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PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE YAQUINA ESTUARY, OREGON

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INTRODUCTION

According to the Statement of Work for this project the "Contractor shall construct a two-dimensional mathematical model of the temperature and salinity structures of the Yaquina Bay, Oregon." Reference is made to the analytical model of Rattray and Officer (1979) which was verified against San Francisco data supplied by Peterson *et al.* (1978). Further, the EPA WASP5 model (Ambrose *et al.*, 1993a, b) was to be used to simulate "...other constituents of interest..." Prime constituents of concern here are temperature and salinity.

This report discusses data collected in the Yaquina Estuary from July 1976 through December 1977 at 6-8 week intervals. Also summarized are recording salinometer, runoff and precipitation data from September 1967 through July 1968. Station names and locations for the 76-77 field data are shown in Figure 1. Figure 2 shows 67-68 recording station locations.

After a brief description of the setting of the Yaquina Estuary, estuarine dynamics and classification, and estuarine chemistry are presented. Then, temperature-salinity relations are reviewed using the Rattray-Officer model in simulating variable distributions reported by Callaway and Specht (1982) and Callaway (1991). Finally, the numerical models DynHyd and WASP are reviewed, some output for each model are shown and the results discussed.

The terms Wasp, WASP, WinWasp, WINWASP are used interchangeably as are DynHyd, DYNHYD, WinDyn and WINDYN.

AREA OF STUDY

ESTUARY CLASSIFICATION

The Yaquina Estuary is typical of small coastal plain estuaries described by Pritchard (1952) as semi-enclosed bodies of water having a free connection with the open sea within which sea water is measurably diluted with fresh water derived from land drainage. Pritchard classified estuaries by considering their vertical salinity structure. Burt and McAlister (1959) discussed the Yaquina and other Oregon estuaries based on Pritchard's classification. Hansen and Rattray (1965, 1966; the latter is referred to as HR in this report) extended the classification. Their method employed circulation and stratification parameters at given cross-sections. Dimensionless ratios of net surface current to mean freshwater velocity (U_s/U_f) and top-to-bottom salinity difference to mean cross-sectional salinity ($\delta S/S_o$) are used to exhibit the physical significance of different systems. Figure 3 shows the classification in terms of the above ratios. The examples given by HR are replotted with an abbreviated description of the different types (1-4). West coast waters shown are the Columbia River (C), Straits of Juan de Fuca (JF), Silver Bay, Alaska (S). A point for the Yaquina River (Y) at mile 14 has been added to the graph from unpublished data collected by the EPA (aka FWPCA). The Yaquina data were taken during a 25 -hour anchor station; the stratification parameter is 0.12 and the circulation parameter is 1.64. The coordinates of the point place the estuary at this river mile, at this time, in type 1b, a case of appreciable stratification. The near vertical dotted line through the point was obtained by computing hourly parameters in order to obtain an idea of the range of values that might be expected under the prevailing conditions. As can be seen, the dots extend into higher stratification values and also extend into type 1a, "...the archetypical well-mixed estuary in which the salinity stratification is slight...".

Vertical profiles of salinity and current and dissolved oxygen are given in Figure 4 which shows periodic stratification of salinity (and oxygen) in the first eight hours followed by well-mixed conditions for the remainder of the time. Oxygen stratification is apparent at the same time but the gradient is directed upward rather than downward as shown at about 1500 hours. If salinity were expressed in terms of the amount of freshwater rather than saltwater, the gradients would be in the same direction; more important, however, is the fact that contours of different substances will rarely be matching. A description of this type of apparent disparity is difficult to rectify by analytical methods and recourse must be made to numerical models incorporating diffusion and, at least, photosynthesis and respiration. The discrepancy is put into perspective by noting that sources of freshwater and oxygen are separate mechanisms.. The freshwater source is mainly from upriver runoff while atmospheric oxygen can be supplied at the surface by reaereation and from within by photosynthesis. Sinks are also different, freshwater decreasing by seepage and evaporation while oxygen decreases by within stream BOD, respiration and bottom demand.

The use of 1-dimensional longitudinal models implies that an estuary is well-mixed vertically and laterally. The Yaquina is well-mixed part of the time, but averaged over a tidal cycle it can still exhibit stratification. In general, increasing the period of averaging serves to smooth out intra-tidal fluctuations. This rationale has been employed in order to average out diurnal tidal fluctuations in some models, primarily for ease of computation and to keep the problem as simple as possible. Figure 4 shows that an anomalous condition can obtain, namely a short-term average and computing interval would well suit 1-dimensional qualifications while a long-term average would put the system into the partially stratified class. Borderline cases such as the above are not all that rare and pronouncements of 1-dimensionality should be made cautiously.

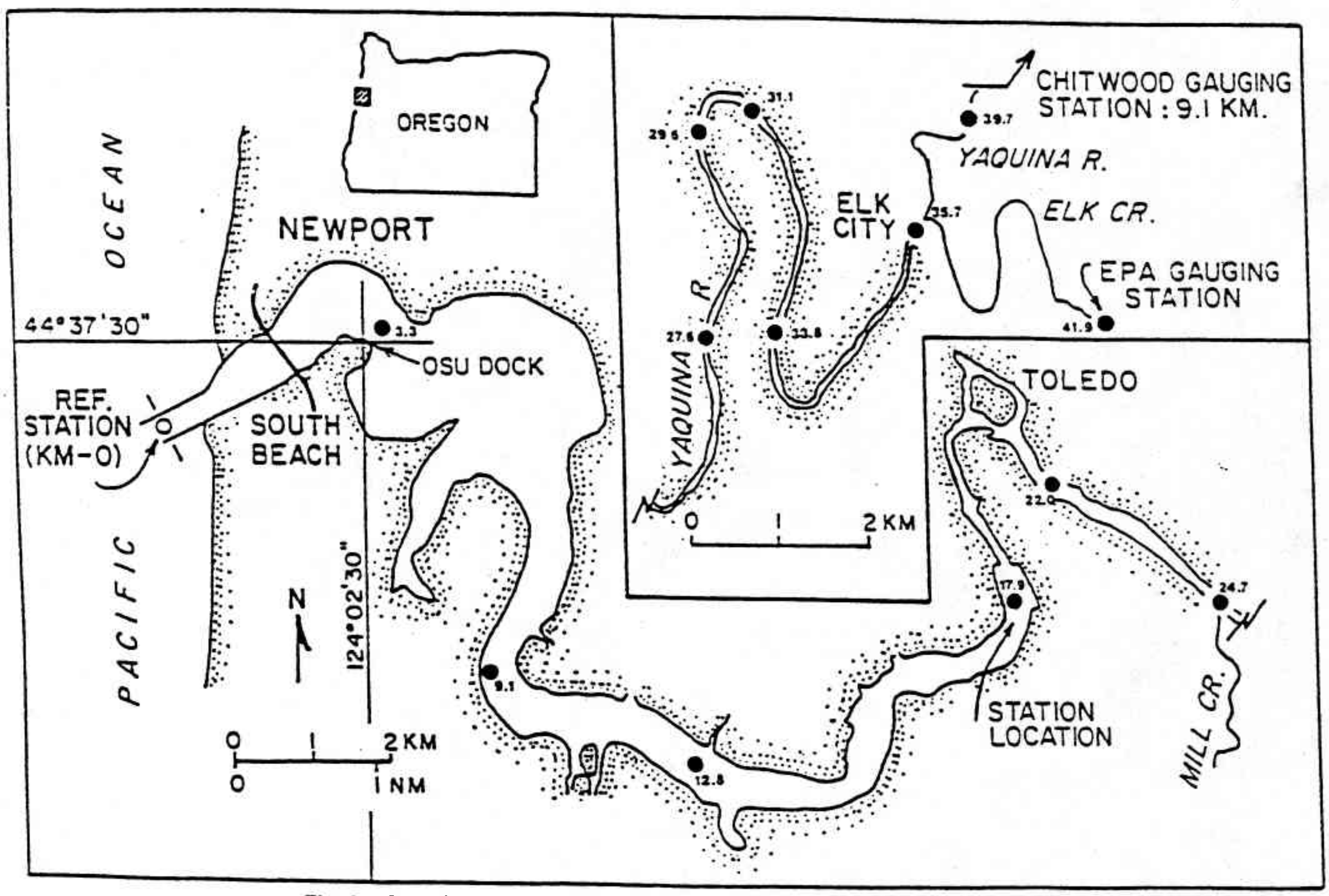
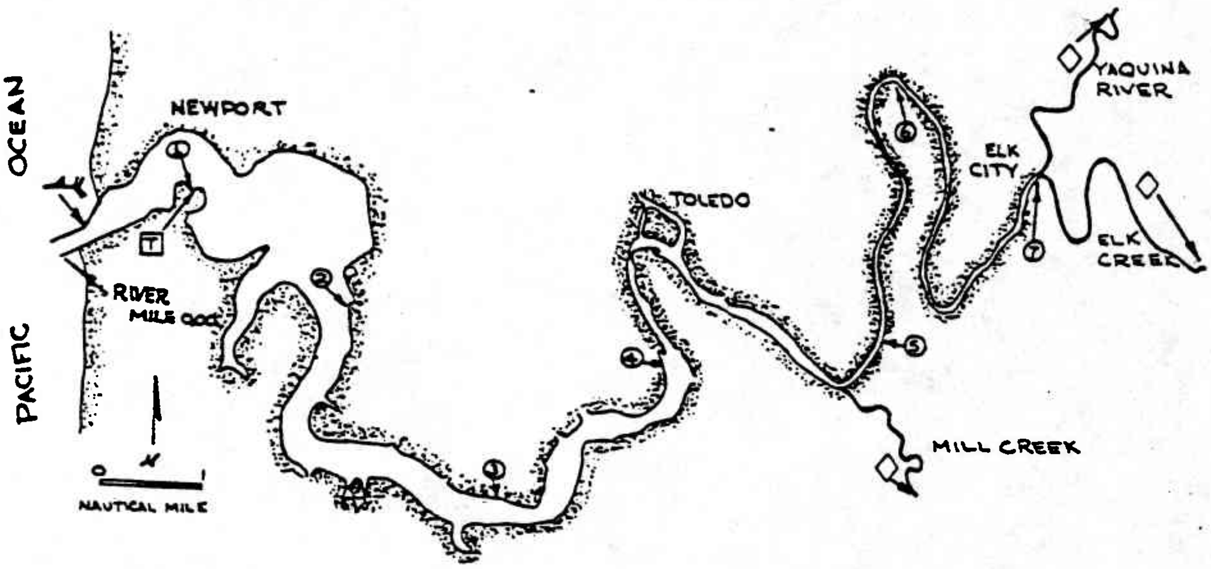


Fig. 1. Location chart and station positions, Yaquina Estuary, Oregon.



Legend

- O Conductivity Meter Location
- ⟵« Wind Recorder Location
- ⊡ Tide Gauge Location
- ◇ Stream Gauge Location

	Station	River Mile* (Nautical)
(1)	OSU Dock	∿ 1.5
(2)	Sawyer's Dock	∿ 3.5
(3)	Fowler's Dock	∿ 7.0
(4)	Criteser's Dock	∿ 9.5
(5)	Burpee	∿14.0
(6)	Charlie's Dock (Fritz)	∿16.0
(7)	Elk City	∿19.5

* River Mile 0.00 is the seaward end of the south jetty.

Figure 2. Recording station locations.

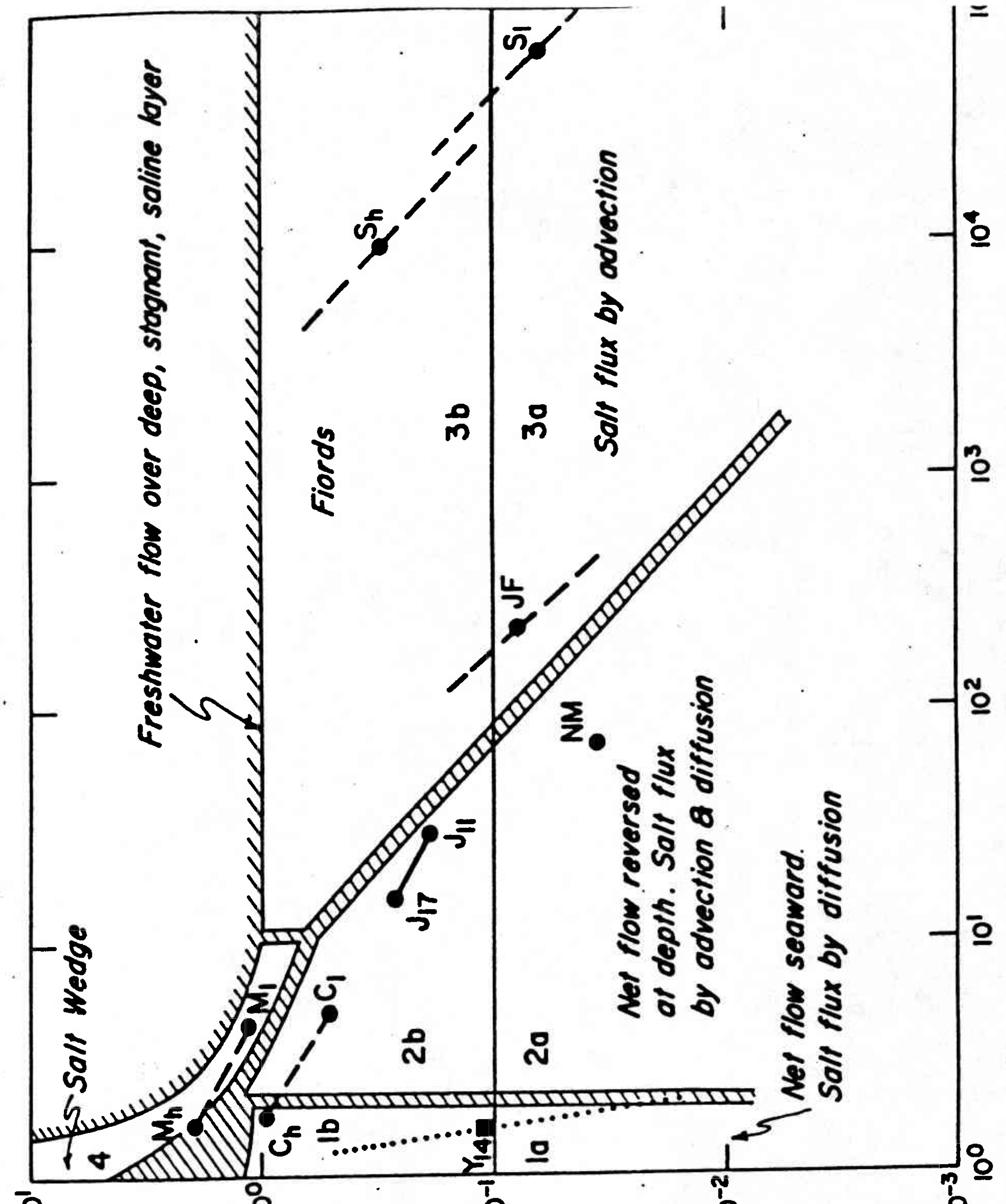


Figure 3. Estuary type classification according to Hansen and Rattray (1966).

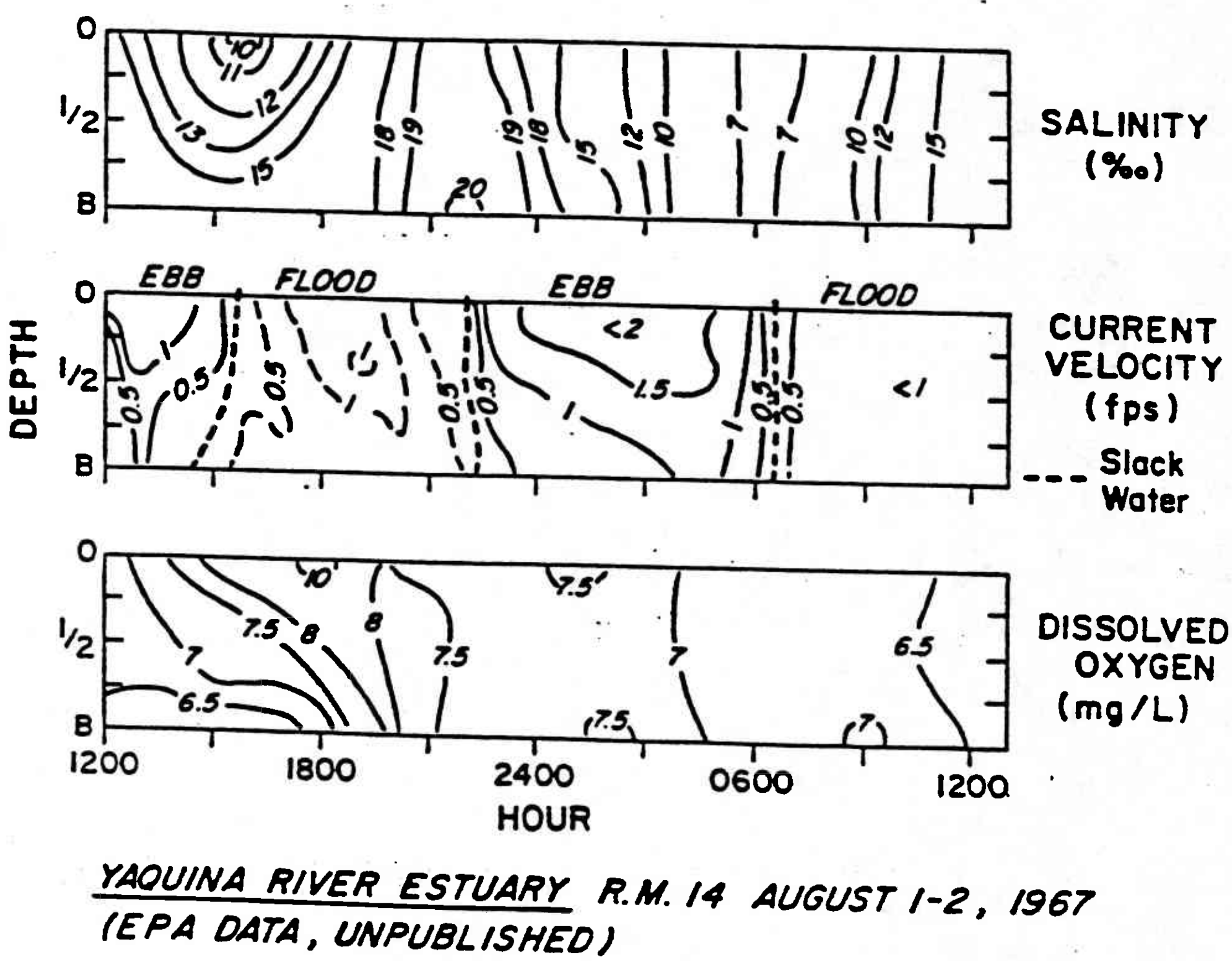


Figure 4. Vertical profiles, dissolved oxygen, salinity, current velocity.

LOCAL COMMUNITIES

Three small communities border the estuary: Newport (1998 population 10,240) located near the estuary entrance, serves as a port for a commercial and sport fishing fleet; Toledo (December 1999 population 3590) is about 10 km upstream of the entrance and is the site of a pulp mill whose principal waste discharge is to the Pacific Ocean is via an outfall (~1.5 km offshore) 3.3 km north of the estuary entrance. In addition to a 0.7 - 1.6 mgd (avg dry/wet weather flow based on permits as of 7/7/99) municipal secondary treatment plant at Toledo, combined storm water waste overflow is discharged to the bay during periods of high flow. Several small seafood processing plants in Newport discharge ~1.0 mgd screened wastes directly to the lower bay. Newport municipal wastewater (1.65 - 2.9 mgd dry/wet weather flow) is discharged to the Pacific through an outfall parallel to the pulp mill line. Elk City (1998 population ~25) is the remaining population center. Neither it nor any of the small residences, businesses or marinas (see Callaway 1981) constitute a significant to waste source in the area.

PHYSICAL SETTING

The Yaquina estuary drainage basin is about 622 km^2 (Kulm and Byrne, 1966). Mean tide range at the entrance is 1.80 m and 1.92 m at Toledo, 20 km upstream (NOAA, 1977a). USGS stream records at Chitwood were used to estimate Yaquina flow; a stream gauge on Elk Creek was maintained by EPA to determine total flow by methods given in Callaway *et al.* (1970). River flow for 5 days previous to a given field data survey was used to calculate the flow during the survey. Mill Creek runoff was generally negligible. Total flows ranged from 1.3 to 87 m^3/s. The cross-sectional area averaged river current, U_f, at km-31 ranged from 0.7 to 43 cm/s. Cross-sectional areas in km^2, A, decreases with X, distance upstream of km-0 as $A \sim 4400\exp(-0.1X)$. Salinity intrusion length in km, L_s, is related to river runoff in m^3/s by $L_s = 32.2 - 2.9 \ln(Q)$. The salinity difference from top to bottom, $\delta S = 1.1 + 0.21\ Q$. These are not exact relationships and will vary with time because the salinity excursion length is as much as 5 km per tidal cycle and the vertical salinity structure can change with wind, tide and river runoff fluctuations.

Extensive tidal flats, shoals and shallow sloughs modify the topography of the estuary. These areas undoubtedly contribute to pore water exchanges with overlying waters but are not considered further here.

The estuary has a surface area of about 11.6 km^2 at mean tide level and 9.1 km^2 at mean low water. Volume at mean higher high water is about $55 \times 10^6\ m^3$ and $26 \times 10^6\ m^3$ at mean lower low water.

CLIMATE

Mean annual air temperature at Newport from 1937 to 1969 was 14.2 °C in August and 6.4 °C in January (Holbrook 1970, cited in Reed, 1978). Mean monthly air temperature 1971 at Toledo ranged from 18.5 °C in August to 6.4 °C in December. Annual rainfall at Newport for 1938-1969 averaged 173.7 ±12.3 cm, and increases some 250-300 cm moving inland into the drainage basin.

No allowance was made to include bank runoff downstream of measurement stations. Minimum precipitation in July was 1.7 cm and 2.6 cm in August (Holbrook, *op. cit.*), the month of primary concern here because of resultant low flow conditions.

WINDS

Winds are seasonal in speed and direction in the Yaquina Bay region. Light offshore winds occur in the winter along with infrequent south-southwest storm winds. Summer is characterized by moderate to strong north-northwest winds. These wind conditions during the summer induce upwelling of relatively cold, saline waters which can move into the Bay and are detectable in the middle and upper reaches of the Bay.

TIDES

Predicted tides are published by NOAA for Yaquina Bay and River and are referred to the Humboldt Bay reference station. Most of the following definitions and terms follow those listed in the NOAA publication.

Predictions are at the entrance bar, Newport, South Beach, Yaquina, Winant and Toledo. Table 1 shows predicted tidal differences and other constants for these places.

TABLE 1.—TIDAL DIFFERENCES AND OTHER CONSTANTS

PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level
			Time		Height				
	Lat.	Long.	High water	Low water	High water	Low water	Mean	Diurnal	
	° ′	° ′	h. m.	h. m.	feet	feet	feet	feet	feet
Bar at entrance	44 37	124 05	+0 03	+0 09	+1.5	+0.1	5.9	7.9	4.2
Newport	44 38	124 03	+0 13	+0 12	+1.6	+0.1	6.0	8.0	4.3
Southbeach	44 38	124 03	+0 02	+0 03	+1.3	+0.1	6.2	8.2	4.4
Yaquina	44 36	124 01	+0 24	+0 25	+1.3	+0.1	6.2	8.2	4.4
Winant	44 35	124 00	+0 32	+0 46	+1.3	0.0	6.3	8.2	4.3
Toledo	44 37	123 56	+0 58	+1 09	+1.7	−0.1	6.3	8.1	4.2

The *datum* is the mean of the lower of the two daily low waters. Nautical chart depths are referred to the low water datum corresponding to that from which predicted tidal heights are determined. The actual depth is obtained by adding tidal height to chart depth.

The *mean range* is the difference in height between mean high and mean low water. The *spring range* is the average semi-diurnal range occurring semi-monthly during new or full moons. The diurnal range is the height difference between mean higher high and lower low water.*Mean sea level* is the average level of the sea above datum.*Mean tide level* (half tide level) is a plane between mean low water and mean high water.

Tides are usually described as diurnal, semi-diurnal or mixed. *Semi-diurnal* tides occur in range with the moon's phases. *Diurnal* tides vary with declination (position of the sun and moon); *mixed* tide characteristics vary with the moon's declination and phase and solar forces.

Yaquina tides are mixed semi-diurnal with a mean range of 1.8 m at Newport, a diurnal range of 2.4 m and mean tide level of 1.3 m. Tide studies by Neal (1966), Goodwin et al. (1970) and Goodwin (1974) show amplification of the tidal range increases with distance upstream. Goodwin *et al.* (*op. cit.*) found a 0.61 m range at Newport resulted in 2.93 m at Elk City. A phase difference of 90-100 degrees (corresponding to a time lag of 0-20 minutes) was found to exist between tide height and current in the Bay (Neal, *op. cit.*). These observed tide ranges and phases indicate the presence of reflected waves and/or resonance conditions of a shallow water standing wave.

CURRENTS

Predicted tidal currents are also published by NOAA (*op. cit.*) for Yaquina Bay and River and referred to the Wrangell Narrows, Alaska, reference station. Predictions are for the bay entrance, highway bridge, Newport, Yaquina, and one mile below Toledo. Table 2 shows the NOAA predictions.

TABLE 2.—CURRENT DIFFERENCES AND OTHER CONSTANTS

PLACE	POSITION		TIME DIFFERENCES		VELOCITY RATIOS		MAXIMUM CURRENTS			
							Flood		Ebb	
	Lat.	Long.	Slack water	Maximum current	Maximum flood	Maximum ebb	Direction (true)	Average velocity	Direction (true)	Average velocity
	° ′	° ′	h. m.	h. m.			deg.	knots	deg.	knots
Yaquina Bay entrance	44 37	124 04	-1 40	-2 35	0.5	0.6	050	2.4	235	2.3
Highway bridge	44 37	124 03	-1 55	-1 25	0.5	0.6	045	1.9	220	2.1
Newport (docks)	44 38	124 03	------	------	------	------	035	0.4	230	0.5
Yaquina, Yaquina River	44 36	124 01	-1 45	-1 15	0.3	0.3	135	1.0	000	1.1
Yaquina River, 1 mile below Toledo	44 36	123 57	-1 00	-0 40	0.4	0.4	330	1.4	130	1.4

Slack water means no current in either flood or ebb direction. *Direction of set* is the direction in degrees true for flood and ebb. At Yaquina Bay entrance flood set is 050° true and for ebb is 235°.

Currents and tides are not necessarily in phase. Long waves in an estuary may be either progressive or standing. A *progressive wave* has only one wave train oscillating in essentially the same place as opposed to a *standing wave* which doesn't oscillate at all. In addition, waves may be reflected and superimposed on waves downstream of the reflection point. This simply means that maximum tide height does not necessarily occur at times of maximum current. These phase differences also apply to the distribution of salinity and other variables introduced at the estuary mouth. It can be shown (see, e.g., Officer, 1976, pps 77-79) that for a standing wave the current velocity is 90 degrees out of phase with tide height. Maximum flood and ebb occur at half tide and slack water

occurs at high and low tides. For a progressive wave, current velocity and tide heights are in phase. Maximum flood and ebb currents occur at high and low tides and slack water occurs at half tide.

If the equation of continuity is reduced to its simplest form in the x-direction for a conservative substance then $\frac{\partial s}{\partial t} = -U\frac{\partial s}{\partial x}$, where $U = C\sin(2\pi t/T)$, s = salinity and T is tidal period. If the longitudinal salinity gradient, $\partial s/\partial x$, is constant, the salinity variation about the mean, Δs, is $\Delta s = \frac{CT}{2\pi}\frac{\partial s}{\partial x}\cos\frac{2\pi t}{T}$, which demonstrates the statement above that the salinity variation is π/2 out of phase with current velocity.

ESTUARINE DYNAMICS: THE HANSEN-RATTRAY CLASSIFICATION SCHEME

The classical papers by HR reveal a great deal about estuarine dynamics in a concise form and are the basis for the following discussion. Certain algebraic additions were made to simplify some of the equations; they serve to suggest that output from 1-dimensional link-node numerical models (discussed later) greatly simplify and mask a complex environment.

Coupling between circulation and salinity distribution is based on two bulk parameters: P= Uf/Ut and a densimetric Froude number Fm = Uf/Ud. Here Uf is river runoff divided by mean cross-sectional area (Q/A), Ud is a densimetric velocity $(g\Delta\rho D/\rho)^{1/2}$ and Ut is the rms tidal velocity. To determine these velocities knowledge of river runoff, depth and tidal current are required. The densimetric velocity for an estuary mean depth of 4 meters is about 1 m/s. Tidal current can usually be obtained from NOAA tables; depth, D, and A from navigational charts and Q from USGS or other gauges.

Critical to the theoretical development is determination of three coefficients: the diffusive fraction, v , an estuarine Rayleigh number, Ra, and a tidal mixing parameter, M. The parameters are related by:

(1) $vRa = 16\ Fm^{-3/4}$

(2) $M/v = (1/20)P^{-7/5}$

Data from five estuaries were utilized by HR (see Fig. 3) to demonstrate that Fm and P were sufficient to determine the circulation parameter Us/Uf and stratification parameter δS/So, where δS is bottom salinity minus surface salinity and So is the tide averaged sectional mean salinity. In turn, knowledge of the bulk parameter was employed in classifying estuaries by type.

Of importance here is to be able to estimate circulation and stratification in the Yaquina either prior to a field investigation or after it. It is used here in relation to data sets obtained along the Yaquina; these data sets are discussed later. The data were not obtained in order to verify HR parameters given or derived below but are used tentatively to assist in the interpretation of the data. Some of the parameters are more of theoretical than practical interest but the formulation is listed in order for comparison with the data of, e.g., Bowden and Gilligan (1971), Murikami (1986) and/or Oey (1984).

The Diffusive fraction, v

The fraction of salt diffused upstream is represented by v. When v = 1, flux is by diffusion only; when $v \Rightarrow 0$, salt flux is by gravitational convection in two-layered flow. From the equation commonly applied to 1-dimensional pollution dispersion problems it was proposed that $UfSo = Kh\partial S/\partial x$ is better represented by $vUfSo = Kho\partial S/\partial x$, where Kho is a reference diffusivity. Hence the coefficient for horizontal dispersion is:

(3) $$Kho = vUfSo/(\partial S/\partial x) .$$

Officer (1976) has shown that v can be obtained from

(4) $$v \rightarrow 1 - \frac{1}{5}\frac{\delta S}{S_o}\frac{U_s}{U_f}$$

For smaller values of Us/Uf:

(5) $$v \simeq 1 - \frac{0.03(U_s/U_f)^2 - 0.045(U_s/U_f) + 0.019}{0.15(U_s/U_f) - 0.1}\frac{\delta S}{So}.$$

Since the bulk parameters are related to P and Fm, substitution of (1), (2) in (4) and (5) will demonstrate that v can be simply calculated from average values of Uf, Ud, Ut. In addition, manipulation of (1), (2) results in determination of all the parameters required in the description of flow and mixing but these require consideration of Ra and M.

The Estuarine Rayleigh Number, Ra

HR employ "...an estuarine analog of the Rayleigh number..." used in convection theory in the characterization of the solution equation. They have

(6) $Ra = gkS_oD^3/AvKho$

where

g = gravitational acceleration

k = factor (0.00075) in the linear equation of state ($\rho = \rho_f(1 + kS)$

Av = vertical viscosity coefficient

Kho = reference coefficient of horizontal diffusivity

For later use, note that gkSoD = U^2_d and substitute (3) into (6):

(7) $$Ra = \frac{U_d^2 D^2 \partial S / \partial x}{\nu A_\nu U_f S_o}$$

This expression can be used to solve for Av in terms of the bulk coefficients.

The Tidal-Mixing Parameter, M

The tidal-mixing parameter is given by

(8) $M = KvKhoB^2/R^2$,

where

Kv = vertical turbulent diffusivity

B = estuary width.

R = river flow.

Since Uf = Q/(BD), equation (8) can be written as

(9) $$M = \frac{vKvSo}{(\partial S / \partial x)U_f^2}$$

From (7) and (9)

(10) $$MRa = \frac{Kv}{Av}\left(\frac{Ud}{Uf}\right)^2 = \frac{KvFm^{-2}}{Av}$$

and from (1) and (3) we have an expression for the ratio of eddy diffusivity to eddy viscosity:

(11) $$\frac{Kv}{Av} = \frac{4}{5}U_f^{-3/20}U_t^{7/5}U_d^{-5/4}$$

The Circulation Parameter, Us/Uf

For the case of zero wind stress, solution of HR equation (15) and (16) gives

(12) $$Us/Uf = -\frac{d\vartheta}{dn}$$

(13) $$\vartheta(n) = \frac{1}{2}(2 - 3n + n^3) - \frac{vRa}{48}(n - 3n^2 + 2n^4)$$

For n = 0,

(14) $\dfrac{U_s}{U_f} = \dfrac{3}{2} + \dfrac{1}{3} F_m^{-3/4}$ after some manipulation and substitution of (1) in (13).

Equation (14) can also be expressed as:

(15) Us/Uf = $\dfrac{3}{2} + \dfrac{1}{3} U_d^{3/4} U_f^{-3/4}$, since $F_m = U_f / U_d$

<u>The Stratification Parameter, δS/So</u>

Solution of HR equation (16)

(16) δS/So = $1 + \nu\zeta + \dfrac{\nu}{M}[(n - \dfrac{1}{2}) - \dfrac{1}{2}(n^2 - \dfrac{1}{3}) - \int_0^n \phi dn + \int_0^1 \int_0^n \phi dn' dn]$

for salinity at n = 0 and n = 1, results in

(17) δS/So = $\dfrac{1}{320}(20P^{7/5})(16F_m^{-3/4}) = P^{7/5} Fm^{-3/4}$, and

(18) δS/So = $U_d^{3/4} U_t^{-7/5} U_f^{13/20}$

For equation (4) we now have

(19) v = 1 - $\dfrac{3}{10} P^{7/5} F_m^{-3/4} - \dfrac{1}{15} F_m^{-3/2}$, and

(20) v = 1 - $\dfrac{3}{10} U_d^{3/4} U_t^{-7/5} U_f^{13/20} - \dfrac{1}{15} U_d^{3/2} U_t^{-7/5} U_f^{-1/10}$

For equation (5) we have

(21) $$v = 1 - \frac{7.68F_m^{-3/2} - 0.72F_m^{-3/4}P^{-7/5} + 0.19P^{-7/5}}{48F_m^{-3/4} - 2}$$

Vertical Eddy Viscosity, Av

From equations (1) and (7) we have

(22) $$16\ Fm^{-3/4} = \frac{U_d^2 D^2 \partial S / \partial x}{AvUfSo};$$

solving for the vertical eddy viscosity

(23) $$Av = \frac{D^2 \partial S / \partial x Ud^{5/4}}{16SoUf^{1/4}}$$

which can also be expressed as

(24) $$Av = \frac{D^2 \partial S / \partial x}{So} Fm^{-1/4} Ud$$

This differs from Officer's expression which, in the notation here, is

(25) $$Av = \frac{D^3 g \partial\rho / \partial x}{24(2Us + Ub - 3Uf)\rho},$$ where ρ = density, Ub = bottom velocity.

The difference is due to the inclusion of a bottom velocity term which in the HR theory is zero through a no-slip boundary condition.

Vertical Eddy Diffusivity, Kv

From equations (2) and (9) we have

(26) $$\frac{1}{20}P^{-7/5} = \frac{KvSo}{(\partial S / \partial x)UfD^2}$$

solving for the eddy diffusivity:

(27) $$\mathrm{Kv} = \frac{D^2}{20}\frac{\partial S / \partial x}{So}\frac{Ut^{7/5}}{Uf^{2/5}}$$

which can also be written

(28) $$\mathrm{Kv} = \frac{D^2}{20}\frac{\partial S / \partial x}{So}P^{-2/5}Ut$$

(29) $$\mathrm{Kv} = \frac{D^2}{20}\frac{(3Us - Ub - 2Uf)}{\delta s}\frac{\partial S}{\partial x}$$

Richardson Numbers Ri, Rf

For completeness, expressions relating to vertical mixing and vertical stability are expressed in terms of the HR parameters.

A bulk Richardson number can be approximated as

(30) $$\mathrm{Ri} = \frac{g\partial\rho / \partial z}{\rho(\partial U / \partial z)^2} \cong \frac{g\Delta\rho / D}{\rho(\Delta U)^2 / D^2} \cong \frac{U_d^2}{U_t^2} = \left(\frac{P}{Fm}\right)^2$$, where the rms velocity is used for U.

The flux Richardson number is

$$(31) \quad Rf = \frac{Kv}{Av} Ri = \frac{4}{5} Ud^{3/4} Ut^{-3/5} Uf^{-3/20} = \frac{4}{5} P^{3/5} Fm^{-3/4}$$

<u>Computed HR Parameters, Yaquina Estuary</u>

Date	$Q(m^3/s)$	$Fm(x10^3)$	$P(x10^3)$	v
07/29/76	2.2	1.93	2.29	0.84
10/14/76	1.3	1.72	3.87	0.59
01/20/77	3.5	3.79	4.58	0.84
03/03/77	46.0	28.66	43.68	0.77
04/21/77	7.8	6.56	9.85	0.78
05/12/77	10.4	8.34	17.94	0.64
06/28/77	4.6	4.74	8.09	0.74
08/22/77	1.9	2.39	5.63	0.57
12/20/77	87.0	54.24	95.90	0.68

The details of the computation of these parameters are not presented here; they may be computed from the above relations. For example, the terms for $\delta S/So$ and Us/Uf can be derived from their approximations, Fm and P, and compared with the data in App. 1,2.. Likewise, all the other parameters can be so calculated.

FIELD DATA

The field data surveys were initiated off the OSU dock (Fig. 5) and ended at Elk City in the freshwater portion of the system. Figure 5 also shows the duration of the field studies relative to Newport predicted tidal currents.

Field procedures, sample collection methods, treatment, preservation and laboratory procedures are discussed in papers by Callaway and Specht (1982) and Callaway *et al.* (1988). Additional information on chemical analyses and procedures not discussed in the report is available upon request. A summary of the data is abstracted from an unpublished report by Callaway (1991). The data were listed in Lotus, dBASE4 and Paradox formats. This was in a pre-Windows era and an MSDOS format is implied. The data are compressed and are available upon request. Nineteen chemical analyses were made in addition to a Marine Algal Assay Procedure for *Dunaliella, Selenastrum* and *Thalassiosira* dry weights (Specht, 1976).

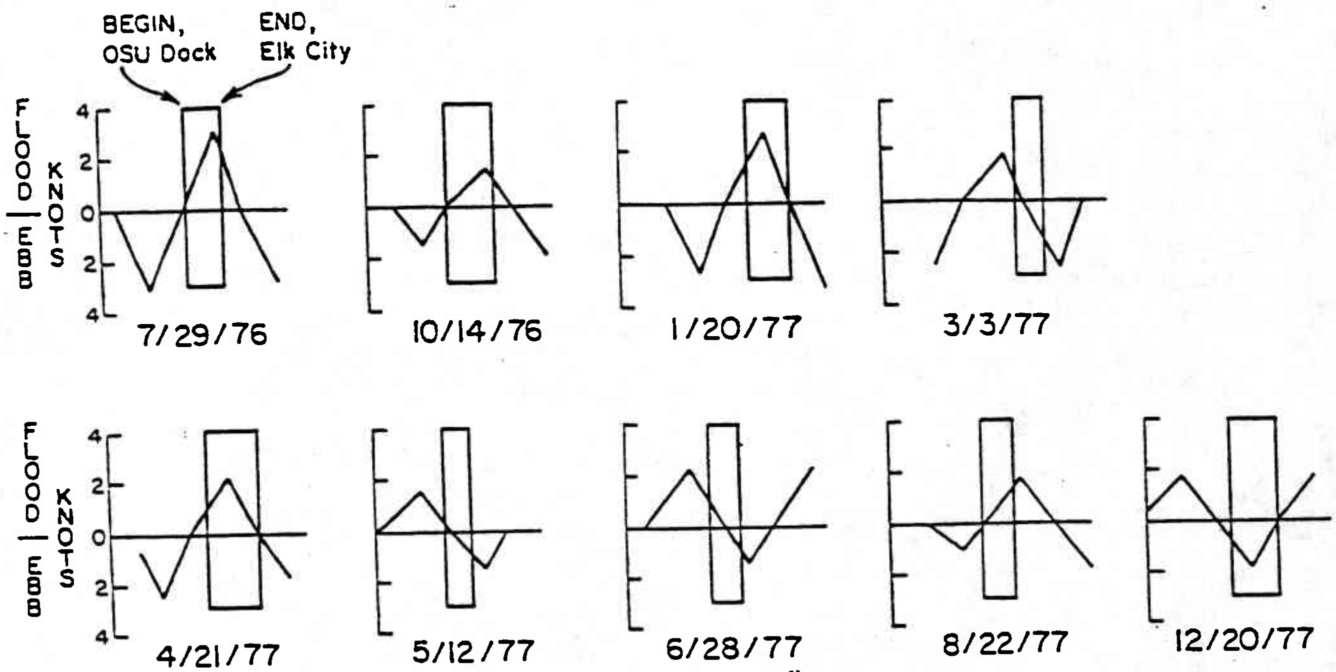


Figure 5. Duration of field studies relative to predicted tidal current at Newport.

DISSOLVED SUBSTANCES

According to Burton (1976), the particular problems of estuarine chemistry, over and above those inherent in the chemistry of any natural water system, arise because of the marked gradients in ionic strength (salinity) and in concentrations of individual chemical species and the generally high concentrations of suspended matter and its variable composition. Added to this are the complexity of estuarine hydrodynamics, sediment resuspension, pore water exchange, biological activity and man-caused pollution processes. The ensuing twenty-some years since Burton's lament have not changed the problem significantly even though chemical methods and modeling techniques have assisted in our understanding of estuarine chemical processes.

Used below is a somewhat arbitrary definition of a "dissolved" substance as that fraction passing through a pre-rinsed Millipore type HA membrane filter having a nominal pore diameter of 0.45μm. It is recognized that for some elements (e.g. Fe, Mn, Al) the dissolved fraction will also comprise species in true solution and possibly polymers and fine particles (see Liss, 1976)

Estuarine Mixing of Dissolved Substances

Although river water salt content is much less than seawater, plant nutrient elements are usually much greater. Ionic strength, pH and redox potential may change during estuarine mixing. Uptake or gain may occur during mixing, i.e., a substance may be defined as conservative or non-conservative. A simple determination of gain or loss is to plot concentration versus salinity. Deviation above or below a straight line connecting river and ocean end concentrations indicates that a non-conservative process obtains. A straight line connection indicates a conservative process. Salinity is the parameter of choice according to Liss (*op.cit.*). Although constituent-salinity plots for well-defined processes (such as silicon, e.g.) are convenient, they may not always be reliable. For instance, some chemical reactions may take place when fresh and saline water mixing first takes place while subsequent (downstream) mixing will exhibit conservative mixing. Liss (*op.cit.*) suggests that to establish non-conservative behavior the deviation from a theoretical dilution line should be 10% or greater.

Liss's cautionary note was reflected in a paper by Officer (1979) who found a loss rate based on a concentration-salinity diagram of $G = L/Rc_0 = (c_0 - c^*_0)/c_0$ where $c^*_0 = c_1 - s_1$ (dc/ds), which is the regression line for constituent end points at s = 0 and s = salinity at the ocean end. Here, L is the loss (per unit time) within the estuary and R is river runoff (unit volume per unit time). Officer noted that reliance on simple conc-sal plots may not be appropriate because of measurement procedures, hydrodynamic complications and the interpretation of data. In a paper by Rattray and Officer (1981) further caution was advised because large errors can occur in the calculated loss rate when the data coverage is less than ideal. The problem is greatest when the net flux at a particular location is large compared to the loss rate and is nearly in balance with the river supply. Bearing in mind the convenience of the conc-sal diagram and the potential misleading results in its use, the graphical method is employed later in this report.

YAQUINA ESTUARY CHEMISTRY

During each Yaquina Estuary boat survey samples were collected and preserved for laboratory analyses. Chemical methods have been discussed in papers already mentioned; the remaining methods can be supplied upon request. The processed raw data are also available .

The data are summarized in Appendix 1 as a series of tables and **are shown for the 8/22/77 survey only**. Briefly, the data are tabulated versus distance upstream surface and bottom salinities and surface and bottom variables. The remainder of this section is a brief narrative of each table.

The identification Table 1-1 ***refers to Appendix 1, Table 1.***

Table 1-1,Chlorophyll-*a*

Table 1-1 shows the data and plots for chlorophyll-a as relative fluorescence. There is a dip in fluorescence from about KM-13 to KM-24. This is reflected in the surface salinity plot from sal-20 to sal-25. Freshwater concentrations range from 110-130 and the seaward from 85-100.

Table 1-2, Conductivity

Table 1-2 shows conductivity in μ-mhos. A partially-mixed state exists from KM-18 to KM-30. Values seaward and landward of this region indicates a well-mixed state. Note that the depression in chlorophyll-*a* (Table 1-1) is in the general region of the partially mixed estuary. The plots of conductivity versus salinity indicate a conservative distribution as would be expected.

Table 1-3, Iron

Table 1-3 shows iron data. The chemistry of iron is much too complex to discuss in detail here. There is a rapid removal in surface and bottom waters of less than 10 o/oo salinity. A similar relationship was observed in the Beaulieu Estuary, England, by Holliday and Liss (1976) although they found a limiting salinity of 15 o/oo. At salinities > 10 o/oo, iron concentrations increased slightly from about 0.015 mg/l to 0.022 mg/l at the entrance.

Table 1-4, Total Manganese

Unfiltered manganese data are shown in Table 1-4 . The distribution of manganese in the Yaquina was discussed in a paper by Callaway *et al.* (*op. cit.*). River concentrations of 0.03 mg/l increased with a slight increase in salinity. Seawater concentrations were 0.006-0.009 mg/l.

Dissolved concentrations for all surveys ranged from 0.005-0.10 mg/l in seawater and 0.002-0.04 mg/l in freshwater. This compares with a summary by Liss (*op. cit.*) of average world-wide river concentration of 0.007 mg/l and seawater of 0.002 mg/l.

Tables 1-5 and 1-6, Phosphorous

Orthophosphate and phosphate phosphorous data are shown in Tables 1-5 and 1-6. The two variables show some slight similarities: a gradual increase seaward with a marked dip in concentration at the seaward end member. There is also an initial loss at the river end. There is an indication of initial estuary non-conservative addition in the salinity plots but it is not clearly defined.

Tables 1-7 to 1-11, Nitrogen species

Nitrogen data species are shown in Tables1-7 to 1-11. They are: dissolved inorganic nitrogen (ninorg), Kjeldahl (nkjel), ammonia (nh3), nitrite (no2) and nitrite-nitrate (n2n3n). The graphical profiles for ninorg and n2n3n are somewhat similar showing an increase from salinity 0 o/oo to 3 o/oo then showing a slight non-conservative addition seaward. The remaining species also show similar characteristics: relatively low seaward and river concentrations with mid-estuary maxima. Peak values are most pronounced for no2 and nh3 at a salinity of about 23 o/oo. The peak occurs at KM-18.2 which is about 1 KM below the Toledo Bridge. There is no obvious explanation for this particular peak and data for the other surveys do not show a similar feature.

Table 1-12. Particle Diameter

Particle size distribution data are shown in Table 1-12. There is no obvious particle diameter-salinity trend other than a gradual increase in diameter seaward. This is also obvious in the plot versus distance upstream.

Table 1-13, Potassium

Burton (*op. cit.*) gives the estimated average concentration of dissolved potassium in river water as 2.3 mg/l and in seawater as 399 mg/l. This compares with the value of 3 mg/l in the Yaquina River and 460-535 mg/l at the seaward end. The salinity plots indicate a conservative distribution.

Table 1-14, Salinity

A plot of salinity with distance upstream is shown in Table 1-14. It is essentially the same as conductivity as would be expected. It shows "complete mixing" at the seaward end and at KM-30.0 and above. In between, "partial mixing" is evident with top to bottom salinity differences of about 2-8 o/oo.

Table 1-15, Silica

Silica data are shown in Table 1-15 and has been discussed in detail in a paper by Callaway and Specht (*op. cit.*). Burton (*op. cit.*) give the estimated average concentration of silicon (as SiO_2) in river water as 13.1 mg/l and, depending on location and depth, as <0.1 to10 mg/l in seawater with the lower value generally in surface waters. This compares with the Yaquina data of about 5 mg/l in river water and 0.2-0.4 mg/l seaward. The salinity data reveal a non-conservative distribution.

Table 1-16, Sulfate

Sulfate data are shown in Table 1-16. Burton (*op. cit.*) has sulfate ranging from 11.2 mg/l in global river waters and up to 2712 mg/l in sea water. Our data show a marked difference in surface and bottom water concentrations with essentially no Mn in salinities less than about 20 o/oo in bottom waters. Above 20 o/oo there is a rapid increase in the bottom layer. Surface waters show a non-conservative addtion in the lower salinities and a conservative distribution seaward.

SUSPENDED MATTER AND THE TURBIDITY MAXIMUM

Festa and Hansen (1976) defined a turbidity maximum (TM) as a region in which the concentration of suspended sediments is greater than in either the landward or seaward source waters. They found that the magnitude and location of the TM depended upon the settling velocity (usually as particle size) of the sediment introduced at both the ocean and river sources and the 'strength' of the estuarine circulation.

A more recent study of the Tamar and Weser estuaries by Grabemann et al. (1997) found that the TM was "...the result of complex interactions between the tidal dynamics, gravitational circulation and erosion and deposition of fine sediment."

Callaway *et al.* (1988) reported on suspended matter and the TM in the Yaquina. They found the TM was most pronounced during low river flows. Their data also show high relative fluorescence (proportional to chlorophyll concentration) and low total suspended matter (TSM) during low flow. Profiles of TSM with distance upstream are shown in Figure 6. The bottom concentrations are usually greater than or equal to the surface concentrations because of material settling through the water column in addition to resuspension processes. The TM's shown in the figure are similar to those reported in other estuaries, namely an increase in suspended matter in the upstream low salinity region of the estuary. The TM is evident at flows less than 10 m^3/s.

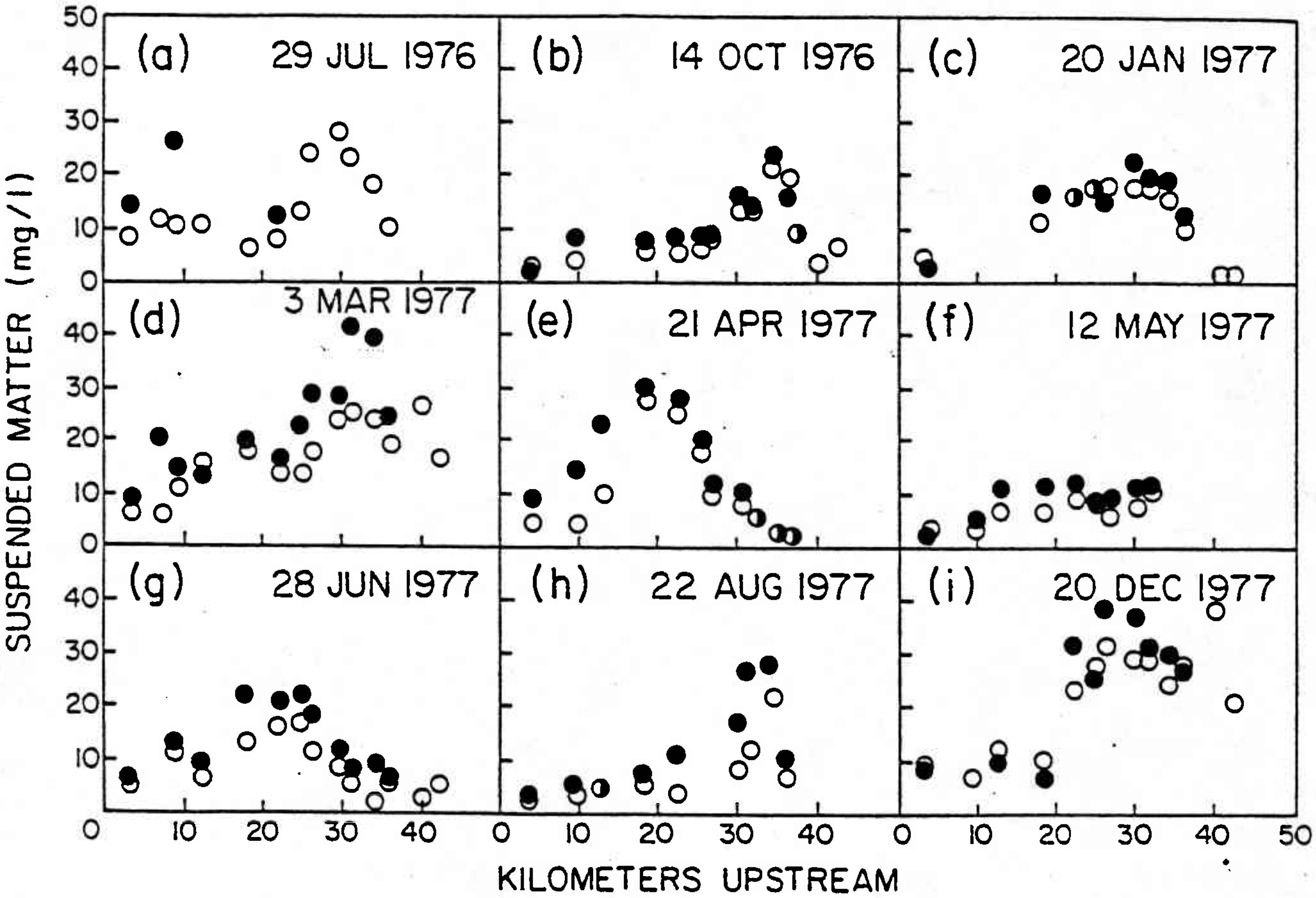
A TM composed primarily of plankton has been found in San Francisco Bay during the summer when riverborne suspended matter is at low concentration and solar insolation is high (Conomos and Peterson, 1974; Peterson *et al.*, 1978). Our data show similar trends: alternately high relative fluorescence and low TSM during low-flow summer periods and the opposite during high-flow, low insolation winter months. The range of both parameters decreases with distance downstream due to the increased dilution effect, and the low ocean input of TSM and surface plankton.

We also found phytoplankton-caused TMs in the Alsea Estuary (~ 32 km south of the Yaquina) on 8/24/77 (EPA, unpub. data). A dinoflagellate (*Peridinium sp.*) bloom (77,000 cells/ml) was in progress at ~km 9-13, where surface salinities ranged from 15-10 o/oo, RF[1] readings from 2940 to 6030 (compared to 178 downstream and 60 upstream), and other parameters such as pH, total Kjeldahl-N, total phosphorus, and total organic carbon were substantially elevated. Continuous vertical transmissometer readings at km-12.9 indicate that the bloom layer was ~1 m thick, RF in the bottom samples was 168 units.

Summer longitudinal salinity, TSM, particle size and diameter and RF for low flow are shown in Appendix 1. Here Q = 2.23 m3/s, Ls = 27 km and $\delta S < 1$o/oo. The TSM maximum of 30 mg/l is at km-29 when S ~ 1 o/oo. Our methods indicated PS decreased from 8 μm in freshwater to 5.5 μm in saline water. At km-25 RF shows a maximum of 470 units at S = 4 o/oo. The TM shown here is typical of those described in other estuaries; namely an increase in suspended matter in the low salinity region of the estuary. This type of maximum was evident at flows of about 10 m^3/s and less. For higher flows the TM was not clearly defined.

For high flow winter conditions (12/20/77), Q = 87 m3/s, Ls = 20km, $\delta S \sim 10$ o/oo at the mouth and 20 o/oo in mid-estuary. The TSM in the saltwater portion is about 10 mg/l increasing abruptly to about 30 mg/l in freshwater. (A distinct color front from clear to brown water was present at the fresh-saltwater interface). Particle diameter apparently decreased seaward from 18 to 7.5 μm. RF values were depressed, all values being less than 25 units; bottom values ranged from 1-10 units greater than surface with the exception of the station at km-23 where the surface was 5 units higher. The TM is not clearly defined as there is an influx of large particles and higher volume of material, probably associated with resuspension and bank scour of higher water stages in the rivers.

1. Relative chlorophyll *a in vivo* fluorescence (RF) was measured in the laboratory within 12 hours of collection with a Turner Model 111 fluorometer (Lorenzen, 1966).



Total suspended matter (mg l⁻¹) vs. distance upstream (km), Yaquina Estuary. Surface samples (O), bottom samples (●).

Figure 6. TSM profiles.

TSM in the Yaquina River was 40 mg/l 21 mg/l in Elk Creek. Nominal particle diameters were 15 and 18 μm, respectively. Assuming a particle density of 2.6, the Stokes settling velocity for spheres of 15 μm diameter is 0.014 cm/s. The average depth from km 25-40 is about 4 m; particles at the surface could settle out in about 10 hours. At km-5, Uf ~ 3 cm/s; if resuspension were to occur it would be related to tidal velocities and not by the non-tidal component associated with river flow. The small particle sizes in the lower 20 km of the estuary suggest that the estuary acts as a sediment trap because settling of larger particles can occur before the horizontal flow carries them out to sea.

TEMPERATURE-SALINITY RELATIONS

A paper by Rattray and Officer (1979) using data in San Francisco Bay reported by Peterson *et al.* (1978) provides a basis for determining the distribution of conservative and non-conservative dissolved substances in natural water bodies. The latter authors developed a numerical model of dissolved silica in the horizontal and vertical dimensions which required numerical integration of the governing equation:

(1) $$\frac{\partial}{\partial_{tt}} Si + uSi_x + wSi_x = K_h Si_{xx} + K_v Si_{zz}$$

based on the two-dimensional, steady-state, gravitational model of Festa and Hansen (1976). As can be seen from Eq. (1) and the earlier discussion on estuarine dynamics, there are many uncertainties involved in the terms including a vertical velocity, w, and horizontal and vertical exchange coefficients, Kx and Kv. Rattray and Officer (*op. cit.*) employed an analytical solution of the simplified conservation equation for salt:

(2) $$\tfrac{d}{dx}(A\bar{u}S) - \tfrac{d}{dx}(AK_x \tfrac{d}{dx}S) = 0$$

and for the concentration of a dissolved substance

(3) $$\tfrac{d}{dx}(A\bar{u}C) - \tfrac{d}{dx}(AK_x \tfrac{d}{dx}C) = -BA\ ,$$

where B is the rate of utilization of C, A is cross-sectional area, $\bar{u}$ is averaged velocity and Kx is a longitudinal diffusion term.

The solution of equations (2) and (3) is:

(4) $$C(x) = C_0 - (C_0 - C_l)\frac{S(x)}{S_l} - \frac{B}{u}[x - l\frac{S(x)}{S_l}] ,$$

where

C(x) = the concentration at x

C_o = concentration at the river end, assumed to be a constant reservoir.

C_l = concentration at the ocean end

u = downstream velocity for constant river flow

S(x) = salinity (o/oo) downstream of the salt intrusion length, l

S_l = ocean salinity

l = salt penetration length (estuary length)

If all the terms in (4) are known except B, then the equation can be solved to estimate it knowing the longitudinal distribution of the C terms from field survey data:

(5) $$B = \frac{-u[(C(x)-C_0)+(C_0-C_l)\frac{S(x)}{S_l}]}{(x-l\frac{S(x)}{S_l})}$$

If the C terms in equation (4) are taken as temperature in degrees centigrade, then B would be in degrees C per unit time. If temperature is taken as the y-coordinate and salinity as the x-coordinate, a straight line joining the ocean and river end concentrations would result in a longitudinal plot of T-S. The straight line indicates a conservative substance. As will be shown, temperature will plot as a conservative 'substance' if residence time is short (high river flow). If the data arcs above the straight line, an addition of 'temperature' is indicated along the estuary; if below, a loss or cooling (to the atmosphere).

For the purposes of this demonstration, B is taken as the heat flux through a water surface divided by heat content: $B = \frac{q_H}{\rho.c_p.d}$, where q_H = net heat flux, ρ = seawater density, c_p = specific heat and d = depth. Equations (4) and (5) are easily solved on a hand calculator and /or a fortran or C program. The programs have been submitted previously and incorporate statistical routines for comparison of predicted and observed properties.

The Data Set

Appendix 2, Tables 2-1 and 2-2, show Yaquina field data collected during 1976-1977 for temperature and salinity, respectively. The data are arranged versus kilometer upstream of the entrance and for surface and bottom samples. Also shown is the river flow in m^3/s. Station names are given as two-letter codes and described elsewhere. The data and their plots are given in Appendix 2 following Table 2-2.

Table 2-3, 7/29/76

Only surface data are available for this cruise. A straight line connecting the river and seaward end values is shown indicating complete mixing as in equation (4):

$$C_0 - (C_0 - C_l)S_{(x)} / S_l.$$

Using the values given in the table, [21.7 - (21.7 - 13.6)$S_{(x)}$/32.9] so that the y-intercept is 21.7 and the slope is - 0.246. Since the data lie above the conservative mixing line 'addition' is indicated within the estuary. The addition would be the sum of heat flux terms in the equation for B, above. In equation (4), B is negative, the second term becomes positive resulting in addition to the conservative term.

Chitwood 7.3 cfs (0.21 m^3/s)

Table 2-4, 10/14/76 Chitwood Aug 10/10 - 10/14/76 8.08 cfs (0.229 m^3/s)

The lowest river flow, 1.3 m^3/s, occurred during this survey. Heat addition within the estuary is evident. A dashed straight line is drawn through the end points suggesting a tentative relationship. The missing data point at KM-9.3 makes the relationship a bit uncertain. A questionable temperature at KM-26.3 is retained.

Table 2-5, 1/20/77 Chitwood 36 cfs (1.02 m^3/s

This set of winter data is the only one to show heat loss within the estuary. Surface and bottom temperatures and salinities are nearly the same at each sampling position. River flow is moderate (3.5 m^3/s) Net heat flux is to the atmosphere indicating a change in sign in B.

Table 2-6, 3/3/77

River flow was 46 m^3/s for this date. Surface salinity was nearly conservative while bottom salinity showed a slight loss except for the ocean end point. Surface temperatures were slightly cooler than in the lower layer in the saline part of the estuary. For waters of about 2 o/oo and less, the trend was reversed.

5 day average
3.47 m^3/s

5/12/77
Chitwood = 101 cfs
2.86 m^3/s

Table 2-7, 5/12/77

River flow for this date was 10.4 m^3/s. There was marked salinity stratification; fresh water was present to about KM-25. Considerable within-estuary warming is evident. Some temperature stratification occurred.

6/28/77
41 cfs
1.16 m^3/s

Table 2-8, 6/28/77 1.29 m^3/s

River flow was 4.6 m^3/s, There was some salinity and temperature stratification. Considerable within-estuary heating is evident. Flushing occurred to about KM-30. Significant curvature of temperature toward the seaward boundary value did not occur until about KM-20. If a straight line were to be drawn it could be anchored at about 15 o/oo indicating net flux seaward of that point.

Table 2-9, 8/22/77 5-day avg 0.23

River flow was 1.9 m^3/s. Temperature plotted against distance upstream shows considerable stratification landward of about KM-18.2. A flat T-S curve is indicated in both surface and bottom layers to about 22 o/oo; seaward there is a sharp dip to the end point similar to that shown for 6/28/77.

Table 2-10, 12/20/77

Flow (87 m^3/s) was the highest for any survey. Salinity stratification of up to 20 o/oo was present; flushing occurred to about KM-18. Considerable vertical temperature stratification is also present in the seaward waters. Surface waters were cooler than in the bottom layer. As in the case for the 3/3/77 data, a near-conservative mixing relation is evident for both surface and bottom TS plots.

Summary of the TS Data

The data sets demonstrate the usefulness of relating a variable to salinity although any conservative constituent could be used. The concept of a conservative and non-conservative property is revealed although it is not an exact relationship, partly because of the length of a survey and time variable tide and runoff conditions. At low river flows the non-conservative relationship with temperature may reveal addition or removal of a variable within the estuary. At high flows a conservative distribution is shown for most variables which points out the importance of residence time when considering the distribution of a substance. Inlets and embayments which are not well flushed out will show markedly different concentrations of different variables depending on residence time and water temperature. Surface and bottom waters may show similar properties with regard to residence time in well-mixed and partially-mixed waters

RECORDING STATION DATA

Instrumentation, calibration and data processing techniques for recording salinometers, stream flow and wind measurements are fully discussed in an unpublished report by Callaway *et al.* (1970). Of primary interest in this report is a discussion of salinity-precipitation-runoff relationships. Figure 7 shows data extent and condition for the recording salinometers. The 'best' data set occurred during April-July 1968. Gaps in the record due to malfunctions of a recorder were interpolated by eye where short gaps appeared.

Figure 8 shows daily averages at selected station. Straight daily averages filter out much of the tides and frequency oscillations. Several of the plots show vertical bars which indicate the salinity extremes at that station over the day indicated. The extremes are a function of tides, runoff, wind, seiches, local bank runoff and evaporation-precipitation processes. The difference between extremes or the length of the bar may change considerably over a few days. The high and low extremes in general do not extend equal amounts from the mean value. The length of a bar gives a rough indication of how much the curves were smoothed by the taking of daily averages.

Since the tides and higher frequencies have been filtered out, the curves in Figure 8 might reasonably be said to retain intermediate period (several days to weeks) variance plus long period (months to years) variance. Yaquina River streamflow seems to be a fairly smooth function of time. This may be due to some residual tidal energy passing through the daily average filter, to wind stirring of stratified water or to some other mechanism.

October of 1967 was the end of an extremely dry summer. The salinity reached 14 o/oo at Charlie's Dock (river mile 16, Figure 2). Soon after the beginning of the fall rains, the salinity at Charlie's dock dropped to zero. During the winter, the salinity fluctuated greatly with each major storm. After the beginning of the dry season in early April, 1968, the salinity began to increase slowly at all station. The general salinity trend during this period is a striking feature in spite of the fact that the summer of 1968 was anomalously wet.

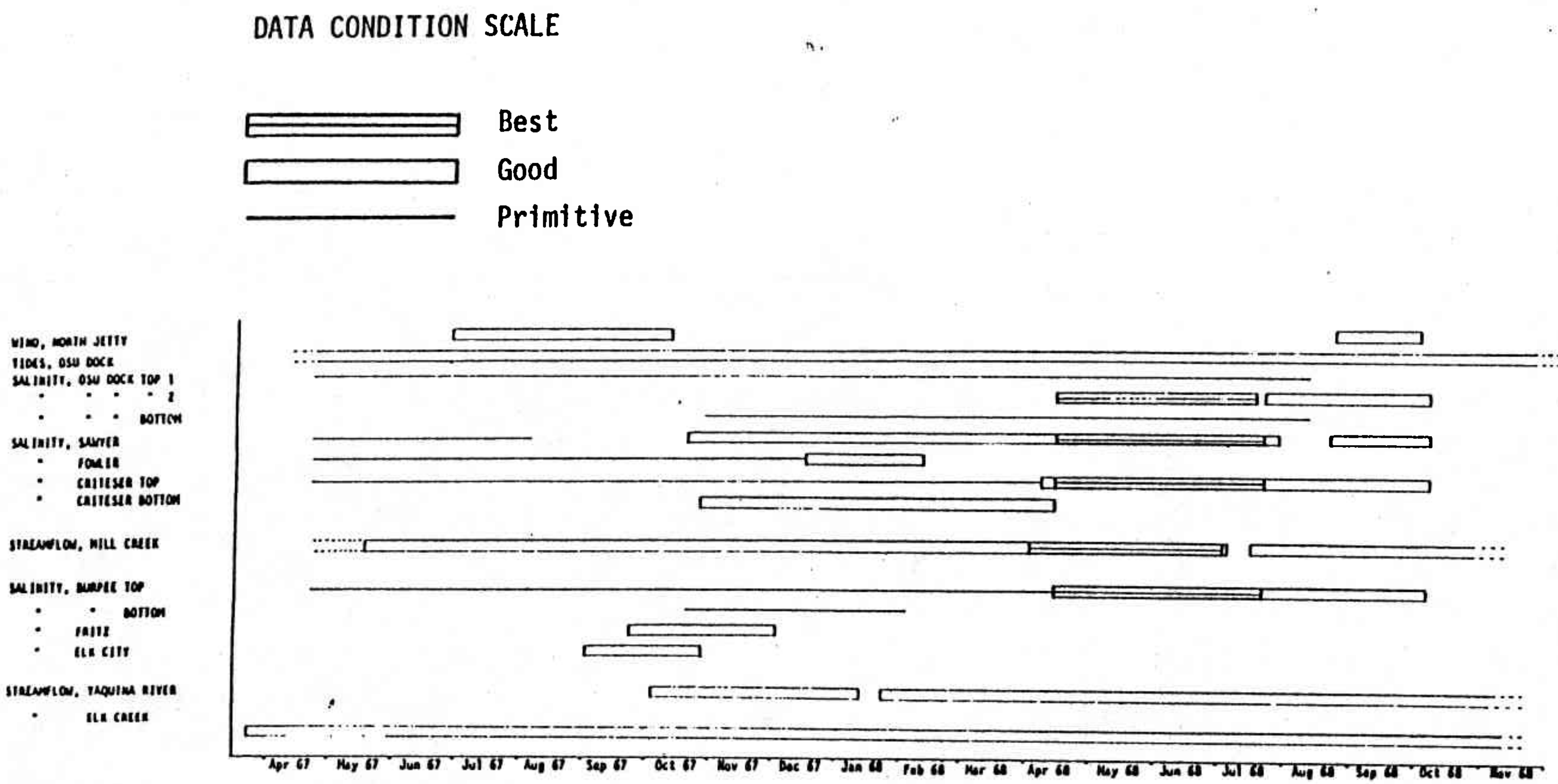


Figure 7. Salinity recorder statistics.

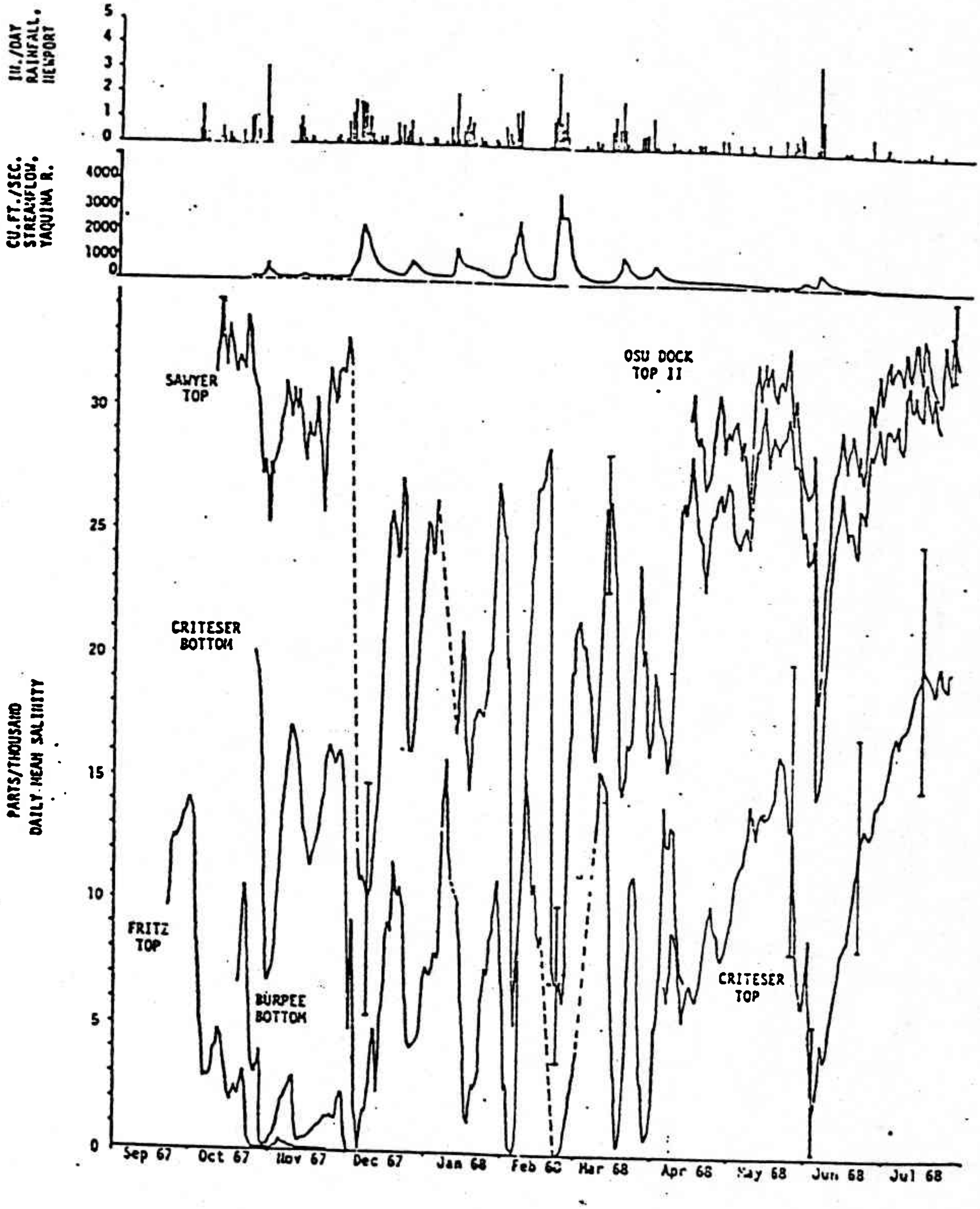


Figure 8 Daily salinity averages, recording station.

Note that during the summer of 1968 salinity variations at intermediate frequencies seem to be relatively coherent between stations, i.e., peaks and troughs in the salinity records seem to show up at the same times. This suggests that these variations may be caused by tides.

NUMERICAL SIMULATION

In a tidal estuary, the primary driving forces are tidal fluctuations at the ocean end and freshwater river inflow. Wind, non-point sources and evaporation-precipitation processes will also influence distributions in addition to reaction rates for toxicants and eutrophication processes. Simulation of estuarine processes requires knowledge of these forces and rates as well as boundary and initial conditions for each constituent. These input parameters are either known or can be estimated. Of prime importance are the boundary values. The 'accuracy' of initial conditions determines the length of time the numerical solution takes to approach a quasi-steady state condition.

Two numerical models developed by EPA are used to simulate conditions in the Yaquina, WASP and DYNHYD. DynHyd can be used alone to develop hydrodynamic conditions such as tidal elevations, flow and velocity with time and/or as input to WASP. WASP (Water Quality Analysis Simulation Program) is used to simulate conventional pollution problems (dissolved oxygen, BOD, nutrients and eutrophication) and toxic pollution (organic chemicals, heavy metals and sediment). The former state model is referred to as EUTRO5 and the latter as TOXI5.

Complex branching flow patterns and irregular shorelines can be treated with acceptable accuracy for many studies. Link-node networks can be set up for wide, shallow water bodies if primary flow directions are well defined. They cannot handle stratified water bodies (except in a steady-state sense) and should be considered as descriptive only.

For what follows it is assumed that the reader is familiar with basic hydrodynamics and numerical procedures. The EPA user's manuals for DynHyd and Wasp are indispensable reading for those interested in using the models; the accompanying fortran code in the manuals is also very useful.

<u>Caveat</u>: The model output and numerical runs were used with AScI's Windows version of DynHyd and Wasp. Recently (May, 1999), the AScI office developing these models (and who were associated with the original DOS versions) has disbanded. It is not known if AScI will continue to support these models. Potential users seem to be left with the original DOS models.

The Hydrodynamic Model DYNHYD

DynHyd can be used as a standalone model or as input into the water quality model WASP. DynHyd is a quasi-2-dimensional model employing 1-dimensional equations describing long wave propagation through a shallow water system while conserving mass and momentum. Coriolis and lateral accelerations are neglected. The equation of motion predicts water velocities and flow. The continuity equation predicts heads and volumes. Channels are represented as rectangular widths and variable depths. Tidal wave length is much greater than depth. Bottom slopes are assumed to be slight.

Equation of Motion

The equation of motion is given by

$$\frac{\partial U}{\partial t} = -U\frac{\partial U}{\partial x} + a_{g,\lambda} + a_f + a_{w,\lambda}$$, where

$a_{g,\lambda}$ = gravitational acceleration

a_f = frictional acceleration

$a_{w,\lambda}$ = wind stress acceleration

U = channel axis velocity

t = time

λ = longitudinal axis

It can shown that the gravitational term $a_{g,\lambda} = -g\frac{\partial H}{\partial x}$, where H is the water surface elevation (head). The frictional term $a_f = -\frac{gn^2}{R^{4/3}}U|U|$ where n is Manning's coefficient, R is the hydraulic radius. The term $U|U|$ ensures that friction will always oppose the direction of flow. The wind term is $a_{w,\lambda} = \frac{c_d}{R^{4/3}} \frac{\rho_a}{\rho_w} W^2 \cos\psi$,

where ψ = the angle between the channel direction and the wind direction, the drag

coefficient C_d = 0.0026 and the ratio of air to water density (ρ_a/ρ_w) is 0.001165.

Trigonometric functions taking into account channel and wind directions determine whether wind accelerates or retards flow are used.

Equation of Continuity

The equation of continuity is given by $\frac{\partial A}{\partial t} = -\frac{\partial Q}{\partial x}$, where

A = channel cross-section area and Q = flow.

For rectangular channels of constant width, B: $\frac{\partial H}{\partial t} = -\frac{1}{B}\frac{\partial Q}{\partial x}$, where

B = width

H = head

$\frac{\partial H}{\partial t}$ = rate of water surface elevation change

$\frac{1}{B}\frac{\partial Q}{\partial x}$ = rate of volume change per unit channel width

Channels are viewed as links conveying water and nodes are junctions which store water. At each time step, depending on conditions at the end of the previous time step or initial condition, a certain amount of water moves through a channel into a node or junction.

This resultant movement determines mass transport and the resultant volume determines the concentration of a variable. The equations are expressed in finite difference form and solved using a modified Runge-Kutta procedure.

Before WASP is run in tidal estuaries, it needs to have as an input tidal flows and volumes for each numerical time step. These are supplied by using EPA's DynHyd5 model. Uses a series of interconnecting branched junctions and channels as a computational network. Boundary and initial conditions drive simulations at 30 second to 5 minute intervals. The resulting flows and volumes are averaged over larger time intervals for input to WASP.

DynHyd was written in fortran and is comprised of some 34 subroutines each consisting of several lines to several pages. For a good understanding of an output variable, it is useful to read the code and trace out the program flow.

Input Parameters, Junctions

Figure 9 is a definition sketch for a junction. Each junction has an associated initial surface elevation (head), surface area and bottom elevation. Volumes and mean depths are calculated internally at each time step.

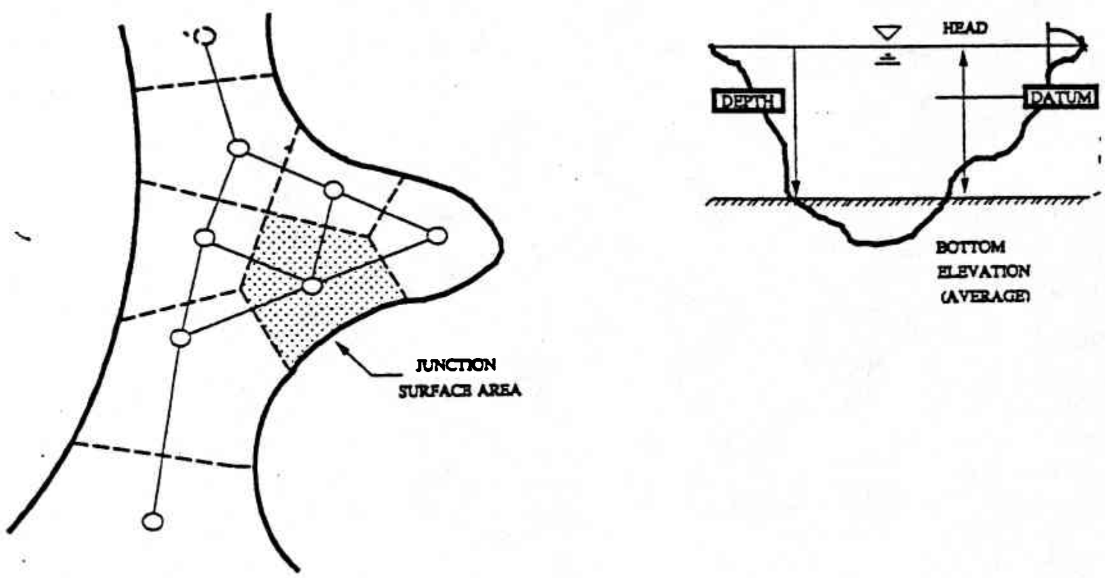


Figure 9. Junction definition sketch.

Input Parameters, Channels

Figure 10 is a definition sketch for a channel. Channels are shown as solid lines connecting the small circles. Channel parameters are length, width, cross-sectional area, roughness (Manning) coefficient, velocity, hydraulic radius, channel orientation.

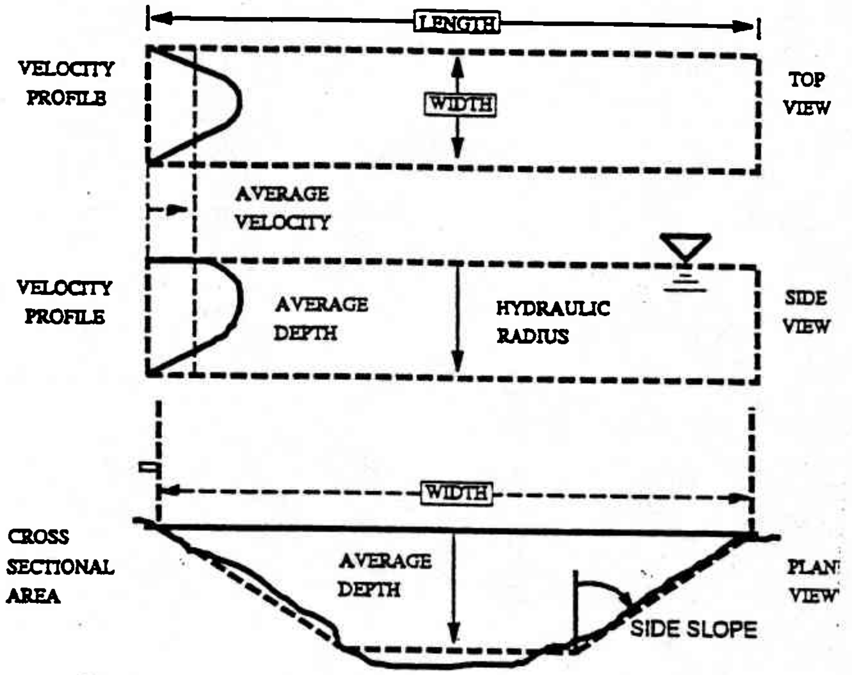


Figure10 Channel definition sketch.

Input Parameters, Other

The remaining input data are constant and/or variable inflows, wind speed and direction, evaporation-precipitation and program control data such as time steps, print intervals, etc.

Model Availability

(See the Caveat under Numerical Simulation)

There are two versions of DynHyd; both use the same fortran code. DynHyd is EPA's DOS version. Documentation can be obtained from NTIS.

WinDynHyd is a Windows version of WASP(AScI, 1998a,b); it provides a front end to the DOS fortran code. Information about AScI's models can be obtained from

<http://www.aesicorp.com>. Old DOS input files can be converted for use with WinDyn. A pre-processor accelerates input for new systems. It also has a post-processor which provides graphics for each output parameter at each junction. The results can be output to a printer or disk or as numerical results. The latter can be further manipulated by using a spreadsheet program such as Quattro. Graphical output for several DynHyd model runs are shown in Appendix 4.

THE WASP SIMULATION

Input Parameters

Input for WASP can be very complex for a new system. But for a simple case of salinity intrusion at the ocean end with constant or variable inflows, input is fairly straightforward since no reaction rates are involved. Once a salinity model has been developed and tested it can be used as a template and runs with various river flows and tidal conditions can be easily generated. For this discussion, only salinity is considered. In brief, the important output hydrodynamic parameters of interest are generated by DynHyd and input to the WASP file as a file name. Initial salinity conditions and boundary values are also read into the WASP file.

The WASP Mass Balance Equation

The mass balance equation in 3 dimensions (x, y, z) for an a water parcel volume is

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z})$$

$$+ \; S_l + S_b + S_k$$

where:

C = constituent concentration

t = time

Ux,... = advective velocities

Ex,... = dispersion coefficients

Sl = direct and diffuse loading rate

Sb = boundary loading rate

Sk = kinetic transformation rate

By assuming lateral and vertical homogeneity the mass balance equation can be integrated to obtain

$$\frac{\partial}{\partial t}(AC) = \frac{\partial}{\partial x}(-U_x AC + E_x A\frac{\partial C}{\partial x}) + A(S_L + S_B) + A(S_K),$$

where A=cross-sectional area.

Dispersive exchange within the water column takes place between connecting segments as:

$$\frac{\partial M_i}{\partial t} = [\frac{E_{ij}(t) A_{ij}}{L_{cij}}](c_j - c_i), \text{ where}$$

M = mass of substance i, g

C = concentration, g/m^3

$E_{ij(t)}$ = dispersion coefficient between segments i,j in m^2/day

A_{ij} = interfacial area between segments i and j, m^2

L_{cij} = a characteristic mixing length between segments i and j, m

The term between square brackets is the total dispersion, m^3/day. It is discussed in the section on WASP hydrodynamic output.

Model Availability

There are three WASP versions known to the author: EPA's WASP5 DOS version, AScI's Windows version and Colorado State University's WASP Builder. The DOS version documentation is available from NTIS. A demonstration of the Windows version (WinWasp) can be downloaded from: <http://www.ascicorp.com> . A graphical post-processor in the Windows version has the ability to view ArcView files. Builder can be downloaded <http://www.colostate.edu/Depts/IDS/builder/builder.htm>. The WASP Builder model has some interesting features such as a sensitivity analysis for input constants and initial conditions. Further, while WASP5 discriminates between a eutrophic and toxic condition, Builder apparently breaks down the latter into a 'Metals' simulation.

YAQUINA SCHEMATIZATION

Yaquina Bay is shown in Appendix 3 as a series of junctions and channels and is taken from that of Reed (*op.cit.*). Reed used the Columbia River model (Callaway and Byram, 1970) which was a precursor to the more versatile WASP model. River flows from Yaquina River and Elk and Mill Creeks are allowed or can be set to 0. Output variables for all parameters can be displayed graphically, printed to disk and sent to Quattro, for example.

The schematization is not entirely arbitrary. Channel length, e.g., must meet computational stability criteria in that the channel length must be equal to or greater than the tidal wave speed plus or minus the channel velocity ($L \geq (\sqrt{gy} \pm U)\Delta t$, where g=gravitational constant, y=mean channel depth, U=channel velocity, Δt=time step). Otherwise, the scheme depends on the topographical features of the estuary/river system. The above discussion of input parameters shows that a considerable effort is required to determine the input data. No scheme will be perfect. It should be borne in mind that changing, say, a single channel length will impact the entire schematization to some degree. How much of an impact it will have cannot be determined ahead of time. For this reason the user is advised to check the input data carefully even though output may not be significantly affected by small errors in channel length, width, etc.

WINDYN Output

Output is shown in Appendix 4. The x-axis is in segment numbers or time. The y-axis shows values in meters, days, etc. and are indicated in the title at the top of each figure. The legend describes the curve times, locations, etc.

Because relative rather than absolute magnitude is of prime interest, time plots are given only for 0600 and 1200 of the same day. Plots could be made for each segment, output variable and time step over a period of days. Plotting all possibilities is clearly impractical and only a few are given here to demonstrate what is achievable.

Figure 4-1, Manning Coefficient, $sec/m^{1/3}$. The Manning bottom roughness coefficient is an input variable for each channel. It can be used to maintain numerical stability and to affect current speed and head. The plot is a reflection of the input of n = 0.02 for segments 1-81 and then an increase in the upper Yaquina and Elk Creek. The choice is based on experience and experimentation.

Figures 4-2 and 4-3, Equation of Motion terms at 0600 and 1200, m/s^2. Note that the y-axis scale is different for each figure. The motion terms for no wind are shown first. The momentum term $(u\partial u/\partial x)$ is essentially flat and near zero for both figures except at the entrance. The sum of the terms will determine the unintegrated velocity. As can be seen, the friction and gravity terms mirror each other although the signs may differ. (See the Equation of Motion section for a discussion.) For both plots, the gravity term is slightly greater than the friction term over segments 20-80. The sign of the terms is reversed in segments 80-94.

Figures 4-4 and 4-5. Equation of Motion terms, m/s^2. This figure includes the wind acceleration term $(a_{w,\lambda} = \frac{C_d}{R}\frac{\rho_a}{\rho_w}W^2)$ in addition to the other three terms. The wind term is the only one that makes use of input channel direction. (Errors in channel direction can markedly affect computed velocities as was the case in some plots in the first Progress Report). Figure 4-5 is an exploded view of Figure4-4. As can be seen, the magnitude switches frequently from + to - which reflects the angle of orientation between channel direction and wind set (10 m/s from the west).

Figures 4-6 through 4-12. Equation of Motion terms, MSC to Elk City, m^2/s. Momentum, friction and gravity terms for stations off the MSC, Yaquina, Toledo and Elk City. Figures 4-8, 4-10 and 4-12 are expanded views of 4-7, 4-9 and 4-11, respectively. As can be seen, the momentum term is generally insignificant in these no-wind runs as compared with the wind output in 4-4 and 4-5. Earlier numerical models usually did not include wind as a driving force and omitted the momentum term as a complicating factor.

WINWASP Output

Although the main hydrodynamic output is associated with DynHyd, several interesting and useful variables are computed within Wasp and are associated with mass and volume conservation.

Output is shown in Appendix 5 . The x-axis displays segment numbers for the schematization. The y-axis values in meters, days, etc., are given in the title at the top of the figure. Because relative rather than absolute magnitudes are of prime interest for this modeling effort plots are given only for times 0600 and 1200 of the same day. An input tide at the estuary entrance with a 12 hour period was used for convenience in scaling and interpretation. Real tides with 7 constituents can be used. The legend to the right of the plot shows the times. Plots could be made for each segment, output variable and time step over a period of days. Plotting all possibilities is clearly impractical and only a few are given here to demonstrate what is achievable. Individual station data is shown and can be used as an aide in interpretation of the field data.

Figure 5-1, Segment Depth, meters. Depths vary with tide phase increasing slightly with distance upstream for 1200 and more abruptly for 0600 near the entrance and above segment 25-71 then decreasing rapidly. (The depth obtained must be added to chart depth to obtain the absolute depth for the time of simulation).

Figure 5-2, Volume, m^3. The two curves are irregular with distance upstream but are similar in outline reflecting the fact that junction surface areas are constant while channel depths and cross-sectional areas are allowed to change with time. The reader is reminded that tide flats are not accurately portrayed here.

Figures 5-3, 5-4 Flow In and Flow Out, m^3. Note that the vertical scales for the two plots are not the same so that one cannot directly overlay one plot on the other for comparison of values. In each plot the curves are similar with respect to change as it was in the volume plot. The peaks at segments 6, 18, 19, 25 are due to the confluence of 4 channels in each segment (see Appendix 3).

Figure 5-5, 5-6, Residence Time, days. Figure 5-6 is an expanded view of segments 40 to 60, Figure 5-5. Several peaks are present at junctions 21, 49, 50, 54 and 77. These segments correspond to inlets with no river runoff within them (see Schematization, Appendix 3.) Estuary flushing rates and residence times are usually discussed in relation to the whole estuary. For instance, flushing time t can be expressed as $t = V/R$, where V is the total estuary freshwater volume and R is river runoff. In contrast the residence times in the figures are given for individual segments. (For a good discussion of simple mixing and flushing concepts, see Officer (1976, pps. 155-161)).

Figure 5-7, Total Dispersion, m^3/day. Total dispersion is computed as discussed in the section on the WASP mass balance equation. The mass rate of change of a substance is taken as equal to the total dispersion times the difference in concentration is connecting segments. In general, the plots of total dispersion and residence are inversely proportional, i.e., a maximum in residence time is a minimum in total dispersion.

Figure 5-8, Segment Temperatures, °C. Segment profiles of temperatures with boundary temperatures of 10 and 20 degrees. The solid line shows initial conditions and the dashed lines show convergence.

Figure 5-9. Segment Salinities, o/oo. Segment profiles of salinity with boundary values of 33o/oo and 0 o/ll. The profiles are for midnight for 7 days. Thje solid line shows initial conditions. Convergence is shown as a progression landward of the dashed lines with time.

Summary and Discussion

This has been a semi-tutorial review of Yaquina Estuary water chemistry and physical processes. Historical data are used to examine processes occurring during different river flows and seasons. It is by no means a complete review of the extensive literature on the Yaquina.

The Yaquina is a fairly simple estuary complicated by extensive tide flats. It exhibits many of the characteristics discussed by Pritchard, Hansen and Rattray and others, namely marked vertical temperature, salinity and other chemical stratification to well-mixed conditions. It is amenable to study because of its smallness (compared to large east coast estuaries).

Some attention is devoted to the Hansen and Rattray classification scheme and to parameters developed by them. Some alternate methods to represent the bulk parameters they derived are presented. They can be of some practical use and do shed light on theoretical aspects of estuarine dynamics.

During low river flows non-conservative conditions usually exist as indicated by plots of variables against (mainly) salinity. During high flows, residence times are considerably diminished and plots exhibit a conservative distribution. During low flow, high insolation periods, temperatures show non-conservative distributions in both the surface and bottom layers. During winter conditions temperature loss to the atmosphere is exhibited. For high river flow, temperatures show a conservative plot suggesting that the time for heat exchange with the atmosphere is small with respect to short residence times.

Numerical model results are presented in some detail. A simple analytical model is shown and its use in the interpretation of field results is discussed particularly with regard with heat exchange. Numerical model studies were limited to 1-dimensional shelf models developed in the past by EPA. These models are quite useful but the user must be wary in interpreting the results. Their limitations are discussed . Only a small portion of the potential of these models is shown. Full utilization of the models with regard to eutrophication and toxicity could be done but would require extensive man-power resources. Fully 3-dimensional models are available but whether their use can be justified is another matter.

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We would like to acknowledge the constructive and useful comments and suggestions of Drs. Walter Frick, Peter Eldridge and Yong-Sik Sin.

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APPENDIX 1

Chemical Data, Yaquina Estuary
1976-1977

APPENDIX 1. CHEMICAL DATA*

Table 1-1.Chlorophyll-*a*, relative fluorescence

Table 1-2, Conductivity-µmhos

Table 1-3, Iron, mg/l

Table 1-4, Total Manganese, mg/l

Table 1-5, Ortho-Phosphorous, mg/l

Table 1-6, Phosphate-Phosphorous, mg/l

Table 1-7, Inorganic Nitrogen, mg/l

Tables 1-8, Kjeldahl Nitrogen, mg/l

Tables 1-9, Ammonia Nitrogen, mg/l

Tables 1-10, Nitrite Nitrogen, mg/l

Tables 1-11, Nitrite-Nitrate Nitrogen, mg/l

Table 1-12. Particle Diameter, µm

Table 1-13, Potassium, mg/l

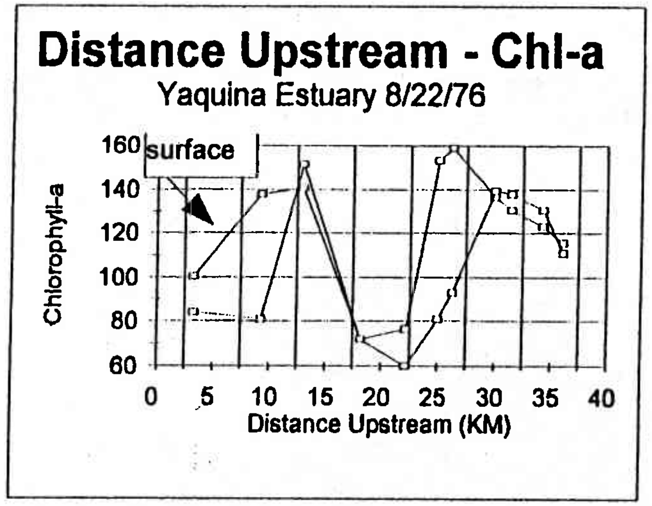
Table 1-14, Salinity, mg/l

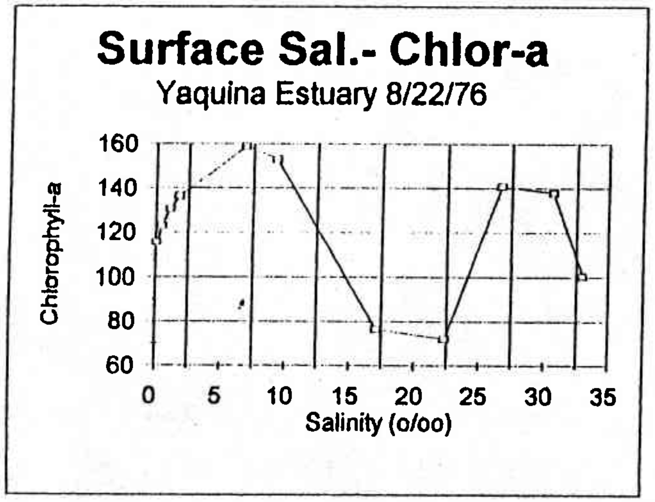
Table 1-15, Silica, mg/l

Table 1-16, Sulfate, mg/l

* *Note added in proof. The year shown is incorrect; 8/22/76 should read 8/22/77.*

KM	surf sal	bott sal	surf chlora	bott chlora
3.3	33.00	33.40	100.5	84.0
9.3	30.70	32.30	138.0	81.0
13.0	26.70	29.20	141.0	151.5
18.2	22.40	22.90	72.0	72.0
22.2	17.10	20.60	76.5	60.0
25.0	9.30	15.90	153.0	81.0
26.3	6.90	14.20	159.0	93.0
30.0	1.80	2.50	136.5	139.5
31.5	1.10	1.10	130.5	138.0
34.3	0.50	0.50	123.0	130.5
36.1	0.10	0.10	115.5	111.0





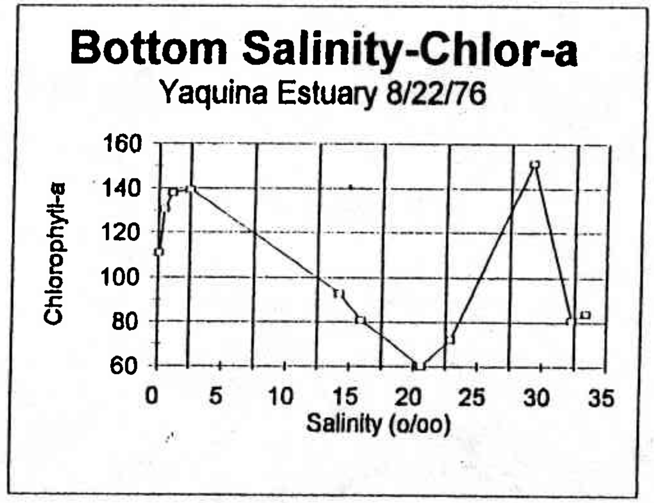
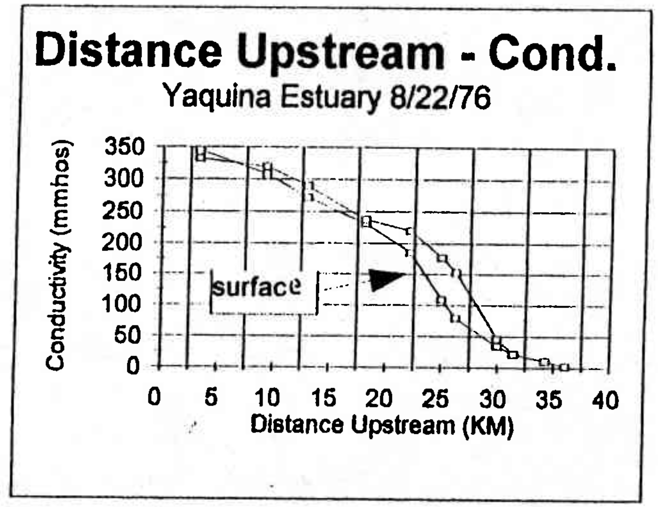
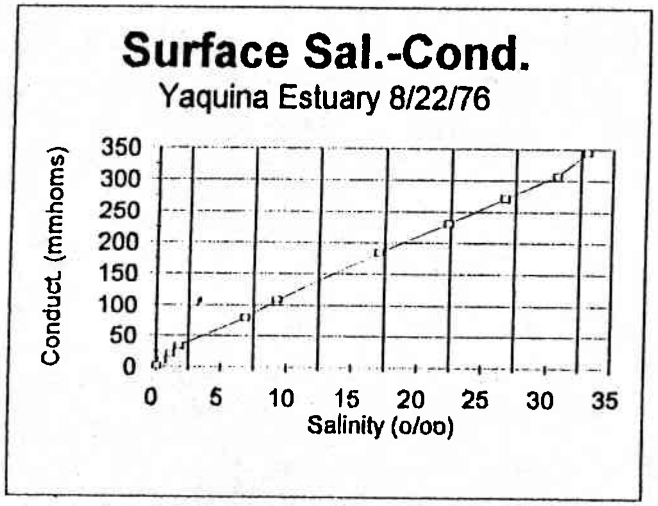


Table 1-1, Chlorophyll-*a*, relative fluorescence

KM	surf sal	bott sal	surf cond	bott cond
3.3	33.00	33.40	345	332
9.3	30.70	32.30	308	320
13.0	26.70	29.20	272	290
18.2	22.40	22.90	231	237
22.2	17.10	20.60	185	220
25.0	9.30	15.90	109	177
26.3	6.90	14.20	79.50	153
30.0	1.80	2.50	34	46
31.5	1.10	1.10	21.40	21.20
34.3	0.50	0.50	10.20	10.40
36.1	0.10	0.10	2.60	2.50





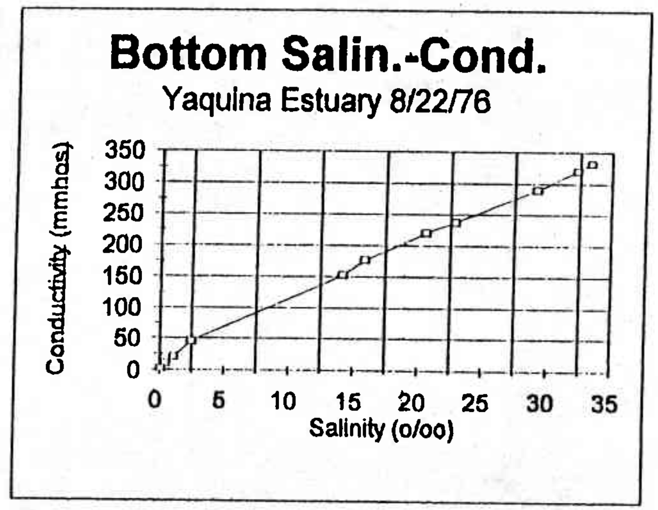
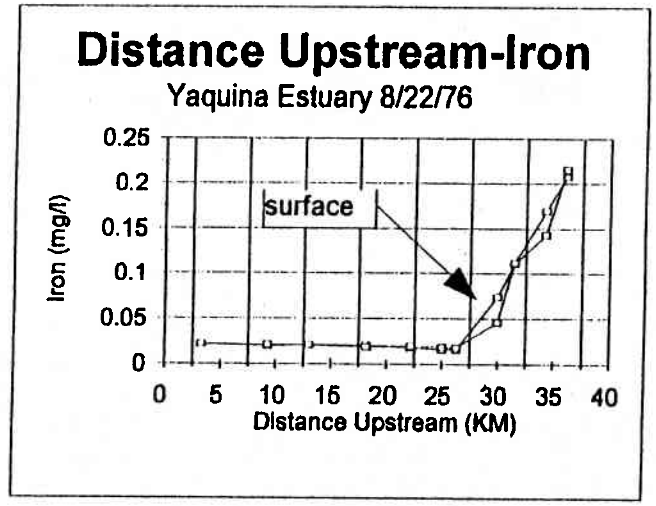
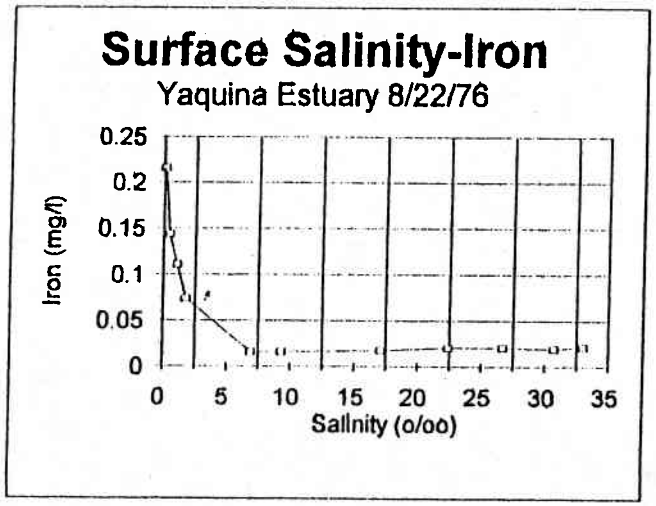


Table 1-2. Conductivity-µmhos

KM	surf sal	bott sal	surf iron	bott iron
3.3	33.00	33.40	0.022	0.022
9.3	30.70	32.30	0.020	0.021
13.0	26.70	29.20	0.021	0.021
18.2	22.40	22.90	0.021	0.019
22.2	17.10	20.60	0.018	0.020
25.0	9.30	15.90	0.016	0.019
26.3	6.90	14.20	0.016	0.018
30.0	1.80	2.50	0.074	0.046
31.5	1.10	1.10	0.111	0.112
34.3	0.50	0.50	0.144	0.170
36.1	0.10	0.10	0.216	0.208





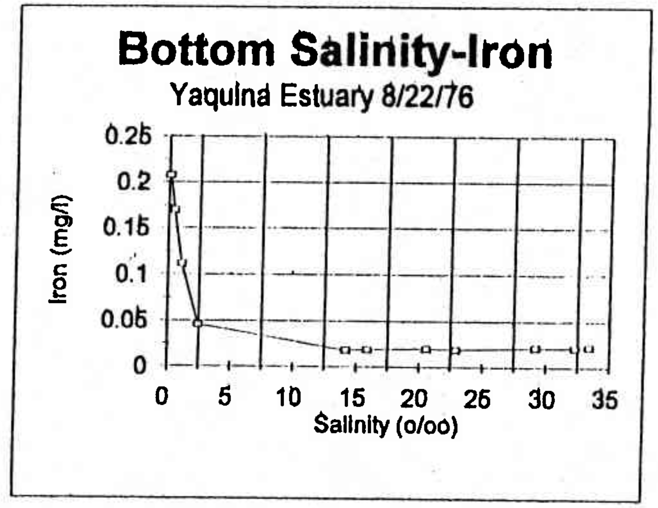
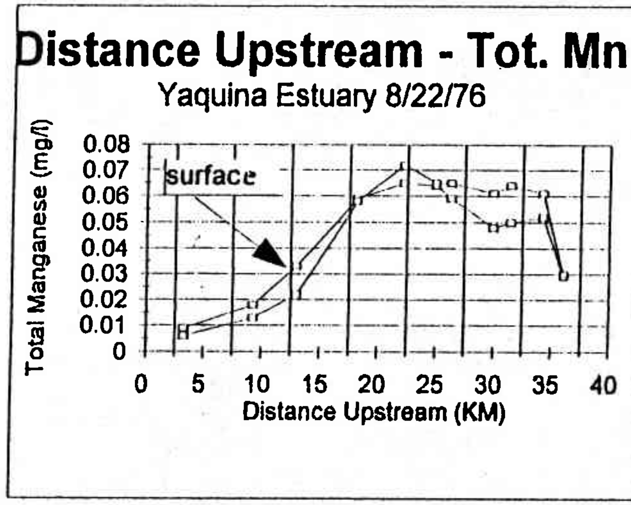
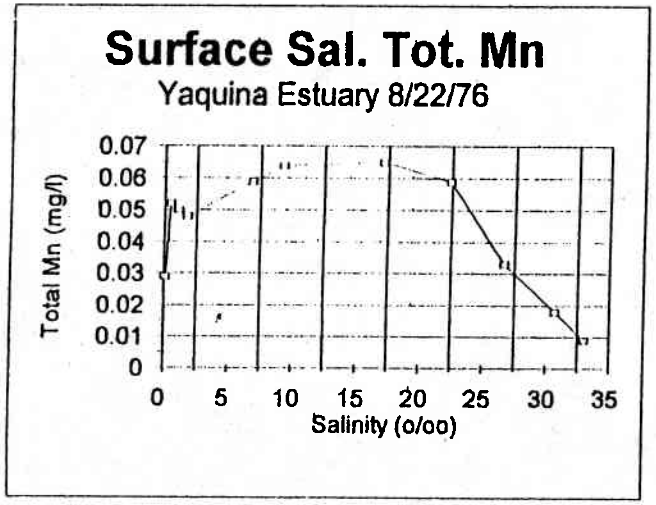


Table 1-3, Iron, mg/l

KM	surf sal	bott sal	unfsurf Mr	unfbot Mn
3.3	33.00	33.40	0.009	0.006
9.3	30.70	32.30	0.018	0.013
13.0	26.70	29.20	0.033	0.022
18.2	22.40	22.90	0.059	0.058
22.2	17.10	20.60	0.065	0.072
25.0	9.30	15.90	0.064	0.065
26.3	6.90	14.20	0.059	0.065
30.0	1.80	2.50	0.048	0.061
31.5	1.10	1.10	0.050	0.064
34.3	0.50	0.50	0.052	0.061
36.1	0.10	0.10	0.029	0.030





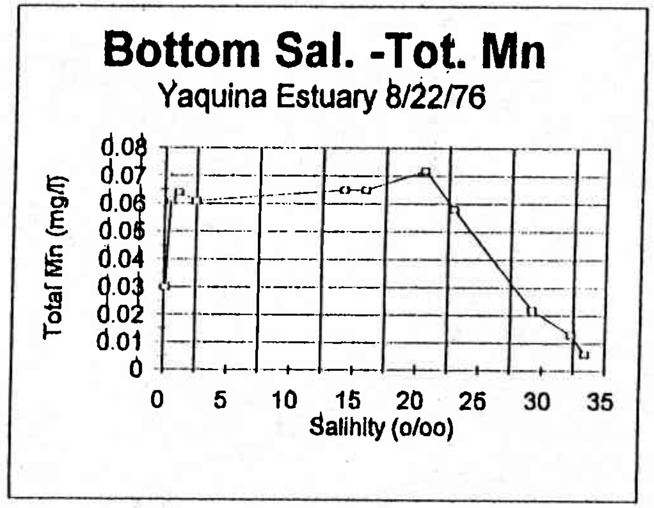
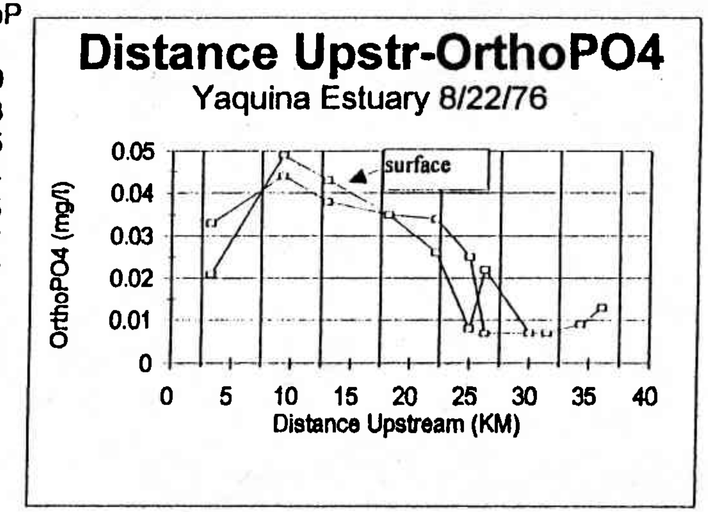
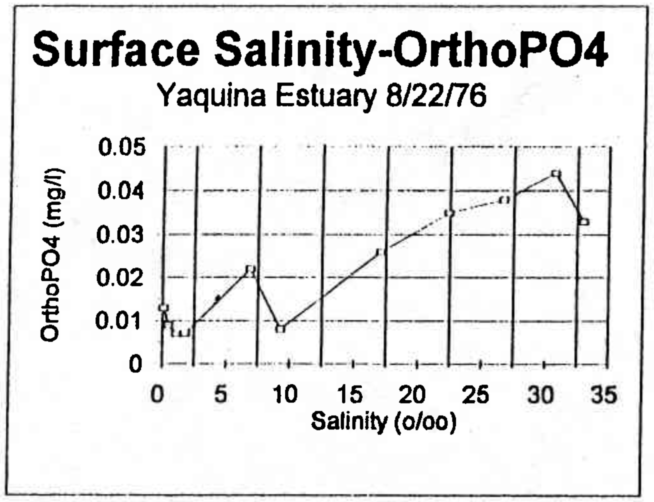


Table 1-4, Total Manganese, mg/l

KM	surf sal	bott sal	surf orthof	bott orthoP
3.3	33.00	33.40	0.033	0.021
9.3	30.70	32.30	0.044	0.049
13.0	26.70	29.20	0.038	0.043
18.2	22.40	22.90	0.035	0.035
22.2	17.10	20.60	0.026	0.034
25.0	9.30	15.90	0.008	0.025
26.3	6.90	14.20	0.022	0.007
30.0	1.80	2.50	0.007	0.007
31.5	1.10	1.10	0.007	0.007
34.3	0.50	0.50	0.009	0.009
36.1	0.10	0.10	0.013	0.013





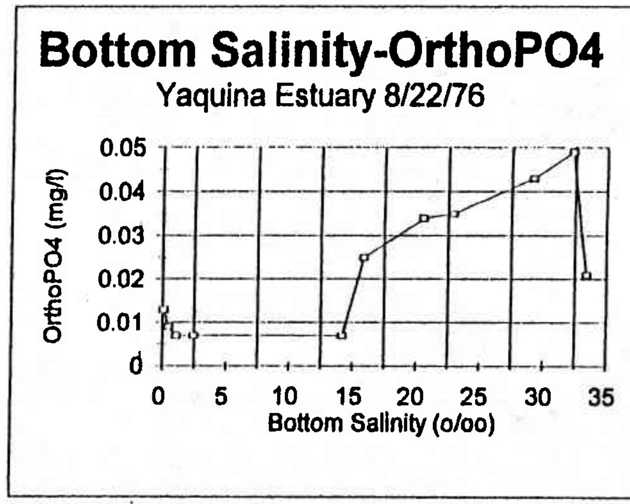


Table 1-5, Ortho-Phosphorous, mg/l

	DISSOLVED		TOTAL	
KM	B_8_22	S_8_22	S_8_22	B_8_22
3.3	0.049	0.030	0.045	0.058
7.2				
9.3	0.031	0.034	0.052	0.037
13.0	0.040	0.018	0.045	0.023
18.2	0.018	0.012	0.063	0.067
18.5				
22.2	0.017	0.020	0.037	0.057
25.0	0.010	0.010	0.021	0.056
26.3	0.012	0.014	0.015	0.029
30.0	0.020	0.013	0.038	0.054
31.5	0.012	0.011	0.066	0.068
34.3	0.011	0.017	0.070	0.071
36.1	0.014	0.010	0.052	0.056
37.4				
40.2		0.012	0.056	
42.2	0.010		0.057	
		1.9	1.9	

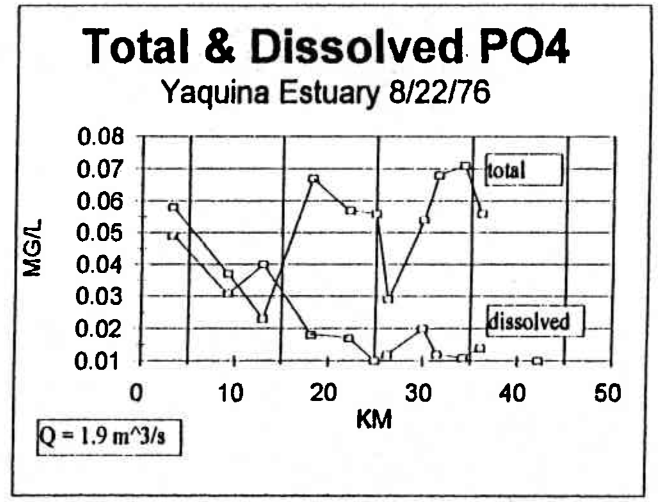
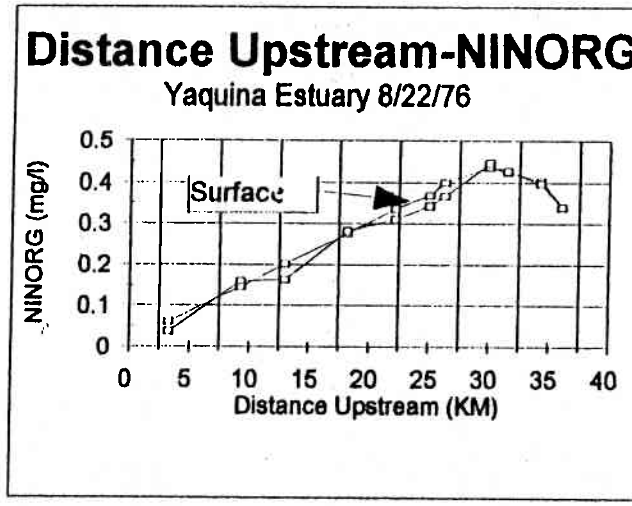
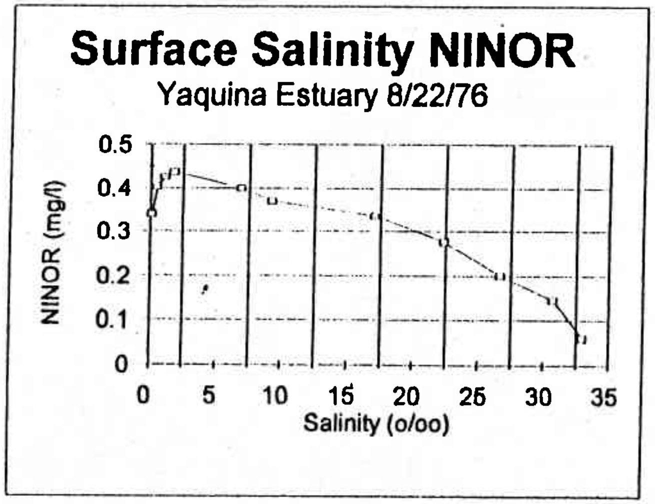


Table 1-6, Phosphate-Phosphorous, mg/l

KM	surf sal	bott sal	surf ninor	bott ninor
3.3	33.00	33.40	0.061	0.037
9.3	30.70	32.30	0.146	0.160
13.0	26.70	29.20	0.202	0.163
18.2	22.40	22.90	0.277	0.283
22.2	17.10	20.60	0.336	0.311
25.0	9.30	15.90	0.369	0.343
26.3	6.90	14.20	0.400	0.367
30.0	1.80	2.50	0.438	0.447
31.5	1.10	1.10	0.426	0.428
34.3	0.50	0.50	0.404	0.398
36.1	0.10	0.10	0.340	0.340





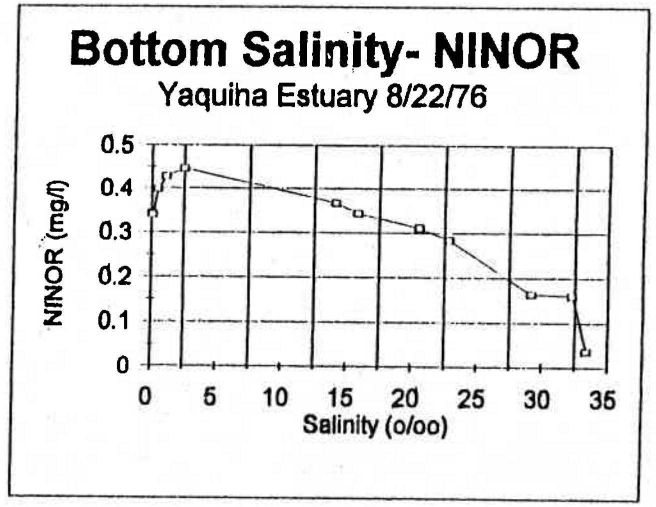
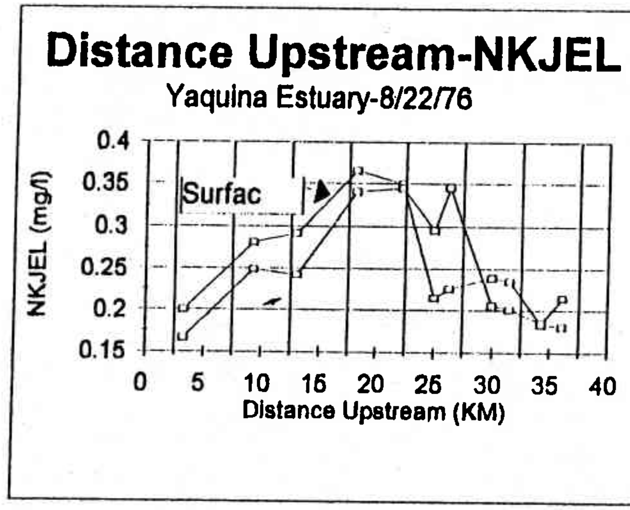
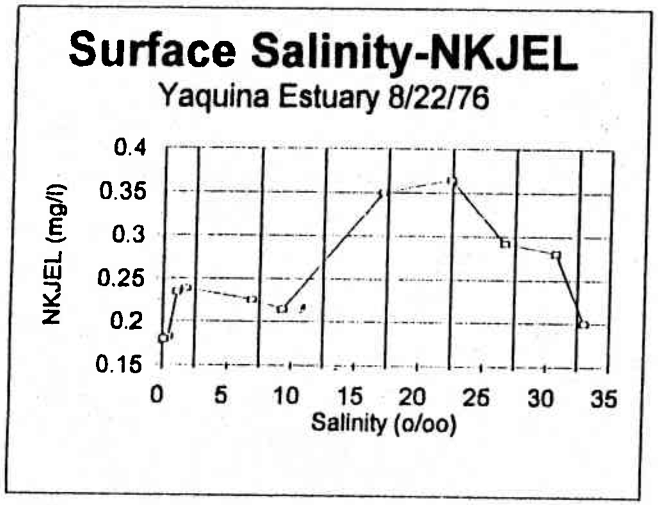
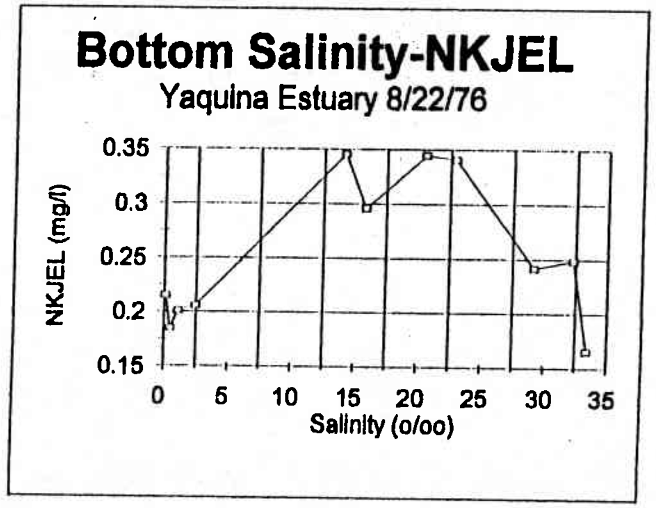


Table 1-7, Inorganic Nitrogen, mg/l

KM	surf sal	bott sal	surf nkjel	bott nkjel
3.3	33.00	33.40	0.200	0.166
9.3	30.70	32.30	0.281	0.249
13.0	26.70	29.20	0.292	0.242
18.2	22.40	22.90	0.365	0.341
22.2	17.10	20.60	0.350	0.345
25.0	9.30	15.90	0.215	0.296
26.3	6.90	14.20	0.226	0.346
30.0	1.80	2.50	0.239	0.206
31.5	1.10	1.10	0.235	0.201
34.3	0.50	0.50	0.183	0.185
36.1	0.10	0.10	0.180	0.215
37.4	0.000	0.000		
40.2	0.05	0.000	0.209	
42.2	0.05	0.000	0.285	

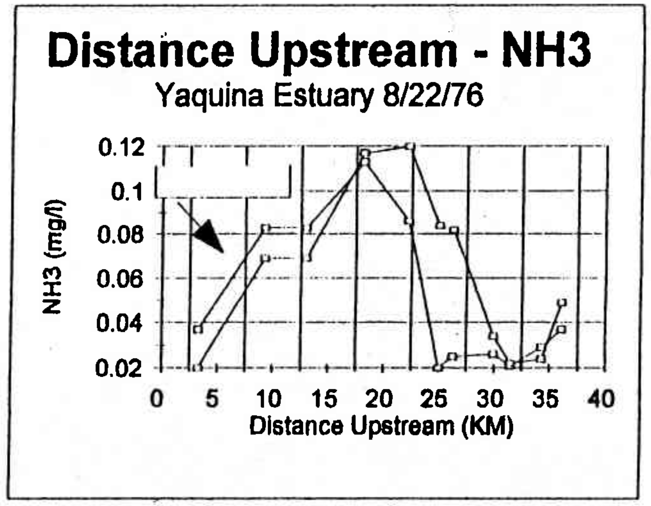


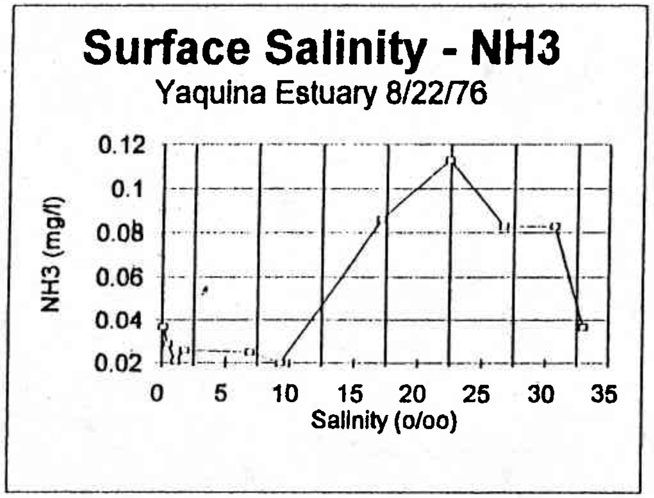


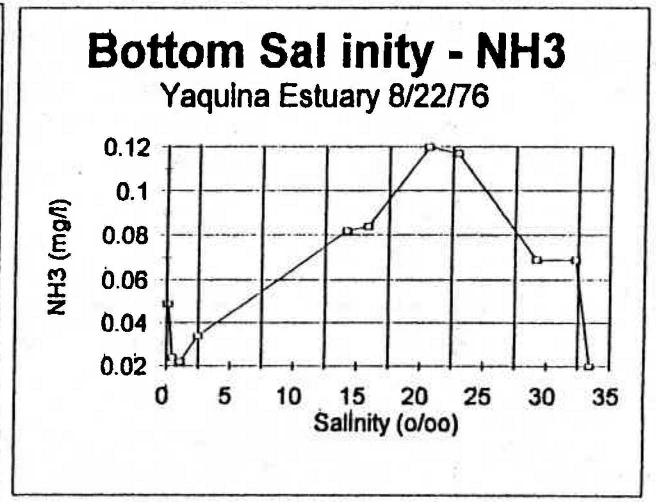


Tables 1-8, Kjeldahl Nitrogen, mg/l

KM	S_8_22	B_8_22	surf nh3	bott nh3
3.3	33.00	33.40	0.037	0.020
9.3	30.70	32.30	0.083	0.069
13.0	26.70	29.20	0.083	0.069
18.2	22.40	22.90	0.113	0.117
22.2	17.10	20.60	0.086	0.120
25.0	9.30	15.90	0.020	0.084
26.3	6.90	14.20	0.025	0.082
30.0	1.80	2.50	0.026	0.034
31.5	1.10	1.10	0.021	0.022
34.3	0.50	0.50	0.029	0.024
36.1	0.10	0.10	0.037	0.049

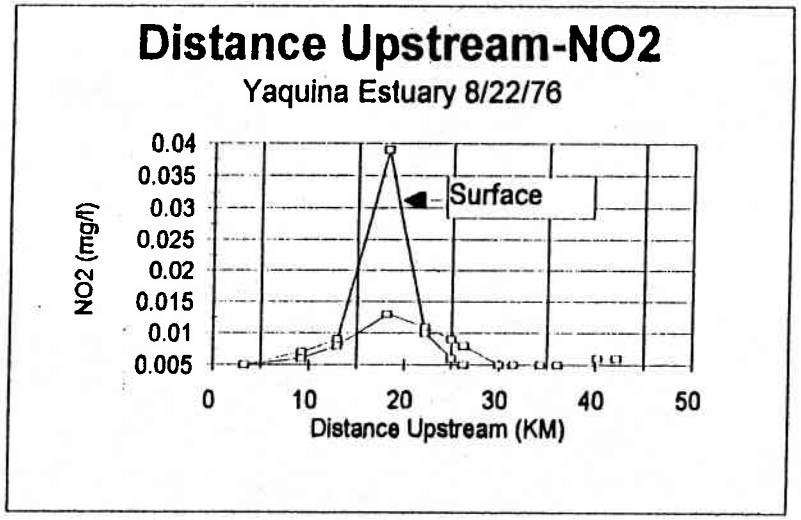


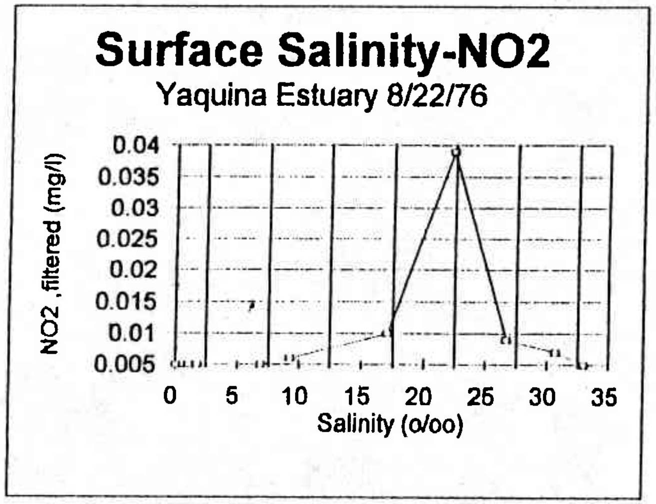


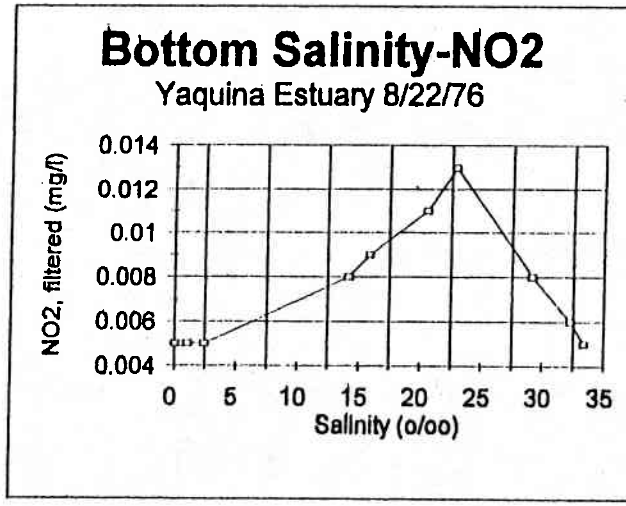


Tables 1-9, Ammonia Nitrogen, mg/l

KM	surf sal	bott sal	surf NO2	bott NO2
3.3	33.00	33.40	0.005	0.005
9.3	30.70	32.30	0.007	0.006
13.0	26.70	29.20	0.009	0.008
18.2	22.40	22.90	0.039	0.013
22.2	17.10	20.60	0.010	0.011
25.0	9.30	15.90	0.006	0.009
26.3	6.90	14.20	0.005	0.008
30.0	1.80	2.50	0.005	0.005
31.5	1.10	1.10	0.005	0.005
34.3	0.50	0.50	0.005	0.005
36.1	0.10	0.10	0.005	0.005
37.4	0.000	0.000		
40.2	0.05	0.000	0.006	
42.2	0.05	0.000	0.006	

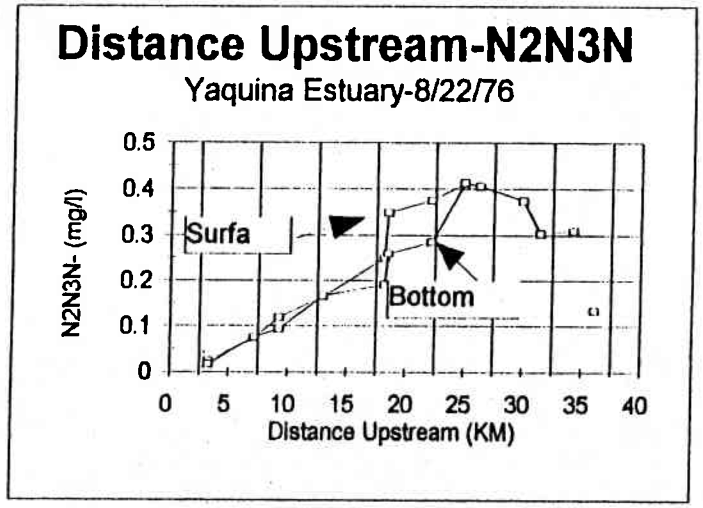


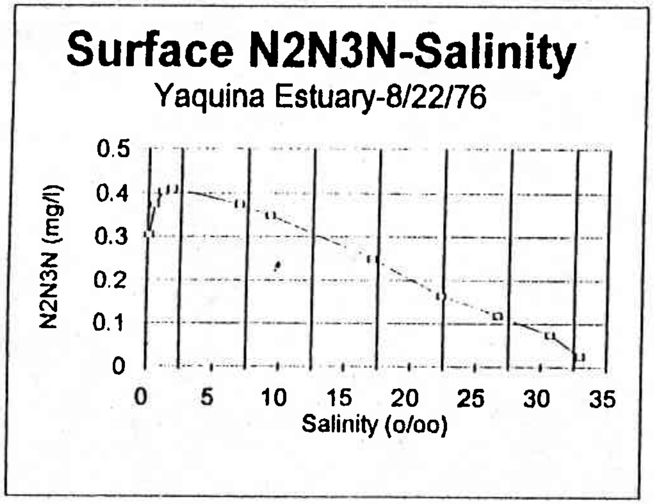


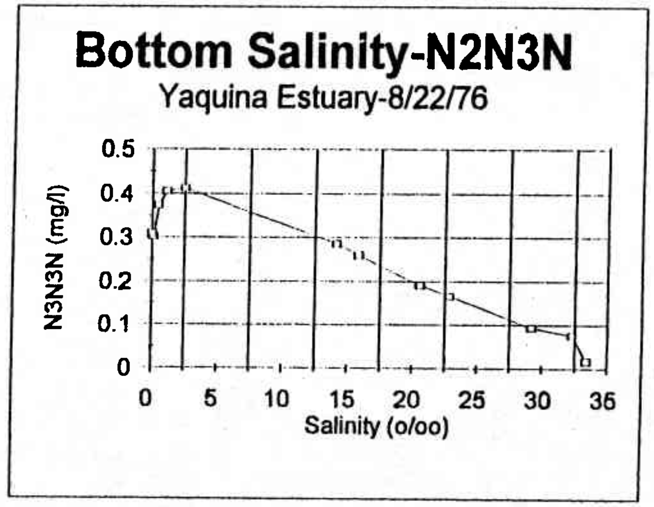


Tables 1-10, Nitrite Nitrogen, mg/l

KM	surf sal	bott sal	surf n2n3r	bott n2n3n
3.3	33.00	33.40	0.024	0.017
7.2	30.70	32.30	0.074	0.076
9.3	26.70	29.20	0.119	0.094
13.0	22.40	22.90	0.164	0.166
18.2	17.10	20.60	0.250	0.191
18.5	9.30	15.90	0.349	0.259
22.2	6.90	14.20	0.375	0.285
25.0	1.80	2.50	0.412	0.413
26.3	1.10	1.10	0.405	0.406
30.0	0.50	0.50	0.375	0.374
31.5	0.10	0.10	0.305	0.303
34.3	0.000	0.000		0.310
36.1	0.05	0.000	0.134	
37.4	0.05	0.000		

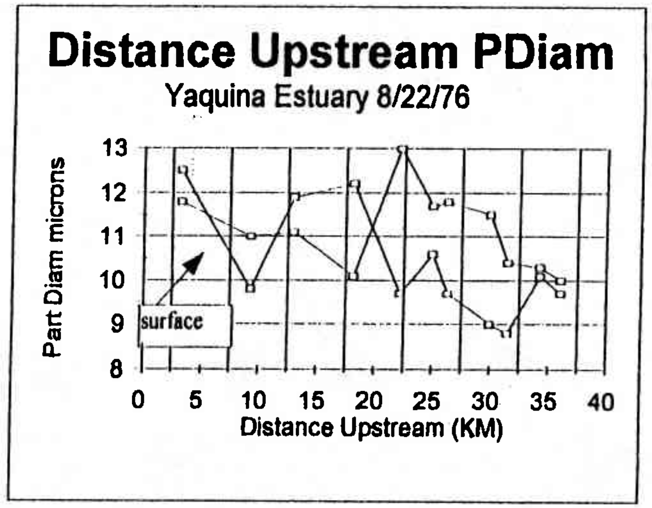


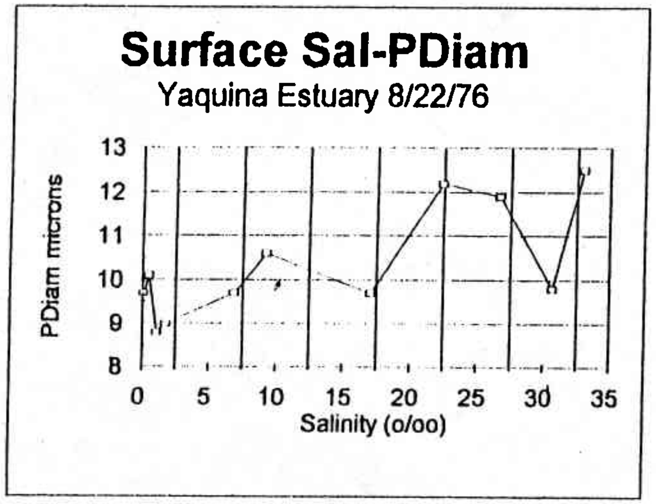




Tables 1-11, Nitrite-Nitrate Nitrogen, mg/l

KM	surf sal	bott sal	surf pdiam	bott pdiam
3.3	33.00	33.40	12.5	11.8
9.3	30.70	32.30	9.8	11.0
13.0	26.70	29.20	11.9	11.1
18.2	22.40	22.90	12.2	10.1
22.2	17.10	20.60	9.7	13.0
25.0	9.30	15.90	10.6	11.7
26.3	6.90	14.20	9.7	11.8
30.0	1.80	2.50	9.0	11.5
31.5	1.10	1.10	8.8	10.4
34.3	0.50	0.50	10.1	10.3
36.1	0.10	0.10	9.7	10.0





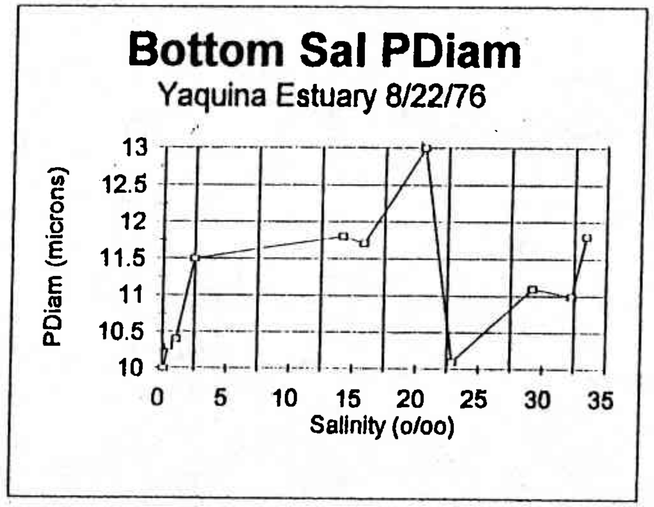
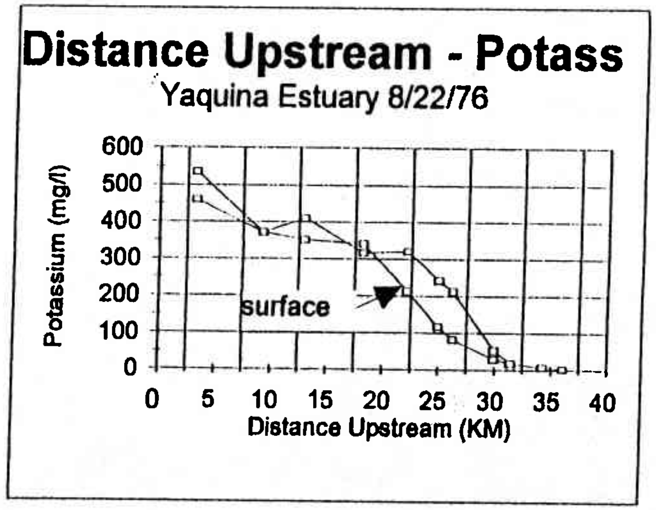
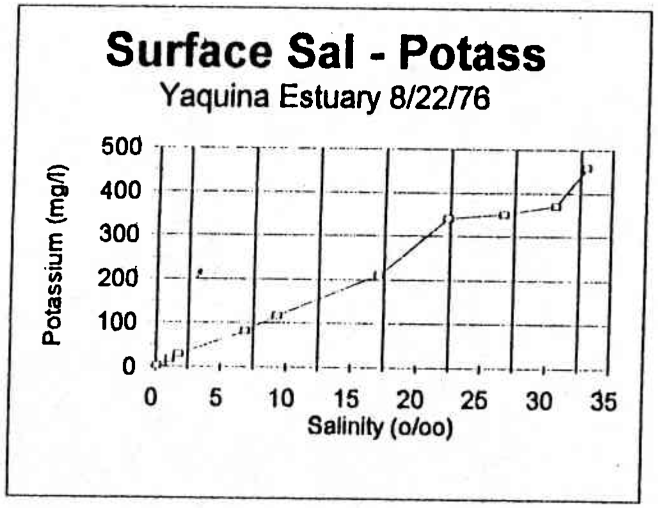


Table 1-12. Particle Diameter, µm

KM	surf sal	bott sal	surf potas	bott potas
3.3	33.00	33.40	460	535
9.3	30.70	32.30	371	371
13.0	26.70	29.20	351	410
18.2	22.40	22.90	341	316
22.2	17.10	20.60	212	321
25.0	9.30	15.90	117	241
26.3	6.90	14.20	82	212
30.0	1.80	2.50	29.6	53.5
31.5	1.10	1.10	17.7	17.7
34.3	0.50	0.50	7.7	7.7
36.1	0.10	0.10	3	2.8





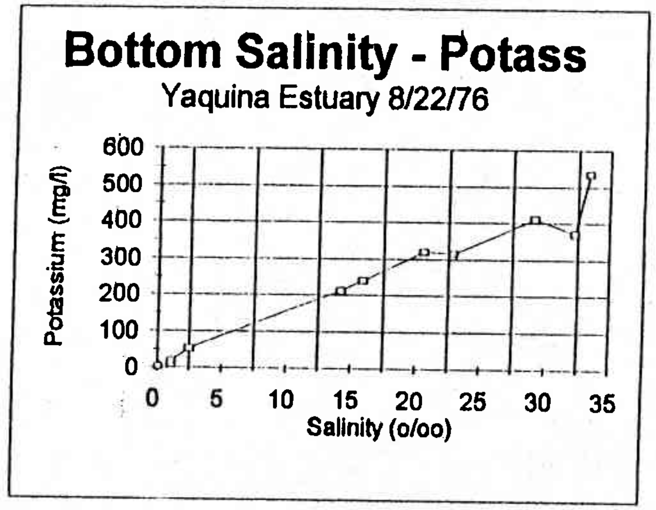


Table 1-13, Potassium, mg/l

KM	surf sal	bott sal
3.3	33.00	33.40
9.3	30.70	32.30
13.0	26.70	29.20
18.2	22.40	22.90
22.2	17.10	20.60
25.0	9.30	15.90
26.3	6.90	14.20
30.0	1.80	2.50
31.5	1.10	1.10
34.3	0.50	0.50
36.1	0.10	0.10

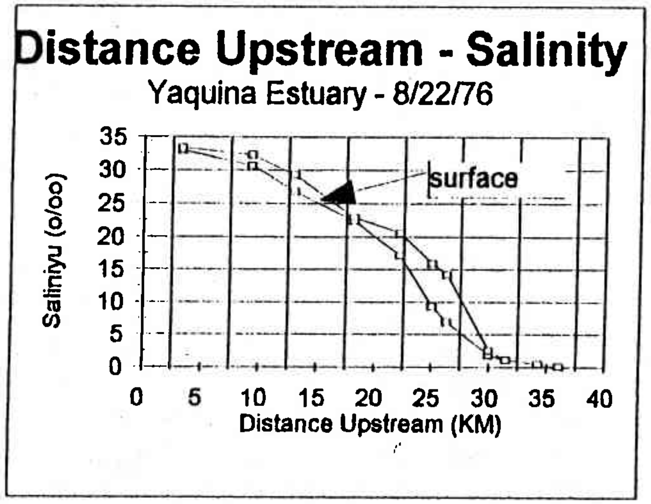
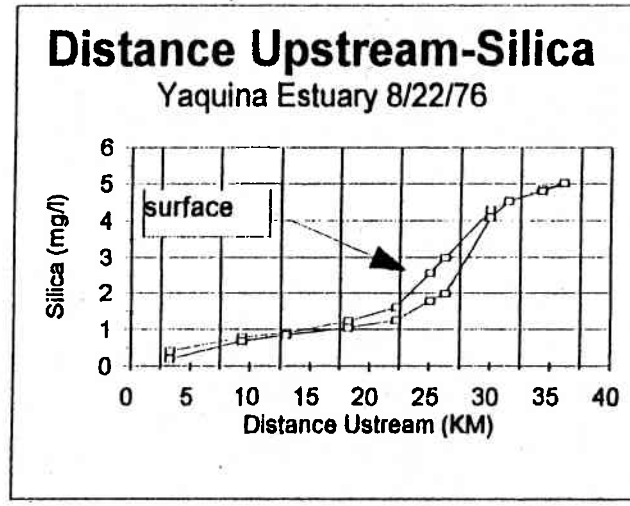
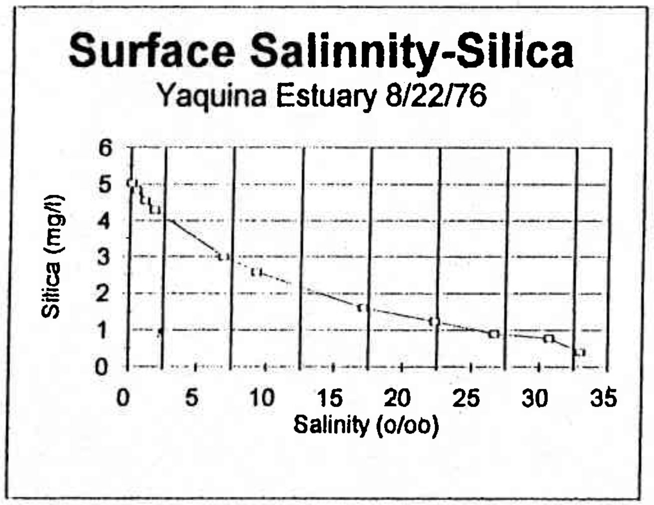


Table 1-14, Salinity, mg/l

KM	surf sal	bott sal	surf silica	bott silica
3.3	33.00	33.40	0.411	0.196
9.3	30.70	32.30	0.785	0.678
13.0	26.70	29.20	0.904	0.848
18.2	22.40	22.90	1.240	1.050
22.2	17.10	20.60	1.610	1.260
25.0	9.30	15.90	2.570	1.780
26.3	6.90	14.20	2.990	1.980
30.0	1.80	2.50	4.290	4.090
31.5	1.10	1.10	4.540	4.520
34.3	0.50	0.50	4.850	4.800
36.1	0.10	0.10	5.030	5.020





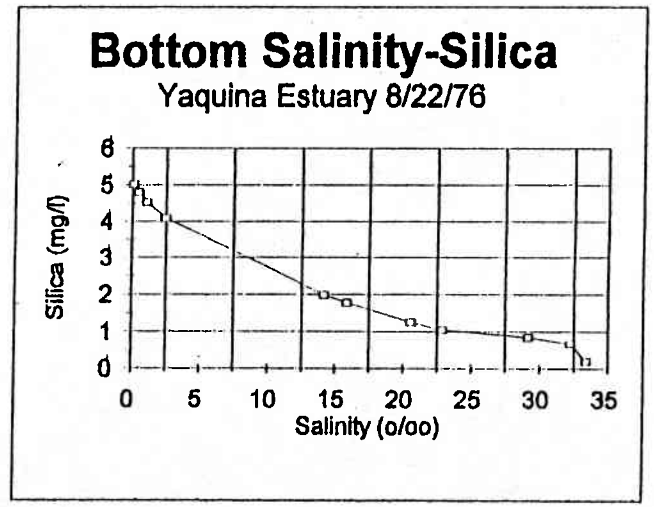
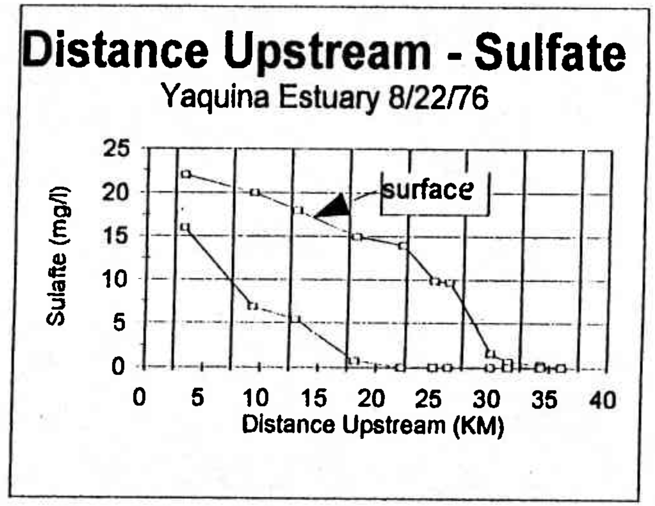
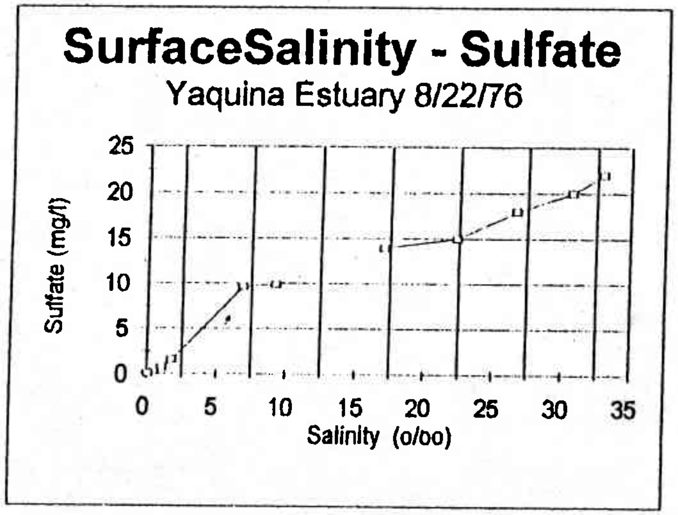


Table 1-15, Silica, mg/l

KM	surf sal	bott sal	surf sulf	bott sulf
3.3	33.00	33.40	22	16
9.3	30.70	32.30	20	6.9
13.0	26.70	29.20	18	5.4
18.2	22.40	22.90	15	0.74
22.2	17.10	20.60	14	0.03
25.0	9.30	15.90	9.90	0.03
26.3	6.90	14.20	9.70	0.03
30.0	1.80	2.50	1.60	0.03
31.5	1.10	1.10	0.66	0.03
34.3	0.50	0.50	0.31	0.03
36.1	0.10	0.10	0.08	0.03





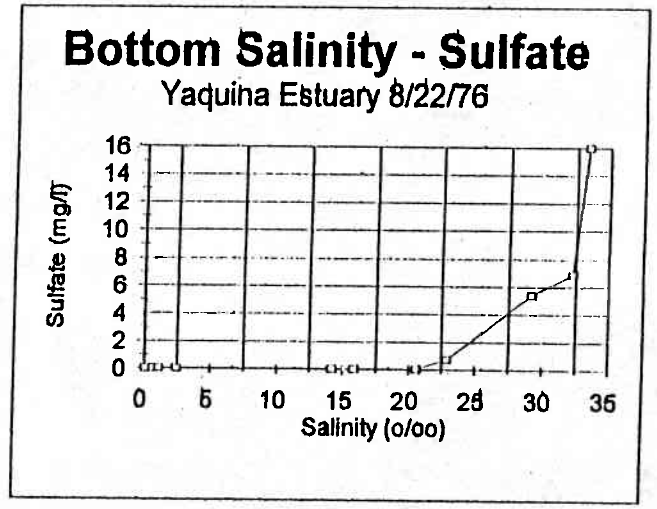


Table 1-16, Sulfate, mg/l

APPENDIX 2

Temperature-Salinity Data, Yaquina Estuary 1976-1977

APPENDIX 2. TEMPERATURE-SALINITY DATA

TEMPERTURE	STN	KM	S_7_29	B_7_29	S_10_14	B_10_14	S_1_20	B_1_20	S_3_3	B_3_3
DEGREES CELSIUS	UD	3.3	13.60		11.50	10.20	9.60	9.60	9.40	9.50
	SB	7.2	17.60						9.27	9.84
STN=Station name	RV	9.3	19.20						8.80	9.50
	FW	13.0							8.30	8.50
KM =	CR	18.2			15.90		7.50	7.60	7.90	7.84
KM's upstream	TL	18.5	22.40							
	GP	22.2	22.70		16.20	15.90	7.10	7.00	7.88	7.80
S_7_29 =	MC	25.0	23.10		16.20	15.90	6.80	6.80	7.75	7.74
Surface sample-	BP	26.3	22.70		16.10	15.90	6.80	6.80	8.50	
on 7/29/76	CD	30.0			16.50	16.00	6.90	6.90	7.90	7.90
	WD	31.5			16.50		7.00	7.00	8.20	
B_1_20 =	FP	34.3			15.80		7.20	7.20		
Bottom sample-	EC	36.1	21.70		15.20		7.80	7.50	8.40	
on 1/20/77	YL	37.4			14.60					
	PB	40.2								
	ER	42.2								
FLOW (M^3/S)--->			2.2	2.2	1.3	1.3	3.5	3.5	46	46

TEMPERTURE	STN	KM	S_5_12	B_5_12	S_6_28	B_6_28	S_8_22	B_8_22	S_12_20	B_12_20
DEGREES CELSIUS	UD	3.3	11.20	9.20	9.90	8.20	13.99	12.51	7.90	10.50
	SB	7.2								
STN=Station name	RV	9.3	12.30	11.20	12.30	11.60	17.35	15.12	7.40	10.20
	FW	13.0	14.80	13.10	117.90	16.20	19.21	17.55	7.20	9.90
KM =	CR	18.2	15.20	14.30	19.70	19.30	20.15	19.74	6.80	8.10
KM's upstream	TL	18.5								
	GP	22.2	14.90	14.40	20.90	20.40	20.45	19.91	6.70	6.70
S_7_29 =	MC	25.0	13.80	13.70	20.80	20.70	21.04	19.88	6.70	6.80
Surface sample-	BP	26.3	13.50	13.20	21.00	20.80	21.40	19.96	6.80	6.80
on 7/29/76	CD	30.0	12.80	12.70	20.60	20.30	20.66	20.36	6.80	6.80
	WD	31.5	12.60	12.50	20.30	20.20	21.19	20.55	6.80	6.80
B_1_20 =	FP	34.3				20.10		19.93		6.80
Bottom sample-	EC	36.1			19.00	19.00	19.59	19.52	7.00	6.90
on 1/20/77	YL	37.4								
	PB	40.2								
	ER	42.2								
FLOW (M^3/S)--->			10.4	10.4	4.6	4.6	1.9	1.9	87	87

Table 2-1. Temperature Data Summary, Yaquina Estuary 1976-1977

SALINTY_PPT UNFILTERED

STN=Station name

KM = KM's upstream

S_7_29 = Surface sample- on 7/29/76

B_1_20 = Bottom sample- on 1/20/77

STN	KM	S_7_29	B_7_29	S_10_14	B_10_14	S_1_20	B_1_20	S_3_3	B_3_3	S_4_21	B_4_21
UD	3.3	32.90		33.40	33.73	33.32	33.32	27.56	31.32	26.50	30.80
SB	7.2	30.10						23.50	29.20		
RV	9.3	27.80		31.14	32.59			15.30	24.70	19.50	25.30
FW	13.0							7.13	13.20	13.40	15.80
CR	18.2			23.07	25.20	14.90	15.80	1.80	3.30	4.70	5.10
TL	18.5	18.00									
GP	22.2	8.84		19.67	21.55	9.80	10.20	0.12	0.12	2.50	2.50
MC	25.0	3.29		13.10	17.80	6.10	6.40	0.05	0.05	1.00	1.00
BP	26.3	1.30		11.12	16.88	4.80	4.90	0.06	0.06	0.10	0.20
CD	30.0			5.50	8.05	0.70	0.80	0.05	0.05	0.05	0.05
WD	31.5			7.58		0.60	0.60	0.05	0.05	0.04	0.04
FP	34.3			1.67		0.10	0.10	0.05	0.05	0.04	0.04
EC	36.1	0.72		0.40		0.07	0.07	0.05	0.05	0.04	0.04
YL	37.4			0.10							
PB	40.2					0.05		0.05			
ER	42.2					0.05		0.05			
FLOW (M^3/S)--->		2.2	2.2	1.3	1.3	3.5	3.5	46	46	7.8	7.8

SALINTY_PPT UNFILTERED

STN=Station name

KM = KM's upstream

S_7_29 = Surface sample- on 7/29/76

B_1_20 = Bottom sample- on 1/20/77

STN	KM	S_5_12	B_5_12	S_6_28	B_6_28	S_8_22	B_8_22	S_12_20	B_12_20
UD	3.3	29.20	32.60	32.40	33.78	33.00	33.40	19.99	29.90
SB	7.2								
RV	9.3	25.70	29.80	31.34	32.06	30.70	32.30	9.01	29.19
FW	13.0	15.30	24.40	25.13	27.54	26.70	29.20	6.77	25.23
CR	18.2	12.00	15.90	17.68	18.38	22.40	22.90	0.90	8.69
TL	18.5								
GP	22.2	3.00	5.80	11.10	12.27	17.10	20.60	0.05	0.05
MC	25.0	0.70	1.00	8.02	8.18	9.30	15.90	0.05	0.05
BP	26.3	0.07	0.07	6.31	6.48	6.90	14.20	0.05	0.05
CD	30.0	0.05	0.05	0.18	0.21	1.80	2.50	0.05	0.05
WD	31.5	0.05	0.05	0.09	0.09	1.10	1.10	0.05	0.05
FP	34.3			0.05	0.05	0.50	0.50	0.05	0.05
EC	36.1			0.05	0.05	0.10	0.10	0.05	0.05
YL	37.4								
PB	40.2			0.05		0.05		0.05	
ER	42.2			0.05		0.05		0.05	
FLOW (M^3/S)--->		10.4	10.4	4.6	4.6	1.9	1.9	87	87

Table 2-2. Salinity Data Summary. Yaquina Estuary. 1976-1977

surf sal	surf temp
32.90	13.60
30.10	17.60
27.80	19.20
18.00	22.40
8.84	22.70
3.29	23.10
1.30	22.70
0.72	21.70

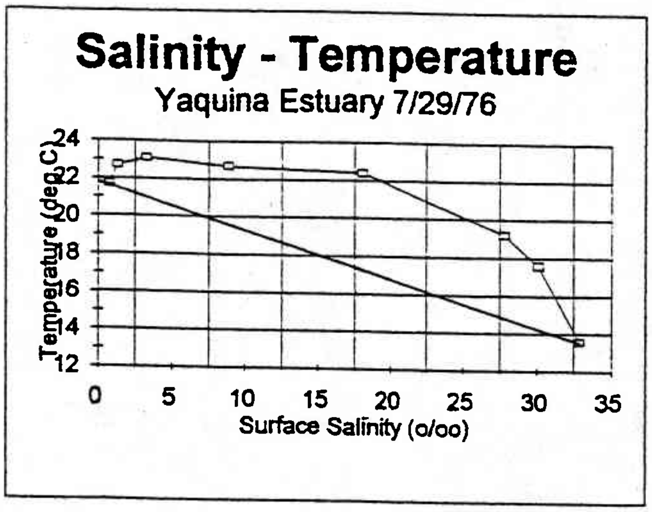


Table 2-3, 7/29/76. Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	33.40	33.73	11.50	10.20
9.3	31.14	32.59		
18.2	23.07	25.20	15.90	
22.2	19.67	21.55	16.20	15.90
25.0	13.10	17.80	16.20	15.90
26.3	11.12	16.88	16.10	15.90
30.0	5.50	8.05	16.50	16.00
31.5	7.58		16.50	
34.3	1.67		15.80	
36.1	0.40		15.20	

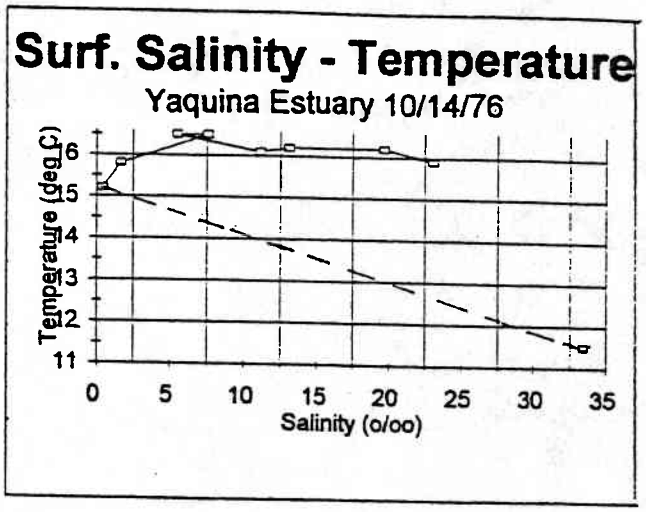
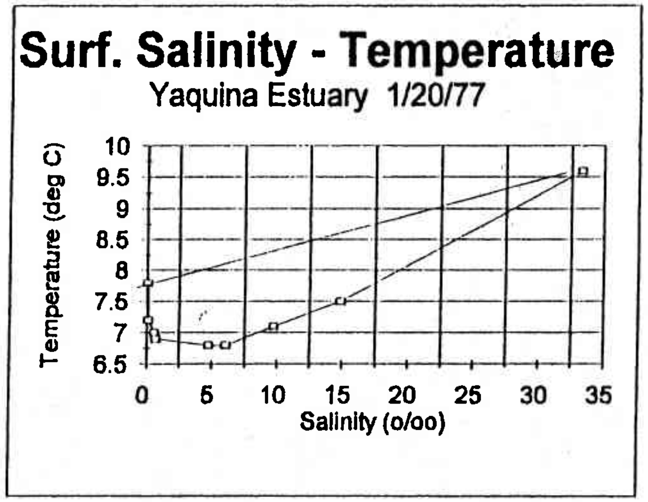


Table 2-4. 10/14/76. Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	33.32	33.32	9.60	9.60
18.2	14.90	15.80	7.50	7.60
22.2	9.80	10.20	7.10	7.00
25.0	6.10	6.40	6.80	6.80
26.3	4.80	4.90	6.80	6.80
30.0	0.70	0.80	6.90	6.90
31.5	0.60	0.60	7.00	7.00
34.3	0.10	0.10	7.20	7.20
36.1	0.07	0.07	7.80	7.50



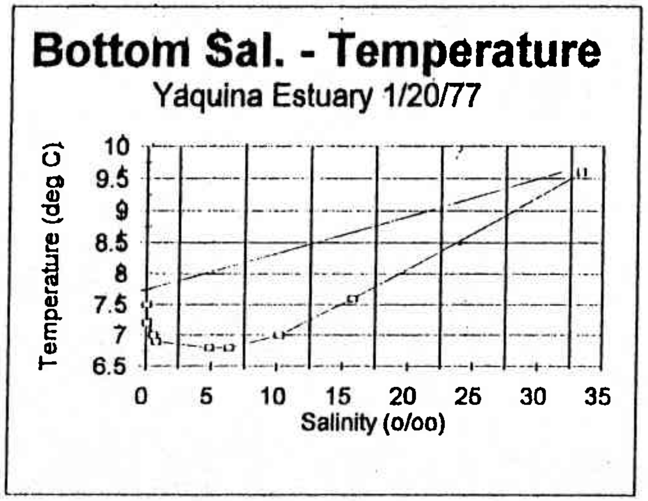
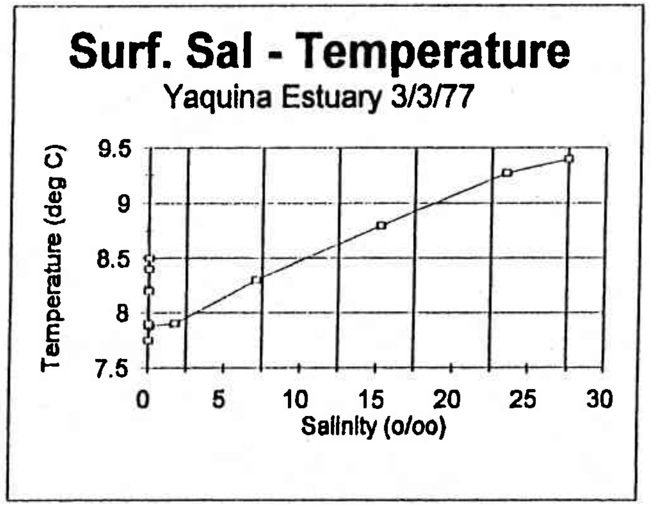


Table 2-5, 1/20/77 Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	27.56	31.32	9.40	9.50
7.2	23.50	29.20	9.27	9.84
9.3	15.30	24.70	8.80	9.50
13.0	7.13	13.20	8.30	8.50
18.2	1.80	3.30	7.90	7.84
22.2	0.12	0.12	7.88	7.80
25.0	0.05	0.05	7.75	7.74
26.3	0.06	0.06	8.50	
30.0	0.05	0.05	7.90	7.90
31.5	0.05	0.05	8.20	
34.3	0.05	0.05		
36.1	0.05	0.05	8.40	



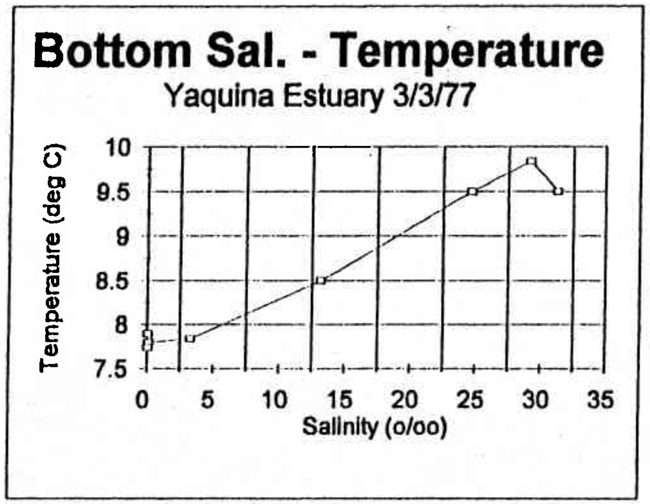
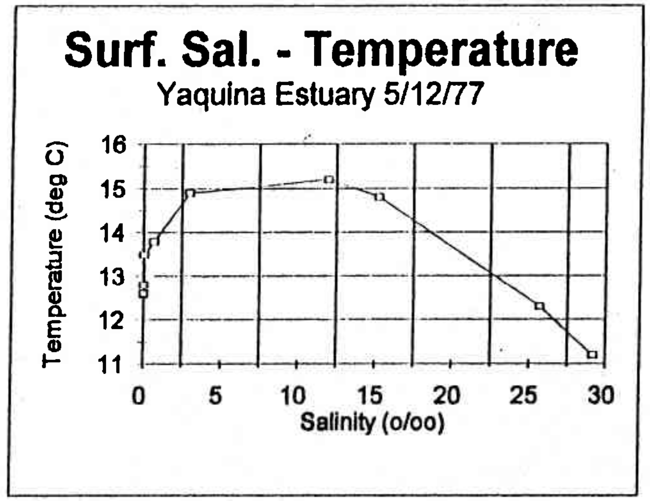


Table 2-6, 3/3/77 Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	29.20	32.60	11.20	9.20
9.3	25.70	29.80	12.30	11.20
13.0	15.30	24.40	14.80	13.10
18.2	12.00	15.90	15.20	14.30
22.2	3.00	5.80	14.90	14.40
25.0	0.70	1.00	13.80	13.70
26.3	0.07	0.07	13.50	13.20
30.0	0.05	0.05	12.80	12.70
31.5	0.05	0.05	12.60	12.50



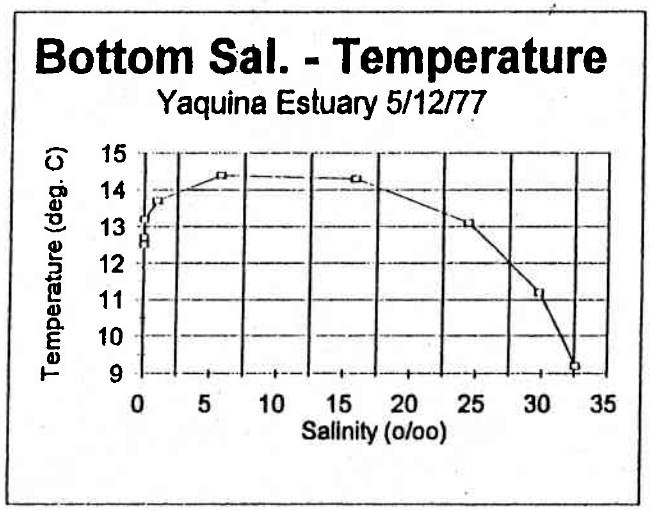
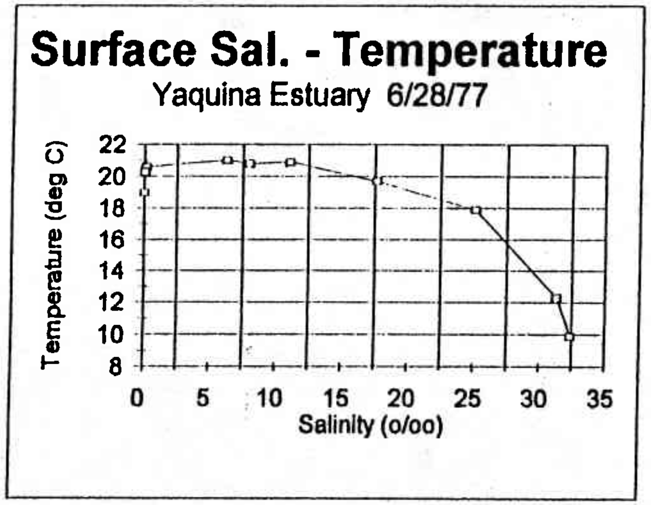


Table 2-7, 5/12/77 Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	32.40	33.78	9.90	8.20
9.3	31.34	32.06	12.30	11.60
13.0	25.13	27.54	17.90	16.20
18.2	17.68	18.38	19.70	19.30
22.2	11.10	12.27	20.90	20.40
25.0	8.02	8.18	20.80	20.70
26.3	6.31	6.48	21.00	20.80
30.0	0.18	0.21	20.60	20.30
31.5	0.09	0.09	20.30	20.20
34.3	0.05	0.05		20.10
36.1	0.05	0.05	19.00	19.00



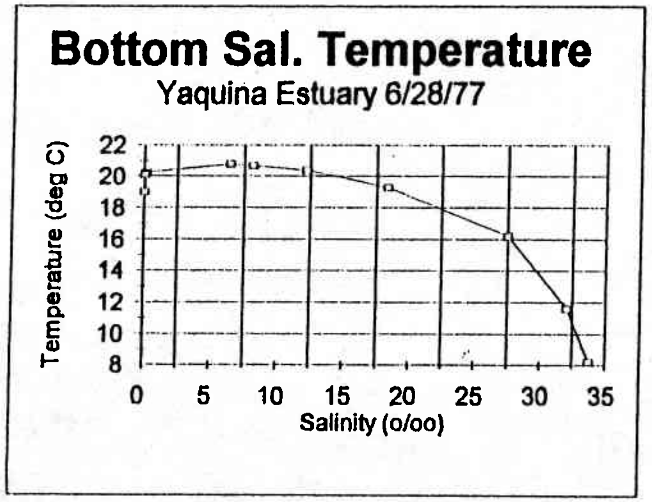
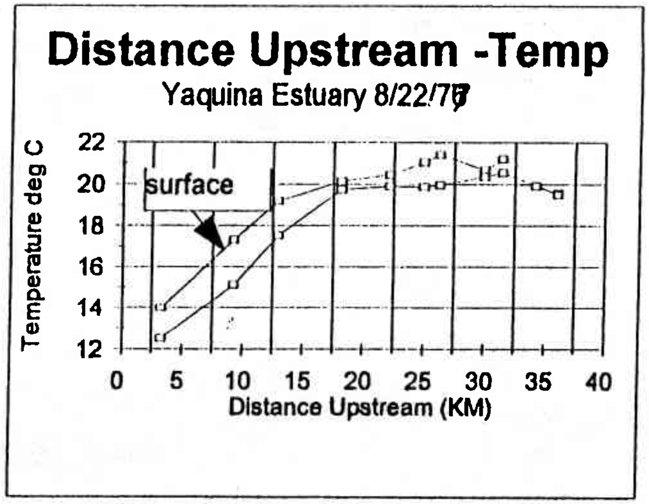
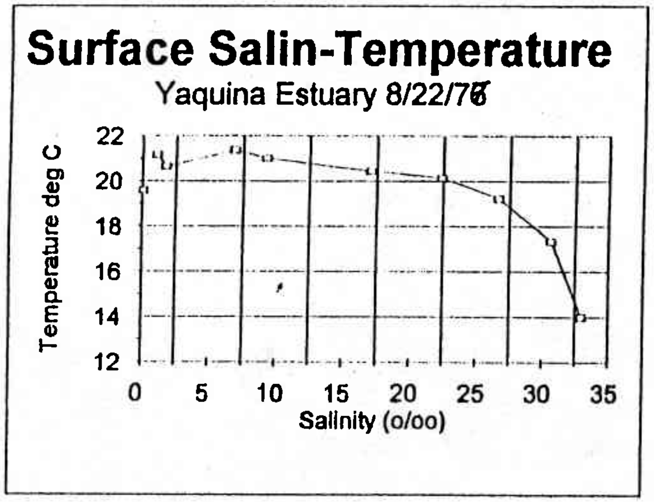


Table 2-8, 6/28/77 Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott sal
3.3	33.00	33.40	13.99	12.51
9.3	30.70	32.30	17.35	15.12
13.0	26.70	29.20	19.21	17.55
18.2	22.40	22.90	20.15	19.74
22.2	17.10	20.60	20.45	19.91
25.0	9.30	15.90	21.04	19.88
26.3	6.90	14.20	21.40	19.96
30.0	1.80	2.50	20.66	20.36
31.5	1.10	1.10	21.19	20.55
34.3	0.50	0.50		19.93
36.1	0.10	0.10	19.59	19.52





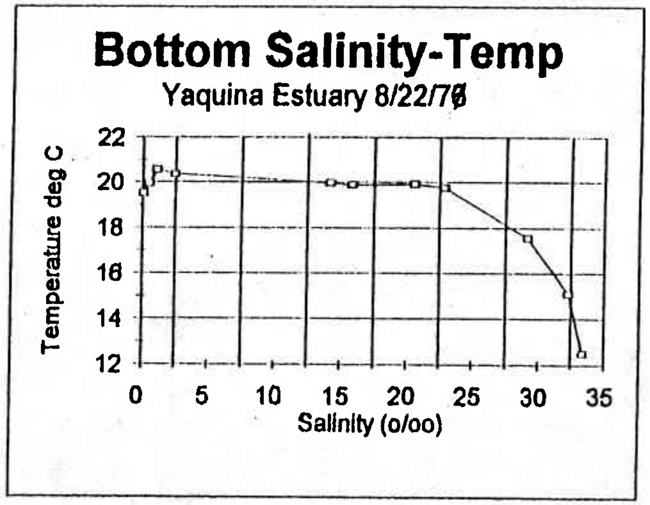
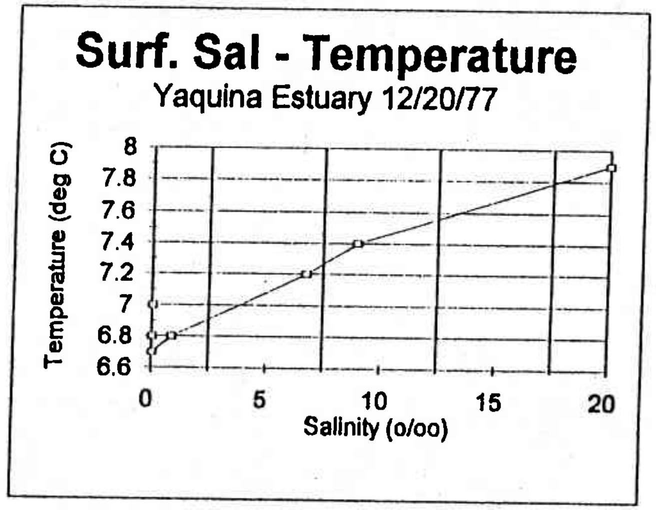


Table 2-9. 8/22/77 Temperature-Salinity data

KM	surf sal	bott sal	surf temp	bott temp
3.3	19.99	29.90	7.90	10.50
9.3	9.01	29.19	7.40	10.20
13.0	6.77	25.23	7.20	9.90
18.2	0.90	8.69	6.80	8.10
22.2	0.05	0.05	6.70	6.70
25.0	0.05	0.05	6.70	6.80
26.3	0.05	0.05	6.80	6.80
30.0	0.05	0.05	6.80	6.80
31.5	0.05	0.05	6.80	6.80
34.3	0.05	0.05		6.80
36.1	0.05	0.05	7.00	6.90



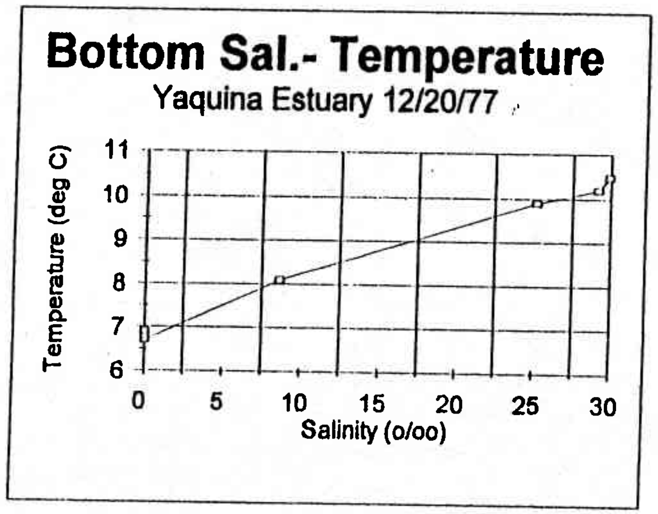
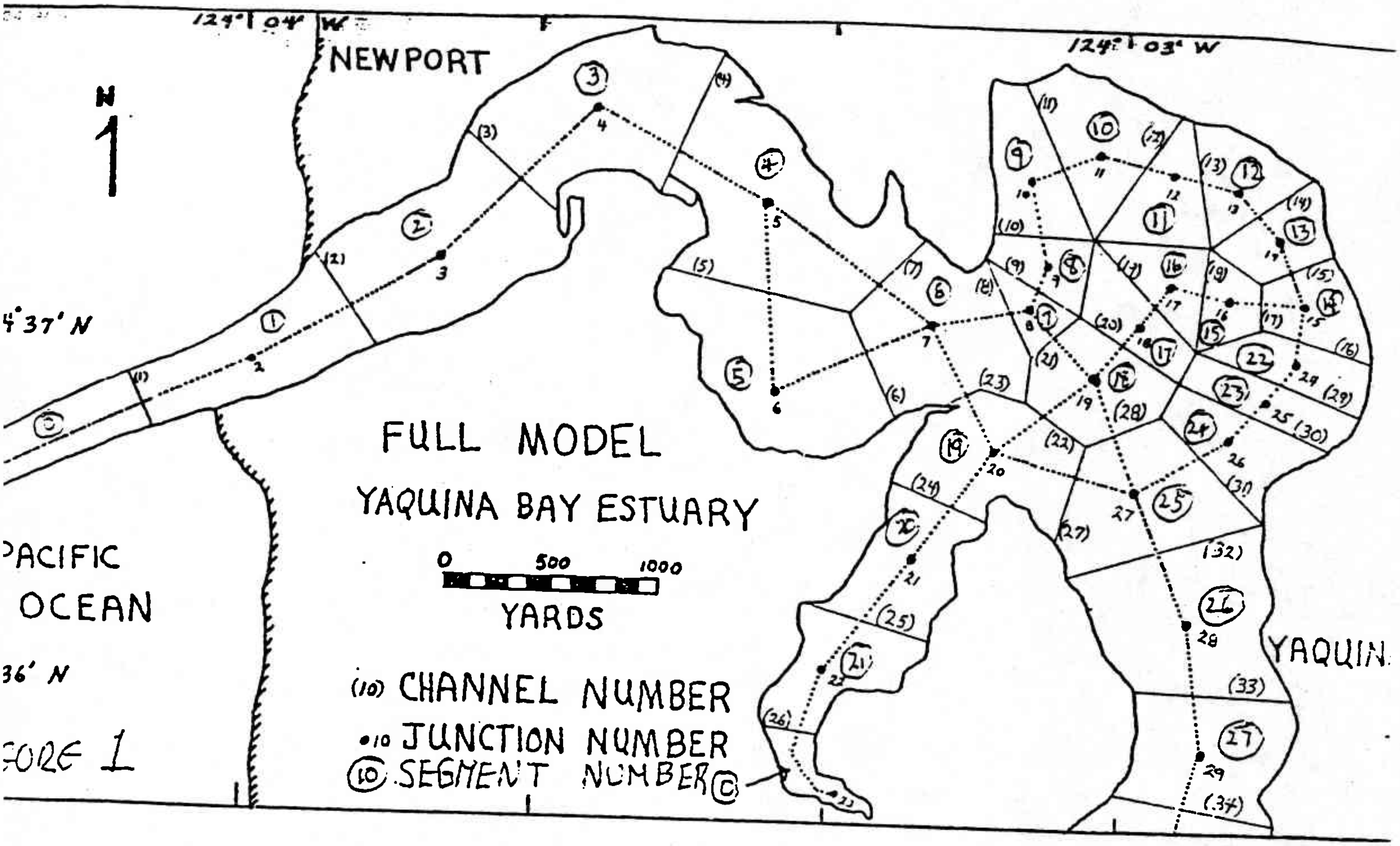
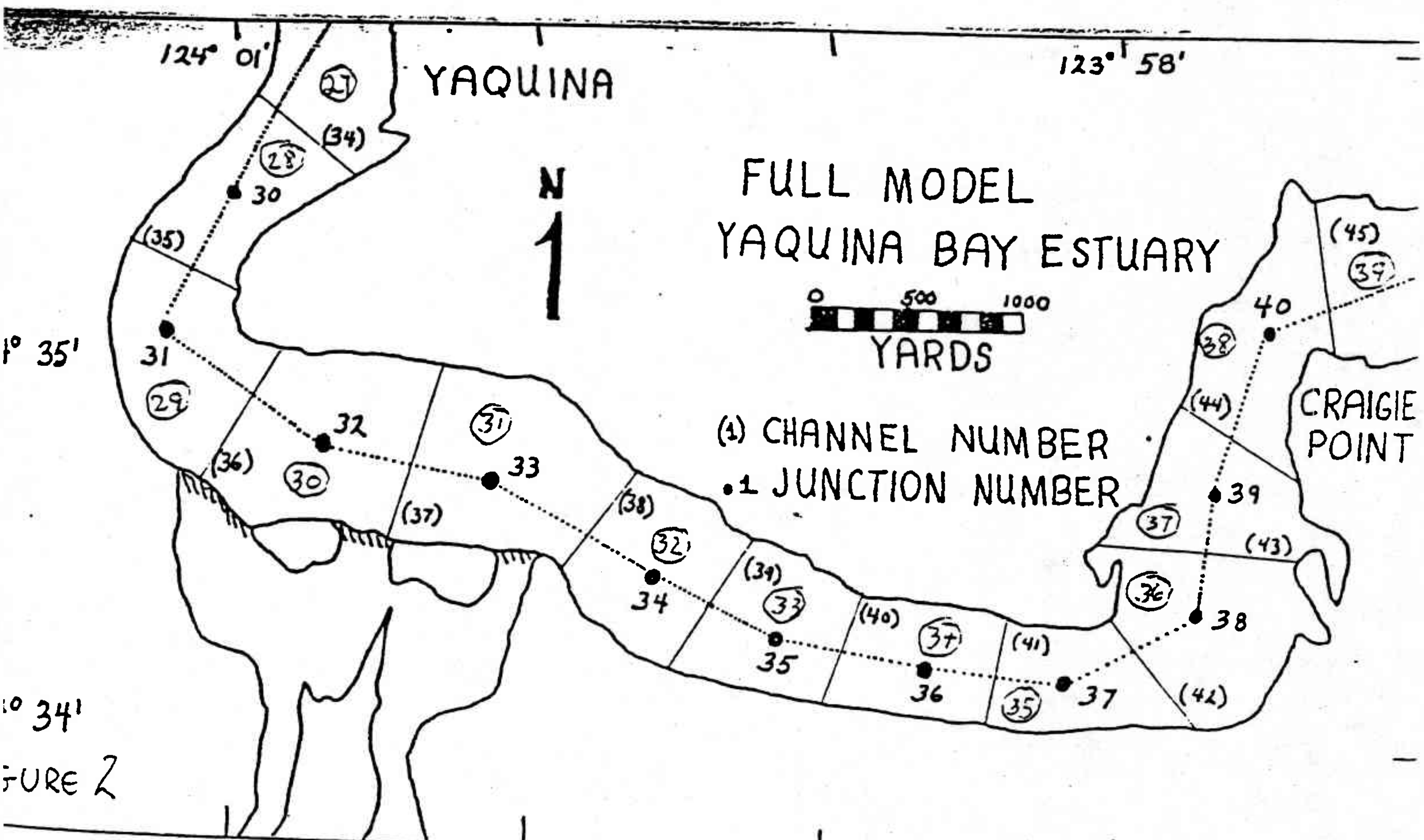


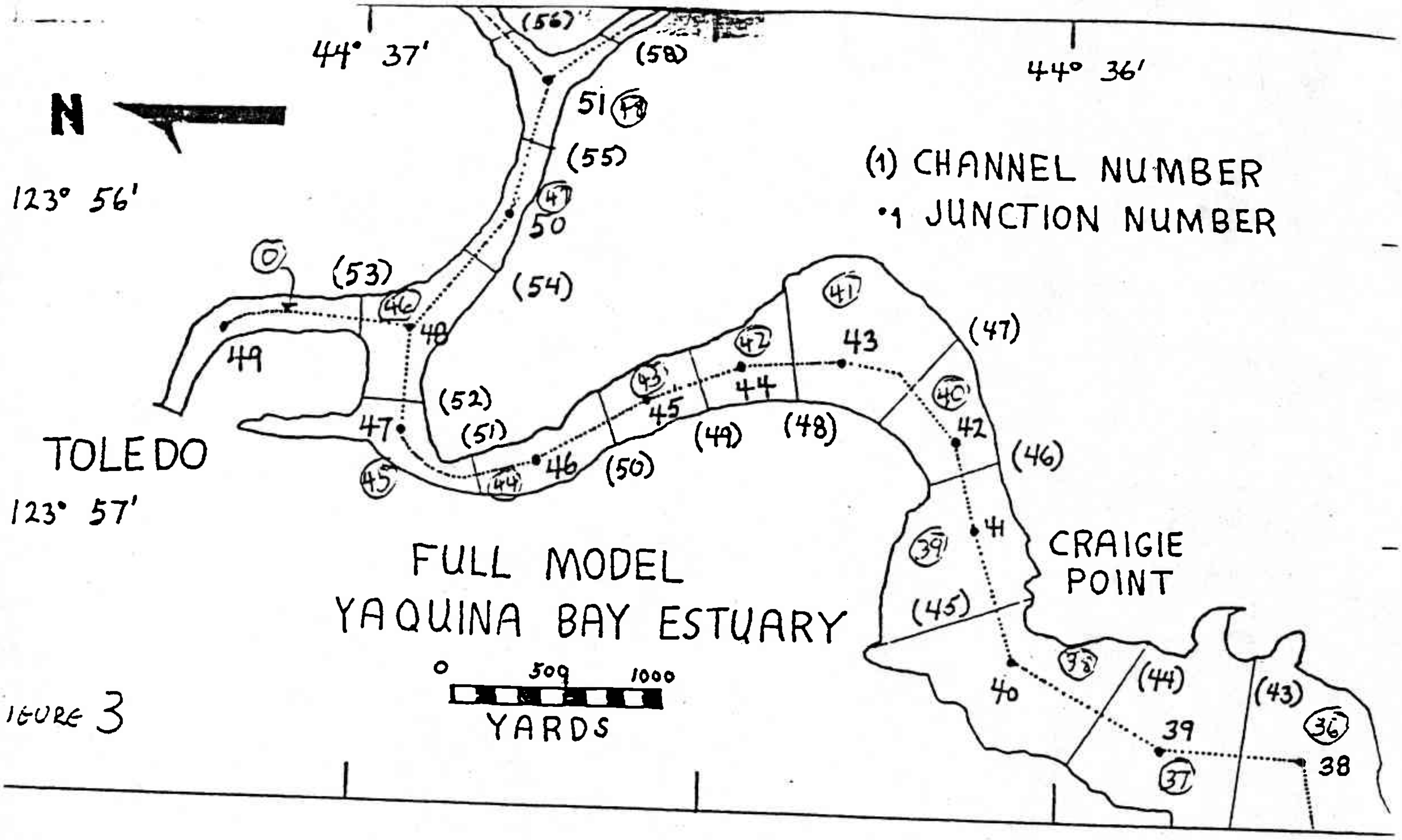
Table 2-10. 12/20/77 Temperature-Salinity data

APPENDIX 3

Schematization, Yaquina Estuary


124° 04' W
124° 03' W
NEWPORT
N
4°37' N
36' N
PACIFIC
OCEAN
FULL MODEL
YAQUINA BAY ESTUARY
0 500 1000
YARDS
(10) CHANNEL NUMBER
•10 JUNCTION NUMBER
(10) SEGMENT NUMBER
YAQUIN


124° 01'
123° 58'
YAQUINA
N
FULL MODEL
YAQUINA BAY ESTUARY
0 500 1000
YARDS
(1) CHANNEL NUMBER
•1 JUNCTION NUMBER
CRAIGIE
POINT
° 35'
° 34'



IGURE 3

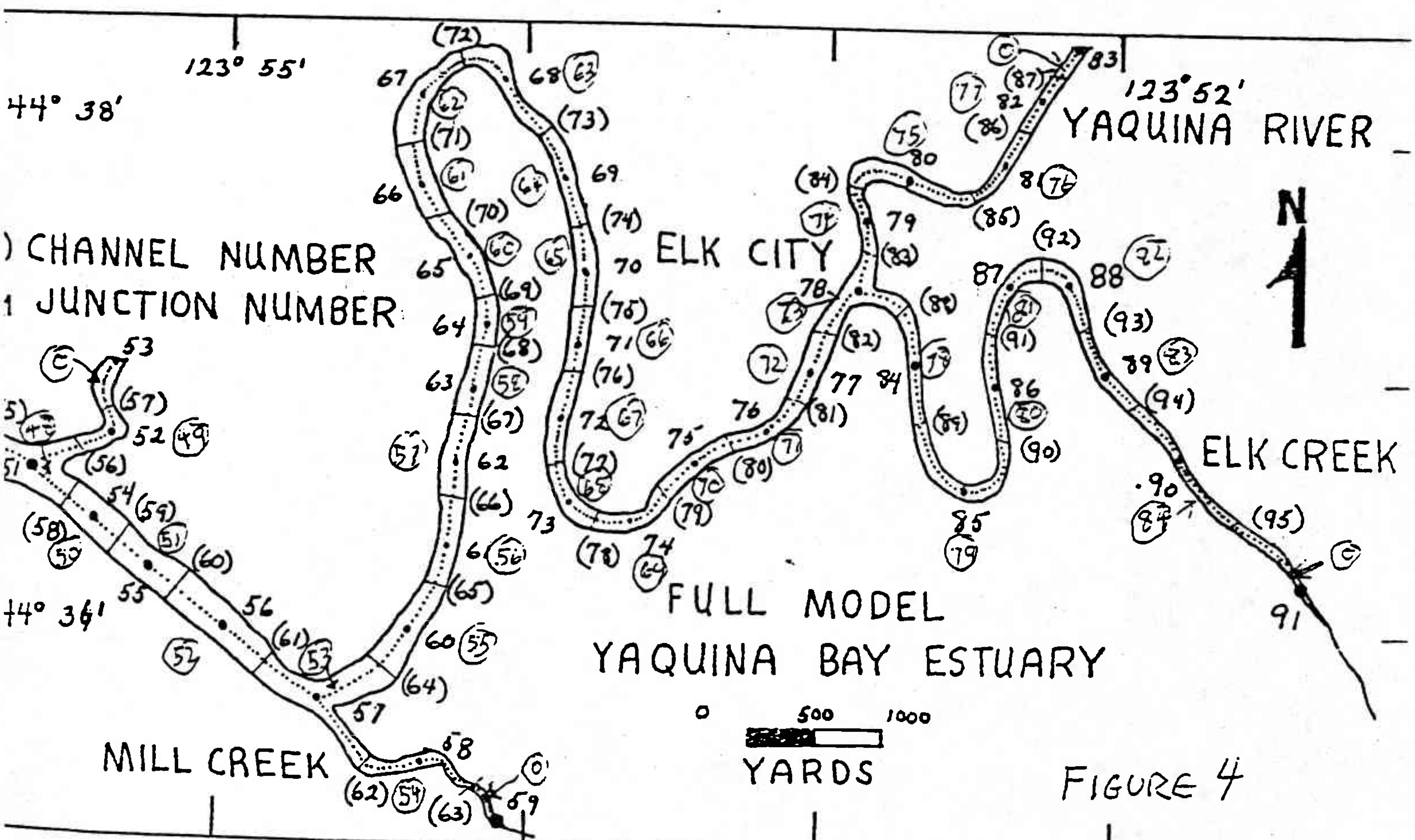


FIGURE 4

APPENDIX 4

WinDyn Output, Yaquina Estuary

APPENDIX 4. WINDYN OUTPUT

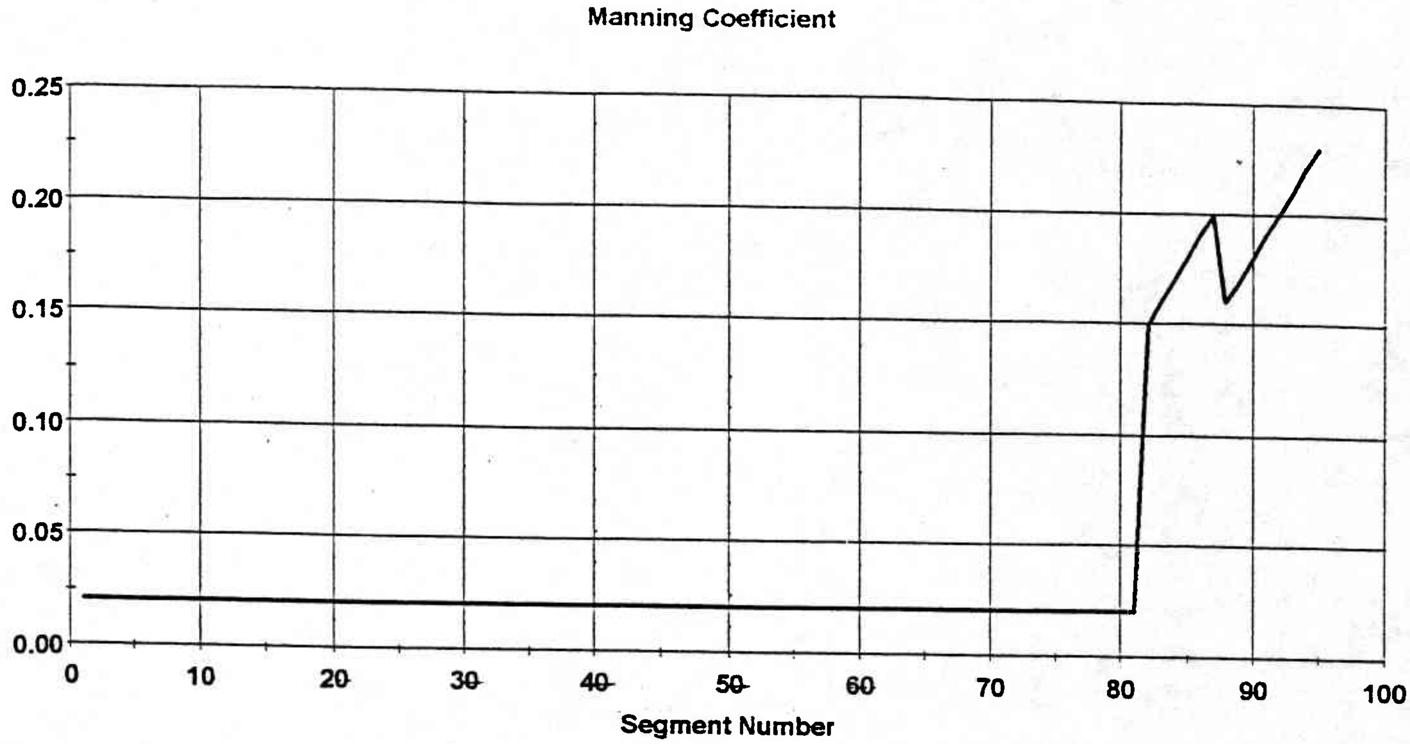


Figure 4-1, Manning Coefficient, sec/m$^{1/3}$.

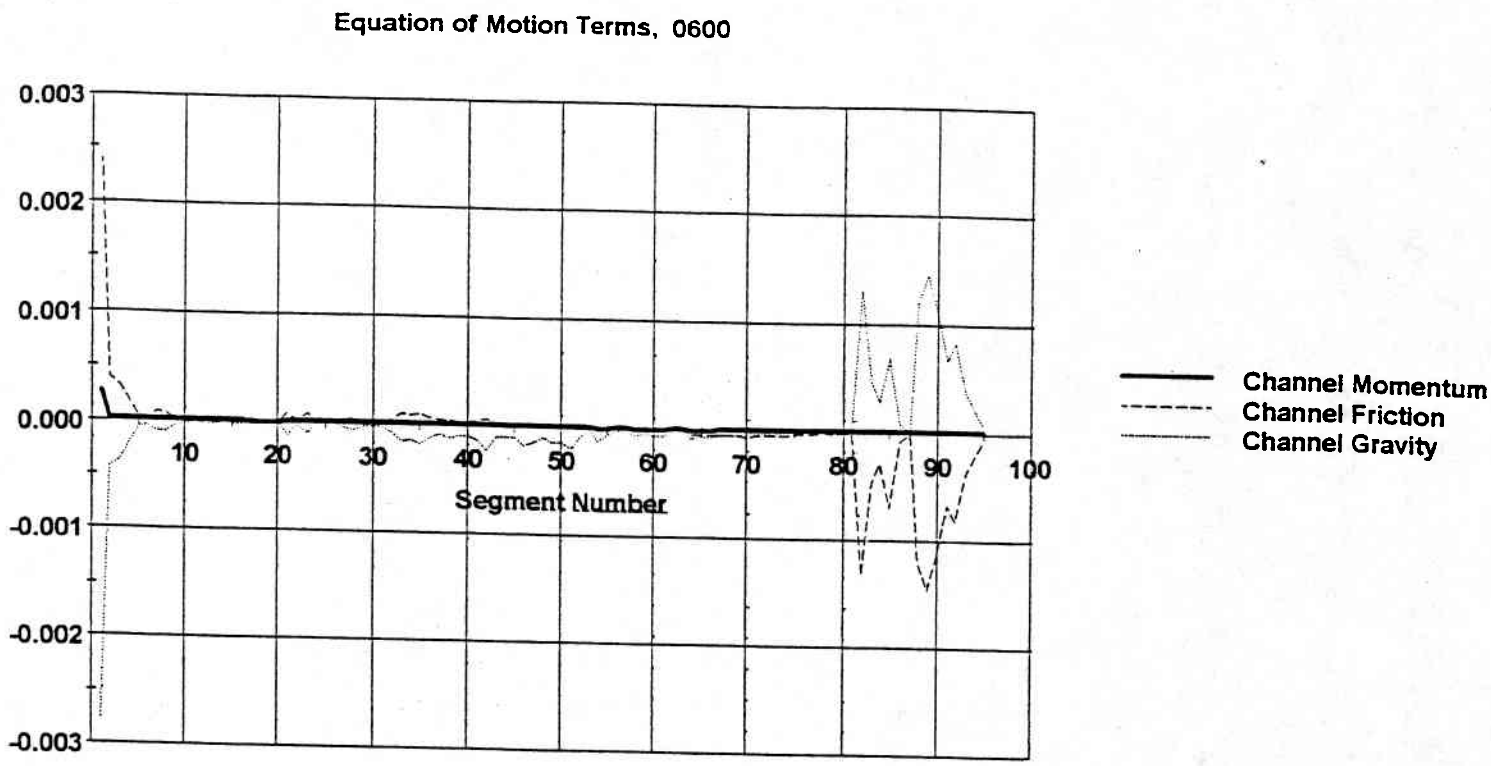


Figure 4-2. Equation of Motion terms at 0600, m/s^2.

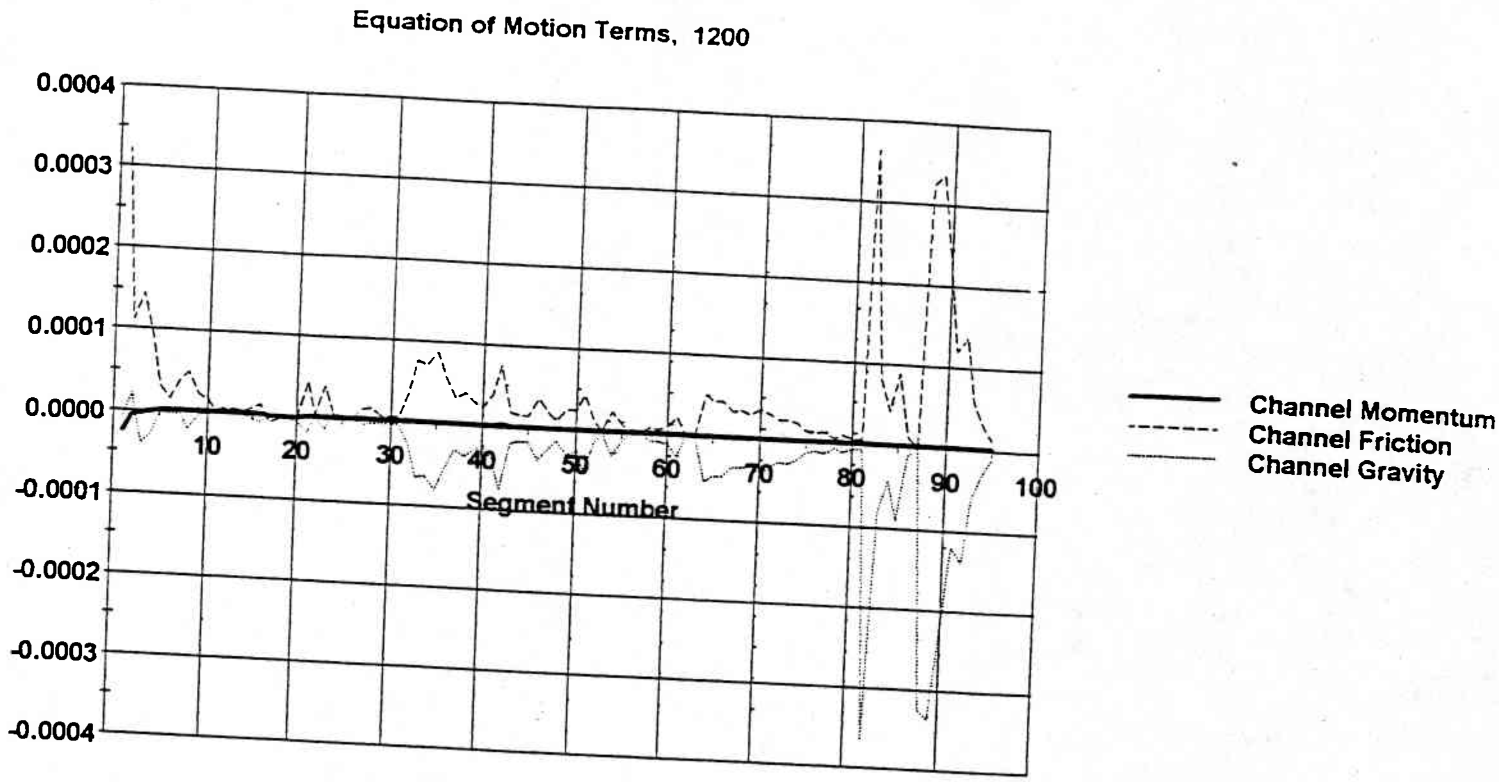


Figure 4-3. Equation of Motion terms at 1200, m/s^2.

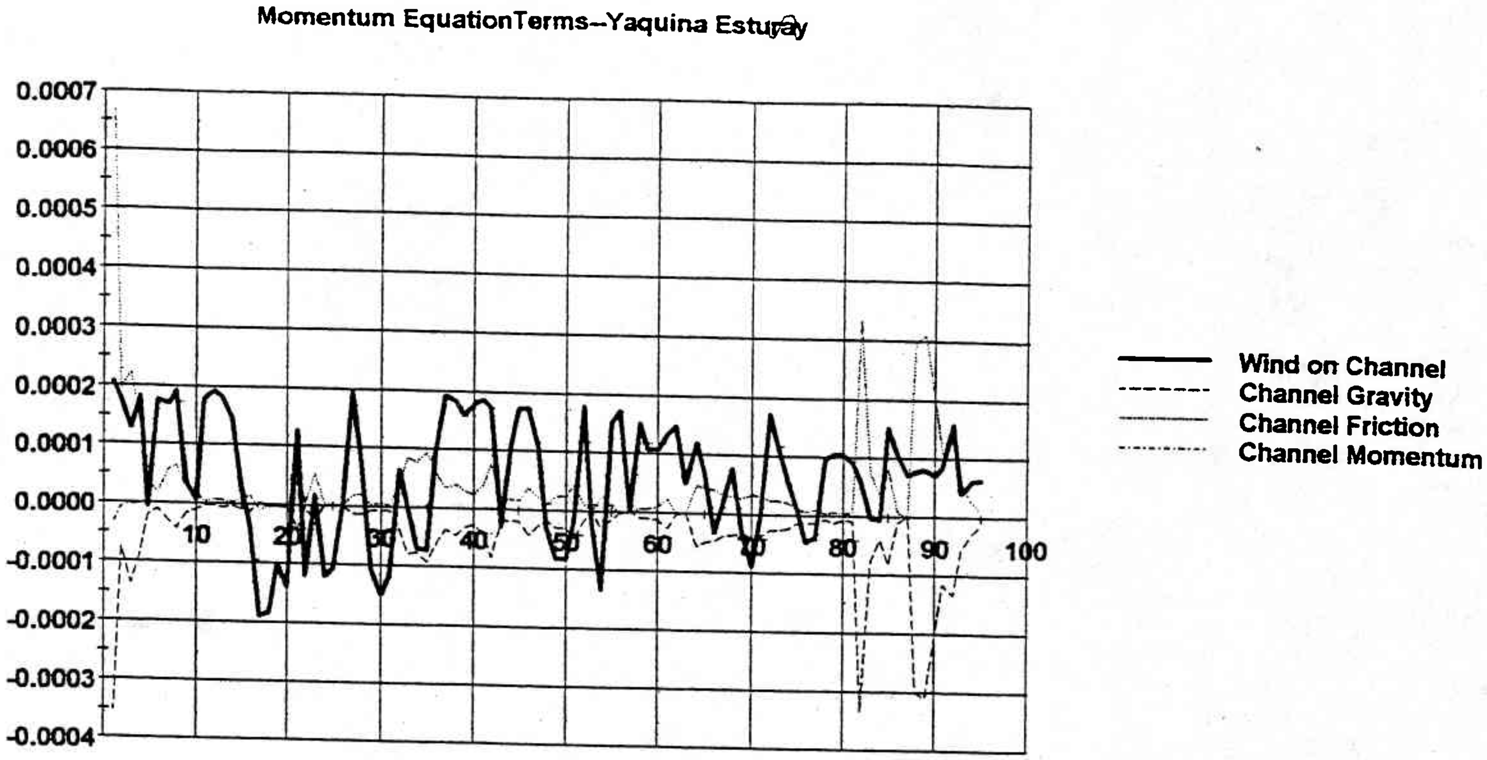


Figure 4-4. Equation of Motion terms with wind, m/s².

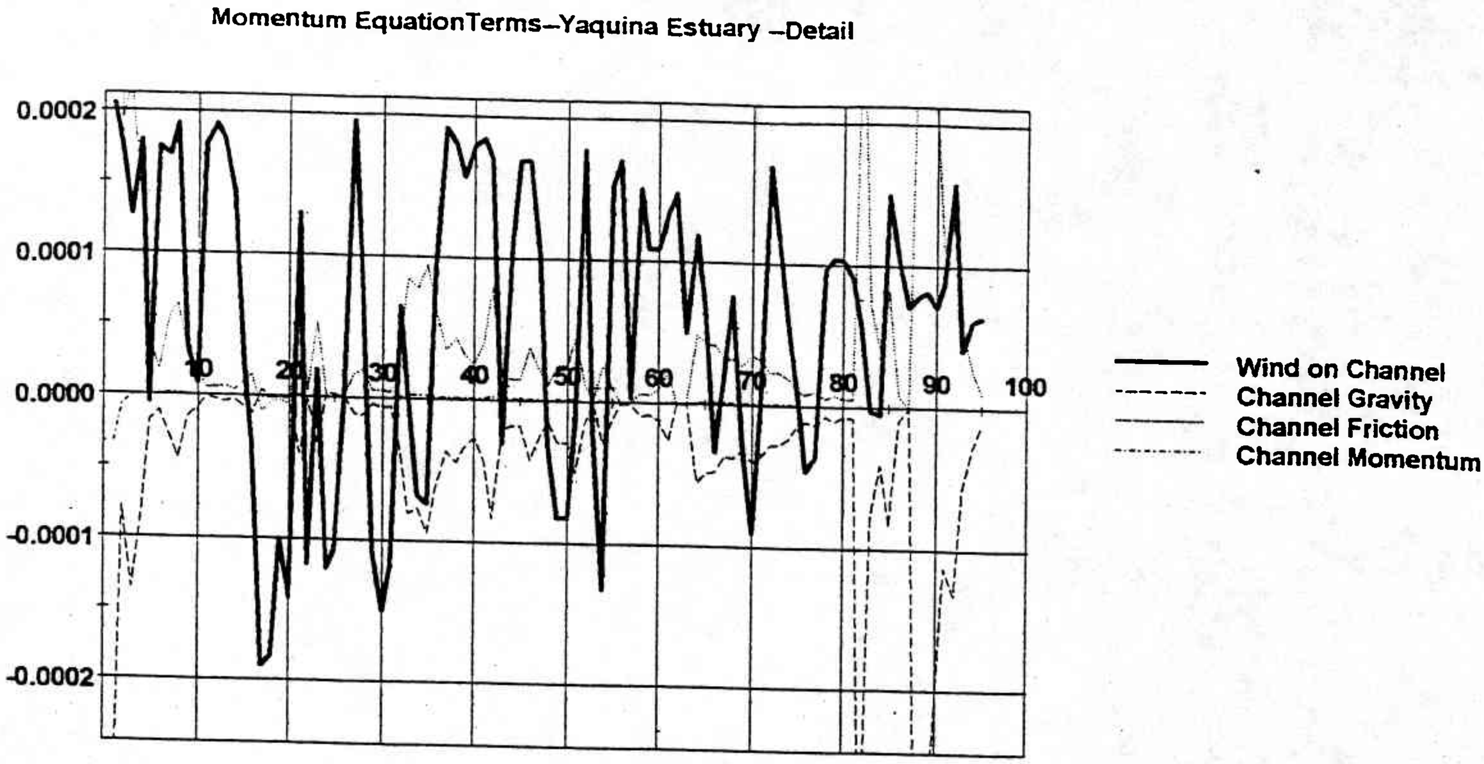


Figure 4-5. Equation of Motion terms with wind. Expanded, m/s^2.

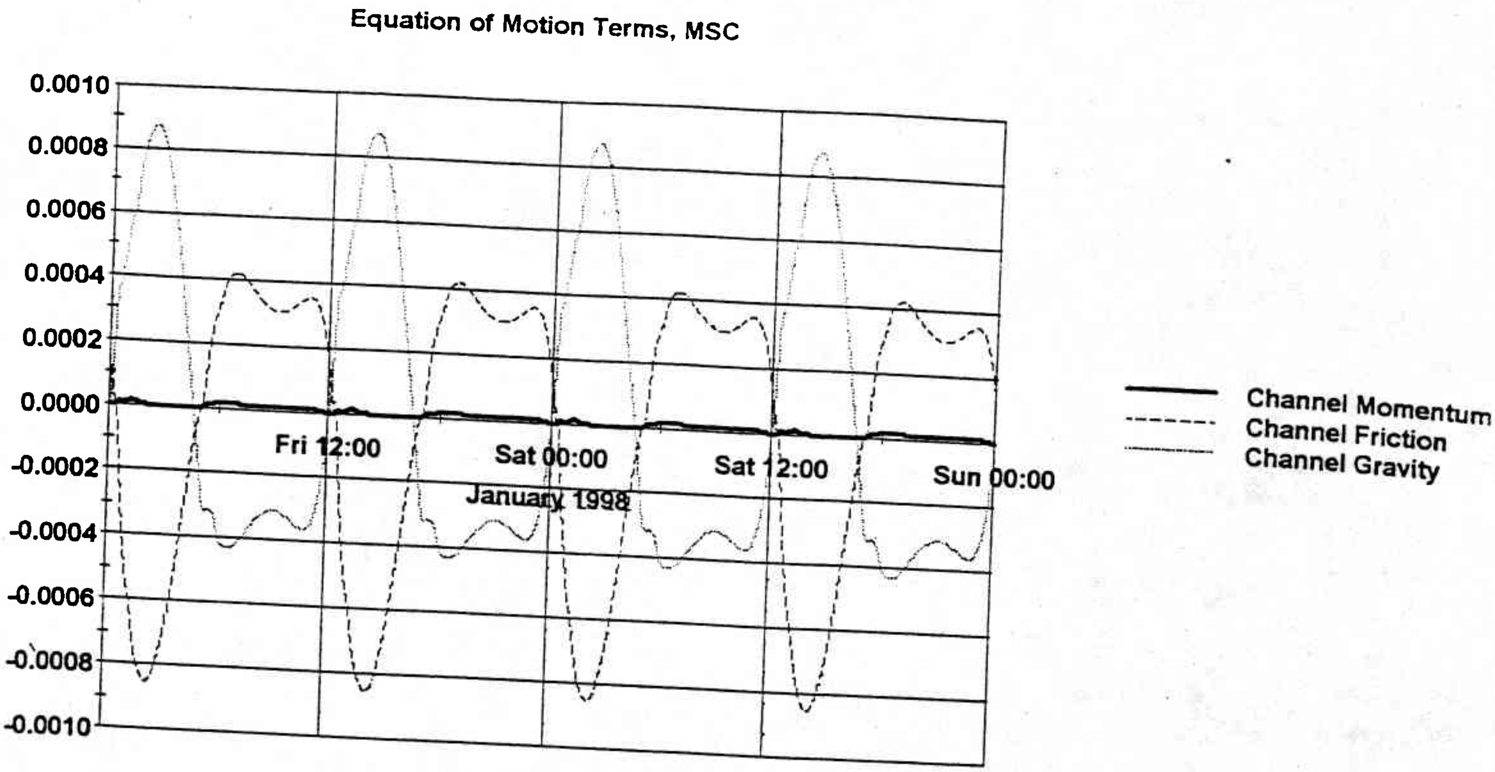


Figure 4-6. Equation of Motion Terms, m^2/s. MSC

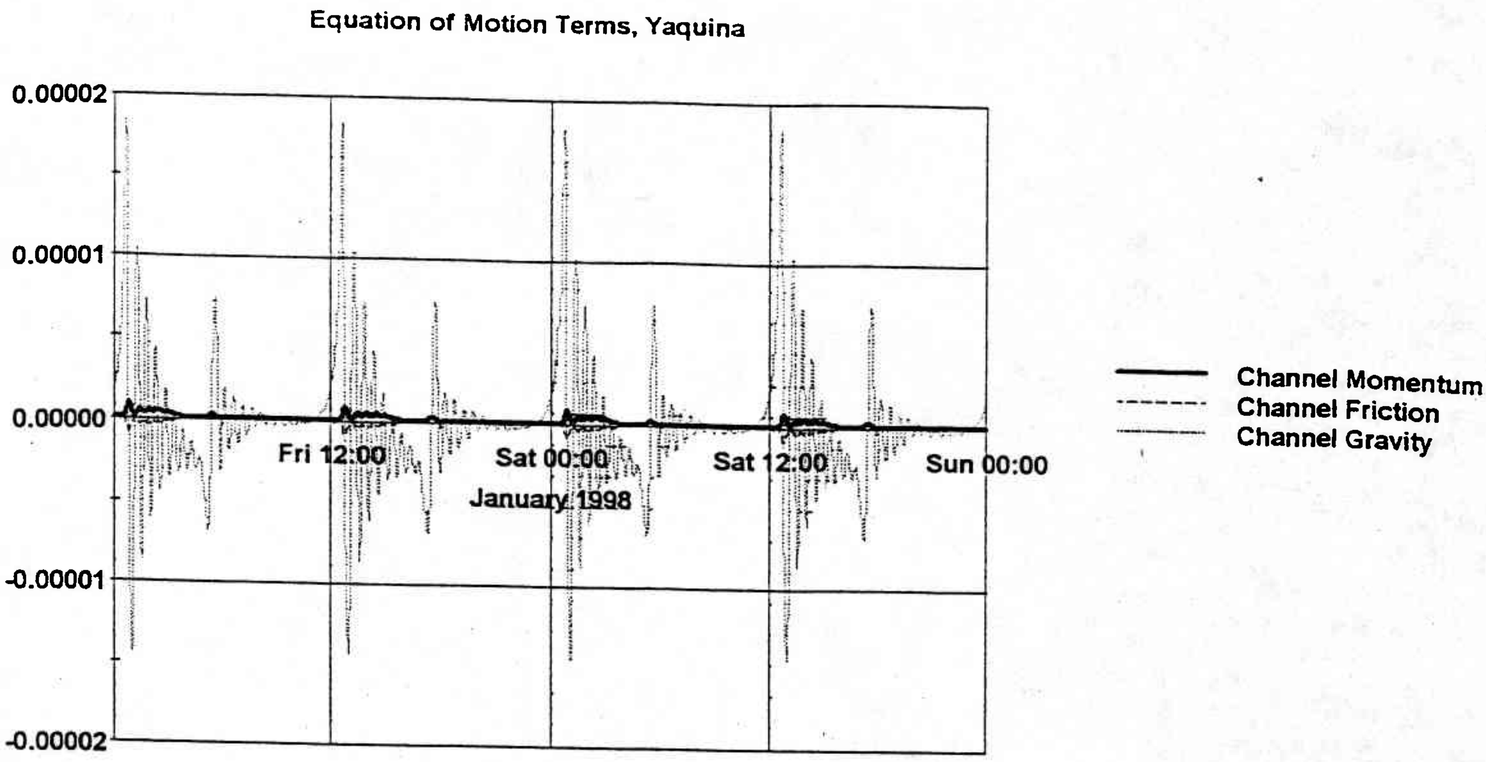


Figure 4-7. Equation of Motion Terms, m^2/s. Yaquina

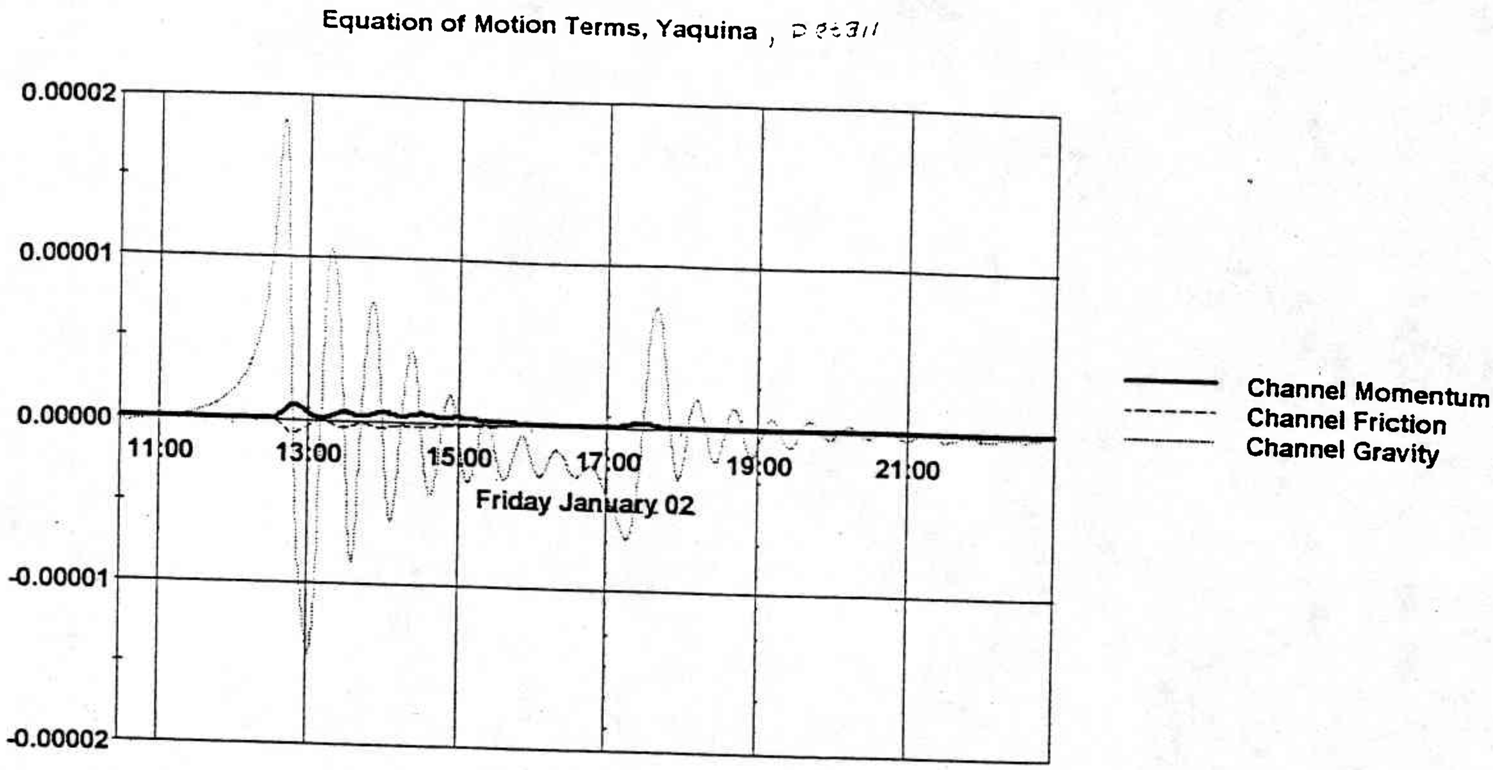


Figure 4-8. Equation of Motion Terms, m^2/s. Yaquina detail

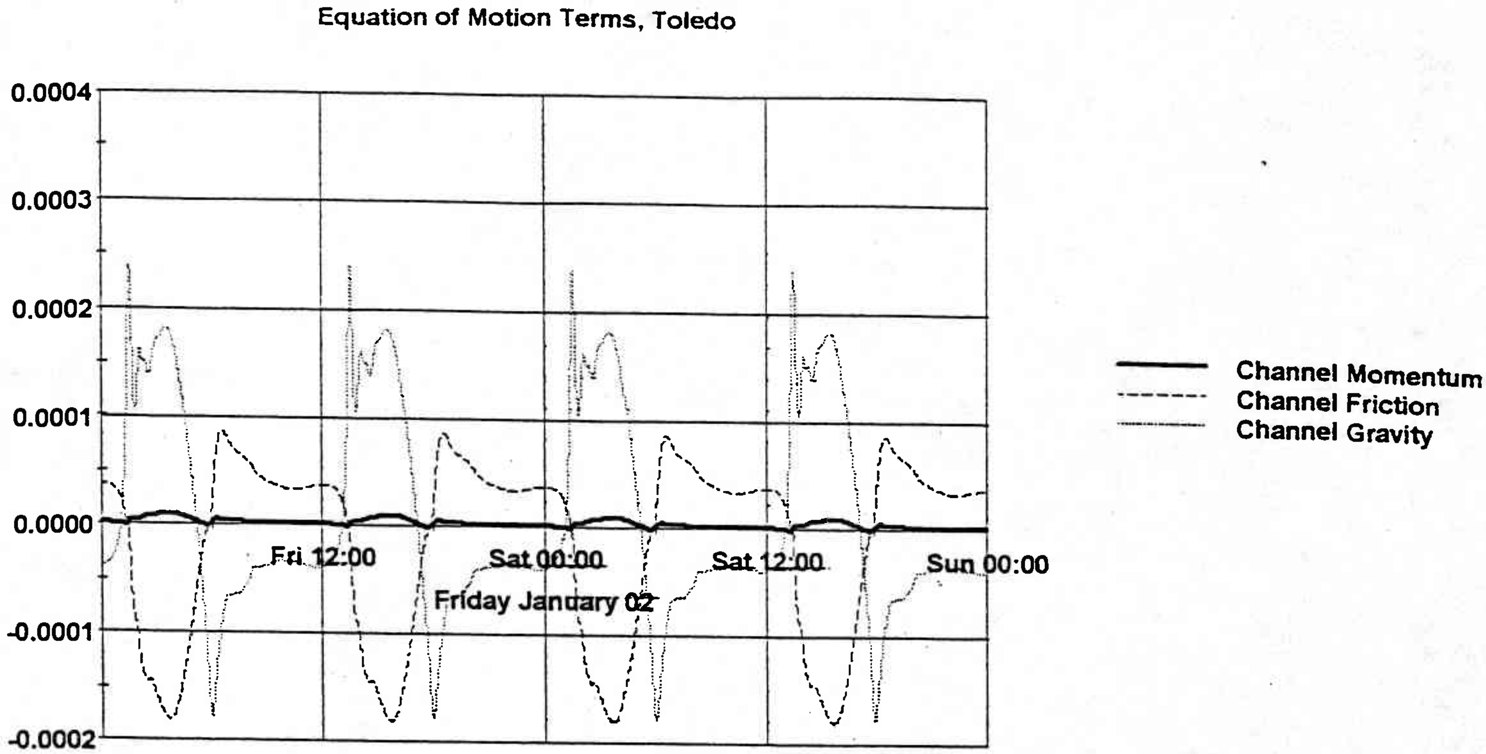


Figure 4-9. Equation of Motion Terms. m^2/s. Toledo

Equation of Motion Terms, Toledo , Detail

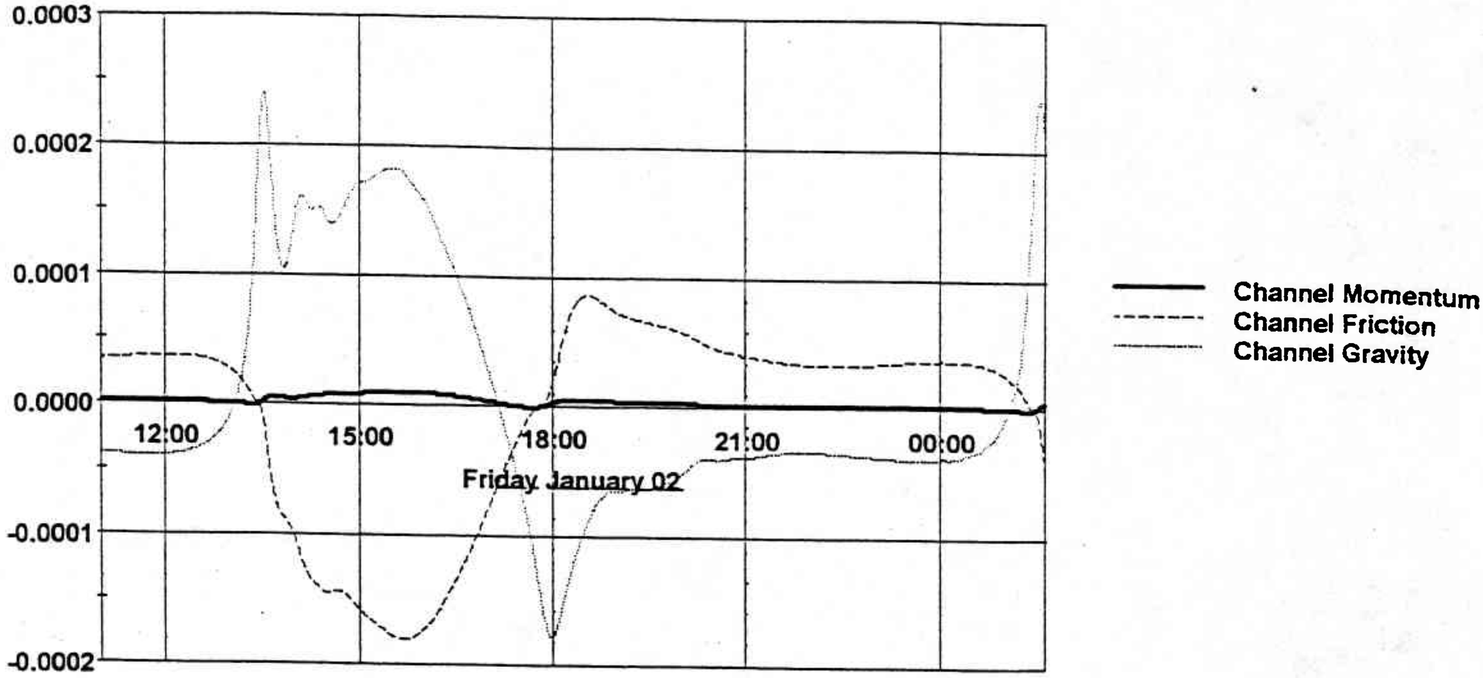


Figure 4-10. Equation of Motion Terms, m^2/s. Toledo detail.

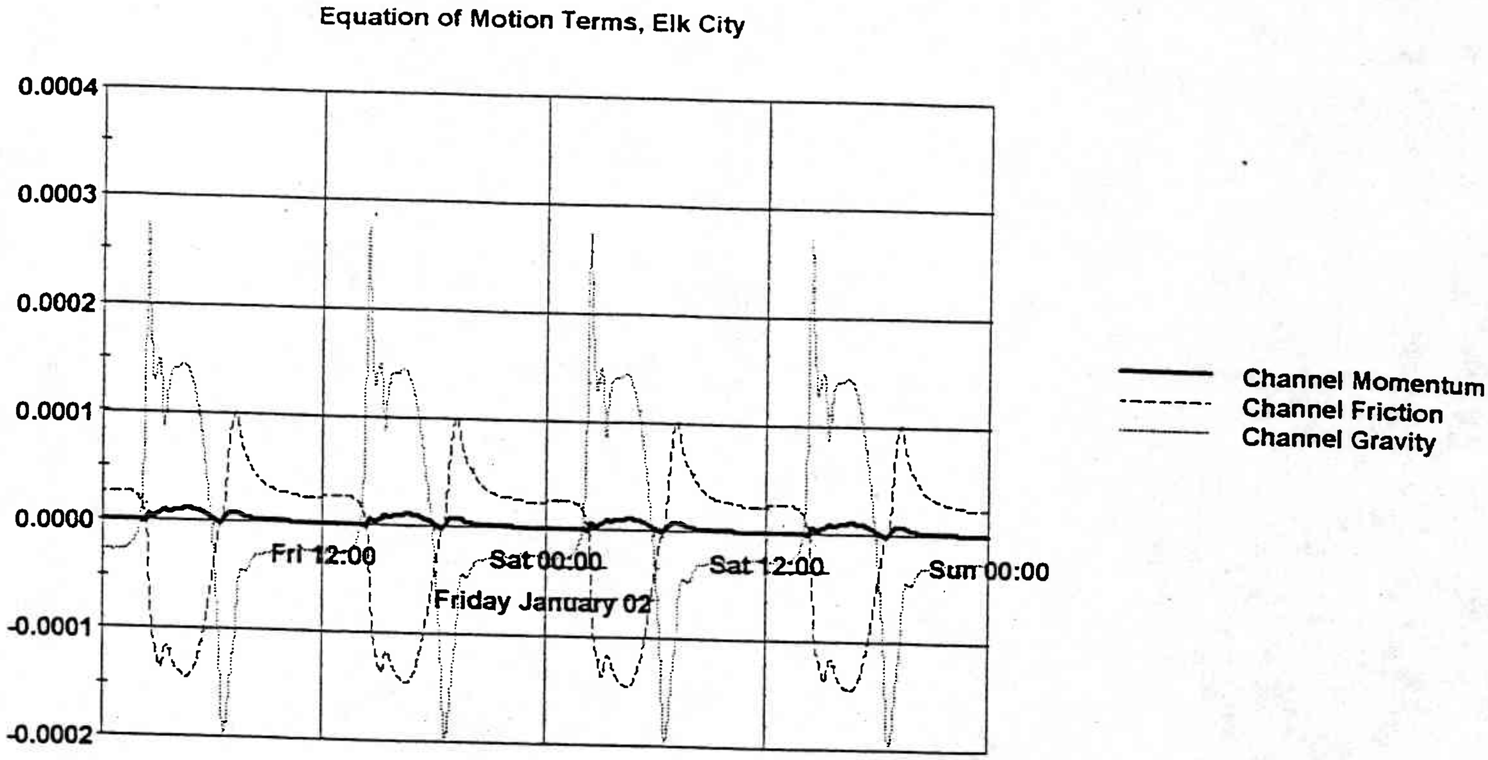


Figure 4-11. Equation of Motion Terms, m^2/s. Elk City

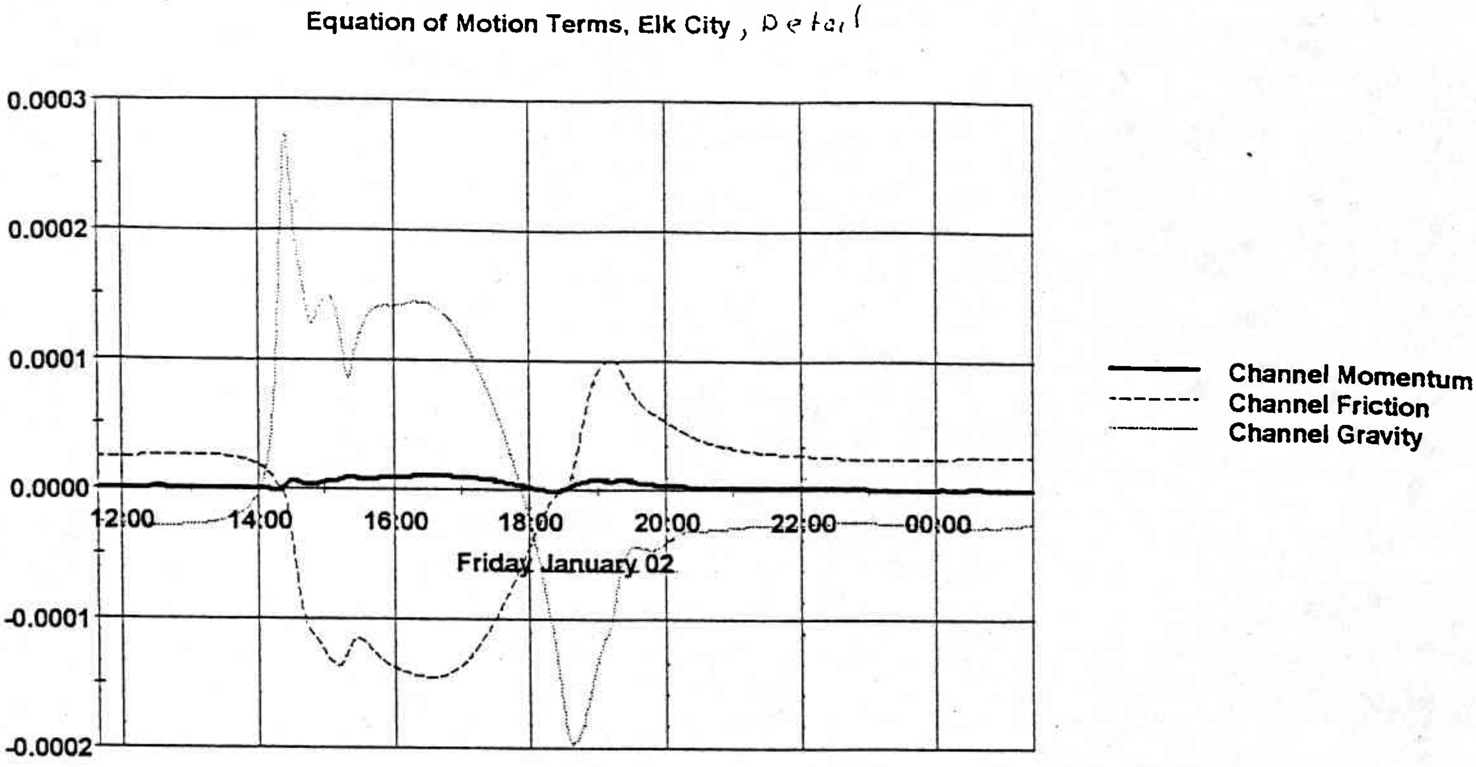


Figure 4-12. Equation of Motion Terms, m^2/s. Elk City detail

APPENDIX 5

WinWasp Output, Yaquina Estuary

APPENDIX 5. WINWASP OUTPUT.

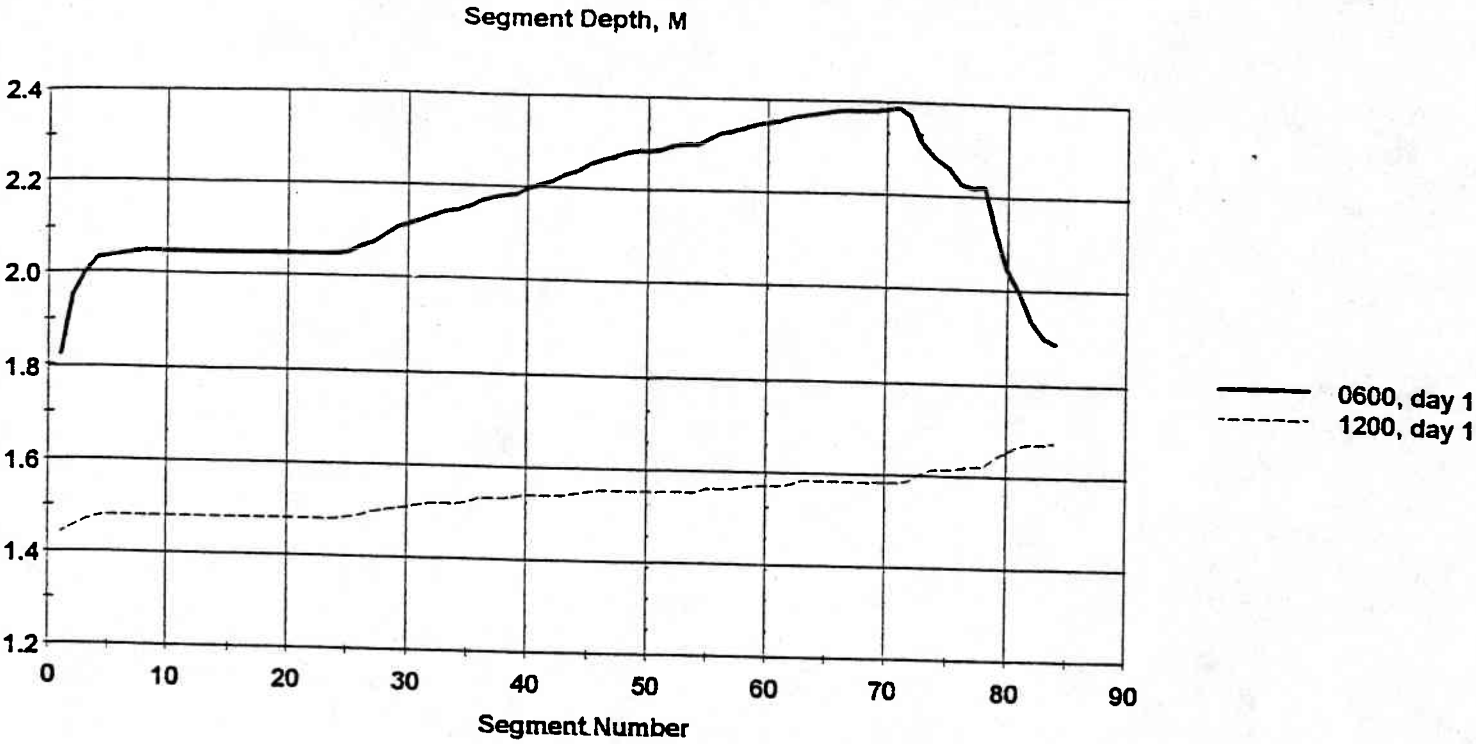


Figure 5-1. Segment Depth, m

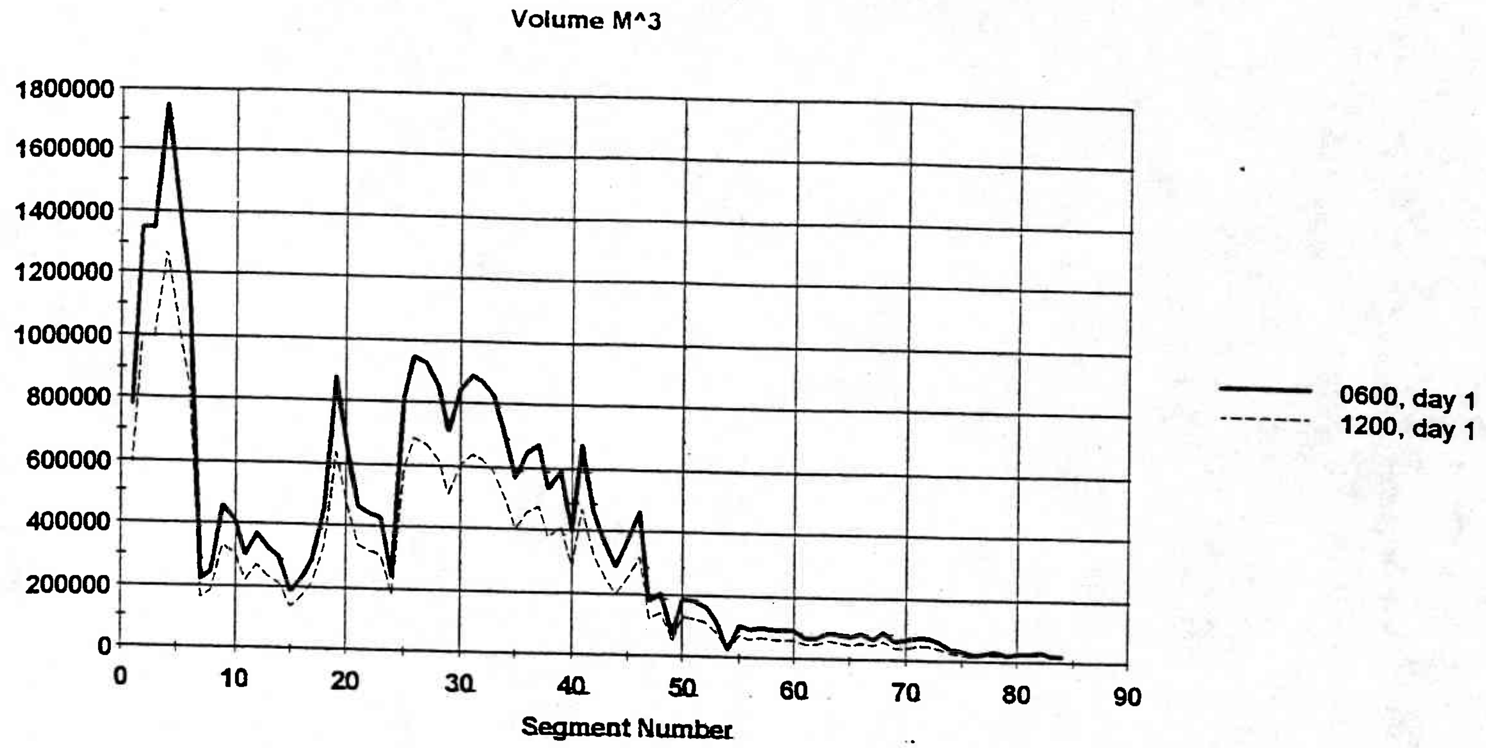
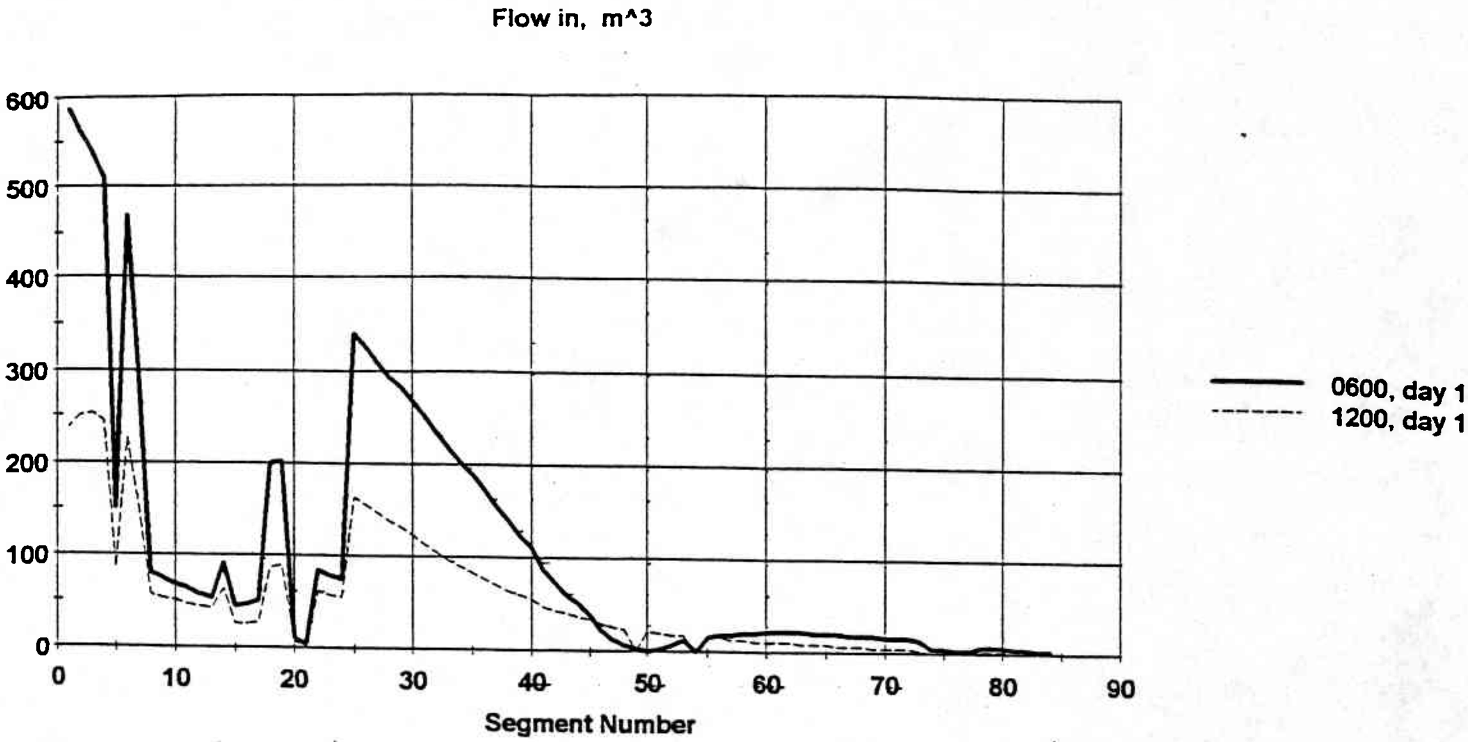
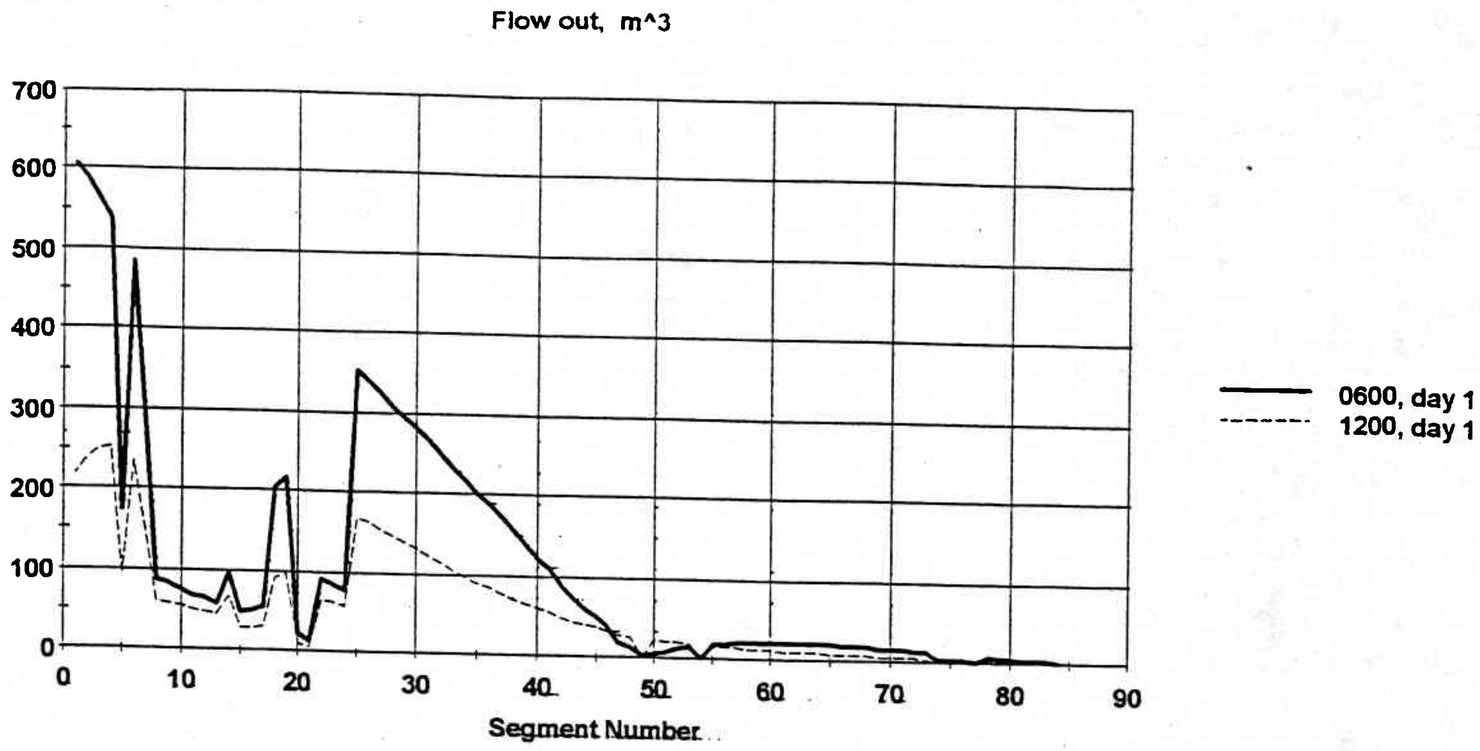


Figure 5-2. Volume, m^3.



Figures 5-3. Flow In, m^3.



Figures 5-4 Flow Out, m³.

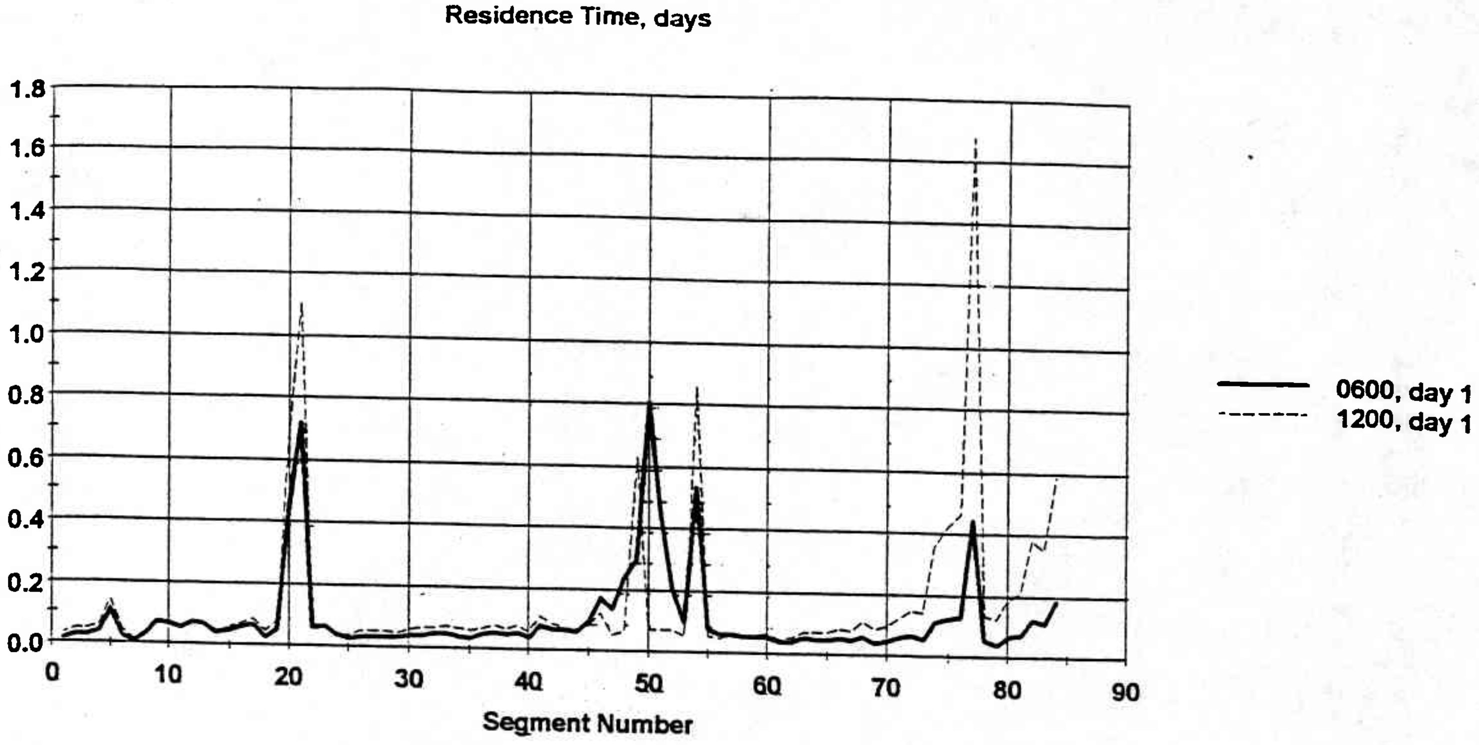


Figure 5-5. Residence Time, days.

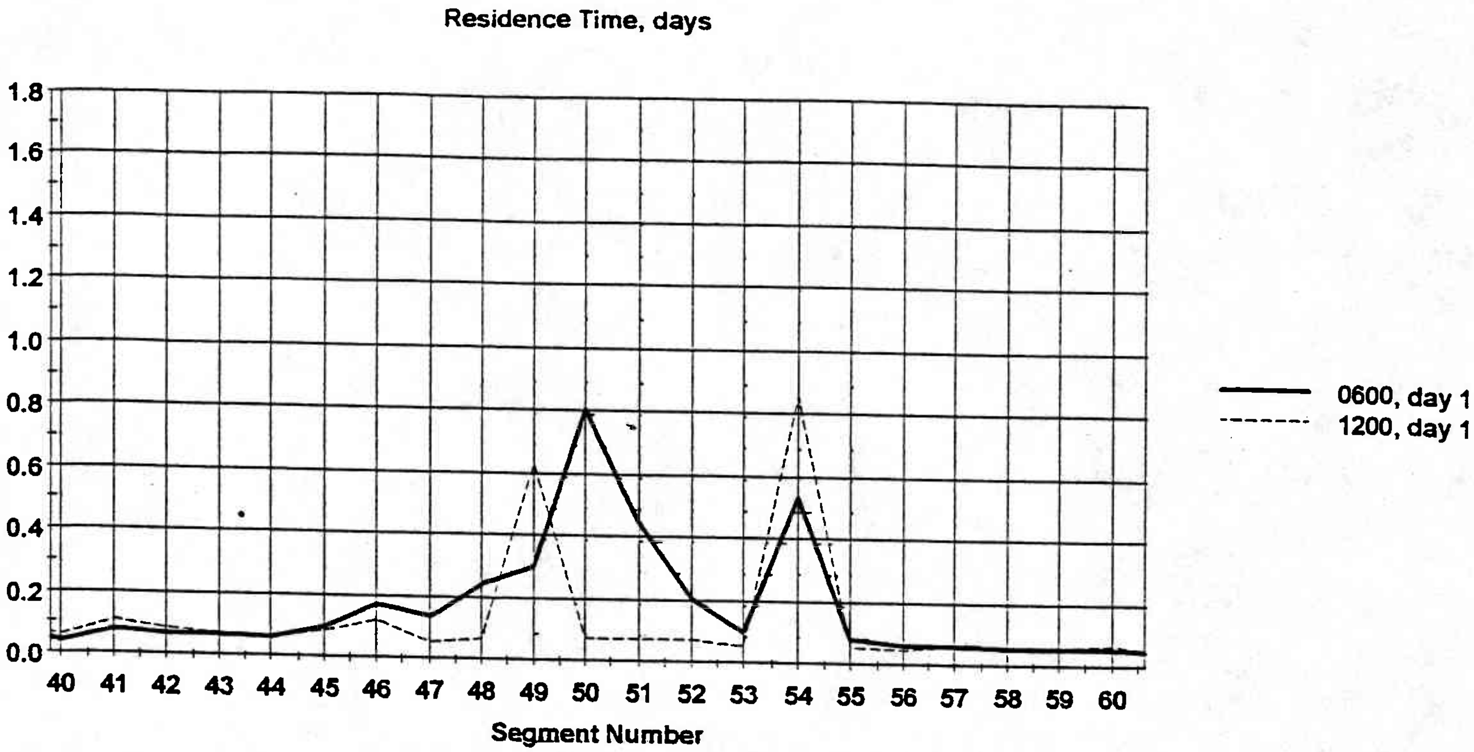


Figure 5-6. Residence Time, days. Detail

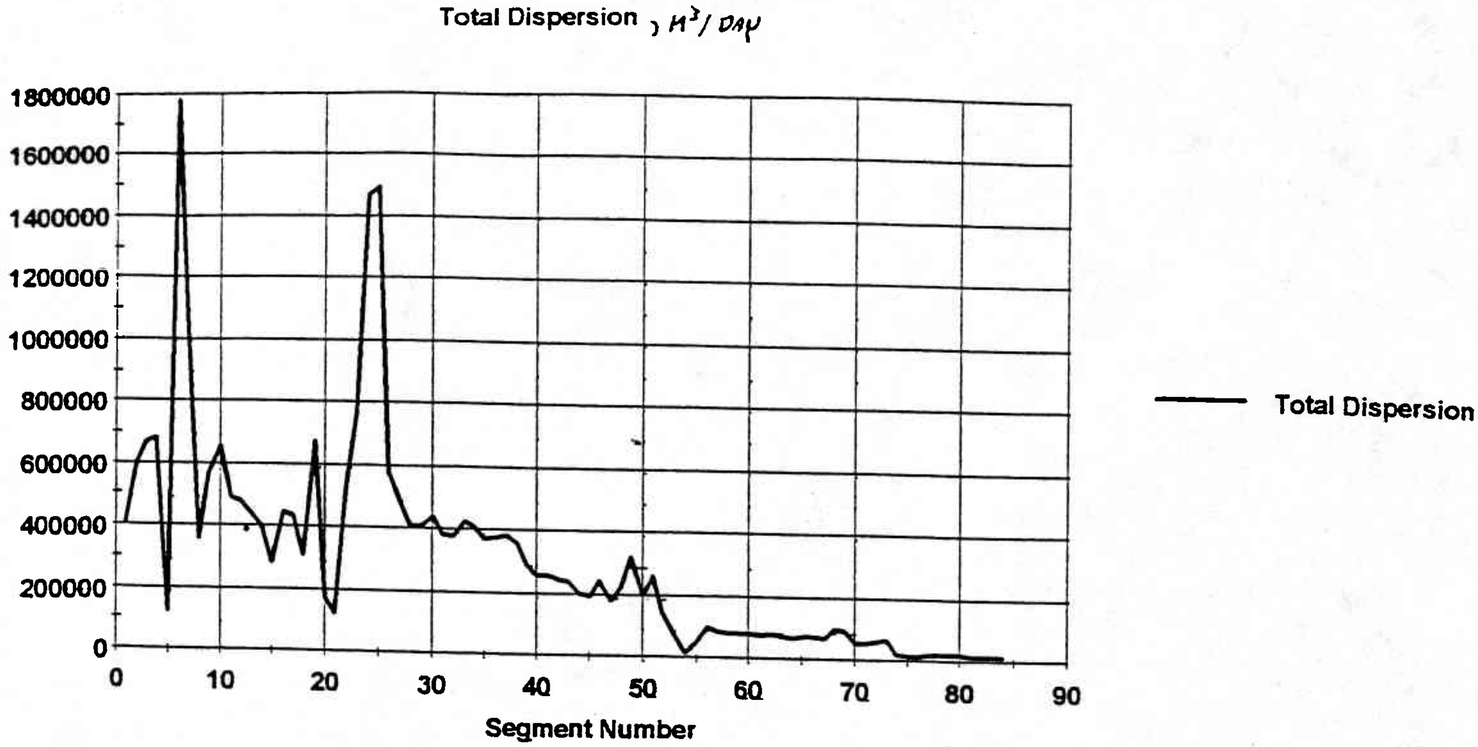


Figure 5-7. Total Dispersion, m^3/day.

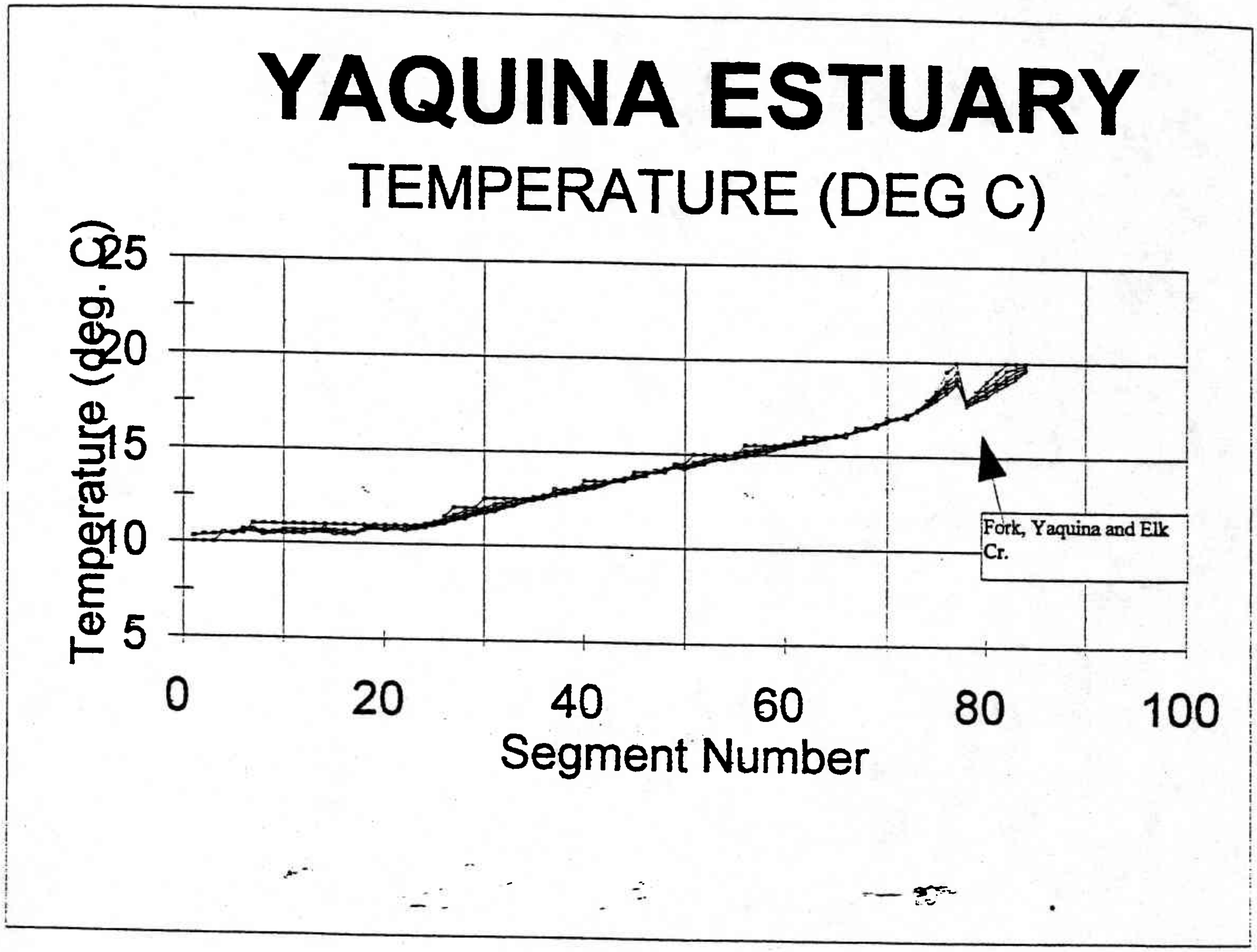


Figure 5-8. Segment Temperature (°C) Profiles vs Time

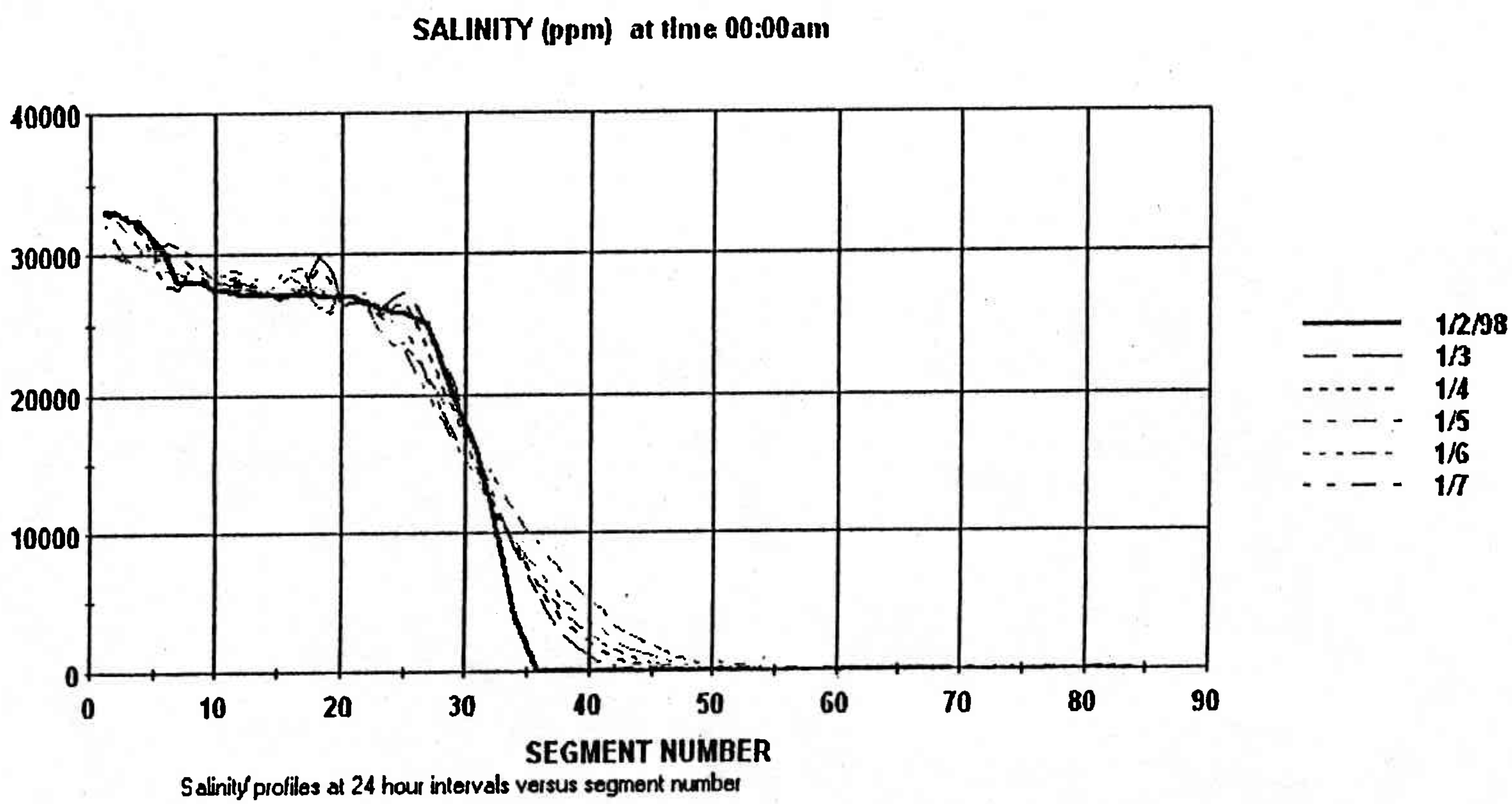


Figure 5-9. Segment Salinity (o/oo) Profiles vs Time.