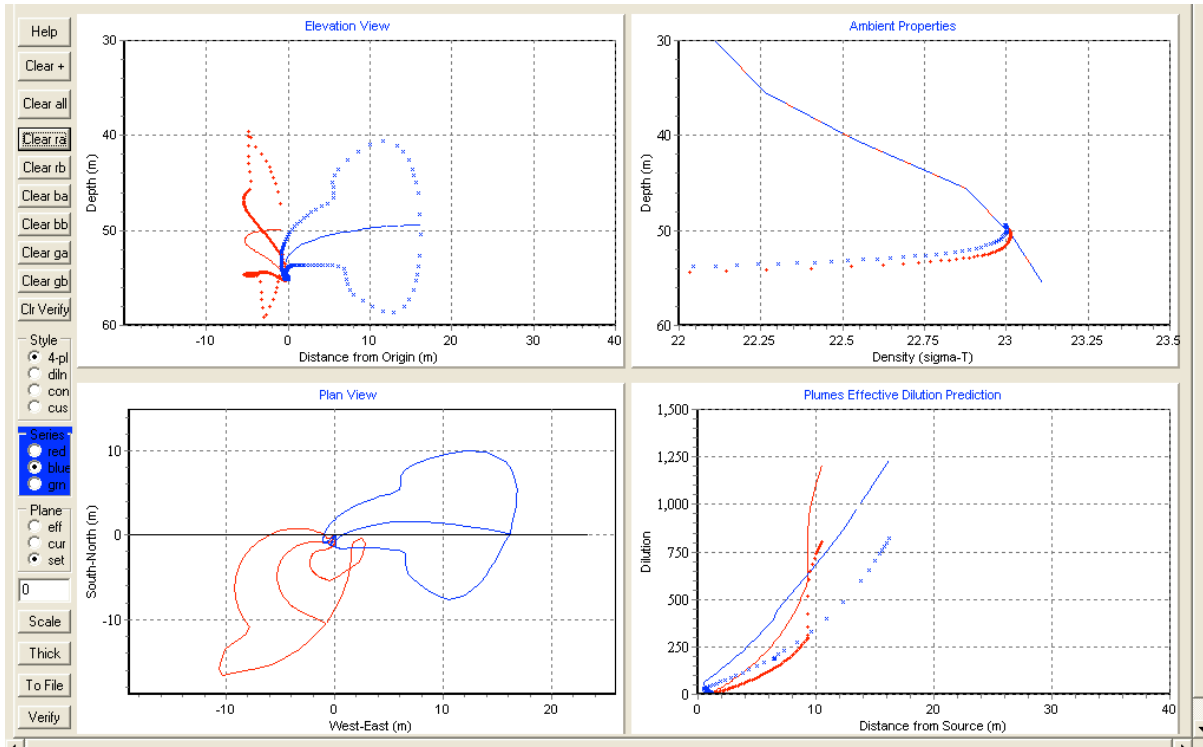
Figure 4.2.5 Like Fig. 4.2.4 using ambient file Distillery.002.db (layer averaged). Current directions in the red trace (left contour) are linearly averaged; directions in the blue trace (right contour) are vector averaged.

In conclusion, this exercise shows that the choice of vector averaging can have profound effects on the outcome of the simulation. In the future the authors hope to change the code so that vector averaging can be applied to constructing the internal data array so that extra rows can be added to show interpolated values correctly.

5.6 DKHW Distillery simulation

```
/ UM3. 9/8/2003 9:27:16 PM
Case 1; ambient file C:\Plumes\Barbadosavg.001.db; Diffuser table record 1: ----------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay  Far-spd   Far-dir   Disprsn    Density
       m       m/s       deg       psu        C      kg/kg       s-1     m/s       deg    m0.67/s2   sigma-T
      0.0    0.0656     184.6     33.77     27.11      0.0       0.0       -         -       0.0003     21.78
      5.5    0.0656     184.6     33.78     27.1       0.0       0.0       -         -       0.0003     21.79
     10.5    0.0644     208.8     33.79     27.08      0.0       0.0       -         -       0.0003     21.81
     15.5    0.0645     233.3     33.84     27.08      0.0       0.0       -         -       0.0003     21.84
     20.5    0.0653     271.9     33.94     27.08      0.0       0.0       -         -       0.0003     21.92
     25.5    0.108      278.1     34.04     27.09      0.0       0.0       -         -       0.0003     21.99
     30.5    0.128      276.4     34.22     27.1       0.0       0.0       -         -       0.0003     22.12
     35.5    0.157      283.9     34.41     27.11      0.0       0.0       -         -       0.0003     22.26
     40.5    0.193      301.7     34.78     27.12      0.0       0.0       -         -       0.0003     22.54
     45.5    0.172      351.8     35.24     27.15      0.0       0.0       -         -       0.0003     22.87
     50.5    0.145      359.6     35.43     27.15      0.0       0.0       -         -       0.0003     23.02
     55.5    0.0885      97.9     35.52     27.07      0.0       0.0       -         -       0.0003     23.11

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-den   Temp Polutnt
   (cm)    (m)   (deg)(Surv-deg)    ()     (m)     (m)     (m)     (m)    (MGD) (kg/m3)   (C) (kg/kg)
   15.0    1.5    0.0    252.0     2.0    20.0    50.0   150.0    55.0    0.75  1009.2   35.0 20000.0

Simulation:
Froude number:     6.541; effluent density (sigma-T)       9.24; effluent velocity      0.93(m/s);
        Depth  Amb-cur   P-dia  Polutnt  Dilutn  x-posn   y-posn
Step     (m)   (cm/s)    (cm)   (kg/kg)    ()     (m)      (m)
   0     55.0    9.415    15.0  20000.0    1.0     0.0      0.0;
 100    54.82    9.613   89.33   2760.7    7.16   -1.055  -0.0941;
 200    53.39   11.22   295.9    381.1    51.79   -3.419   0.521;
 211    53.23   11.4    336.0    306.7    64.34   -3.739   0.511; begin overlap;
 300    51.93   12.87   689.9     84.66  233.1    -6.502  -1.334;
 342    51.34   13.53   872.1     55.79  353.7    -7.167  -3.273; merging;
 356    51.2    13.7   1094.0     48.52  406.6    -7.199  -3.84; bottom hit;
 395    50.63   14.33  1664.4     31.17  633.0    -6.358  -6.485; trap level;
 400    50.58   14.41  1749.2     29.78  662.5    -6.164  -6.777;
 424    50.17   14.67  1528.3     23.3   846.9    -4.002  -8.969; end overlap;
 450    49.89   14.83  1549.5     17.33 1138.3     1.194 -12.17; local maximum rise or fall;
 473    50.38   14.58  1797.8     11.37 1735.2    11.72  -15.93; trap level;
 ;
9:27:18 PM. amb fills: 2
/ DKHW
Case 1; ambient file C:\Plumes\Barbadosavg.001.db; Diffuser table record 1: ----------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol     Decay  Far-spd   Far-dir   Disprsn    Density
       m       m/s       deg       psu        C      kg/kg       s-1     m/s       deg    m0.67/s2   sigma-T
      0.0    0.0656     184.6     33.77     27.11      0.0       0.0       -         -       0.0003     21.78
      5.5    0.0656     184.6     33.78     27.1       0.0       0.0       -         -       0.0003     21.79
     10.5    0.0644     208.8     33.79     27.08      0.0       0.0       -         -       0.0003     21.81
     15.5    0.0645     233.3     33.84     27.08      0.0       0.0       -         -       0.0003     21.84
     20.5    0.0653     271.9     33.94     27.08      0.0       0.0       -         -       0.0003     21.92
     25.5    0.108      278.1     34.04     27.09      0.0       0.0       -         -       0.0003     21.99
     30.5    0.128      276.4     34.22     27.1       0.0       0.0       -         -       0.0003     22.12
     35.5    0.157      283.9     34.41     27.11      0.0       0.0       -         -       0.0003     22.26
     40.5    0.193      301.7     34.78     27.12      0.0       0.0       -         -       0.0003     22.54
     45.5    0.172      351.8     35.24     27.15      0.0       0.0       -         -       0.0003     22.87
     50.5    0.145      359.6     35.43     27.15      0.0       0.0       -         -       0.0003     23.02
     55.5    0.0885      97.9     35.52     27.07      0.0       0.0       -         -       0.0003     23.11

Diffuser table:
   P-dia  P-elev V-angle H-angle   Ports Spacing AcuteMZ ChrncMZ P-depth Ttl-flo Eff-den   Temp Polutnt
   (cm)    (m)   (deg)(Surv-deg)    ()     (m)     (m)     (m)     (m)    (MGD) (kg/m3)   (C) (kg/kg)
   15.0    1.5    0.0    252.0     2.0    20.0    50.0   150.0    55.0    0.75  1009.2   35.0 20000.0

Simulation:
Froude number:     6.541; effluent density (sigma-T)       9.24; effluent velocity      0.93(m/s);
        Depth  Amb-cur   P-dia  Polutnt  Dilutn  x-posn   y-posn
Step     (m)   (cm/s)    (cm)   (kg/kg)    ()     (m)      (m)
   0     55.0    9.415    15.0  20000.0    1.0     0.0      0.0;
   2     54.98   9.415    41.4  10460.3    1.912  -0.374  -0.337;
   3     54.97   9.415    42.4  10204.1    1.96   -0.378  -0.341;
   4     54.97   9.415    43.5   9955.2    2.009  -0.383  -0.345;
  18     54.96   9.415    65.4   6402.0    3.124  -0.48   -0.413;
  23     54.94   9.415    78.7   5105.9    3.917  -0.542  -0.447;
  24     54.94   9.415    83.0   4761.9    4.2    -0.563  -0.457;
  30     54.9    9.415   106.0   3307.4    6.047  -0.695  -0.501;
  31     54.9    9.415   109.3   3138.7    6.372  -0.717  -0.506;
  33     54.87   9.415   118.7   2714.4    7.368  -0.785  -0.515;
  35     54.84   9.415   130.0   2293.6    8.72   -0.874  -0.517;
  36     54.82   9.415   135.2   2127.2    9.402  -0.918  -0.514;
  39     54.76   9.415   149.4   1745.5   11.46   -1.047  -0.493;
  40     54.74   9.415   153.8   1646.5   12.15   -1.088  -0.482;
  44     54.6    9.415   177.2   1227.0   16.3    -1.324  -0.391;
  45     54.55   9.415   184.4   1128.9   17.72   -1.398  -0.352;
  49     54.37   9.415   210.4    848.5   23.57   -1.679  -0.171;
  53     54.13   9.415   239.6    638.0   31.35   -2.002   0.0942;
  57     53.77   9.415   281.3    446.6   44.78   -2.483   0.57;
  63     53.2    9.415   344.4    283.0   70.68   -3.278   1.488;
  68     52.5    9.415   419.6    180.0  111.1    -4.376   2.895;
  74     51.58   9.415   518.4    111.5  179.3    -6.107   5.257;
  80     50.54   9.415   631.9     71.94 278.0    -8.698   8.917;
  81     50.4    9.415   647.4     68.25 293.0    -9.13    9.535; trap level;
 125     49.21   9.415   784.9     45.44 440.1   -16.71   20.47;
 126     49.21   9.415   785.5     45.38 440.7   -16.88   20.73;
 126     49.21   9.415   785.5     45.38 440.7   -16.88   20.73; local maximum rise or fall;
```
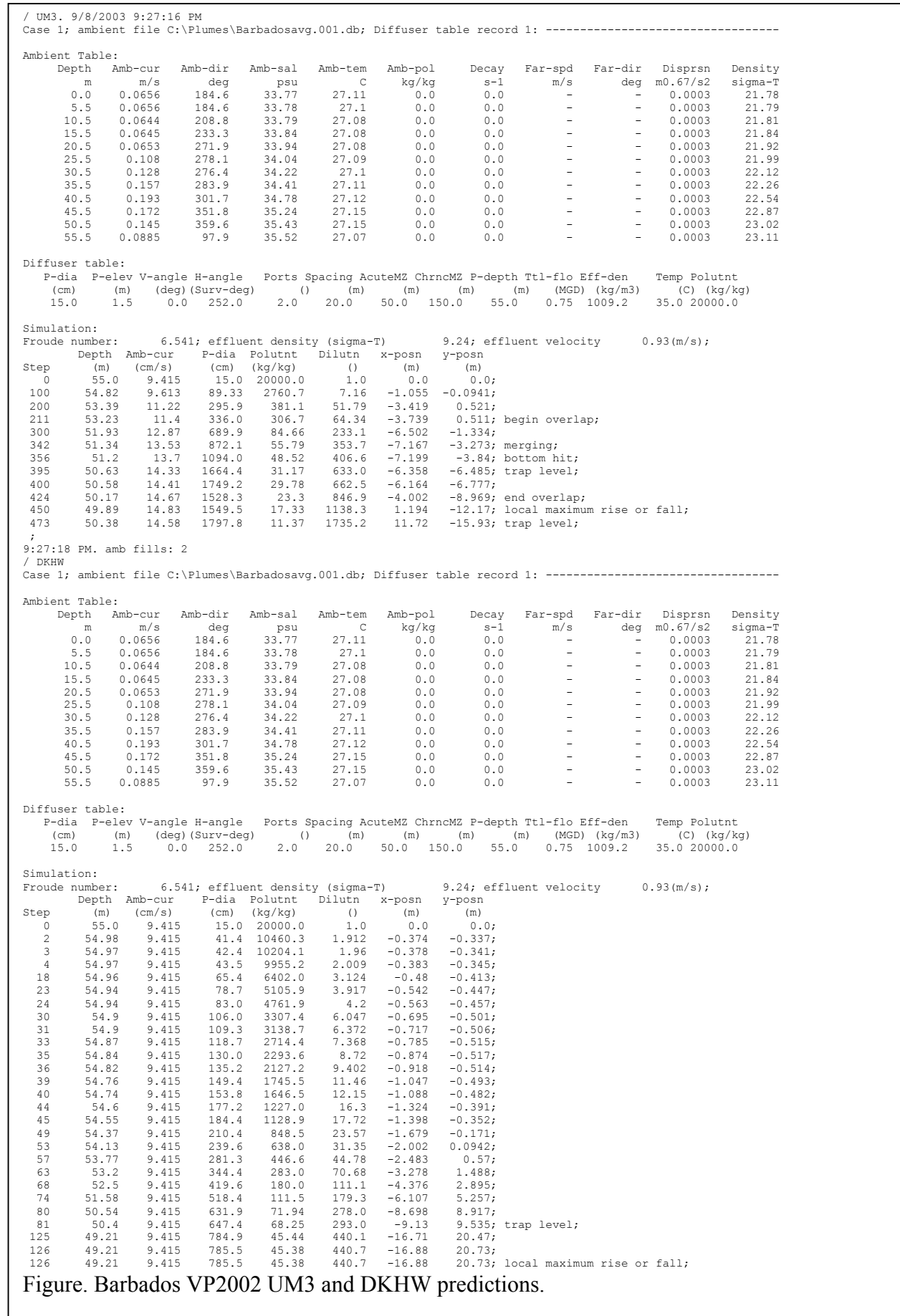
Figure. Barbados VP2002 UM3 and DKHW predictions.

Model   The above simulations used <mark>VPx</mark> UM3. The best simulation is considered to be
               the blue one using the Barabadosavg.001.db ambient input file. Note the smoothly
               spiraling trajectory compared to the corkscrew-like trajectory using the original,
               high-resolution ambient file, Barabados.001.db in red. The Barabadosavg.001.db
               file produces a spurious simulation (the narrow plume, straight trajectory) because
               the surface layer has a depth of 0.5m, not zero as required for the surface layer. In
               the latter case VP is unable to correctly create the internal ambient array.
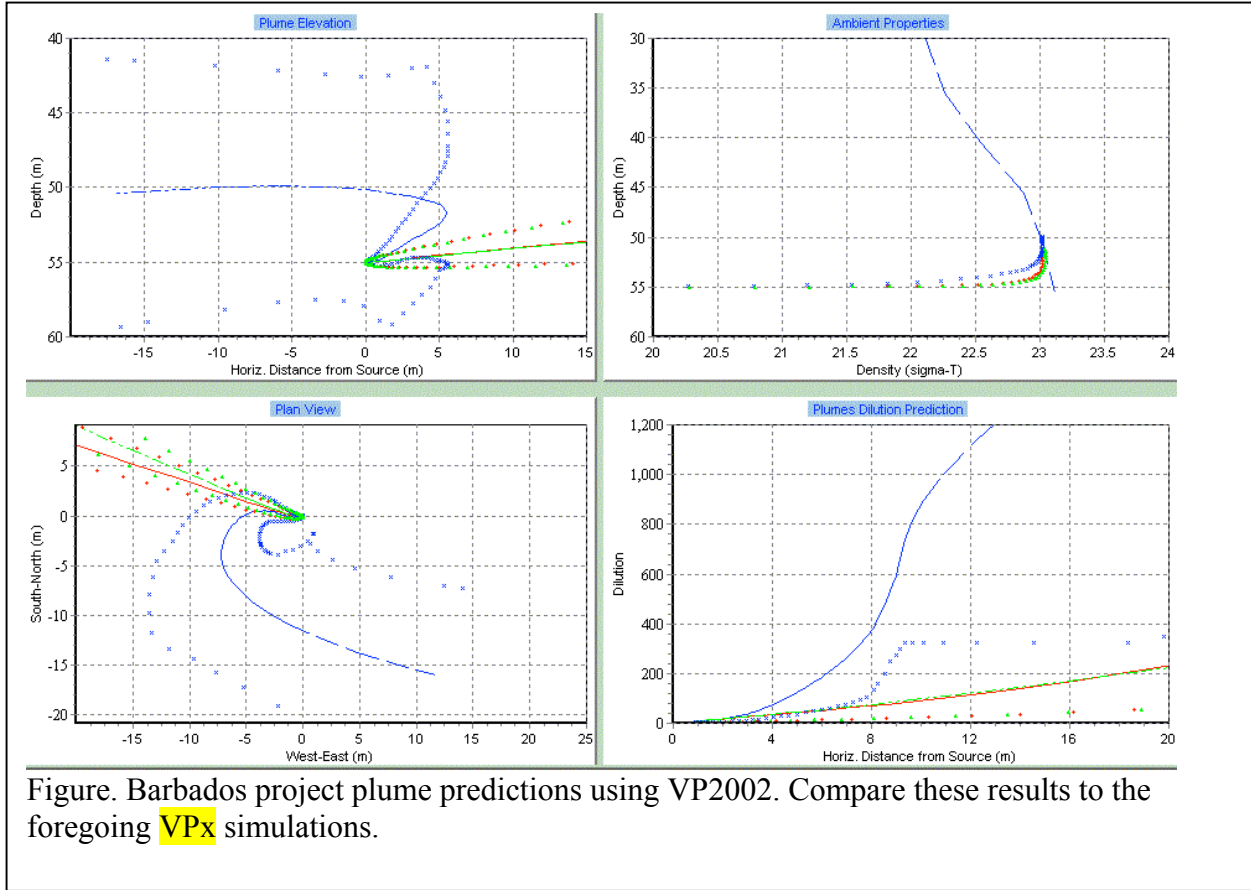
Modifications

It would be nice to build a data pasting functionality into Visual Plumes.

Practice
- Compare VP2002 with the experimental VPx. Note that VPx runs the 58-layer problem
  much faster than VP2002. VPx is recommended for analyzing this problem.
- Try customizing the graphics and using the To File button to save the graphics.
- VP only produces bitmap (bmp) files when the To File button is pressed.
- Programs such as Paint may be used to convert VP bmp files to gif files that are much
  smaller in size but alter the VP colors significantly.

Limitations, troubleshooting

- Keeping ambient files and case synchronized
- Keeping inheritance straight
- In reducing the number of layers to force VP to plot the density profile down to the depth
  of the diffuser, the client replaced the surface layer (the first line in the ambient table;
  depth = 0) with one with a depth = 0.5m. VP must have a surface zero layer to function
  properly. Running VP with the ambient file Barbadosshort.001.db shows what happens
  when a zero surface depth row is not provided.
- When multiple ambient layers are input the data should be checked for smoothness.
  While there can be problems with current stratification, assuming that current is
  unidirectional, as Cormix (see simulations below) appears to do, is not the answer either.

Figure. Barbados project plume predictions using VP2002. Compare these results to the foregoing VPx simulations.

In the VP2002 simulation below, compare the trajectories to the foregoing VPx simulations. The VP2002 plume trajectory for the 58-layer plume differs radically from the VPx simulation, an indication that VP2002 does not properly handle more than 20 layers. Note that the 58-layer has not been plotted to the depth of the diffuser. The apparent direction of the plumes in the Plume Elevation panel could be controlled by the effluent or current plane buttons on the graphics tab.

6. Small stream applications; Project Ideal-Cr[eek]

Synopsis

In the early 1990s Norm Glenn of the Washington Department of Ecology faced a growing problem, evaluating the state's numerous discharges to shallow streams. He found that none of the readily available plume models at the time dealt with the problem effectively. For example, as a part of an effort to discourage poor design, the Cormix model (Doneker and Jirka 1990) was specifically programmed not to run these cases. However, many of these were existing discharges for which a way to appraise their efficacy was needed. Other models were ineffective because they did not consider the physics of plume interaction with solid boundaries.

Whether through technical assistance or an EPA mixing zone workshop, Norm Glenn and the author began to collaborate on modifying the DOS Plumes program to enable its models, UM and RSB, to be set up to estimate effluent dilution in shallow streams. The approach was based on the reflection technique successfully exploited by Davis and Shirazi in their surface discharge PDS model (Davis 1999), now a part of Visual Plumes. The approach is described in the Washington State mixing zone manual (Bailey, G.C. 1994) and is sometimes referred to as the DOS Plumes "Very Shallow Water" capability.

This example illustrates well a similar, more general approach to the problem of discharges into small, often shallow, streams built into the experimental version of Visual Plumes, VPx. This is the first version of Visual Plumes that is sensitive to boundaries at this level of sophistication. In addition to a small stream capability, VPx also introduces isopleth-based graphical plume boundaries. The latter facilitates the analysis of plumes intersecting mixing zone boundaries. The Verify button on the graphics tab may be used to import mixing zone coordinates into VP to help the analysis. When the plume has entirely entrained the ambient stream, overall entrainment into the plume ceases, but VPexe includes an algorithm that allows it to estimate the continued homogenization of the plume across the stream cross-section.

This problem, patterned on Arcade Creek, an urban creek in Sacramento, California, illustrates the effect of ambient background concentration on plume pollutant concentrations. There is a background concentration above which a water quality criterion cannot be met. Conversely, it may be used to show that there is a river flow threshold below which water quality criteria cannot be met.

The approach is described in a paper included herein, called "Modulating Storm Drain Flows to Reduce Stream Pollutant Concentrations," (Frick and Denton 2003).

The near-field isopleth mapping capability is currently limited to the UM3 model.

Exercise objectives

The objective of the IdealCr project is to learn to adapt VPexe to discharges to small streams. Parameters and settings found on the settings tab play an important role in this exercise. It is easy to overlook these parameters or to be confused by the number of options and parameters found on the settings tab, so it is important to be aware of the clues to troubleshooting unexpected behavior. The absence of closed isopleths can be due to several causes including the specification of a concentration isopleth value that exceeds the source strength, a concentration isopleth value that is changed by VPexe when concentration units are changed of which the user remains unaware, and an early termination of the simulation caused by one of several stopping conditions or criteria. As an example of the latter, VP is programmed to stop the near field simulation when the plume hits the surface. To avoid unwanted model behavior, it is very helpful to examine the text output for messages that are clues to odd behavior. In many small stream applications, if the surface-hit message appears on the last line of output, the "Do not stop on surface hit" option should be checked on the UM3-options-and-controls panel on the settings tab. The presence of a spuriously large isopleth value will also be reported in the text output.

Streams present considerable challenges to the analyst. Measurement programs may not be possible to determine depth and velocity associated with critical or known flows. In such cases, if approximate stream dimensions and the landform slope are known, the Mannings equation, or other flow-stage relationships, may be used to estimate stream depth and velocity. The Quattro spreadsheet Streamflow.wb3 may be adapted to solve the Mannings equation for various stream conditions.

- Familiarize yourself with the Isopleth plume boundary option on the diffuser tab.
- Find and set isopleth values and stream width limits on the settings tab.
- Remember to check the text output for clues to unexpected VPexe behavior.
- Find the "stop condition" overrides, like the "Do not stop on surface hit" option, on the settings tab.
- Learn to save graphics files.
- Consider solving the Mannings equation by adapting the spreadsheet file Streamflow.wb3.
- Recognize input conditions and output messages that signal spurious model behavior.
- Be aware that some options and parameters are not stored by VP between runs, for example, the "Do not stop on surface hit" option is always reset to off at the beginning of each VP session.
- Check the Isopleth plume boundary option on the Model Configuration panel on the diffuser tab.
-
-

Preliminary inputs

Diffuser tab

Diffuser and effluent parameters are defined in the following figure. Noteworthy is the slight change in effluent flow going from Case 1 to Case 3. Over this range of values the critical isopleth goes from closing to not closing.
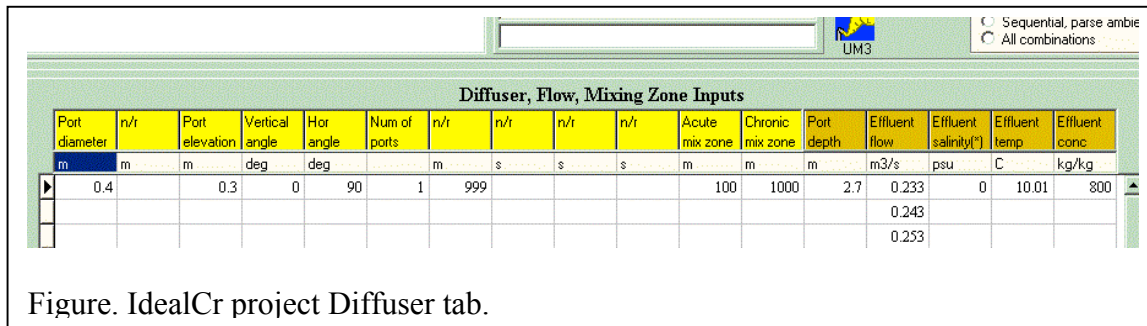

Figure. IdealCr project Diffuser tab.

Amb
ient
tab

Amb
ient
para
mete
rs

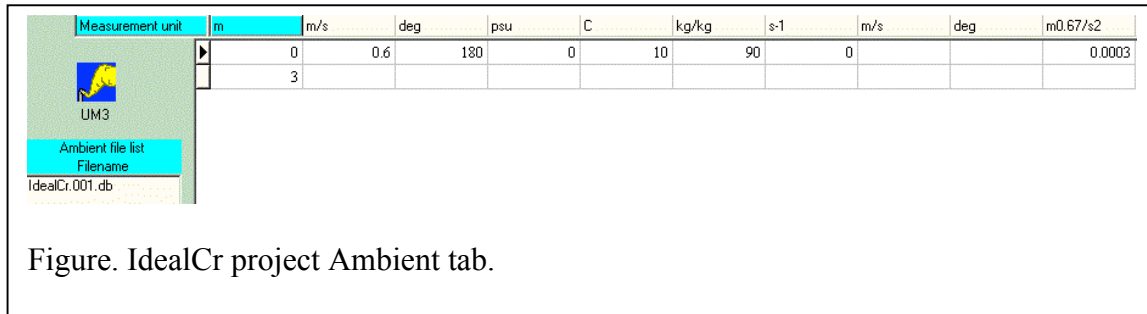are defined in the following figure. The input requirements are simple.

Figure. IdealCr project Ambient tab.
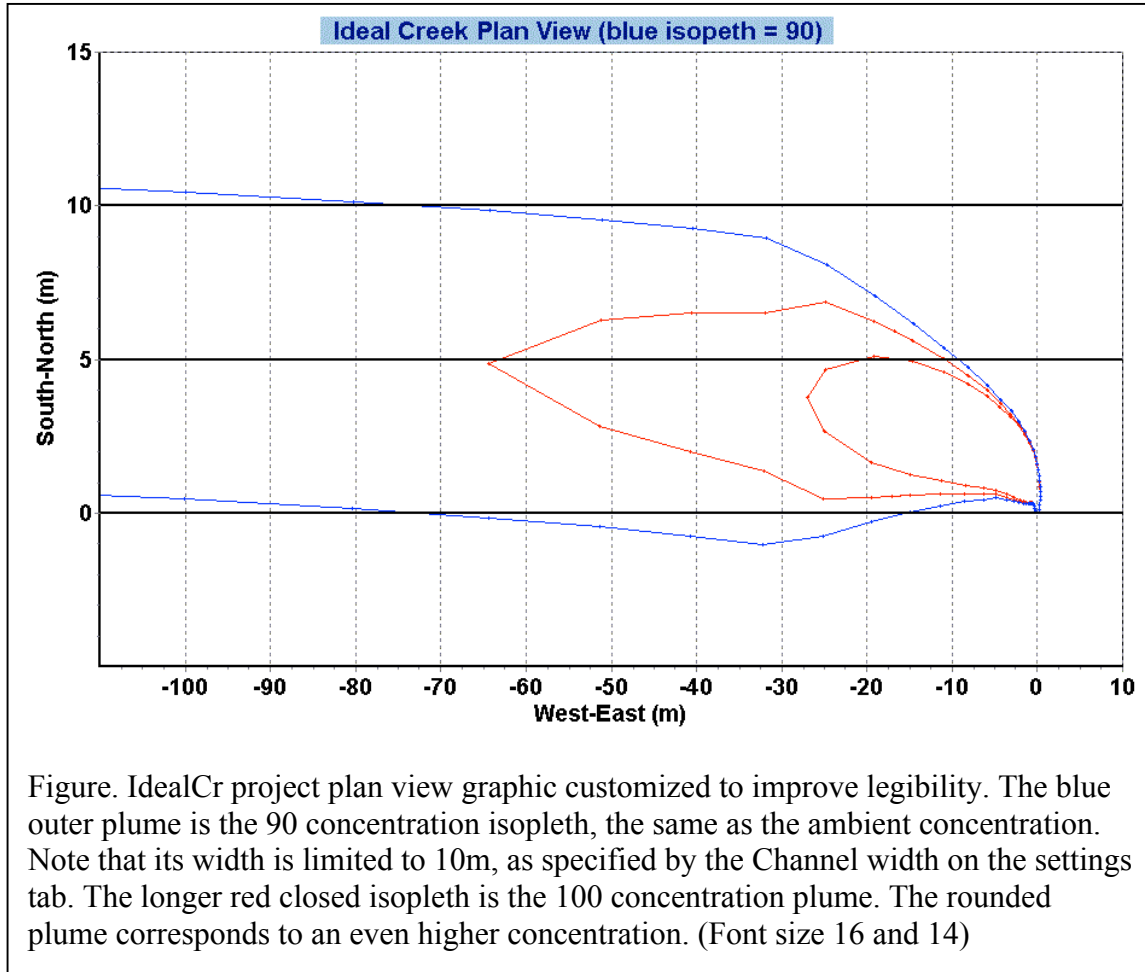
Setti
ngs
Tab

- C
  h
  a
  n

nel width: 6m
- Check option "Do not stop on surface hit"
- Farfield isopleth values of interest: 90, 100, etc.
- Channel width = 10m

Model   UM3

Practice

- Try different graphic colors and other customization. Try to match the appearance of the plume path graphic below. Use the To-file button to save the graphic and note that large bitmap (bmp) files are created. Note that VP saves the 4-panel graphics in higher resolution than appears on the screen.
- Try constructing ASCII txt files to define bank geometry
- Compare VP2002 with the experimental version
- Set the Plume Elevation graphics projection plane on the "Plane" radio button panel
- Increase the stream width to see how that affects the shape of the plume.

- Vary the isopleth concentration and observe the size of the area within the isopleth.
- How would the VPx PDS model work on this problem?
-
-

Ideal Creek Plan View (blue isopeth = 90)

Figure. IdealCr project plan view graphic customized to improve legibility. The blue outer plume is the 90 concentration isopleth, the same as the ambient concentration. Note that its width is limited to 10m, as specified by the Channel width on the settings tab. The longer red closed isopleth is the 100 concentration plume. The rounded plume corresponds to an even higher concentration. (Font size 16 and 14)

Theory

- Flow ratios, dilution ratios, and maximum volume dilution
- Power profile
- Program time step resolution
-
-

Limitations, troubleshooting

- Concentration units must be in kg/kg. The next official edition of VP will address this problem.
- There is not a "Zone of Flow Establishment (ZOFE)" message when the isopleth value is great than the source concentration.
- Remember the check option "Do not stop on surface hit" is ephemeral. If it is applicable, it must be checked every time VPx is run. The next official edition of VP will probably store this setting in the project Lst file.
- Remember to specify the desired isopleth value on the settings tab.
- Check that the isopleth value was not inadvertently placed in the Max detailed graph edit box, this is easy to do.
- Make sure the channel width is properly defined on the settings tab.

7. Surface discharge model PDSW and plume interaction; Project Thermal

Synopsis

Two major concerns of the State of Washington are the health of salmon populations, as impacted by thermal discharges to rivers, and the common discharge to water bodies from side channels, such as combined sewer overflows (CSO). The Visual Plumes PDS model, as a dedicated surface discharge model, is well suited to these problems.

The Joliet project involves two power plants discharging in close proximity from opposite sides of the Des Plaines River in Joliet, Illinois, an established community on old Route 66 southwest of Chicago. Early in the 1900s Chicago solved its drinking water contamination problems by diverting its sewage to the Illinois River system. The previous practice of discharging to Lake Michigan near drinking water intakes had led to cholera epidemics. The diversion solved the drinking water problem but led to the eutrophication of the Des Plaines River. This condition has vastly improved under the Clean Water Act and fish have returned to the waterway. However, there is evidence that thermal pollution prevents the resurgence of cold water species. Some believe that by merging the two Joliet power plants effectively block fish migration and cause additional stress on fish population. The author was asked to review a study performed for the industry.

This case study is based on a technical assistance. The extensive text between the dividing lines below is taken from the project technical assistance report. It is followed by a discussion of the plume model performed to support the report's findings.

Visual Plumes thermal plume modeling of Joliet #9 and Joliet #29

Walter Frick

"Deliberative process, FOIA-exempt"

Abstract

Information on Joliet Stations 9 and 29 collected between June and September 2002 and reported by EA Engineering, Science, and Technology (2003) is examined and independently modeled in some detail. The EA monitoring report suggests that the two plumes do not interact at the criterion level (93F or 33.89C) nor that the Aug 1, 2002 Joliet 29 93.5F (34.17C) plume exceeds 26ac. However, an independent analysis shows that contouring programs such as applied by AutoCad or SigmaPlot are prone to contouring across temperature ridge lines (that is, artificially severing elevated temperature areas connected by plumes traversing the river) when the monitoring grid exhibits great disparity in sampling resolution in orthogonal directions, viz. at 10ft intervals across the river and 500ft intervals or more along the axis of the river. The Visual Plumes plume model PDS (Davis 1999; Frick et al. 2003) is used to show that Joliet Stations 9 and 29 plumes will interact given certain conditions, notably in the presence of an initial cross-river component of momentum of the Joliet #9 plume and the recognition that the Joliet #9

plume will elevate the background temperature of the Joliet #29 plume, indirectly enlarging the Joliet #29 plume even when the background temperature is below the criterion temperature. In addition to establishing a connection between the plumes, the analysis for Aug 1, 2002 using conditions believed to be representative of river flow and other parameters at the time, suggests that a 93F-isotherm plume existed that was greater in area than 26ac mixing zone criterion.

The Visual Plumes modeling results, notably plume temperatures, are compared to the output from the Joliet 29 Near-Field Thermal Compliance Model (Paulsen 2001). The primary conclusion derived from this work is that, to be useful, the latter model must be modified to account for increases in ambient (upstream) temperature in vicinity of the Joliet #29 plume due to the addition of heat by the Joliet #9 plume. This could be achieved by devising a similar temperature model for the Joliet #9 plume and using its output to define the upstream temperature for the Joliet 29 plume.

An Appropriate Model for the Problem and Solid Surface Interaction

The Visual Plumes PDS model is generally recommended for problems involving thermal plumes discharged from surface side channels into larger water bodies, including lakes and rivers. The PDS model uses the reflection technique to model plume behavior at the surface air-water interface. It does not similarly model plume-bottom or plume-bank interaction. The effect is to overestimate entrainment, or mixing with the surrounding ambient water, tending to report smaller areas of elevated temperature than it would if mixing were constrained by these surfaces. Furthermore, the model idealizes the physical contours of the receiving water to be linear, thus the banks are assumed to be straight. Both assumptions can lead to the plume being portrayed, or plotted, over land surfaces. While this is of course not realistic, it should be borne in mind that more mixing is calculated by the model under these conditions than would be if the plume were also reflected from these surfaces, leading to less reduction in plume temperature. In other words, PDS will underestimated the area within elevated isotherms when bank or bottom interaction is indicated. The reported result are in this regard more favorable to the discharger than they would otherwise be. Nevertheless, the PDS model is considered to be an appropriate model to estimate the size of the Joliet #9 and #29 plumes and their interaction. It should be pointed out that a text file called PDS.out is created in the working directory following each run that contains more detailed output from PDS than is reported in VP5.

The Discharges

Joliet Station 29 discharges from the north side of the river. The source is considered to be the mouth of the slough discharging next to the relative origin of the problem; the coordinates of the origin, (0,0), is the end of the long spit forming the south bank of the Joliet Station 29 cooling water discharge channel.

Joliet Station 9 discharges from the south side of the river, upstream of Joliet Station 29. The source is harder to define because the cooling water discharge channel opens into a bay in the river. The southern shore promontory of this bay tends to deflect the source into the river channel, an effect that is difficult to model with redefining the origin of this source somewhat downstream of the mouth of the channel itself. The adjustment is primarily an angular one so defined to give the plume an orientation with respect to the compass suggested by Joliet Station 9 plume portrayed in Fig. 4-3 of the EA monitoring report.

The Des Plaines River

The coordinates of the river banks from about 500m above Joliet Station 9 to 2500m downstream of Joliet Station 29 are contained in an ASCII plain text file that can be plotted in the Visual Plumes "Path" graphics panel using the Verify button. The coordinates were hand digitized by drawing horizontal lines across a site map found in the EA monitoring report at 100m intervals. This process was facilitated by first using a photocopier reduction facility to produce a scale of 1cm = 100m. This took some trial and error. (The digitizing table that would have allowed assisted digitizing was inoperative.) At points of special interest, additional points were digitized at higher resolution. The results are shown in Fig. 1.
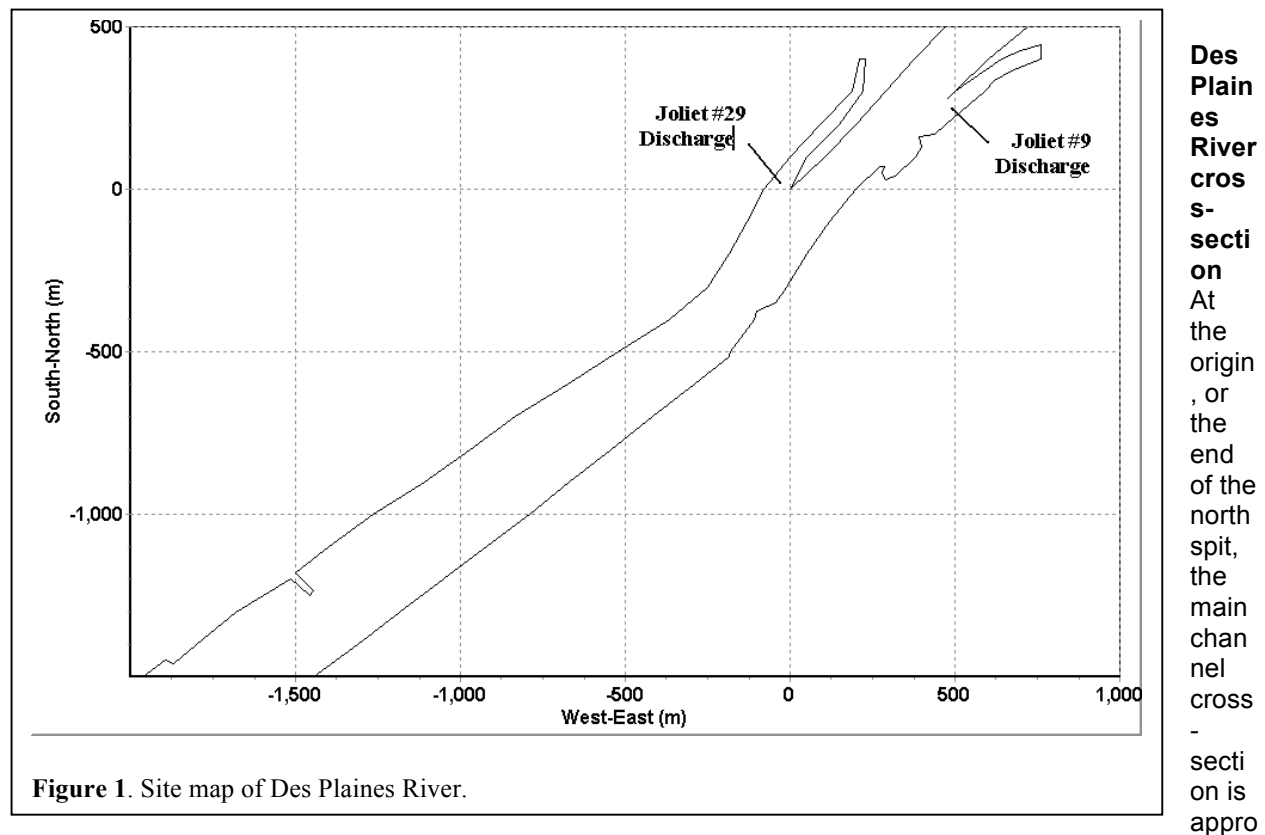
Figure 1. Site map of Des Plaines River.

Des Plaines River cross-section At the origin, or the end of the north spit, the main channel cross-section is approximately trapezoidal with a depth of 12ft, a bottom width of about 260ft, and a top width of about 430ft (the -250 cross-section in Fig. 4-12 of the EA monitoring report). The Visual Plumes units conversion capability is one way to convert these values to SI units, being about 3.7, 79, and 131m respectively. Thus the cross-sectional area is approximately 385m^2. At the end of the Joliet Station 9 spit the main channel is also approximately trapezoidal with a depth of about 11ft, surface width of 420ft and a bottom width of 150ft (the -1250 cross-section in Fig. 4-12 of the EA monitoring report; 3.4, 46, and 128m respectively). Its cross-sectional area is 291m^2.

Des Plaines River flow and average current velocity Knowledge of the cross-sectional area and the river flow allows an average current velocity to be computed. For the purposes of the plume model, current should be representative of the local current that affects the plume trajectory. For example, assuming no withdrawal, for a minimum river flow of 2000cfs (56.6m^{3}sec^{-1}) the corresponding average current at the Joliet Station 9 spit is 19.4cm-sec^{-1} and upstream of the Joliet Station 29 spit it is 14.7cm-sec^{-1}.

Power plants affect the local river flow The intake for Joliet Station 29 is upriver of both the intake and discharge point of Joliet Station 9. Therefore, given a river flow of 2000cfs, if Joliet Station 29 withdraws 1500cfs and Joliet Station 9 withdraws 500cfs, then Joliet Station 9 effectively discharges into stagnant water (the local current speed is zero) and the current at the Joliet Station 29 plume is only 0.0596cm-sec^{-1}.

A range of river flows is given in Table 3-1 of the EA monitoring report. On Aug 1, 2002 it ranged from 2404-3604cfs for an estimated average flow of 3004cfs. Tables 3-2 and 3-3 give corresponding power plant cooling water flows (withdrawals) of 592 and 1537 for #9 and #29 respectively (16.5 and 43.5m^{3}sec^{-1}).

The same tables specify intake temperatures (87.5 and 87.3F for #9 and #29 respectively, or 30.8 and 30.7C) and discharge temperatures ((94.4 and 101.5F for #9 and #29 respectively, or 34.7 and 38.6C).

An example spreadsheet for calculating the corresponding currents is given in Figure 2. The corresponding average current velocities upstream of the #9 and #29 discharges are estimated to be 10.8 and 8.6cm-sec^{-1}.

English Units	Computation of current velocities in the Des Plaines River					
	Cross-section					
	Joliet 29	Joliet 9				
Transect	-250	-1250				
Top width	430	420				
Btm width	260	150				
Avg depth	12	11				
Area	4140	3135				
Aug 1, 2002 Flows						
					River	
Withdrawal	1537	582		Min	2404	
River upstream	3004			Max	3604	
River net	1467	885		Avg	3004	
Current at -1250		0.282297				
Current at -250	0.354348					
Current (m/sec)	0.108	0.086				

Figure 2. Spreadsheet for estimating current velocities

The Visual Plumes Coordinate System

In its main diffuser and ambient tables, Visual Plumes allows horizontal angles to be input in scientific or surveying conventions. On the special settings and graphic tabs angles must be input according to scientific convention.

In scientific convention east corresponds to zero degrees and angles increase in a counter-clockwise direction. In engineering convention north corresponds to zero degrees and angles increase in a clockwise direction. In most cases Visual Plumes supports the input of negative angles. The latter is only available when bearing units may be specified.

Specifying effluent angles Specifying representative angles of discharge (direction of the flow at the source) may be difficult. The larger the cross-section of the effluent conduit the more variable the flow across the cross-section is likely to be. Another consideration is curvature in the river. As described in more detail above, the PDS model in Visual Plumes essentially assumes receiving water with horizontally uniform properties. Bank interaction is not specifically modeled. Thus, when PDS shows plumes that encroach on the banks, it means that the model is generally
predicting more dilution (generally temperature reduction) than is it would if bank interaction were specifically modeled.

In general, greater cross-current effluent plume angles contribute to more dilution than plumes that discharge in a more co-flowing direction.

For Joliet Station 29, the effluent direction is estimated to be flowing towards the -105deg direction, or 15deg west of south. For Joliet Station 9 it is estimated to be -160deg, or 20deg south of west.

River current directions Similar comments apply to determining representative river current directions. Joliet Station 29 and Joliet Station 9 current directions are approximately -150 (210deg) and 225deg respectively. The river flows approximately in a southwest direction.

Discharge Conduit Specifications

Conduit cross-sections When the PDS model is selected in Visual Plumes the label of the Port diameter column in the diffuser table on the diffuser tab changes to Conduit width and the second column, normally not required (n/r), acquires the Conduit depth label. In other words, a rectangular conduit is assumed. When the actual cross-section varies from rectangular, typically one adjusts the two inputs so that the effluent velocity is conserved.

For Joliet Station 29 a representative width and depth are 80 and 10ft respectively. (24.4 and 3.048m.) Because its effective origin is displaced by the headland of the bay, a representative Joliet Station 9 width and depth are more difficult to establish. 82 and 4ft respectively. (25 and 1.22m.)

Conduit discharge point origin To simulate and display both plumes on the same plan-view graphic, two projects are created. One is run first, after which the second is opened and is run next. Generally Visual Plumes is used assuming the effluent discharges at the origin, however, the user may offset the origin by checking the PDS origin check box in the lower left corner of the special settings tab. Visual Plumes will then interpret PDS output in terms relative to the offset specified on this panel. For example, the Joliet Station 9 plume originates at about 27deg north of east at a distance from the origin of 550m. The Joliet Station 29 plume originates at about 170 deg CCW from east at a distance from the origin of 30m.

If monitoring data are available, as is the case here, a trial and error and error process may be used to optimize the process to give best results. This process led to a refinement of the distances and angles to the source origins expressed in the previous paragraph.

Plume Interaction

The proximity of the plumes to each other and their apparent discharge angles (based on examination of Fig. 4-3 of the EA monitoring report) suggests that the plumes are likely to interact significantly under low-flow conditions. The two plumes corresponding to Aug 1, 2002 conditions are simulated and shown in Fig. 3. The simulated sources are located at the upstream end of the plumes, the open part of the initial trapezoids. True north is towards the top of the figure and east is to the right. The trapezoids represent the PDS zone of flow establishment (ZOFE). In this distance the plume dilutes by a factor of two and turbulence has reached the middle of the plume, finally beginning to reduce the velocity at that point and establishing a Gaussian profile of properties across the plume. At the source plume properties are assumed to be uniform.

Establishing Background Conditions

Visual Plumes may be used in a sensitivity mode to show how its plume increases greatly in length when the effective current is zero, as would happen when both power plants use essentially all of the river flow for condensing water. In such a scenario a corresponding representative temperature in the Joliet Station 9 plume should be selected to express the background temperature for the Joliet Station 29 plume, as the 89.1F isotherm was selected as the merging temperature in Fig. 3.
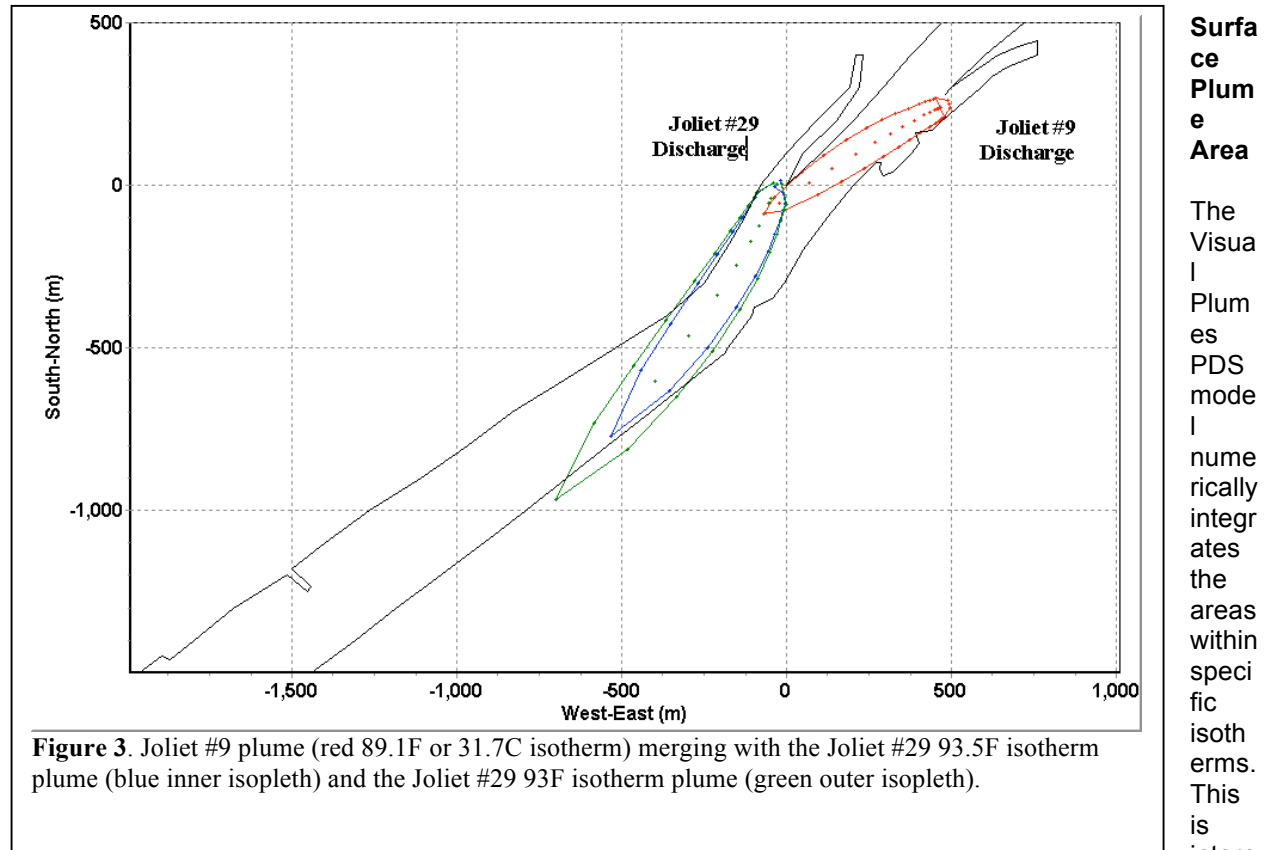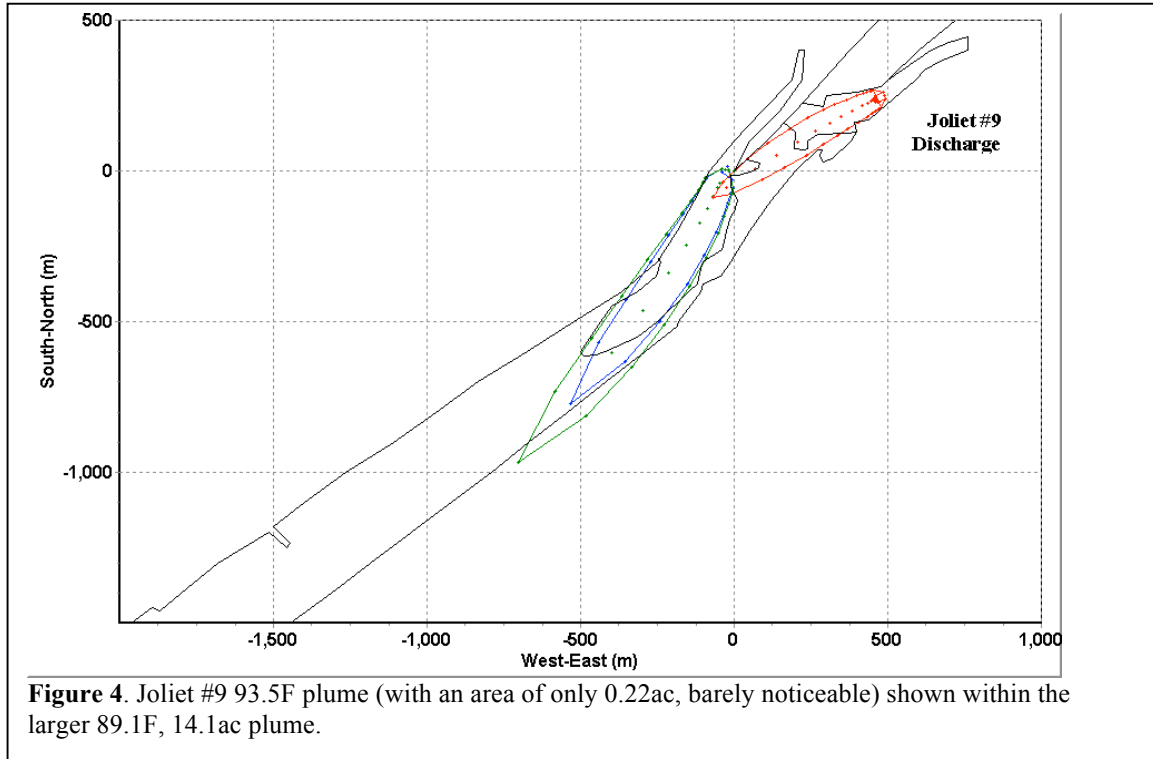
Figure 3. Joliet #9 plume (red 89.1F or 31.7C isotherm) merging with the Joliet #29 93.5F isotherm plume (blue inner isopleth) and the Joliet #29 93F isotherm plume (green outer isopleth).

Surface Plume Area

The Visual Plumes PDS model numerically integrates the areas within specific isotherms. This is interpreted by Visual Plumes and output as text, see Appendix A, Visual Plumes Text Output supporting the modeling results described herein. It is not specified by the low heat transfer coefficient, that is selected on the Visual Plumes settings tab, was used in this analysis. Based on the output the surface area of the plume in the 93.5F blue isotherm shown in Fig. 3 is 25.1ac (25.079). This corresponds closely to the yellow area shown in Fig. 4-3 of the EA monitoring report and reported to be 22ac. Both are smaller than the criterion mixing zone area of 26ac.

A slight downward adjustment in the merging temperature of the Joliet #9 plume would have the effect of decreasing the Joliet #29 93.5F isotherm area. This may well be appropriate.

However, the surface area of the plume in the 93.0F green isotherm shown in Fig. 3 is 40.8ac, over 62% larger than the 93.5F plume. Based on a comparison of the plume predictions to the plumes depicted in the EA monitoring report, it may be concluded that PDS does a good job of estimating the relative relationship between plumes within different isotherms. Indeed, an examination of the EA monitoring report data and contouring shows that the length of the 93F plume is approximately twice as long as the 93.5F plume. Thus the effect of applying the rounding convention referred to in the footnote on page 7 of the EA monitoring report has an enormous influence on how the surface plumes are depicted and perceived.

It is worth noting that the simulated Joliet #9 93.5F plume is much smaller than the plume contoured in Fig. 4-3 of the EA monitoring report, 0.22ac compared to 8.2ac. This discrepancy may have many causes, including the temporal variability in the river flow reflected in the range of flows. Under low-flow river conditions the current in the vicinity of the Joliet #9 plume may be essentially zero or even negative (upstream). Under these conditions plume effluent will likely spread upstream and be re-circulated, raising both background and possibly even intake temperatures. The corresponding plumes and the 93.5F monitored isotherms are shown in Fig. 4.

Figure 4. Joliet #9 93.5F plume (with an area of only 0.22ac, barely noticeable) shown within the larger 89.1F, 14.1ac plume.

The Joliet 29 Near-Field Thermal Compliance Model

Joliet 29 Near-Field Thermal Compliance Model description The Joliet 29 Near-Field Thermal Compliance Model is described in Attachment 1 to a letter from Daniel R. Paulsen to Beth Unser (Paulsen 2001). The spreadsheet model calculates the fully-mixed plume-receiving water temperature in degrees F, T_{FM}.

$$T_{FM} = (T_{EF} Q_{CW} + k T_{US} Q_{AV})/(Q_{CW} + k Q_{AV})$$

where (with temperatures in degrees F and flow in cfs). The dependent variable and independent variables are:

T_{FM} Calculated fully-mixed receiving water temperature
T_{EF} Calculated effective condenser cooling water discharge temperature after mixing with cooling tower discharge
Q_{CW} Condenser cooling water flow. Flow is based on the number of circulating water pumps on at the time in question. Each of the four circulating water pumps is rated at 230,000gpm (512.5 cfs).
Q_{AV} Available receiving stream dilution flow. Available dilution flow is determined by subtracting condenser cooling water flow from the upstream river flow. If the upstream river flow is equal to or less that the condenser cooling water flow, the available receiving stream dilution flow is zero. Upstream river flow is the average vlaue of flow recorded during the 24-hour period preceding the time in question. The primary source of flow data is the gaging station operated by the Army Corps of Engineers at the Brandon Road Lock and Dam. Secondary sources for flow data are the gaging station on the Chicago Sanitary and Ship Canal at Romeoville operated by the United States Geological Survey, and the Des Plaines River gaging station at Riverside, operated by the Army Corps of Engineers.
T_{US} Upstream river flow temperature is continuously monitored by Bailey and Endeco systems in the station intake canal.
k   A coefficient apparently intended to represent the proportion of receiving stream dilution flow mixing with and diluting the Joliet #29 discharge flow. It is 0.5 in the model.

ERD-Athens version of the Joliet 29 Near-Field Thermal Compliance Model The Joliet 29 Near-Field Thermal Compliance Model has been created independently by the author and faithfully replicates the

corresponding values found in Paulsen (2001). The availability of both the Joliet 29 Near-Field Thermal Compliance Model and the Visual Plumes model makes it possible to compare both absolute outputs (actual simulated temperatures) and relative outputs (differences in and ratios of differences of mixed temperature compared to differences in cooling water temperature).

Main deficiency of the Joliet 29 Near-Field Thermal Compliance Model The most important deficiency in the compliance model is the omission of the influence of the Joliet #9 plume on the Joliet #29 plume. This omission will in most cases tend to contribute to causing the calculated mixed temperature to be less than a more realistic calculated mixed temperature including the temperature rise due to the Joliet #9 plume. This does not apply to cases where the river flow is less than that withdrawn by Joliet #29 (i.e., $Q_{AV} = 0$) or Joliet #9 is not operating. If $Q_{AV} = 0$ and Joliet #9 is operating, there will tend to be recirculation, upstream intrusion of Joliet #9 effluent and potential recirculation of previously discharged effluent tending to further raise the temperature in the river.

If T_{US}, the upstream river flow temperature, is substantially different from the actual river flow temperature in the area of plume mixing, then the model will not accurately represent the temperature dilution process in the area of mixing. The heat added to the river by the Joliet #9 plume can cause the downstream river temperature at the point of discharge mixing to be considerably greater than T_{US}, the upstream river flow temperature.

This omission will normally tend to contribute to causing the calculated mixed temperature to be less than a more realistic calculated mixed temperature including the temperature rise due to the Joliet #9 plume.

Illustrative example The spreadsheet table found in Paulsen (2001) illustrates the problems associated with the thermal compliance model. The operating conditions on Aug 1, 2002 may be roughly compared to the 3050cfs row of the spreadsheet, i.e., the Joliet #29 cooling water flow is about 1500cfs and the Joliet #9 cooling water flow is about 500cfs. If T_{EF}, the calculated effective condenser cooling water discharge temperature, were 100F and the river temperature were exactly 88F then the fully mixed plume temperature would be calculated to be 93.24F.

The important point to understand is that whether or not Joliet #9 is generating, the calculated fully mixed plume temperature will be the same because T_{US}, the upstream river flow temperature monitored continuously by Bailey and Endeco systems in the station intake canal, not the river temperature in the vicinity of the Joliet #29 plume, is used to weight the Joliet #29 plume river dilution water.

Example: The Aug 1, 2002 plume The Joliet #29 plumes shown in Fig. 4 are based on a background temperature of 89.1F, compared to a 87.5F Joliet #9 intake temperature, thought to be more representative of conditions in the vicinity of the Joliet #9 plume (compared to the far upstream value of 86.6F). If the Joliet #9 plume raised the river temperature in this fashion, an increase of 1.6F, and this temperature were used to estimate T_{US}, then the fully mixed plume temperature corresponding to the above example would be calculated to be 93.56F, an increase of 0.32F. Incidentally, this change would increase the fully mixed temperature above 93.5F.

The corresponding experiments, ambient water temperatures of 87.5 and 89.1F, using the PDS model obtains similar results. At a distance of about 300m from the Joliet #29 plume source, not totally comparable to the fully mixed plume temperature, the corresponding temperatures are 94.53 and 95.15F respectively, an increase of 0.62F. This illustrates the importance of including the thermal effect of the Joliet #9 plume on the Joliet #29 plume.

The fact that the PDS model includes heat loss to the atmosphere while the compliance model is conservative in this regard brings into question the higher temperature difference of the former compared to the latter. Part of the answer is attributed to the fact that the compliance model assumes only half the river water mixes with the Joliet #29 plume. If the mixing coefficient, k, is increased from 0.5 to 1.0 the fully mixed temperature increase is about 0.52F, more in line with the PDS result which does not constrain entrainment, or mixing.

Improving the Joliet 29 Near-Field Thermal Compliance Model To be useful, the Joliet 29 Near-Field Thermal Compliance Model must be modified to account for increases in ambient (upstream) temperature in vicinity of the Joliet #29 plume due to the addition of heat by the Joliet #9 plume. This could be achieved by devising a similar temperature model for the Joliet #9 plume and using its output to define the upstream temperature for the Joliet 29 plume.

Caveat   One should not lose sight of the fact that the mass-balance temperature model assumes full mixing, in other words, average values. In the zone of mixing there will be a range of temperatures. Centerline temperatures in the Joliet #29 plume will generally be greater than the calculated average temperatures, with the exception of cases in which the ambient water in the vicinity of the Joliet #29 plume is for some reason greater than those found in the Joliet #29 plume. In the latter case, centerline values, while tending to be high, will actually be less than receiving water temperatures.

In normal circumstances, the ratio of centerline to average difference can be expected to be on the order of two to one.
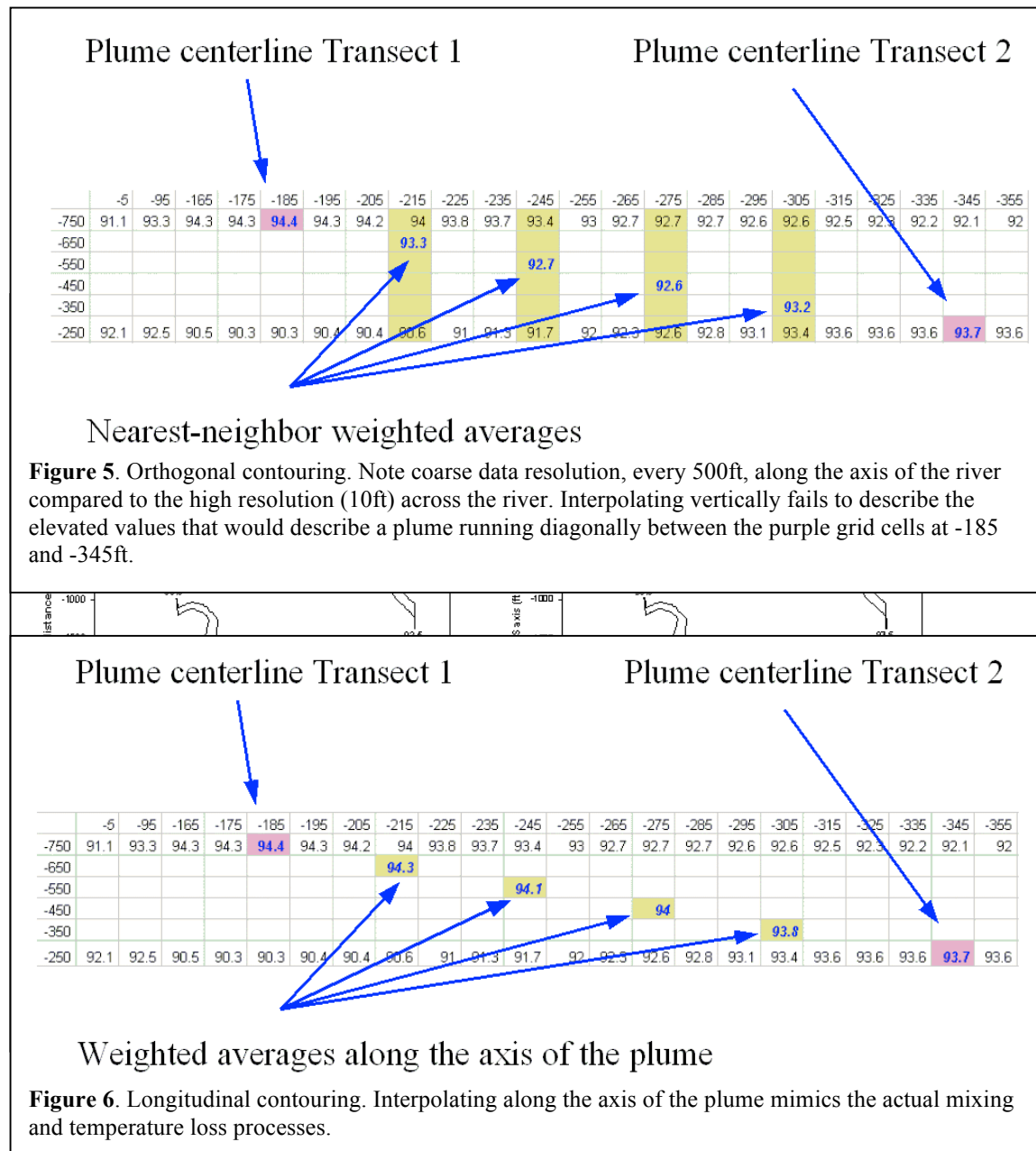
Contouring

For a change in river temperature from 87.5 to 89.1F, a difference of 1.6F, the corresponding fully mixed plume temperature change would be 0.32F.

The data on which the contours given in Fig. 4-3 of the EA monitoring report was digitized and contoured independently using SigmaPlot and Surfer software. Like AutoCad, both applications disconnect the Joliet #9 and Joliet #29 plumes. The reason for this may be understood by considering a small subset of the temperature on the -750 and -1250 river transects, between which the plume is suspected to cross diagonally.

Fig. 5 presents the data in a way to explain the disconnect achieved by using all three commercial contouring applications. Programs such as SigmaPlot effectively interpolated vertically with the result that the two elevated regions at -185 and -345 are disconnected at the 93.5 and 93.0F isotherm levels.

A better algorithm would be set up to recognize the presence of the plume and to interpolate along the axis of the plume. This procedure is depicted in Fig. 6.

The results of the orthogonal and longitudinal methodologies are compared in Fig. 7. Clearly careful and intelligent interference on the part of the analyst can change the results of the contouring, in the former case shown disconnected and in latter shown connected.

Plume centerline Transect 1 — Plume centerline Transect 2

	-5	-95	-165	-175	-185	-195	-205	-215	-225	-235	-245	-255	-265	-275	-285	-295	-305	-315	-325	-335	-345	-355
-750	91.1	93.3	94.3	94.3	94.4	94.3	94.2	94	93.8	93.7	93.4	93	92.7	92.7	92.7	92.6	92.6	92.5	92.3	92.2	92.1	92
-650								93.3														
-550											92.7											
-450													92.6									
-350																	93.2					
-250	92.1	92.5	90.5	90.3	90.3	90.4	90.4	90.6	91	91.3	91.7	92	92.3	92.6	92.8	93.1	93.4	93.6	93.6	93.6	93.7	93.6

Nearest-neighbor weighted averages

Figure 5. Orthogonal contouring. Note coarse data resolution, every 500ft, along the axis of the river compared to the high resolution (10ft) across the river. Interpolating vertically fails to describe the elevated values that would describe a plume running diagonally between the purple grid cells at -185 and -345ft.

Plume centerline Transect 1 — Plume centerline Transect 2

	-5	-95	-165	-175	-185	-195	-205	-215	-225	-235	-245	-255	-265	-275	-285	-295	-305	-315	-325	-335	-345	-355
-750	91.1	93.3	94.3	94.3	94.4	94.3	94.2	94	93.8	93.7	93.4	93	92.7	92.7	92.7	92.6	92.6	92.5	92.3	92.2	92.1	92
-650								94.3														
-550											94.1											
-450													94									
-350																	93.8					
-250	92.1	92.5	90.5	90.3	90.3	90.4	90.4	90.6	91	91.3	91.7	92	92.3	92.6	92.8	93.1	93.4	93.6	93.6	93.6	93.7	93.6

Weighted averages along the axis of the plume

Figure 6. Longitudinal contouring. Interpolating along the axis of the plume mimics the actual mixing and temperature loss processes.

Conclusions

Based on Visual Plumes PDS modeling, technical rounding considerations, a review of the Joliet 29 Near-Field Thermal Compliance Model, and on mathematical contouring artifacts it is possible to draw several conclusions about the methods used by the NPDES applicant and statements made on their behalf. First, an examination of contouring algorithms shows that programs such as AutoCad and SigmaPlot are likely to disconnect elevated regions from each when the regions are connected by thin ridge lines, or plumes, and the grid spacing in one dimension is much larger than the grid spacing in the orthogonal direction, as is the case in the monitoring study described in the EA monitoring report. Second, a restructuring of the gridded monitoring data does lead to the connection of the two plumes at the criterion 93F and the artificial 93.5F rounding criterion levels. Third, a review of the Joliet 29 Near-Field Thermal Compliance Model shows that it does not generally account for the increase in river temperature caused by the Joliet #9 plume, an increase that generally affects the temperature of the water entrained by the Joliet #29 plume.

This deficiency can be overcome by creating a similar model for the Joliet #9 plume and using its output temperature to estimate the upstream temperature of the Joliet #29 plume. Fourth, Visual Plumes PDS modeling supports the previous conclusions. PDS simulations show that the Joliet #9 plume has sufficient momentum to cross the Des Plaines River and interact significantly with the downstream Joliet #29 plume. Finally, the technicality of rounding grossly affects the reader's perception of the size of the surface plumes in question. Based on PDS runs, plumes defined by the 93.0F criterion temperature are generally much larger than those defined by a nominal 93.5F criterion temperature. Based on the former criterion and on the number of cases sampled during the summer of 2002, two of eight cases exhibiting plumes in excess of the mixing zone area criterion, it appears likely that many more than 5% of the cases for the period of the monitoring study exceeded 26ac in area. This finding is supported by the Visual Plumes PDS modeling.

_____

Exercise objectives

The objective of the Joliet project are to

- Become familiar with the Visual Plumes PDSW model.
- Practice backing up your project files and cleaning your Plumes subdirectory, but leave your last project to avoid creating a trail of default projects with names like VP Plume 0, VP Plume 1, etc..
- Become familiar with the PDS model parameters and options, the isopleth value, the plume origin in plan space, and the heat transfer rate setting.
- Create multiple sub-projects (one for the north-shore discharge, Joliet #29, and one for the upstream south-shore discharge, Joliet #9).
- Become familiar with the PDS output.
- Think about some of the assumptions that go into PDS, especially its handling of boundaries. Are these assumptions conservative or not?
- Learn how the source origin is established? An understanding of the direction conventions is essential. This can be supplemented with a trial and error approach.
- Learn to establish background temperature for the downstream plume.

Preliminary inputs for the upstream discharge

Diffuser tab

Diffuser and effluent parameters are defined in the following figure. The "Parameters for selected row" button has been pressed to reveal Froude number, an effluent density calculation, and port velocity. No effluent time-series are specified.

Ambient tab

Ambient parameters are defined in the following figure.

Measurement unit	m	cm/s	deg	psu	F	ppm	s-1	m/s	deg	m0.67/s2
	0	6.44	225	0	87.5	0				
	12									

PDS

Ambient file list
Filename
Joliet9-1Aug2002.001.db

Figure. Joliet project ambient tab.

Settings Tab

- C h a n nel width: 150m (Does this value impact the simulation?)
- PDS sfc model heat transfer [rate]: low
- PDS origin checked and values of 550m and 27deg.
- Farfield isopleth value. (Note that the units conversion capability does not extend to the edit boxes on the settings tab. Often the diffuser or ambient tables may be used as staging areas for converting units.)
-
-

Model   VPx PDSW

Practice

- Change the Farfield isopleth value until you are satisfied the plume will represent the interaction temperature with the downstream plume. The author settled on a temperature of 31.8C, see Figure below.
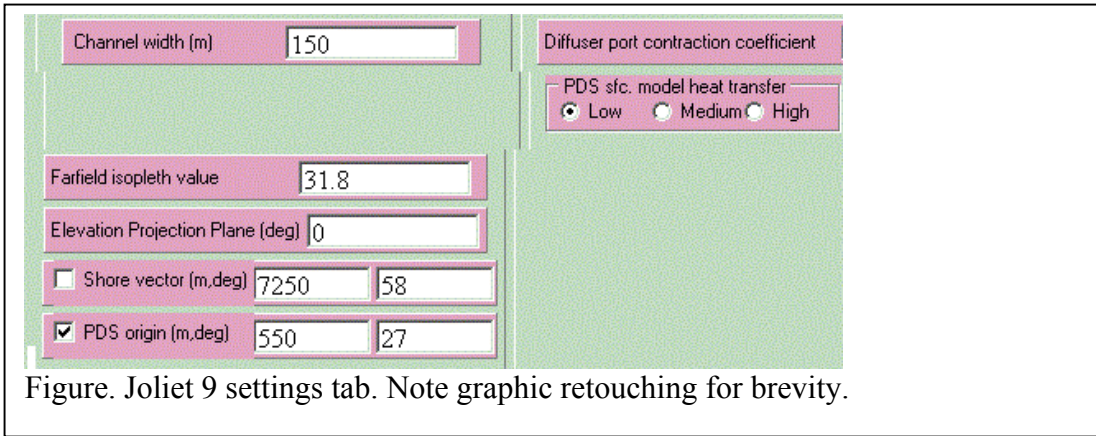

Figure. Joliet 9 settings tab. Note graphic retouching for brevity.

- T
r
y

o
u
t
p
u
t
t
i

ng the simulation to a text file using the Output settings File radio buttons.
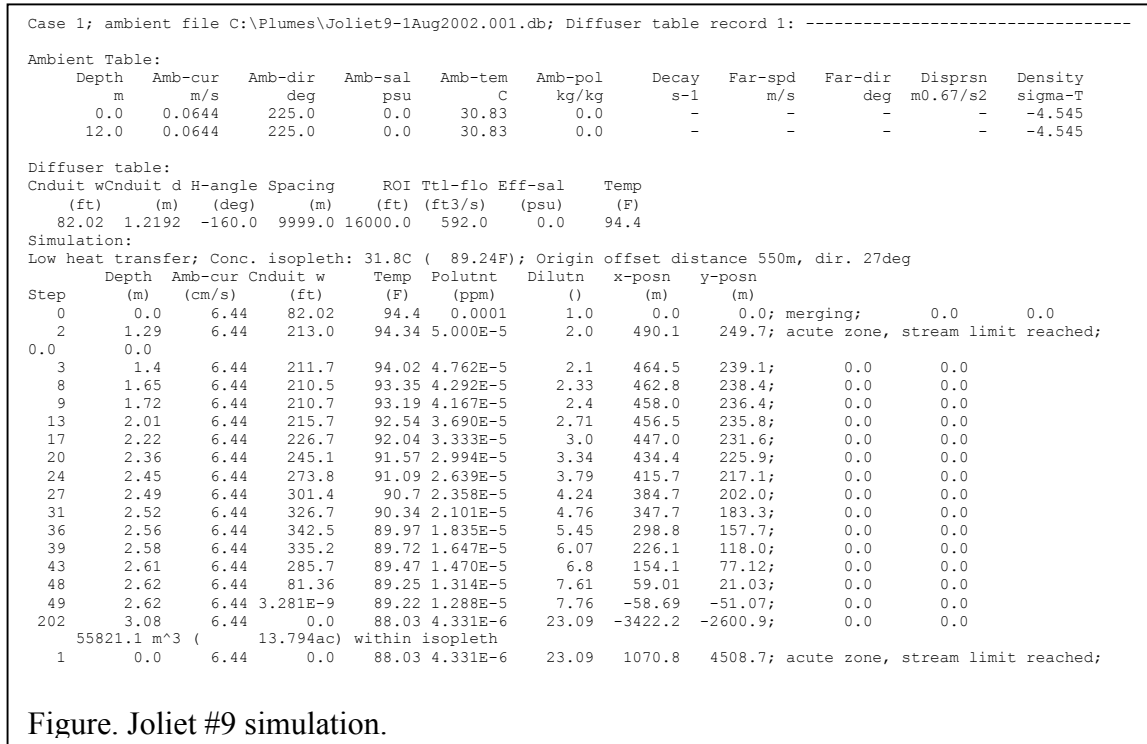- Examine the output for estimates of area within the isotherm, see Figure below.
-
-

```
Case 1; ambient file C:\Plumes\Joliet9-1Aug2002.001.db; Diffuser table record 1: ---------------------------------

Ambient Table:
     Depth   Amb-cur   Amb-dir   Amb-sal   Amb-tem   Amb-pol    Decay   Far-spd   Far-dir   Disprsn    Density
       m       m/s       deg       psu        C       kg/kg      s-1      m/s      deg   m0.67/s2   sigma-T
      0.0     0.0644     225.0      0.0      30.83      0.0       -        -        -        -        -4.545
     12.0     0.0644     225.0      0.0      30.83      0.0       -        -        -        -        -4.545

Diffuser table:
Cnduit wCnduit d H-angle Spacing    ROI Ttl-flo Eff-sal    Temp
   (ft)    (m)    (deg)    (m)     (ft) (ft3/s)  (psu)     (F)
  82.02  1.2192  -160.0  9999.0 16000.0  592.0    0.0     94.4
Simulation:
Low heat transfer; Conc. isopleth: 31.8C (  89.24F); Origin offset distance 550m, dir. 27deg
        Depth  Amb-cur Cnduit w    Temp  Polutnt   Dilutn   x-posn    y-posn
Step     (m)   (cm/s)    (ft)      (F)    (ppm)      ()       (m)      (m)
   0     0.0    6.44    82.02     94.4   0.0001     1.0      0.0      0.0; merging;       0.0       0.0
   2     1.29   6.44    213.0    94.34 5.000E-5     2.0     490.1     249.7; acute zone, stream limit reached;
0.0      0.0
   3     1.4    6.44    211.7    94.02 4.762E-5     2.1     464.5     239.1;      0.0       0.0
   8     1.65   6.44    210.5    93.35 4.292E-5     2.33    462.8     238.4;      0.0       0.0
   9     1.72   6.44    210.7    93.19 4.167E-5     2.4     458.0     236.4;      0.0       0.0
  13     2.01   6.44    215.7    92.54 3.690E-5     2.71    456.5     235.8;      0.0       0.0
  17     2.22   6.44    226.7    92.04 3.333E-5     3.0     447.0     231.6;      0.0       0.0
  20     2.36   6.44    245.1    91.57 2.994E-5     3.34    434.4     225.9;      0.0       0.0
  24     2.45   6.44    273.8    91.09 2.639E-5     3.79    415.7     217.1;      0.0       0.0
  27     2.49   6.44    301.4     90.7 2.358E-5     4.24    384.7     202.0;      0.0       0.0
  31     2.52   6.44    326.7    90.34 2.101E-5     4.76    347.7     183.3;      0.0       0.0
  36     2.56   6.44    342.5    89.97 1.835E-5     5.45    298.8     157.7;      0.0       0.0
  39     2.58   6.44    335.2    89.72 1.647E-5     6.07    226.1     118.0;      0.0       0.0
  43     2.61   6.44    285.7    89.47 1.470E-5     6.8     154.1      77.12;     0.0       0.0
  48     2.62   6.44    81.36    89.25 1.314E-5     7.61    59.01      21.03;     0.0       0.0
  49     2.62   6.44 3.281E-9    89.22 1.288E-5     7.76    -58.69    -51.07;     0.0       0.0
 202     3.08   6.44      0.0    88.03 4.331E-6    23.09  -3422.2   -2600.9;      0.0       0.0
    55821.1 m^3 (      13.794ac) within isopleth
   1     0.0    6.44      0.0    88.03 4.331E-6    23.09   1070.8    4508.7; acute zone, stream limit reached;
```

Figure. Joliet #9 simulation.

Preliminary inputs for the downstream discharge

This material was prepared with a previous experimental version, Vpexp. With VPx these two
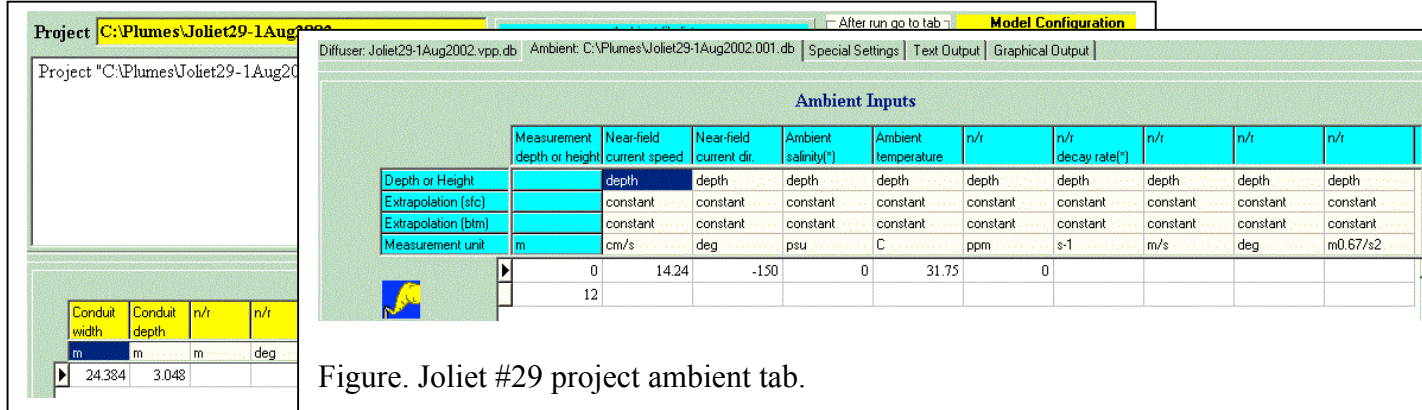projects can now be combined into one.

Figure. Joliet #29 project ambient tab.

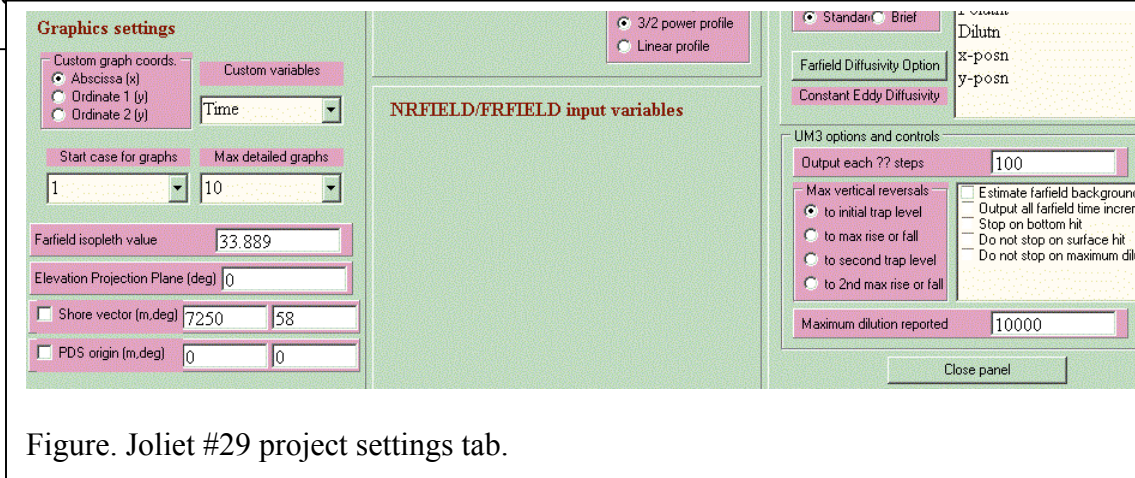Figure. Joliet #29 project diffuser tab.

Figure. Joliet #29 project settings tab.

Running the downstream plume

Once the Joliet #9 and Joliet #29 projects are created separately their graphs may be superimposed by first running the former project and then opening the latter from the File-Open menu. On opening the second project, Visual Plumes will issue the message "Yes, clear graphics, or, No, retain graphics." Respond No.

Now go to the graphics tab and select another color for the Joliet #29 plume, like blue. Then run PDS again. The plumes can now be seen separately. The results on the 4-panel graphics Plan View should look something like thi

Figure. Plan view of the combined Joliet #9 and Joliet #29 runs.
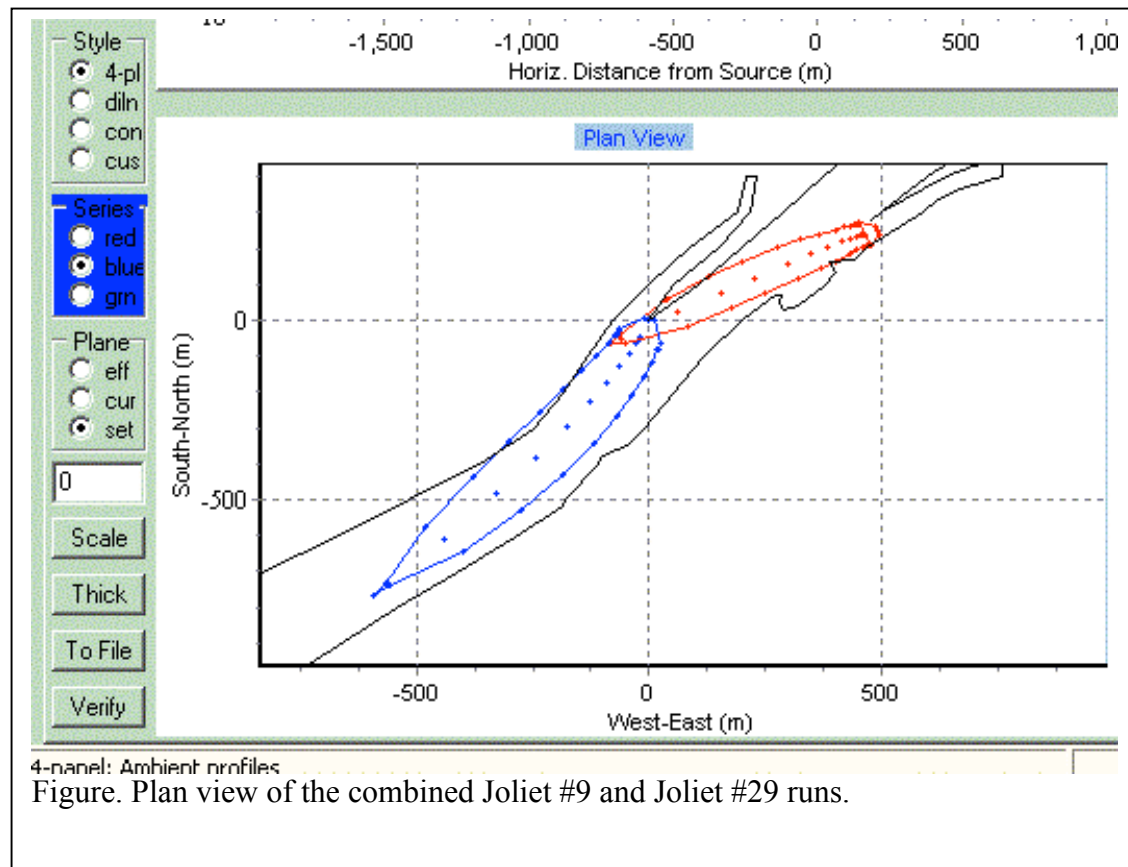
Theory

- Flow ratios, dilution ratios, and maximum volume dilution
- The author is considering ways to confine simulated plumes to specified arbitrary boundaries.
- While it is not the case with this problem, near-field plume simulations often require very small time steps, or grids. Far-field finite element or finite difference numerical models, in comparison, are better served by fairly large cell dimensions. The temporal and spatial scales of the two models are quite different. This makes linking them quite difficult. If the proper transition from near-field to far-field models is not done well, considerable artificial dispersion can occur there.

Limitations, troubleshooting

- If you get unexpected results, check the settings tab to assure applicable values and options are correct.
- Concentration units must be in kg/kg. The next official edition of VP will address this problem.
- Change the background temperature for the Joliet #29 run to see how it affects the area within the isopleth.

Problem: Dominguez Channel, tidal background buildup

Synopsis

The Dominguez Channel example is based on a major transportation project. The City of Los Angeles, some of which is situated on a large, low-lying coastal plain, is building a rail system between the harbor and downtown, a distance of about 30km. Part the route is being excavated below the water table, necessitating the removal of large volumes of groundwater during construction. As an old industrial center the groundwater is unusually high in heavy metals, including copper. The original plan was to discharge to Dominguez Channel, requiring a National Pollution Discharge Elimination System (NPDES) permit.

Initial mixing zone model runs indicated that water quality criteria would be met, however, this analysis did not include the buildup of background pollution in the channel due to the tidal re-circulation of previously discharged effluent. To estimate the buildup using VP it is necessary to establish the water velocity at the discharge point. Information was available to estimate the dry weather flow in the channel and so was the maximum tidal current speed in the channel as a function of distance from its mouth. Based on this data a time-series record was synthesized using a cosine function of the appropriate lunar frequency. Alternatively, commercial tide models may be used to synthesize, and predict, tidal currents. The first two days of the time-series record representing the sum of the steady freshwater drift and the sinusoidal velocity is shown in the Figure below.
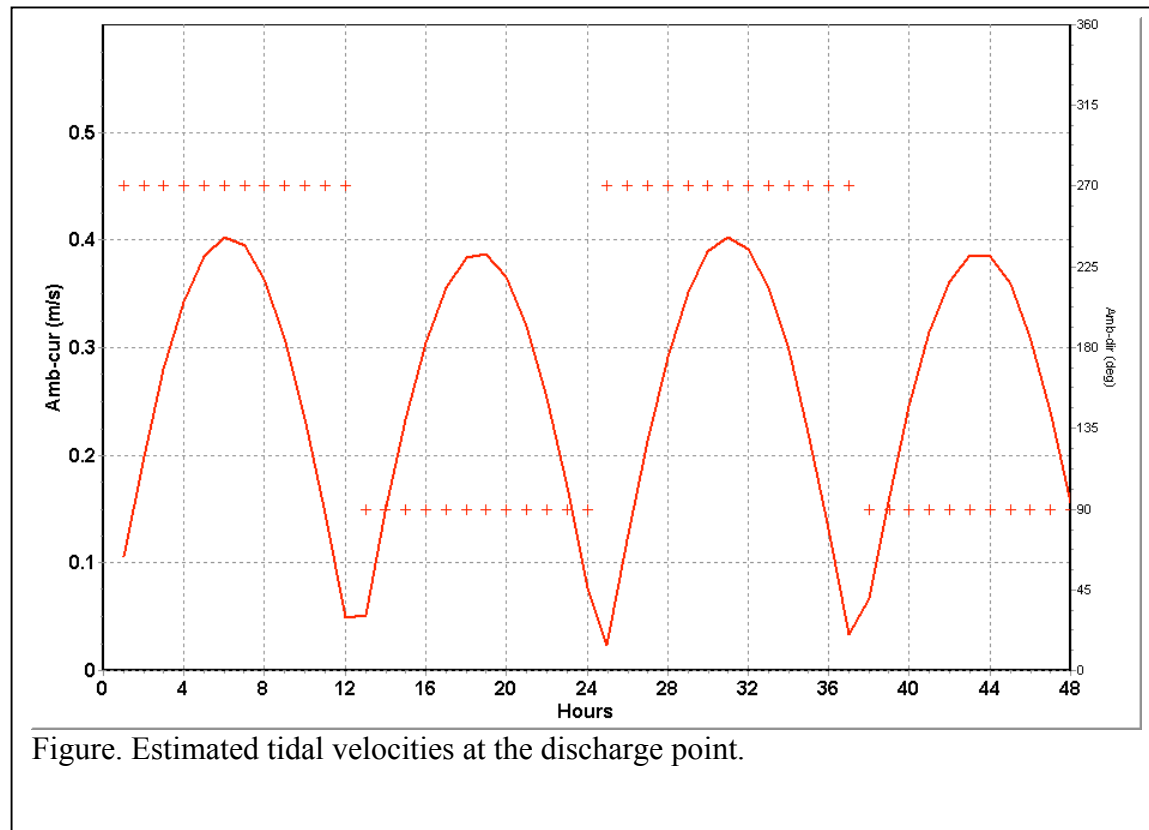
Figure. Estimated tidal velocities at the discharge point.

Note that, as VP uses a consistent coordinate system, it is necessary to include direction as a

Problem: time-series capability, tidal background buildup

time-series file as well, even though only two direction corresponding to upstream and upstream are synthesized (+ symbols in the preceding figure). In other words, velocity requires both speed and direction to be uniquely specified.

Instructions for creating, formatting, and interpreting time-series files is given in the Visual Plumes manual starting on page 5.1. The first few lines of the corresponding file starting with the header line are

```
0.5 1920 m/s 0 constant constant m 0 5 DomCa000.spd
0.1062 0.1062
0.1990 0.1990
0.2796 0.2796
0.3428 0.3428
0.3847 0.3847
0.4025 0.4025
0.3952 0.3952
0.3632 0.3632
0.3085 0.3085
0.2346 0.2346 ....
```

The effective dilutions for the simulation period are shown in the following figure. Note that minimum effective dilution, the ratio of the effluent concentration to the plume element concentration, declines steadily over a period of days finally approaching a value of about 3. In contrast, the minimum volume dilution, not shown, is about 25.

Figure. Predicted effective dilution in Dominguez Channel as a function of time.
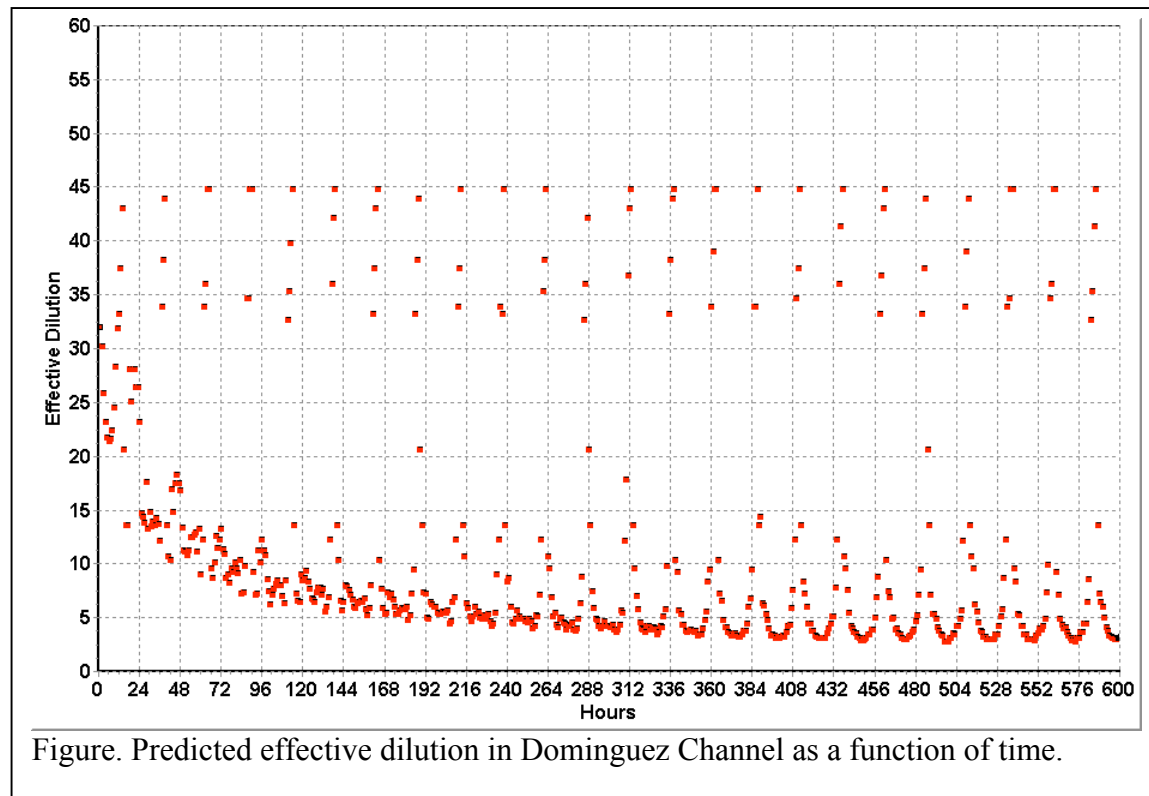
The concentration graphic, following figure, shows that the residence time corresponds to about 500 cases (250 hours), or about ten days.

Problem: time-series capability, tidal background buildup
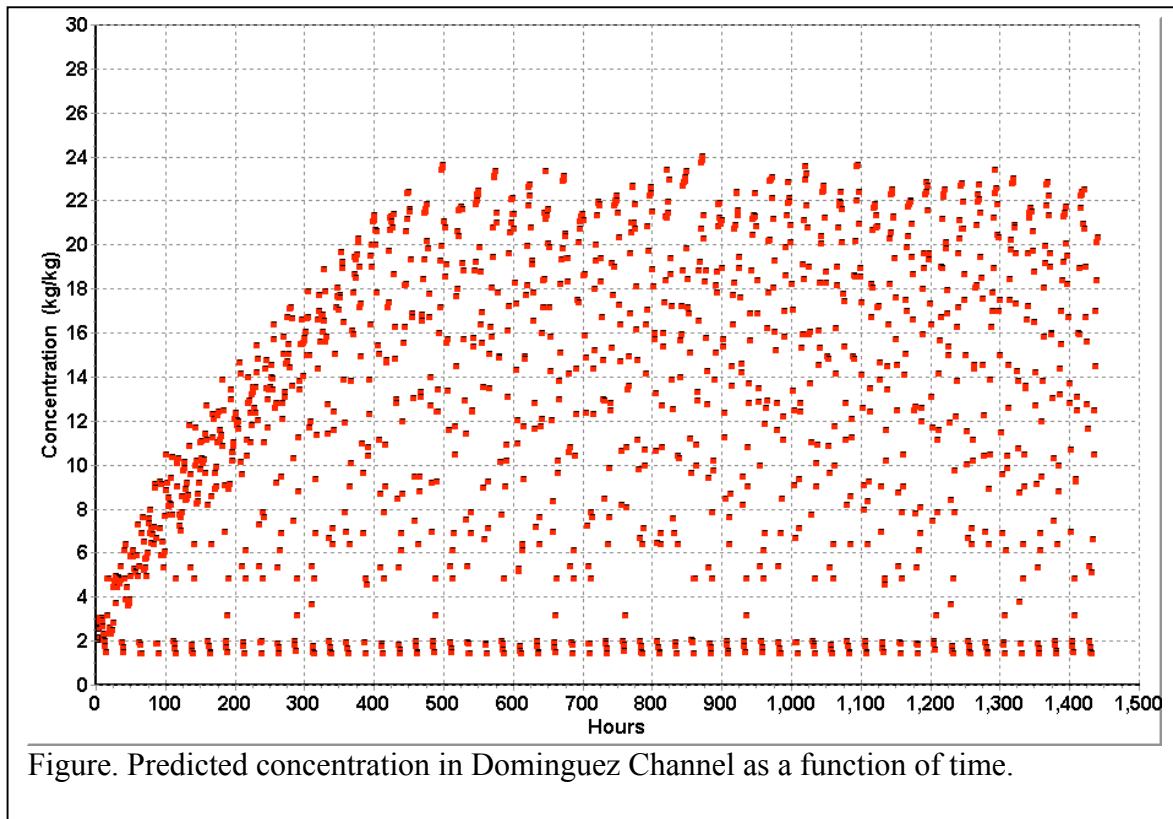
Figure. Predicted concentration in Dominguez Channel as a function of time.

Subsequently it was decided to discharge the groundwater to the sanitary sewer system. It is not known whether the VP analysis was a basis for that decision.

Exercise objectives

The objective of the xDomCh project is to learn to implement VP's tidal background pollutant concentration buildup capability.

- Familiarize yourself with the Model Configuration selections needed to implement the background buildup capability.
- Familiarize yourself with the UM# tidal pollutant buildup parameters that appear on the settings tab when the Tidal pollution buildup option is checked on the diffuser tab.
- Study Sections 5.1 and 6.2 in the Visual Plumes manual.
- Understand the significance of the number of internal array cells used during the simulation. An indicator of fetch concentration resolution or detail, an optimum number is greater than 190 bins but less than 200 bins.
- Become more familiar with the dilution, concentration, and generic graphics
- Learn to set up and link in time-series files.
- Become more familiar with the Graphics settings panel on the settings tab.
-

Problem: time-series capability, tidal background buildup

Preliminary inputs

<u>Diffuser Tab</u>

Figure. Project xDomCh diffuser tab (note the selected options on the Model Configuration panel and the editorial distortion of the diffuser table).

The actual proposed outfall was a simple tributary channel discharging from the side of the channel. For detailed near-field simulations of this outfall the PDSW model may have been appropriate. The volume dilution would have been poor but adequate, perhaps 10:1. However, once it is determined that background concentration is likely to play a key role in limiting effective dilution, the details of the discharge become unimportant. In this case an imaginary diffuser was modeled to obtain optimally high volume dilutions, ranging from about 25 to 60. The student can uncheck the Graph effective dilution option to see how volume dilution varies with time. Doing so shows that it is insensitive to background concentration and its buildup.

The Current vector averaging option assures that cross-channel current directions do not occur. This can be a problem when current direction varies with depth. In this project it has no effect as currents are not stratified.

Note the beginning and ending time settings that are required input when time-series files are linked to the project, see the next section.

<u>Ambient Tab</u>

The ambient tab is shown in the following figure. Most noteworthy is the linkage to two ambient time-series files. After the ASCII time-series files have been prepared in accordance with

Problem: time-series capability, tidal background buildup

instructions found in the Visual Plumes manual, linkage is established by clicking on the appropriate column's "click for file" cell. Visual Plumes will establish the appropriate linkage. The time settings on the diffuser tab indicate 720 hours of simulations (30 days) will be simulated at run time. The time increment is 0.5 hours.
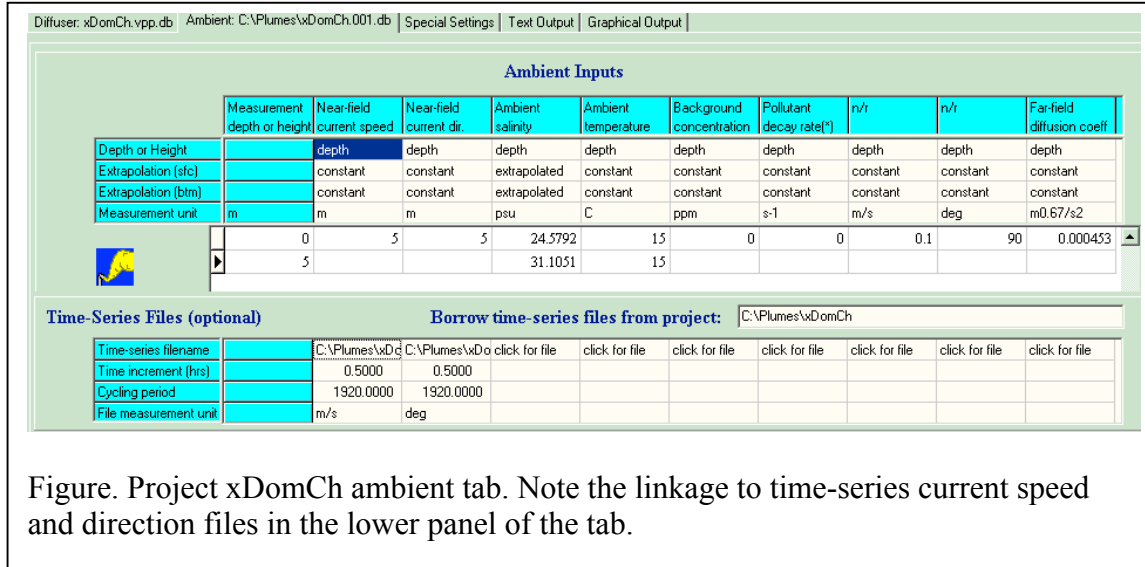

Figure. Project xDomCh ambient tab. Note the linkage to time-series current speed and direction files in the lower panel of the tab.

e. The important new cells for setting up the tidal background buildup capability are shown displayed on dark blue, added for clarity. The product of the channel width and depth should represent the cross-sectional area of the channel. The cross-section will be approximate as the depth of the channel varies with time. The channel segment length is arbitrarily set to 250m. By varying the value the user can optimize the resolution of the simulation, that is, using as many of the 200 bins available to the simulation, see Sec. 6.2 of the Visual Plumes manual.
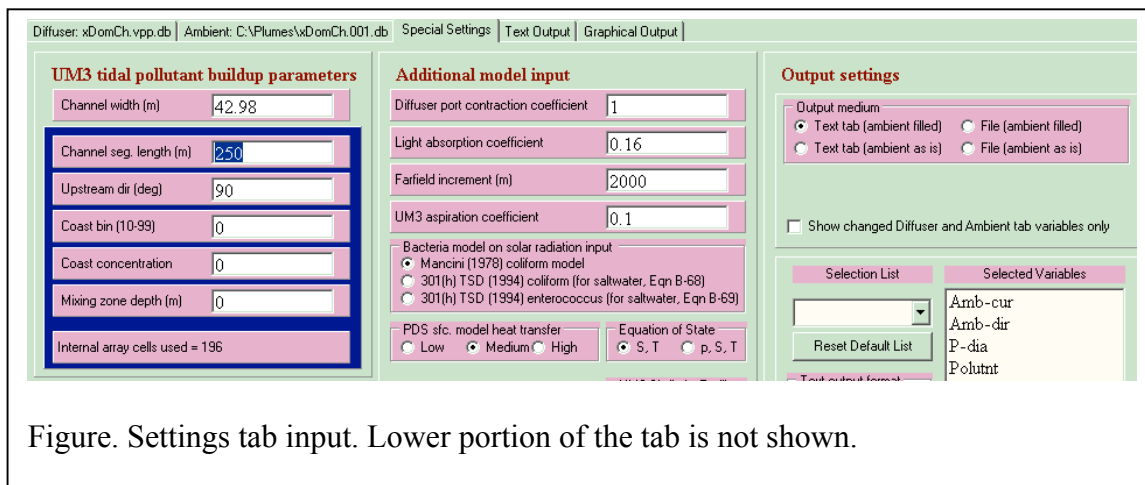

Figure. Settings tab input. Lower portion of the tab is not shown.

used" panel indicates VP has been run.

- Channel width: 42.98m
- Channel segment length: 250m

Problem: time-series capability, tidal background buildup

- Upstream direction: 90deg
-
-

The upstream direction must be specified. UM3 uses vectors to define currents at run time. The dot product of the current and the direction vectors then determines whether movement is upstream or downstream during any given model time increment.

Model   UM3

Practice

- Deselect the Graph effective dilution option on the Model Configuration panel to see the effect on the dilution graphic.
- Try changing the depth of the channel to see its effect on bins used and on simulation results.
-
-

Theory

- Symmetry of dispersion, flow routing and its absence in Visual Plumes
-
-

Limitations, troubleshooting

- Flow must be essentially one dimensional
- Upstream constraints
-
-

Reference

Frick, W.E., P.J.W. Roberts, L.R. Davis, J. Keyes, D.J. Baumgartner, and K.P. George 2002. Dilution models for effluent discharges, 4th Edition (Visual Plumes). EPA/600/R-03/025, USEPA, Athens, Georgia.

Problem: Beach Bacteria

Synopsis

An abstract submitted to the ASLO/TOS Ocean Research 2004 Conference (Frick, Baumgartner, Molina, Khangaonkar, and Robertson 2003) elaborates on the potential value of integrated near-field, far-field circulation and transport, and pathogen, or bacteria, models:

"Orange County, California has 124 miles of coastal and bay beaches that provide the public valuable aesthetic and recreational opportunities. The closure of almost six miles of prime urban beach, Huntington Beach, in July and August 1999 led to a public outcry that culminated in the Orange County Sanitation District (OCSD) decision to abandon its 301(h) discharge permit. The District is now upgrading from an equal blend of primary and secondary effluents to full secondary treatment and chlorination at the cost of hundreds of millions of dollars. This despite the fact that a science review panel, charged with evaluating known physical mechanisms and reviewing substantial empirical evidence compiled since the closure, found no strong or consistent link between the ocean discharge four miles offshore and incidences of high bacteria concentrations in the surf zone.

"Could these events have been prevented? In 1999 there were no generally available computer models to allow plant operators to estimate the location of the discharge waste field at all times. All that was known from monitoring was that permit criteria near the outfall were met. However, had such a modeling capability existed it is possible the predictions would have helped improve monitoring design and would have served to alarm plant managers. A pattern of beach waste-field encroachment or the existence of renegade sources might have been established. In either case the District would have been a position to take positive action to avert imminent and disastrous beach closures.

"In response to the OCSD experience the U.S. EPA Visual Plumes model has been modified to simulate the movement of the waste-field plume over long periods. Linked with time-series files describing plant flow, concentrations, and other variables, Visual Plumes estimates the movement of the waste field based current meter and other ambient measurements. It uses the Progressive Vector Diagram approach to simulate current velocities in the far field. A derivative model called Visual Beach is under development. Visual Beach is being designed to include the Environmental Fluid Dynamics Code (EFDC) to better define the current field. It is planned to better estimate background concentrations in the immediate vicinity of the rising plumes. Ultimately dynamic linkage to forecasted winds may make a prognostic capability possible.

"This presentation describes some of the salient features and outputs of the operational Visual Plumes model and outlines proposed capabilities of the Visual Beach model. Results of the prototype Visual Beach model are presented as well.

Problem: beach bacteria prediction using the time-series capability

> These developments are put in the context of other solutions being pursued by the District to model and monitor bacteria concentration patterns between the outfall and area beaches in the attempt to prevent future beach closures."

The problem developed here is based on realistic, but not necessarily accurate, OCSD outfall parameters and synthesized and actual ambient data.

Exercise objectives

The objective of the XBeachBacteria project is to learn to use Visual Plumes' bacteria models, such as the Mancini model, and its near-field and far-field plume models to assess the potential of beach bacteria contamination based on time series of flow and ambient conditions. Time-series files are surrogates for real-time input that would allow a model to run continuously to constantly update the predicted location and extent of an outfall waste field. Such a capability would facilitate developing prognoses of future waste-field movement, allowing treatment plant operators to optimize treatment levels to avoid beach closures.

- Further exercise of setting up time-series input files and linking them to VP.
- Becoming familiar with the available indicator bacteria decay models in VP.
- Exercising the bacteria models to understand the variation of decay rates with depth.
- Understanding the time-series file borrowing feature.
- Changing isopleth values.
-
-

Preliminary inputs

Diffuser Tab

The following figure presents diffuser tab input. Note that four different isopleths are identified and can be run by clicking on a row and moving the arrow in the left-hand margin of the diffuser table.

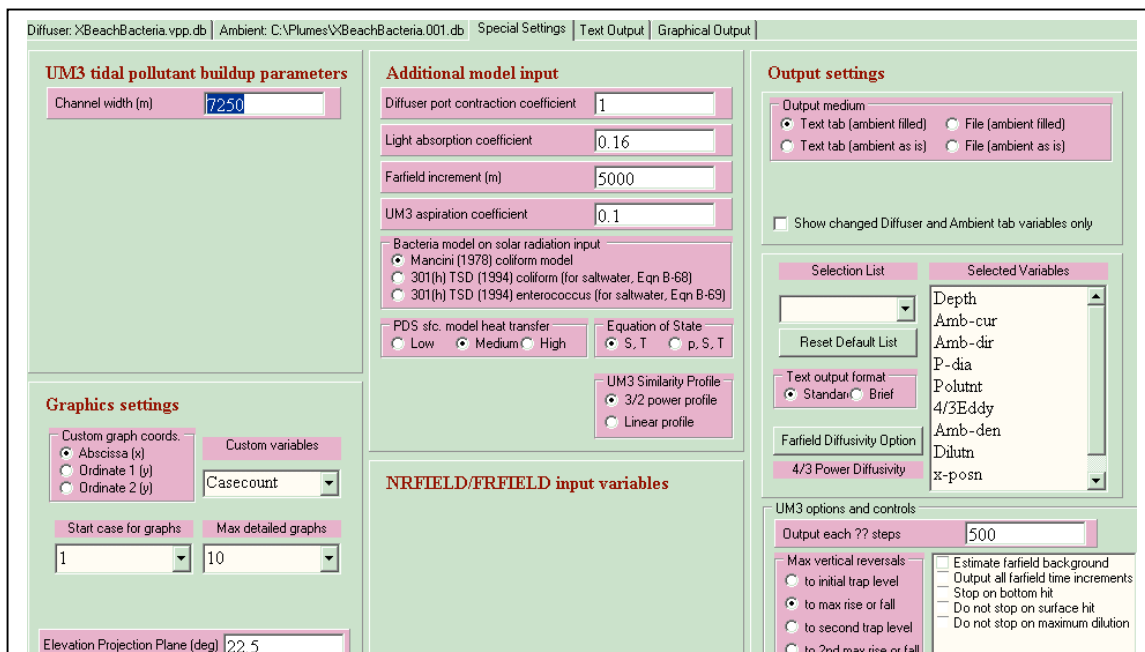Problem: beach bacteria prediction using the time-series capability
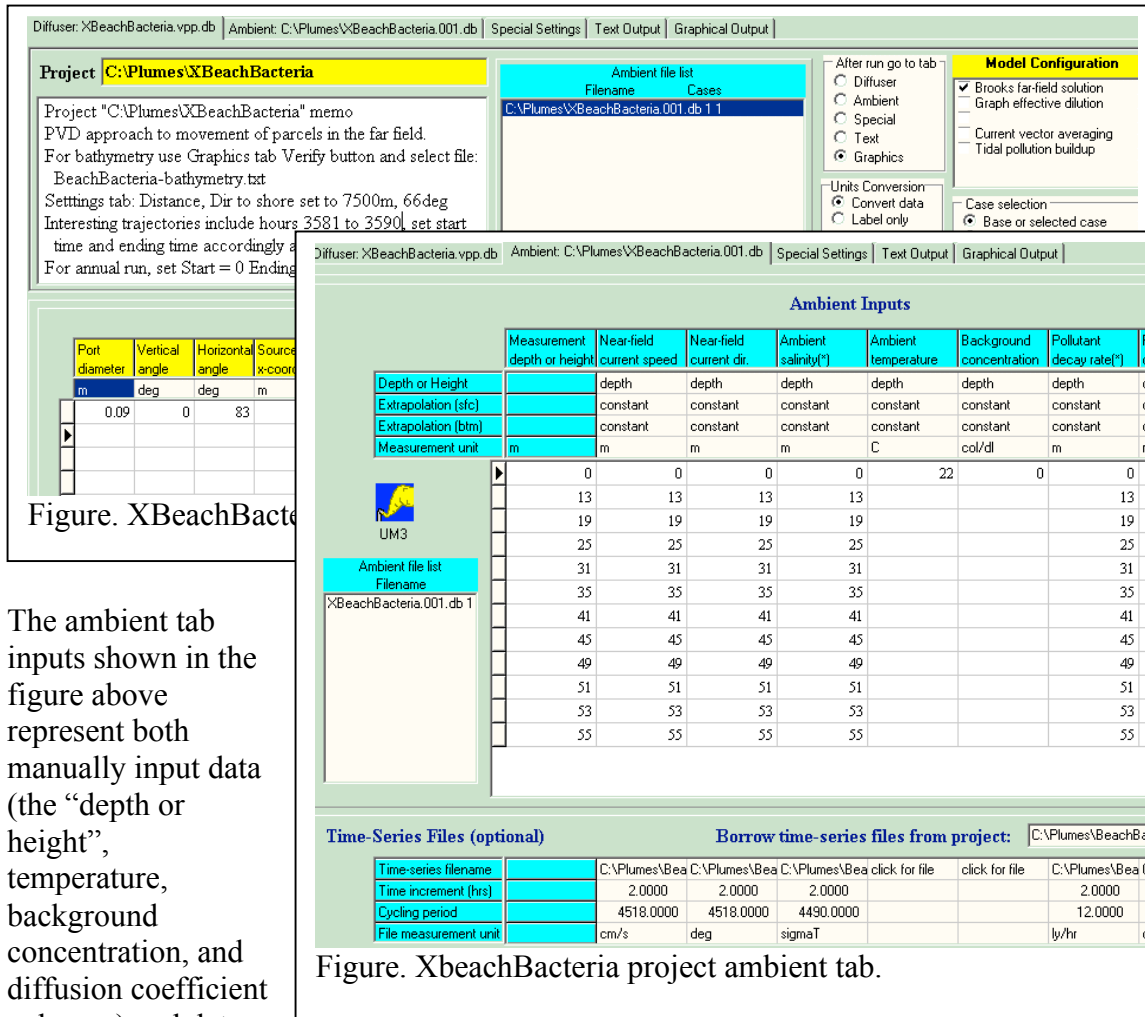
Figure. XBeachBacte

The ambient tab inputs shown in the figure above represent both manually input data (the "depth or height", temperature, background concentration, and diffusion coefficient columns) and data

Figure. XbeachBacteria project ambient tab.

read from the time-series files at the time of linkage (all the other columns). As in the Dominguez Channel case, the time-series files must be set up in advance and linked to VP.

The settings tab is shown in the following figure.

Problem: beach bacteria prediction using the time-series capability

- Mancini model is checked
- Maximum vertical reversals is set to maximum plume rise
- Shore vector is set to the approximate actual distance (7250m) to govern decrease in shoreward velocity as the plume element encroaches the shore. A much larger value may be specified to essentially keep this mechanism from functioning.
-
-
-

Model   UM3

Practice

- See what happens when a large shore vector value is specified or the angle to shore is changed.
- Artificially change the depth of the diffuser to see what happens when bacteria are exposed to additional sunlight.
-
-

Theory

- Certainty in bacteria decay models
-
-
-

Limitations, troubleshooting

- It is assumed that currents are the same everywhere, except for the "shore vector" attenuation of the shoreward component of the current velocity.
-
-

Problem: beach bacteria prediction using the time-series capability

?.0 Appendices

?.1 Similarity profiles

This manuscript records supporting theory to some of the changes made to Visual Plumes to output concentration isopleths when running the UM3 model. It may be used as background for reviewing the Frick-Denton Benson manuscript (Frick and Denton, 2003), for which the changes were necessary.

Users of plume models, such as Visual Plumes (Frick et al. 2003), are frequently interested in estimates of concentrations at the center, i.e., along the centerline, of plumes. If the model predicts average properties, as the Visual Plumes UM3 model does, profiles of concentration, of which the Gaussian distribution is a well-known example, are used to estimate the relationship between these properties. Some of the intricacies of such distributions are developed below.

The ratio of the centerline and average plume element concentrations is sometimes called the peak-to-mean ratio.

It is convenient to express concentration profiles in terms of the relative radius, f,

(A-1) $\quad f = r / b$

where b is the radius of the plume.

In addition to the Gaussian profile, the three-half power profile found in Kannberg and Davis (1976) has been used with both the Visual Plumes DKHW and UM3 models. The three-half power profile is

(A-2) $\quad g(f) = \left(1 - f^{3/2}\right)^2$

and approximates the Gaussian distribution. The simple mean of this distribution given a circular cross-section is 0.257 of centerline value, thus, the simple peak-to-mean ratio, k, is 3.89.

Measurements of plumes leading to the distribution given by Eqn. 2 generally appear to represent flux measurements, in other words, measurements are relative to the quantities of fluid captured through different cross-sections and must be integrated as fluxes involving velocities. The UM3 model is a Lagrangian model that uses a material element as its control volume. Ideally, a simple concentration profile should suffice to relate concentrations within the element. UM3 has often been criticized reporting overly large peak-to-mean ratios, found to be nearer to a value of 2.0 by various researchers (Tian 2002, Roberts ??). Given that the longitudinal velocity distribution in the plume shares the same profile, the material element the appropriate distribution of properties may be better given by another 3/2 power profile

(A-3) $\quad g(f) = 1 - f^{3/2}$

The corresponding k for this distribution is only 2.33.

Still simpler and giving k values similar to reported values is the distribution

Problem: beach bacteria prediction using the time-series capability

(A-4) $\quad g(f) = 1 - f^2$

where $k = 2.0$. For a line source $k = 1.5$.

Water carrier mass dilution

If ambient water can serve as a marker, and in theory it can, then a concentration profile implies a corresponding distribution of dilution across the plume cross-section. The definition of average dilution of the plume element, S_{avg}, may be expressed in terms of the mass of ambient water, M, mixed with the mass of the original material plume element, m,

$$S_{avg} = \frac{M + m}{m}$$

(A-5)

The average dilution is an important UM3 quantity derived from its entrainment equation. Eqn. 5 may be generalized to represent the point-wise dilution, $S(f)$. Allowing dM and dm to represent the respective masses along f, and, letting C_a and C_e represent the local ambient and effluent concentrations of a tracer

$$C(dM + dm) = dM C_a + dm C_e$$

$$C = \frac{dM C_a}{dM + dm} + \frac{dm C_e}{dM + dm} = \frac{dM}{dm} \frac{C_a}{S} + \frac{C_e}{S} = \frac{dM}{dm} \frac{C_a}{S} + \frac{dm}{dm} \frac{C_a}{S} - \frac{dm}{dm} \frac{C_a}{S} + \frac{C_e}{S}$$

$$C = C_a - \frac{C_a}{S} + \frac{C_e}{S}$$

(A-6)

When speaking specifically about dilution in isolation of a pollutant then the water molecules in original material element defined at the source may be tagged. They might be heavy water, for example. Then the ambient concentration is effectively zero and Eqn. 6 may be manipulated to provide an equation more useful than Eqn. 5. It follows from Eqn. 6 that

$$C_{avg} = \frac{C_e}{S_{avg}}$$

(A-7)

and

$$C_{CL} = \frac{C_e}{S_{CL}}$$

(A-8)

and finally

$$C = \frac{C_e}{S}$$

(A-9)

Eqns. 7 - 9 may be used to show that

$$S = \frac{S_{avg}}{kg(f)}$$

(A-10)

Finally,

$$C = C_a - \frac{C_a kg(f)}{S_{avg}} + \frac{C_e kg(f)}{S_{avg}}$$

(A-11)

Problem: beach bacteria prediction using the time-series capability

Although C_a is assumed to be uniformly constant, in fact it will in general vary with depth, making the plume distribution approximate.

Significance of distributions on models such as the Visual Plumes UM3 model

The primary predictions of the Visual Plume UM3 model are not affected by the adopted profile. This is due to the fact that UM3, as pointed out above, predicts average dilutions. Centerline dilutions are estimated by superimposing a profile of properties. The results obtained using the 3/2 power profile have been consistently criticized to result in centerline concentrations that are too conservative. This observation agrees with the finding that the zone of established flow is associated with an average dilution of approximately 2:1, more consistent with the distribution given by Eqns. 3 and 4 than by Eqn. 2. In this work Visual Plumes UM3 is modified for the distribution given by Eqn. 11. Thus, earlier versions are considerably more conservative with respect to the prediction of the centerline concentration.

Using Eqns. 4 and 11 and solving for f yields

$$f = \sqrt{1 - \frac{S_{avg}(C - C_a)}{k(C_e - C_a)}}$$

(A-12)

Effective dilution

The average mass dilution described by Eqn. 5 only describes the concentration of a pollutant in a plume when the ambient pollutant concentration is zero. At other times it gives a non-conservative estimate of concentrations. Similar statements are true for the centerline and points throughout the plume. A good estimate of actual dilution of pollutants is given by the effective dilution, defined as the ratio of effluent concentration to subsequent plume concentration at any point. The effective dilution, S_{eff}, is

$$S_{eff} = \frac{C_e}{C}$$

(A-13)

Visual Plumes allows both S and S_{eff} to be reported. The former is most useful for understanding plume dynamics and whenever the ambient concentration is zero. The latter is recommended whenever the the primary concern is pollutant concentration and the ambient concentration is not zero.

Estimating concentration contours beyond the stream dilution limit

When using plume models such as Visual Plumes UM3 it is important to understand that the streamflow limits the amount of dilution that can occur. This is effectively what Eqn. 5 says. When this limit is reached UM3 issues a stream-limit statement to warn the user that beyond that point additional dilution is not supported by conditions, however, it continues the simulation as if additional diluting water were available. This feature of the model can be exploited to give further estimates of how the concentrated portion of the plume might continue to become more uniform downstream.

Problem: beach bacteria prediction using the time-series capability

Unless the concentration isopleth to be contoured is equal to the ambient concentration, the concentration isopleth will be narrower than the width of the plume itself. Thus, when the stream limit is reached, the concentrated core of the plume will typically occupy only a fraction of the stream. In the plume fringes, in other words, along the banks, the concentrations will be less than the contour concentration. As the plume material continues to flow downstream a mixing process similar to the one used in the model will result in the centerline concentration decreasing as the bank concentrations increase, eventually, if sufficient fetch is available and there are not radical changes in stream conditions, the plume reaching a uniform concentration. If the ultimate uniform concentration is higher than the contoured concentration the ultimate contours will conform to the banks, otherwise the contour may broaden briefly before ultimately closing as the width of the concentrated core reaches zero.

UM3 may be used to estimate the contours of the criterion concentration beyond the stream dilution limit by assuring that the mass of pollutant in the plume element remains constant beyond that point. The model entrainment equation may then simulate the continued carrier fluid mixing process on which the appropriate concentration profile is simply superimposed so that the in-stream portion of the pollutant mass remains constant. It is then simply a matter of solving for the width of the contour to continue to plot the stream core beyond the point of the stream dilution limit being reached. This procedure depends on being able to integrate the concentration profile across the plume or stream, whichever is narrower.

Pollutant mass in the plume element

If the chosen concentration profile represents the plume pollutant concentrations anywhere in the plume then, in general,

(A-14) $$C = (C_{CL} - C_a)g(f) + C_a$$

When plume dilution has reached its stream dilution limit it is assumed that the cross-section is no longer round but takes on the shape of the stream cross-section, for simplicity assumed to be rectangular. This condition implies that the profile is approximately one-dimensional in the horizontal, the concentration being uniform in the vertical dimension. The pollutant mass in the plume element may then be found by integrating Eqn. 13 across the cross-section. Assuming the centerline is in the middle of the stream, the pollutant mass, P_f, within the limits $-f$ to $+f$ is

(A-15) $$P == \int_{-f}^{f} C\rho Z h df = \rho Z h \int_{-f}^{f} \left((C_{CL} - C_a)g(f) + C_a \right) a$$

where ρ is the density of the water, assumed to be constant, Z is the depth of the stream, h is the length of the plume element, and M_f is the plume element mass within the integration limits. The corresponding expression for P_b, the total pollutant mass in the plume element in unconfined water, is

(A-16) $$P_b = \left(C_{CL} - C_a\right)\frac{2}{3} M_b + C_a M_b$$

where M_b is corresponding total plume element mass.

Once plume dilution ceases as the stream limit is reached the plume element mass and the pollutant mass in the plume remain constant, assuming no decay or diluting water additions, as from a downstream confluence. Eqn. 14 may then be used to solve for the centerline

Problem: beach bacteria prediction using the time-series capability

concentration in terms of f, M_f, and P_f. In this way the unconstrained growth of the plume may be used to simulate the process of uniformly mixing the pollutant within the bank-constrained plume element, i.e., within M_f.

Model limitations

Some already described, notably.... Outside bank plume depiction.

References

Bailey, G.C. 1994. Water Quality Program, permit writer's manual. Pub. 92-109. Washington Dept. of Ecology, Water Quality Program. Olympia, WA

Baumgartner, D.J. and W.E. Frick 2002. Designing ocean outfalls to minimize environmental and human health risks. Poster. SETAC Europe 12th Annual Meeting, 12-16 May 2002, Vienna, Austria

Baumgartner, D.J., W.E. Frick, and P.J.W. Roberts 1994. Dilution Models for Effluent Discharges (3rd Ed). EPA/600/R_94/086, U.S. Environmental Protection Agency, Pacific Ecosystems Branch, Newport, OR

Cheung, V. 1991. Mixing of a round buoyant jet in a current. Ph.D. thesis, Dept. of Civil and Structural Engineering, University of Hong Kong, Hong Kong, China

Davis, L.R. 1999. Fundamentals of environmental discharge modeling. CRC Press LLC, Boca Raton, FL, 165 pp.

Doneker, R.L. and G.H. Jirka 1990. Expert system for hydrodynamic mixing zone analysis of conventional and toxic submerged single port discharges (CORMIX1). EPA/600/3_90/012, ERL, Office of Research and Development, USEPA, Athens, GA

EA Engineering, Science, and Technology 2003. Thermal plume surveys on the Des Plaines River near Joliet Stations 9 and 29, June-September 2002. EA Engineering, Science, and Technology, Deer field, IL 60015

Fan, L.N. 1967. Turbulent buoyant jets into stratified or flowing ambient fluids. Report No. KH_R_15, W.M. Keck Lab. of Hydraulics and Water Resources, California Institute of Technology, Pasadena, CA

Frick, W.E., 2003. Diverse models for solving contrasting outfall problems. In: Proceedings of the 4th International Exhibition and Conference on Environmental Technology. 30 Jan - 2 Feb 2003. Technical Chamber of Greece, Athens, Greece

Frick, W.E., D.J. Baumgartner, M. Molina, T. Khangaonkar, and G. Robertson 2003. Using public-domain models to estimate beach bacteria concentrations. Abstract submitted to ASLO/TOS Ocean Research 2004 Conference, Special Session on Sources, Transport, and Fate of Contaminants in the Southern California Bight (SS9.02), February 15-20, 2004, Honolulu, Hawaii

Frick, W.E. and D.L. Denton 2003. Modulating Storm Drain Flows to Reduce Stream Pollutant Concentrations. Submitted to the First Interagency Conference on Research in the Watersheds, 27-30 October 2003, Benson, AZ

References

Frick, W.E., P.J.W. Roberts, L.R. Davis, J. Keyes, D.J. Baumgartner, and K.P. George, 2003. Dilution models for effluent discharges, 4th Edition, Visual Plumes. EPA/600/R-03/025, Mar 2003, Ecosystems Research Div., NERL, U.S. EPA, Athens, GA

Frick, W.E., P.J.W. Roberts, L.R. Davis, J. Keyes, D.J. Baumgartner, and K.P. George, 2003. Dilution models for effluent discharges, 4th Edition (Visual Plumes). USEPA, Athens, Georgia. EPA/600/R-03/025. 148 pp.

Frick, W.E. 1984. Non-empirical closure of the plume equations. Atmospheric Environment, Vol. 18, No. 4, 653-662

Frick, W.E. 1981. Volcano plumes. Letter. *American Scientist*, **69**, p. 4

Lee, J., V. Cheung, W. Wang, and S. Cheung (2000). Lagrangian modeling and visualization of rosette outfall plumes. Proc. Hydroinformatics 2000, Iowa, July 23-27, 2000. (CDROM)

Lee, J.H.W. and V. Cheung 1990. Generalized Lagrangian model for buoyant jets in current. *J. of Environmental Engineering* **116**, 1085-1106

Kannberg, L.D. and L.R. Davis, 1976. An experimental/analytical investigation of deep submerged multiple buoyant jets. USEPA Ecological Research Series, EPA-600/3-76-101, USEPA, Corvallis, OR

Paulsen, D.R. 2001. Midwest Generation, LLC-Joliet 29 Generating Station NPDES Permit No. IL0064254; Attachment 1, Joliet 29 Near-Field Thermal Compliance Model. Letter to Mr. James Filippini data May 1, 2001

Rosenfeld, C.L. 1980. Observations on the Mount St. Helens eruption. *American Scientist*, **68**, pp. 495-509

Tian, X., 2002. 3DLIF and its applications to studies of the near field mixing in wastewater discharges. Ph.D. dissertation, Georgia Institute of Technology, July 2002

Winiarski, L.D. and W.E. Frick 1976. Cooling tower plume model. USEPA Ecological Research Series, EPA-600/3-76-100, USEPA, Corvallis, OR