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Hydrography and Hydrodynamics of Virginia Estuaries VII: Mathematical Model Studies of Water Quality of the Pagan Estuary

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HYDROGRAPHY AND HYDRODYNAMICS
OF VIRGINIA ESTUARIES

VII. Mathematical Model Studies of Water Quality
in the Pagan Estuary

A. Y. Kuo
J.-K. Lewis
and
C. S. Fang

SPECIAL REPORT NO. 107
in Applied Marine Science and Ocean Engineering

VIRGINIA INSTITUTE OF MARINE SCIENCE
Gloucester Point, Virginia 23062

William J. Hargis, Jr.
Director
January 1976
HYDROGRAPHY AND HYDRODYNAMICS OF
VIRGINIA ESTUARIES

VII. Mathematical Model Studies of
Water Quality of the Pagan Estuary

by

A. Y. Kuo
J. K. Lewis
and
C. S. Fang

PREPARED UNDER

THE COOPERATIVE STATE AGENCIES PROGRAM
OF
THE VIRGINIA STATE WATER CONTROL BOARD
AND THE VIRGINIA INSTITUTE OF MARINE SCIENCE

Project Officers

Dale Jones
Michael Bellanca

Virginia State Water Control Board

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ABSTRACT

The Cooperative State Agencies (CSA) program is a continuing activity of the Virginia State Water Control Board and the Virginia Institute of Marine Science, devoted to the development of useful water quality models of Virginia's tidal water. The program has progressed through the major tributaries into the phase of modeling the minor estuaries in which there are actual or potential water quality problems. The Pagan River is one such estuary. The town of Smithfield is located on the Pagan, about five miles (8.05 kilometers) from its juncture with the James. The river receives domestic wastes and industrial wastes from the meat packing plants located in Smithfield. Since the river is relatively narrow at this point, a critical oxygen sag has been observed near Smithfield, with minimum values of dissolved oxygen falling frequently below 3 mg/liter.

An intensive field survey was conducted in August 1974. Additional slack water runs were conducted in 1975. The hydrographic and water quality data, combined with measured bathymetric profiles, were used to construct and calibrate a one-dimensional, time-dependent mathematical model. The model simulates the distribution of dissolved oxygen, biochemical oxygen demand (both NBOD and CBOD) and salinity. The model predicts accurately the dissolved oxygen sag near Smithfield.
I. Summary and Conclusions

1. The Pagan River drainage basin lies on the fringe of a metropolitan area and is moderately industrialized. Besides a number of manufacturing industries, there are packing plants for the peanuts and pork raised in the area. The climate of southeastern Virginia is classified as humid, subtropical.

2. An intensive survey was carried out in August, 1974. Time series data on salinity, temperature and dissolved oxygen (DO) were collected at six anchor stations. During the same period, four slack-water runs were made, collecting data on salinity, temperature and dissolved oxygen.

3. Immediately prior to the sampling period, a batch dye release was made. Dye concentration was monitored by both the slack-water runs and the anchor stations.

4. Additional slack-water runs were conducted in April and July, 1975. Salinity, temperature, dissolved oxygen and biochemical oxygen demand (both CBOD and NBOD) were measured at the surface and bottom at ten stations along the river. In conjunction with the July slack-water runs, major waste dischargers were requested to monitor their BOD and TKN (total Kjeldahl nitrogen) discharge rates by the Tidewater Regional Office of the State Water Control Board.
5. Tidal action in the Pagan River is strong, with the amplitude of cross-sectional average tidal currents exceeding 1.0 ft/sec (30.5 cm/sec) at some transects.

6. Little vertical stratification in salinity was observed. The river may be classified as a sectionally homogeneous estuary. At times when freshwater inflow is low, the salinity intrudes all the way to the fall line (at mile 10.5, or kilometer 16.9) immediately downstream of Wrenns Millpond. Tidal periodicity in salinity is marked.

7. Freshwater runoff is usually slight (below 10 cfs, or 0.28 m³/sec) from July to October, and the flushing and dispersion of pollutants are dominated by tidal action. No gravitational circulation exists to augment the flushing capability.

8. A critical oxygen sag has been observed in the vicinity of Smithfield, with minimum values of dissolved oxygen falling frequently below 3 mg/liter.

9. A mathematical model of water quality in the Pagan River was constructed and calibrated. This model is a real time model, including tidal motion, with time-integration carried out by an implicit scheme. The variables modeled are salinity, dissolved oxygen, and both nitrogenous and carbonaceous biochemical oxygen demand. Bottom oxygen demand is included along with point-source loadings.
II. Introduction

The Cooperative State Agencies (CSA) program is a continuing joint project of the Virginia State Water Control Board and the Virginia Institute of Marine Science engaged in water quality modeling of Virginia estuaries. Besides the major estuaries, there are a number of minor estuaries deserving of model study because of actual or potential water quality problems. The Pagan River (Figures 1 & 2) is one such estuary.

The town of Smithfield is located on the Pagan River, about five statute miles (8.05 kilometers) upstream from its juncture with the James River. Besides domestic wastes, the stream receives organic wastes from several meat packing plants located in Smithfield. Since the river is relatively narrow at this point, a condition of low dissolved oxygen is frequently found to occur near Smithfield. A modeling study should help to determine how much treatment is needed in order to rectify this situation.

This report summarizes the observational work utilized in construction and verification of the model, the model itself and the results of the model study. The model employed is a one-dimensional, real-time model with several model parameters including dissolved oxygen, salinity and carbonaceous and nitrogenous biochemical oxygen demand.

Over the years, VIMS has occasionally sampled salinity and temperature at the mouth of the Pagan, as part
Figure 1. Map showing the location of the Pagan River.
Figure 2. The Pagan River estuary of Virginia.
(1 statute mile = 1.61 kilometers)
of the biological field studies. However, these spot samples have never included dissolved oxygen. Fortunately, regular monitoring is carried out by the Water Control Board at monthly intervals year-round. In this effort, temperature, dissolved oxygen, biochemical oxygen demand, nutrients and coliform are sampled at four points accessible by truck.
III. Description of Study Area

The Pagan River is a small tributary of the James River lying within Isle of Wight County, on the south bank of the James (see Figure 1). Economic activity along the river includes lumbering, farming (most notably peanut and hog production) and a variety of industries. The chief industries are the packing of seafood, peanut products and meat, and pulpwood paper, concrete products, truck bodies and millwork.

Topographically, the drainage basin of the Pagan River is small (67 square miles or 174 square kilometers) and low-lying, with sizeable areas of marshland along the banks. Tidal currents exceed 1.0 foot per second (0.305 meters per second) in amplitude and the tidal wave, which has a range of nearly 3 feet (0.91 meters) propagates the length of the river (about 10.5 miles or 16.9 kilometers) in a matter of minutes.

Smithfield is the only town on the Pagan River and lies on its south side approximately five miles (8.05 kilometers) from the mouth. Four point sources of pollutants are located around Smithfield, of which the two meat packing plants (Smithfield Packing Co. and ITT Gwaltney, Inc.) discharge the major portion of the biochemical oxygen demanding materials. A local low DO problem was observed as a result of these two major point sources.
IV. Hydrographic Survey

1. Field Survey

In August, 1974, an intensive survey was conducted in the Pagan River including anchor stations, slack water runs and a dye release. Six anchor stations were occupied for daylight periods of thirteen hours on two successive days. At these stations conductivity and temperature were measured and dissolved oxygen and dye were sampled. The sampling stations are shown in Figure 3. On the same two days four slack water runs were made, two at high water and two at low water. On the slack water runs, temperature and conductivity were measured and samples for dissolved oxygen and dye were collected at ten stations along the river, including one out of the mouth in the James.

The dye release consisted of one-third barrel (10 gallons or 37.9 liters) of 20% solution Rhodamine WT, released at mile 5.2 (8.4 kilometer) at high water slack two days before the anchor stations were occupied. Dye concentration was sampled along with water quality variables.

Current meters were placed in three vertical strings, at stations located at mile 0.0, 4.73, and 6.61 (0.0, 7.6, and 10.6 kilometer) (see Figure 3). These meters recorded average speed and direction at twenty-minute intervals for a period of nine to fifteen days encompassing the period of intensive survey.
Figure 3. Locations of transects at which the bathymetric profiles and water quality data were measured. (The numbers in parentheses indicate the distances from river mouth in statute miles, 1 mile = 1.61 kilometers).
In spring, 1974, eleven bathymetric profiles were taken to provide geometrical data for the model. Three more bottom profiles were added in the spring of 1975. Their locations are shown in Figure 3.

Additional slack water runs were made in April and July of 1975. One run at low water slack was made on April 30 in which salinity and temperature were measured and samples for dissolved oxygen and 5-day BOD were collected. On July 3 a slack run at high water and another at low water were made, with TKN as an additional parameter measured. In conjunction with the July slack water runs, the major waste dischargers on the Pagan were requested by the Tidewater Regional Office of the State Water Control Board to monitor their waste discharge rates, both BOD and TKN.

2. Instruments and Analyses

Conductivity and temperature were measured using an InterOcean Model 513 CTD instrument. Salinity was calculated from conductivity and temperature according to a regression formula based on laboratory calibration. Temperatures are accurate to 0.1°C; salinity is accurate to 0.1 parts per thousand (ppt). Dye concentration was measured in the laboratory using a Turner Associates model 10-000 fluorometer. Dye concentration is accurate to one percent of full scale or 0.05 parts per billion (ppb), whichever is greater.

Dissolved oxygen concentration was determined in the laboratory by means of titration (Winkler method, Azide
modification). The accuracy of this method is considered to be 0.1 milligrams per liter.

A Raytheon model DE719 fathometer was used for bottom profiling. The accuracy of the depth soundings is 0.5 feet (15 centimeters).

3. Results and Discussion

The water quality and current meter data were compiled, edited, keypunched and stored in the VIMS data file on a magnetic disk. The water quality data are summarized in Appendix A.

The three sets of salinity data show little vertical variation at most stations. The only observed stratification existed in the 2 mile (3.22 kilometer) reach of the river near the mouth in July, 1975. The data clearly shows that this stratification was caused by the stratification of the water column in the James River. This stratified structure was destroyed by tidal mixing in the inner part of the Pagan. The temporal variation of salinity shows a strong tidal periodicity. The amplitude of tidal variation in salinity increases with distance from the river mouth, with the range of variation reaching as high as 7 ppt at the most upstream station (mile 6.61, kilometer 10.6). This indicates that tidal mixing dominates throughout the estuary and that the estuary is essentially a well-mixed type (Cameron and Pritchard, 1963).
The DO data of August, 1974, also show little vertical stratification and discernible temporal variation with respect to the tidal phase. A DO sag was observed around the town of Smithfield where the two major point-sources of waste discharge are located. DO level below 5 mg/l was observed in the 2 mile (3.22 kilometer) reach of river around mile 5.5 (kilometer 8.85) during most part of the tidal cycle, with the minimum of 2 mg/l observed frequently. The same DO sag was also observed on April 30, 1975. The minimum DO was about 5 mg/l, higher than that observed in August, 1974, because of the lower water temperature (16°C) and higher freshwater discharge at this time of the year. The low water slack data of July 3, 1975, shows a large variation of dissolved oxygen from surface to bottom, despite the fact that little stratification in salinity and temperature existed. The vertical average DO indicated a peak, instead of a sag, around mile 5.0 (kilometer 8.05). Furthermore, it was noted that DO supersaturation occurred in the surface water in this reach of the river. It is thus speculated that a phytoplankton bloom might have occurred at that time, but, unfortunately, no data was collected at that time that could be used to support or disprove the speculation.

Appendix B contains a graphical summary of the dye study result. The dye concentration at the river mouth (figure B1) was about 0.5 parts per billion at 6 a.m. (around slack water before flood), August 21. Figure B7 also indicates that a detectable dye concentration was found beyond
the river mouth at approximately the same time. It can therefore be concluded that some dye was flushed out of the Pagan River the second day following dye release. The amounts of dye which remained in the Pagan on August 21 and 22 may be calculated from the longitudinal concentration distributions shown in figures B7 and B8 respectively.

The river was divided into reaches as described in Section V-1. Multiplying the volume of each reach with the dye concentration in the reach at slack water before flood and summing over all reaches, it was obtained that 6.46 lb. (2.93 kilograms) and 4.80 lb. (2.18 kilograms) of dye remained in the Pagan River on August 21 and 22 respectively. If flushing was the only mechanism that caused the loss of dye from the Pagan, a flushing rate of 0.3 per day would be required to reduce the 6.46 lb. (2.93 kilograms) of dye on August 21 (1.75 days after dye release) to 4.80 lb. (2.18 kilograms) on August 22 (2.75 days after dye release). The flushing rate, \( \gamma \), was estimated from the relationship

\[
4.80 = 6.46 \exp (- \gamma), \text{ or }
\]

\[
\gamma = - \ln \frac{4.80}{6.46} = 0.3 \text{ (1/day)}.
\]

Since the flushing rate increased as the dye patch moved downstream, the flushing rate for the first 1.75 days following the dye release would be smaller than 0.3 per day. Therefore, the amount of dye which remained in the river at
slack before flood on August 21 would be greater than

\[16.7 \exp(-0.3 \times 1.75) = 9.9 \text{ lb (or 4.49 kg)}\]

where the 16.7 lb (7.58 kilograms) is the amount of dye originally released. Since only 6.46 lb (2.93 kilogram) of dye was actually detected at slack before flood, August 21, it was concluded that dye must have been lost to the river bottom or marsh areas on river banks. In fact, visual observation by field crews during intensive hydrographic survey reported that the Pagan River water had a much higher turbidity than most of other Virginia estuaries. Because of the high rates of dye lost, either by absorption or flushing, and because of uncertainties involved in quantifying these lost rates, the results of the dye study could not be used in calibration of the model.

The cross-sectional profiles of the 14 transects are shown in Appendix C. These profiles were constructed from bathymetric data, corrected to mean tide level according to the tide tables and time of sounding. Longitudinal distance from the mouth of the river was determined from a National Ocean Survey (NOS) navigation chart.
V. Mathematical Model Study

The one-dimensional estuarine water quality model, developed under the CSA program, was used to study the water quality in the Pagan River. It is a real time, intra-tidal model employing the implicit finite difference scheme for numerical integration. The model has been applied to the major tidal rivers of Virginia and described in detail by Kuo, et al. (1975).

1. Segmentation of the River

The length of the river is divided into 32 reaches with transects located 0.25 miles (0.4 kilometers) apart (Figure 4). The geometric parameters of the transects were obtained by interpolating the field data of the 14 bathymetric profiles. Figure 5 shows the cross-sectional area of the transects as a function of distance from the river mouth. The values from the smoothed curve were actually used in the model.

2. Point Sources of Pollutants

Table 1 is a list of the point sources of pollutants. Because of their small discharge rates, the Smithfield STP, the Pinewood Heights STP, and the Battery Park Fish and Oyster Co. have negligible effect on the dissolved oxygen concentration in the river. The model reach numbers indicate the numerical identity of the reaches into which the point sources discharge. The discharge locations are also indicated in Figure 4.
Figure 4. Locations of point sources of pollutants and transects dividing the river into model segments. (The numbers outside parentheses indicate the transect numbers of the model, those inside the parentheses indicate the distances from mouth in miles, 1 mile = 1.61 kilometers).
Figure 5. Cross-sectional areas versus distance along the river. 
(1 statute mile = 1.61 kilometers)
<table>
<thead>
<tr>
<th>Source</th>
<th>Distance From River Mouth (SM)</th>
<th>Model Reach Number</th>
<th>August, 1974</th>
<th>Waste Discharge Rate</th>
<th>July, 1975</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Flow Rate (MGD)</td>
<td>BOD5 (mg/l)</td>
<td>TKN (mg/l)</td>
</tr>
<tr>
<td>Smithfield STP</td>
<td>6.7</td>
<td>6</td>
<td>0.26</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Pinewood Heights STP</td>
<td>6.3</td>
<td>7</td>
<td>-</td>
<td>5*</td>
<td>-</td>
</tr>
<tr>
<td>Smithfield Packing Co.</td>
<td>5.8</td>
<td>9</td>
<td>1.35</td>
<td>175</td>
<td>64</td>
</tr>
<tr>
<td>ITT Gwaltney, Inc.</td>
<td>4.0</td>
<td>16</td>
<td>0.95</td>
<td>60*</td>
<td>75*</td>
</tr>
<tr>
<td>Battery Park Fish and Oyster Co.</td>
<td>0.9</td>
<td>29</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

+ 1 lb/day

* data obtained by SWCB, April, 1974

** much lower than usual, data not used in the model
The data of BOD discharge rates of August, 1974, were furnished by the State Water Control Board and those of July, 1975, were provided by dischargers through SWCB. The effluent's BOD$_5$ concentration measured and reported by Smithfield Packing Co. for July, 1975 was much lower than those usually reported and doubt has been raised by SWCB personnel concerning its accuracy. In the model analysis, 1974 data of BOD$_5$ concentration of Smithfield Packing Co. was also used for July, 1975 simulation, since the reported 1975 data is so low that verification cannot be achieved with it.

3. Model Calibration and Results

Since there is no gauging station at the Pagan River, no freshwater discharge record is available. Instead of calibrating the dispersion coefficient with salinity data, the empirical constant for the dispersion coefficient obtained from the Rappahannock River simulation (Kuo, et al., 1975) was adopted. The salinity data were used to determine the freshwater discharge for each of the model simulations. The input data of freshwater discharge at the head of the estuary were adjusted until the model output of salinity distribution agreed best with the field data. The optimum freshwater discharges were determined to be 3 cfs and 6 cfs for August 1974 and July 1975 respectively. Figures 6 and 8 show the comparison of field data with model results. The model assumes freshwater runoff increased downstream in proportion
Figure 6. Longitudinal salinity distribution, August 21-22, 1974. (1 statute mile = 1.61 kilometers)
Figure 7. Longitudinal distribution of dissolved oxygen, August 21-22, 1974. (1 statute mile = 1.61 kilometers)
Figure 8. Longitudinal salinity distribution, July 3, 1975.
(1 statute mile = 1.61 kilometers)
to drainage area increment. The error introduced by this assumption tends to be magnified if the drainage area increment becomes large in comparison with the drainage area at the head. The Pagan River has a total drainage area increment of 57 mi\(^2\) (148 km\(^2\)) along its 10.5 mile (16.9 kilometers) course while the drainage area at its head is only 10 mi\(^2\) (25.9 km\(^2\)). Therefore, agreement between the model results and field data of salinity distribution in every detail can not always be achieved. A remedy for this is to incorporate in the model the detailed information of freshwater increment along the river, which is, unfortunately, not available.

The NBOD and CBOD data of July 1975 were used to calibrate the weighting factor for advection and the decay rates of NBOD and CBOD. The field data are compared with model results in figures 9 and 10. The effluent from Smithfield Packing Company is clearly demonstrated by the concentration peaks of both NBOD and CBOD around river mile 5.8 (kilometer 9.3). The effluent from ITT Gwaltney, Inc., is barely discernible at the break of the NBOD curve around river mile 4.0 (kilometer 6.4). The comparatively smaller effect of Gwaltney as compared to Smithfield Packing is due to the combination of smaller discharge rate and larger river volume at the discharge location.

The dissolved oxygen data of August 1974 were used to calibrate the benthic oxygen demand and verify the DO
Figure 9. Longitudinal distribution of carbonaceous oxygen demand, July 3, 1975. (1 statute mile = 1.61 kilometers)
Figure 10. Longitudinal distribution of nitrogenous oxygen demand, July 3, 1975. (1 statute mile = 1.61 kilometers)
distribution. Figure 7 shows the field data in comparison with model results. A DO minimum of 3.8 mg/l was predicted around mile 5.8 (kilometer 9.3) as a result of point source discharges of pollutants.

In all of the model calibration runs, the non-point source contribution to BOD was incorporated through the concentration of freshwater input. Both the CBOD and NBOD concentrations of the freshwater inflow were assured to be 1.0 mg/l. Because the freshwater drainage was so small, the contribution from non-point sources was negligible compared with point sources. The model simulation indicated that the point sources alone were responsible for the BOD distribution in the estuary for the low-flow period.

4. Sensitivity Analysis

The purpose of sensitivity analysis was to demonstrate the effects of varying the input rate constants on model results. The approach adopted in this sensitivity analysis was to assume two values for each rate, one significantly higher and the other significantly lower than the calibrated value. All of the model runs simulated the August 1974 loading condition that had been previously calibrated. Three sensitivity analyses were made by independently varying either the BOD decay rate, benthic oxygen demand, or the dispersion coefficient while maintaining all other input data unchanged. The sensitivity of the DO profile to different forms of equations determining reaeration rates was not analyzed, since it was concluded that the DO profile was
extremely insensitive to the more commonly used equations (Clark and Jaworski, 1972).

The simulated CBOD, NBOD, and DO profiles based on different BOD decay rates are shown in figures 11, 12, and 13. Figure 13 illustrates that the decay rates have a considerable effect on the DO distribution, and in particular on the minimum DO. Increasing the decay rates by a factor of 2 over the calibrated values results in a lowering of the critical sag point from 3.9 mg/l to 2.5 mg/l. Decreasing the decay rates by a factor of 2 results in a less than 1.0 mg/l increase in minimum DO.

The DO profile is shown to be sensitive to the change in the benthic demand rate in figure 14. The solid curve represents the calibrated result for which the benthic demand rate is 1.0 mg/m²/day upstream of mile 4.75 (kilometer 7.65) and 1.5 mg/m²/day downstream. The other two curves show the DO profiles corresponding to uniform benthic demand rates of 1.0 and 0.0 mg/m²/day respectively.

Figures 15, 16, 17, and 18 show the effects of the dispersion coefficient on the distributions of salinity, CBOD, NBOD, and DO. It is seen that the dispersion coefficient has a more pronounced effect on the distributions of CBOD, NBOD, DO than that of salinity. The high sensitivity to dispersion coefficient is due to the fact that dispersion is an important transport mechanism in estuaries where the longitudinal density gradient induces gravitational circulation,
and, thus, the dispersion by 'shear effect'. The effect of dispersion coefficient is amplified by the high gradients in the vicinities of the peaks of CBOD and NBOD distributions and the sag of DO distributions.
Figure 11. Effects of decay rate on CBOD distributions.
Figure 12. Effects of decay rate on NBOD distributions.
Figure 13. Effects of CBOD and NBOD decay rates on DO profiles.
Figure 14. Effects of benthic demand rate on DO profiles.
Figure 15. Effects of dispersion coefficient on salinity distributions.

DISTANCE UPSTREAM FROM MOUTH (STATUTE MILES)

(Salinity is measured in parts per thousand, %o.)

- - - TWICE THE CALIBRATED VALUES

- - - CALIBRATED VALUES

- - - 1/3 OF CALIBRATED VALUES

1 statute mile = 1.61 kilometers
Figure 16. Effects of dispersion coefficient on CBOD distributions.
Figure 17. Effects of dispersion coefficient on NBOD distributions.
Figure 18. Effects of dispersion coefficient on DO profiles.
References


APPENDIX A

Graphical Summary of Water Quality Data
SALINITY SURFACE ○
BOTTOM △

DISSOLVED OXYGEN SURFACE □
BOTTOM X

MILE 0.88
Salinity Surface \textit{O} Aug. 21, 1974

Low Water Slack

Dissolved Oxygen Surface \textit{O}

Bottom $\triangle$

Distance Upstream (Statute Miles)
SALINITY SURFACE O AUG. 21, 1974
BOTTOM A

DISSOLVED OXYGEN SURFACE O
BOTTOM X

AUG. 21, 1974
HIGH WATER SLACK

DISTANCE UPSTREAM (STATUTE MILES)
SALINITY SURFACE O
BOTTOM △
DISSOLVED OXYGEN SURFACE □
BOTTOM X
AUG. 22, 1974
HIGH WATER SLACK

DISTANCE UPSTREAM (STATUTE MILES)
The graph shows the relationship between biochemical oxygen demand (ppm) and temperature (°C) at different distances upstream (statute miles) on April 30, 1975, at Low Water Slack. The data points are categorized by surface (square), bottom (X), and surface (circle) markers.
JULY 3, 1975
HIGH WATER SLACK

SALINITY (%)

DISTRIBUTED OXYGEN (mg/l)

DISTANCE UPSTREAM (STATUTE MILES)
JULY 3, 1975
HIGH WATER SLACK

TEMPERATURE
+ MID-DEPTH
△ BOTTOM

TOTAL BOD
□ SURFACE
△ BOTTOM

NBOD
○ SURFACE
△ BOTTOM

DISTANCE UPSTREAM (STATUTE MILES)

BIODEOXYGEN DEMAND (ppm)

TEMPERATURE (°C)
APPENDIX B

Graphical Summary of Dye Data
PAGAN RIVER
MILE 0.0
AUG. 21, 1974
AUG. 22, 1974
PAGAN RIVER
MILE 5.17

- AUG. 21, 1974
- AUG. 22, 1974

DYE CONCENTRATION (PPB)
PAGAN RIVER  SLACK WATER

SLACK BEFORE FLOOD  AUG. 21, 1974

SLACK BEFORE EBB  AUG. 21, 1974

DYE CONCENTRATION (PPB)

DISTANCE UPSTREAM (STATUTE MILES)
PAGAN RIVER

SLACK WATER

- - SLACK BEFORE FLOOD AUG. 22, 1974
- - SLACK BEFORE EBB AUG. 22, 1974

DYE CONCENTRATION (PPB)

DISTANCE UPSTREAM (STATUTE MILES)

-2 0 2 4 6 8 10
APPENDIX C

Cross-sectional Profiles
PAGAN RIVER 0.0 MILES
PAGAN RIVER  0.88 MILES
PAGAN RIVER 1.4 MILES
PAGAN RIVER 2.22 MILES
PAGAN RIVER 4.73 MILES
PAGAN RIVER 6.03 MILES
PAGAN RIVER 6.61 MILES