ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCE
UNIVERSITY OF MIAMI

Report to the Department of
Environmental Resources Management
Metropolitan Dade County

CANAL DISCHARGES INTO SOUTH BISCAYNE BAY

by

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CANAL DISCHARGES INTO SOUTH BISCAYNE BAY

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I. INTRODUCTION

Three major canals (Snapper Creek, Black Creek and Mowry) drain into South Biscayne Bay. For the period October 1975 to September 1976 the maximum, minimum and average discharges are shown in Table I-1.

The relatively small discharges do not influence the flow patterns in the bay significantly however the water quality is affected.

II. OBJECTIVES

The objectives of this study are to estimate the zone of influence of the canal discharges in South Biscayne Bay using field dye studies and existing mathematical models. Specifically:

1) Carry out dye dispersion experiments and plot the extent of dye spreading.

2) Use these dye studies to determine the smaller scale mixing characteristics in the vicinity of each canal.

3) Use mathematical models to simulate realistic operational conditions.

III. FIELD PROGRAM

The field program consisted of drogue and dye studies. The drogue studies were conducted to help determine the area to be monitored and amount of dye to use for the dispersion experiments. The dye studies were designed to provide maximum information about small scale dispersion and to determine dispersion coefficients for the numerical model DISPER.

Table I-1. Canal discharges in cfs (m^3/sec)

	Max	Min	Average
Snapper Creek	1230 (34.8)	0	228 (6.5) 27 years
Black Creek	1630 (46.2)	0	101 (2.9) 6 years
Mowry	1720 (48.7)	0	172 (4.9) 6 years

III.1. Drogue studies

In order to examine advective water motion in the vicinity of the three canals, drogues were dropped at several different depths and their horizontal displacement was determined over a period of several hours prior to the dye experiments.

The drogue study at Snapper Creek was conducted without means for determining location accurately and was therefore mainly of qualitative use. Three drogues at 3, 5 and 7 ft were deployed and observed during a flood period. The drogues all moved south parallel to the shoreline with the 3-ft drogue travelling approximately 1.5 miles and the two other drogues somewhat less. The separation between the top and bottom drogue at the end of the study was approximately 1000 ft.

Figure III-1 illustrates the drogue study at Black Creek. Winds on this day were 5 - 8 mph out of the SE. The 1- and 2-ft drogues beyond the breakwater exhibit the NE - SW motion typical of the tidal currents in this region of the bay. The 1-ft drogue within the confines of the breakwater shows a characteristic E-W motion due to the sheltering effect of the breakwater. Net displacement of the outer drogues is about 7000 ft whereas for the inner drogue, it is about 1800 ft. The tide at Black Creek lags Miami Harbor by about 2 - 3 hrs, so that the displacement in Figure III-1 is entirely on the flood tide.

The drogue paths indicate that in the absence of significant wind and dispersion a substance would be expected to move back and forth in an E-W direction with the weak tidal currents until

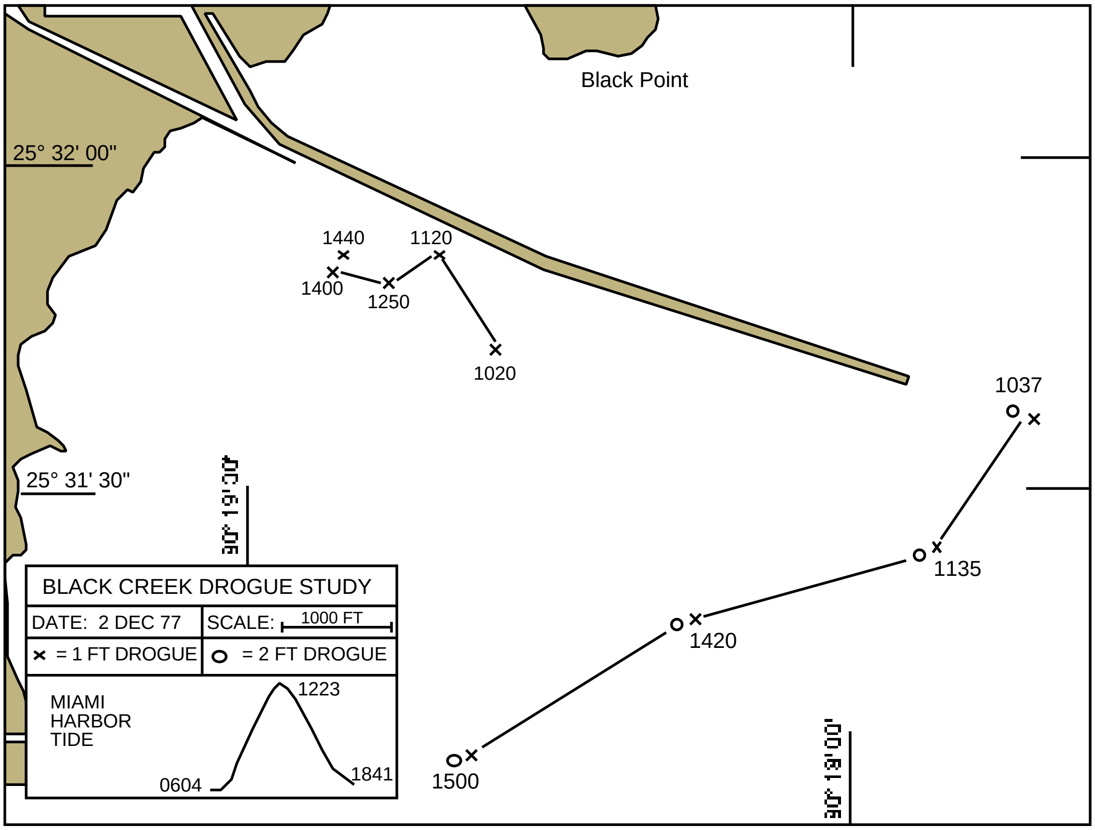


Figure III-1. [NO CAPTION IN ORIGINAL.]

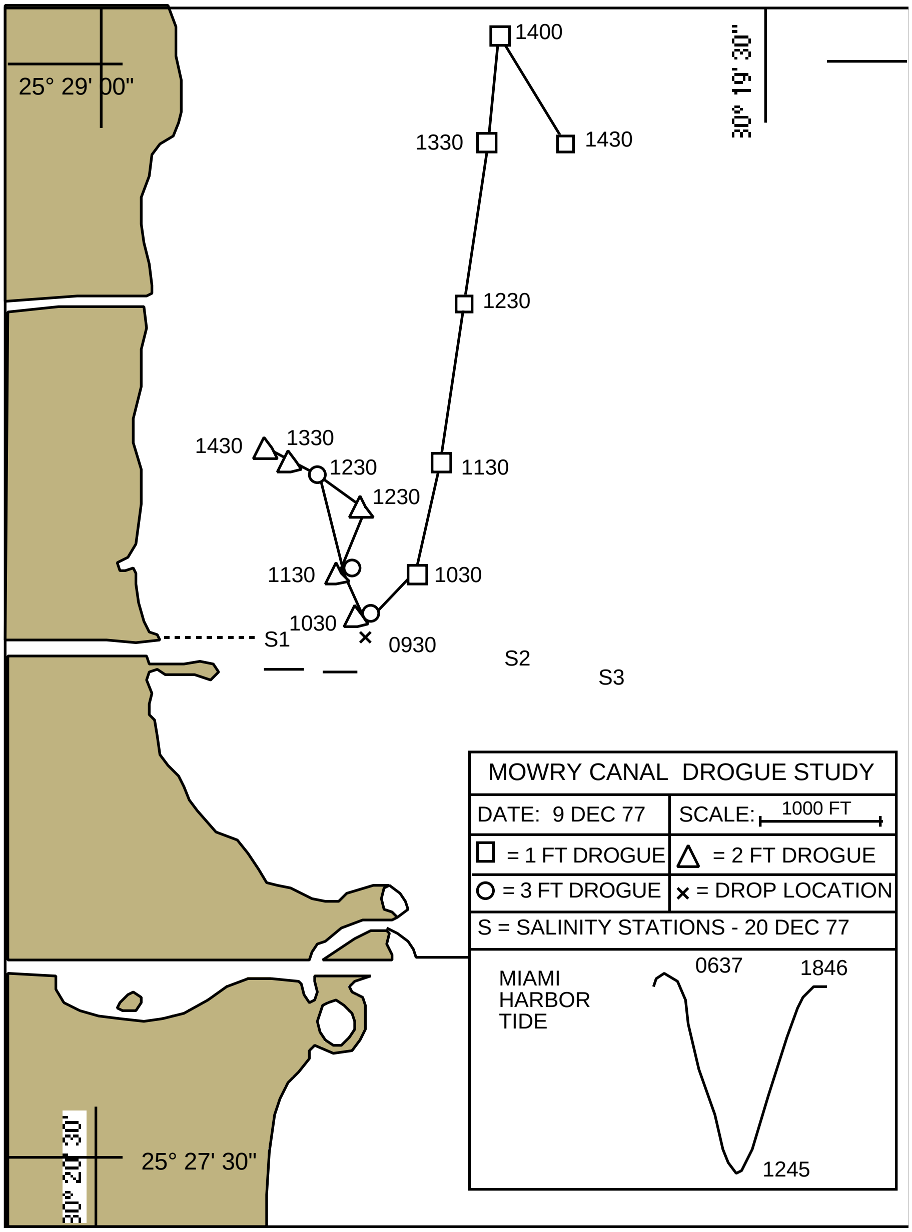


Figure III-2. [NO CAPTION IN ORIGINAL.]

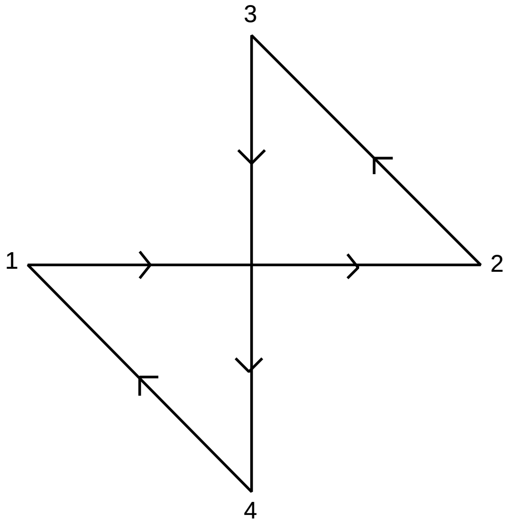


Figure III-3. Typical pattern of line tracks run through dye patch. Numbers indicate successive end points of line segments at which sextant "fixes" were taken.

it reached the end of the breakwater. At that point it would come under the influence of the more rapid tidal currents of the bay proper and would be dispersed much more quickly.

A similar study was conducted in the region of Mowry Canal by deploying drogues at 1-, 2-, and 3-ft depths. Figure III-2 indicates that the motion in the region consists of a two-layer flow. The 1-ft drogue, representing the near-surface flow, shows a rapid northerly displacement whereas the 2- and 3-ft drogues exhibit relatively little displacement which is directed to the north with a shoreward component. The surface drogue, under the influence of the lighter fresher surface water moves bayward and enters the more rapid northerly directed tidal currents of that region. Outflowing surface water is replaced by a shoreward flow of denser bottom water which may explain the shoreward motion of the deeper drogues. As a result the 1-ft drogue is displaced about 5000 ft to the north whereas the 2-ft drogue is displaced northwesterly 1800 ft. The 3-ft drogue, traveling in the same direction as the 2-ft drogue, was stuck on the bay bottom before the end of the experiment. During the study the wind was out of the southeast at 8 mph with apparently little effect on drogue displacements.

III.2. Dye experiments

Field experiments for the three canals in south Biscayne Bay were all conducted in basically the same manner. A quantity of DuPont 20% Rhodamine WT liquid dye solution was injected outside the mouth of the canals and its concentration monitored using a Turner Designs fluorometer equipped with a flow-through cuvette. The Turner Designs fluorometer is capable of measuring minute concentrations of fluorescent dye down to <0.1 part per billion. Rhodamine WT (20%) has a specific gravity of 1.19 and is highly miscible with water. To avoid settlement, the dye mixture should be diluted with bay water before release.

The apparatus used in the field experiments consisted of the fluorometer through which bay water was continuously passed using a small electric pump. A Rustrak recorder connected to the fluorometer produced an analog record of the fluorometer read-out at a recording rate of 1 point/2 sec. The entire apparatus was placed on a small outboard boat and was run on a 12-volt wet cell battery. Bay water was continuously conveyed to the fluorometer via a hose attached to a V-fin depressor which was towed below the water surface.

Dye was diluted with bay water in a large bucket and was injected by hand-pumping it through the vertical water column so that it would be introduced at all levels. The boat's engine was then used to mix it more thoroughly at the point of injection. At the injection point, a buoy was dropped and its position noted using a sextant. The buoy served as a convenient point for obtaining readings of dye concentration. In addition, at this point, current speed and direction were taken with a Teledyne-Gurley current meter, wind was measured with a small fisherman's hand-held wind gauge, and salinity and temperature profiles were obtained with a Beckman portable salinometer. Monitoring of the dye concentration was then begun by running the boat at slow speed along straight-line paths lengthwise and crosswise through the elongated dye patch. A drogue was placed near the center of the dye patch to follow the horizontal advection of the dye under the influence of the local current regime. It was convenient to run four tracks through the dye in order to obtain as complete a picture of the dye patch as possible. However, it was occasionally necessary to run more line tracks. An example of the pattern of tracks was to run east from the buoy through the dye until a zero reading was recorded, stop the boat, determine position with a sextant, run northwest to a zero concentration, determine position, run south to zero concentration, determine position, and finally run northwest back to the buoy (See Figure III-3). The two main tracks then form an 11V pattern with the four end points connected by the two other tracks. The time elapsed in running this pattern is of the order of 1 hour.

The recorded analog record of concentration was digitized and the readings plotted on a map. Isopleths of dye concentration were then drawn so that the resulting contours give a fairly complete quasi-synoptic picture of the dye patch at various times following injection. They also give a graphic representation of the history of dye spreading under the influence of the local current regime as well as diffusion.

The first of the series of dye studies was conducted near the mouth of Snapper Creek on November 2, 1977 when 5 gallons of dye were injected at 0640 and monitored until 1756 hrs. On December 7, 1977 2 gallons of dye were injected near the mouth of Black Creek at 0910 and monitored until 1544 hrs. Upon returning on the following morning, a substantial amount of dye was still present in the region. Dye concentration was, therefore, recorded from 0957 to 1349 hrs. A dye study at the mouth of Mowry Canal was begun by injecting 2 gallons of dye at 0830 hrs. on December 19, 1977. However, within an hour, the weir controlling water outflow from Mowry Canal was opened, releasing a large quantity of fresh water into the bay. The rapid currents caused by the sudden water release led to increased spreading of the dye. In addition, the large volume of fresh water created a vertically stratified water column as well as a horizontal density gradient that inhibited a homogeneous spreading of the dye patch. As a result, when measuring dye concentration at a single depth along a straight line path, the recorded concentrations often varied erratically in moving through different regimes of water stratification. These factors caused a fair amount of difficulty in monitoring the dye patch. Despite these difficulties dye concentration readings were taken until 1708 hrs. The experiment was repeated on December 20 but with the same problem. Two gallons of dye were injected at 0915 hrs. Again, within the hour, fresh water was released from the canal creating the same difficulties as on the previous day. Concentration measurements were made until 1440 hrs. When dye could no longer be detected in significant concentration. The unpredictability of the canal discharge rate is a major obstacle in carrying out a meaningful dye study.

IV. ANALYSIS OF DATA

Measurements of dye concentration were plotted on charts and isopleths of concentration were drawn to give a quasi-synoptic picture of horizontal dye distribution.

Figures IV-1 to IV-7 show isopleths of dye concentration near the mouth of Snapper Creek for the experiment of 2 November 1977. The general trend during the study period is for the dye patch to assume an elliptical shape with the long axis oriented parallel to the shoreline. The elongation of the dye patch is a reflection of vertical shearing motion caused by the tidal currents. In this region of Biscayne Bay, tidal currents, which are usually the dominant current component, tend to be oriented in a northeasterly-southwesterly direction, i.e., parallel to the shoreline. Note that, with the exception of Figure IV-7, the dye patch shows relatively little tendency to spread outward from the shore. Winds during the day are light out of the east at 3-5 mph, and no significant stratification was found.

The presence of isolated peak concentrations in these figures is an indication of difficulties encountered in conducting this experiment in shallow water. At the time of injection, a quantity of dye was concentrated in the sea grass on the bay bottom and was gradually released through the first 2 - 3 hours of the experimental period. Whereas the zero isopleth is considered accurate for the first three tracks, the other isopleths are only crude estimates since actual concentrations exceeded the instrument range at times during those runs. This also explains in part the apparent increase with time of the total mass of dye. An additional factor, which should be considered in interpreting the earlier runs is the inhomogeneous vertical distribution that must be expected. Only after a period long enough to cause thorough vertical mixing can the measurements be used in a quantitative sense.

Figures IV-8 to IV-12 are the results of the experiment conducted near the mouth of Black Creek on 7 - 8 December 1977. Figure IV-8 indicates that there is an initial elongation of the dye patch probably as a result of vertical velocity shear induced by the ebbing tide. No further elongation is present in Figures IV-9 and IV-10 which may be attributed to slack tide and the sheltering effect of the breakwater. The dye patch has a longitudinal axis oriented W-E parallel to the breakwater and exhibits W-E advective motion under the influence of tidal currents. In spite of moderate winds (10 mph) from the northwest, the dye patch shows little tendency to be wind affected. This also appears to be the result of sheltering by the breakwater. No freshwater is released from the canal and the density field is found to be vertically homogeneous.

By the morning of 8 December 1977, the dye patch has been dispersed and has lost its elliptical shape (Figures IV-11 and IV-12). Winds out of the east (10 - 15 mph) during this day may have reduced exchange of water between the small embayment and the bay proper. As a result, dye is still present in significant concentration 29 hours after injection (see Figure IV-12). The smaller spreading rate found at Black Creek compared to Snapper Creek is consistent with the smaller depth at that location. It is interesting to note the relatively small effect of rather strong winds on the subsurface dye distribution. It is likely that wind has a very significant effect on a very thin surface layer (<0.5 ft). However, this could not be measured.

On 19 December 1977, a dye experiment was conducted at the mouth of Mowry Canal (Figures IV-13 to IV-15) under rather unfavorable environmental conditions. A strong vertical and horizontal salinity gradient caused by intermittent fresh water discharge from the canal made single-depth concentration measurements questionable. Note, for example, the salinity stratification at the point of dye injection illustrated in Figure IV-16 at 3 times during the day. However, some observations can be made from the general shape and orientation of the dye patch. Figure IV-13 shows the rapid spreading of the dye within 2 hours of injection under the

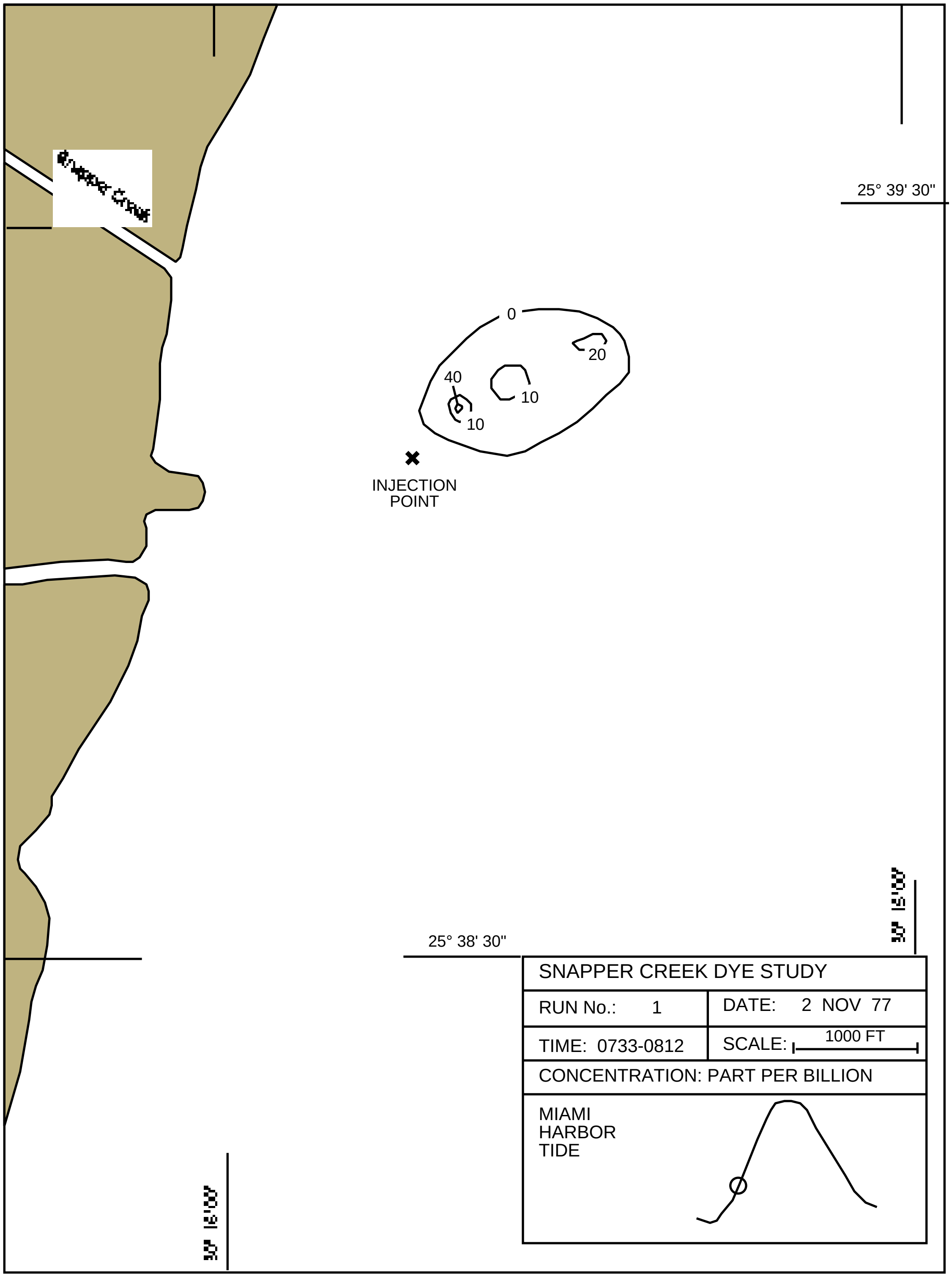
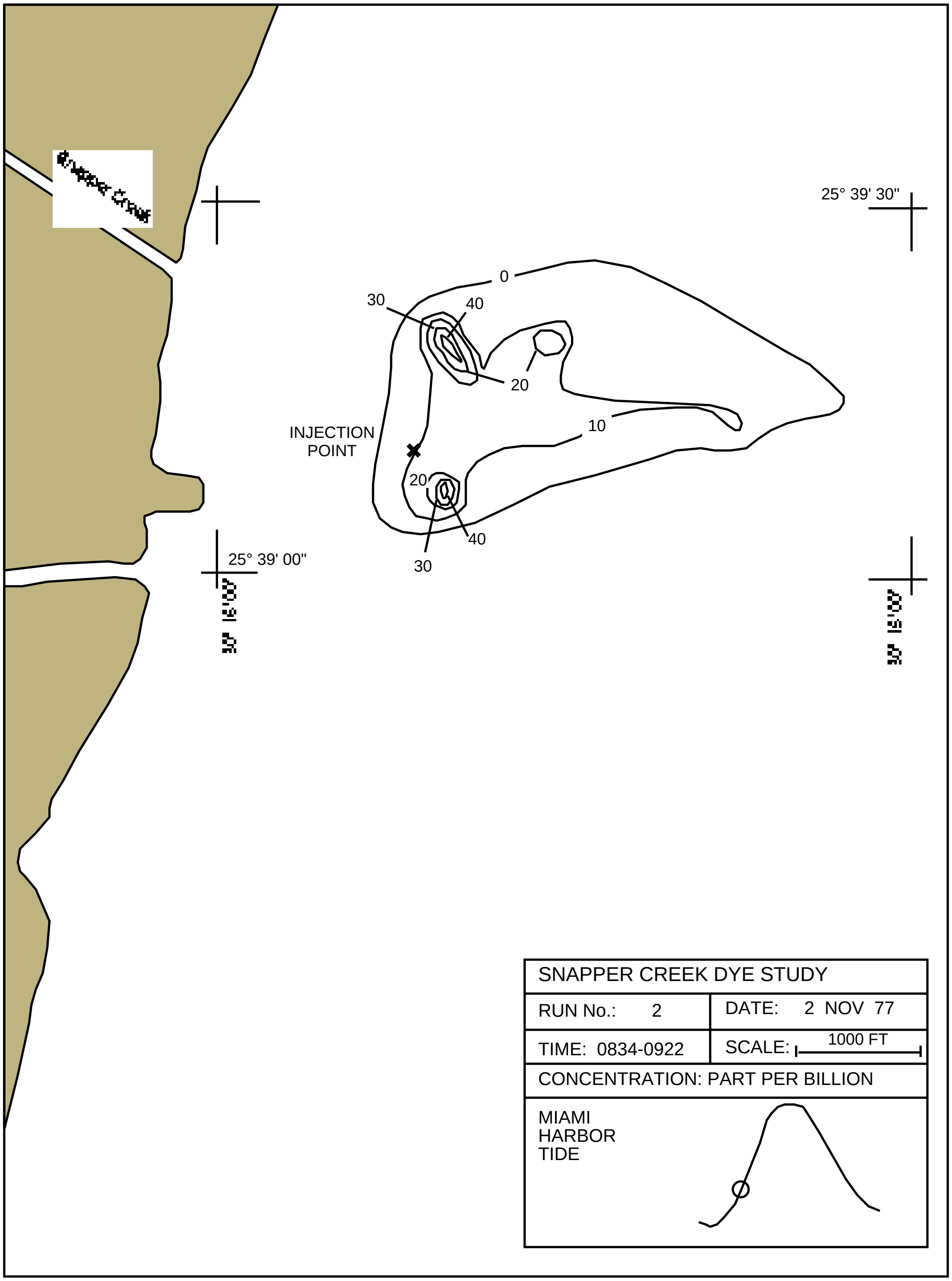


Figure IV-1. [NO CAPTION IN ORIGINAL.]



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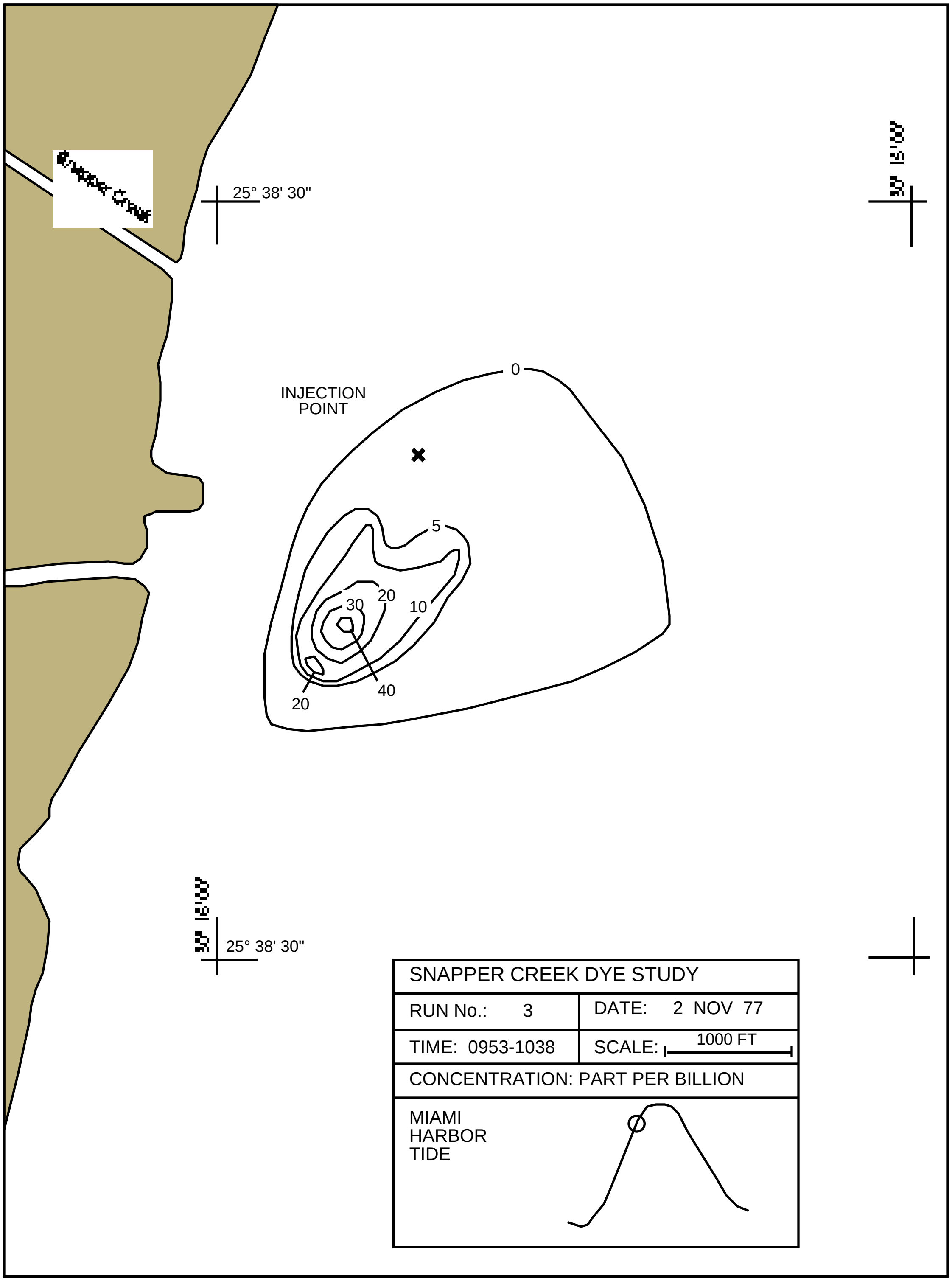

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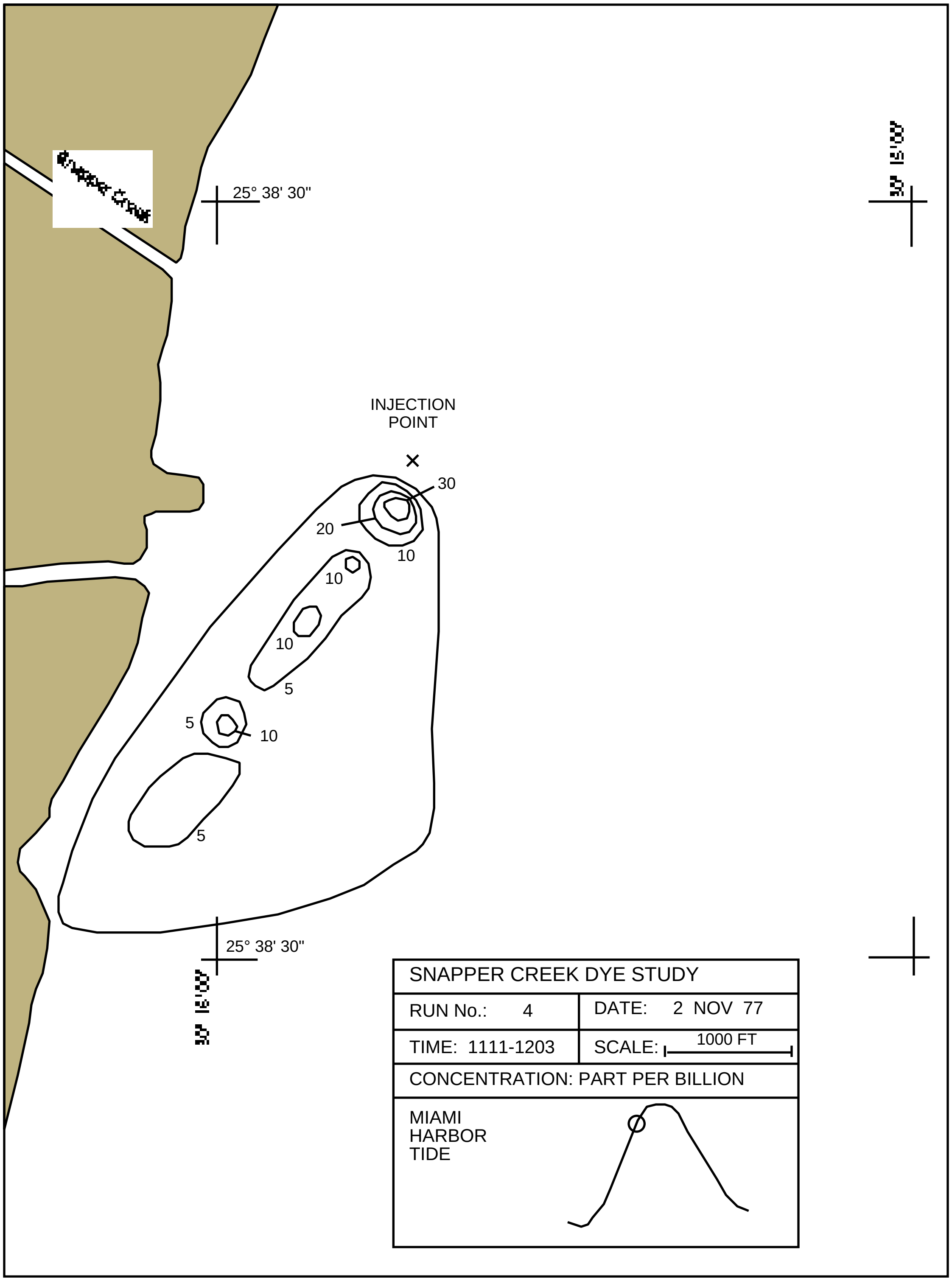

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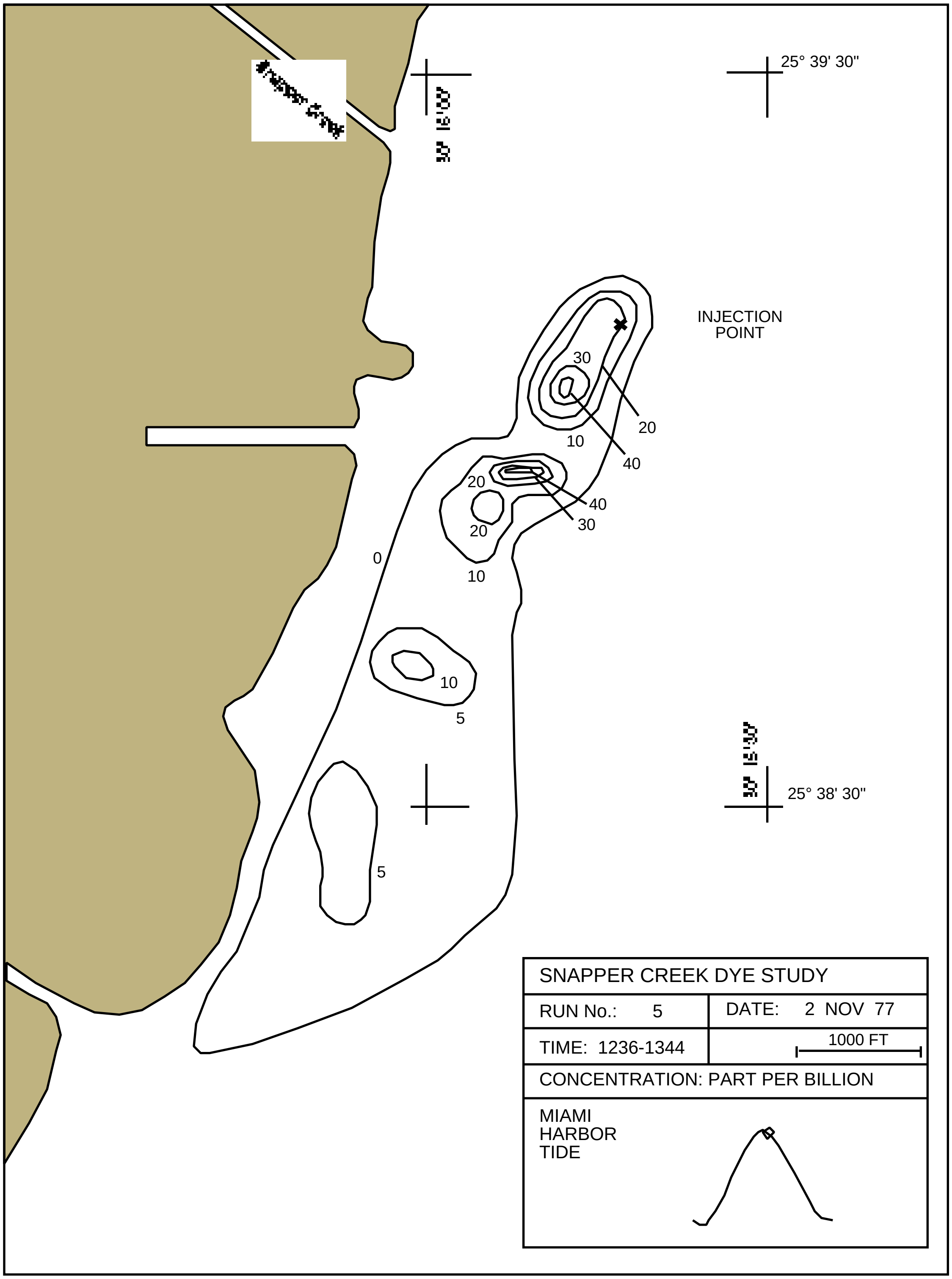

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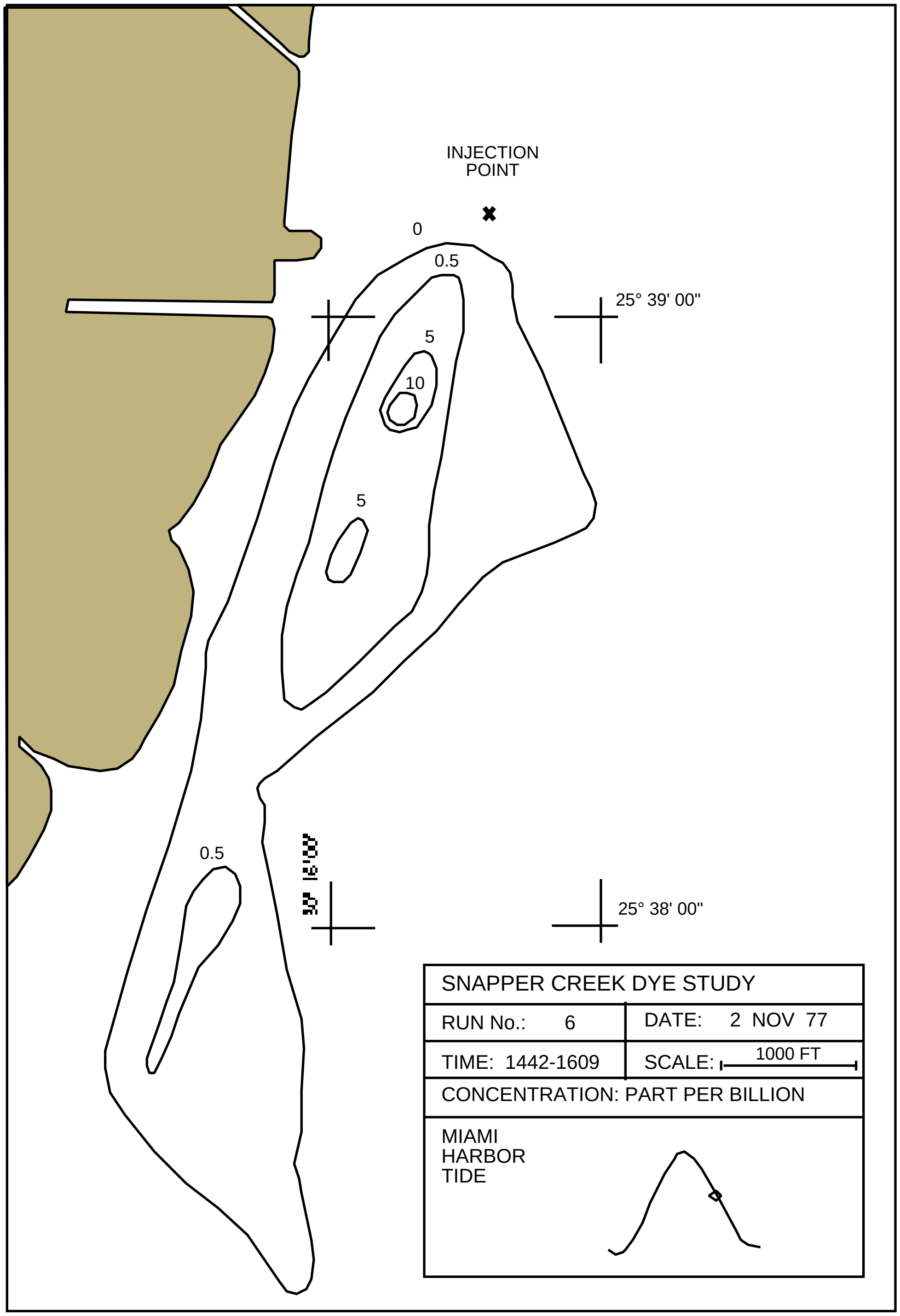

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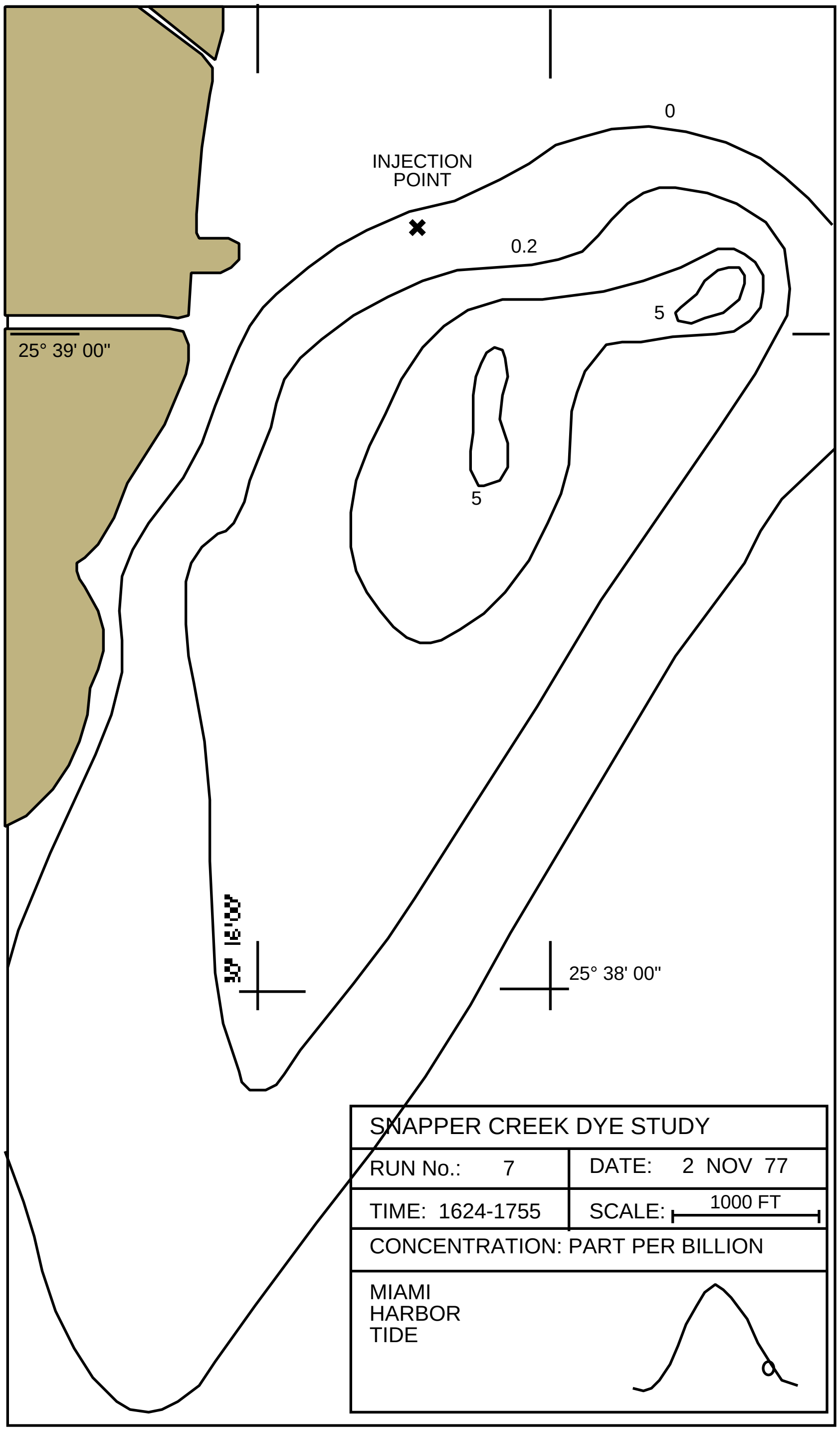

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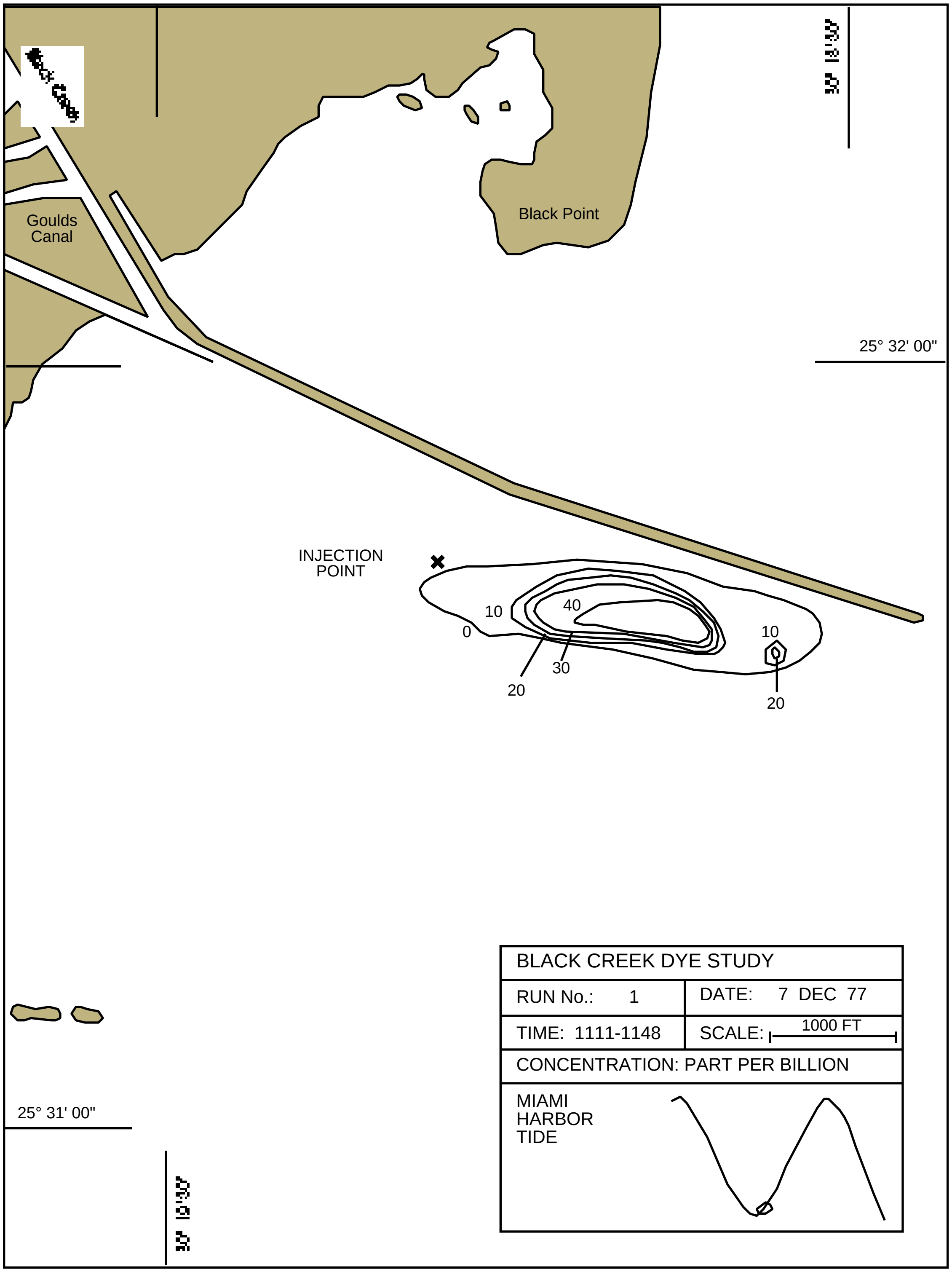
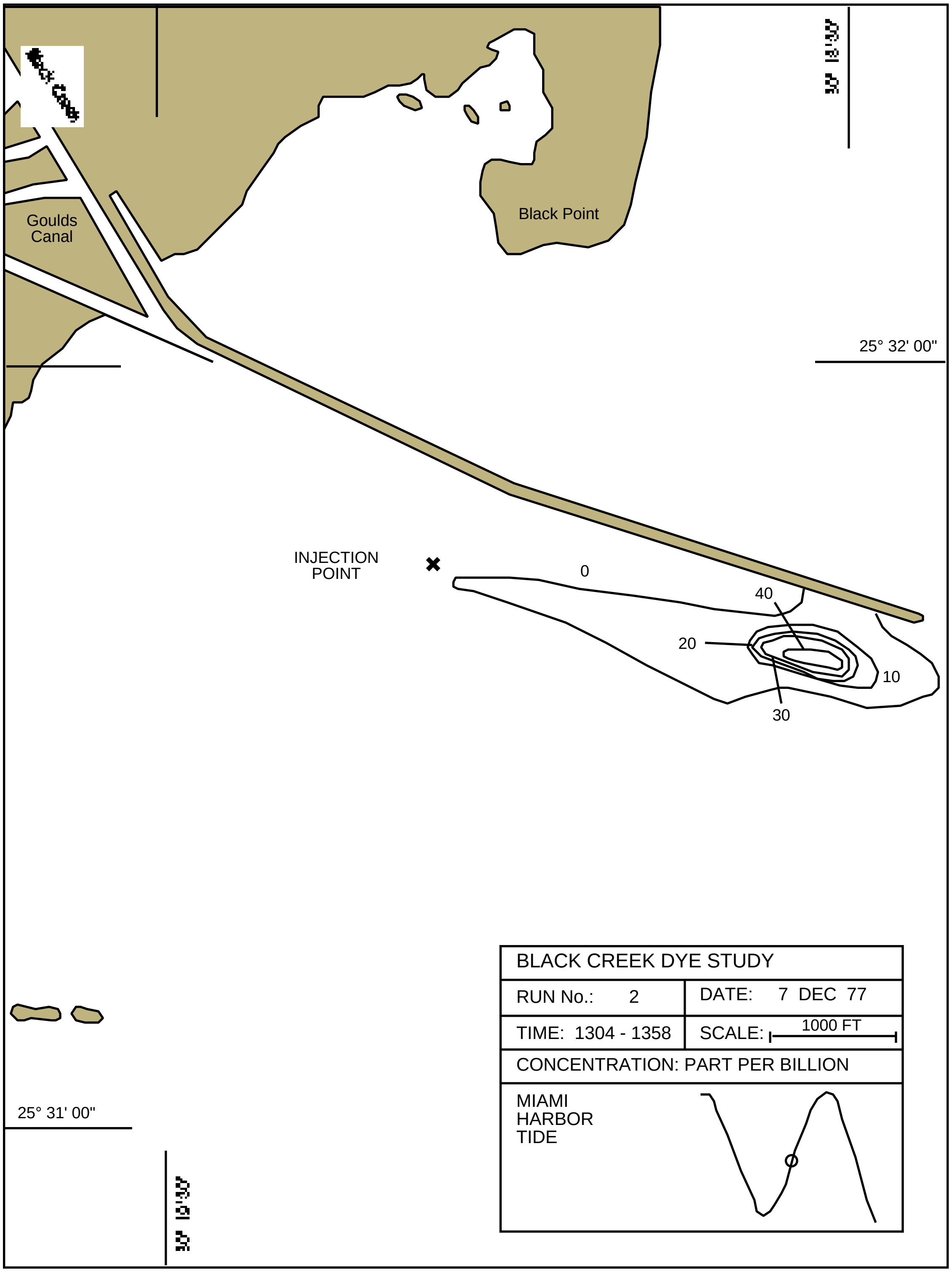


Figure IV-8. [NO CAPTION IN ORIGINAL.]



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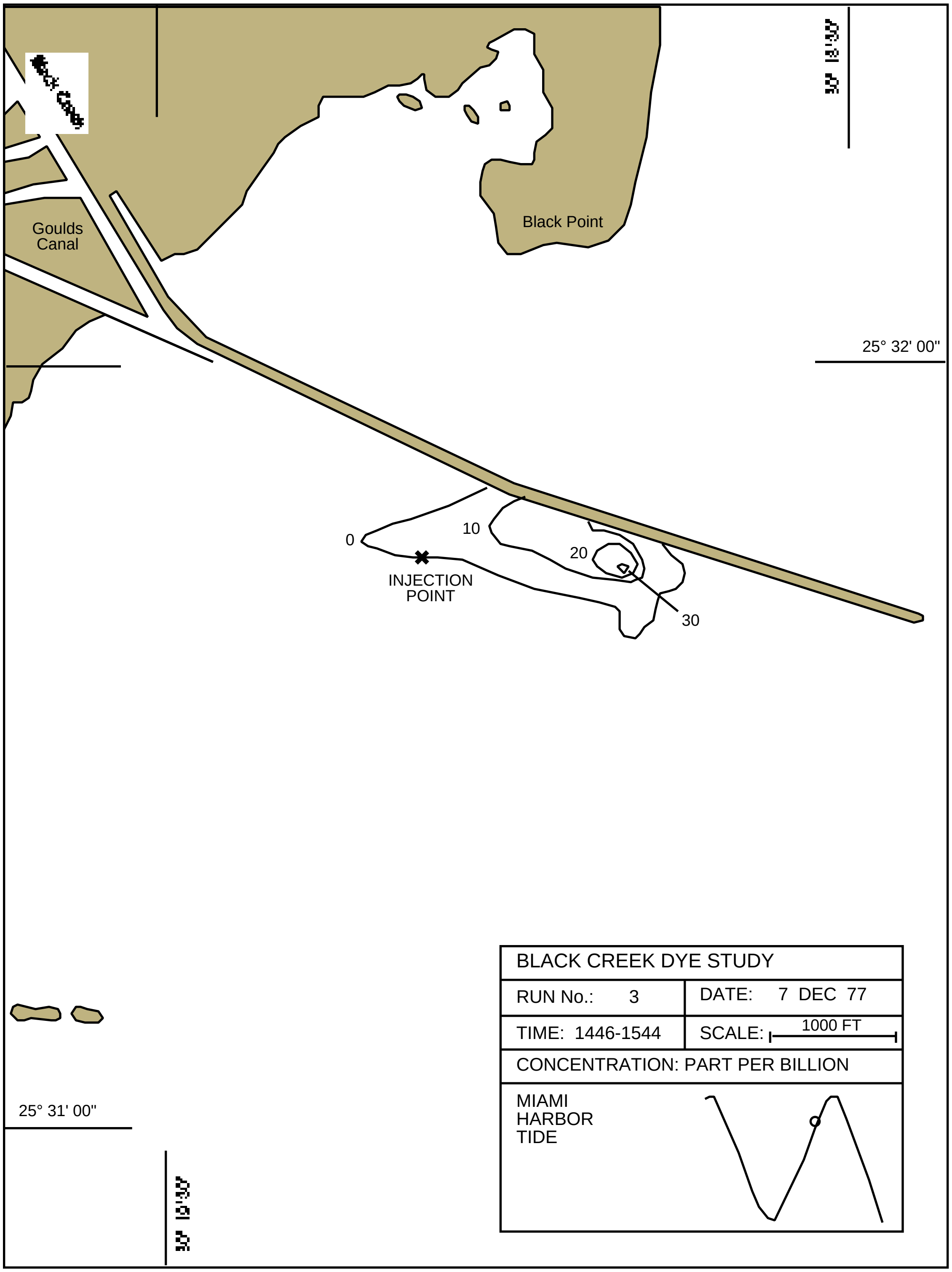

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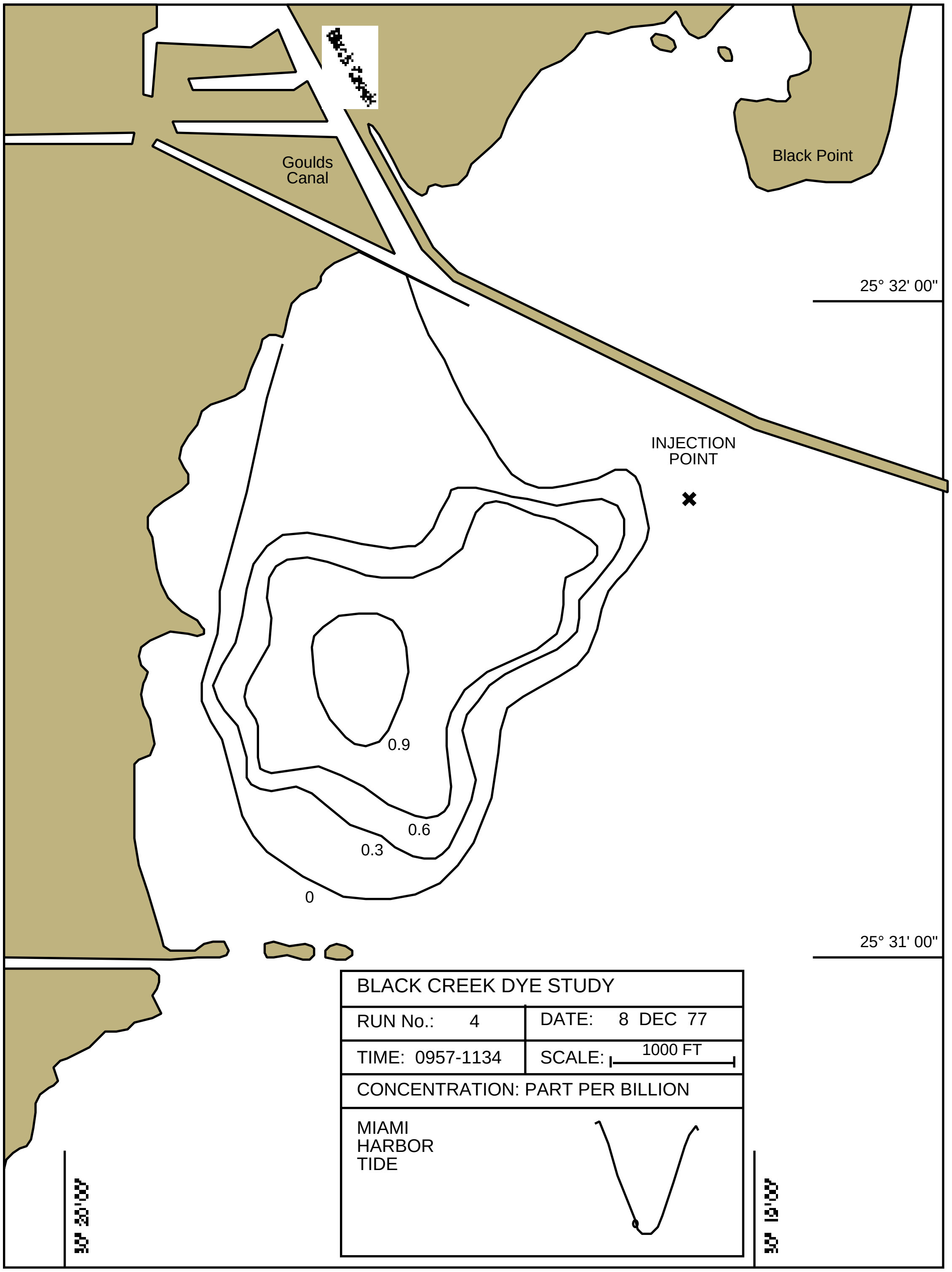


Figure IV-11. [NO CAPTION IN ORIGINAL.]

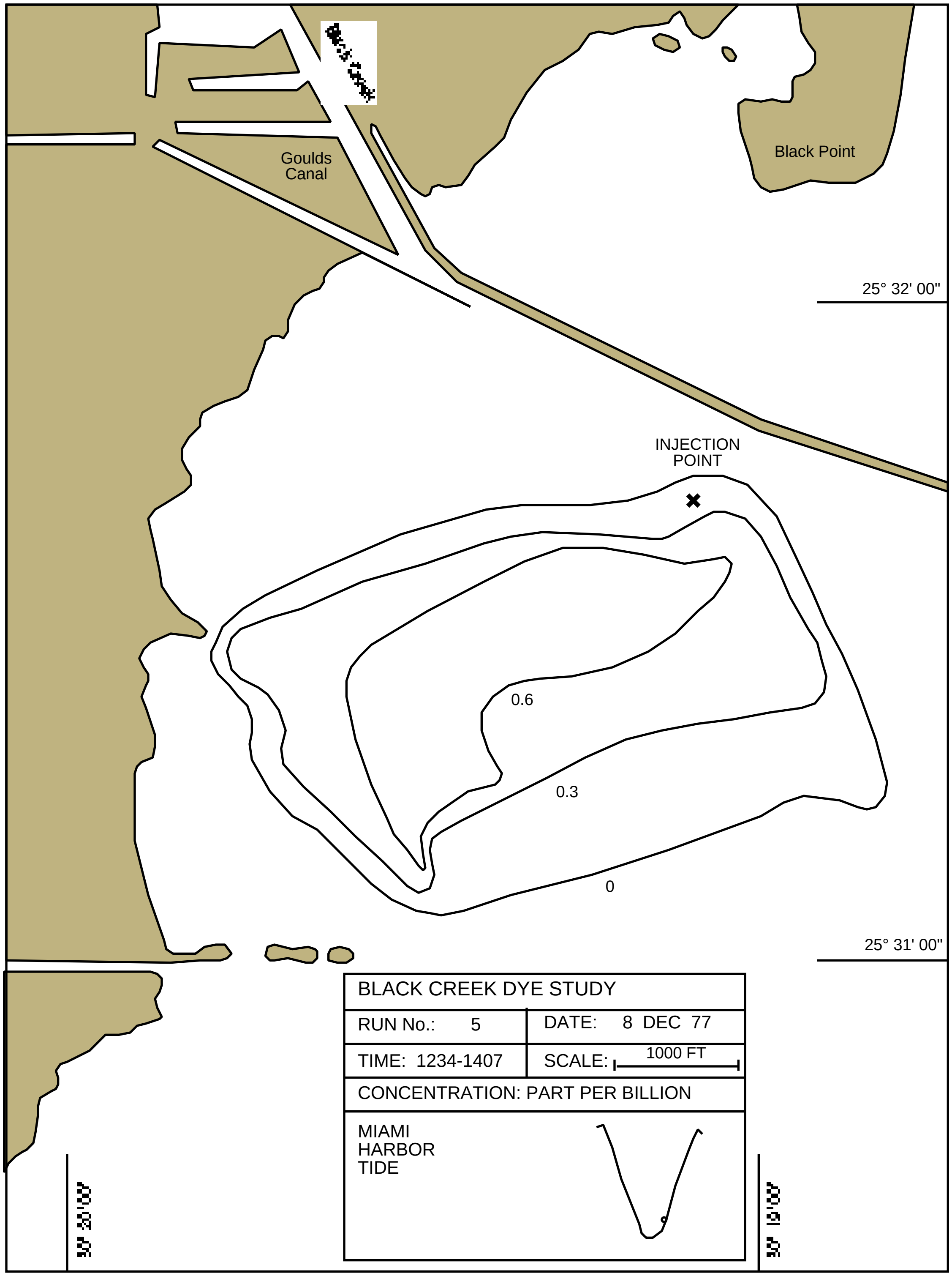
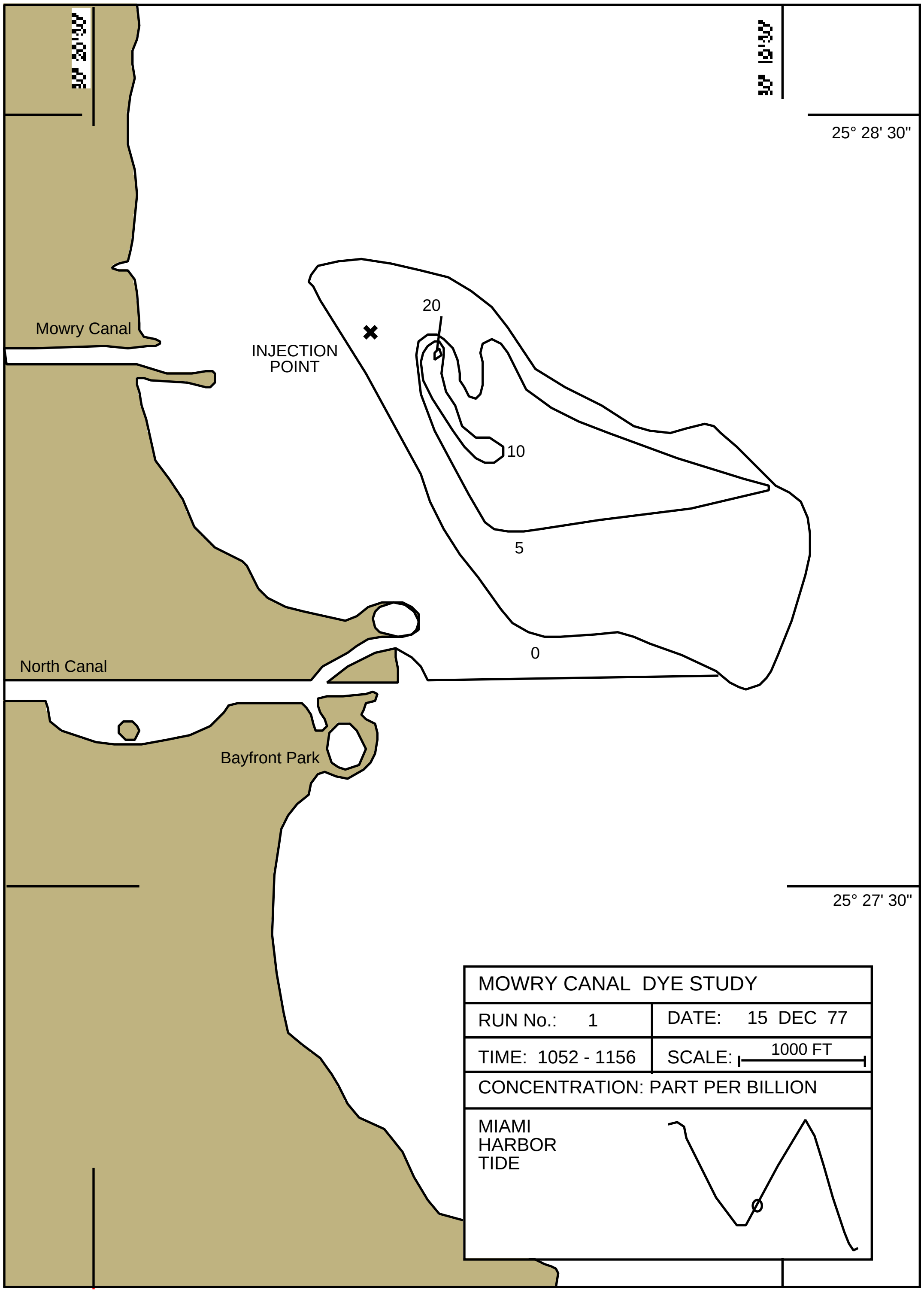


Figure IV-12. [NO CAPTION IN ORIGINAL.]



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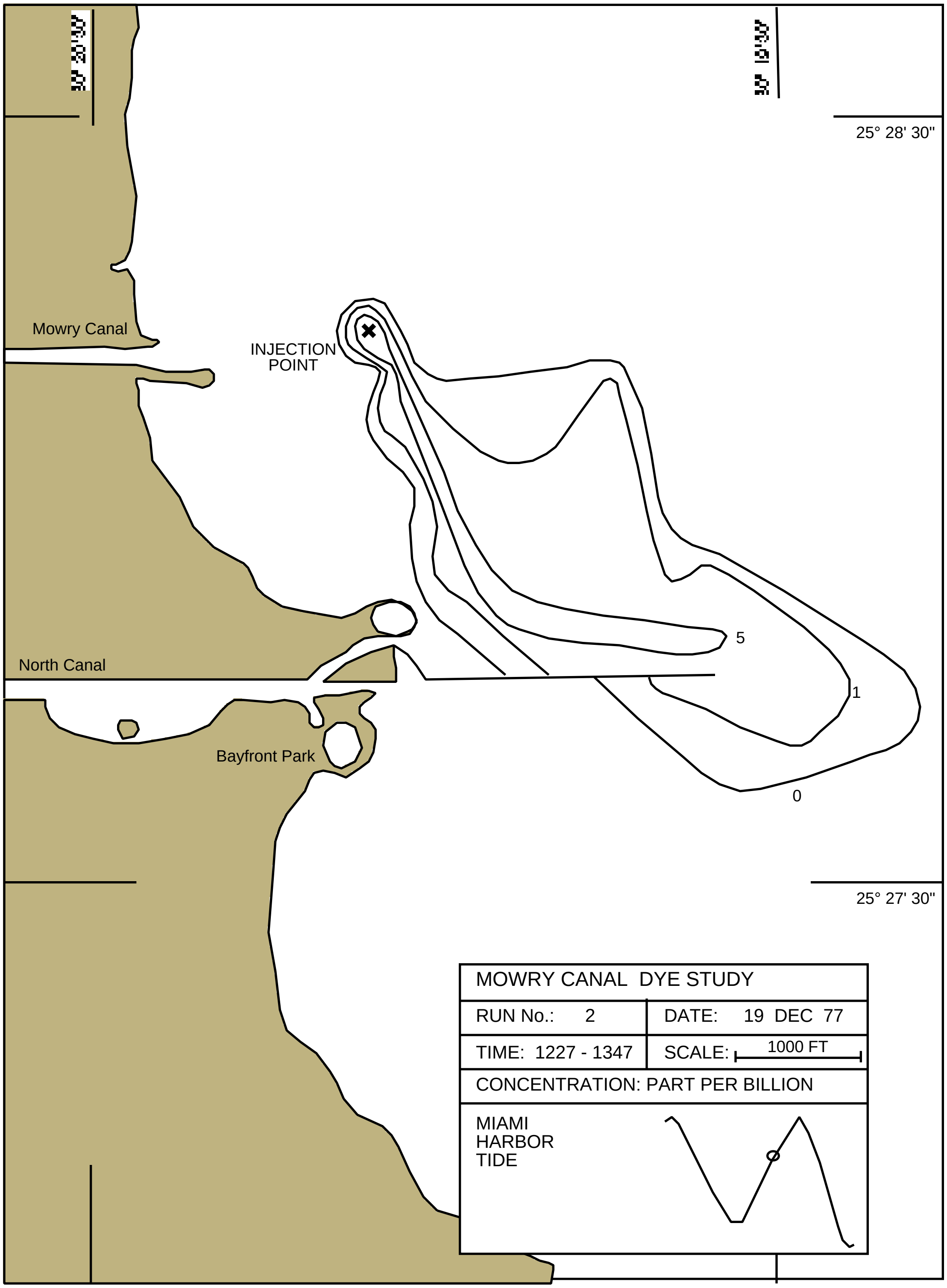

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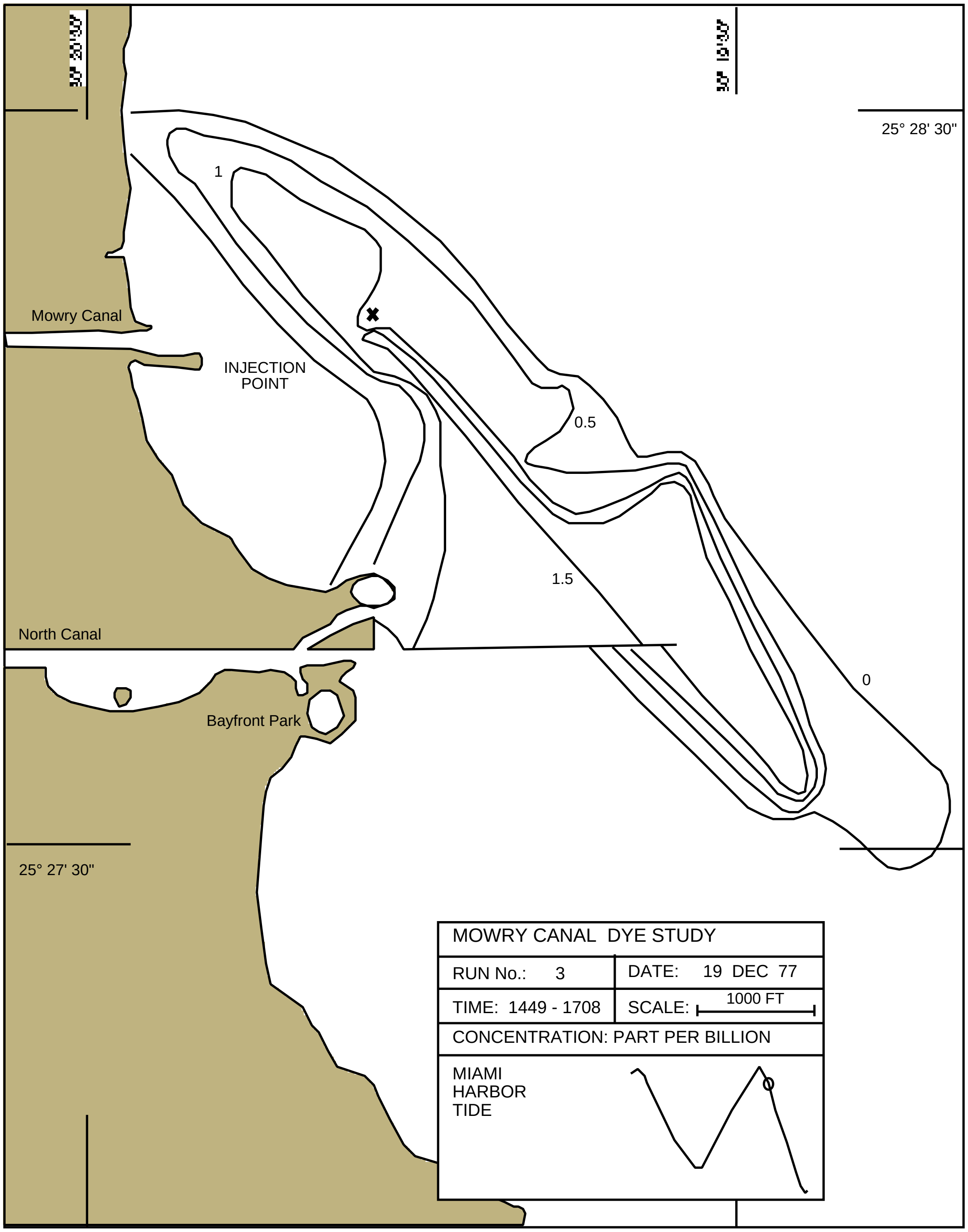

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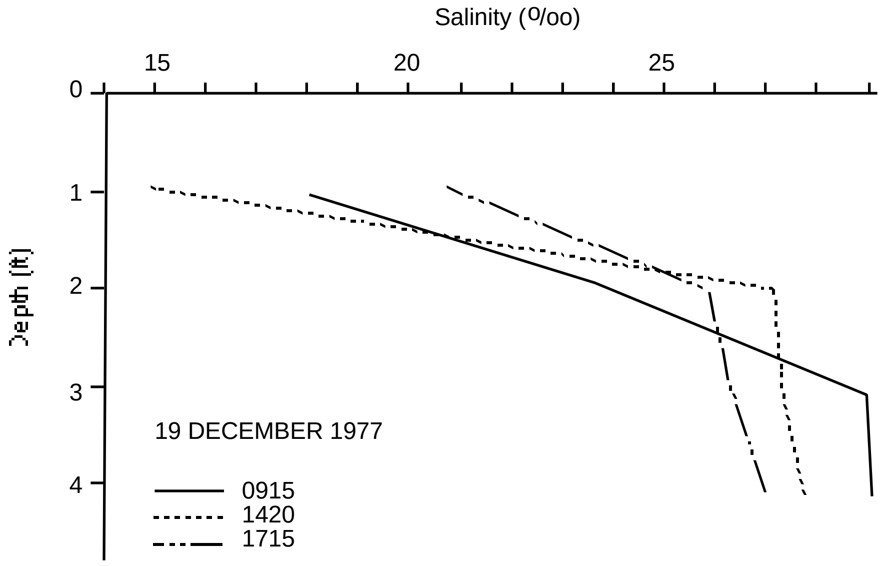


Figure IV-16. Salinity profiles at point of dye injection. Mowry Canal.

influence of canal outflow and a moderate wind from NW (10 - 15 mph). It appears that the dye patch becomes rapidly elongated and aligned with the predominant wind direction. Unfortunately, the tidal currents also flow in that general direction during flood so that definite conclusions cannot be drawn.

When the experiment was repeated on 20 December 1977, results were disappointing since similar difficulties were again encountered (see Figures IV-17 to IV-19). Figure IV-20 shows the vertical salinity profiles at three stations along a line perpendicular to the shore near the beginning and end of the experimental period, respectively. (Locations are shown in Figure III-2 as stations S1, S2, and S3.) By comparing the three profiles in each figure, the degree of horizontal stratification also becomes apparent. Figure IV-18 shows the dye patch 3 hours after injection. At the time of the field experiment, it appeared that a portion of the dye patch had broken off and had been carried to the northeast with the outgoing tide. The shape of the dye patch suggests a rapid dispersal of dye as it enters a more rapid current regime away from the relatively sheltered region near the mouth of Mowry Canal.

Comparison of the two sets of figures (Figures IV-13 to IV-15 and IV-17 to IV-19) possibly shows best the difference in dye distribution under different wind conditions. In Figures IV-13 to IV-15, the wind is moderate out of the N to NW, whereas, in Figures IV-17 to IV-19, there is virtually no wind. The tide is similar on the two days.

The plots of dye distribution for the three canals were used to calculate estimates of the longitudinal dispersion coefficient, K_x. These estimates are computed from the gross statistical observable properties of the dye distribution. The reader is referred to Officer (1976) for a detailed discussion of the method.

We begin by assuming homogeneous, anistropic dispersion under steady flow. The time scale for vertical mixing is assumed small compared with a tidal cycle and the depth is uniform. The longitudinal axis is taken in the direction of mean flow and the horizontal streamlines are taken to be parallel to that axis. Under these assumptions, the longitudinal dispersion coefficient is

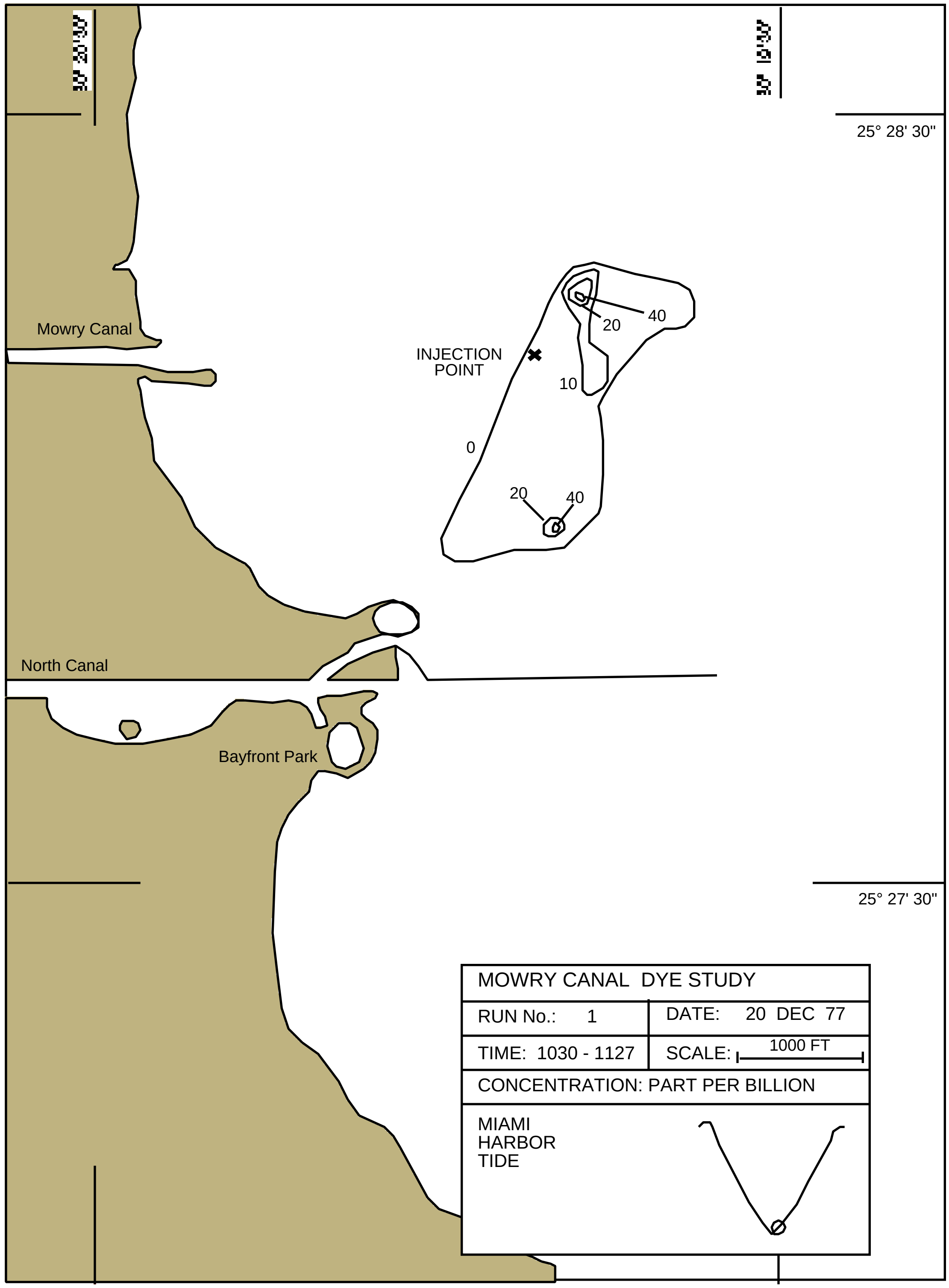
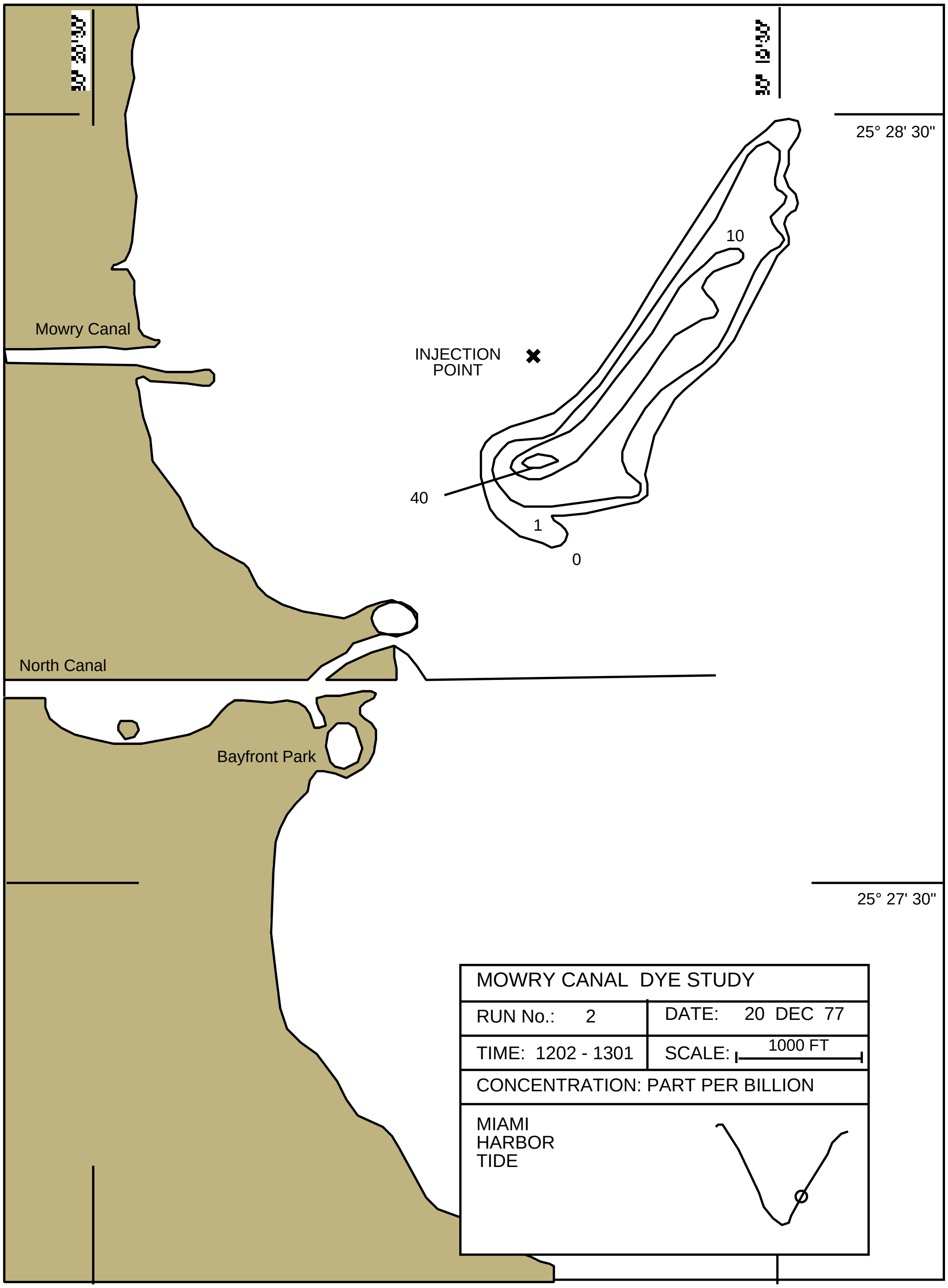


Figure IV-17. [NO CAPTION IN ORIGINAL.]



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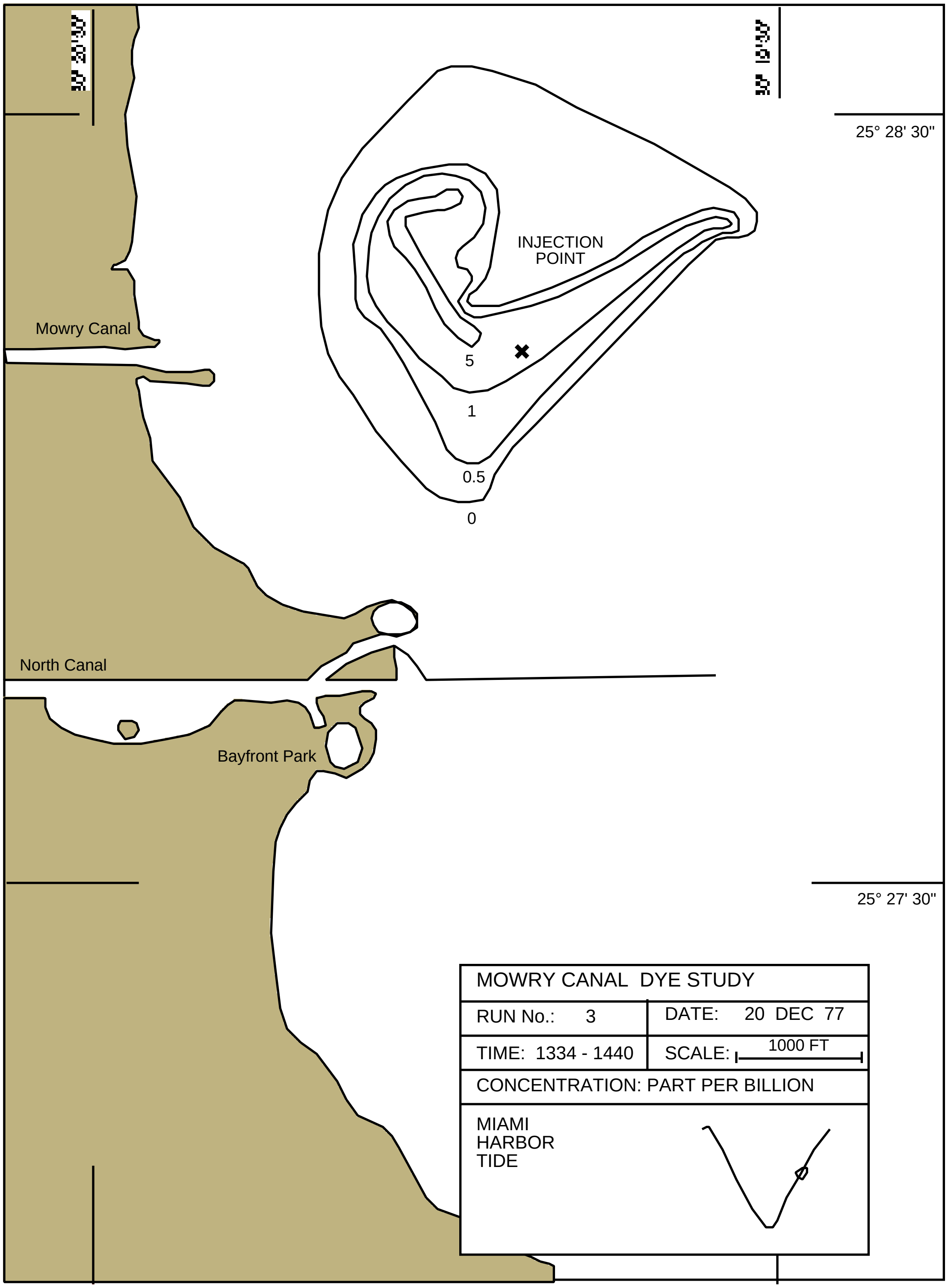

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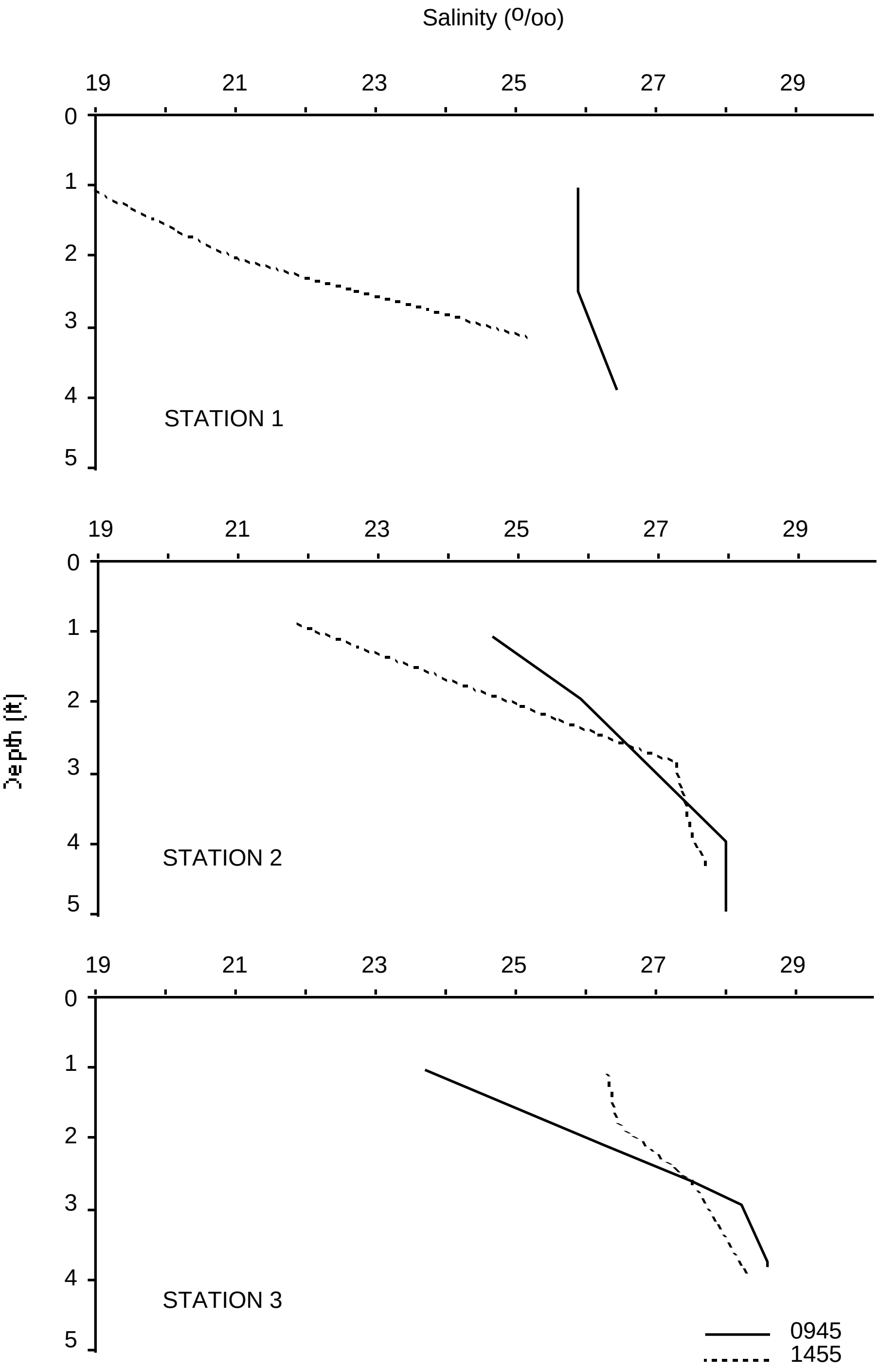


Figure IV-20. Salinity profiles - 20 December 77, Mowry Canal.

Table IV-1. Computed dispersion coefficients.

Canal	Track number	K_x (m^2/sec)
Snapper creek	1-3	UR*
	4	3.97
	5	4.80
	6	4.76
	7	6.19
	Average =	4.68
Black Creek	1	UR
	2	0.52
	3	0.40
	4 (N --> S)	0.53
	4 (W --> E)	0.50
	5 (N --> S)	0.52
	5 (W --> E)	0.56
	Average =	0.51
Mowry Canal	1	4.75
	2	5.89
	3-6	UR
	Average+	5.32

* UR - Unreliable data

$$K_x = \frac{\sigma_x^2}{2t}$$

where σ_x^2 is the vertically averaged variance of dye concentration in the longitudinal direction and t is time after dye injection. The value of a σ_x^2 is computed from

$$\sigma_x^2 = \frac{\int_{-\infty}^{\infty}\int x^2 c \, dx \, dy}{\int_{-\infty}^{\infty}\int c \, dx \, dy} - \left[\frac{\int_{-\infty}^{\infty}\int xc \, dx \, dy}{\int_{-\infty}^{\infty}\int c \, dx \, dy}\right]^2$$

The second term on the right represents the square of the longitudinal coordinate of the center of mass of the dye plume and, therefore, σ_x^2 is the variance of dye concentration along the x-axis. Note that we have made no assumption regarding the vertical velocity structure so that K_x contains effects of turbulence and vertical velocity shear. We next assume that the horizontal mean current is sufficiently slow varying so that it simply changes the position of the center of mass of the dye distribution.

Values of K_x were computed for the various sets of measurements of dye concentration for each of the three study sites. The x-direction is taken along the long axis of the dye plumes as

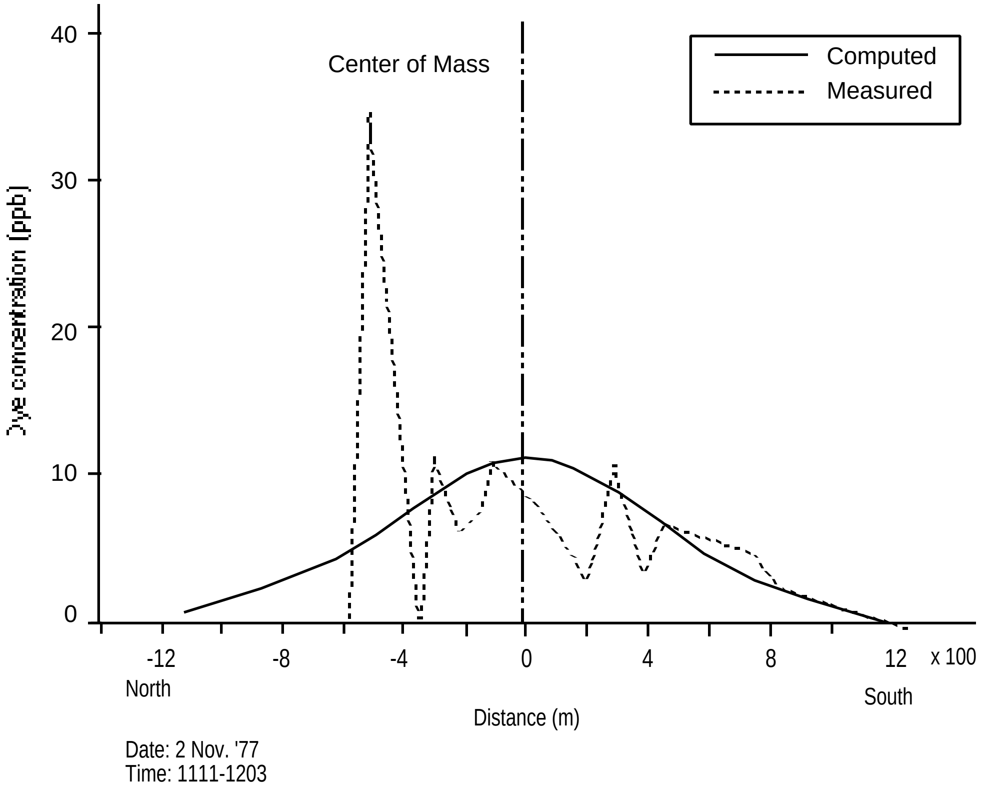


Figure IV-21. Snapper Creek - Run 4. Longitudinal dye distribution.

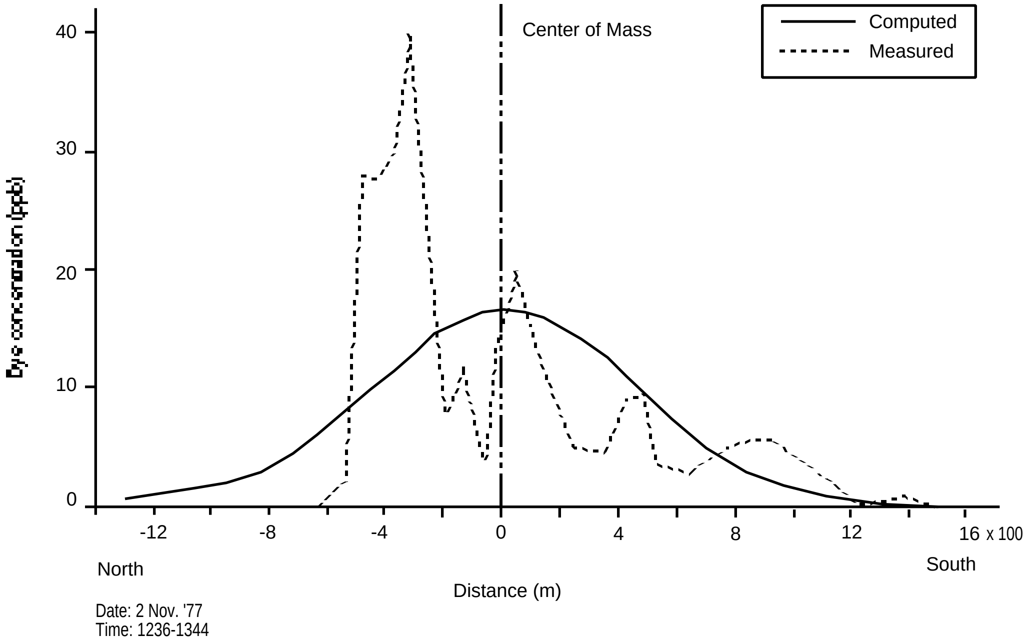
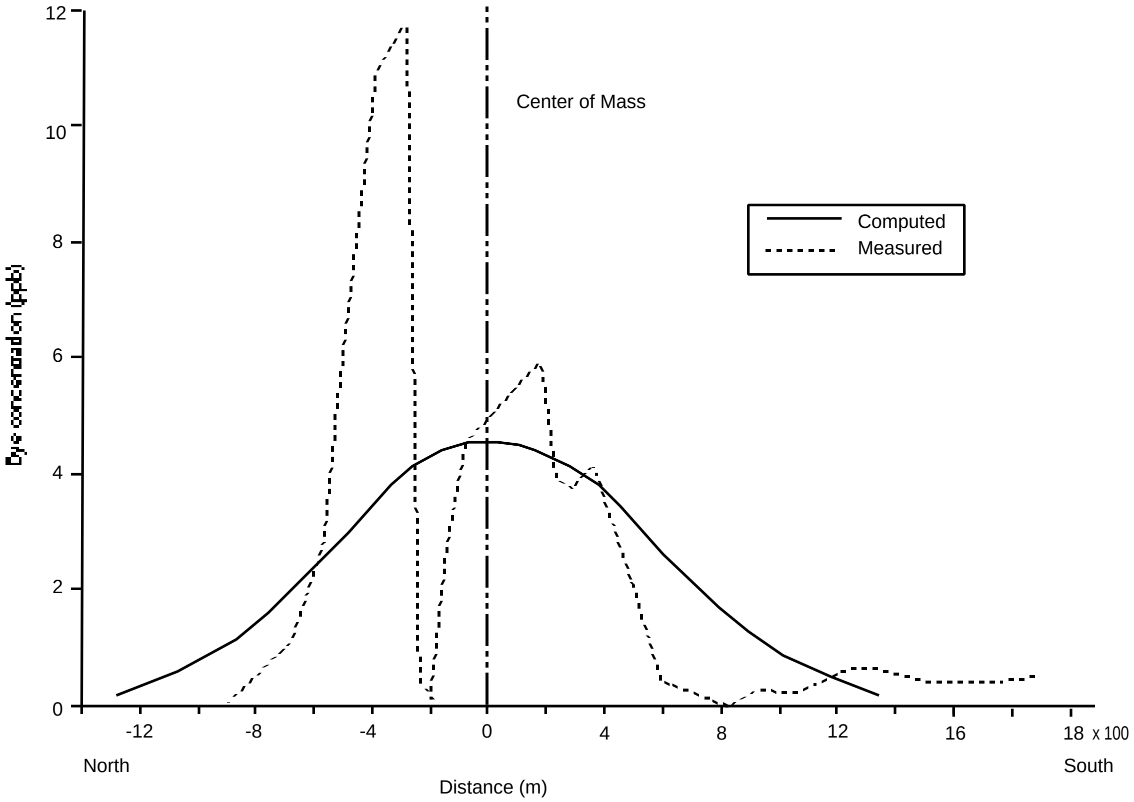


Figure IV-22. Snapper Creek - Run 5. Longitudinal dye distribution.



Date: 2 Nov. '77
Time: 1442-1609

Figure IV-23. Snapper Creek - Run 6. Longitudinal dye distribution.

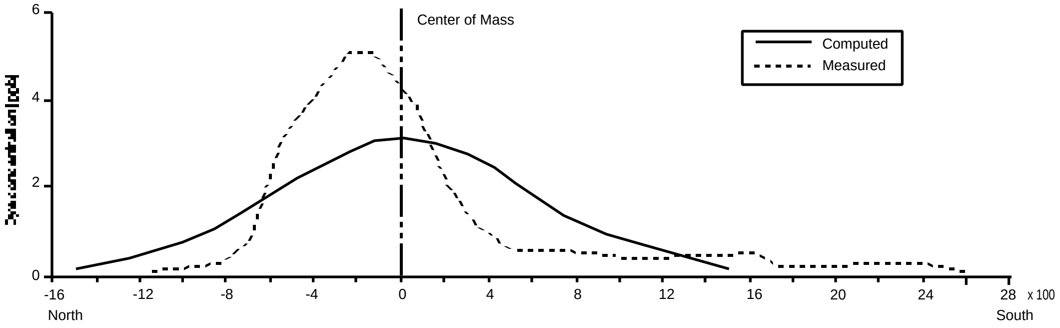


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Figure IV-24. Snapper Creek - Run 7. Longitudinal dye distribution.

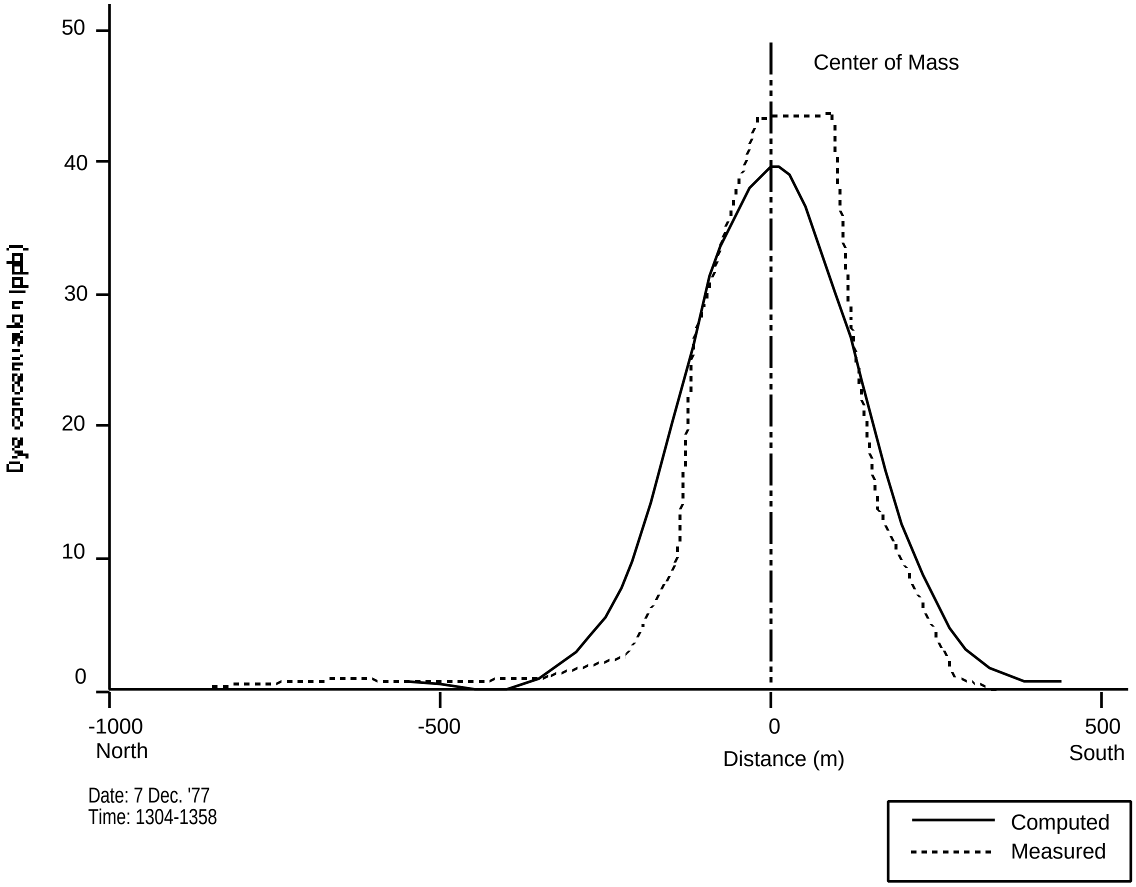


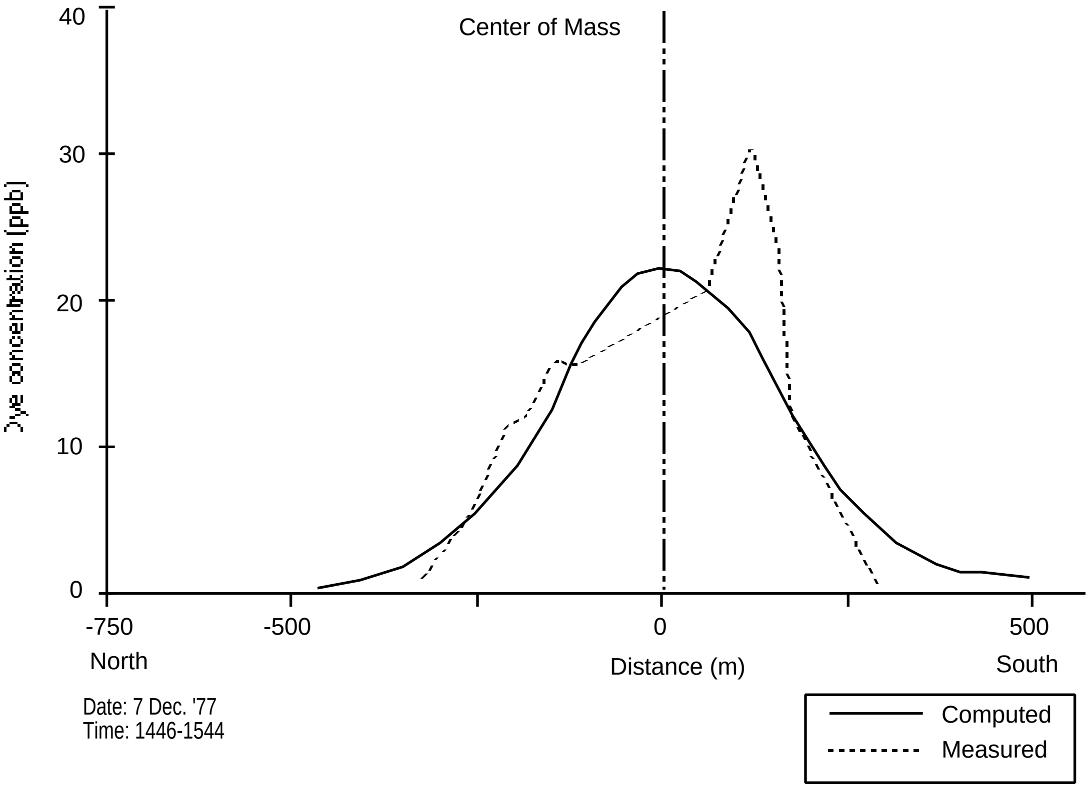
Figure IV-25. Black Creek - Run 2. Longitudinal dye distribution.

shown in Figures IV-21 to IV-32. Several of the sets of measurements were considered to be questionable because of difficulties encountered in the field. Those which gave K_x values substantially different from the Majority of computed K_x's could reasonably be attributed to measurement errors and were therefore not considered further in the computations. An average K_x was then computed for each site from those values which were judged to be reasonably accurate. Results are tabulated in Table IV-1.

In order to check the validity of the computed average K_x values, the measured longitudinal distribution of dye concentration was compared with a Gaussian distribution computed with the average K_x estimates. If we assume an instantaneous plane source in a plane perpendicular to the longitudinal axis, then the longitudinal distribution of dye concentration can be described by

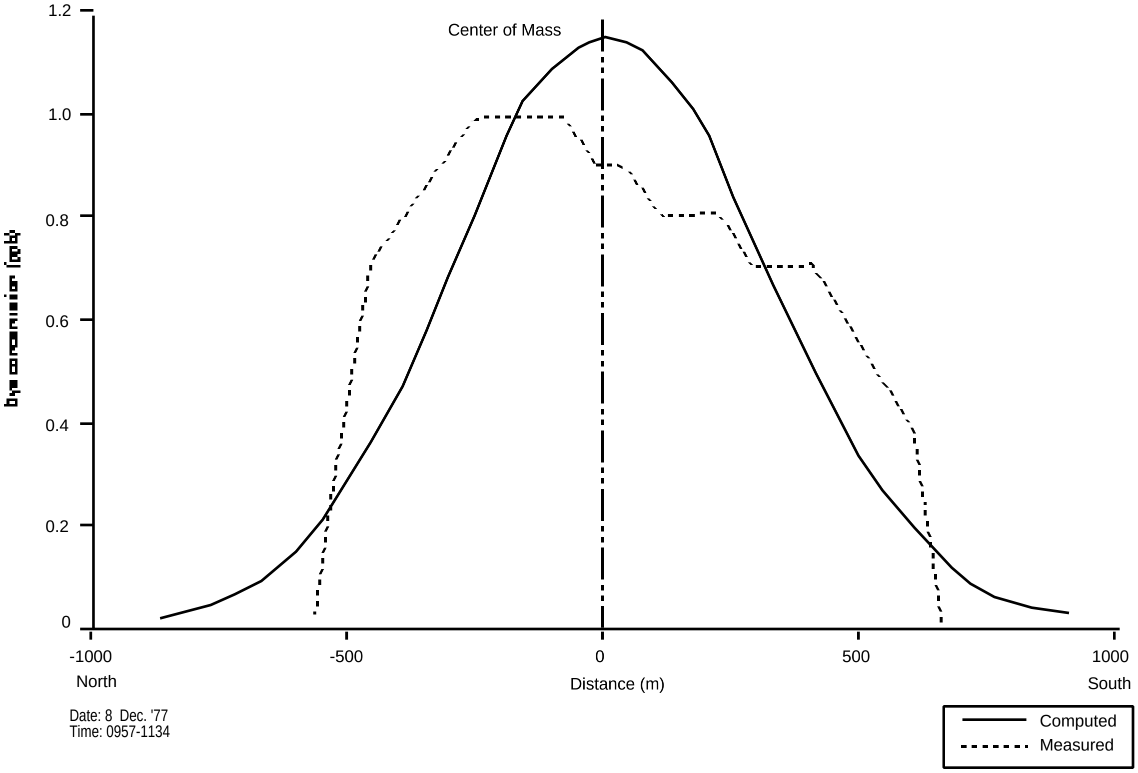
$$C\,(x,t) = \frac{m}{\rho\,\sqrt{4\pi\,K_x t}}\; e^{-x^2/4K_x t}$$

where m is the total mass per unit area of injected dye and ρ is the density of the bay water (~1 g/cm^3) [Officer (1976), page 27]. The x in the exponent represents the distance with respect to the center of mass of dye and t is the time after dye injection.



Date: 7 Dec. '77
Time: 1446-1544

Figure IV-26. Black Creek - Run 3. Longitudinal dye distribution.



Date: 8 Dec. '77
Time: 0957-1134

Figure IV-27. Black Creek - Run 4. Lateral dye distribution.

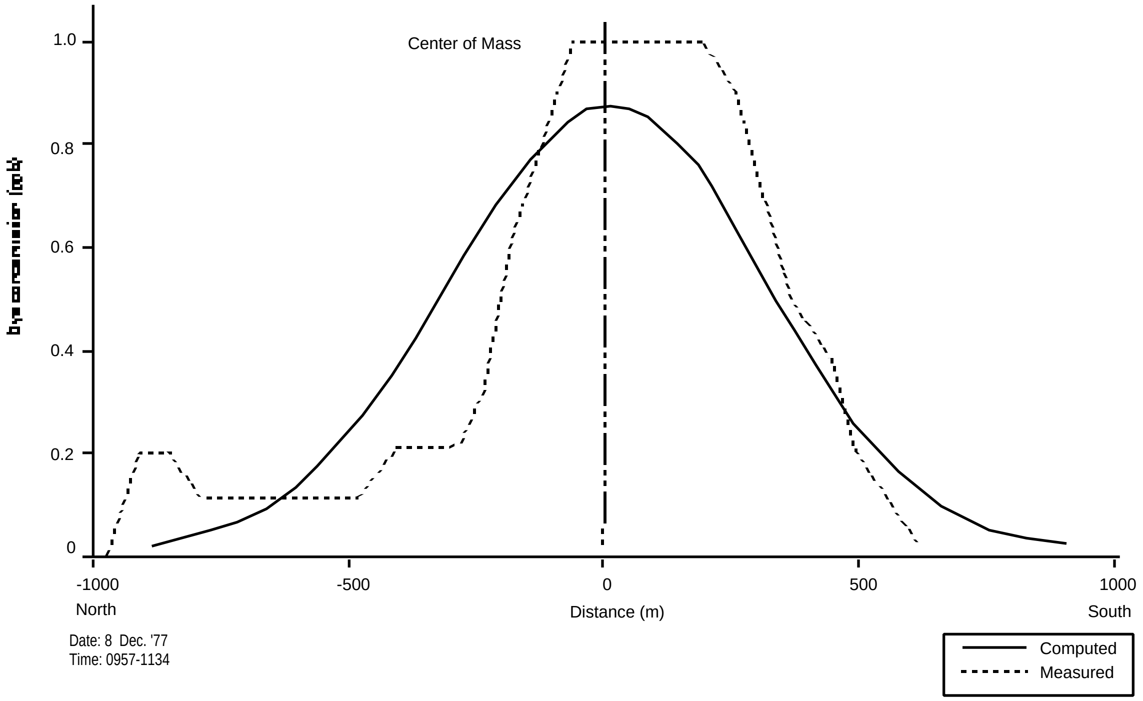


Figure IV-28. Black Creek - Run 4. Longitudinal dye distribution.

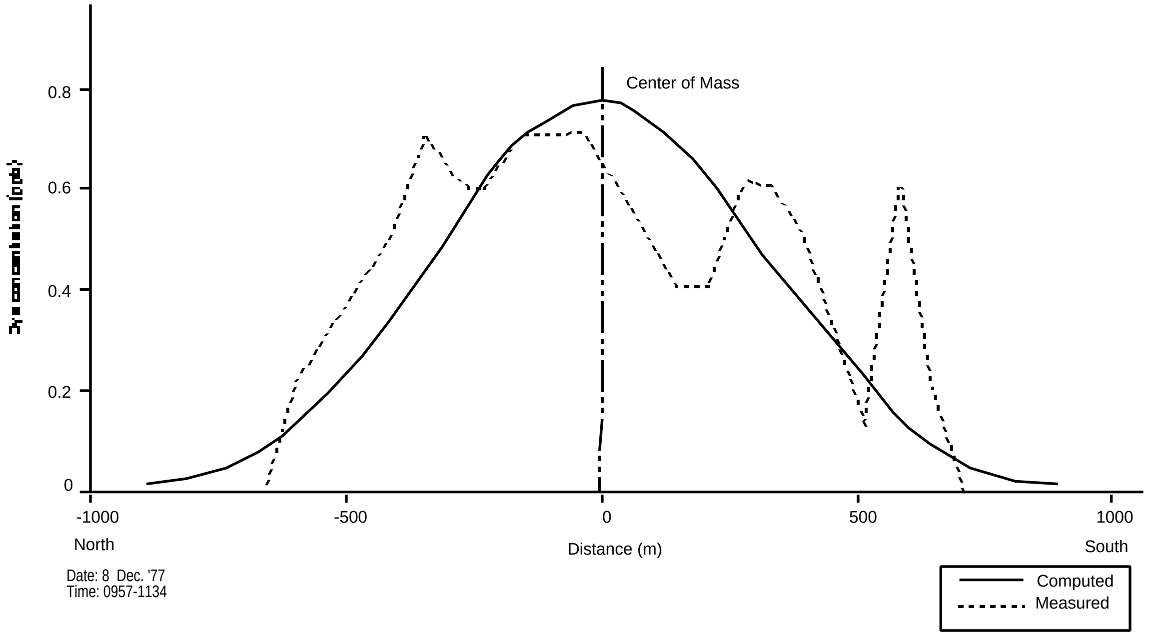
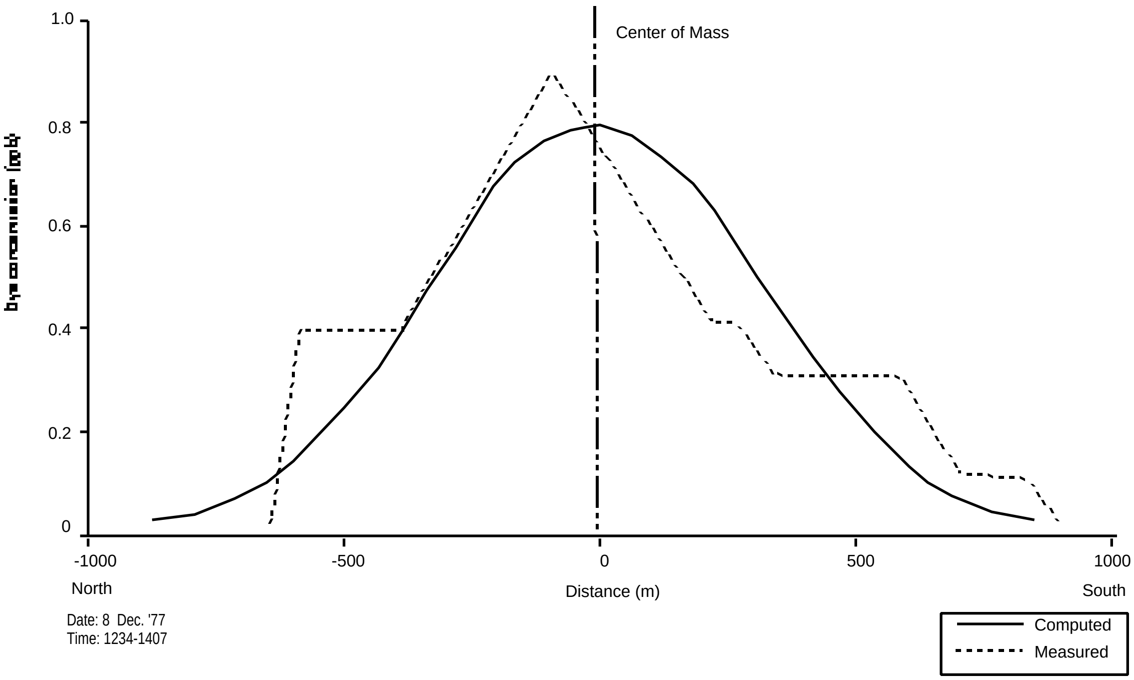
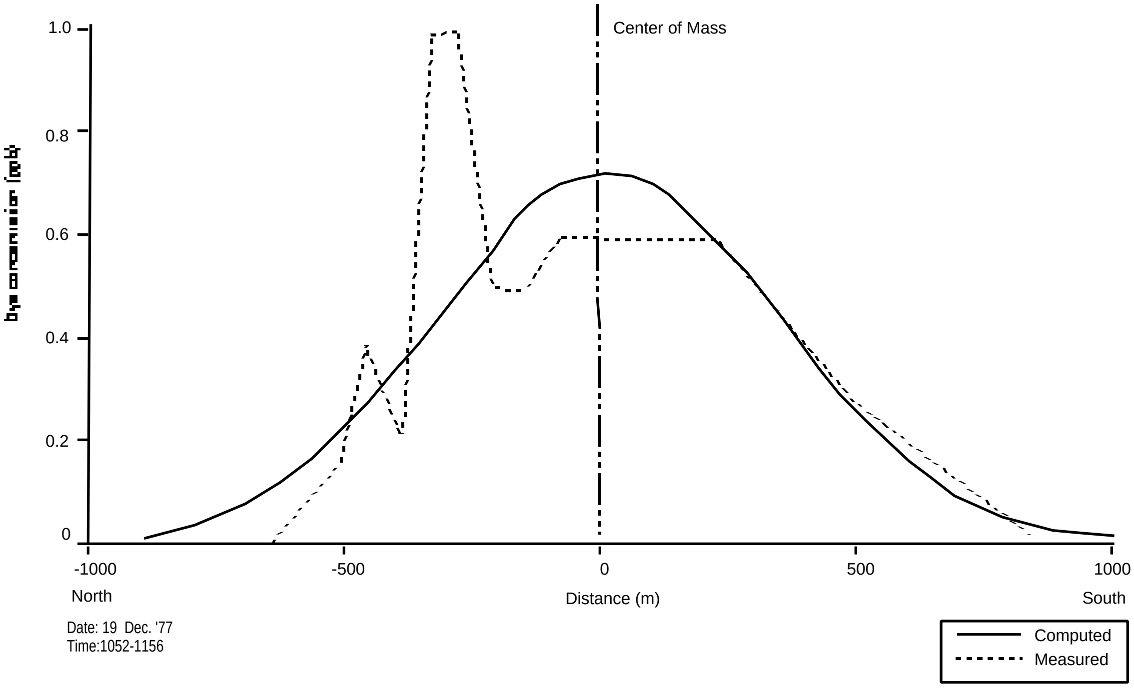


Figure IV-29. Black Creek - Run 5. Longitudinal dye distribution.



Date: 8 Dec. '77
Time: 1234-1407

Figure IV-30. Black Creek - Run 5. Lateral dye distribution.



Date: 19 Dec. '77
Time:1052-1156

Figure IV-31. Mowry Canal - Run 1. Longitudinal dye distribution.

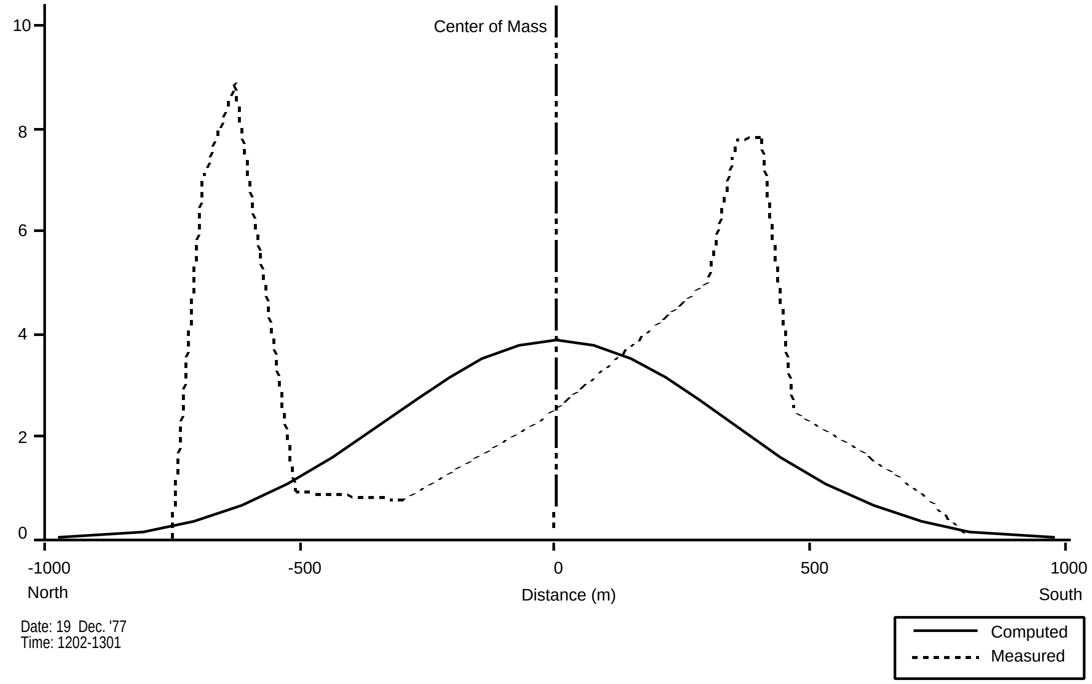


Figure IV-32. Mowry Canal - Run 2. Longitudinal dye distribution.

In theory m represents the mass per unit area of dye at the time of injection in one-dimensional dispersion, but in practice, we must deal with effects of lateral dispersion and measurement errors due to the time-variation in vertical structure of dye concentration. Therefore, in order to make a more meaningful comparison between observed and computed longitudinal dye distribution, the value of m was computed for each track from the observed dye concentration so that $m = \sum c \cdot \Delta x$, where c is the observed concentration at length interval Δx. In practice, then, m is no longer the mass of dye at time of injection but rather the observed total mass per unit area in the longitudinal direction at the time of measurement.

Figures IV-21 to IV-24 are plots of observed and computed longitudinal dye distribution near the mouth of Snapper Creek. The agreement between the-computed and observed distributions is only fair because of the rather erratic pattern of peaks in the measured distribution. Field observations indicated that these peaks result from dye being gradually released from the bottom of the bay where it had become Concentrated in the sea grass. However, the measured distribution generally agrees within a factor of 2-3 with the computed and agrees well with longitudinal extent. Fairly good agreement is achieved in Track 7 (Figure IV-24) 10-1/2 hours after dye injection, since the dye has become more thoroughly mixed with the bay water. The agreement in magnitude is generally within a factor of 2 and the longitudinal extent of the dye agrees well with the Gaussian curve.

The results of the dye experiment at Black Creek were considerably more amenable to this type of analysis. Figures IV-25 to IV-30 show that agreement between measured and computed dye distribution is excellent both in magnitude and longitudinal extent. For Tracks 4 and 5 (Figures IV-27 to IV-30) two longitudinal distributions are plotted (W-*E and N-S), since the dye patch was much more circular than in other cases. The good agreement found at this location may be attributed to the improved injection of dye (better vertical distribution) and the smaller currents, such that the experimental conditions better approximate the theoretical assumptions.

The dye experiments at Mowry Canal were conducted with limited success. Measured dye distribution in Track 1 compares fairly well with the Gaussian curve with the exception of one anomolous peak (see Figure IV-31). The comparison in Track 2, Figure IV-32, is poor. This is the result of difficulties in obtaining reasonable field measurements because of the presence of vertical and horizontal density stratification. Because of difficulties encountered in the experiment of 20 December 1977, especially since a portion of the dye plume was lost, the field data was considered questionable. As a result the dispersion coefficient for this data was not computed.

Comparison of the observed longitudinal dye distribution and the Gaussian distributions resulting from the computed dispersion coefficients indicate that the K values obtained for the three canals are good estimates. The degree of agreement between measured and computed distributions is particularly significant when one considers that the range of values cited in the literature for K_x in bays spans several orders of magnitude. In spite of the simplifying assumptions made about flow in the study region and the difficulties encountered in field measurements, we may assume that the computed dispersion coefficients are representative within a factor of 2 or 3.

It is interesting to make an intercomparison of the average K_x computed for the three sites. The dispersion coefficient for Black Creek was found to be 0.51 which may serve as a lower limit for K_x in shallow sheltered regions of Biscayne Bay. In the more open region of Snapper Creek, the value is an order of magnitude higher. Since environmental conditions at Snapper Creek were moderate (no stratification in the water column and light to moderate winds) that dispersion coefficient may describe average conditions. Under more extreme conditions, such as strong winds and freshwater inflow, its value may be up to an order of magnitude higher than the one found here. The dispersion coefficient computed for Mowry Canal is nearly the same as the one for Snapper Creek and may reflect somewhat extreme conditions in relatively shallow and sheltered water, i.e., strong vertical and horizontal stratification, moderate winds, and significant vertical velocity shear.

V. MODEL SIMULATION AND PREDICTIONS

For the purpose of this study, which is to provide data for establishing a coastal sampling network, the zone of influence of the three canals draining into South Biscayne Bay is defined as the maximum extent of contamination from a continuous discharge.

The modeling work consists of two tasks. One Is to calibrate and verify the model against the field experiments. The other is to carry out simulations of the hypothetical continuous discharge situations. The contaminant concentration distribution is dependent on several important processes, of which the more essential are: discharge characteristics, convective transport, dispersion and decay.

The historic records of canal discharge rates indicate that these are sufficiently small even under maximum conditions so that only highly localized changes in the velocity field would be expected. The model was run with a discharge rate of 20 m^3/sec from each of the canals and the results confirmed that only insignificant changes to the velocity fields occurred away from the canal mouths.

The velocity fields used in determining the convective transport were obtained using the hydrodynamic model CAFE already established for South Biscayne Bay (Swakon and Wang, 1977, and Valle, 1978).

The order of magnitude of the dispersion coefficients have been established through the field experiments. Because of the relatively small values ($E \leq 5\ m^2/sec$) the grid used for the hydrodynamic computations, Figure V-1, was found to be too coarse for accurate predictions of dispersion. Consequently, the area in the vicinity of the mouths of each canal was further refined as shown in Figures V-2 to V-3.

V.1. Verification of Dye Experiments

To verify the dispersion model, the dye injection experiments at Snapper Creek, Black Creek and Mowry Canal are simulated. Figure V-4a-d show comparisons between simulated and measured dye distributions at Snapper Creek at different times. It is seen that the model tends to overestimate the spreading rate somewhat during the earlier stages. This exaggerated spreading rate is mainly due to the models inability to handle dye clouds that do not extend over at least several grid elements. During the later stages the spreading rate is predicted quite well as seen on Figures V-4c-d. Since the field experiments are associated with some uncertainty and the predicted results are on the conservative side, the model predictions should be valid estimates of the extent of spreading for this location. A longshore dispersion coefficient of 5 m^2/sec and a lateral dispersion coefficient 1 m^2/sec are used for the model simulation.

The Black Creek location involves a complicated geography which makes it hard to model accurately. The most outstanding feature is the breakwater running from west to east starting just north of the Black Creek canal mouth. This breakwater stretches for approximately 1 mile, however, during high water several parts of the breakwater are inundated. For purposes of modeling the partially enclosed area just north of the breakwater is considered a passive water body. In schematizing the Black Creek location, attempt is made to approximate the complicated boundaries as well as possible, however, a compromise has to be made between accuracy and cost of the modeling approach. Figures V-5a-d show the comparison of the model simulation and field experiment at Black Creek. Since grid elements could not easily be made less than 2,000 feet the breakwater is somewhat shortened in the model. The effect of this shortening and the increased initial rate of spreading caused by the numerical grid dispersion is evident in Figures V-5a-d. In the experiment, the dye apparently did not spread around the tip of the breakwater and whether some amount of dye actually flowed over the breakwater was not determined. Because of the shortening of the breakwater the model simulation shows the dye spreads into the area north of the breakwater. The movement and spreading of the dye during the later stages, see Figures V-5c-d, is modeled somewhat better. The spreading rate seems quite reasonable in the model. Again, it should be remembered that the field data is associated with large uncertainty and that no transects were made north of the breakwater. Homogeneous, isotropic dispersion is assumed for this simulation, with a dispersion coefficient of 1 m^2/sec.

The last experimental site at the mouth of Mowry Canal is less complicated than the Black Creek location. Although, a breakwater exists at the mouth of North Canal to the south, this is neglected during the modeling studies. The effect of the breakwater is to deflect the dye plume towards east as seen on Figures V-6a-b. However, because of its greater distance from the mouth of Mowry Canal, the breakwater does not play the same sheltering role as at the Black Creek location. It was therefore determined that the breakwater could conservatively be left out during the modeling studies. Figures V-6a-b show the comparisons between the model simulations and the field experiments on December 19 and 20. Isotropic spreading in the model was assumed with a dispersion coefficient of 5 m^2/sec. The initial spreading rate is as before

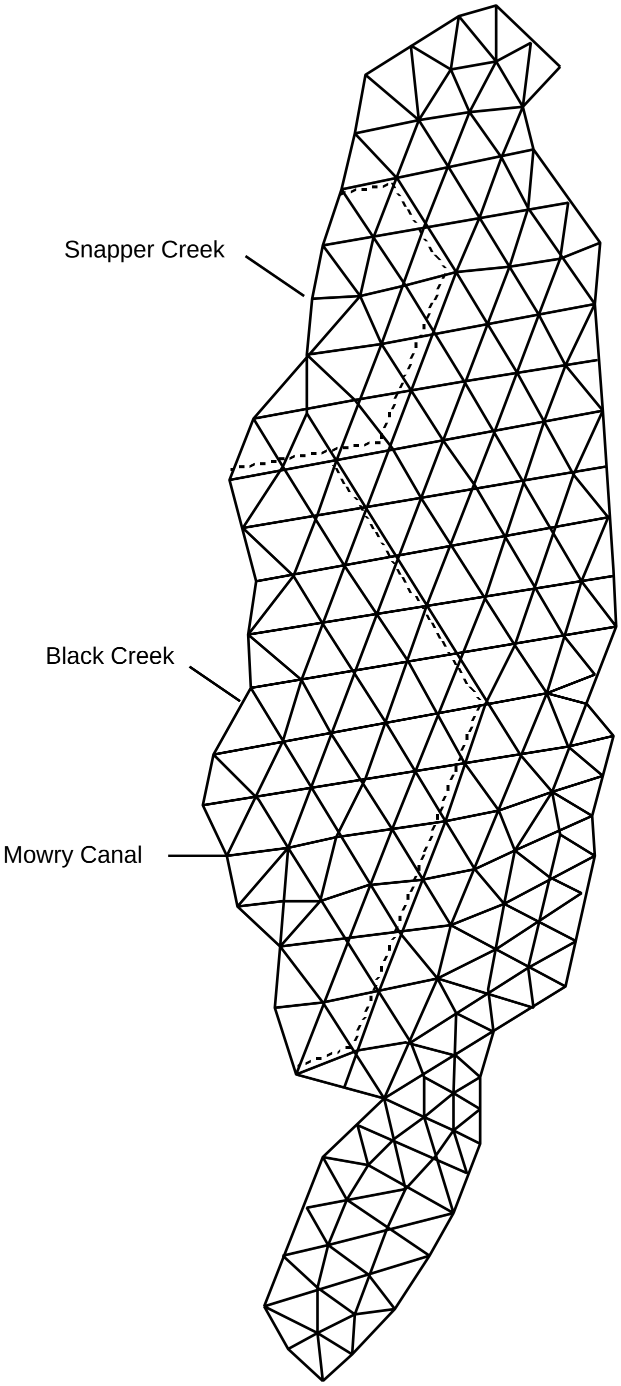


Figure V.1. Finite element grid of south Biscayne Bay. Areas of grid refinement are indicated.

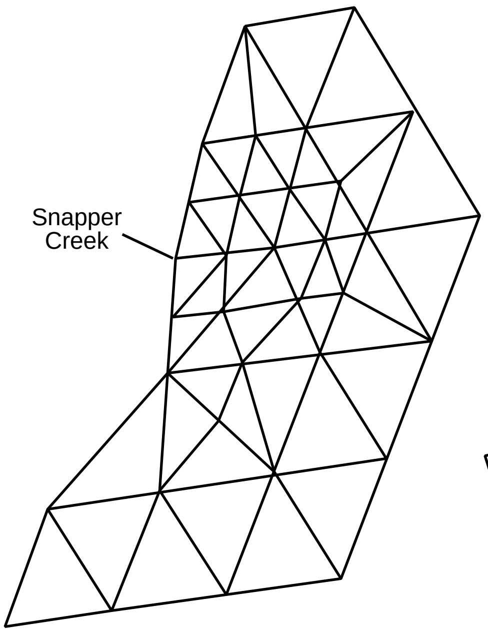


Figure V.2. Refinement grid at Snapper Creek.

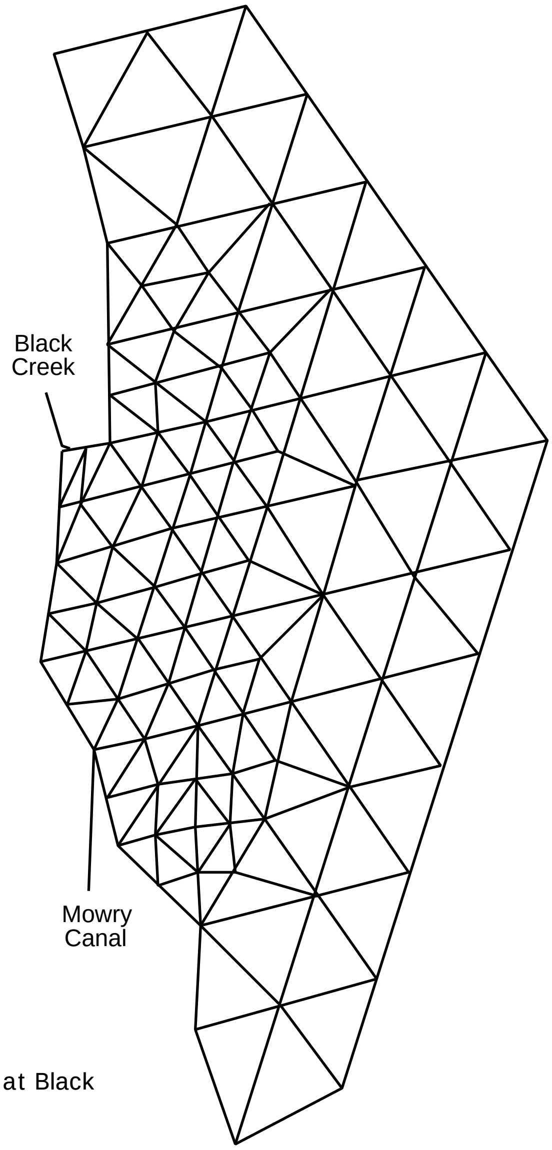
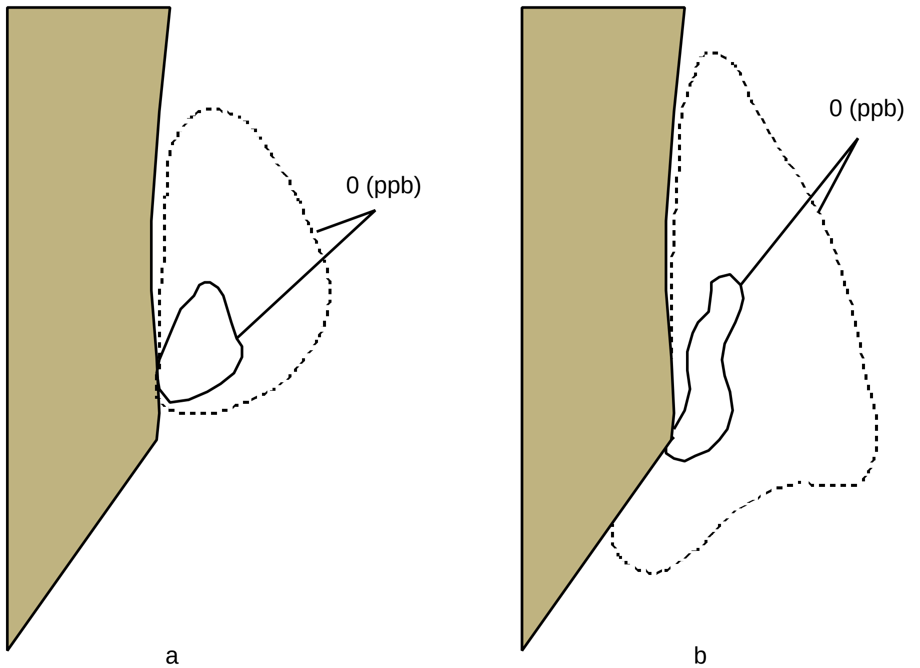
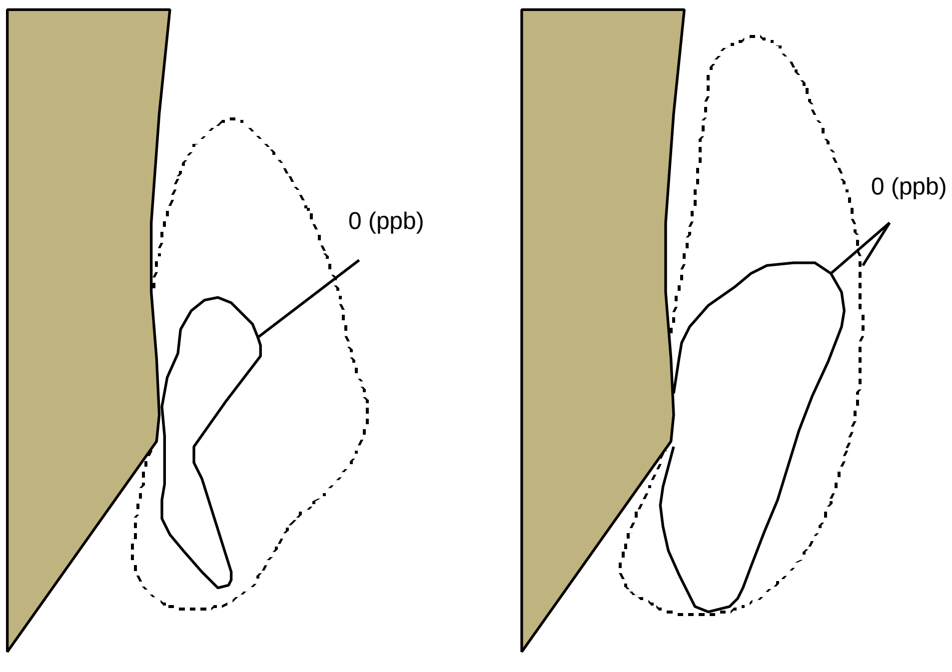


Figure V.3. Grid refinement at Black Creek and Mowry Canal.



a
Time 18000 (sec)

b
Time 24000 (sec)



c
Time 32000 (sec)

d
Time 38000 (sec)

Figure V.4. Snapper Creek experiment and experiment simulation. Deployment dye time 0 (sec).

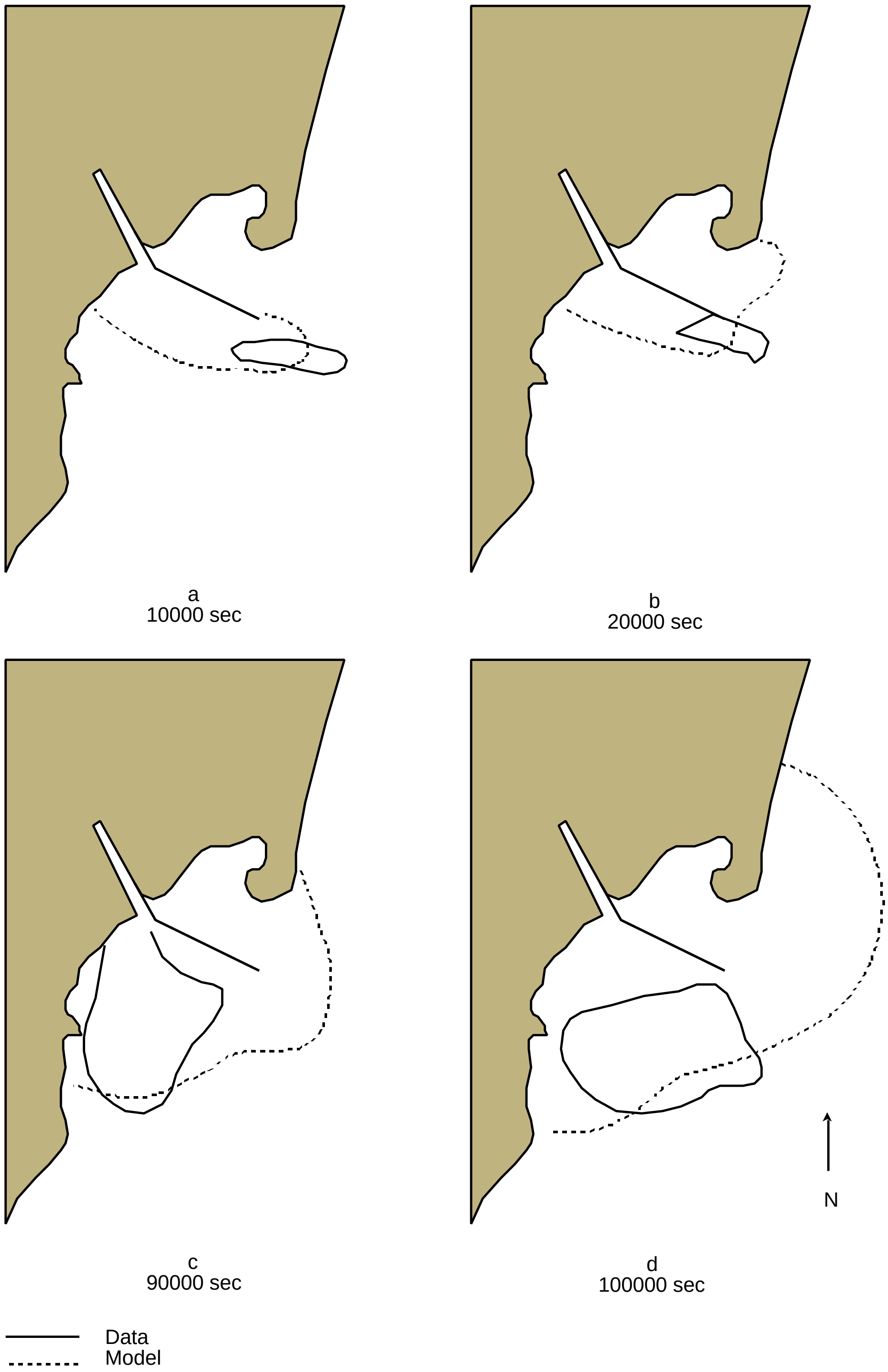


Figure V.5. Black Creen experiment and model simulation.

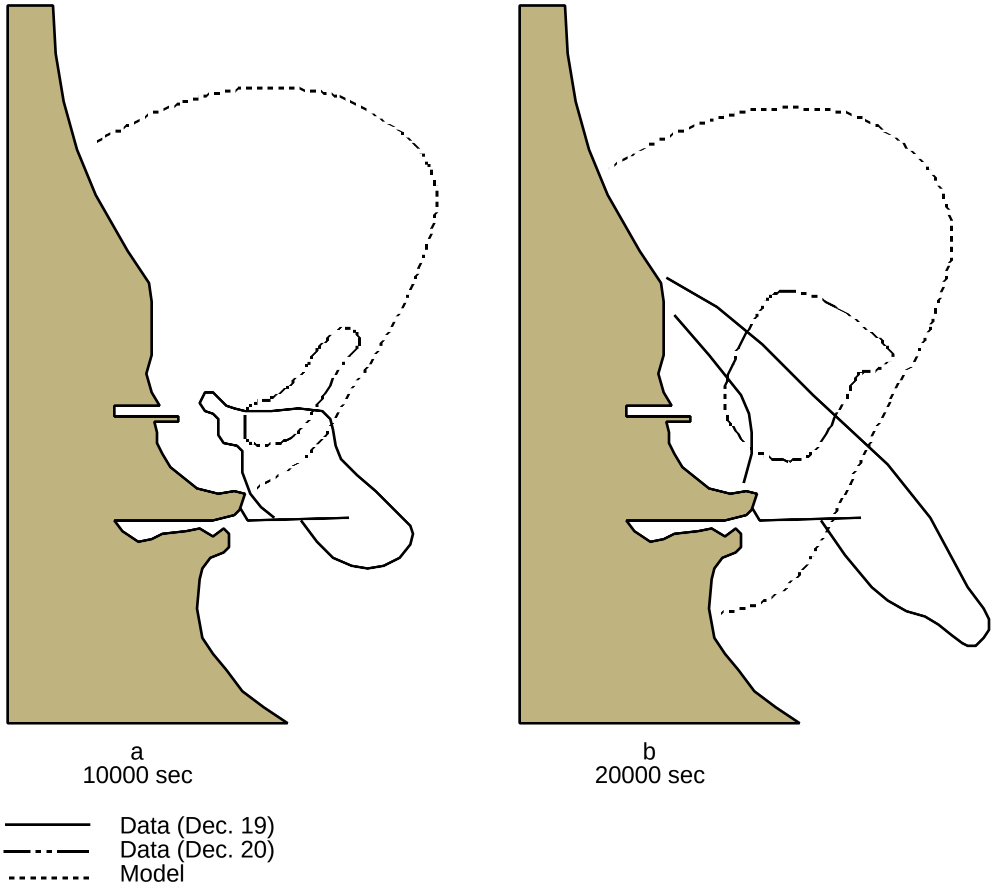


Figure V.6. Mowry Canal experiment and model simulation.

too large. In addition, the model is unable to simulate the wind drift caused by the strong northwesterly wind on December 19. The agreement between the measurements on the second day is much better. The rather poor agreement on December 19 is attributed to a strong local stratification due to the freshwater inflow. The combination of strong winds and stratification causes a situation which cannot realistically be modeled with a vertically integrated model. Under less adverse situations it appears that the model can perform satisfactorily as the comparison between December 20 and the model simulations show.

The verification process indicates that the model results are conservative under normal conditions and that the dispersion coefficient found in the field of order 5 m^2/sec is reasonable. Under conditions of significant freshwater inflow and strong winds the spreading of matter may be locally enhanced by the shear flow effects. Such conditions are however, not expected to persist over large times and areas. Hence, the model's capability of estimating the spreading of a contaminant from a continuous discharge is not significantly affected. Extreme conditions may, as a first approximation, be accounted for by increasing the dispersion coefficient.

V.2. Prediction of zone of influence of canals

As mentioned earlier the factors primarily affecting the spreading of a contaminant are: convective transport, dispersion and decay. (For more detailed discussion see Csanady 1973 and Officer 1976). The simulation of dye experiments and a separate study, Valle (1978) has shown that the hydrodynamic finite element model, CAFE, as applied to South Biscayne Bay, reasonably estimates the average convection. From the analysis of the dye experiments realistic ranges of values for the dispersion coefficients are obtained. Remaining to be prescribed is the decay coefficient. The dispersion model allows the contaminant to undergo a first order decay process:

$$\frac{\delta c}{\delta t} = -kc$$

where c = concentration and k = decay coefficient. For continuous discharges the decay rate is of utmost importance for determining the final extent of the contaminant. Unfortunately, the decay rate varies within a range from no decay to 50% die off in a few hours. For the model prediction two values were used corresponding to half life periods of 0.4 day and 0.8 day. Many of the chemical processes (e.g. oxidation of BOD, reaeration) seem to have reaction rates in this range.

To develop confidence in the predicted results and to allow reasonable interpolation (extrapolation) a number of runs with different prescribed coefficients were made for Snapper Creek, Black Creek and Mowry Canal. A summary of all runs is presented in Table V-1.

For normal conditions at Snapper Creek we should expect, on the basis of the experimental data in Chapter 4, a longshore dispersion coefficient, $E_x = 10\ m^2/sec$ and a lateral $E_y = 5\ m^2/sec$. Figures V-7 and V-8 show the concentration distribution in mass units per unit volume using these values and a decay rate, k, of $0.00002\ sec^{-1}$ and $0.00001\ sec^{-1}$ respectively, (half life = $(\ln^2/k)$. Figure V-9 show what is likely to be an extreme situation in terms of dispersion for Snapper Creek.

At Black Creek and Mowry Canal we must consider the offshore region as well, when predicting the spread from a continuous source since it is likely that contaminant will spread into the central deeper portions of the bay. It is therefore not unrealistic to expect overall coefficients of $E_x = 10\ m^2/sec$ and $E_y = 5\ m^2/sec$ as normal dispersion for these locations. Figures V-10 and V-11 show the effect of water discharge from Black Creek. Figure V-12 show model sensitivity to a radical increase in dispersive transport.

Table V-1. Summary of model predictions.

Figure	Location	E_x [m^2/sec]	E_y [m^2/sec]	k [sec^{-1}]	Half-life [days]	Injection [mass/sec]
V-7	Snapper Creek	10	5	0.00002	0.4	105
V-8	Snapper Creek	10	5	0.00001	0.8	105
V-9	Snapper Creek	25	10	0.00001	0.8	105
V-10	Black Creek	25	10	0.00002	0.4	521
V-11*	Black Creek	25	10	0.00002	0.4	521
V-12	Black Creek	40	40	0.00002	0.4	521
V-13	Black Creek and Mowry Canal	10	5	0.00001	0.8	521, 987
V-14	Mowry Canal	10	5	0.00002	0.4	987

* All runs include a canal discharge of 20 m^3/sec except the one marked with an asterisk (zero discharge).

Because of the small distance between Black Creek and Mowry Canal there can be significant interaction between contaminant released simultaneously. Figure V-13 shows the resulting concentration distributions for this situation. Finally Figure V-14 shows a situation with release from Mowry Canal only.

All the runs are made for a period of 300,000 sec (~3.5 days) which is sufficient for development of a quasi-steady state. The numerical scheme used to generate the model results is afflicted with small numerical errors. In the presentation of iso-concentration curves a bay dilution of about 250 is therefore taken as the limit of contamination, since model resolution does not allow distinguishment between further dilution and numerical errors.

VI. CONCLUSIONS

The small scale mixing and transport processes taking place in the vicinity of the mouth of Snapper Creek, Black Creek and Mowry Canal have been quantified through dye dispersion experiments. For normal conditions the longitudinal (direction of current) dispersion coefficient ranges between 0.5 m^2/sec to 5 m^2/sec for shallow protected regions and deeper open areas respectively. Under extreme conditions of vertical stratification and strong winds a significant increase in spreading is observed locally. The equivalent dispersion coefficient increases similarly. Due to the small canal discharge rates stratification does not persist in the bay interior, such that a base value of 5 m^2/sec is reasonable for dispersion studies in the bay.

Calibration of the numerical model, DISPER, against the dye experiment indicates that a typical value of 5 m^2/sec best describes the observed spreading rates using the refined grids. Without grid refinement numerical dispersion obscures the results.

In prediction of contaminant spreading from continuous releases the most important factor is the decay rate. Results are only moderately sensitive to changes in the dispersion coefficients.

V. REFERENCES

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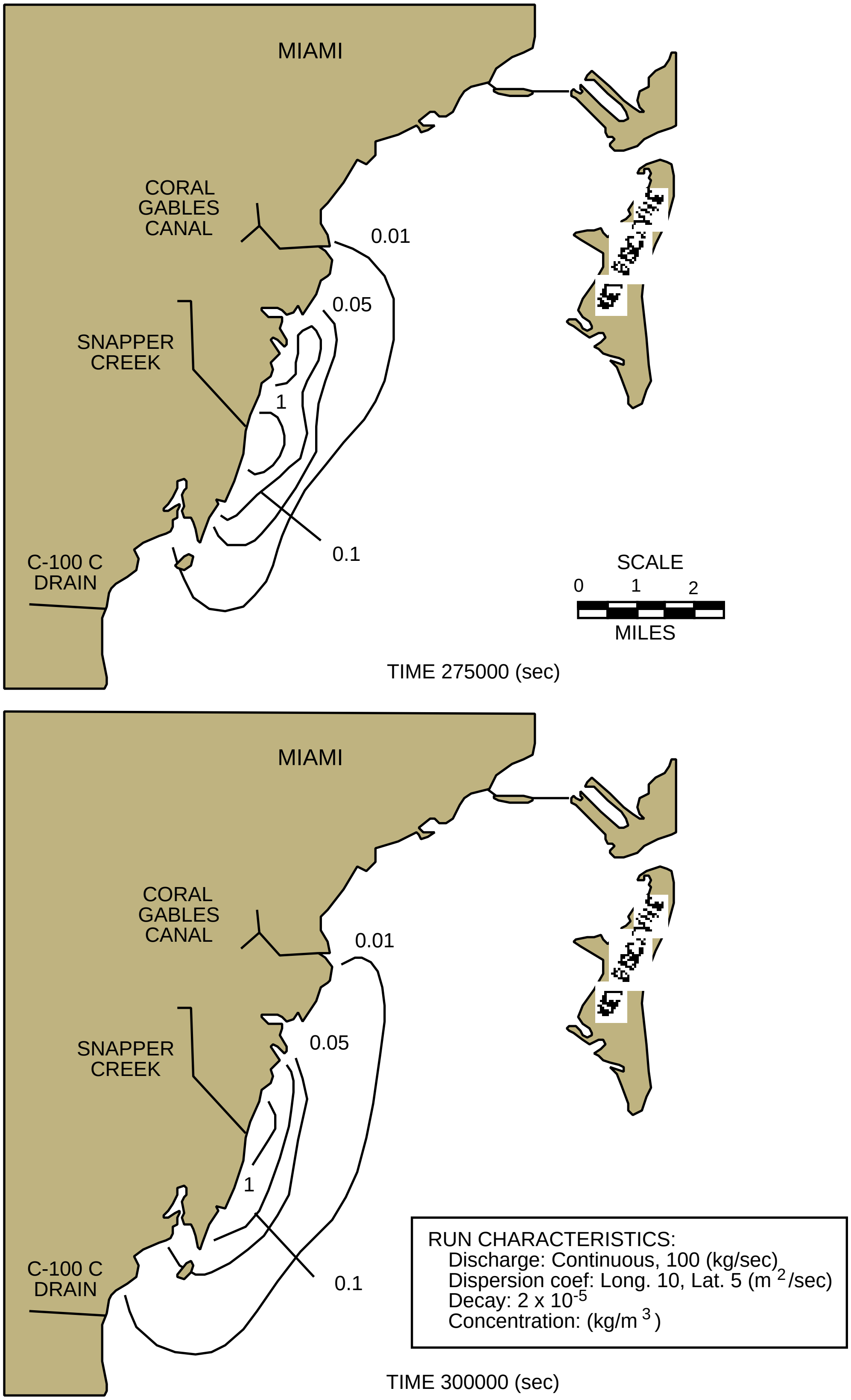
Officer, C. B. (1976). "Physical oceanography of estuaries”. Wiley-Interscience.

Swakon, E. A. and Wang, J. D. (1977). “Modeling of tide and wind induced flow in South Biscayne Bay and Card Sound”. Technical Bulletin No. 37.

Valle, J. C. (1978). "Modeling of dispersion in South Biscayne Bay”. M.S. thesis (unpublished).



RUN CHARACTERISTICS:
Discharge: Continuous, 100 (kg/sec)
Dispersion coef: Long. 10, Lat. 5 (m^2/sec)
Decay: 2×10^{-5}
Concentration: (kg/m^3)

Figure V.7. Simulation of Snapper Creek Canal outflow.

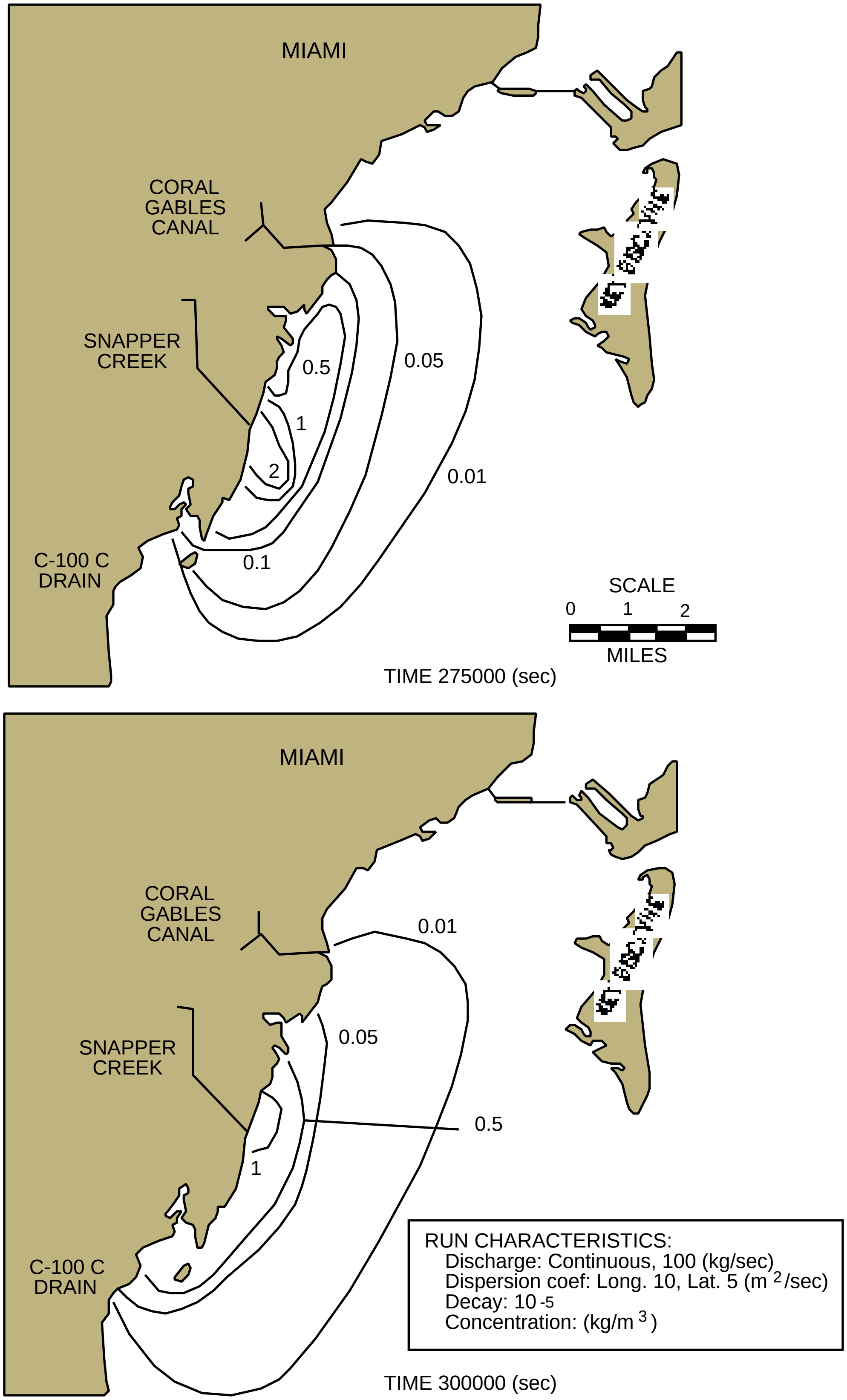
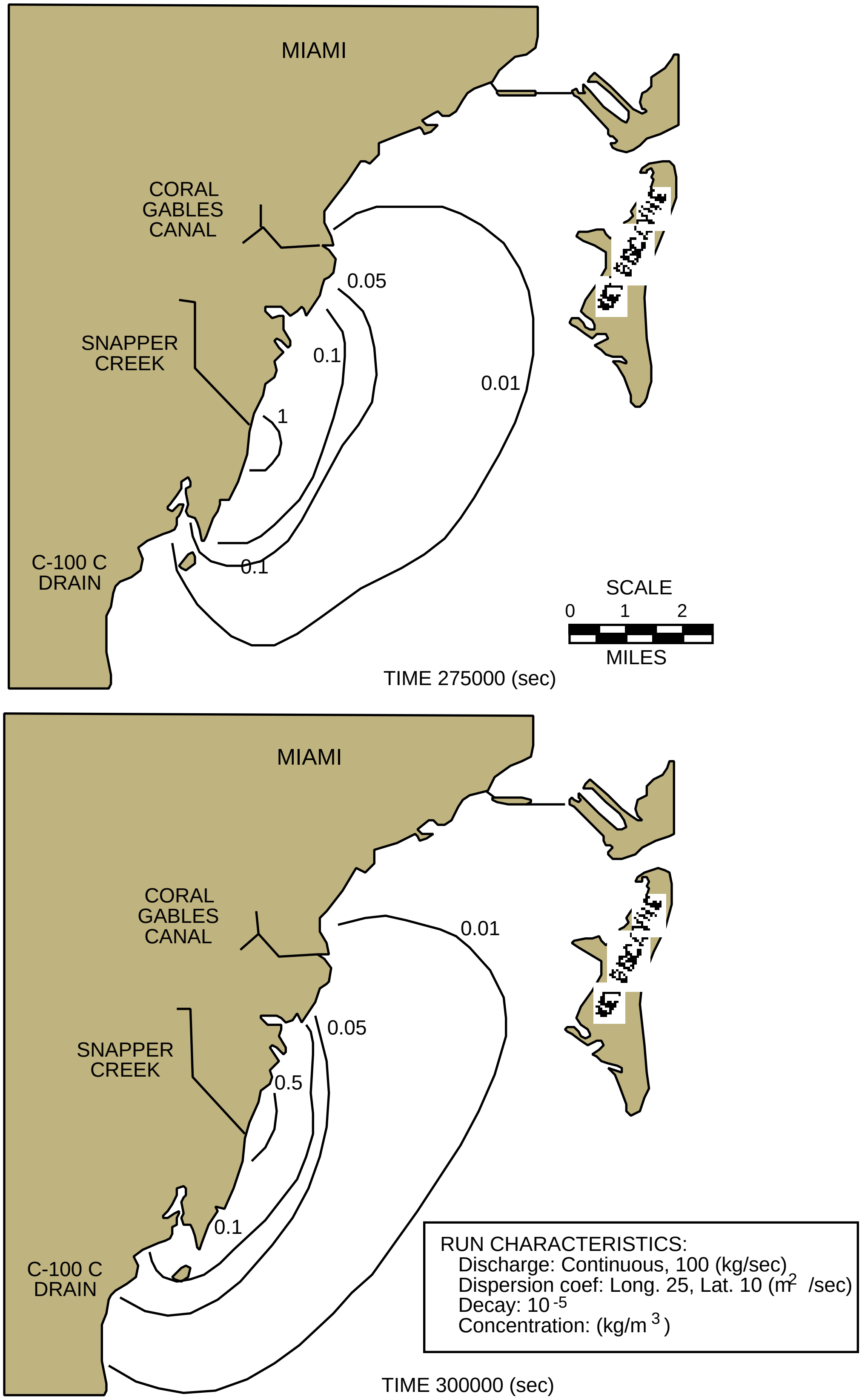


Figure V.8. Simulation of Snapper Creek Canal outflow.



RUN CHARACTERISTICS:
Discharge: Continuous, 100 (kg/sec)
Dispersion coef: Long. 25, Lat. 10 (m^2 /sec)
Decay: 10^{-5}
Concentration: (kg/m^3)

Figure V.9. Simulation of Snapper Creek Canal outflow.

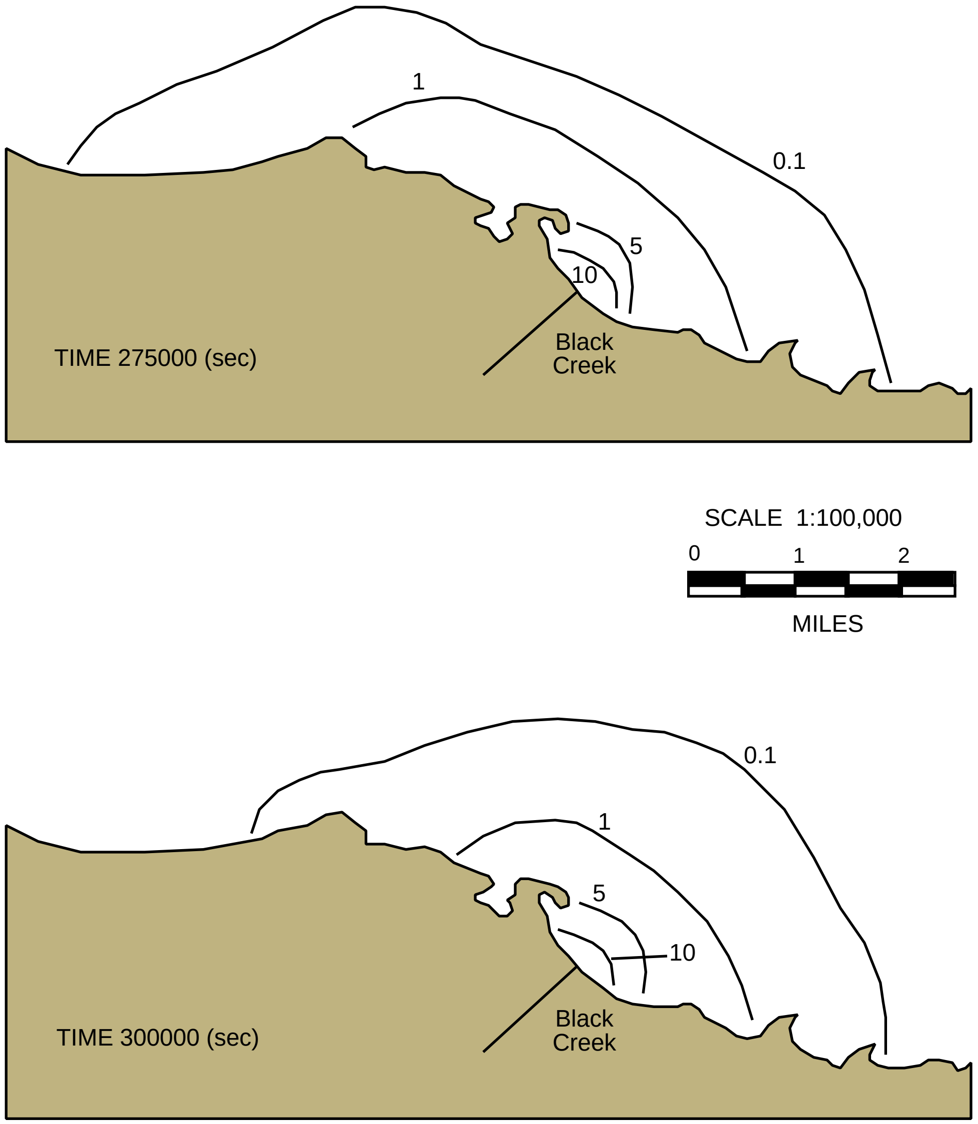


Figure V.10. Continuous discharge at Black Creek. Injection rate 521 [mass/sec], $E_x = 25$ m^2/sec. $E_y = 10$ m^2/sec, k = 0.00002 sec^{-1}.

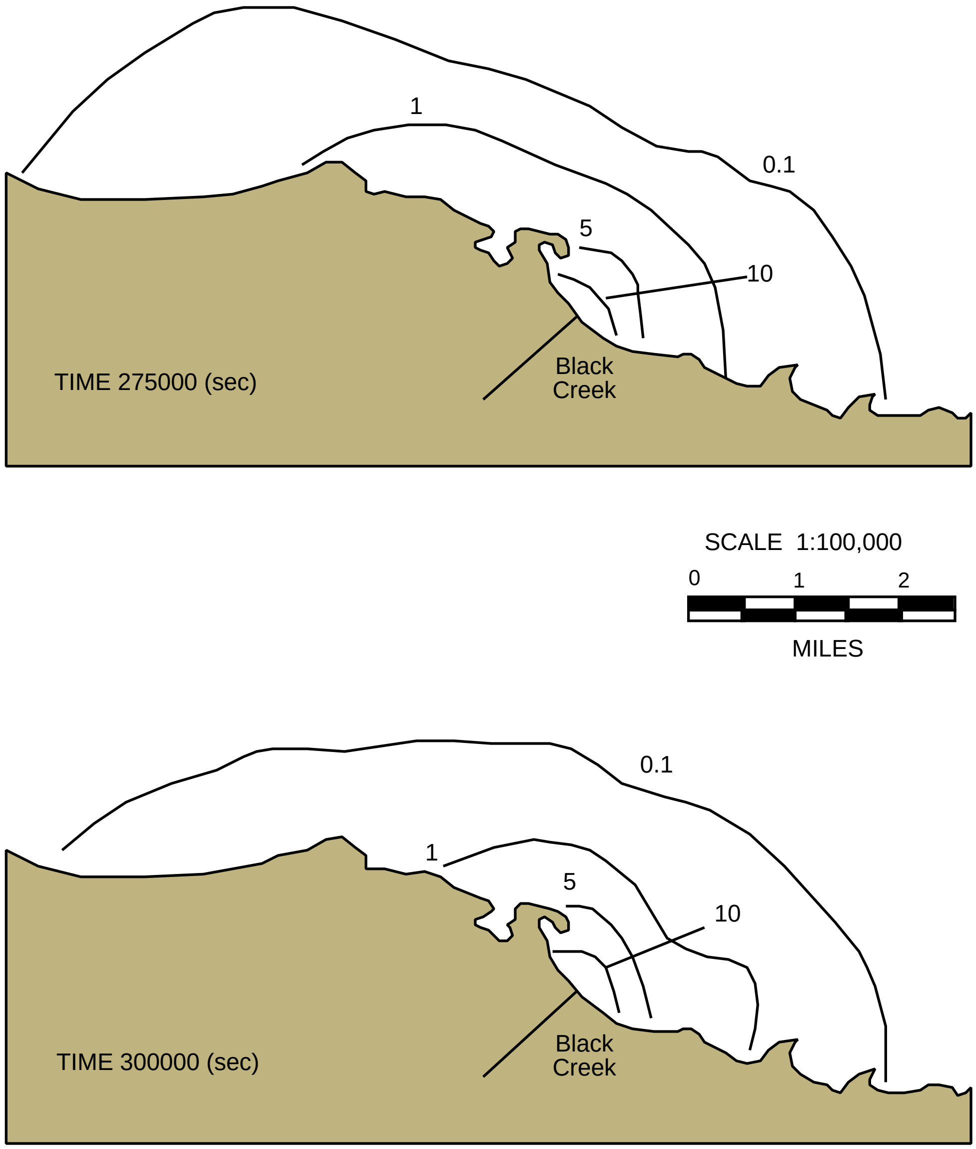


Figure V.11. Continuous discharge at Black Creek. Injection rate 521 [mass/sec], E_x = 25 m^2/sec. E_y = 10 m^2/sec, k = 0.00002 sec^{-1}. Zero canal discharge.

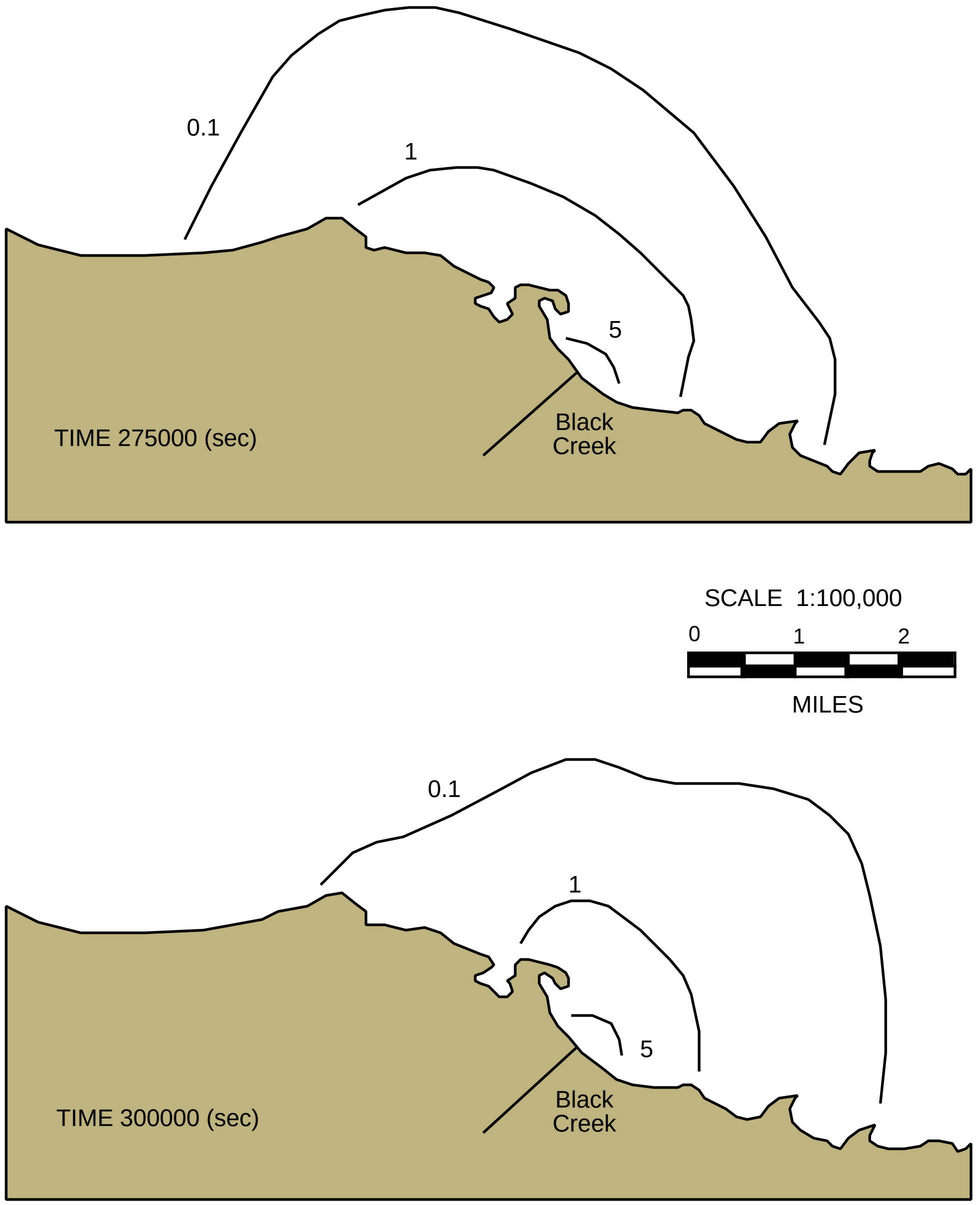


Figure V.12. Continuous discharge at Black Creek. Injection rate 521 [mass/sec], E_x = 40 m^2/sec. E_y = 40 m^2/sec, k = 0.00002 sec^{-1}.

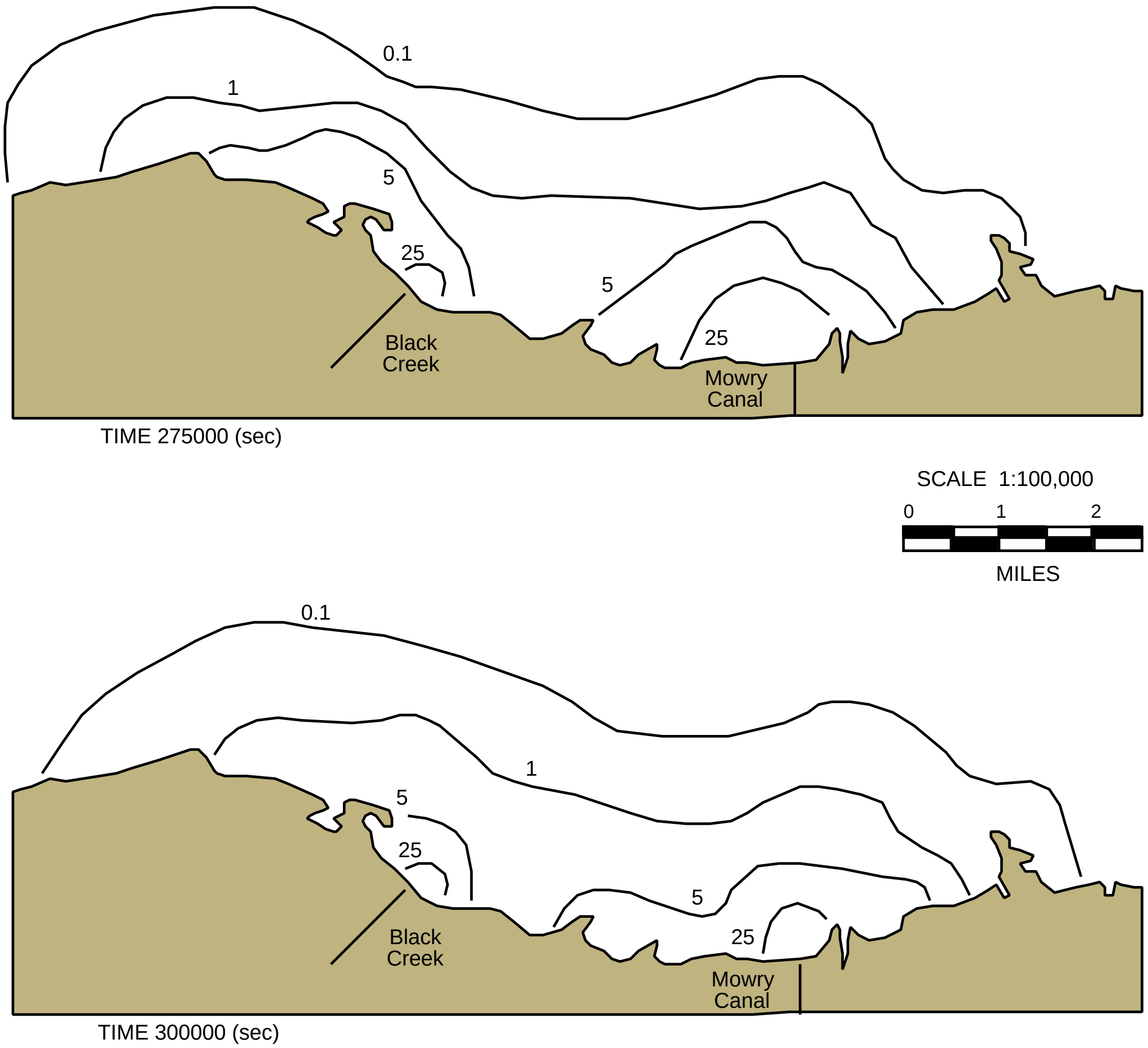
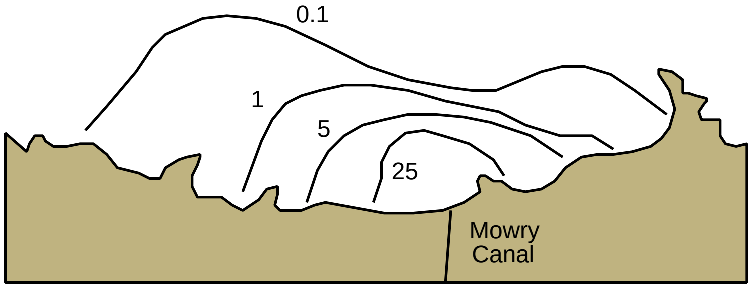
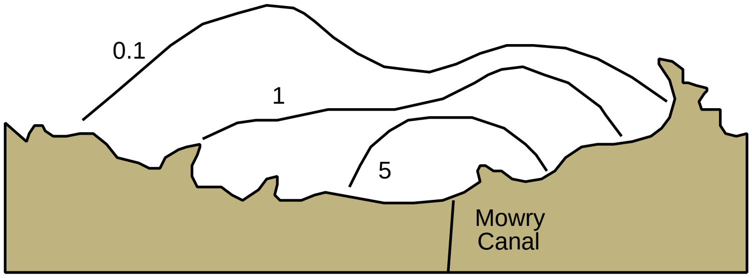


Figure V.13. Continuous discharge at Black Creek and Mowry Canal. Injection rate 521 and 987 [mass/sec], E_x = 10 m^2/sec. E_y = 5 m^2/sec, k = 0.00002 sec^{-1}.



TIME 275000 (sec)



TIME 300000 (sec)

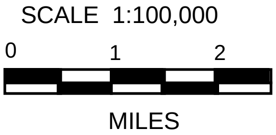


Figure V.14. Continuous discharge at Mowry Canal. Injection rate 987 [mass/sec], E_x = 10 m^2/sec. E_y = 5 m^2/sec, k = 0.00002 sec^{-1}.