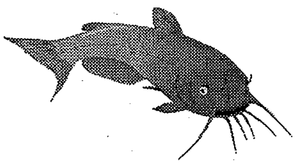
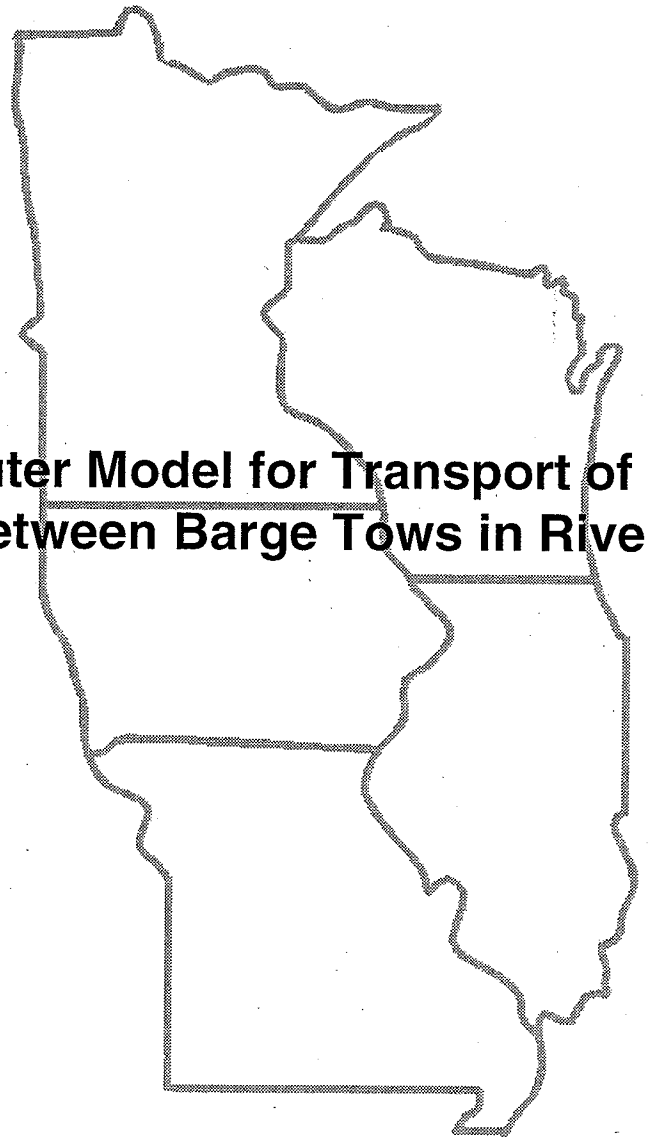
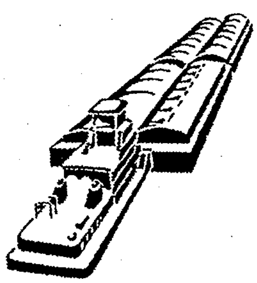
ENV Report 26

Interim Report For The Upper Mississippi River — Illinois Waterway System Navigation Study





Computer Model for Transport of Larvae Between Barge Tows in Rivers



September 2003

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Upper Mississippi River - Illinois Waterway System Navigation Study

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Computer Model for Transport of Larvae Between Barge Tows in Rivers

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Interim report

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ABSTRACT: For two separate tows, each composed of one or more barges and a self-propelled vessel, or towboat, traveling in the same direction in a river, some percentage of the water and fish larvae that go through the propellers of the second towboat may have also gone through the propellers of the first or leading towboat. A computer program has been developed for calculating this percentage. For this calculation, the river is schematized as a rectangular channel with constant depth and constant velocity. Being located at a certain percentage of the total width of a rectangular channel is essentially equivalent to being at the same percentage of total flow rate in a natural channel.

The flows from the propellers of a towboat are analyzed as jets. The distances between tows are assumed to be large enough that the flow from the propellers of the leading towboat will become fully mixed over the river depth before the second towboat encounters this water. Thus, all of the analyses are done in terms of two-dimensional, depth-averaged conditions. The propeller jets are generated by a moving source, while the analysis was done in a stationary coordinate system. Thus, it was necessary to transform the momentum or thrust from the propeller jets in a moving coordinate system into an equivalent momentum in a stationary coordinate system.

For tows traveling upstream, the jets are treated as being in a co-flow, i.e., a flow which is going in the same direction as the jet. Since the jets can persist for large distances (on the order of a kilometer), an approximate analysis was done to account for the effects of boundary friction on the jets. The end of the jet region is determined based on a tolerance for the magnitude of the jet velocity relative to the river flow velocity. After the jet velocities decrease to being within this tolerance, ambient river diffusion is used to determine the mixing of the water from the propellers of the first towboat. Based on the jet velocities, the river flow velocity, the speed of the tows, and the distance between the tows, the program determines whether the second towboat encounters the water from the first set of propellers in the jet region or in the ambient diffusion region and then calculates the makeup of the intake water for the second set of propellers. For these calculations, the river is divided into a number of vertical strips. The calculations are done for the center of the first tow at the center of each of the vertical strips. For each location of the first tow, the second one can also be at the center of each of the vertical strips. The jet calculations for tows traveling upstream were verified by comparison with laboratory measurements of velocities downstream from a stationary towboat.

The calculations for tows traveling downstream are similar except that the propeller jets are now directed against the river flow so the analysis is based on jets in counter flows. Since the jet and river flows are opposed to each other, the region of jet flow is small enough that the effects of boundary friction are not included in these calculations. The end of the jet region is taken to be when the water from the propellers returns to the cross section where the jet was generated.

Contents

Preface

The work reported herein was conducted as part of the Upper Mississippi River - Illinois Waterway (UMR-IWW) System Navigation Study. The information generated for this interim effort will be considered as part of the plan formulation process for the System Navigation Study.

The UMR-IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts of Rock Island, St. Louis, and St. Paul under the authority of Section 216 of the Flood Control Act of 1970. Commercial navigation traffic is increasing and, in consideration of existing system lock constraints, will result in traffic delays that will continue to grow in the future. The system navigation study scope is to examine the feasibility of navigation improvements to the Upper Mississippi River and Illinois Waterway to reduce delays to commercial navigation traffic. The study will determine the location and appropriate sequencing of potential navigation improvements on the system, prioritizing the improvements for the 50-year planning horizon from 2000 through 2050. The final product of the System Navigation Study is a Feasibility Report which is the decision document for processing to Congress.

This study was conducted by Dr. Ed Holley, Water Resources Consultant, Austin, TX, for the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The study was conducted under the direction of Mr. Thomas A. Richardson, Director, CHL.

COL James R. Rowan was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 River

Geometry and Hydraulics

The river is schematized as a rectangular channel, B wide and H deep, with an average velocity of V_{river}. The longitudinal coordinate is x, which is positive in the downstream direction and is measured from the origin of the propeller jets of a self-propelled vessel. The transverse coordinate is y, with y = 0 at the left bank and y = B at the right bank. The discussion of jet models begins with laterally unbounded flows (Chaper 2, paragraphs entitiled "Model for unbounded co-flowing jets" and "Model for jets in unbounded counter flow") and then proceeds to a channel B wide (Chapter 2, "Application to tows," "Effects of boundary friction," and "General considerations").

Manning's equation in SI units is

$$V_{river} = \frac{1}{Mann} R_h^{2/3} S_f^{1/2} \tag{1}$$

where

Mann = Manning's roughness coefficient (normally called n)

R_h = hydraulic radius

S_f = friction slope

For this project, it was assumed that the river channels have large B/H ratios so $R_h \approx H$. Thus, Manning's equation was used in the form

$$V_{river} = \frac{1}{Mann} H^{2/3} S_f^{1/2} \tag{2}$$

Using Equation 2, the shear velocity can be written for regions of negligible jet velocity as

$$u_* = \sqrt{g}\, \frac{Mann\ V_{river}}{H^{1/6}} \tag{3}$$

Ambient Diffusion

The two primary mechanisms for lateral transport in rivers are advection and diffusion. By definition, diffusion is a spreading or mixing process relative to the streamlines, which are the lines along which advection takes place. Thus, the diffusion that is calculated in this model or any model must be viewed as taking place relative to streamlines. In a rectangular channel defined previously, the streamlines are straight and parallel to the banks. In an actual river, the streamlines can move laterally as the cross-sectional geometry changes. In the computer model (Chapter 4), a tow (i.e., a twoboat and one or more barges) that is located 25 m from the bank in a river that is 125 m wide is 20 percent of the width from the bank. To account for streamlines moving laterally in a river channel, this 20 percent can be interpreted as being at a location such that 20 percent of the total river flow is between the tow and the bank (Yotsukura and Sayre 1976; Fischer et al. 1979).

Diffusion coefficients

The ambient transverse mass diffusion coefficient associated with the river flow is called DiffCoef, which can be written as

$$\text{DiffCoef} = \alpha_y H u_* \tag{4}$$

where α_y is a dimensionless diffusion coefficient.

Some typical values of α_y are given in Table 1 from Fischer et al. (1979) and Holley and Jirka (1986).

Table 1
Typical Values of α_y

Conditions	α_y
Manmade, essentially prismatic channels	0.015
Rivers with low sinuosity	0.3 to 0.4
Rivers with greater sinuosity	≥ 0.6

Concentration distributions for infinitely wide channel

For two-dimensional (2-D), depth-averaged conditions where a conservative mass is released uniformly over the depth at a rate of $\dot{m}$ per unit depth (so the dimensions of $\dot{m}$ are M/TL) along a vertical line at $x = 0$ and $y = y_o$, the concentration distribution in a laterally unbounded flow (i.e., with no effects from lateral boundaries) with a constant velocity is given by (Holley and Jirka 1986)

$$C = \frac{\dot{m}}{V_{river}\ \sigma_c \sqrt{2\pi}} \exp\left[- \frac{(y - y_o)^2}{2\sigma_c^2} \right] \tag{5}$$

where σ_c is the standard deviation of the concentration distribution.

For a constant diffusion coefficient and a constant velocity,

$$\sigma_c^2 = \frac{2\ (\text{DiffCoef})\, x}{V_{river}} \tag{6}$$

so

$$C = \frac{\dot{m}}{\sqrt{4\pi V_{river}\ (\text{DiffCoef})\, x}} \exp\left[- \frac{V_{river}(y - y_o)^2}{4\ (\text{DiffCoef})\ x} \right] \tag{7}$$

If the initial condition is a partial plane source with mass released uniformly at a rate of $\dot{m}$ per unit depth from y_1 to y_2 where $y_2 > y_1$, then the concentration at any x and y in a laterally unbounded flow is

$$C = \frac{\dot{m}}{2V_{river}(y_2 - y_1)} \left\{ \text{erf}\left[\frac{y - y_1}{2} \sqrt{\frac{V_{river}}{(\text{DiffCoef})\ x}} \right] - \text{erf}\left[\frac{y - y_2}{2} \sqrt{\frac{V_{river}}{(\text{DiffCoef})\ x}} \right] \right\} \tag{8}$$

Effects of finite width

The effects of the river banks (actually the sides of the assumed rectangular cross section in this case) can be included in the calculated concentration distributions by using the method of images, since the governing equation for the mass transport is linear.

Vertical line source. For a vertical line source located at any y_o in the rectangular cross section, the images (including the actual source) are located at

$$y_{o_{mk}} = 2mB - (-1)^k y_o \tag{9}$$

where m and k = integer indices with $-\infty < m < \infty$ k = 1, 2.

To account for the side boundaries, Equation 7 must be replaced with

$$C = \frac{\dot{m}}{\sqrt{4\pi V_{river}\ (DiffCoef)\, x}} \sum_{m=-\infty}^{\infty} \sum_{k=1}^{2} \exp\left[- \frac{V_{river}\left[y - 2mB + (-1)^k y_o \right]^2}{4\ (DiffCoef)\ x} \right] \tag{10}$$

If any part of the concentration distribution calculated by Equation 7 or other similar expressions for unbounded flows is outside the channel width, the method of images effectively reflects that part back into the channel. If any of the reflected part falls outside the opposite side of the channel, then that part is reflected back into the channel, and so on.

These equations for a vertical line source are given for reference purposes; they are not used in the computer program.

Partial plane source. In the computer program, the first part of the calculations is for the jets from the propellers (Chapter 2). Ambient diffusion starts at the end of the jet region where the larvae are spread across part of the river width. For the ambient diffusion calculations, the width of the river is subdivided into Ny vertical strips of width $\Delta y = B/Ny$. The variables in the program are dimensioned so that Ny must be ≤50. Using the index i for each strip, the center of the width of each strip is at y_{oi}, and the left side is at

$$y_{1_i} = y_{o_i} - \frac{\Delta y}{2} = \left(i - \frac{1}{2} \right) \Delta y \tag{11}$$

where i varies from 1 to Ny. The right side is at

$$y_{2_i} = y_{o_i} + \frac{\Delta y}{2} = \left(i + \frac{1}{2} \right) \Delta y \tag{12}$$

The concentration at each y_{oi} at the end of the jet mixing region is called $(C_{trans})_i$, where the subscript trans indicates the transition from jet mixing to ambient. C_{trans} is assumed to be constant over the Δy centered at y_{oi}. Each Δy at the end of the jet region is then effectively a partial plane source with a mass flux of $\dot{m}$ per unit depth from y_1 to y_2 where

$$\dot{m}_i = \left(C_{trans} \right)_i V_{river}\ \Delta y \tag{13}$$

For a river of width B, the images for y_{1i} and y_{2i} are at

$$y_{1imk} = \frac{dy}{2} - 2mB + (-1)^k y_o \tag{14}$$

and

$$y_{2imk} = -\frac{dy}{2} - 2mB + (-1)^k y_o \tag{15}$$

so that each image of a source over Δy is another source between y_{1imk} and y_{2imk} for each combination of m and k values (except for the values m = 0 and k = 1, since these values give the actual source).

Since $y_2 - y_1 = \Delta y$ for each strip, the contribution (C_i) of each strip at the end of the jet region to the concentration at the end of the ambient diffusion calculations is

$$C_i = \frac{(C_{trans})_i}{2} \sum_{m=-\infty}^{\infty} \sum_{k=1}^{2} \left\{ \text{erf}\left[\frac{y - y_{1imk}}{2} \sqrt{\frac{V_{river}}{\text{DiffCoef}\, x}} \right] - \text{erf}\left[\frac{y - y_{2imk}}{2} \sqrt{\frac{V_{river}}{\text{DiffCoef}\, x}} \right] \right\} \tag{16}$$

Using Equation 16 for each strip at the end of the jet region gives the concentration at any y after ambient diffusion as

$$C = \sum_{i=1}^{Ny} C_i \tag{17}$$

As m increases in either the positive or negative direction in Equations 10 or 16, the images are farther and farther from the channel and make smaller and smaller contributions to the calculated concentration. Thus, as a practical matter, the summation over m begins with m = 0 and goes to larger positive and negative values of m until the contributions to the summation become negligibly small. The summation over m can then be stopped.

2 Jet Models

General Concepts

Vertical uniformity

The diameters of propellers of towboats are generally less than the water depth in a river or navigation channel. Thus, the jets immediately behind the towboats are not uniformly distributed over the depth. This initial vertical variation of velocity was not considered in modeling the jets and the diffusion of larvae in the jets for two reasons:

a. Because of the distance between the tows traveling in the same direction, the water and larvae that have gone through the propellers of the leading towboat will probably be uniformly mixed over the depth before the second towboat reaches that water.

b. Even if this vertical uniformity is not achieved by the jet and river mixing, any residual nonuniformity will not be very important. The water that goes through the propellers of the second towboat must first flow around and/or under the barges being pushed by that second towboat so that the disturbance of the barges will normally keep any vertical nonuniformity from reaching the propellers of the second towboat. Thus, the analysis used for the propeller jets is a 2-D analysis based on the thrust (or momentum flux) of the propeller jets per unit depth of the river and the analogy between momentum transport and mass transport.

Analogy between mass and momentum transport

The desired output from the jet models is the distribution of larvae that have gone through the propellers of a towboat. Thus, the interest is basically in mass transport while jet models fundamentally give information about velocity distributions or equivalently about momentum transport. There are two transport mechanisms that are important for the larvae, namely advection and diffusion. Advection is the same for mass and momentum, since the flow velocity accomplishes the advection for both. Also, there is a general similarity or analogy between momentum and mass diffusion, but mass diffuses more rapidly than momentum in jets and in many other types of diffusion (Hinze 1959; Fischer et al. 1979; Holley and Jirka 1986). The diffusion in the lateral (y) direction for momentum is represented by ε_y, which is an eddy viscosity or a turbulent diffusion coefficient for momentum, while k_y is the lateral diffusion coefficient for mass. The ratio of the two coefficients is a turbulent Schmidt number ($\mathbf{S_t}$) where

$$\mathbf{S_t} = \frac{\varepsilon_y}{k_y} \tag{18}$$

For jets, the difference in the rates of turbulent diffusion for mass and momentum is normally expressed by λ, which is the ratio of the nominal jet width for mass to that for momentum. Since the width of a concentration or velocity distribution is proportional to the square root of the turbulent diffusion coefficient associated with the spreading of the distribution (Holley and Jirka 1986),

$$\lambda = \frac{1}{\sqrt{\mathbf{S_t}}} = \sqrt{\frac{k_y}{\varepsilon_y}} \tag{19}$$

so that

$$\sigma_c = \lambda_j \sigma_v \tag{20}$$

where

σ_c = standard deviation of a concentration distribution

$\lambda = \lambda_j$ for 2-D jets

σ_v = standard deviation for a velocity distribution.

A typical value of λ_j for 2-D jets is 1.35 (Holley and Jirka 1986), giving a turbulent Schmidt number of 0.55. The parameters used in the model were $\lambda_j = 1.35$ for tows traveling upstream and 1.24 for tows traveling downstream (i.e., paragraph entitled "Model for jets in unbounded counter flow," Chapter 2).

For later reference, it is mentioned here that diffusion coefficients for heat and mass are approximately equal to each other (Hinze 1959) and that the turbulent Prandtl number ($\mathbf{P_t}$) is analogous to the Schmidt number in that it is the ratio of the eddy viscosity to the diffusion coefficient for heat. Turbulent Prandtl and Schmidt numbers are larger for shear flows than for free turbulent flows. For turbulent flow in a pipe, the average $\mathbf{P_t}$ is approximately 0.78 (Schlichting 1960). From Equation 19 with $\mathbf{P_t} = \mathbf{S_t}$, the corresponding average λ_s for shear flows is 1.13.

Moving source

The propeller jets from towboats are generated by a moving source while jet models are for stationary sources. For these calculations, it is assumed that plug flow conditions exist in the river, i.e., that there is no longitudinal mixing of momentum or mass for the jets or the larvae. This assumption allows a jet that is generated at any instant to develop just as if it were from a stationary source at location of the towboat at the instant of generation. Naturally, it is necessary to account for the relative velocities in determining the equivalence between stationary and moving jets (paragraph entitled "Propeller Jets").

Side boundaries

Jet models are generally for unbounded flows, but the jets from towboats have a high probability of being affected by the riverbanks. The method of images in paragraph entitled "Effects of finite width" is valid only for linear problems. Since the equations of motion are nonlinear in terms of the velocities, the method of images cannot be applied directly to the velocities calculated from jet models. However, the equations are essentially linear in terms of momentum flux. Thus, superposition associated with the method of images can be applied to the momentum fluxes (not the velocities) calculated from jet models and then velocities can be calculated from the superimposed momentum fluxes. An equivalent way of viewing the superposition is to say that velocities are first calculated for an unbounded flow field using a jet model, next the velocities are used to obtain the momentum fluxes, then the analogy between momentum transport and mass transport is used to obtain mass concentrations for unbounded flows, and finally the method of images is used to account for the effects of the boundaries on the concentration. The superposition inherent in the method of images can be applied directly to the concentrations since the governing equations for mass transport are linear.

Propeller Jets

The volumetric flow rate (Q_{prop}) through one propeller of diameter D turning at n rev/s is

$$Q_{prop} = \frac{V_a \pi D^2}{8} + \sqrt{\frac{V_a^2 \pi^2 D^4}{64} + \frac{K_t n D^6 \pi}{4 z_{prop}}} \tag{21}$$

where

V_a = advance velocity

K_t = thrust coefficient

z_{prop} = 1 for Kort nozzles or 2 for open propellers, and

$$V_a = V_b(1 - w) \tag{22}$$

where

w = wake fraction

V_b = (absolute value of the) velocity of the towboat relative to the water

(Equations 21 throught 25 came from Maynord (1997). Equations 21 through 27 are for a coordinate system moving with the towboat.) The initial thrust (T_o) developed by one propeller is

$$T_o = \rho Q_{prop} V_2 \tag{23}$$

where

ρ = water density

V_2 = velocity added by the propeller relative to the towboat

The thrust coefficient (K_t) is

$$K_t = \frac{T_o}{\rho n^2 D^4} \tag{24}$$

From Equations 23 and 24,

$$V_2 = \frac{K_t n^2 D^4}{Q_{prop}} \tag{25}$$

In a coordinate system moving with the unit of tow, the excess momentum flux due to one propeller is equal to the thrust developed by that propeller. Thus, in the moving coordinate system,

$$T_o = \rho U_o \left(U_o - V_b \right) A_o \tag{26}$$

where

U_o = initial propeller jet velocity in the moving coordinate system = $V_a + V_2$

A_o = initial jet area = $\pi D_o^2/4$

D_o = the contracted propeller jet diameter (which is equal to D for open propellers).

U_o is the total velocity in the moving coordinate system and U_o - V_b is the excess velocity, i.e., the velocity difference in the jet relative to the surrounding flow.

Since the velocities are different in a coordinate system moving with the tows and in a stationary coordinate system, the momentum fluxes change when the coordinate system is changed. The initial total jet velocity in a stationary coordinate system is $U_o - V_b + V_{river}$ for tows moving upstream, while it is $U_o - V_b - V_{river}$ for tows moving downstream. Thus, the initial total jet velocity will be written as $U_o - V_b + \delta_{UD}V_{river}$ where

$$\delta_{UD} = \begin{cases} +1 & \text{for tows going upstream} \\ -1 & \text{for tows going downstream} \end{cases} \tag{27}$$

Then for either case, the initial excess momentum flux (M_o) from two propeller jets in a stationary coordinate system is

$$M_o = \rho\left(U_o - V_b + \delta_{UD}V_{river}\right)\left(U_o - V_b\right)\left(2A_o\right) \tag{28}$$

where

$U_o - V_b + \delta_{UD}V_{river}$ = total velocity in the jet

$U_o - V_b$ = excess velocity in the stationary coordinate system as well as the moving one

For a 2-D approximation of the propeller jets, U_{ie2D} (Figures 1 and 2) is the initial value of the excess jet velocity in a stationary coordinate system. Note that U_{ie2D} is the excess velocity, i.e., the velocity change from V_{river}, while U_o is the total velocity. Also, U_{ie2D} is in a stationary coordinate system, while U_o is in a moving coordinate system. It is assumed that U_{ie2D} is uniform over an area equal to $2b_oH$ where H is the river depth and the initial jet (half) width is taken as

$$b_o = \frac{B_s + D_o}{2} \tag{29}$$

since the total width of the two propeller jets is $B_s + D_o$ where B_s = distance between propeller shafts. Then,

$$M_o = \rho U_{ie_{2D}}\left(U_{ie_{2D}} + \delta_{UD}V_{river}\right)\left(2b_oH\right) \tag{30}$$

since it is essential to have the correct momentum flux in the 2-D approximation of the jet. Solving for U_{ie2D} gives

$$U_{ie2D} = \frac{1}{2}\left(-\delta_{UD}V_{river} + \sqrt{V_{river}^2 + \frac{2M_o}{\rho b_o H}}\right) \tag{31}$$

While Equation 31 is valid for tows going in either direction, it is used in the computer program only for tows traveling downstream.

From this point forward, all velocities are in a stationary coordinate system unless explicitly stated otherwise.

Tows Traveling Upstream

Model for unbounded co-flowing jets

For tows moving upstream, the jets from the propellers of a towboat are modeled as 2-D co-flowing jets, i.e., jets in the same direction as, and aligned with, a flow which surrounds the jet (Figure 1).

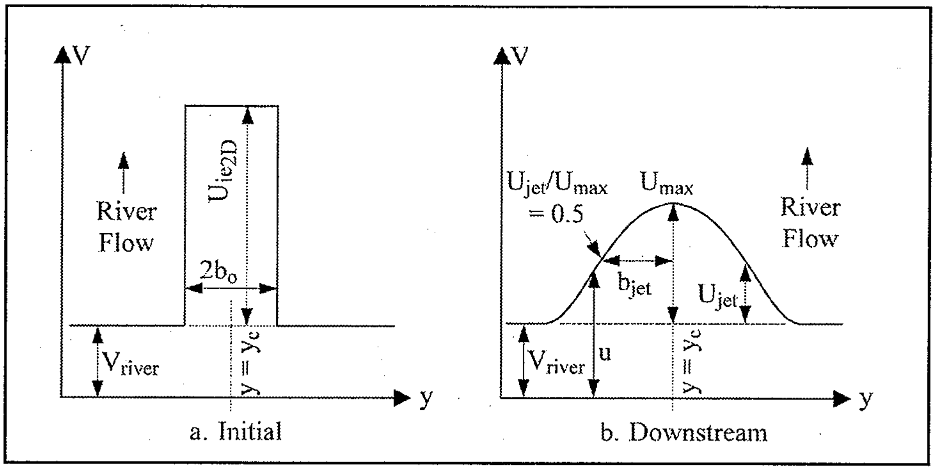

Figure 1. Velocity distributions for co-flowing jets (no scale)

Assuming the river flow velocity to be uniform, the total depth-averaged velocity (u) at any point is

$$u = V_{river} + U_{jet} \tag{32}$$

where U_{jet} is the velocity added by the jet. In a wide river with the jet far from the banks,

$$U_{jet} = U_{max} f\left(\frac{y - y_c}{b_{jet}}\right) = U_{max} f(\eta) \tag{33}$$

where

U_{max} = maximum jet or excess velocity at longitudinal distance (x)

y_c = transverse coordinate of the center line of the jet

b_{jet} = nominal jet width defined as the value of $y - y_c$ at which $U_{jet}/U_{max} = 0.5$

f = a similarity function for the excess jet velocity, $\eta = (y - y_c)/b_{jet}$.

Bradbury (1965) gave

$$f(\eta) = \exp\left[-0.675\eta^2\left(1 + 0.027\eta^4\right)\right] \tag{34}$$

F_1 and F_2 are integrals of the similarity function given by

$$F_1 = \int_0^\infty f(\eta)d\eta \tag{35}$$

and

$$F_2 = \int_0^\infty \left[f(\eta)\right]^2 d\eta \tag{36}$$

from which $F_1 = 1.022$ and $F_2 = 0.748$. From Equation 34, the standard deviation (σ_v) of the velocity distribution is

$$\sigma_v = 0.765\ b_{jet} \tag{37}$$

The momentum thickness (θ) is defined as

$$\theta = \frac{M}{2\rho V_{river}^2 H} \tag{38}$$

where M for laterally unbounded flows is

$$M = \rho H \int_{-\infty}^{\infty} U_{jet}\left(U_{jet} + V_{river}\right)dy \tag{39}$$

Combining Equations 33, 35, 36, 38, and 39 gives

$$\theta = b_{jet}F_2\psi\left(\psi + \frac{F_1}{F_2}\right) \tag{40}$$

or

$$\psi = -\frac{1}{2F_{ratio}} + \sqrt{\frac{1}{4F_{ratio}^2} + \frac{\theta}{b_{jet}F_2}} \tag{41}$$

where

$$\psi = \frac{U_{max}}{V_{river}} \tag{42}$$

and $F_{ratio} = F_2/F_1 = 0.732$.

For co-flowing jets, Patel (1971) gave the change of jet width as

$$\frac{db_{jet}}{dx} = C_2 \frac{U_{max}}{U_{max} + V_{river}} \tag{43}$$

where C_2 is an empirical constant which Patel evaluated to be 0.052.

The conservation of jet or excess momentum can be expressed for laterally unbounded flows from Equation 39 as

$$\frac{\partial M}{\partial x} = \frac{d}{dx}\left[\int_{-\infty}^{\infty} \rho U_{jet}\left(U_{jet} + V_{river}\right) dy\right] = 0 \tag{44}$$

Using this expression, Patel gave the variation of ψ as

$$\frac{1}{2\psi^2} + \frac{1}{\psi} + \left(\frac{F_2}{F_1}\right)^2 \ln\left[\frac{\frac{F_2}{F_1}}{\frac{F_2}{F_1} + \frac{1}{\psi}}\right] + \frac{\left(\frac{F_2}{F_1}\right)^2\left(1 - \frac{F_2}{F_1}\right)}{\frac{F_2}{F_1} + \frac{1}{\psi}} - \frac{F_2}{F_1}\left(1 - \frac{F_2}{F_1}\right) = 2C_2F_1\frac{x^*}{\theta} \tag{45}$$

where x^* = distance from the virtual origin of the jet (Equation 56), i.e., the distance from a hypothetical jet with zero initial width and with the same momentum flux as the actual jet.

To obtain U_{jet} at any x and y for a jet with constant excess momentum flux, Equation 45 can be used to get ψ, Equation 42 to get U_{max}, Equation 40 to get b_{jet} from θ (Equation 57), and Equations 33 and 34 to get U_{jet}. Equation 32 can be used to get u. Since the momentum flux for the propeller jets is not constant due to boundary friction, a different procedure is used in the computer program (paragraph entitled "Computational scheme").

Application to tows

Effects of boundary friction. Since most jet models assume that the jets are in unbounded flows, the models do not include the effects of boundary friction. However, the propeller jets from towboats are in relatively shallow water and they have large excess momentum fluxes. Thus, the jets can persist for such large distances that the effects of frictional resistance on removing excess momentum from the jets must be considered. This section of text describes the approximate method that was developed to account for the change in jet momentum due to the boundary shear stresses.

Assuming that the flow depth is approximately constant throughout the width and length of the jet, that the flow is steady, and that the channel is a wide rectangle so the hydraulic radius is approximately equal to the depth, the depth-integrated momentum equation gives the change in momentum flux as

$$\frac{dm_T}{dx} = \gamma H S_o - \tau_o \tag{46}$$

where

m_T = total momentum flux per unit width ($\rho u^2 H$)

u = total velocity = $V_{river} + U$, $U = U_{jet} - V_d$

V_d = velocity defect resulting from the wake of the tows (to account for the effects of this wake as well as the propeller jets)

S_o = channel slope

The average boundary shear stress (τ_o) is

$$\tau_o = \gamma H S_f \tag{47}$$

where γ = specific weight of water. Eliminating S_f and using Equation 1 gives

$$\tau_o = \gamma \frac{(u \text{ Mann})^2}{H^{1/3}} \tag{48}$$

Integrating in the lateral direction from $y_c - \mu B_b$ to $y_c + \mu B_b$, where B_b is the total width of the tows and μ is large enough that this integration is effectively from $-\infty$ to $+\infty$ as far as the jet and wake are concerned, and assuming that the flow is laterally unbounded, the change in the total momentum flux (M_T) for the river flow plus the jet and wake is given by

$$\frac{dM_T}{dx} = 2\mu B_b \gamma H S_o - \gamma \frac{(\text{Mann } V_{river})^2}{H^{1/3}} \int_{y_c-\mu B_b}^{y_c+\mu B_b} \left[1 + 2\frac{U}{V_{river}} + \left(\frac{U}{V_{river}}\right)^2 \right] dy \tag{49}$$

Further assuming that

$$\gamma H S_o = \gamma \frac{(\text{Mann } V_{river})^2}{H^{1/3}} \tag{50}$$

in the region occupied by the jet and wake, just as would be the case for uniform flow if there were no jet, then the change in the excess momentum (M) associated with the jet and momentum deficit in the wake (M_d) is

$$\frac{d(M\text{-}M_d)}{dx} = -\gamma \frac{(\text{Mann } V_{river})^2}{H^{1/3}} \int_{y_c-\mu B_b}^{y_c+\mu B_b} \left[2\left(\frac{U_{jet} - V_d}{V_{river}}\right) + \left(\frac{U_{jet} - V_d}{V_{river}}\right)^2 \right] dy \tag{51}$$

where U_{jet} - V_d has been substituted for U.

Assuming that the terms involving just U_{jet} contribute only to changing M and likewise that V_d changes only M_d, then

$$\frac{dM}{dx} = -\gamma \frac{(\text{Mann } V_{river})^2}{H^{1/3}} \int_{y_c-\mu B_b}^{y_c+\mu B_b} \left[2\frac{U_{jet}}{V_{river}} + \left(\frac{U_{jet}}{V_{river}}\right)^2 - \alpha_{jet} \frac{2U_{jet}V_d}{V_{river}^2} \right] dy \tag{52}$$

and

$$\frac{dM_d}{dx} = \gamma \frac{(\text{Mann } V_{river})^2}{H^{1/3}} \int_{y_c-\mu B_b}^{y_c+\mu B_b} \left[-2\frac{V_d}{V_{river}} + \left(\frac{V_d}{V_{river}}\right)^2 - (1-\alpha_{jet}) \frac{2U_{jet}V_d}{V_{river}^2} \right] dy \tag{53}$$

where α_{jet} is an unknown factor for distributing the effects of the cross product term ($U_{jet}V_d$) between the momentum for the jet and that for the wake. Equation 52 is the primary equation of interest, but some discussion about the relative magnitudes of the terms in the equations is necessary before the analysis can proceed. In order for towboats to be able to move barges, it is necessary that the initial values of U_{jet}/V_{river} be much greater than unity; for example, the initial depth-averaged jet velocity for a 2-D representation of the jets might be on the order of 2 m/s in a stationary coordinate system when V_{river} = 0.5 m/s.

However, for a 32-m wide tow with a towboat having a total thrust of 400 kN in a river 5 m deep, the initial value of V_d is on the order of 0.7 m/s assuming that one-quarter of the thrust is used to overcome the wave drag, that three-quarters is used to overcome the form and surface drag, and that a negligible amount is needed to change the elevation of the tow as a result of moving up or down the stream slope. With these assumptions, the flux of momentum deficit in the wake is equal to three-quarters of the propeller thrust in a stationary coordinate system. Thus, in the early part of the jet, the $(U_{jet}/V_{river})^2$ term is dominant in Equation 52 assuming $\alpha_{jet} < 1$. As the jet velocities decrease, the velocity defect in the wake also decreases. For small velocities (U_{jet} and V_d), the problem could be linearized since the second-order terms become small. Thus, since the cross product term ($U_{jet}V_d$) from Equation 52 is small for both short and large distances, it is reasonable to drop it from the equation. Integrating the remaining terms for large μ and using Equations 33 through 36, Equation 38, and Equation 42, the result is

$$\frac{d\theta}{dx} = -\frac{g\,Mann^2\,b_{jet}}{H^{4/3}}\left[2F_1\psi + F_2\psi^2\right] \tag{54}$$

Note that μ is not in this equation.

Initial conditions. The initial excess momentum flux (M_o) in the river is given by Equation 28 or Equation 30. It was assumed that the initial velocity distribution for tows traveling upstream is as shown in Figure 1b with the correct M_o (Equation 28). Then from Equation 41,

$$\psi_o = -\frac{1}{2F_{ratio}} + \sqrt{\frac{1}{4F_{ratio}^2} + \frac{\theta_o}{b_o F_2}} \tag{55}$$

The initial values of θ_o and b_o come respectively from Equation 38 with $M = M_o$ and Equation 29. The virtual origin from Equation 45 is then at

$$x_o = \frac{\theta_o}{2C_2F_1}\,FNLHS(\psi_o) \tag{56}$$

so that the distance from the virtual origin (x^* in Equation 45) is the downstream distance (x) from the original position of the jet plus x_o (but Equation 45 is not used in the program so x_o is not needed in the program).

Computational scheme. Equation 54 was integrated in the computer program with an explicit numerical technique. Letting subscript A indicate the cross section at the beginning of Δx in the integration and subscript B indicate the cross section at the end of Δx, then

$$\theta_B = \theta_A - \frac{g\ Mann^2\ b_{jet_A}}{H^{4/3}}\left[2F_1\psi_A + F_2\psi_A^2\right]\Delta x \tag{57}$$

From Equation 43,

$$b_{jet_B} = b_{jet_A} + C_2\frac{\psi_A}{\psi_A + 1}\Delta x \tag{58}$$

and from Equation 41,

$$\psi_B = -\frac{1}{2F_{ratio}} + \sqrt{\frac{1}{4F_{ratio}^2} + \frac{\theta_B}{b_B F_2}} \tag{59}$$

U_{maxB} can be obtained from Equation 42 and U_{jet} from Equation 33 and Equation 34.

Most of the test cases were run with $\Delta x = 1$ m. A couple of cases with $\Delta x = 5$ m gave essentially the same results as $\Delta x = 1$ m. It is recommended that a Δx of 1 m be used unless the validity of using a larger value is confirmed by comparative runs with different Δx values for the river of interest. The value of Δx is not used for tows traveling downstream.

End of jet region. In the computer program, there are three conditions that can indicate an end to the jet region for tows traveling upstream:

a. The excess momentum may become fully mixed across the channel width. If the absolute value of the difference between $(U_{jet})_{y=0}$ and $(U_{jet})_{y=B}$ is less than 0.001 m/s, then the jet calculations are stopped. If the momentum is fully mixed across the channel width, there is no need for subsequent ambient mixing calculations since the larvae would also be fully mixed across the width of the river. While this condition might occur for a narrow river, it did not occur in any of the test cases that were run.

b. The jet velocities may get so small that the jet is effectively dissipated. At each step of the calculations (text entitled "Computational scheme"), a check is made to determine if $U_{maxB} \leq V_{rtrans}V_{river}$ where V_{rtrans} is an input parameter to specify the ratio (V_r) of maximum jet velocity to river velocity at the transition (trans) from jet to ambient mixing. If $U_{maxB} \leq V_{rtrans}V_{river}$, the jet calculations are stopped.

c. The second tow may reach the jet before either of the above criteria is satisfied. In this case, there is no need for ambient mixing calculations. Using the plug flow assumption mentioned in Chapter 2, "General

Concepts," the time required for the jet from a towboat moving upstream (subscript US) to move through Δx is

$$\Delta t_{jetUS} = \frac{\Delta x}{V_{river} + 0.5U_{max}} \tag{60}$$

if it is assumed that the average velocity across the width of the jet is half of U_{max}. As Equation 57 is being integrated numerically, Δt_{jetUS} values for each Δx are summed to give the total jet travel time (t_{jetUS}) for x_B at the end of each Δx step. The distance that the second tow travels during t_{jetUS} is $t_{jetUS}(V_b - V_{river})$ where V_b is the absolute value of the speed of the tow relative to the water. Thus, if

$$x_B \geq Dist_b - t_{jetUS}\,(V_b - V_{river}) \tag{61}$$

where x_B is the distance to the end of a Δx step in the integration for the jet region and $Dist_b$ is the distance between the tows, then the second tow will reach the jet before the end of the jet-mixing region is reached. Equation 57 constitutes the third criterion for stopping the jet calculations.

An implication of item *c* above is that the flow distance available for transverse mixing of the water that has gone through the propellers of the first towboat can be much less than the distance between the tows. If a river has a flow velocity of 0.4 m/s and a tow is moving upstream at a speed of 3 m/s relative to the water, then in a given time interval, the river flows only 15 percent as far as the tow travels. If the tow is moving downstream, then the river flows only 12 percent as far as the tow travels.

Since the standard deviation of a distribution resulting from a diffusion process is proportional to the square root of the diffusion coefficient, Equation 19 and Equation 37 give the standard deviation (σ_c) of the concentration distribution at the end of the jet mixing region in a laterally unbounded flow as

$$\sigma_c = 0.765\lambda_j\, b_{jet} \tag{62}$$

where b_{jet} is calculated from Equation 58. Using $\lambda_j = 1.35$ (text entitled "Analogy between mass and momentum transport"), σ_c is calculated from Equation 62 and this value is then used in Equation 5 to calculate the concentration distribution at the center of each Δy strip the end of the jet mixing region. The concentration over the width of each Δy is assumed to be uniform and equal to the concentration at the center of that Δy. If this distribution extends outside the channel width, the parts outside the channel are reflected back into the channel, as is done in the method of images.

Tows Traveling Downstream

Model for jets in unbounded counter flow

For tows traveling downstream, the jets from the propellers of the towboats are traveling upstream against the river flow (Figure 2). Thus, at some distance upstream (x_{jetDS}), a stagnation point exists. The flow of the water that originally went through the propellers is reversed, and this water flows back downstream around the region where the water that has more recently gone through the propellers is flowing upstream.

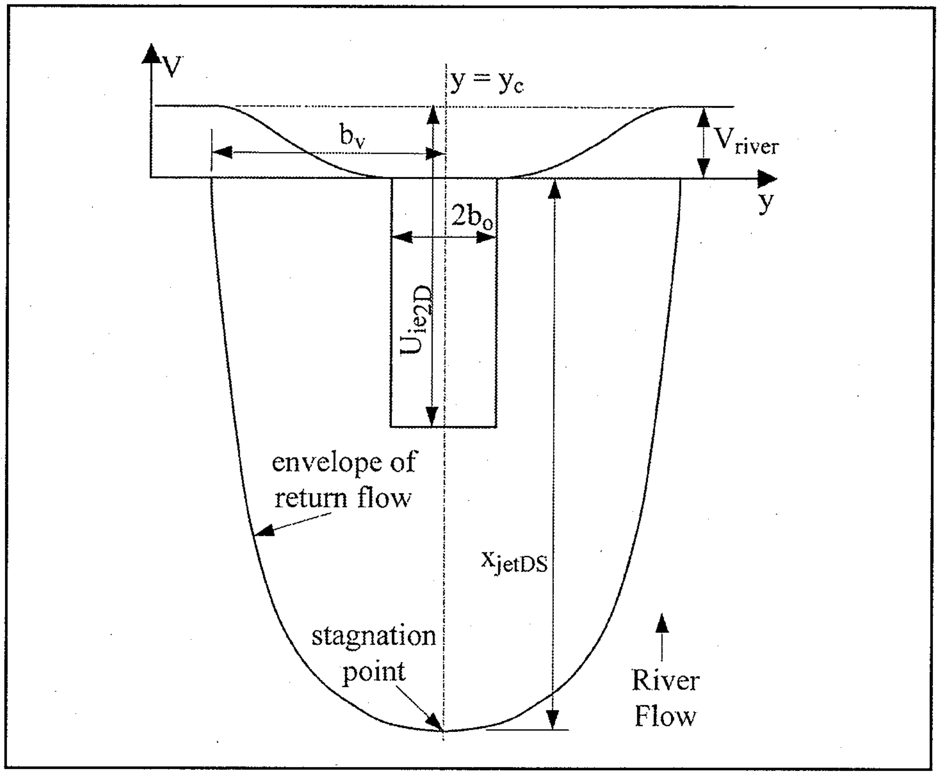

Figure 2. Envelop for counter-flowing jets (no scale)

Dimensional analysis for large ψ_{oDS}, where $\psi_{oDS} = U_{ie2D}/V_{river} - 1$, shows that any linear dimension for 2-D jets in counter flows is proportional to $\psi_{oDS}^2 b_o$, where b_o is the initial half width of the jet. Experimental results for $\psi_{oDS}^2 > 5$ or $\psi_{oDS} > 2.2$ for 2-D jets give (Balachandar et al. 1992)

$$x_{jet_{DS}} = 3.4 b_o \psi_{oDS}^2 \qquad (63)$$

and

$$b_v = 3.0\psi_{oDS}^2 b_o \tag{64}$$

The measurements of Balachandar et al. (1992) were for wall jets, but the authors demonstrated by comparison with the calculations of Hopkins and Robertson (1967) that the results are essentially the same as for free jets.

Equation 64 is for a stationary jet. For towboats, the source of the jet will have moved downstream by the time that the water from the jet comes back to the cross section where the jet was generated. To account for the fact that the return propeller jet does not need to flow around the original jet, it was assumed in the computer program that the width of the velocity distribution would be b_o less than given by Equation 64, so that

$$b_v = \left(3.0\psi_{oDS}^2 - 1\right) b_o \tag{65}$$

Application to tows

General considerations. As was done for tows traveling upstream, the analysis for tows traveling downstream is based on an assumption that jets from the propellers of the towboats rapidly become fully mixed over the flow depth so that it is reasonable to use a 2-D analysis. Also, since the jets for towboats traveling downstream are directed opposite to the river flow, these jets will not persist as long as the jets for tows traveling upstream. Thus, the effects of bed friction on the propeller jets for towboatss traveling downstream are neglected. The fact that Balachandar et al. (1992) found similar results for free jets and wall jets helps to support this assumption.

End of jet region. In the computer program, it is assumed that the average velocity with which the water travels between the propeller and the stagnation point (Figure 2) for tows traveling downstream is $(U_{ie2D} - V_{river})/2$, since the velocity decreases from $U_{ie2D} - V_{river}$ at the propellers to zero at the stagnation point. It is also assumed that the average velocity in the return flow back from the stagnation point is $V_{river}/2$, since the return flow velocity is V_{river} at the outer edge of the return flow envelope and zero where the return flow meets the upstream jet flow (Sekundov 1969). Thus, the time (t_{jet2DS}) for the water to travel from the propellers to the stagnation point and back to the cross section where the jet originated is

$$t_{jet_{DS}} = \frac{x_{jet_{DS}}}{(U_{ie_{2D}} - V_{river})/2} + \frac{x_{jet_{DS}}}{V_{river}/2} \tag{66}$$

In the computer program, there are three conditions that can indicate an end of the jet region for tows traveling downstream:

a. When the return flow reaches the cross section where the jet originated, it is assumed that the jet flow has ceased and that ambient diffusion has begun. The flow distance in which ambient diffusion occurs is called x_{diffDS} and the diffusion time is $t_{diffDS} = x_{diffDS}/V_{river}$. The distance that the second tow travels during the time that the jet is in the jet flow region is $t_{jetDS}\{V_b + V_{river}\}$, while the distance that it travels during the diffusion time is $t_{diffDS}\{V_b + V_{river}\}$. The second tow reaches the water from the jet of the first towboat when the second tow has traveled the distance between the tows, plus the diffusion distance, i.e., when $t_{jetDS}\{V_b + V_{river}\} + t_{diffDS}\{V_b + V_{river}\} = Dist_b + x_{diffDS}$. The value of x_{diffDS} is determined by solving this equation, which gives

$$x_{diffDS} = \frac{V_{river}}{V_b}\left(Dist_b - t_{jetDS}\left\{V_b + V_{river}\right\}\right) \tag{67}$$

The ambient diffusion calculations are then started with a concentration distribution which is assumed to be Gaussian (if there are no influences of the boundaries) and to have a standard deviation (σ_c) given by

$$\sigma_{co} = \frac{\lambda_{DS} b_v}{3} \tag{68}$$

where b_v comes from Equation 65 and the divisor of 3 comes from the assumption that the half width of a Gaussian distribution is 3σ. As discussed in text entitled "Analogy between mass and momentum transport," the width (b_c) of a concentration distribution will be greater than the width (b_v) of a velocity distribution. However, the ratio of b_c to b_v for the jets in counter flow will probably be less than the value of 1.35 mentioned previously for tows traveling upstream, since the width (b_v) comes partly from jet behavior and partly from the spreading which takes place in the return flow where $\lambda \approx 1.13$. Thus, it was assumed that $\lambda_{DS} = (1.35 + 1.13)/2 = 1.24$ (discussed previously).

b. If x_{diffDS} is negative but $|x_{diffDS}| < x_{jetDS}$, then the second tow reaches the water from the propellers of the first tow at a distance x_{return} downstream of the stagnation point, i.e., after that water has reached the stagnation point, but while it is in the return flow region. The time for the water from the propeller jets to reach this cross section is ($x_{jetDS}/0.5\{U_{ie2D} - V_{river}\} + x_{return}/0.5V_{river}$). The time for the second tow to reach this cross section is $(Dist_b - x_{jet_{DS}} + x_{return})/(V_b + V_{river})$. Equating these two times and solving for x_{return}, the result is

$$x_{return} = \frac{Dist_b - \left(1 + \frac{V_{river} + V_b}{(U_{ie_{2D}} - V_{river})/2}\right) x_{jet_{DS}}}{1 + 2\frac{V_b}{V_{river}}} \tag{69}$$

Assuming that the envelope of the return flow (Figure 2) is a parabola, then

$$\sigma_{co} = \frac{\lambda_{DS} b_v}{3} \sqrt{\frac{x_{return}}{x_{jet_{DS}}}} \tag{70}$$

c. If

$$\frac{DistBarges - x_{jet_{DS}}}{V_b + V_{river}} < \frac{x_{jet_{DS}}}{(U_{ie_{2D}} - V_{river})/2} \tag{71}$$

then the second tow will reach the jet from the propellers of the first towboat before that jet reaches the stagnation point. In the program, it is assumed that this condition will not occur. If the inputs give a situation that satisfies Equation 71, then an error message is printed. No information could be found in the literature on the velocity or concentration distribution in the region between the origin of the jet and the stagnation point. Also, tows which are traveling at 3 m/s and which are 5 min apart would be 900 m apart, which is approximately equal to the largest $x_{jet_{DS}}$ in the test cases that were run.

If any part of the concentration distribution at the end of the jet region based on Equation 68 or 70 is outside the channel width, that part is reflected back into the channel. If any of the reflected part falls outside the opposite side of the channel, then that part is reflected back into the channel, and so on.

3 Laboratory Experiments

Test Conditions

Laboratory experiments on propeller jets from towboats were conducted in the Coastal and Hydraulics Laboratory of the U.S. Army Engineer Research and Development Center, Vicksburg, MS, in a towing tank that also has through flow. The towing tank is 122 m long. The remaining numerical values for the laboratory measurements are given at prototype scale unless stated otherwise. In the central part of the tank longitudinally, a prismatic channel bed was installed with bed elevations (z_0) as given in Table 2. The bottom elevation at y = 520.5 m was interpolated to give a point with zero depth on the right-hand side of the channel. The water depth at the thalweg was 4.88 m, giving a cross-sectional area of 1,770 m^2. For the flow rate of 2,850 m^3/s, the cross-sectional average velocity was 1.61 m/s. In Table 2, H is the water depth and V is a depth-averaged velocity which was calculated by assuming that the velocity is proportional to $H^{2/3}$, as would be the case if Manning's equation applied locally with Mann and the friction slope being the same at all points. The calculated velocities are also shown in Figure 3.

Measurements

Velocities were measured behind a tow consisting of barges with a total width of 32.0 m and a length of 258.5 m. There was a towboat with two operating propellers. The center line of the barges and towboat was at y = 298.7 m. For the velocity measurements, acoustic doppler velocity (ADV) meters were positioned in the cross section and the towing carriage and barges were stationary at various distances upstream from the ADVs. The measured velocities are given in Table 3 where x is the distance downstream of the propellers and y is the distance from the left bank. The shaded column gives the velocities on a line through the center of the towboat. Measurements were made at four depths. The underlined values were interpolated to fill in missing values. The italicized, underlined value for 80-percent depth is a value that was corrected (changed) to be consistent with the surrounding values. There are two sets of background velocities that were measured with the barges well downstream of the ADVs.

Table 2
Model Geometry and Calculated Velocities

y m	z_o m	H m	V m/s
0.0	11.15		
0.0	4.88	0.00	0.00
34.5	2.46	2.42	1.20
95.3	2.39	2.49	1.23
156.3	2.06	2.82	1.33
247.7	0.58	4.30	1.76
298.7	0.10	4.78	1.89
308.7	0.00	4.88	1.92
400.2	0.56	4.32	1.77
461.1	1.40	3.48	1.53
515.8	2.97	1.91	1.03
520.5	4.88	0.00	0.00
524.6	6.53		
524.6	11.15		

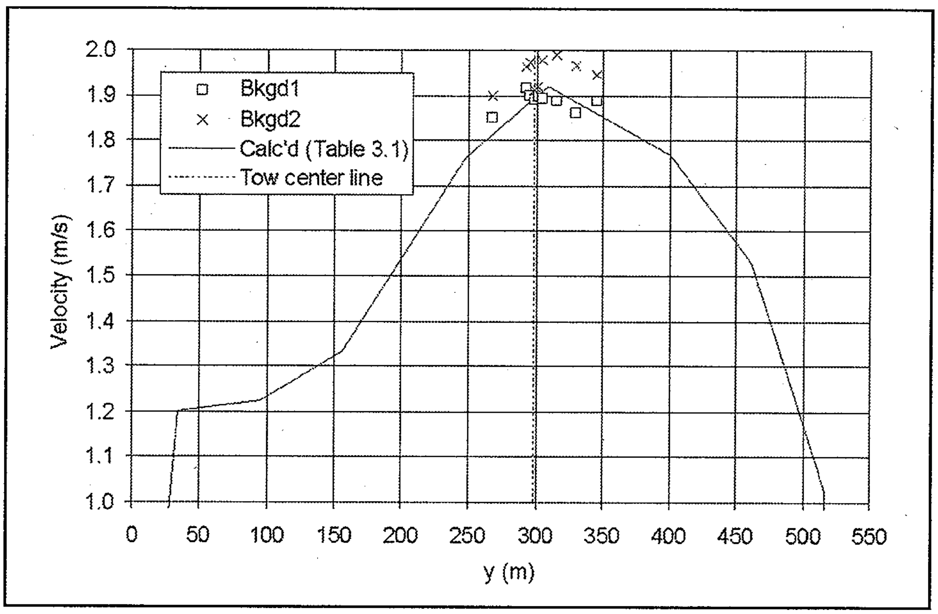

Figure 3. Velocities without towboat and barges

For x from 15 to 457.5 m, the ADVs were 25 m upstream of the downstream end of the false floor in the channel, and this is the location at which the first set of background velocities (Bkgd1) was measured. For x from 579.3 m to 868.9 m, the ADVs were 6.1 m upstream of the downstream end of the false floor. The second set of background velocities (Bkgd2) was obtained at this cross section.

Table 3
Measured Velocities in m/s

20 % depth x (m)	y (m) 267.4	292.7	295.7	298.7	301.7	304.7	314.7	330.0	345.2
15.0	2.124	2.636	3.778	3.375	4.260	1.943	1.801	2.186	2.222
30.0	2.105	2.444	3.117	3.764	3.523	2.204	1.854	2.182	2.217
45.0	2.048	2.514	3.330	3.913	3.463	2.326	1.963	2.142	2.185
75.0	2.104	2.581	3.090	3.488	3.173	2.467	2.178	2.131	2.177
122.5	2.090	2.612	2.873	3.299	3.011	2.498	2.222	2.136	2.173
182.5	2.127	2.592	2.780	2.971	2.943	2.558	2.256	2.174	2.187
260.0	2.162	2.582	2.669	2.858	2.775	2.555	2.283	2.182	2.153
350.0	2.242	2.559	2.596	2.679	2.682	2.529	2.308	2.185	2.180
457.5	2.261	2.469	2.552	2.650	2.616	2.506	2.275	2.225	2.176
Bkgd1	2.110	2.182	2.195	2.175	2.173	2.173	2.181	2.153	2.154
579.3	2.170	2.311	2.298	2.435	2.443	2.423	2.391	2.364	2.258
716.5	2.200	2.308	2.265	2.461	2.401	2.358	2.312	2.340	2.233
868.9	2.176	2.306	2.297	2.319	2.335	2.315	2.289	2.302	2.218
Bkgd2	2.173	2.195	2.215	2.024	2.241	2.225	2.236	2.190	2.167
40 % depth x (m)	**y (m) 267.4**	**292.7**	**295.7**	**298.7**	**301.7**	**304.7**	**314.7**	**330.0**	**345.2**
15.0	2.053	1.857	2.559	2.310	2.814	1.846	1.736	2.090	2.148
30.0	2.030	2.103	2.727	3.212	3.221	2.365	1.815	2.078	2.113
45.0	1.902	2.038	2.794	3.199	2.854	2.339	1.917	2.100	2.180
75.0	2.017	2.174	2.810	3.166	3.114	2.458	2.109	2.120	2.108
122.5	2.061	2.306	2.735	2.953	2.994	2.611	2.216	2.105	2.111
182.5	2.064	2.384	2.689	2.818	2.857	2.602	2.263	2.137	2.114
260.0	2.129	2.402	2.584	2.645	2.708	2.600	2.270	2.187	2.119
350.0	2.135	2.358	2.562	2.579	2.571	2.494	2.252	2.186	2.132
457.5	2.157	2.447	2.487	2.373	2.498	2.520	2.275	2.218	2.108
Bkgd1	1.998	2.077	2.076	2.058	2.075	2.084	2.069	1.978	2.049
579.3	2.130	2.190	2.303	2.376	2.361	2.356	2.196	2.238	2.123
716.5	1.988	1.973	2.156	2.163	2.134	2.163	2.132	2.124	2.079
868.9	2.086	2.213	2.160	2.254	2.237	2.228	2.192	2.133	2.074
Bkgd2	2.117	2.151	2.160	2.168	2.158	2.173	2.149	2.150	2.150
60 % depth x (m)	**y (m) 267.4**	**292.7**	**295.7**	**298.7**	**301.7**	**304.7**	**314.7**	**330.0**	**345.2**
15.0	1.988	1.693	1.836	2.217	2.738	1.767	1.730	2.057	2.184
30.0	1.955	1.957	2.195	2.968	2.982	1.904	1.815	2.059	2.125
45.0	1.951	1.984	2.359	3.083	2.837	1.954	1.882	2.068	2.112

(Continued)

Table 3 (Concluded)									
60 % depth					**y (m)**				
x (m)	**267.4**	**292.7**	**295.7**	**298.7**	**301.7**	**304.7**	**314.7**	**330.0**	**345.2**
75.0	2.003	2.159	2.534	3.111	2.776	2.145	2.059	2.089	2.129
122.5	2.025	2.332	2.560	2.960	2.715	2.242	2.234	2.097	2.114
182.5	2.014	2.410	2.521	2.770	2.715	2.411	2.286	2.141	2.128
260.0	2.079	2.444	2.463	2.650	2.715	2.421	2.293	2.173	2.127
350.0	2.125	2.421	2.467	2.529	2.517	2.429	2.272	2.165	2.131
457.5	2.132	2.422	2.338	2.190	2.493	2.389	2.257	2.211	2.112
Bkgd1	1.985	2.033	2.047	1.976	1.960	1.985	2.037	1.994	1.981
579.3	2.004	2.134	2.220	2.220	2.212	2.153	2.136	2.082	1.951
716.5	2.218	2.254	2.278	2.298	2.319	2.217	2.281	2.107	2.100
868.9	1.971	2.023	2.058	2.093	2.118	2.237	2.109	2.078	1.943
Bkgd2	1.943	2.068	2.086	2.060	2.040	2.070	2.173	2.072	2.041
80 % depth					**y (m)**				
x (m)	**267.4**	**292.7**	**295.7**	**298.7**	**301.7**	**304.7**	**314.7**	**330.0**	**345.2**
15.0	1.692	1.460	1.487	2.088	2.234	1.483	1.592	1.880	1.946
30.0	1.667	1.625	1.766	2.491	2.643	1.728	1.635	1.829	1.902
45.0	1.709	1.755	1.914	2.601	2.632	1.920	1.767	1.883	1.865
75.0	1.712	1.900	2.142	2.796	2.713	2.080	1.920	1.862	1.858
122.5	1.785	2.036	2.241	2.802	2.641	2.202	2.068	1.909	1.887
182.5	1.882	2.128	2.269	2.664	2.626	2.303	2.100	1.926	1.929
260.0	1.820	2.193	2.271	2.664	2.414	2.273	2.087	1.939	1.917
350.0	1.820	2.199	2.258	2.423	2.414	2.225	2.081	1.946	1.916
457.5	1.839	2.244	2.236	2.301	2.414	2.442	2.054	1.966	1.913
Bkgd1	1.802	1.882	1.782	1.846	1.877	1.831	1.768	1.805	1.866
579.3	1.874	2.095	2.030	2.205	2.160	2.082	1.936	2.004	1.935
716.5	1.873	2.148	2.052	2.105	2.071	2.071	1.941	1.976	1.968
868.9	1.868	2.035	2.066	1.986	2.032	1.986	1.927	1.974	1.960
Bkgd2	1.864	1.969	1.958	1.957	1.745	1.972	1.943	1.992	1.960

The four velocities along each vertical line were integrated to obtain depth-averaged velocities. For the integration, the velocity was assumed to be constant in the top 20 percent of the flow depth and equal to the value measured at 20-percent depth. The velocity was assumed to have a parabolic variation in the bottom 20 percent with a velocity of zero at the bed. For the integration, a trapezoidal variation of velocity was assumed between the measured values from 20-percent depth to 80-percent depth. The resulting depth-averaged velocities are given in Table 4 and Figure 4, which also shows the points at which the velocity measurements were made and the center line of the towboat and barges. The depth-averaged background velocities are shown in Figure 3. Based on the measured background velocities and the calculated velocities (Figure 3), the background velocity was assumed to be 1.89 m/s in the region of the flow where the tows were located.

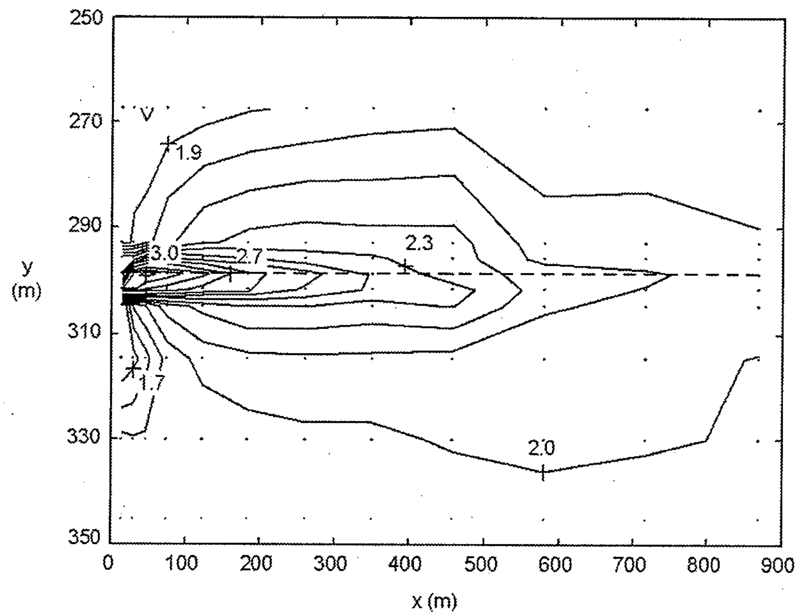

Figure 4. Contours of depth-averaged velocity in m/s

Table 4
Depth-Averaged Velocities in m/s

	y (m)								
x (m)	267.4	292.7	295.7	298.7	301.7	304.7	314.7	330.0	345.2
15.0	1.840	1.841	2.359	2.405	2.910	1.652	1.605	1.924	1.987
30.0	1.817	1.924	2.332	2.946	2.914	1.918	1.664	1.909	1.957
45.0	1.784	1.968	2.476	3.037	2.791	2.004	1.761	1.916	1.949
75.0	1.835	2.084	2.496	2.954	2.763	2.146	1.935	1.916	1.934
122.5	1.861	2.186	2.444	2.826	2.661	2.234	2.039	1.927	1.937
182.5	1.893	2.233	2.405	2.631	2.610	2.307	2.077	1.957	1.955
260.0	1.915	2.256	2.340	2.538	2.480	2.301	2.084	1.979	1.942
350.0	1.949	2.237	2.311	2.391	2.385	2.262	2.083	1.980	1.954
457.5	1.965	2.238	2.252	2.245	2.346	2.303	2.068	2.012	1.943
Bkgd1	1.850	1.916	1.899	1.890	1.897	1.893	1.888	1.861	1.888
579.3	1.915	2.047	2.068	2.164	2.152	2.115	2.035	2.041	1.944
716.5	1.938	2.039	2.045	2.122	2.094	2.067	2.029	2.009	1.965
868.9	1.900	2.014	2.015	2.029	2.046	2.051	1.996	1.993	1.926
Bkgd2	1.899	1.962	1.971	1.909	1.919	1.976	1.989	1.966	1.946

To use the computer program to calculate the velocities from the propeller jets, it was necessary to know the thrust or momentum flux from the jets. Using the first background velocities for 15 m ≤ x ≤ 457.5 m and the second background velocities for 579.3 m ≤ x ≤ 868.9 m, the measured excess momentum flux was calculated from

$$M = \int_{277.4\text{ m}}^{355.2\text{ m}} \int_{z_o}^{4.88\text{ m}} \rho u\left(u - u_{bkgd}\right)\, dz\, dy \tag{72}$$

where

u = measured velocity at each point

z = vertical coordinate.

In the vertical direction, the variation of the integrand was assumed to be the same as previously stated for the velocities. The resulting values of the excess momentum are shown in Table 5 and Figure 5. Because the values of the excess momentum for the last three cross sections apparently differ from the trend for the more upstream cross sections, the excess momentum for the last three cross sections was recalculated using the first background velocity reading. The resulting values are shown in Table 5 and Figure 5.

Table 5
Excess Momentum from Measured Velocities and from Computer Model

x m	Background	M kN	Background	M kN	Calculated M kN
15.0	1	76			223
30.0	1	107			220
45.0	1	130			218
75.0	1	172			216
122.5	1	197			213
182.5	1	211			209
260.0	1	207			204
350.0	1	192			198
457.5	1	190			191
579.3	2	73	1	118	183
716.5	2	63	1	108	175
868.9	2	37	1	81	165

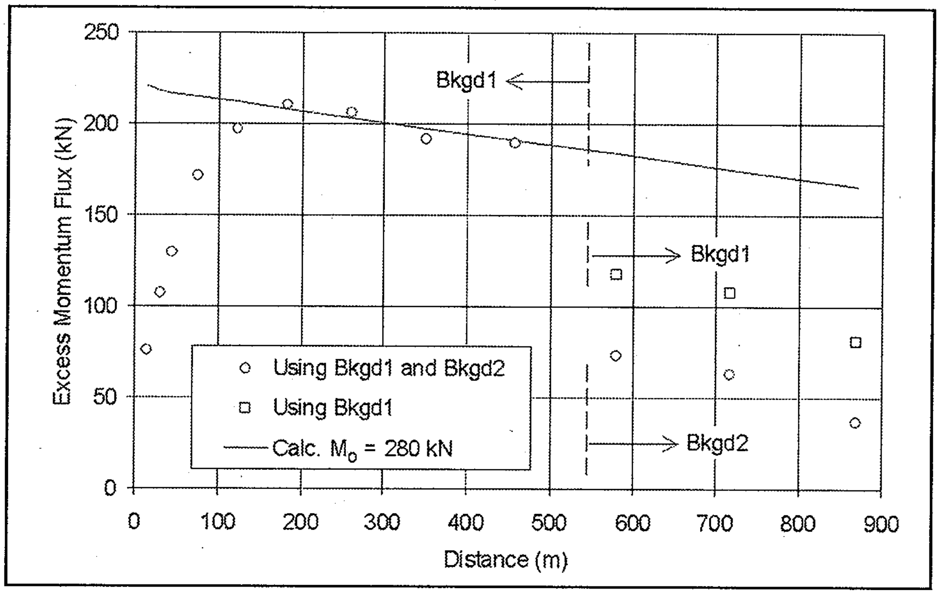

Figure 5. Excess momentum from measured velocities and from computer model

Calculations

The tow created a wake or a momentum deficit. There is possible evidence of this wake in the measured velocities on the port side of the tow (Figure 4) in the region where the measured velocities were smaller than the background velocity. However, if the region of lower velocities is viewed as being a wake, then there is also a problem in that the wake indicated by the velocity contours is wider than it should be for the short distances behind the tows. Nevertheless, this apparent width can probably be attributed to the fact that the contours were obtained by interpolation between measurements at y = 314.7 m and y = 330 m. The reason that there is no wake apparent on the starboard side is probably that there were no velocity measurements from y = 267.4 m to y = 292.7 m.

As a result of the wake of the tows, the propeller jets were created inside the wake. For comparison of calculated and measured velocity distributions, an approximation was used for the velocity defect associated with the wake. The velocity defect resulting from the wake is not included in the computer program for determining the distribution of water and larvae that go through the propellers. The rationale for the different approaches is as follows:

a. The model for larvae is based on an analogy between mass and momentum transport.

b. In momentum transport, a jet is a source of momentum while a wake is a sink of momentum since it gives a momentum deficit.

c. Therefore, including the wake in the larvae calculations would be equivalent to having a sink for the larvae (i.e., removing part of the larvae that went through the propeller). This condition is the essence of the reason that the wake was not used in the larvae calculations.

d. Nevertheless, both the jet and the wake were needed for comparison with lab measurements, since the measurements were of velocities (momentum), not concentrations.

Velocity defect resulting from drag on barges

The drag force on the model barges was measured to be 10.9 N. (All numerical values in this section are at model scale unless stated differently.) Since the momentum defect in a wake is equal to the sum of the surface drag and form drag (not the wave drag), the first step in calculating the velocity defect in the wake was to estimate what part of the total drag was surface drag (F_s) and form drag (F_f) so that the wave drag could be eliminated. The surface and form drag forces were estimated separately.

The surface drag was estimated from the drag on smooth flat plates. For length Reynolds numbers (Re_L) less than 10^7, the shear coefficient (C_f) for a smooth plate with no laminar boundary layer near the front part of the plate is (Roberson and Crowe 1997)

$$C_s = \frac{0.074}{(Re_L)^{1/5}} \tag{73}$$

The surface drag force is

$$F_s = C_s A_s \frac{\rho V^2}{2} \tag{74}$$

where

A_s = surface area

ρ = water density = 1,000 kg/m^3

Using a model length ratio (L_r) of 1/25 for a Froude model, the model values for the drag calculation are $V_{river} = (1.89\text{ m/s})\,L_r^{1/2} = 0.38$ m/s, L = total length of barges = (259 m)L_r = 10.3 m, and ν (kinematic viscosity) = 10^{-6} m^2/s. Assuming that the velocity outside the boundary layer on the sides of the barges is equal to V_{river}, then $Re_L = V_{river}L/\nu = 3.9 \times 10^6$, giving $C_s = 0.00355$. A_s for the sides is $2hL = 2.26$ m^2 where h = draft = (2.74 m)L_r = 0.11 m. Equation 74 gives $F_s = 0.58$ N for the sides.

To estimate the flow velocity under the barges, it was assumed that the channel bed and the bottom of the barges were hydraulically smooth. Even it were assumed that the channel bed had the same roughness as new steel pipe ($k = 4.6 \times 10^{-5}$ m (Roberson and Crowe 1997)), the relative roughness would be $k/4R_h = 4.6 \times 10^{-5}/(4 \times 0.191) = 6.0 \times 10^{-5}$. For the channel Reynolds number of $4R_hV/\nu = 4 \times 0.191 \times 0.38/10^{-6} = 2.9 \times 10^5$, the friction factor for a relative roughness of 6.0×10^{-5} is only about 3 percent larger than for a smooth surface. Thus, the Darcy-Weisbach friction factor for the channel bed was taken as 0.015 for a smooth surface giving a slope of the energy grade line (S_f) for the channel flow as 1.44×10^{-4}. Also, if the surface roughness of the barges were the same as new steel pipe, the length relative roughness would be $L/k = 2.2 \times 10^5$. The local shear coefficients for boundary layers on plates for $Re_x \leq 2 \times 10^7$ and $L/k = 2.2 \times 10^5$ are the same as for smooth plates (Schlichting 1960 (Fig. 21.11)). Since the length Reynolds number for flow under the barge was much less than 2×10^7, as shown below, the roughness of the model barge surfaces did not affect the surface drag. It is further assumed that the slope of the energy grade line for flow under the barges is the same as for the flow outside the barges, that the flow depth under the barges is $(4.78 \text{ m} - 2.74 \text{ m})L_r = 0.082$ m using the prototype water depth of 4.78 m at the center line of the barges, and that the flow under the barges was 2-D so that the hydraulic radius under the barges was $R_h = 0.082/2 = 0.041$ m. The power consumed in flowing against the friction under the barges is F_sV, where F_s is the surface drag on the bottom of the barges and on the channel bed and V is the velocity of flow under the barges. The head loss due to flow under the barges is $F_sV/(\gamma Q)$, where γ is the specific weight of water and Q is the volumetric flow rate under the barges. The slope of the energy grade line was then $F_sV/(\gamma QL)$ or $F_s/(\gamma\{H\text{-}h\}B_bL)$ where B_b = width of barges = $(32 \text{ m})L_r = 1.28$ m. Equating this expression to the friction slope for the channel flow (1.44×10^{-4}), F_s was obtained as 1.51 N. Assuming that this drag was equally distributed between the channel bed and the bottom of the barges, then F_s on the bottom of the barges is 0.75 N. If it was assumed that the boundary layer thickness under the barges was small enough that the boundary layer developed essentially as it would for infinitely deep flow, then Equations 73 and 74 could be used to solve for the average flow velocity under the barges. The result was 0.17 m/s, which is slightly less than half the value away from the barges and which assumes that the cross-sectional area of the barges caused negligible blockage in the flow cross section. This velocity gave a length Reynolds number of 1.8×10^6, which is much less than the limit of 2×10^7 given above for assuming that the barge surface was hydraulically smooth. The total surface drag from the sides and the bottom of the barges was 1.33 N.

The form drag (F_f) was calculated from

$$F_f = C_f A_p \frac{\rho V_{river}^2}{2} \quad (75)$$

where

C_f = form drag coefficient

A_p = frontal area of barges = hB_b = 0.141 m^2

C_f could be determined only approximately. First, C_f was estimated for a grate of parallel bars having curved leading edges and being perpendicular to the flow. This calculation is equivalent to assuming that the barges stretch across the full width of the channel and looking at the form drag associated with flow under the barges. Thus, the velocity under the barges was taken as 0.17 m/s, as calculated above. Using continuity, the equivalent approach velocity would then be $0.17[(4.78\text{-}2.74)L_r]/[4.78L_r] = 0.073$ m/s. The drag coefficient for this approximation of the barges would then be 3.3 (Idelchik 1986) giving a form drag force 1.24 N for the barges. To estimate the part of the form drag resulting from the flow around the sides of the barges, the flow was assumed to be 2-D, just as if the barges extended from the water surface to the channel bed. For this assumption, C_f is on the order of 1.0 (Idelchik 1986). However, flow under the barge reduces this C_f. This trend is evident from the fact that C_f is 2.0 for a 2-D square rod but 1.1 for three-dimensional (3-D) flow around a cube (Roberson and Crowe 1997). Similarly, C_f is 1.2 for a 2-D semicircular shell with the curved side facing into the flow and 0.39 for a hemispherical shell. Thus, C_f was assumed to be 0.5 rather than 1.0 for the form drag associated with flow around the sides of the barges. This part of the drag force was then 5.09 N using the model velocity of 0.38 m/s.

It is recognized that these various components of the drag are not independent and that some of the assumptions may be questionable. Nevertheless, the surface plus form drag was assumed to be the sum of the four parts calculated above (7.7 N). Comparison with the measured drag force of 10.9 N indicates that the wave drag was apparently 3.2 N. Since the force ratio for a Froude model is equal to L_r^3, the prototype drag corresponding to the calculated surface plus form drag was 120,000 N.

The wake was assumed to be two-dimensional as discussed in Chapter 2, paragraph entitled "Vertical uniformity." The momentum deficit in the upstream part of a wake is equal to the surface plus form drag force on the barges so that the initial momentum deficit (M_{do}) was 120,000 N for the prototype.

In terms of the velocities, the momentum deficit per unit area at any point in the wake is $\rho(V_{river} - V_d)V_d$, where V_d is the velocity defect. The initial momentum deficit can be distributed in a width equal to the width of the barges plus the momentum thickness associated with the surface drag on each side of the barges. This momentum thickness (θ_s) on each side at model scale was $F_s/(2h\rho V_r^2) = 0.58/[2(0.11)(1000)(0.38^2)] = 0.018$ m. Because of the small value of θ_s and because of the approximate nature of the calculations, θ_s was neglected in distributing the initial momentum deficit. Assuming the initial velocity defect (V_{do}) to be uniform in the wake, then

$$M_{do} = \rho B_b H(V_{river} - V_{do})V_{do} \tag{76}$$

giving

$$V_{d_o} = \frac{V_{river} \pm \sqrt{V_{river}^2 - \frac{4M_{d_o}}{\rho B_b H}}}{2} = \frac{0.38 \pm \sqrt{0.38^2 - \frac{4(7.7)}{1000(1.28)(0.19)}}}{2} = \begin{cases} 0.257 \text{ m/s} \\ 0.123 \text{ m/s} \end{cases} \tag{77}$$

for the model. Writing M_{do} as $\rho B_b(V_o)(V_{river} - V_o)$, where V_o = the initial flow velocity = $V_{river} - V_{do}$ in the wake, and solving for V_o shows that one of the solutions in Equation 77 is V_o and the other one is V_{do}. The selection of which root of the equation to use for V_{do} was based on the fact that solving for V_{do} neglecting V_{do}^2 as being a small term (as is definitely the case downstream of the barges) gives $V_{do} = 0.045$ m/s. Thus, 0.123 m/s from Equation 77 was selected as the value for V_{do}, meaning that the average velocity in the wake immediately behind the barges was 0.123 m/s less than the flow beside the barges or V_{do}/V_{river} was 0.32. The prototype velocity corresponding to V_o of 0.257 m/s was 1.29 m/s. Figure 6 shows this value in comparison to velocities measured in the wake of the barges but away from the propeller jets. This figure indicates that the calculated value of V_o was apparently too small, presumably because of the many assumptions in the effort to estimate the surface and form drag forces. Based on extrapolating the measured velocities in Figure 6 to a distance of zero, V_o for the prototype was assumed to be 1.65 m/s, giving $V_{do} = 0.24$ m/s for the prototype and $M_{do} = 60{,}600$ N from Equation 76 with $V_{river} - V_{do} = V_o$.

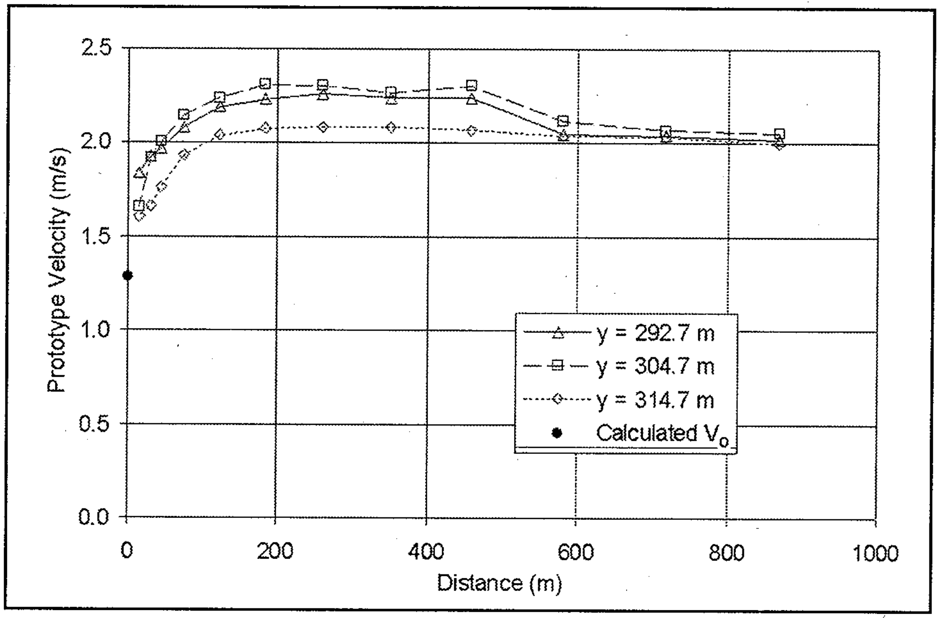

Figure 6. Measured velocities for estimating initial velocity in wake

Using the analogy between momentum and mass transport, this momentum deficit is similar to the situation for which Equation 8 gives the concentration distribution. Replacing the mass flux per unit area (CV_{river}) by the flux of momentum deficit per unit area [$\rho(V_{river} - V_d)V_d$] or C by $\rho(V_{river} - V_d)V_d/V_{river}$ and $\dot{m}$ by M_{do}/H in Equation 8, then

$$V_d = \frac{V_{river}}{2}\left(1-\sqrt{1-2F}\right) \tag{78}$$

where

$$F = \frac{M_{d_o}}{\rho V_{river}^2 B_b H}\left\{\mathrm{erf}\left[\frac{y-y_1}{2}\sqrt{\frac{V_{river}}{\varepsilon_y\, x}}\right]-\mathrm{erf}\left[\frac{y-y_2}{2}\sqrt{\frac{V_{river}}{\varepsilon_y\, x}}\right]\right\} \tag{79}$$

$y_1 = y_c - B_b/2$, $y_2 = y_c + B_b/2$, y_c = y at the center line of the barges, and ε_y = lateral eddy viscosity. No images were used for comparison of the calculations with the laboratory measurements, since the measurements and the use of dye for visualization of the mixing behind the barges in the laboratory indicated that neither the propeller jets nor the wake got near the sides of the channel.

The eddy viscosity for the wake was estimated from 2-D wakes behind circular cylinders. Using the notation for barges, Schlichting's (1960) eddy viscosity can be written as

$$\varepsilon_y = 0.0444 \frac{M_{d_o}}{\rho V_{river} H} \tag{80}$$

Using

$M_{do} = 60{,}600$ N

$V_{river} = 1.89$ m/s

$H = 4.78$ m

then $\varepsilon_y = 0.30\ m^2/s$ for the prototype.

Momentum flux from jets

The jet model for tows traveling upstream (Chapter 2), the velocity defect for the wake (Equations 78 and 79), and a friction factor of 0.015 (Chapter 3, paragraph entitled "Velocity defect resulting from drag on barges") were used to calculate velocities for comparison with the laboratory measurements. If the prototype had a surface similar to the model, the friction factor would be smaller than for the model because of the higher Reynolds number in the prototype and the fact that the model surface was hydraulically smooth, or nearly so. The model friction factor was used in these calculations, since the purpose was to compare calculated values with values measured in the model, not to make calculations for a prototype. The depth was assumed to be constant and equal to the depth at the center line of the barges (4.78 m). The undisturbed velocity was assumed to be 1.89 m/s. Different values of the initial thrust or momentum flux (M_o) were tried until there was reasonable agreement with the excess momentum obtained from integrating the measured velocities (Table 5). As a result of the boundary friction (Chapter 3), the momentum decreases with increasing x.

Given the amount and type of variation in the excess momentum from the measured velocities (Figure 5), it was difficult to decide what constituted good agreement between the measurements and the calculations. As is indicated by Figure 5, emphasis was placed on the measurements for $182.5\ m \leq x \leq 457.3$ m. The last three cross sections were discounted because of the variation from the trend of the upstream points. The first five points were discounted because they indicated an increasing momentum flux, which is not possible without an additional downstream force being applied to the water downstream of the jets. Also, the jets caused the measured velocities to be highly nonuniform in the vertical direction for many of the measurement points in the first five cross sections. With the highly variable velocities, there apparently were not enough measurement points to provide for a reliable numerical integration to obtain the momentum flux. Based on the comparison between the calculated and empirical fluxes of excess momentum shown in Figure 5, the initial value of the momentum flux from the jets was taken to be 280 kN.

Comparison of measured and calculated velocities

Superposition of the flux of excess momentum per unit area for the propeller jets (Equation 33 and related expressions) and the flux of momentum deficit per unit area for the wake of the tow (Equation 78) gave the change in depth-averaged velocity (ΔV) from the background value as

$$\Delta V = \sqrt{\left(V_{river} + U_{jet}\right)U_{jet} - \left(V_{river} - V_d\right)V_d} \tag{81}$$

The velocity deficit in the wake was included in the calculations for only the model because the calculations were to be compared with measured velocities (paragraph entitled "Calculations"). Since the interest for the prototype calculations is in the distributions of larvae that have been through the propellers, the prototype calculations consider only the distribution of momentum for the propeller jets (Chapter 2, paragraph entitled "Effects of boundary friction"). Since the measured velocities are given at prototype scale, the numerical values in this section for the calculations to be compared with the measurements are also given at prototype scale.

The calculated and measured velocities are compared in Figure 7. The fact that the depth-averaged velocity is frequently near to the minimum velocity may seem strange. However, the velocities in the lower 20 percent of the depth (for which there are no measurements) are decreasing toward zero. Thus, in viewing the figures, it must be remembered that the average velocity is not the average of the plotted points; rather it is the average of the plotted points plus a point at zero velocity that is not plotted. The lack of uniformity of the jet-induced velocities in the vertical direction for the first few cross sections is apparent in the figure. It is felt that the comparison of measurements and calculations in Figures 5 and 7 constitutes adequate verification of the model being used for the jet calculations for barges traveling upstream. The calculations for the model did not pass the transition point for going from jet mixing to mixing associated with the ambient flow.

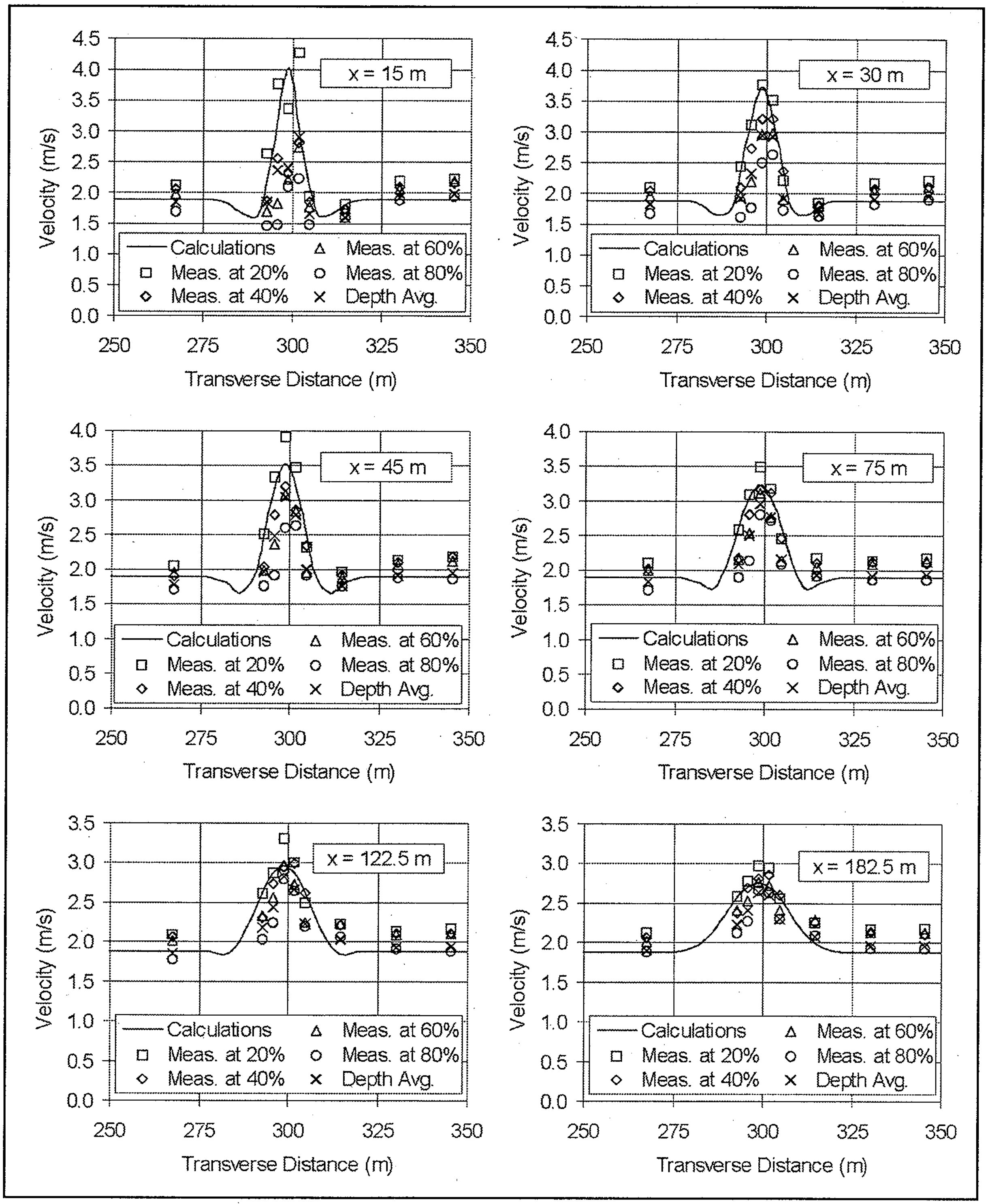

Figure 7. Measured and calculated depth-averaged velocities (Continued)

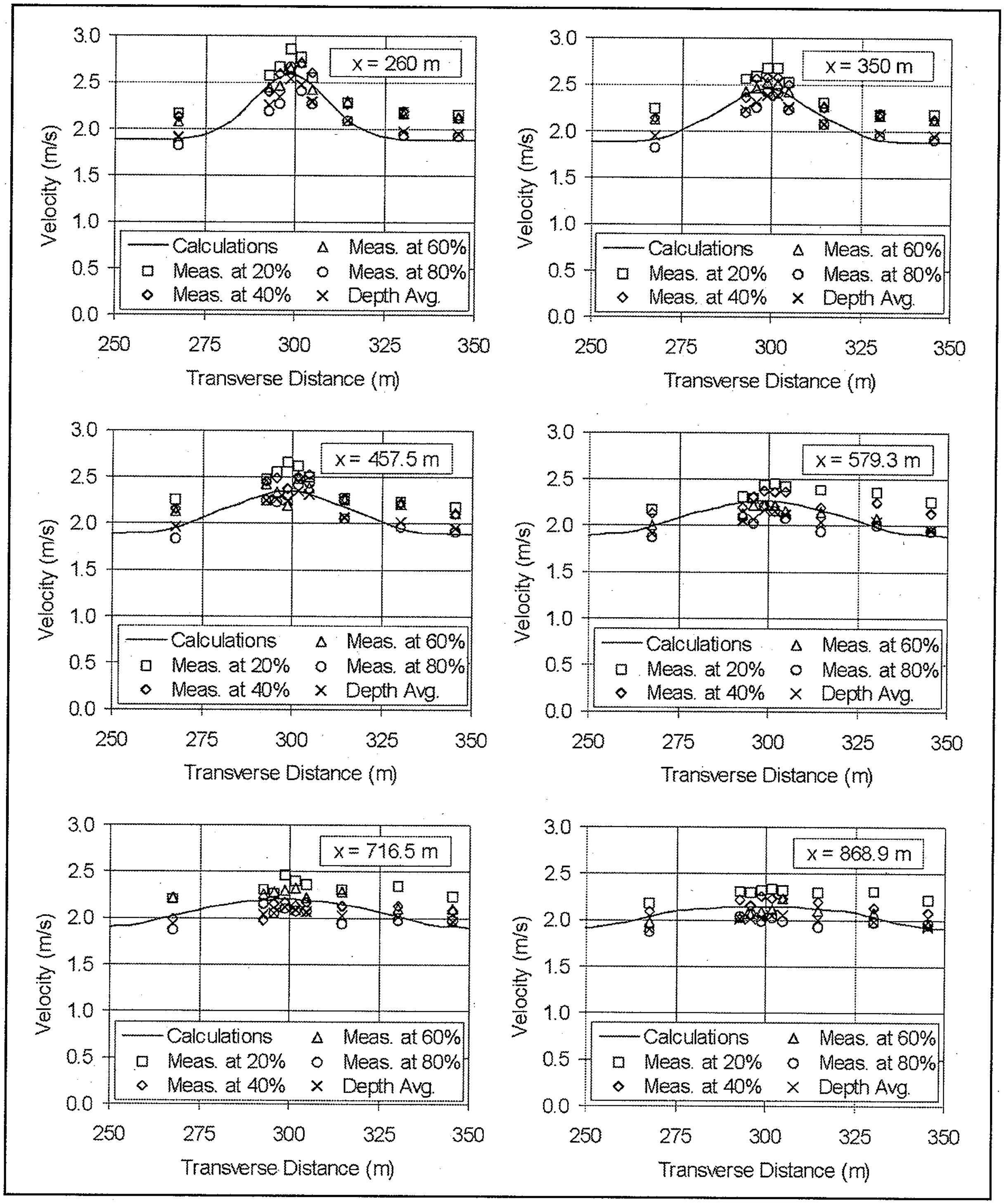

Figure 7. (Concluded)

4 Computer Model

Program

A listing of the computer program is in Appendix A. The program is written in QuickBasic. Even though the program is written to make calculations for two tows traveling in the same direction, it can be also used for tows traveling in opposite directions. The direction of travel of the second tow is used only to determine when and where the second tow will encounter the water from the propellers of the first towboat. Thus, if a second tow traveling in the opposite direction from the first tow reaches the water from the first propellers at the same time as the second towboat in the program, the makeup of the intake water will be the same as calculated by the program.

The majority of the information used by the program to calculate the distribution of larvae that have been through the propellers of the first towboat has been described in Chapters 1 and 2. The major parts of the program are as follows:

a. The width (B) of the river is subdivided into Ny vertical strips of width $\Delta y = B/Ny$. The center of the width of each strip is at y_o, which is also called y_c in some parts of the program. The program does calculations of the makeup of the intake water for a second towboat with both the first tow and the second tow at the center of each vertical strip into which the river width is divided. For the calculations, NDist values can be input for the distances between the tows ($Dist_b$).

b. For tows traveling upstream:

(1) The jet calculations are made according to Chapter 2, paragraph entitled "Tows Traveling Upstream." As the jet calculations are being made, the conditions described in Chapter 2, paragraph entitled "Initial conditions," are checked to determine if the jet calculations should be stopped for the current $Dist_b$.

(2) If the jet calculations proceed to the transition point between jet and ambient mixing, the concentration distribution at the end of the jet region (Chapter 2, paragraph entitled "Initial conditions") is used as

the initial condition for the ambient mixing calculations, which are done as described in Chapter 1, paragraph entitled "Ambient Diffusion."

(3) Whether the second towboat reaches the larvae from the propellers of the first towboat in the jet region or in the ambient mixing region, the flow rate through the propellers of the second towboat is used to determine the makeup of the water going through the propellers of the first, or leading, towboat, i.e., to determine the percentage of the intake water that went through the propellers of the leading towboat. This calculation assumes that the velocity in the river is uniform. The flow rate through the propellers divided by the river depth times the speed of the tow relative to the flowing water plus or minus the river velocity (depending on the direction of travel) gives the width (B_Q) from which the flow into the propellers comes. This width is assumed to be centered about the center line of the second towboat for barges away from the riverbanks. The intake water then comes from $y_{b2} \pm B_Q/2$, where y_{b2} is the transverse position of the center line of the second tow. If $y_{b2} + B_Q/2$ extends past the right riverbank, then the intake water is assumed to come from $y = B - B_Q$ to $y = B$, where B is the river width. Similarly, if $y_{b2} - B_Q/2$ extends past the left bank, then the water comes from $y = 0$ to $y = B_Q$.

c. For tows traveling downstream:

(1) The jet calculations are made according to Chapter 2, paragraph entitled "Tows Traveling Downstream."

(2) If the jet calculations proceed to the transition point between jet and ambient mixing, the concentration distribution at the end of the jet region (Chapter 2, paragraph entitled "End of jet region") is used as the initial condition for the ambient mixing calculations (Chapter 1, paragraph entitled "Ambient Diffusion").

(3) The makeup of the intake water for tows traveling downstream is done as described previously in paragraph entitled "Program," item *b*(3).

Input

The program listing contains a line for specifying the name of the input file, but this name is blank in the program as supplied with this report. If the program is being run in interpretive mode, the name of the input file can be included in the program listing. In the program listing, the file name must be inside quotation marks ("). A blank input file name in the listing causes the program to request the input file name when the program is run. The file name with the necessary path information can then be entered from the keyboard. When entering the file name from the keyboard, the quotation marks are not needed. QuickBasic uses the DOS convention that a directory (folder) name can be no longer than eight characters and that a file name can have only eight characters plus a three-character extension. If longer file names are used (as is permitted in Windows), QuickBasic truncates the file names, so distinction between file names can be lost if the ending characters are the distinctive part of the names.

A sample input file is shown in Appendix B. An effort has been made to use descriptive variable names in the program and in the input file, and descriptive information is included in the input file. Everything that is proceeded by a single quote (') in the file is skipped by the program or is read and echoed to the output file. The blank lines between the various categories of input must be present in the input file, since there are statements in the program to skip these blank lines. The input file format is the same for tows traveling both upstream and downstream even though all of the input values are not used for both cases.

There can be either one or two output files. The number of output files (NOF) is specified by the NOF value on the first line of the input file. NOF should be 1 or 2. (The program will still run with the input file format for the program that was supplied with the draft report, that had only one output file, and that did not require a value for NOF.) The first output file provides the calculated output in a compact format (Appendix C) for printing. If a second output file is specified, the output is essentially the same as the first file except that the calculated values are tab delimited and the output values are given in floating point (decimal) rather than integer format. In the first file, the first line of each set of calculated values gives 1,000 times the percent of larvae passing through each m^2 for each dy strip, since the values are in integer format. The factor of 1,000 is not used in the second output file since the values are in floating point format. The output file name(s) should include necessary path information. If two runs are made with the same output file name, QuickBasic overwrites the first output file the second time the program is run without requesting confirmation to do so. The number of title lines is arbitrary and can be zero, but there must be a value for Ntitle in the input file. That is, the input line for Ntitle cannot be deleted. If the input thrust is zero, the other inputs will be used by the program to calculate the thrust. If the input thrust is greater than zero, the program calculates the propeller speed (n) corresponding to the input thrust. The input value is stored as ninput. A message is written to the output files that the propeller speed has been recalculated. The message includes the values of both ninput and n.

Output

The output from the program in Appendix A and the input file in Appendix B are shown in Appendix C along with some other output files. The first part of the output gives the date, start time, and input and output file names. Next, the title lines are printed, followed by an echo of the input, plus some parameters calculated from the input. The remainder of the input gives the makeup of the intake water for the second tow along with any pertinent notes on the calculations. The output file ends with the time when the execution was finished and the elapsed time for running the program. The execution times in the output files in Appendix C are for a Dell Dimension computer, with a Pentium 200 MHz processor in a DOS window under Windows 95, or a Dell Latitude laptop computer, with a 233 MHz processor in a DOS window under Windows 98.

The output files are primarily for demonstration purposes for three rivers, for upstream and downstream travel, and for open propellers and Kort nozzles. Each of the outputs has $Dist_b$ = 1,000 m, 2,000 m, 5,500 m, 11,000 m, and 22,000 m. The difference in the times of arrival of two tows at the same cross section of a river is $Dist_b/(V_b - \delta_{UD}V_{river})$. Thus, for tows traveling upstream at 3 m/s relative to the flow in a river with a velocity of 0.5 m/s, the distances between tows correspond to times of 6.7 min, 13.3 min, 37 min, 73 min, and 147 min. For tows traveling downstream at 3 m/s relative to the flow, the times are 4.7, 9.5, 26, 52, and 105 min.

Because of the assumptions of constant depth and constant velocity, there is a lot of repetition of intake values since the tows have different transverse locations in the channel at a given $Dist_b$. As the results show, most of the intake values for the second towboats are rather small, meaning that the water which goes through the propellers of the second towboat is largely different from the water which went through the propellers of the first towboat.

Output 3 for Lagrange and for $x \geq 5{,}500$ m shows that all of the intake values are 5 to 6 percent. This condition occurs because the larvae from the first set of propellers are almost fully mixed across the width of the river and the intake comes from about 5 to 6 percent of the river width. As the first part of the input shows, $Q_{prop}/Q_{river} \approx 18$ percent. This number is misleading, since Q_{prop} is in a moving coordinate system while Q_{river} is in a stationary system. The more important values are B_Q and B. For this output, $B_Q/B = 5.5$ percent. Similarly, in Output 5, the intake values are essentially uniform at 1 percent for the larger $Dist_b$ values because the larvae are well mixed across the width and B_Q/B = 1.1 percent. Output 6 illustrates an error that can occur if the number of vertical strips (i.e., the Ny value) is too small. The error is only at $Dist_b$ = 1,000 m. The error exists because dy is too large relative to the width of the concentration distribution at this $Dist_b$. The remainder of the output does not have this error. Output 7 is part of an output file to illustrate the elimination of the error by increasing Ny and thereby decreasing dy.

References

Balachandar, R., Robillard, L., and Ramamurthy, A. S. (1992). "Some characteristics of counter flowing wall jets," *Journal of Fluids Engineering, Transactions of ASME* 114, 554-558.

Bradbury, L. J. S. (1965). "The structure of a self-preserving turbulent jet," *Journal of Fluid Mechanics* 23, 31-64.

Chow, V. T. (1959). *Open channel hydraulics.* McGraw-Hill, New York..

Fischer, H. B. et al. (1979). *Mixing in inland and coastal waters.* Academic Press, New York.

Hinze, J. O. (1959). *Turbulence.* McGraw-Hill, New York.

Holley, E. R., and Jirka, G. H. (1986). "Mixing in rivers," Technical Report E-86-11, U.S. Army Corps of Engineers, Washington, DC.

Hopkins, D. F., and Robertson, J. M. (1967) "Two-dimensional incompressible fluid jet penetration," *Journal of Fluid Mechanics* 29(2), 273-287.

Idelchik, I. E. (1986). *Handbook of hydraulic resistance.* 2nd ed., (translated by G. R. Malyavskaya), Hemisphere Publishing, Washington, DC.

Maynord, S. T. (1990). "Velocities induced by commercial navigation," Technical Report HL-90-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1997). "Inflow zone and discharge through propeller jets," *PIANC Bulletin* (in press).

Patel, R. P. (1971) "Turbulent jets and wall jets in uniform streaming flow," *Aeronautical Quarterly* 22, 311-326.

Roberson, J. A., and Crowe, C. T. (1997). *Engineering fluid mechanics.* 6th ed., Wiley, New York.

Schlichting, H. (1960). *Boundary Layer Theory.* 4th ed., (translated by J. Kestin), McGraw-Hill, New York.

Sekundov, A. N. (1969). "The propagation of a turbulent jet in an opposing stream." *Turbulent jets of air, plasma, and real gas*. G. N. Abramovich, Consultants Bureau, ed., Plenum Publ. Corp., New York, 99-109.

Yotsukura, N., and Sayre, W. W. (1976). "Transverse mixing in natural channels," *Water Resources Research* 12, 695-704.

Appendix A
Program Listing

```
'PROGRAM DiffLarv.bas (v. 3, May 22, 1999)

'This program uses SI units.

DECLARE SUB Uexcess (Vriver, yb1, B, bjet, C2, x, y, Umax, U)
DECLARE SUB AmbDiff (mcmax percent, yo, B, Vriver, DiffCoef, x, y, dy, Ccoef, C)
DECLARE SUB Gauss (mcmax percent, yo, B, Vriver, DiffCoef, x, y, Ccoef, C)
DIM intakex(50, 50), Distb(20), Ctrans(50, 50), Ctransmax(50)
DIM Conc(50, 50), ytrial(3), Uy(3), yc(50)

'Error function
DEF FNerf (x)
  fp = .47047
  fa1 = .3480242#
  fa2 = -.0958798#
  fa3 = .7478556#
  ft = 1 / (1 + fp * x)
  FNerf = 1 - (fa1 * ft + fa2 * ft ^ 2 + fa3 * ft ^ 3) * EXP(-x ^ 2)
  IF (x < 0) THEN
    ft = 1 / (1 + fp * (-x))
    FNerf = -(1 - (fa1 * ft + fa2 * ft ^ 2 + fa3 * ft ^ 3) * EXP(-x ^ 2))
  END IF
END DEF

'Similarity function for co-flowing jets
DEF FNfeta (eta)
  FNfeta = EXP(-.675 * eta * eta * (1 + .027 * eta ^ 4))
END DEF

'Setup
CLS
pi = 3.141593
g = 9.81 'm/s^2
F1 = 1.022
F2 = .748
Fratio = F2 / F1
lambdaUS = 1.35
lambdaDS = 1.24

'The input filename with the necessary path information may be placed
'between the quote marks in the next executable program line.  If there
'are no characters between the quote marks, the program requests the
'input filename to be entered from the keyboard when the program is run.
infile$ = ""

IF infile$ = "" THEN
  PRINT "Enter input file name with necessary path information: "
  INPUT infile$
END IF

'Input and output files
OPEN infile$ FOR INPUT AS #3
INPUT #3, NOF$
FOR i = 1 TO 80
  C$ = LEFT$(NOF$, i)
  IF C$ = "'" THEN NOF = 1: GOTO 15
  IF C$ <> "" THEN
    NOF = VAL(C$)
    INPUT #3, C$
    GOTO 15
  END IF
```

```
NEXT i

15 'continue
INPUT #3, outfile1$
OPEN outfile1$ FOR OUTPUT AS #1
PRINT #1, DATE$, TIME$
T1 = TIMER
PRINT #1,
PRINT #1, "Input file:   "; infile$
PRINT #1, "Output files: "; outfile1$
IF NOF = 2 THEN
  INPUT #3, outfile2$
  PRINT #1, "              "; outfile2$
  OPEN outfile2$ FOR OUTPUT AS #2
  PRINT #2, DATE$; CHR$(9); TIME$
  PRINT #2,
  PRINT #2, "Input file:   "; infile$
  PRINT #2, "Output files: "; outfile1$
  PRINT #2, "              "; outfile2$
END IF

'Descriptive information
LINE INPUT #3, A$
LINE INPUT #3, A$
INPUT #3, Ntitle percent, A$
IF Ntitle percent = 0 THEN GOTO 50
PRINT #1,
IF NOF = 2 THEN PRINT #2,

FOR ititle percent = 1 TO Ntitle percent
  LINE INPUT #3, A$
  PRINT #1, A$
  IF NOF = 2 THEN PRINT #2, A$
NEXT ititle percent

50 '-------------------------------------------------------------------------50

PRINT TIME$, "Inputs"

'Inputs for calculations
LINE INPUT #3, C$
INPUT #3, C$
PRINT #1, : PRINT #1, "--- CALCULATIONS ---"
IF NOF = 2 THEN PRINT #2, : IF NOF = 2 THEN PRINT #2, "--- CALCULATIONS ---"
INPUT #3, converge, C$
PRINT #1, converge; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, converge; CHR$(9); C$
INPUT #3, Vrtrans, C$
PRINT #1, Vrtrans; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Vrtrans; CHR$(9); C$
INPUT #3, Ny percent, C$
PRINT #1, Ny percent; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Ny percent; CHR$(9); C$
INPUT #3, dx, C$
PRINT #1, dx; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, dx; CHR$(9); C$
INPUT #3, NDist percent, C$
PRINT #1, NDist percent; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, NDist percent; CHR$(9); C$
LINE INPUT #3, A$

FOR iDist percent = 1 TO NDist percent
```

```
  INPUT #3, Distb(iDist percent)
  Distb(iDist percent) = CLNG(Distb(iDist percent))
NEXT iDist percent

'Inputs for tow
LINE INPUT #3, A$
LINE INPUT #3, A$
B$ = "--- TOW ---"
PRINT #1, : PRINT #1, B$
IF NOF = 2 THEN PRINT #2, : IF NOF = 2 THEN PRINT #2, B$
LINE INPUT #3, dir1$
LENdir = LEN(dir1$)
dir$ = LEFT$(dir1$, 1)
dir$ = UCASE$(dir$)
direction$ = "upstream "
IF dir$ = "D" THEN direction$ = "downstream "
IF dir$ = "U" OR dir$ = "D" THEN GOTO 100
PRINT #1,
PRINT #1, "ERROR."
PRINT #1, "Need u, U, d, or D for direction of tow movement in first"
PRINT #1, "column of input file."
PRINT
PRINT "ERROR."
PRINT "Need u, U, d, or D for direction of tow movement in first"
PRINT "column of input file."
GOTO 9000

100 '----------------------------------------------------------------------100

'Identify text from line input for direction of tow movement.

FOR idir percent = 1 TO 20
  apos$ = MID$(dir1$, idir percent + 1, 1)
  IF apos$ = "'" THEN GOTO 200
NEXT idir percent

200 '----------------------------------------------------------------------200

D$ = MID$(dir1$, idir percent + 1, LENdir - idir percent)
PRINT #1, " "; dir$; CHR$(9); D$
IF NOF = 2 THEN PRINT #2, " "; dir$; CHR$(9); D$
INPUT #3, Vb, V$
PRINT #1, Vb; CHR$(9); V$
IF NOF = 2 THEN PRINT #2, Vb; CHR$(9); V$
INPUT #3, w, C$
PRINT #1, w; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, w; CHR$(9); C$
INPUT #3, Kt, C$
PRINT #1, Kt; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Kt; CHR$(9); C$
INPUT #3, n, C$
PRINT #1, n; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, n; CHR$(9); C$
ninput = n
INPUT #3, TkN, C$
PRINT #1, TkN; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, TkN; CHR$(9); C$
T = TkN * 1000
INPUT #3, D, C$
PRINT #1, D; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, D; CHR$(9); C$
INPUT #3, zprop, C$
```

```
PRINT #1, zprop; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, zprop; CHR$(9); C$
INPUT #3, Ds, C$
PRINT #1, Ds; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Ds; CHR$(9); C$
INPUT #3, Bs, C$
PRINT #1, Bs; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Bs; CHR$(9); C$
INPUT #3, Bb, C$
PRINT #1, Bb; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Bb; CHR$(9); C$

'Inputs for river
'The origin of the coordinate system for the river is on the left bank
'with positive x in the downstream direction and positive y to the
'right looking downstream.
LINE INPUT #3, C$
INPUT #3, C$
C$ = "--- RIVER ---"
PRINT #1, : PRINT #1, C$
IF NOF = 2 THEN PRINT #2, : IF NOF = 2 THEN PRINT #2, C$
INPUT #3, Vriver, C$
PRINT #1, Vriver; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Vriver; CHR$(9); C$
INPUT #3, H, C$
PRINT #1, H; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, H; CHR$(9); C$
INPUT #3, B, C$
PRINT #1, B; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, B; CHR$(9); C$
dy = B / Ny percent
PRINT #1, CINT(100 * dy) / 100; CHR$(9);
IF NOF = 2 THEN PRINT #2, CINT(100 * dy) / 100; CHR$(9);
PRINT #1, "'dy[m] = width of vertical strip for calculations"
IF NOF = 2 THEN PRINT #2, "'dy[m] = width of vertical strip for calculations"
Qriver = Vriver * H * B
C$ = "'Qriver[m^3/s] = river discharge"
PRINT #1, CINT(Qriver); CHR$(9); C$
IF NOF = 2 THEN PRINT #2, CINT(Qriver); CHR$(9); C$
INPUT #3, Mann, C$
PRINT #1, Mann; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Mann; CHR$(9); C$
INPUT #3, alphay, C$
PRINT #1, alphay; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, alphay; CHR$(9); C$
'fDW = Darcy-Weisbach friction factor
fDW = Mann ^ 2 * 8 * g / H ^ (1 / 3)
'DiffCoef = transverse diffusion coefficient for ambient diffusion
DiffCoef = alphay * H * SQR(fDW / 8) * Vriver
C$ = "'DiffCoef[m^2/s] = ambient transverse diffusion coefficient"
PRINT #1, USING " #.####"; DiffCoef; : PRINT #1, CHR$(9); C$
IF NOF = 2 THEN
  PRINT #2, USING " #.####"; DiffCoef;
  PRINT #2, CHR$(9); C$
END IF
INPUT #3, rho, C$
PRINT #1, rho; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, rho; CHR$(9); C$

'Inputs for jet
LINE INPUT #3, C$
INPUT #3, C$
```

```
C$ = "--- JET ---"
PRINT #1, : PRINT #1, C$
IF NOF = 2 THEN PRINT #2, : IF NOF = 2 THEN PRINT #2, C$
INPUT #3, C2, C$
PRINT #1, C2; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, C2; CHR$(9); C$

'Jet parameters
Va = Vb * (1 - w)

'If input thrust (TkN) > 0, find prop speed (n) that gives the input
'thrust.  If TkN = 0, then find the thrust for the given prop speed.
nmin = 0: nmax = 30
n = .5 * (nmin + nmax)
inmax percent = 25
IF TkN = 0 THEN
  inmax percent = 1
  n = ninput
  nmin = ninput
  nmax = ninput
END IF

FOR in percent = 1 TO inmax percent
  Qprop = (Va * pi * D * D) ^ 2 / 64
  Qprop = Qprop + Kt * n * n * D ^ 6 * pi / (4 * zprop)
  Qprop = Va * pi * D * D / 8 + SQR(Qprop)
  'V2 = velocity added by propellers
  V2 = Kt * n * n * D ^ 4 / Qprop
  'Do (contracted jet diameter) is called Dzero in the program.
  Dzero = SQR(4 * Qprop / (pi * (V2 + Va)))
  'Uo = initial jet velocity for round jet relative to tow boat.
  Uo = Va + V2
  Ttry = rho * Uo * (Uo - Vb) * pi * Dzero * Dzero / 4
  IF (nmax - nmin) < converge THEN GOTO 300
  IF Ttry > T THEN nmax = n
  IF Ttry < T THEN nmin = n
  n = .5 * (nmin + nmax)
NEXT in percent

300 '-----------------------------------------------------------------300

B$ = "'Qprop[m^3/s] = discharge through one propeller"
PRINT #1, CINT(10 * Qprop) / 10; CHR$(9); B$
IF NOF = 2 THEN PRINT #2, CINT(10 * Qprop) / 10; CHR$(9); B$
C$ = "'Qratio[-] = ratio of total propeller flow to Qriver"
Qratio = 2 * Qprop / Qriver
IF Qratio > 1 THEN
  PRINT #1, "Qprop/Qriver ="; CINT(100 * Qratio) / 100;
  PRINT #1, "The program is not valid for values greater than 1."
  IF NOF = 2 THEN PRINT #2, "Qprop/Qriver ="; CINT(100 * Qratio) / 100;
  IF NOF = 2 THEN PRINT #2, "The program is not valid for values greater than 1."
  PRINT "Qprop/Qriver ="; CINT(100 * Qratio) / 100;
  PRINT "The program is not valid for values greater than 1."
  GOTO 9000
END IF
PRINT #1, CINT(1000 * Qratio) / 1000; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, CINT(1000 * Qratio) / 1000; CHR$(9); C$
C$ = "'Va[m/s] = advance velocity"
PRINT #1, Va; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, Va; CHR$(9); C$
C$ = "'V2[m/s] = velocity added by propeller"
PRINT #1, CINT(100 * V2) / 100; CHR$(9); C$
```

```
IF NOF = 2 THEN PRINT #2, CINT(100 * V2) / 100; CHR$(9); C$
C$ = "'Do[m] = jet diameter at vena contracta"
PRINT #1, CINT(100 * Dzero) / 100; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, CINT(100 * Dzero) / 100; CHR$(9); C$
C$ = "'Uo[m/s] = initial jet velocity for round jet relative to barge"
PRINT #1, CINT(100 * Uo) / 100; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, CINT(100 * Uo) / 100; CHR$(9); C$
C$ = "'TkN[kN] = thrust (initial momentum flux) in one jet"
PRINT #1, TkN; CHR$(9); C$
IF NOF = 2 THEN PRINT #2, TkN; CHR$(9); C$

deltaUD = 1
IF dir$ = "D" THEN deltaUD = -1
'Mo = total momentum flux in stationary coordinate system
Mo = 2 * rho * (Uo - Vb + deltaUD * Vriver) * (Uo - Vb) * pi * Dzero ^ 2 / 4
PRINT #1, CINT(Mo / 2 / 1000); CHR$(9);
PRINT #1, "'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system"
IF NOF = 2 THEN PRINT #2, CINT(Mo / 2 / 1000); CHR$(9);
IF NOF = 2 THEN PRINT #2, "'Mo/2[kN] = init. mom. flux in one jet in stationary
coord. system"

'BQ = width of region from which water comes
BQ = 2 * Qprop / (H * (Vb + deltaUD * Vriver))
PRINT #1, CINT(100 * BQ) / 100; CHR$(9);
PRINT #1, "'BQ[m] = width from which prop inflow comes"
PRINT #1, CINT(1000 * BQ / dy) / 1000; CHR$(9);
PRINT #1, "'BQ/dy = prop intake width over width of vertical calculation strip"
IF NOF = 2 THEN
  PRINT #2, CINT(100 * BQ) / 100; CHR$(9);
  PRINT #2, "'BQ[m] = width from which prop inflow comes"
  PRINT #2, CINT(1000 * BQ / dy) / 1000; CHR$(9);
  PRINT #2, "'BQ/dy = prop intake width over width of vertical calculation strip"
END IF

IF n > 0 AND TkN > 0 THEN
  PRINT #1,
  PRINT #1, "WARNING.  Both the input prop speed and the input thrust are"
  PRINT #1, "greater than zero.  The program has calculated a new prop speed"
  PRINT #1, "corresponding to the input thrust and has overridden the input"
  PRINT #1, "value of the prop speed.  The input value and the new value of"
  PRINT #1, "n used by the program are given below."
  PRINT #1, ninput; CHR$(9);
  PRINT #1, "'ninput[rev/sec] = input rotational speed of propellers"
  PRINT #1, CINT(100 * n) / 100; CHR$(9);
  PRINT #1, "'n[rev/sec] = calculated rotational speed of propellers"
  PRINT #1,
  IF NOF = 2 THEN
    PRINT #2,
    PRINT #2, "WARNING.  Both the input prop speed and the input thrust are"
    PRINT #2, "greater than zero.  The program has calculated a new prop speed"
    PRINT #2, "corresponding to the input thrust and has overridden the input"
    PRINT #2, "value of the prop speed.  The input value and the new value of"
    PRINT #2, "n used by the program are given below."
    PRINT #2, ninput; CHR$(9);
    PRINT #2, "'ninput[rev/sec] = input rotational speed of propellers"
    PRINT #2, CINT(100 * n) / 100; CHR$(9);
    PRINT #2, "'n[rev/sec] = calculated rotational speed of propellers"
    PRINT #2,
  END IF
  PRINT
  PRINT "WARNING.  Both the input prop speed and the input thrust are"
  PRINT "greater than zero.  The program has calculated a new prop speed"
```

```
    PRINT "corresponding to the input thrust and has overridden the input"
    PRINT "value of the prop speed.  The input value and the new value of"
    PRINT "n used by the program are given below."
    PRINT ninput; CHR$(9);
    PRINT "'ninput[rev/sec] = input rotational speed of propellers"
    PRINT CINT(100 * n) / 100; CHR$(9);
    PRINT "'n[rev/sec] = calculated rotational speed of propellers"
    PRINT
  END IF

  PRINT TIME$, "Calculations for jet"
  bo = .5 * (Bs + Dzero)
  xprint = 100
  Nprint percent = 1

  'Parameters for tows traveling upstream
  thetao = Mo / (2 * rho * Vriver ^ 2 * H)
  psio = -.5 / Fratio + SQR(.25 / Fratio ^ 2 + thetao / (F2 * bo))
  thetaA = thetao
  bjetA = bo
  psiA = psio
  xA = 0
  tjetUS = 0
  Uie2DUS = .5 * (-Vriver + SQR(Vriver ^ 2 + 2 * Mo / (rho * bo * H)))
  integrate$ = "Y"
  message$ = "Y"

  'Initial velocity for tows traveling downstream
  Uie2DDS = .5 * (Vriver + SQR(Vriver ^ 2 + 2 * Mo / (rho * bo * H)))

  IF Uie2DUS <= 0 OR Uie2DDS <= 0 THEN
    PRINT #1,
    PRINT #1, "ERROR."
    PRINT #1, "The input parameters are such that the initial jet velocity"
    PRINT #1, "from the props is less than the river flow velocity."
    PRINT #1, "This situation is not possible."
    IF NOF = 2 THEN
      PRINT #2,
      PRINT #2, "ERROR."
      PRINT #2, "The input parameters are such that the initial jet velocity"
      PRINT #2, "from the props is less than the river flow velocity."
      PRINT #2, "This situation is not possible."
    END IF
    PRINT
    PRINT "ERROR."
    PRINT "The input parameters are such that the initial jet velocity"
    PRINT "from the props is less than the river flow velocity."
    PRINT "This situation is not possible."
    GOTO 9000
  END IF

  ytrial(1) = 0
  ytrial(2) = B

  IF dir$ = "U" THEN GOTO 400

  'Parameters used for tows going downstream
  psioDS = Uie2DDS / Vriver - 1
  xjetDS = 3.4 * bo * psioDS ^ 2
  tjetDS = xjetDS / (.5 * (Uie2DDS - Vriver)) + xjetDS / (.5 * Vriver)
  sigmaco = (3 * psioDS ^ 2 - 1) * lambdaDS * bo / 3
```

```
400 '--------------------------------------------------------------------400

FOR iDist percent = 1 TO NDist percent  '+ + + + + + + + + + + + + + + + + + START
iDist percent

  FOR iy percent = 1 TO Ny percent
    yc(iy percent) = (iy percent - .5) * dy
  NEXT iy percent

  PRINT #1,
  PRINT #1,
  PRINT #1, "Distance between tows traveling in the "; direction$;
  PRINT #1, "direction ="; Distb(iDist percent); "m."
  IF NOF = 2 THEN
    PRINT #2,
    PRINT #2,
    PRINT #2, "Distance between tows traveling in the "; direction$;
    PRINT #2, "direction ="; Distb(iDist percent); "m."
  END IF

  PRINT
  PRINT
  PRINT "Distance between tows traveling in the "; direction$;
  PRINT "direction ="; Distb(iDist percent); "m."

  IF dir$ = "U" THEN GOTO 500

  'For tows traveling downstream

  IF (Distb(iDist percent) - xjetDS) / (Vb + Vriver) < xjetDS / (.5 * Uie2DDS) THEN

    PRINT #1, "The two tows traveling downstream are so close that the ";
    PRINT #1, "second tow reaches"
    PRINT #1, "the propeller jet before it stagnates against the river ";
    PRINT #1, "flow.  The program is "
    PRINT #1, "not valid for this situation."
    IF NOF = 2 THEN
      PRINT #2, "The two tows traveling downstream are so close that the ";
      PRINT #2, "second tow reaches"
      PRINT #2, "the propeller jet before it stagnates against the river ";
      PRINT #2, "flow.  The program is "
      PRINT #2, "not valid for this situation."
    END IF
    GOTO 5500

  END IF

  IF dir$ = "D" THEN GOTO 1010

500 '--------------------------------------------------------------------500

'Calculations for tows traveling upstream

'Find x at which the maximum jet velocity has decreased to Vrtrans times
'the initial velocity.  Because of the decreasing momentum in the jets
'due to boundary shear, it is necessary to integrate with respect to x.

IF integrate$ = "N" THEN GOTO 1700

  PRINT "x values in m to show progress of calculations ";
  PRINT "through the jet region:"
  AmbDiffFlag$ = "Y"
```

```
  FOR ix percent = 1 TO 25000 '+ + + + + + + + + + + + + + + + + + + + + + START ix
percent

    xB = xA + dx

    IF Nprint percent * xprint <= xB THEN
      PRINT CINT(xB);
      Nprint percent = Nprint percent + 1
    END IF

    'Calculate momentum flux (theta) and jet parameters at end of dx.

    thetaB = 2 * F1 * psiA + F2 * psiA ^ 2
    thetaB = thetaA - thetaB * dx * g * Mann ^ 2 * bjetA / H ^ 1.333333
    bjetB = bjetA + C2 * dx * psiA / (psiA + 1)
    psiB = -1 / Fratio + SQR(.25 / Fratio ^ 2 + thetaB / (F2 * bjetB))
    UmaxB = psiB * Vriver

    tjetUS = tjetUS + dx / (Vriver + .5 * UmaxB)
    xjetUS = xB
    RiverDist = xB

    'Update parameters for next dx step.
    thetaA = thetaB
    bjetA = bjetB
    psiA = psiB
    UmaxA = UmaxB
    xA = xB

    'Check for small jet velocities.
    IF UmaxB <= Vrtrans * Vriver THEN
      PRINT
      integrate$ = "N"
      GOTO 1010
    END IF

    'Check to determine if uniformly mixed conditions exist.  Stop jet
    'calculations if they do exist.

    'Subroutine Uexcess is for calculating excess jet velocities in 2D (x,y)
    'after mixing has established uniform conditions over the depth.

    FOR iy percent = 1 TO 2
      CALL Uexcess(Vriver, 0, B, bjetB, C2, xB, ytrial(iy percent), UmaxB, UB)
      Uy(iy percent) = UB
    NEXT iy percent

    IF Uy(1) > .001 AND Uy(2) > .001 AND ABS(Uy(1) - Uy(2)) < .001 THEN

      PRINT #1,
      PRINT #1, "The excess velocity due to the propeller jets is uniformly"
      PRINT #1, "mixed across the channel width at x ="; xB;
      PRINT #1, "m even though the"
      PRINT #1, "excess velocity is"; CINT(100 * Uy(1)) / 100;
      PRINT #1, "m/s, which is "
      PRINT #1, "larger than the velocity convergence tolerance."
      PRINT #1,
      IF NOF = 2 THEN
        PRINT #2,
        PRINT #2, "The excess velocity due to the propeller jets is uniformly"
        PRINT #2, "mixed across the channel width at x ="; xB;
```

```
        PRINT #2, "m even though the"
        PRINT #2, "excess velocity is"; CINT(100 * Uy(1)) / 100;
        PRINT #2, "m/s, which is "
        PRINT #2, "larger than the velocity convergence tolerance."
        PRINT #2,
      END IF
      PRINT
      PRINT "The excess velocity due to the propeller jets is uniformly"
      PRINT "mixed across the channel width at x ="; xB; "m even though the"
      PRINT "excess velocity is"; CINT(100 * Uy(1)) / 100; "m/s, which is "
      PRINT "larger than the velocity convergence tolerance."
      PRINT
      integrate$ = "N"
      GOTO 1010

    END IF

    'Check for second tow in jet mixing region.  If it is, stop jet
    'calculations for this Distb.

    'For intake calculations
    IF xB >= Distb(iDist percent) - tjetUS * (Vb - Vriver) THEN

      AmbDiffFlag$ = "N"
      PRINT #1, "The second tow is within the jet mixing region.  There ";
      PRINT #1, "is no ambient"
      PRINT #1, "diffusion for this case."
      IF NOF = 2 THEN
        PRINT #2, "The second tow is within the jet mixing region.  There ";
        PRINT #2, "is no ambient"
        PRINT #2, "diffusion for this case."
      END IF
      PRINT
      PRINT "The second tow is within the jet mixing region.  There ";
      PRINT "is no ambient"
      PRINT "diffusion for this case."
      GOTO 1010

    END IF

  NEXT ix percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = END ix
percent

  PRINT #1, "At x ="; xB / 1000; "km, the maximum jet velocity is";
  PRINT #1, CINT(1000 * maxVel) / 1000; "m/s, which is not"
  PRINT #1, "within the convergence tolerance."
  PRINT #1,
  IF NOF = 2 THEN
    PRINT #2, "At x ="; xB / 1000; "km, the maximum jet velocity is";
    PRINT #2, CINT(1000 * maxVel) / 1000; "m/s, which is not"
    PRINT #2, "within the convergence tolerance."
    PRINT #2,
  END IF
  PRINT "At x ="; xB / 1000; "km the maximum jet velocity is";
  PRINT CINT(1000 * maxVel) / 1000; "m/s, which is not"
  PRINT "within the convergence tolerance."
  PRINT
  PRINT "Do you wish to continue the calculations (Y/N)?"
  PRINT
1007 A$ = INKEY$: IF A$ = "" THEN BEEP: GOTO 1007
  IF UCASE$(A$) = "N" THEN GOTO 9000
```

```
1010 '------------------------------------------------------------------1010
  xtrans = xB

  'For tows traveling downstream, calculate the standard deviation of the
  'concentration distribution at the end of the jet region and the distance
  'in which ambient diffusion will occur.

  IF dir$ = "D" THEN

    xdiffDS = Vriver * (Distb(iDist percent) - tjetDS * (Vb + Vriver)) / Vb
    RiverDistDS = xdiffDS
    xdum = .5 * sigmaco ^ 2
    sigmac = sigmaco
    AmbDiffFlag$ = "Y"
    xtrans = 0

    IF xdiffDS < 0 THEN

      AmbDiffFlag$ = "N"
      PRINT #1, "The second tow reaches the water from the prop jet of ";
      PRINT #1, "the first tow before"
      PRINT #1, "that water returns to the cross section where it went ";
      PRINT #1, "through the prop of the"
      PRINT #1, "first tow.  There is ";
      PRINT #1, "no ambient diffusion for this case."
      IF NOF = 2 THEN
        PRINT #2, "The second tow reaches the water from the prop jet of ";
        PRINT #2, "the first tow before"
        PRINT #2, "that water returns to the cross section where it went ";
        PRINT #2, "through the prop of the"
        PRINT #2, "first tow.  There is ";
        PRINT #2, "no ambient diffusion for this case."
      END IF
      PRINT "The second tow reaches the water from the prop jet of ";
      PRINT "the first tow before"
      PRINT "that water returns to the cross section where it went ";
      PRINT "through the prop of the"
      PRINT "first tow.  There is ";
      PRINT "no ambient diffusion for this case."
      xreturn = (1 + (Vriver + Vb) / (.5 * Uie2DDS)) * xjetDS
      xreturn = (Distb(iDist percent) - xreturn) / (1 + 2 * Vb / Vriver)
      RiverDistDS = -(xjetDS - xreturn)
      sigmac = sigmaco * SQR(xreturn / xjetDS)

    END IF

  END IF

  IF dir$ = "U" THEN sigmac = .765 * bjetB * lambdaUS

  xdum = .5 * sigmac ^ 2
  Cmax = 1 / (sigmac * Vriver * H * SQR(2 * pi))
  CcoefDS = Cmax
  mcmax percent = 2 * CINT(3 * sigmac / B)
  IF mcmax percent < 1 THEN mcmax percent = 1

  'Calculate distribution of larvae at xtrans from analogy with momentum
  'transport.  Ctrans is the fraction of larvae per m^3 for the center of
  'each vertical strip dy wide at the location of the second tow if it
  'encounters the jet in the jet region or, if not, at the end of the jet
  'mixing region.
```

```
   'The subroutine Gauss gives the Gaussian concentration distribution
   '(accounting for the channel boundaries) at the beginning of the ambient
   'diffusion region or at the location of the second tow if it reaches
   'the jet in the jet region.

   FOR ib1 percent = 1 TO Ny percent '+ + + + + + + + + + + + + + + + + + + + + +
START ib1 percent

     yb1 = (ib1 percent - .5) * dy
     Ctransmax(ib1 percent) = 0
     masstrans = 0

     FOR iy percent = ib1 percent TO Ny percent  '+ + + + + + + + + + + + + + + + + +
+ + START iy percent

       CALL Gauss(mcmax percent, yb1, B, 1, 1, xdum, yc(iy percent), Cmax, C)
       Ctrans(ib1 percent, iy percent) = C
       IF C > Ctransmax(ib1 percent) THEN Ctransmax(ib1 percent) = C
       masstrans = masstrans + C

       IF C < Cmax / 10000 THEN GOTO 1500

     NEXT iy percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END iy
percent

1500 '-------------------------------------------------------------------1500

     FOR iy percent = ib1 percent - 1 TO 1 STEP -1  '+ + + + + + + + + + + + + + +
START iy percent

       CALL Gauss(mcmax percent, yb1, B, 1, 1, xdum, yc(iy percent), Cmax, C)
       Ctrans(ib1 percent, iy percent) = C
       IF C > Ctransmax(ib1 percent) THEN Ctransmax(ib1 percent) = C
       masstrans = masstrans + C

       IF C < Cmax / 10000 THEN GOTO 1600

     NEXT iy percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END iy
percent

1600 '-------------------------------------------------------------------1600

     masstrans = masstrans * H * Vriver * dy

     IF ABS(masstrans - 1) < .05 THEN GOTO 1650
     IF message$ = "N" THEN GOTO 1650
     PRINT #1,
     PRINT #1, "Mass balance error at end of jet mixing region for tows ";
     PRINT #1, "traveling ";
     PRINT #1, direction$; "= ";
     PRINT #1, CINT(1000 * (masstrans - 1)) / 10; " percent"
     PRINT #1, "Increase Ny percent in the input file to decrease the error."
     PRINT #1,
     IF NOF = 2 THEN
       PRINT #2,
       PRINT #2, "Mass balance error at end of jet mixing region for tows ";
       PRINT #2, "traveling ";
       PRINT #2, direction$; "= ";
       PRINT #2, CINT(1000 * (masstrans - 1)) / 10; " percent"
       PRINT #2, "Increase Ny percent in the input file to decrease the error."
       PRINT #2,
```

```
    END IF
    PRINT
    PRINT "Mass balance error at end of jet mixing region for tows ";
    PRINT "traveling ";
    PRINT direction$; "= ";
    PRINT CINT(1000 * (masstrans - 1)) / 10; " percent.  ";
    PRINT "Increase Ny percent in the input file to decrease the error."
    PRINT
    PRINT "Do you want to continue (Y/N)?"
    BEEP
1625 A$ = INKEY$: IF A$ = "" THEN GOTO 1625
    IF UCASE$(A$) = "N" THEN GOTO 9000
    message$ = "N"

1650 '

  NEXT ibl percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = = END ibl
percent

1700 '------------------------------------------------------------------1700

  'Determine distance that water flows while second tow is traveling the
  'distance between the two tows

  xdiffUS = Vriver * (Distb(iDist percent) - xtrans - tjetUS * (Vb - Vriver)) / Vb
  RiverDist = xdiffUS + xtrans
  xdiff = xdiffUS
  IF dir$ = "D" THEN
    xdiff = xdiffDS
    RiverDist = RiverDistDS
  END IF

  PRINT "River distance from initial position of leading tow =";
  PRINT CINT(RiverDist); "m."
  PRINT #1, "River distance from initial position of leading tow =";
  PRINT #1, CINT(RiverDist); "m."
  PRINT #1, "Line 1: 1000 times percent of larvae passing through each ";
  PRINT #1, "square m for each dy strip."
  PRINT #1, "Line 2: Percent of larvae passing through each dy strip."
  PRINT #1, "Line 3: Percent of larvae in intake of second towboat."
  PRINT #1, "Col. 1: Transverse position (m) of centerline of leading ";
  PRINT #1, "towboat."
  PRINT #1, "Other columns: Values for transverse position of dy strip ";
  PRINT #1, "(Lines 1 & 2) or centerline"
  PRINT #1, "of second towboat (Line 3)."
  PRINT #1,
  IF NOF = 2 THEN
    PRINT #2, "River distance from initial position of leading tow =";
    PRINT #2, CINT(RiverDist); "m."
    PRINT #2, "Line 1: percent of larvae passing through each ";
    PRINT #2, "square m for each dy strip."
    PRINT #2, "Line 2: Percent of larvae passing through each dy strip."
    PRINT #2, "Line 3: Percent of larvae in intake of second towboat."
    PRINT #2, "Col. 1: Transverse position (m) of centerline of leading ";
    PRINT #2, "towboat."
    PRINT #2, "Other columns: Values for transverse position of dy strip ";
    PRINT #2, "(Lines 1 & 2) or centerline"
    PRINT #2, "of second towboat (Line 3)."
    PRINT #2,
  END IF

 'Print headers
```

```
PRINT #1, "          y or yb2 (m)"
PRINT #1, "      ";
IF NOF = 2 THEN PRINT #2, CHR$(9); "y or yb2 (m)"
FOR iy percent = 1 TO Ny percent
  PRINT #1, USING "#####.#"; yc(iy percent);
  IF NOF = 2 THEN
    PRINT #2, CHR$(9);
    PRINT #2, USING "#####.#"; yc(iy percent);
  END IF
NEXT iy percent
PRINT #1,
PRINT #1, "yb1(m)"
IF NOF = 2 THEN
  PRINT #2,
  PRINT #2, "yb1(m)"
END IF

PRINT "Transverse locations of leading tow in m to show ";
PRINT "progress of calculations:"

'From calculated concentrations, determine makeup of intake water for the
'second tow.
'First set all intake values to zero and then calculate only non-zero
'values.  Also, use symmetry of the intake values about the tow
'centerline (when tows are far enough away from banks) to reduce number
'of intake values which need to be calculated.

FOR ib1 percent = 1 TO Ny percent
  FOR ib2 percent = 1 TO Ny percent
    intakex(ib1 percent, ib2 percent) = 0
  NEXT ib2 percent
NEXT ib1 percent

'The ib1 percent loop moves the first tow across the width of the channel to the
'center of each dy.

FOR ib1 percent = 1 TO Ny percent '+ + + + + + + + + + + + + + + + + + + + + + +
START ib1 percent

  yb1 = (ib1 percent - .5) * dy
  PRINT CINT(10 * yb1) / 10;

  Ctransmax = 0

  'Set concentration for second tow equal to concentrations at end of jet
  'region if the second tow reaches the prop jet in the jet region, i.e.,
  'if there is no ambient diffusion.

  IF AmbDiffFlag$ = "N" THEN

    FOR iy percent = 1 TO Ny percent
      Conc(ib1 percent, iy percent) = Ctrans(ib1 percent, iy percent)
    NEXT iy percent

    GOTO 3020

  END IF

  'Calculate ambient diffusion starting with concentrations from jet mixing

  'Determine approximate number of images needed for ambient diffusion
  'calculations.
```

```
    mcmax percent = 2 * CINT(3 * SQR(2 * DiffCoef * xdiff / Vriver) / B)
    IF mcmax percent < 1 THEN mcmax percent = 1

    'Sum the contributions from each vertical strip (designated by iytrans percent
    'and ytrans) at xtrans to the concentrations which the cross section
    'where the second tow is located.

    FOR iy percent = 1 TO Ny percent

      Csum = 0

      FOR iytrans percent = 1 TO Ny percent
        IF Ctrans(ib1 percent, iytrans percent) < Ctransmax(ib1 percent) / 1000 THEN
GOTO 2500
        ytrans = (iytrans percent - .5) * dy
        Co = Ctrans(ib1 percent, iytrans percent)
        DC = DiffCoef
        CALL AmbDiff(mcmax percent, ytrans, B, Vriver, DC, xdiff, yc(iy percent),
dy, Co, C)
        Csum = Csum + C

2500 '-----------------------------------------------------------------2500

      NEXT iytrans percent

      Conc(ib1 percent, iy percent) = Csum

    NEXT iy percent

3020 '-----------------------------------------------------------------3020

    PRINT #1,
    PRINT #1, USING "####.#"; yb1;
    IF NOF = 2 THEN PRINT #2, : PRINT #2, USING "####.#"; yb1;
    FOR iy percent = 1 TO Ny percent
      PRINT #1, USING "#######"; 100000 * Conc(ib1 percent, iy percent) * Vriver;
      IF NOF = 2 THEN PRINT #2, CHR$(9); 100 * Conc(ib1 percent, iy percent) *
Vriver;
    NEXT iy percent
    PRINT #1,

    PRINT #1, USING "####.#"; yb1;
    IF NOF = 2 THEN PRINT #2, : PRINT #2, USING "####.#"; yb1;
    FOR iy percent = 1 TO Ny percent
      PRINT #1, USING "#######"; 100 * Conc(ib1 percent, iy percent) * dy * H *
Vriver;
      IF NOF = 2 THEN PRINT #2, CHR$(9); 100 * Conc(ib1 percent, iy percent) * dy *
H * Vriver;
    NEXT iy percent
    PRINT #1,

    'Calculate makeup of water going into props of second towboat

    PRINT #1, USING "####.#"; yb1;
    IF NOF = 2 THEN PRINT #2, : PRINT #2, USING "####.#"; yb1;

    FOR ib2 percent = 1 TO Ny percent '+ + + + + + + + + + + + + + + + + + + + +
START ib2 percent

      yb2 = yc(ib2 percent)
```

```
        IF BQ <= dy THEN
          intake = Conc(ib1 percent, ib2 percent) * BQ
          GOTO 3000
        END IF

        'BL = left side of intake region
        BL = yb2 - BQ / 2
        IF BL < 0 THEN BL = 0
          'BR = right side of intake region
          BR = BL + BQ
          IF BR > B THEN
          BR = B
          BL = B - BQ
          IF BL < 0 THEN BL = 0
        END IF

        'iyL percent gives the dy strip in which BL is located
        iyL percent = FIX(BL / dy) + 1
        'iyR percent gives the dy strip in which BR is located
        iyR percent = FIX(BR / dy) + 1
        IF iyR percent > Ny percent THEN iyR percent = Ny percent

        intake = Conc(ib1 percent, iyL percent) * (yc(iyL percent) + dy / 2 - BL)
        dum = Conc(ib1 percent, iyR percent) * (BR - (yc(iyR percent) - .5 * dy))
        intake = intake + dum
        IF iyR percent - iyL percent = 1 THEN GOTO 3000

        FOR iy percent = iyL percent + 1 TO iyR percent - 1
          intake = intake + Conc(ib1 percent, iy percent) * dy
        NEXT iy percent

3000 '-------------------------------------------------------------------3000

        intakex(ib1 percent, ib2 percent) = 100 * intake * H * Vriver

      NEXT ib2 percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = END ib2
percent

      FOR ib2 percent = 1 TO Ny percent
        PRINT #1, USING "#######"; intakex(ib1 percent, ib2 percent);
        IF NOF = 2 THEN PRINT #2, CHR$(9); intakex(ib1 percent, ib2 percent);
      NEXT ib2 percent

      PRINT #1,
      IF NOF = 2 THEN PRINT #2,

      IF intakex(ib1 percent, 1) = 0 AND intakex(ib1 percent, Ny percent) = 0 THEN
        ib1z percent = ib1 percent
        GOTO 3750
      END IF

3500 '-------------------------------------------------------------------3500

    NEXT ib1 percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = END ib1
percent

    GOTO 5000

3750 '-------------------------------------------------------------------3750

    FOR ib2 percent = ib1z percent TO Ny percent '+ + + + + + + + + + + + + + + + + +
+ + START ib2 percent
```

```
    IF intakex(ib1z percent, ib2 percent) > 0 THEN GOTO 3800
    ib2z percent = ib2 percent
    Nvalues percent = 2 * (ib2z percent - ib1z percent) - 1
    Svalues percent = ib2z percent - ib1z percent - 1
    GOTO 3825

3800 '-------------------------------------------------------------------3800

  NEXT ib2 percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END ib2
percent

3825 '-------------------------------------------------------------------3825

  'Move repeating values across channel

  FOR ib1 percent = ib1z percent + 1 TO Ny percent - Svalues percent - 1  '+ + + + +
+ + + + + START ib1 percent

    FOR ib2 percent = ib1 percent - Svalues percent TO ib1 percent + Svalues percent
      Conc(ib1 percent, ib2 percent) = Conc(ib1 percent - 1, ib2 percent - 1)
      intakex(ib1 percent, ib2 percent) = intakex(ib1 percent - 1, ib2 percent - 1)
    NEXT ib2 percent

  NEXT ib1 percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END ib1
percent

  FOR ib1 percent = Ny percent - Svalues percent TO Ny percent  '+ + + + + + + + + +
+ + + + + START ib1 percent

    FOR ib2 percent = ib1 percent - Svalues percent TO Ny percent
      Conc(ib1 percent, ib2 percent) = Conc(Ny percent - ib1 percent + 1, Ny percent
- ib2 percent + 1)
      intakex(ib1 percent, ib2 percent) = intakex(Ny percent - ib1 percent + 1, Ny
percent - ib2 percent + 1)
    NEXT ib2 percent

  NEXT ib1 percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END ib1
percent

4000 '-------------------------------------------------------------------4000

  FOR ib1 percent = ib1z percent + 1 TO Ny percent '+ + + + + + + + + + + + + + + +
+ + START ib1 percent

    yb1 = (ib1 percent - .5) * dy
    PRINT #1,
    IF NOF = 2 THEN PRINT #2,
    PRINT #1, USING "####.#"; yb1;
    IF NOF = 2 THEN PRINT #2, USING "####.#"; yb1;
    FOR iy percent = 1 TO Ny percent
      PRINT #1, USING "#######"; 100000 * Conc(ib1 percent, iy percent) * Vriver;
      IF NOF = 2 THEN
        PRINT #2, CHR$(9); 100 * Conc(ib1 percent, iy percent) * Vriver;
      END IF
    NEXT iy percent
    PRINT #1,

    PRINT #1, USING "####.#"; yb1;
    IF NOF = 2 THEN PRINT #2, :  PRINT #2, USING "####.#"; yb1;
    FOR iy percent = 1 TO Ny percent
```

```
Vriver;
      IF NOF = 2 THEN
        PRINT #2, CHR$(9);
        PRINT #2, 100 * Conc(ibl percent, iy percent) * dy * H * Vriver;
      END IF
    NEXT iy percent
    PRINT #1,

    PRINT #1, USING "####.#"; ybl;
    IF NOF = 2 THEN PRINT #2, :  PRINT #2, USING "####.#"; ybl;
    FOR ib2 percent = 1 TO Ny percent
      PRINT #1, USING "#######"; intakex(ibl percent, ib2 percent);
      IF NOF = 2 THEN PRINT #2, CHR$(9); intakex(ibl percent, ib2 percent);
    NEXT ib2 percent

    PRINT #1,
    IF NOF = 2 THEN PRINT #2,

  NEXT ibl percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END ibl
percent

5000 '------------------------------------------------------------------5000

  PRINT #1,
  PRINT #1, "Depending on the width of the river and the number (Ny percent) of ";
  PRINT #1, "vertical strips"
  PRINT #1, "used across the width of the river, some of the sailing lines ";
  PRINT #1, "near the"
  PRINT #1, "banks of the river may not be physically possible.  No check ";
  PRINT #1, "is made of"
  PRINT #1, "the width of the tows relative to the sailing lines for which "
  PRINT #1, "calculations are made."
  IF NOF = 2 THEN
    PRINT #2,
    PRINT #2, "Depending on the width of the river and the number (Ny percent) of ";
    PRINT #2, "vertical strips"
    PRINT #2, "used across the width of the river, some of the sailing lines ";
    PRINT #2, "near the"
    PRINT #2, "banks of the river may not be physically possible.  No check ";
    PRINT #2, "is made of"
    PRINT #2, "the width of the tows relative to the sailing lines for which "
    PRINT #2, "calculations are made."
  END IF

5500 '------------------------------------------------------------------5500

NEXT iDist percent '= = = = = = = = = = = = = = = = = = = = = = = = = = = = END iDist
percent

IF NOF = 2 THEN PRINT #2,
PRINT

9000 '------------------------------------------------------------------9000

PRINT #1, : PRINT #1, TIME$, "End",
IF NOF = 2 THEN PRINT #2, TIME$; CHR$(9); "End"; CHR$(9);
PRINT : PRINT TIME$, "End",
DelT = TIMER - T1
minutes = FIX(DelT / 60)
seconds = DelT - 60 * minutes
PRINT #1, minutes; "minute(s)"; CINT(10 * seconds) / 10; "seconds"
IF NOF = 2 THEN PRINT #2, minutes; "minute(s)"; CINT(10 * seconds) / 10; "seconds"
```

```
PRINT minutes; "minute(s)"; CINT(10 * seconds) / 10; "seconds"
CLOSE

T = TIMER
FOR i = 1 TO 2
BEEP
9100 IF TIMER - T < i THEN GOTO 9100
NEXT i

END

SUB AmbDiff (mcmax percent, yo, B, Vriver, DiffCoef, x, y, dy, Ccoef, Csum)

'This subroutine is for calculating concentrations in 2D (x,y)
'starting with the concentrations from the jet mixing.

Csum = 0

'k accounts for each of 2 in set in transverse direction
FOR k percent = 1 TO 2
  'm percent accounts for center of sets of 2 in transverse direction
  FOR m percent = -mcmax percent TO mcmax percent
    ykm = (-1) ^ k percent * yo + 2 * m percent * B
    ybar2 = y + dy / 2 - ykm
    ybar1 = y - dy / 2 - ykm
    arg2 = ybar2 * SQR(Vriver / (DiffCoef * x)) / 2
    arg1 = arg2 * ybar1 / ybar2

    C = Ccoef * (FNerf(arg2) - FNerf(arg1)) / 2
    Csum = Csum + C

  NEXT m percent
NEXT k percent

END SUB

SUB Gauss (mcmax percent, yo, B, Vriver, DiffCoef, x, y, Ccoef, Csum)

'This subroutine is for calculating concentrations in 2D (x,y)
'starting with the concentrations from the jet mixing.

Csum = 0
'k accounts for each of 2 in set in transverse direction
FOR k percent = 1 TO 2
  'm percent accounts for center of sets of 2 in transverse direction
  FOR m percent = -mcmax percent TO mcmax percent
    ykm = (-1) ^ k percent * yo + 2 * m percent * B
    ybar = (y - ykm)
    arg = Vriver * ybar * ybar / (4 * DiffCoef * x)
    C = Ccoef * EXP(-arg)
    Csum = Csum + C

  NEXT m percent
NEXT k percent

END SUB

SUB Uexcess (Vriver, Bc, B, bjet, C2, x, y, Umax, U)

'This subroutine is for calculating jet velocities in 2D (x,y)
'after the mixing has established uniform conditions over the depth.
```

```
sumMom = 0
'm percent accounts for center of sets of 2 in transverse direction
FOR m percent = 1 TO 25

'max stores maximum contribution to excess velocity for each set of four
'values for +/-m percent and for k percent =1,2 to determine when to stop the
summation.
max = 0
'k account for each of 2 in set in transverse direction
  FOR k percent = 1 TO 2
    FOR msign percent = 1 TO 2
      ykm = (-1) ^ k percent * Bc + (-1) ^ msign percent * 2 * m percent * B
      ybar = SQR((y - ykm) ^ 2)
      eta = ybar / bjet
      ExcessVel = Umax * EXP(-.6749 * eta ^ 2 * (1 + .027 * eta ^ 4))
      IF ExcessVel > max THEN max = ExcessVel
      sumMom = sumMom + ExcessVel * (ExcessVel + Vriver)
    NEXT msign percent
  NEXT k percent
IF max < .00001 * Umax THEN GOTO 102
NEXT m percent

102 '

'Now calculate for m percent = 0 and k percent = 1 and 2
FOR k percent = 1 TO 2
  ykm = (-1) ^ k percent * Bc
  ybar = SQR((y - ykm) ^ 2)
  eta = ybar / bjet
  ExcessVel = Umax * EXP(-.6749 * eta ^ 2 * (1 + .027 * eta ^ 4))
  sumMom = sumMom + ExcessVel * (ExcessVel + Vriver)
NEXT k percent

U = .5 * (-Vriver + SQR(Vriver ^ 2 + 4 * sumMom))

END SUB
```

Appendix B
Sample Input File

Note: The program will still run with the input file format for the previous version of the program that was supplied with the draft report.

```
2       'NOF[-] = number of output files (1 or 2)
'Output file names
"c:\DiffTest\LGopenU.out"
"c:\DiffTest\LGopenU.txt"

'Descriptive information
3       'Ntitle[-] = number of lines of descriptive information (May be 0.)
Lagrange.
Open propeller.
Barges moving upstream.

'Inputs for calculations
0.0001 'converge[-] = convergence tolerance for bisection method calculations
0.25    'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
15      'Ny percent[-] = no. of vertical strips across width of river (<= 50)
1       'dx[m] = length increment for integration of mom. eq. for upstr. travel
5       'NDist percent[-] = no. of distances between barges for output (<= 20)
List x values [m] on next line(s) from smaller to larger x (NDist percent values):
1000    2000    5500
11000    22000

'Inputs for tow
u       'direction of tow movement; u or U = upstream; d or D = downstream
3       'Vb[m/s] = speed of tows relative to the flowing water
0.8     'w[-] = wake fraction
0.36    'Kt[-] = thrust coefficient
3.2     'n[rev/s] = rotational speed of propellers
209     'T[kN] = thrust of one propeller
2.74    'D[m] = propeller diameter
2       'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
1.37    'Ds[m] = vert. distance from water surface to propeller shaft
6       'Bs[m] = horizontal distance between propeller shafts
32      'Bb[m] = total width of tow

'Inputs for river
0.4     'Vriver[m/s] = flow velocity
4.2     'H[m] = river depth
150     'B[m] = river width
0.030   'Mann = Manning's coefficient
0.4     'alphay = dimensionless ambient transverse diffusion coefficient
1000    'rho[kg/m^3] = density of river water

'Inputs for jet
0.052   'C2[-] = spreading coefficient for co-flowing jets
```

Appendix C
Sample Output File

1) Lagrange, Open Impeller, Upstream

```
05-22-1999    21:51:31

Input file:   C:\DiffTest\LGopenU.inp
Output files: C:\DiffTest\LGopenU.out
              C:\DiffTest\LGopenU.txt

Lagrange.
Open propeller.
Tow moving upstream.

--- CALCULATIONS ---
 .0001      'converge[-] = convergence tolerance for bisection method calculations
 .25        'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15         'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1          'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5          'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 U          'direction of tow movement; u or U = upstream; d or D = downstream
 3          'Vb[m/s] = speed of tow relative to the flowing water
 .8         'w[-] = wake fraction
 .36        'Kt[-] = thrust coefficient
 3.2        'n[rev/s] = rotational speed of propellers
 209        'T[kN] = thrust of one propeller
 2.74       'D[m] = propeller diameter
 2          'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37       'Ds[m] = vert. distance from water surface to propeller shaft
 6          'Bs[m] = horizontal distance between propeller shafts
 32         'Bb[m] = total width of tow

--- RIVER ---
 .4         'Vriver[m/s] = flow velocity
 4.2        'H[m] = river depth
 150        'B[m] = river width
 252        'Qriver[m^3/s] = river discharge
 .03        'Mann = Manning's coefficient
 .4         'alphay = dimensionless ambient transverse diffusion coefficient
 0.0497     'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000       'rho[kg/m^3] = density of river water

--- JET ---
```

```
 .052       'C2[-] = spreading coefficient for co-flowing jets
 30.7       'Qprop[m^3/s] = discharge through one propeller
 .244       'Qratio[-] = ratio of total propeller flow to Qriver
 .6         'Va[m/s] = advance velocity
 9.21       'V2[m/s] = velocity added by propeller
 2          'Do[m] = jet diameter at vena contracta
 9.81       'Uo[m/s] = initial jet velocity for round jet relative to tow
 209        'TkN[kN] = thrust (initial momentum flux) in one jet
 154        'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
 4.3        'BQ[m] = width from which prop inflow comes

WARNING.  Both the input prop speed and the input thrust are
greater than zero.  The program has calculated a new prop speed
corresponding to the input thrust and has overridden the input
value of the prop speed.  The input value and the new value of
n used by the program are given below.
 3.2        'ninput[rev/sec] = input rotational speed of propellers
 3.73       'n[rev/sec] = calculated rotational speed of propellers


Distance between tows traveling in the upstream direction = 1000 m.
The second tow is within the jet mixing region.  There is no ambient
diffusion for this case.
For second tow with sailing lines at the indicated distances from the
left bank, the water which goes through the propellers contains the following
percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.
```

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	19	14	7	3	1	0	0	0	0	0	0	0	0	0	0
15.0	14	12	9	5	2	1	0	0	0	0	0	0	0	0	0
25.0	7	9	10	9	5	2	1	0	0	0	0	0	0	0	0
35.0	3	5	9	10	9	5	2	1	0	0	0	0	0	0	0
45.0	1	2	5	9	10	9	5	2	1	0	0	0	0	0	0
55.0	0	1	2	5	9	10	9	5	2	1	0	0	0	0	0
65.0	0	0	1	2	5	9	10	9	5	2	1	0	0	0	0
75.0	0	0	0	1	2	5	9	10	9	5	2	1	0	0	0
85.0	0	0	0	0	1	2	5	9	10	9	5	2	1	0	0
95.0	0	0	0	0	0	1	2	5	9	10	9	5	2	1	0
105.0	0	0	0	0	0	0	1	2	5	9	10	9	5	2	1
115.0	0	0	0	0	0	0	0	1	2	5	9	10	9	5	3
125.0	0	0	0	0	0	0	0	0	1	2	5	9	10	9	7
135.0	0	0	0	0	0	0	0	0	0	1	2	5	9	12	14
145.0	0	0	0	0	0	0	0	0	0	0	1	3	7	14	19

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 2000 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	13	11	8	5	3	1	0	0	0	0	0	0	0	0	0
15.0	11	10	8	6	4	2	1	0	0	0	0	0	0	0	0
25.0	8	8	8	7	5	3	2	1	0	0	0	0	0	0	0
35.0	5	6	7	7	6	5	3	2	1	0	0	0	0	0	0
45.0	3	4	5	6	7	6	5	3	2	1	0	0	0	0	0
55.0	1	2	3	5	6	7	6	5	3	2	1	0	0	0	0
65.0	0	1	2	3	5	6	7	6	5	3	2	1	0	0	0
75.0	0	0	1	2	3	5	6	7	6	5	3	2	1	0	0
85.0	0	0	0	1	2	3	5	6	7	6	5	3	2	1	0
95.0	0	0	0	0	1	2	3	5	6	7	6	5	3	2	1
105.0	0	0	0	0	0	1	2	3	5	6	7	6	5	4	3
115.0	0	0	0	0	0	0	1	2	3	5	6	7	7	6	5
125.0	0	0	0	0	0	0	0	1	2	3	5	7	8	8	8
135.0	0	0	0	0	0	0	0	0	1	2	4	6	8	10	11
145.0	0	0	0	0	0	0	0	0	0	1	3	5	8	11	13

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 5500 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tows with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	9	8	7	6	5	3	2	1	1	0	0	0	0	0	0
15.0	8	8	7	6	5	3	2	2	1	1	0	0	0	0	0
25.0	7	7	6	6	5	4	3	2	1	1	1	0	0	0	0
35.0	6	6	6	5	5	4	3	3	2	1	1	1	0	0	0
45.0	5	5	5	5	5	4	4	3	3	2	1	1	1	0	0
55.0	3	3	4	4	4	5	4	4	3	3	2	1	1	1	0
65.0	2	2	3	3	4	4	4	4	4	3	3	2	1	1	1
75.0	1	2	2	3	3	4	4	4	4	4	3	3	2	2	1
85.0	1	1	1	2	3	3	4	4	4	4	4	3	3	2	2
95.0	0	1	1	1	2	3	3	4	4	5	4	4	4	3	3
105.0	0	0	1	1	1	2	3	3	4	4	5	5	5	5	5
115.0	0	0	0	1	1	1	2	3	3	4	5	5	6	6	6
125.0	0	0	0	0	1	1	1	2	3	4	5	6	6	7	7
135.0	0	0	0	0	0	1	1	2	2	3	5	6	7	8	8
145.0	0	0	0	0	0	0	1	1	2	3	5	6	7	8	9

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 11000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	8	7	7	6	5	4	3	2	1	1	0	0	0	0	0
15.0	7	7	6	6	5	4	3	2	1	1	1	0	0	0	0
25.0	7	6	6	5	5	4	3	2	2	1	1	0	0	0	0
35.0	6	6	5	5	5	4	3	3	2	2	1	1	0	0	0
45.0	5	5	5	5	4	4	4	3	3	2	2	1	1	1	0
55.0	4	4	4	4	4	4	4	4	3	3	2	2	1	1	1
65.0	3	3	3	3	4	4	4	4	4	3	3	2	2	1	1
75.0	2	2	2	3	3	4	4	4	4	4	3	3	2	2	2
85.0	1	1	2	2	3	3	4	4	4	4	4	3	3	3	3
95.0	1	1	1	2	2	3	3	4	4	4	4	4	4	4	4
105.0	0	1	1	1	2	2	3	3	4	4	4	5	5	5	5
115.0	0	0	0	1	1	2	2	3	3	4	5	5	5	6	6
125.0	0	0	0	0	1	1	2	2	3	4	5	5	6	6	7
135.0	0	0	0	0	1	1	1	2	3	4	5	6	6	7	7
145.0	0	0	0	0	0	1	1	2	3	4	5	6	7	7	8

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	7	7	6	6	5	4	3	2	1	1	1	0	0	0	0
15.0	7	7	6	5	5	4	3	2	2	1	1	0	0	0	0
25.0	6	6	6	5	5	4	3	2	2	1	1	1	0	0	0
35.0	6	5	5	5	4	4	3	3	2	2	1	1	1	0	0
45.0	5	5	5	4	4	4	4	3	3	2	2	1	1	1	1
55.0	4	4	4	4	4	4	4	3	3	3	2	2	1	1	1
65.0	3	3	3	3	4	4	4	4	3	3	3	2	2	2	1
75.0	2	2	2	3	3	3	4	4	4	3	3	3	2	2	2
85.0	1	2	2	2	3	3	3	4	4	4	4	3	3	3	3
95.0	1	1	1	2	2	3	3	3	4	4	4	4	4	4	4
105.0	1	1	1	1	2	2	3	3	4	4	4	4	5	5	5
115.0	0	0	1	1	1	2	2	3	3	4	4	5	5	5	6
125.0	0	0	0	1	1	1	2	2	3	4	5	5	6	6	6
135.0	0	0	0	0	1	1	2	2	3	4	5	5	6	7	7
145.0	0	0	0	0	1	1	1	2	3	4	5	6	6	7	7

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

21:51:40 End 0 minute(s) 9 seconds

2) Lagrange, Kort Nozzle, Upstream

```
06-13-1997    16:53:48

Input file:  c:\DiffLarv\LGkortU.inp
Output file: c:\DiffLarv\LGkortU.out

Lagrange.
Kort nozle.
Tow moving upstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 U         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tows relative to the flowing water
 .8        'w[-] = wake fraction
 .57       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 1         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow

--- RIVER ---
 .4        'Vriver[m/s] = flow velocity
 4.2       'H[m] = river depth
 150       'B[m] = river width
 252       'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0497    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 45        'Qprop[m^3/s] = discharge through one propeller
 .358      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
```

```
 7.04     'V2[m/s] = velocity added by propeller
 2.74     'Do[m] = jet diameter at vena contracta
 7.64     'Uo[m/s] = initial jet velocity for round jet relative to tow
 209      'TkN[kN] = thrust (initial momentum flux) in one jet
 138      'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
 6.31     'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
 3.2      'ninput[rev/sec] = input rotational speed of propellers
 3.14     'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the upstream direction = 1000 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	28	20	10	4	1	0	0	0	0	0	0	0	0	0	0
15.0	20	18	13	8	3	1	0	0	0	0	0	0	0	0	0
25.0	10	13	15	13	7	3	1	0	0	0	0	0	0	0	0
35.0	4	8	13	15	13	7	3	1	0	0	0	0	0	0	0
45.0	1	3	7	13	15	13	7	3	1	0	0	0	0	0	0
55.0	0	1	3	7	13	15	13	7	3	1	0	0	0	0	0
65.0	0	0	1	3	7	13	15	13	7	3	1	0	0	0	0
75.0	0	0	0	1	3	7	13	15	13	7	3	1	0	0	0
85.0	0	0	0	0	1	3	7	13	15	13	7	3	1	0	0
95.0	0	0	0	0	0	1	3	7	13	15	13	7	3	1	0
105.0	0	0	0	0	0	0	1	3	7	13	15	13	7	3	1
115.0	0	0	0	0	0	0	0	1	3	7	13	15	13	8	4
125.0	0	0	0	0	0	0	0	0	1	3	7	13	15	13	10
135.0	0	0	0	0	0	0	0	0	0	1	3	8	13	18	20
145.0	0	0	0	0	0	0	0	0	0	0	1	4	10	20	28

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 2000 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	20	17	12	7	4	2	1	0	0	0	0	0	0	0	0
15.0	17	15	12	9	5	3	1	0	0	0	0	0	0	0	0
25.0	12	12	12	10	8	5	3	1	0	0	0	0	0	0	0
35.0	7	9	10	11	10	7	5	3	1	0	0	0	0	0	0
45.0	4	5	8	10	11	10	7	5	3	1	0	0	0	0	0
55.0	2	3	5	7	10	10	10	7	5	3	1	0	0	0	0
65.0	1	1	3	5	7	10	10	10	7	5	3	1	0	0	0
75.0	0	0	1	3	5	7	10	10	10	7	5	3	1	0	0
85.0	0	0	0	1	3	5	7	10	10	10	7	5	3	1	0
95.0	0	0	0	0	1	3	5	7	10	10	10	7	5	3	2
105.0	0	0	0	0	0	1	3	5	7	10	11	10	8	5	4
115.0	0	0	0	0	0	0	1	3	5	7	10	11	10	9	7
125.0	0	0	0	0	0	0	0	1	3	5	8	10	12	12	12
135.0	0	0	0	0	0	0	0	0	1	3	5	9	12	15	17
145.0	0	0	0	0	0	0	0	0	0	2	4	7	12	17	20

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 5500 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	13	12	11	9	7	5	3	2	1	1	0	0	0	0	0
15.0	12	12	10	9	7	5	3	2	1	1	0	0	0	0	0
25.0	11	10	10	8	7	6	4	3	2	1	1	0	0	0	0
35.0	9	9	8	8	7	6	5	4	3	2	1	1	0	0	0
45.0	7	7	7	7	7	7	6	5	4	3	2	1	1	0	0

55.0	5	5	6	6	7	7	7	6	5	4	3	2	1	1	1
65.0	3	3	4	5	6	7	7	7	6	5	4	3	2	1	1
75.0	2	2	3	4	5	6	7	7	7	6	5	4	3	2	2
85.0	1	1	2	3	4	5	6	7	7	7	6	5	4	3	3
95.0	1	1	1	2	3	4	5	6	7	7	7	6	6	5	5
105.0	0	0	1	1	2	3	4	5	6	7	7	7	7	7	7
115.0	0	0	0	1	1	2	3	4	5	6	7	8	8	9	9
125.0	0	0	0	0	1	1	2	3	4	6	7	8	10	10	11
135.0	0	0	0	0	0	1	1	2	3	5	7	9	10	12	12
145.0	0	0	0	0	0	1	1	2	3	5	7	9	11	12	13

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 11000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	12	11	10	8	7	5	4	2	2	1	1	0	0	0	0
15.0	11	11	10	8	7	5	4	3	2	1	1	0	0	0	0
25.0	10	10	9	8	7	6	4	3	2	2	1	1	0	0	0
35.0	8	8	8	8	7	6	5	4	3	2	1	1	1	0	0
45.0	7	7	7	7	7	6	6	5	4	3	2	1	1	1	1
55.0	5	5	6	6	6	6	6	5	5	4	3	2	2	1	1
65.0	4	4	4	5	6	6	6	6	5	5	4	3	2	2	2
75.0	2	3	3	4	5	5	6	6	6	5	5	4	3	3	2
85.0	2	2	2	3	4	5	5	6	6	6	6	5	4	4	4
95.0	1	1	2	2	3	4	5	5	6	6	6	6	6	5	5
105.0	1	1	1	1	2	3	4	5	6	6	7	7	7	7	7
115.0	0	0	1	1	1	2	3	4	5	6	7	8	8	8	8
125.0	0	0	0	1	1	2	2	3	4	6	7	8	9	10	10
135.0	0	0	0	0	1	1	2	3	4	5	7	8	10	11	11
145.0	0	0	0	0	1	1	2	2	4	5	7	8	10	11	12

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	11	10	9	8	7	5	4	3	2	1	1	0	0	0	0
15.0	10	10	9	8	7	5	4	3	2	2	1	1	0	0	0
25.0	9	9	9	8	7	6	5	4	3	2	1	1	1	0	0
35.0	8	8	8	7	7	6	5	4	3	2	2	1	1	1	0
45.0	7	7	7	7	6	6	5	5	4	3	2	2	1	1	1
55.0	5	5	6	6	6	6	6	5	4	4	3	2	2	2	1
65.0	4	4	5	5	5	6	6	5	5	4	4	3	3	2	2
75.0	3	3	4	4	5	5	5	6	5	5	5	4	4	3	3
85.0	2	2	3	3	4	4	5	5	6	6	5	5	5	4	4
95.0	1	2	2	2	3	4	4	5	6	6	6	6	6	5	5
105.0	1	1	1	2	2	3	4	5	5	6	6	7	7	7	7
115.0	0	1	1	1	2	2	3	4	5	6	7	7	8	8	8
125.0	0	0	1	1	1	2	3	4	5	6	7	8	9	9	9
135.0	0	0	0	1	1	2	2	3	4	5	7	8	9	10	10
145.0	0	0	0	0	1	1	2	3	4	5	7	8	9	10	11

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

16:56:13 End 2 minute(s) 25 seconds

3) Lagrange, Kort Nozzle, Downstream

```
06-13-1997    17:04:57

Input file:  c:\DiffLarv\LGkortD.inp
Output file: c:\DiffLarv\LGkortD.out

Lagrange.
Kort nozzle.
Tows moving downstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 D         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tows relative to the flowing water
 .8        'w[-] = wake fraction
 .57       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 1         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow tow

--- RIVER ---
 .4        'Vriver[m/s] = flow velocity
 4.2       'H[m] = river depth
 150       'B[m] = river width
 252       'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0497    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 45        'Qprop[m^3/s] = discharge through one propeller
 .358      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
 7.04      'V2[m/s] = velocity added by propeller
 2.74      'Do[m] = jet diameter at vena contracta
```

```
7.64      'Uo[m/s] = initial jet velocity for round jet relative to tow
209       'TkN[kN] = thrust (initial momentum flux) in one jet
116       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
8.25      'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
3.2       'ninput[rev/sec] = input rotational speed of propellers
3.14      'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the downstream direction = 1000 m.
The two tows traveling downstream are so close that the second tow reaches the propeller jet before it stagnates against the river flow. The program is not valid for this situation.

Distance between tows traveling in the downstream direction = 2000 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	20	18	15	11	8	5	3	1	1	0	0	0	0	0	0
15.0	18	17	15	11	8	6	3	2	1	0	0	0	0	0	0
25.0	15	15	13	12	9	7	5	3	2	1	0	0	0	0	0
35.0	11	11	12	11	10	9	7	5	3	2	1	0	0	0	0
45.0	8	8	9	10	11	10	9	7	5	3	2	1	0	0	0
55.0	5	6	7	9	10	10	10	8	7	5	3	2	1	0	0
65.0	3	3	5	7	9	10	10	10	8	7	5	3	2	1	1
75.0	1	2	3	5	7	8	10	10	10	8	7	5	3	2	1
85.0	1	1	2	3	5	7	8	10	10	10	9	7	5	3	3
95.0	0	0	1	2	3	5	7	8	10	10	10	9	7	6	5
105.0	0	0	0	1	2	3	5	7	9	10	11	10	9	8	8
115.0	0	0	0	0	1	2	3	5	7	9	10	11	12	11	11
125.0	0	0	0	0	0	1	2	3	5	7	9	12	13	15	15
135.0	0	0	0	0	0	0	1	2	3	6	8	11	15	17	18
145.0	0	0	0	0	0	0	1	1	3	5	8	11	15	18	20

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 5500 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
15.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
25.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
35.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
45.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
55.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
65.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
75.0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
85.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
95.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
105.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
115.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
125.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
135.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
145.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 11000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5

15.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
25.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
35.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
45.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
55.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
65.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
75.0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
85.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
95.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
105.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
115.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
125.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
135.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
145.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	5.0	15.0	25.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0
5.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
15.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
25.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
35.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
45.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
55.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
65.0	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5
75.0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
85.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
95.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
105.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
115.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
125.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
135.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6
145.0	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of

```
the width of the tows relative to the sailing lines for which
calculations are made.

17:07:09      End            2 minute(s) 11.9 seconds
```

4) Pool 8, Open Impeller, Upstream

```
06-13-1997    20:58:34

Input file:  c:\DiffLarv\P8openU.inp
Output file: c:\DiffLarv\P8openU.out

Pool 8
Open propeller.
Tows moving upstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 U         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tow relative to the flowing water
 .8        'w[-] = wake fraction
 .36       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 2         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow

--- RIVER ---
 .3        'Vriver[m/s] = flow velocity
 4.7       'H[m] = river depth
 425       'B[m] = river width
 599       'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0409    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 30.7      'Qprop[m^3/s] = discharge through one propeller
 .102      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
 9.21      'V2[m/s] = velocity added by propeller
 2         'Do[m] = jet diameter at vena contracta
```

```
 9.81      'Uo[m/s] = initial jet velocity for round jet relative to tow
 209       'TkN[kN] = thrust (initial momentum flux) in one jet
 151       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
 3.96      'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
 3.2       'ninput[rev/sec] = input rotational speed of propellers
 3.73      'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the upstream direction = 1000 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	12	2	0	0	0	0	0	0	0	0	0	0	0	0	0
42.5	2	9	2	0	0	0	0	0	0	0	0	0	0	0	0
70.8	0	2	9	2	0	0	0	0	0	0	0	0	0	0	0
99.2	0	0	2	9	2	0	0	0	0	0	0	0	0	0	0
127.5	0	0	0	2	9	2	0	0	0	0	0	0	0	0	0
155.8	0	0	0	0	2	9	2	0	0	0	0	0	0	0	0
184.2	0	0	0	0	0	2	9	2	0	0	0	0	0	0	0
212.5	0	0	0	0	0	0	2	9	2	0	0	0	0	0	0
240.8	0	0	0	0	0	0	0	2	9	2	0	0	0	0	0
269.2	0	0	0	0	0	0	0	0	2	9	2	0	0	0	0
297.5	0	0	0	0	0	0	0	0	0	2	9	2	0	0	0
325.8	0	0	0	0	0	0	0	0	0	0	2	9	2	0	0
354.2	0	0	0	0	0	0	0	0	0	0	0	2	9	2	0
382.5	0	0	0	0	0	0	0	0	0	0	0	0	2	9	2
410.8	0	0	0	0	0	0	0	0	0	0	0	0	0	2	12

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 2000 m.

The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	10	4	0	0	0	0	0	0	0	0	0	0	0	0	0
42.5	4	6	3	0	0	0	0	0	0	0	0	0	0	0	0
70.8	0	3	6	3	0	0	0	0	0	0	0	0	0	0	0
99.2	0	0	3	6	3	0	0	0	0	0	0	0	0	0	0
127.5	0	0	0	3	6	3	0	0	0	0	0	0	0	0	0
155.8	0	0	0	0	3	6	3	0	0	0	0	0	0	0	0
184.2	0	0	0	0	0	3	6	3	0	0	0	0	0	0	0
212.5	0	0	0	0	0	0	3	6	3	0	0	0	0	0	0
240.8	0	0	0	0	0	0	0	3	6	3	0	0	0	0	0
269.2	0	0	0	0	0	0	0	0	3	6	3	0	0	0	0
297.5	0	0	0	0	0	0	0	0	0	3	6	3	0	0	0
325.8	0	0	0	0	0	0	0	0	0	0	3	6	3	0	0
354.2	0	0	0	0	0	0	0	0	0	0	0	3	6	3	0
382.5	0	0	0	0	0	0	0	0	0	0	0	0	3	6	4
410.8	0	0	0	0	0	0	0	0	0	0	0	0	0	4	10

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 5500 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	7	5	2	1	0	0	0	0	0	0	0	0	0	0	0
42.5	5	4	3	2	0	0	0	0	0	0	0	0	0	0	0
70.8	2	3	4	3	1	0	0	0	0	0	0	0	0	0	0
99.2	1	2	3	4	3	1	0	0	0	0	0	0	0	0	0
127.5	0	0	1	3	4	3	1	0	0	0	0	0	0	0	0
155.8	0	0	0	1	3	4	3	1	0	0	0	0	0	0	0
184.2	0	0	0	0	1	3	4	3	1	0	0	0	0	0	0

212.5	0	0	0	0	0	1	3	4	3	1	0	0	0	0	0
240.8	0	0	0	0	0	0	1	3	4	3	1	0	0	0	0
269.2	0	0	0	0	0	0	0	1	3	4	3	1	0	0	0
297.5	0	0	0	0	0	0	0	0	1	3	4	3	1	0	0
325.8	0	0	0	0	0	0	0	0	0	1	3	4	3	1	0
354.2	0	0	0	0	0	0	0	0	0	0	1	3	4	3	2
382.5	0	0	0	0	0	0	0	0	0	0	0	2	3	4	5
410.8	0	0	0	0	0	0	0	0	0	0	0	0	2	5	7

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 11000 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	6	4	3	1	0	0	0	0	0	0	0	0	0	0	0
42.5	4	4	3	2	1	0	0	0	0	0	0	0	0	0	0
70.8	3	3	3	3	2	1	0	0	0	0	0	0	0	0	0
99.2	1	2	3	3	3	2	1	0	0	0	0	0	0	0	0
127.5	0	1	2	3	3	3	2	1	0	0	0	0	0	0	0
155.8	0	0	1	2	3	3	3	2	1	0	0	0	0	0	0
184.2	0	0	0	1	2	3	3	3	2	1	0	0	0	0	0
212.5	0	0	0	0	1	2	3	3	3	2	1	0	0	0	0
240.8	0	0	0	0	0	1	2	3	3	3	2	1	0	0	0
269.2	0	0	0	0	0	0	1	2	3	3	3	2	1	0	0
297.5	0	0	0	0	0	0	0	1	2	3	3	3	2	1	0
325.8	0	0	0	0	0	0	0	0	1	2	3	3	3	2	1
354.2	0	0	0	0	0	0	0	0	0	1	2	3	3	3	3
382.5	0	0	0	0	0	0	0	0	0	0	1	2	3	4	4
410.8	0	0	0	0	0	0	0	0	0	0	0	1	3	4	6

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	5	4	3	1	1	0	0	0	0	0	0	0	0	0	0
42.5	4	4	3	2	1	0	0	0	0	0	0	0	0	0	0
70.8	3	3	3	2	2	1	0	0	0	0	0	0	0	0	0
99.2	1	2	2	3	2	2	1	0	0	0	0	0	0	0	0
127.5	1	1	2	2	3	2	2	1	0	0	0	0	0	0	0
155.8	0	0	1	2	2	3	2	2	1	0	0	0	0	0	0
184.2	0	0	0	1	2	2	3	2	2	1	0	0	0	0	0
212.5	0	0	0	0	1	2	2	3	2	2	1	0	0	0	0
240.8	0	0	0	0	0	1	2	2	3	2	2	1	0	0	0
269.2	0	0	0	0	0	0	1	2	2	3	2	2	1	0	0
297.5	0	0	0	0	0	0	0	1	2	2	3	2	2	1	0
325.8	0	0	0	0	0	0	0	0	1	2	2	3	2	2	1
354.2	0	0	0	0	0	0	0	0	0	1	2	2	3	3	3
382.5	0	0	0	0	0	0	0	0	0	0	1	2	3	4	4
410.8	0	0	0	0	0	0	0	0	0	0	0	1	3	4	5

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

20:59:19 End 0 minute(s) 45.1 seconds

5) Pool 8, Open Impeller, Downstream

```
06-13-1997    21:01:10

Input file:  c:\DiffLarv\P8openD.inp
Output file: c:\DiffLarv\P8openD.out

Pool 8
Open propeller.
Tows moving downstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 D         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tow relative to the flowing water
 .8        'w[-] = wake fraction
 .36       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 2         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow

--- RIVER ---
 .3        'Vriver[m/s] = flow velocity
 4.7       'H[m] = river depth
 425       'B[m] = river width
 599       'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0409    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 30.7      'Qprop[m^3/s] = discharge through one propeller
 .102      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
 9.21      'V2[m/s] = velocity added by propeller
 2         'Do[m] = jet diameter at vena contracta
```

```
9.81      'Uo[m/s] = initial jet velocity for round jet relative to tow
209       'TkN[kN] = thrust (initial momentum flux) in one jet
139       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
4.84      'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
3.2       'ninput[rev/sec] = input rotational speed of propellers
3.73      'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the downstream direction = 1000 m.
The two tows traveling downstream are so close that the second tow reaches the propeller jet before it stagnates against the river flow. The program is not valid for this situation.

Distance between tows traveling in the downstream direction = 2000 m.
The two tows traveling downstream are so close that the second tow reaches the propeller jet before it stagnates against the river flow. The program is not valid for this situation.

Distance between tows traveling in the downstream direction = 5500 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	3	3	3	2	2	1	1	1	0	0	0	0	0	0	0
42.5	3	3	3	2	2	1	1	1	0	0	0	0	0	0	0
70.8	3	3	2	2	2	2	1	1	1	0	0	0	0	0	0
99.2	2	2	2	2	2	2	1	1	1	1	0	0	0	0	0
127.5	2	2	2	2	2	2	2	1	1	1	1	0	0	0	0
155.8	1	1	2	2	2	2	2	1	1	1	1	1	0	0	0
184.2	1	1	1	1	2	2	2	2	1	1	1	1	1	0	0
212.5	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1
240.8	0	0	1	1	1	1	1	2	2	2	2	1	1	1	1
269.2	0	0	0	1	1	1	1	1	2	2	2	2	2	1	1
297.5	0	0	0	0	1	1	1	1	2	2	2	2	2	2	2

325.8	0	0	0	0	0	1	1	1	1	2	2	2	2	2	2
354.2	0	0	0	0	0	0	1	1	1	2	2	2	2	3	3
382.5	0	0	0	0	0	0	0	1	1	1	2	2	3	3	3
410.8	0	0	0	0	0	0	0	1	1	1	2	2	3	3	3

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 11000 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
42.5	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
70.8	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
99.2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
127.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
155.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
184.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
212.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
240.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
269.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
297.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
325.8	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
354.2	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
382.5	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
410.8	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 22000 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the

first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	14.2	42.5	70.8	99.2	127.5	155.8	184.2	212.5	240.8	269.2	297.5	325.8	354.2	382.5	410.8
14.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
42.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
70.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
99.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
127.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
155.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
184.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
212.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
240.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
269.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
297.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
325.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
354.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
382.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
410.8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

21:01:15 End 0 minute(s) 5 seconds

6) Pool 26, Open Impeller, Upstr., Mass Balance Error at 1000 m

```
06-13-1997    21:43:18

Input file:  c:\DiffLarv\P26openU.inp
Output file: c:\DiffLarv\P26openU.out

Pool 26
Open propeller.
Tows moving upstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 U         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tow relative to the flowing water
 .8        'w[-] = wake fraction
 .36       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 2         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow

--- RIVER ---
 .5        'Vriver[m/s] = flow velocity
 7.2       'H[m] = river depth
 625       'B[m] = river width
 2250      'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0974    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 30.7      'Qprop[m^3/s] = discharge through one propeller
 .027      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
 9.21      'V2[m/s] = velocity added by propeller
 2         'Do[m] = jet diameter at vena contracta
```

```
9.81      'Uo[m/s] = initial jet velocity for round jet relative to tow
209       'TkN[kN] = thrust (initial momentum flux) in one jet
156       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
2.44      'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
 3.2      'ninput[rev/sec] = input rotational speed of propellers
 3.73     'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the upstream direction = 1000 m. The second tow is within the jet mixing region. There is no ambient diffusion for this case.

Mass balance error at end of jet mixing region for tows traveling upstream = 16.9 percent. Increase Ny percent in the input file to decrease the error.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62.5	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
104.2	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
354.2	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 2000 m. The second tow is within the jet mixing region. There is no ambient

diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0
62.5	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0
104.2	0	1	5	1	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	1	5	1	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	1	5	1	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	1	5	1	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	1	5	1	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	1	5	1	0	0	0	0	0	0
354.2	0	0	0	0	0	0	0	1	5	1	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	1	5	1	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	1	5	1	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	1	5	1	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	1	5	1	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	1	5	1
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 5500 m.
The second tow is within the jet mixing region. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
62.5	1	3	1	0	0	0	0	0	0	0	0	0	0	0	0
104.2	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	1	3	1	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	1	3	1	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	1	3	1	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	1	3	1	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	1	3	1	0	0	0	0	0	0

354.2	0	0	0	0	0	0	0	1	3	1	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	1	3	1	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	1	3	1	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	1	3	1	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	1	3	1	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 11000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1 (m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0
62.5	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0
104.2	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0
354.2	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	4

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the upstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following

percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0
62.5	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
104.2	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	1	2	1	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	1	2	1	0	0	0	0	0	0
354.2	0	0	0	0	0	0	0	1	2	1	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	1	2	1	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	1	2	1	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

21:43:45 End 0 minute(s) 27.5 seconds

7) Pool 26, Open Impeller, Upstr., Mass Balance Error Corrected

```
Only part of the output file is given here.

06-13-1997    21:46:06

Input file:  c:\DiffLarv\P26openU.inp
Output file: c:\DiffLarv\P26opnU2.out

Pool 26 with Ny = 30.
Open propeller.
Tows moving upstream.

--- CALCULATIONS ---
 .0001     'converge[-] = convergence tolerance for bisection method calculations
 .25       'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 30        'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1         'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5         'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 U         'direction of tow movement; u or U = upstream; d or D = downstream
 3         'Vb[m/s] = speed of tow relative to the flowing water
 .8        'w[-] = wake fraction
 .36       'Kt[-] = thrust coefficient
 3.2       'n[rev/s] = rotational speed of propellers
 209       'T[kN] = thrust of one propeller
 2.74      'D[m] = propeller diameter
 2         'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37      'Ds[m] = vert. distance from water surface to propeller shaft
 6         'Bs[m] = horizontal distance between propeller shafts
 32        'Bb[m] = total width of tow

--- RIVER ---
 .5        'Vriver[m/s] = flow velocity
 7.2       'H[m] = river depth
 625       'B[m] = river width
 2250      'Qriver[m^3/s] = river discharge
 .03       'Mann = Manning's coefficient
 .4        'alphay = dimensionless ambient transverse diffusion coefficient
 0.0974    'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000      'rho[kg/m^3] = density of river water

--- JET ---
 .052      'C2[-] = spreading coefficient for co-flowing jets
 30.7      'Qprop[m^3/s] = discharge through one propeller
 .027      'Qratio[-] = ratio of total propeller flow to Qriver
 .6        'Va[m/s] = advance velocity
```

```
 9.21      'V2[m/s] = velocity added by propeller
 2         'Do[m] = jet diameter at vena contracta
 9.81      'Uo[m/s] = initial jet velocity for round jet relative to tow
 209       'TkN[kN] = thrust (initial momentum flux) in one jet
 156       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
 2.44      'BQ[m] = width from which prop inflow comes

WARNING.  Both the input prop speed and the input thrust are
greater than zero.  The program has calculated a new prop speed
corresponding to the input thrust and has overridden the input
value of the prop speed.  The input value and the new value of
n used by the program are given below.
 3.2       'ninput[rev/sec] = input rotational speed of propellers
 3.73      'n[rev/sec] = calculated rotational speed of propellers


Distance between tows traveling in the upstream direction = 1000 m.
The second tow is within the jet mixing region.  There is no ambient
diffusion for this case.
For second tow with sailing lines at the indicated distances from the
left bank, the water which goes through the propellers contains the following
percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.
```

Transverse position in m of second tow:

yb1(m)	10.4	31.2	52.1	72.9	93.8	114.6	135.4	156.2	177.1	197.9	218.8	239.6	260.4	281.2	302.1
10.4	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0
31.3	3	7	2	0	0	0	0	0	0	0	0	0	0	0	0
52.1	0	2	7	2	0	0	0	0	0	0	0	0	0	0	0
72.9	0	0	2	7	2	0	0	0	0	0	0	0	0	0	0
93.8	0	0	0	2	7	2	0	0	0	0	0	0	0	0	0

8) Pool 26, Open Impeller, Downstream

```
06-13-1997    21:39:31

Input file:  c:\DiffLarv\P26openD.inp
Output file: c:\DiffLarv\P26openD.out

Pool 26
Open propeller.
Tows moving downstream.

--- CALCULATIONS ---
 .0001      'converge[-] = convergence tolerance for bisection method calculations
 .25        'Vrtrans[-] = (max. jet vel.)/(river velocity) for end of jet region
 15 'Ny percent[-] = no. of vertical strips across width of river (<= 50)
 1  'dx[m] = length increment for integration of mom. eq. for upstr. travel
 5  'NDist percent[-] = no. of distances between tows for output (<= 20)

--- TOW ---
 D  'direction of tow movement; u or U = upstream; d or D = downstream
 3  'Vb[m/s] = speed of tow relative to the flowing water
 .8 'w[-] = wake fraction
 .36        'Kt[-] = thrust coefficient
 3.2        'n[rev/s] = rotational speed of propellers
 209        'T[kN] = thrust of one propeller
 2.74       'D[m] = propeller diameter
 2  'zprop[-] = 1 for Kort nozzles; = 2 for open propellers
 1.37       'Ds[m] = vert. distance from water surface to propeller shaft
 6  'Bs[m] = horizontal distance between propeller shafts
 32 'Bb[m] = total width of tow

--- RIVER ---
 .5 'Vriver[m/s] = flow velocity
 7.2        'H[m] = river depth
 625        'B[m] = river width
 2250       'Qriver[m^3/s] = river discharge
 .03        'Mann = Manning's coefficient
 .4 'alphay = dimensionless ambient transverse diffusion coefficient
 0.0974     'DiffCoef[m^2/s] = ambient transverse diffusion coefficient
 1000       'rho[kg/m^3] = density of river water

--- JET ---
 .052       'C2[-] = spreading coefficient for co-flowing jets
 30.7       'Qprop[m^3/s] = discharge through one propeller
 .027       'Qratio[-] = ratio of total propeller flow to Qriver
 .6 'Va[m/s] = advance velocity
 9.21       'V2[m/s] = velocity added by propeller
 2  'Do[m] = jet diameter at vena contracta
```

```
9.81      'Uo[m/s] = initial jet velocity for round jet relative to tow
209       'TkN[kN] = thrust (initial momentum flux) in one jet
134       'Mo/2[kN] = init. mom. flux in one jet in stationary coord. system
3.41      'BQ[m] = width from which prop inflow comes
```

WARNING. Both the input prop speed and the input thrust are greater than zero. The program has calculated a new prop speed corresponding to the input thrust and has overridden the input value of the prop speed. The input value and the new value of n used by the program are given below.

```
3.2       'ninput[rev/sec] = input rotational speed of propellers
3.73      'n[rev/sec] = calculated rotational speed of propellers
```

Distance between tows traveling in the downstream direction = 1000 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0
62.5	1	7	1	0	0	0	0	0	0	0	0	0	0	0	0
104.2	0	1	7	1	0	0	0	0	0	0	0	0	0	0	0
145.8	0	0	1	7	1	0	0	0	0	0	0	0	0	0	0
187.5	0	0	0	1	7	1	0	0	0	0	0	0	0	0	0
229.2	0	0	0	0	1	7	1	0	0	0	0	0	0	0	0
270.8	0	0	0	0	0	1	7	1	0	0	0	0	0	0	0
312.5	0	0	0	0	0	0	1	7	1	0	0	0	0	0	0
354.2	0	0	0	0	0	0	0	1	7	1	0	0	0	0	0
395.8	0	0	0	0	0	0	0	0	1	7	1	0	0	0	0
437.5	0	0	0	0	0	0	0	0	0	1	7	1	0	0	0
479.2	0	0	0	0	0	0	0	0	0	0	1	7	1	0	0
520.8	0	0	0	0	0	0	0	0	0	0	0	1	7	1	0
562.5	0	0	0	0	0	0	0	0	0	0	0	0	1	7	1
604.2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 2000 m.
The second tow reaches the water from the prop jet of the first tow before that water returns to the cross section where it went through the prop of the first tow. There is no ambient diffusion for this case.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0
62.5	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0
104.2	1	2	3	2	1	0	0	0	0	0	0	0	0	0	0
145.8	0	1	2	3	2	1	0	0	0	0	0	0	0	0	0
187.5	0	0	1	2	3	2	1	0	0	0	0	0	0	0	0
229.2	0	0	0	1	2	3	2	1	0	0	0	0	0	0	0
270.8	0	0	0	0	1	2	3	2	1	0	0	0	0	0	0
312.5	0	0	0	0	0	1	2	3	2	1	0	0	0	0	0
354.2	0	0	0	0	0	0	1	2	3	2	1	0	0	0	0
395.8	0	0	0	0	0	0	0	1	2	3	2	1	0	0	0
437.5	0	0	0	0	0	0	0	0	1	2	3	2	1	0	0
479.2	0	0	0	0	0	0	0	0	0	1	2	3	2	1	0
520.8	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1
562.5	0	0	0	0	0	0	0	0	0	0	0	1	2	3	3
604.2	0	0	0	0	0	0	0	0	0	0	0	0	1	3	5

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 5500 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0
62.5	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0
104.2	1	2	2	2	1	0	0	0	0	0	0	0	0	0	0
145.8	1	1	2	2	2	1	0	0	0	0	0	0	0	0	0
187.5	0	0	1	2	2	2	1	0	0	0	0	0	0	0	0
229.2	0	0	0	1	2	2	2	1	0	0	0	0	0	0	0
270.8	0	0	0	0	1	2	2	2	1	0	0	0	0	0	0

312.5	0	0	0	0	0	1	2	2	2	1	0	0	0	0	0
354.2	0	0	0	0	0	0	1	2	2	2	1	0	0	0	0
395.8	0	0	0	0	0	0	0	1	2	2	2	1	0	0	0
437.5	0	0	0	0	0	0	0	0	1	2	2	2	1	0	0
479.2	0	0	0	0	0	0	0	0	0	1	2	2	2	1	0
520.8	0	0	0	0	0	0	0	0	0	0	1	2	2	2	1
562.5	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3
604.2	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 11000 m.
For second tow with sailing lines at the indicated distances from the left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0
62.5	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0
104.2	1	2	2	2	1	0	0	0	0	0	0	0	0	0	0
145.8	1	1	2	2	2	1	0	0	0	0	0	0	0	0	0
187.5	0	0	1	2	2	2	1	0	0	0	0	0	0	0	0
229.2	0	0	0	1	2	2	2	1	0	0	0	0	0	0	0
270.8	0	0	0	0	1	2	2	2	1	0	0	0	0	0	0
312.5	0	0	0	0	0	1	2	2	2	1	0	0	0	0	0
354.2	0	0	0	0	0	0	1	2	2	2	1	0	0	0	0
395.8	0	0	0	0	0	0	0	1	2	2	2	1	0	0	0
437.5	0	0	0	0	0	0	0	0	1	2	2	2	1	0	0
479.2	0	0	0	0	0	0	0	0	0	1	2	2	2	1	0
520.8	0	0	0	0	0	0	0	0	0	0	1	2	2	2	1
562.5	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3
604.2	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

Distance between tows traveling in the downstream direction = 22000 m.
For second tow with sailing lines at the indicated distances from the

left bank, the water which goes through the propellers contains the following percentages of water which went through the propellers of the leading towboat.
yb1 = transverse position of first tow.

Transverse position in m of second tow:

yb1(m)	20.8	62.5	104.2	145.8	187.5	229.2	270.8	312.5	354.2	395.8	437.5	479.2	520.8	562.5	604.2
20.8	3	2	1	1	0	0	0	0	0	0	0	0	0	0	0
62.5	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0
104.2	1	2	2	1	1	1	0	0	0	0	0	0	0	0	0
145.8	1	1	1	2	1	1	1	0	0	0	0	0	0	0	0
187.5	0	1	1	1	2	1	1	1	0	0	0	0	0	0	0
229.2	0	0	1	1	1	2	1	1	1	0	0	0	0	0	0
270.8	0	0	0	1	1	1	2	1	1	1	0	0	0	0	0
312.5	0	0	0	0	1	1	1	2	1	1	1	0	0	0	0
354.2	0	0	0	0	0	1	1	1	2	1	1	1	0	0	0
395.8	0	0	0	0	0	0	1	1	1	2	1	1	1	0	0
437.5	0	0	0	0	0	0	0	1	1	1	2	1	1	1	0
479.2	0	0	0	0	0	0	0	0	1	1	1	2	1	1	1
520.8	0	0	0	0	0	0	0	0	0	1	1	1	2	2	1
562.5	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2
604.2	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3

Depending on the width of the river and the number (Ny percent) of vertical strips used across the width of the river, some of the sailing lines near the banks of the river may not be physically possible. No check is made of the width of the tows relative to the sailing lines for which calculations are made.

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14. ABSTRACT

For two separate tows, each composed of one or more barges and a self-propelled vessel, or towboat, traveling in the same direction in a river, some percentage of the water and fish larvae that go through the propellers of the second towboat may have also gone through the propellers of the first or leading towboat. A computer program has been developed for calculating this percentage. For this calculation, the river is schematized as a rectangular channel with constant depth and constant velocity. Being located at a certain percentage of the total width of a rectangular channel is essentially equivalent to being at the same percentage of total flow rate in a natural channel.

The flows from the propellers of a towboat are analyzed as jets. The distances between tows are assumed to be large enough that the flow from the propellers of the leading towboat will become fully mixed over the river depth before the second towboat encounters this water. Thus, all of the analyses are done in terms of two-dimensional, depth-averaged conditions. The propeller jets are generated by a moving source, while the analysis was done in a stationary coordinate system. Thus, it was necessary to transform the momentum or thrust from the propeller jets in a moving coordinate system into an equivalent momentum in a stationary coordinate system.

(Continued)

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14. ABSTRACT (Concluded).

For tows traveling upstream, the jets are treated as being in a co-flow, i.e., a flow which is going in the same direction as the jet. Since the jets can persist for large distances (on the order of a kilometer), an approximate analysis was done to account for the effects of boundary friction on the jets. The end of the jet region is determined based on a tolerance for the magnitude of the jet velocity relative to the river flow velocity. After the jet velocities decrease to being within this tolerance, ambient river diffusion is used to determine the mixing of the water from the propellers of the first towboat. Based on the jet velocities, the river flow velocity, the speed of the tows, and the distance between the tows, the program determines whether the second towboat encounters the water from the first set of propellers in the jet region or in the ambient diffusion region and then calculates the makeup of the intake water for the second set of propellers. For these calculations, the river is divided into a number of vertical strips. The calculations are done for the center of the first tow at the center of each of the vertical strips. For each location of the first tow, the second one can also be at the center of each of the vertical strips. The jet calculations for tows traveling upstream were verified by comparison with laboratory measurements of velocities downstream from a stationary towboat.

The calculations for tows traveling downstream are similar except that the propeller jets are now directed against the river flow so the analysis is based on jets in counter flows. Since the jet and river flows are opposed to each other, the region of jet flow is small enough that the effects of boundary friction are not included in these calculations. The end of the jet region is taken to be when the water from the propellers returns to the cross section where the jet was generated.