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by

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ABSTRACT

The tritium distribution in the Savannah River estuary and adjacent marine waters was measured to provide information on the dilution, mixing, and movement of Savannah River water in this region. The Savannah River marine region was chosen because the average tritium concentration in this river is 5 pCi/ml, whereas other rivers in the southeastern United States average less than 0.5 pCi/ml. The increased tritium concentration in the Savannah River is due to releases from the Savannah River Plant of the Department of Energy. Tritium measurements have proved particularly effective in estimating the flushing time of the Savannah River estuary (2.4 days) and in delineating the relative contribution to the water masses in Ossabaw and Port Royal Sounds from the river and from sea water. Ossabaw and Port Royal Sounds are located approximately 20 km south and north of the Savannah River estuary, respectively.

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INTRODUCTION

The emphasis of many oceanographic studies has shifted to areas closer to the shore because of its importance for recreation, resource development, and marine life. An understanding of coastal currents is a first step toward evaluating the influence on biological, chemical and geological processes occurring in the near shore region. Elevated tritium concentrations in the Savannah River provide a unique opportunity to determine the movement of Savannah River water in the estuary and contiguous marine waters (Fig. 1). Tritium in the Savannah River is due to fallout from nuclear weapons tests, natural production by cosmic rays, and releases from the Savannah River Plant (SRP), a Department of Energy facility operated by the E. I. du Pont de Nemours and Company.

SRP has three production nuclear reactors, two nuclear fuel separations plants, a heavy water plant, and a fuel fabrication facility. Most of the tritium released from SRP comes from: 1) the neutron activation of the heavy water moderator, deuterium oxide, used not only to moderate the neutrons in the reactor, but also to remove the heat produced by the nuclear reactions occurring within the reactor; 2) the irradiation of lithium in the reactors to produce tritium; and 3) the tritium resulting from uranium fission[1]. Tritium is released to surface streams from the reactor area fuel and target storage basins and indirectly by discharge from the separations area to seepage basins.

This would result in an annual dose commitment of 0.5 mrem, if 1.2 l of the water is consumed daily. This is ∿0.5% of the natural radiation dose.

Although the tritium content has been used to determine the travel time and dispersion coefficients for the Savannah River[3], it has not been used to study the movement of Savannah River water in the marine region. The purpose of this paper is to report the results of studies 1) tritium-salinity relationships in the Savannah River estuary, 2) the flushing of the estuary, and 3) the dilution and movement of tritium in the estuary and inland marine waters.

ANALYTICAL METHODS

Samples were distilled prior to analysis to avoid counting and/or enrichment problems. Tritium concentrations greater than 1 pCi/mL were determined by liquid scintillation counting. When samples were less than 1 pCi/ml, gas proportional counting and/or enrichment schemes were used. The two enrichment methods were gas chromatography[4] and electrolysis[5,6]. Analytical measurement errors for all samples averaged ±15%.

SAVANNAH RIVER ESTUARY

The Savannah River estuary has a main (north) and a secondary channel (Fig. 2). The main channel is a harbor of nearly constant cross-sectional shape and is an example of a moderately stratified estuary. The main channel is maintained by dredging to a minimum width of ∿120 meters at a mean low water, a length of ∿35 km, and a depth of ∿11 meters[7]. The South Channel is relatively shallow, 2.5 meters, is 16 km long, and is of minor importance in the transport of tritium. Studies conducted in the estuary determined the tritium-salinity relationship for dilution studies and estimated an approximate flushing time for the estuary. The flushing time of an estuary is a crude estimate of how long a conservative pollutant will remain in an estuary.

To determine the tritium-salinity relationship, tritium concentrations and the salinity of surface water samples were measured at several locations in the Savannah River estuary (Fig. 2). The samples were collected during a period of relatively constant tritium concentrations in the Savannah River. The tritium concentration (Fig. 3) decreased toward the mouth of the estuary, because the tritium content of Gulf Stream sea water (∿0.05 pCi/ml) is less than that of Savannah River water. The observed linear relationship is analogous to the temperature-salinity analysis of water masses[8]. The linear plot obtained from the data indicates that only two water types are present in the estuary: Savannah River and South Atlantic Bight water. If the tritium-salinity curve is extrapolated to 0 salinity, the intercept is 4.4 pCi/ml, which compares to the 4.4 pCi/ml measured at the fresh water station.

The flushing time for the Savannah River estuary was calculated from tritium and hydraulic data by three different methods: 1) the tidal prism method; 2) the fraction freshwater method; and 3) tritium data using the fraction freshwater method. These methods usually underestimate the flushing times and also assume that the estuary is not stratified[9].

1. Tidal Prism Method

The tidal prism method assumes that the water entering on flood tide is fully mixed with that in the estuary, and that the volumes of sea water and river water added together equal the volume of the tidal prism. The tidal prism is that volume of water between the high- and low-water marks. On the ebb tide, the same volume of water is removed, and the fresh water content must equal the increment of river flow. The water volume estimates were obtained from the Savannah Harbor Investigation and Model Study.

For the Savannah River estuary:

$$T \text{ (flushing time)} = \frac{\text{Volume at low water + tidal prism}}{\text{tidal prism}}$$

$$= \frac{5.39 \times 10^7 \text{ m}^3 + 1.29 \times 10^7 \text{ m}^3}{1.29 \times 10^7 \text{ m}^3}$$

$$= 4.2 \text{ tidal cycles or } \sim 2.1 \text{ days} \qquad (1)$$

2. Fraction Fresh Water

The fraction freshwater method uses the residence time formula[10]:

$$T \text{ (flushing time)} = \frac{\text{Total amount of freshwater in estuary}}{\text{River flow rate}}$$

The total amount of fresh water in the Savannah River estuary was calculated from estuary water volume and fraction freshwater present at both high and low water using data from the Savannah Harbor Investigation and Model Study[7]. These data represent an average for all hydraulic conditions of the Savannah River estuary.

Low Water:

$$T = \frac{5.39 \times 10^7 \text{ m}^3 \times 0.73}{1.98 \times 10^3 \text{ m}^3/\text{sec} \times 86,400 \text{ sec/day}}$$

$$= 2.3 \text{ days}$$

High Water:

$$T = \frac{6.68 \times 10^7 \times 0.26}{1.98 \times 10^2 \text{ m}^3/\text{sec} \times 86,400 \text{ sec/day}}$$

Average flushing time = 1.7 days.

3. Tritium Method

Samples were collected in the Savannah River estuary following a tritium release from the SRP. The results shown in Figure 4 were used to estimate a flushing time. The tritium analog of the fraction freshwater calculation was used, but only surface concentrations were taken. The average tritium content in the estuary was calculated to be 727 Ci. The input rate, 2166 Ci/week, was calculated by averaging the tritium input at a monitoring location below the plant for three weeks in May. Tritium flushing time was calculated to be:

$$T = \frac{727 \text{ Ci}}{2166 \text{ Ci/week}} \times \frac{7 \text{ days}}{\text{week}}$$

$$= 2.4 \text{ days}$$

These three flushing times are in good agreement, but represent the minimum time a conservative pollutant would reside in the Savannah River estuary.

SAVANNAH RIVER WATER IN THE INLAND MARINE WATERS

Water movement is governed by wind, tidal action, interconnecting creeks, coastal currents, and freshwater flow. With the aid of the U. S. Coast Guard, samples of surface water were collected from the inland marine area (Fig. 5). In general, lower salinities were found south of the Savannah River as a result of a general southward current, which is substantiated by the higher tritium concentrations.

To evaluate the mixing of water in this area, salinity versus tritium plots for the Coosawhatchie and Ogeechee River water were added to Figure 3 to yield Figure 6. The source of the sea water is considered to be the Gulf Stream with a 0.05 pCi/ml tritium concentration and 36.1 ppt salinity. Points that lie on or within ∿15% of the lines are considered to be a dilution of that river source with sea water; points between the two lines represent water mixes from the Savannah River, nearby rivers, and sea water. Since the Ogeechee and Coosawhatchie Rivers are nearly identical in tritium concentration, they are lumped as one freshwater source for this analysis. A method for estimating the relative fresh seawater contributions from the different sources is as follows:

$$T = \frac{(T1 \cdot M1) + (T2 \cdot M2) + (TS \cdot MS)}{M1 + M2 + MS} \qquad (3)$$

where tritium concentration (T) at a location fed by three sources is the sum of the products of tritium measured at the Savannah River (T1), a nearby river (T2), and sea water (TS), and the respective contributing water volumes M1, M2, and MS. The salinity at the same location is

$$S + \frac{(S1 \cdot M1) + (S2 \cdot M2) + (SS \cdot MS)}{M1 + M2 + MS} \qquad (4)$$

where S1, S2, and SS are the salinities for each source of water. The water volumes can be normalized:

$$1 = \frac{M1}{M} + \frac{M2}{M} + \frac{MS}{M} \qquad (5)$$

where M is the total water volume and the following assumptions are made:

(1) The salinities of the rivers are essentially 0 when compared to the Gulf Stream (0.02 ppt compared to 36.2%)

(2) The tritium content of the Gulf Stream is negligible when compared to the rivers (0.05pCi/ml to ∿1pCi/ml).

Substituting and simplifying:

$$\frac{MS}{M} = \frac{SS}{36.2} \quad \text{(sea water relative volume)} \qquad (6)$$

$$\frac{M2}{M} = \frac{(T1 \cdot SS) - (T \cdot SS) - (S \cdot T1)}{SS(T1-T2)} \quad \text{(one river's relative volume)} \qquad (7)$$

$$\frac{M1}{M} = 1 - \frac{M2}{M} - \frac{MS}{M} \quad \text{(other river's relative volume)} \qquad (8)$$

The relative riverwater and seawater volume contributions for samples AS, BS, AN and BN (Fig. 6) were calculated by using equations 6, 7, and 8 (Table I). The samples from the Port Royal Sound region (AN, BN) had almost equal mixtures of Savannah and Coosawhatchie River water, whereas one Ossabaw Sound sample (AS) showed an abundance of Ogeechee River water. A second Ossabaw Sound region sample (BS) contained more Savannah River water than Ogeechee River water. Based on these results, the transport route of Savannah River water is extremely complex and not easily delineated, but in the upper inland marine waters, interconnecting waterways may be important.

CONCLUSION

The relatively high concentration of tritium in the Savannah River provides a useful tool to study mixing processes in this coastal environment. In the Savannah River estuary, the tritium concentration decreased from the upper to the lower estuary due to its dilution with sea water. The tritium dilution in the estuary was inversely proportional to the salinity and could be used as an indication of the amount of tritium dilution that can be expected for steady river tritium concentrations. The estuarine flushing time for tritium was estimated to be about 2.4 days, which compared favorably with tidal prism (2.0 days) and fraction freshwater (1.6 days) estimate methods. The inland marine water dilution of tritium could be described by a three source box model to show the relative water contributions from the Savannah River, nearby rivers, and sea water.

TABLE I. Relative contribution of Savannah River, Gulf Stream, and local freshwater sources to the water in Ossabaw and Port Royal Sounds

		Salinity (ppt)	Tritium (pCi/ml)	Relative Volume (%)	
				AN	BN
Port Royal Sound					
Sample AN		25.8	0.8		
Sample BN		27.9	0.6		
Source Water:	Gulf Stream	36.2	0	71	77
	Savannah River	0	4.4	14	11
	Coosawhatchie R.	0	1.0	15	12
				AS	BS
Ossabaw Sound					
Sample AS		10.5	1.0		
Sample BS		23.4	1.2		
Source Water:	Gulf Stream	36.2	0	29	64
	Savannah River	0	4.4	14	26
	Little Ogeechee River	0	0.7	57	10

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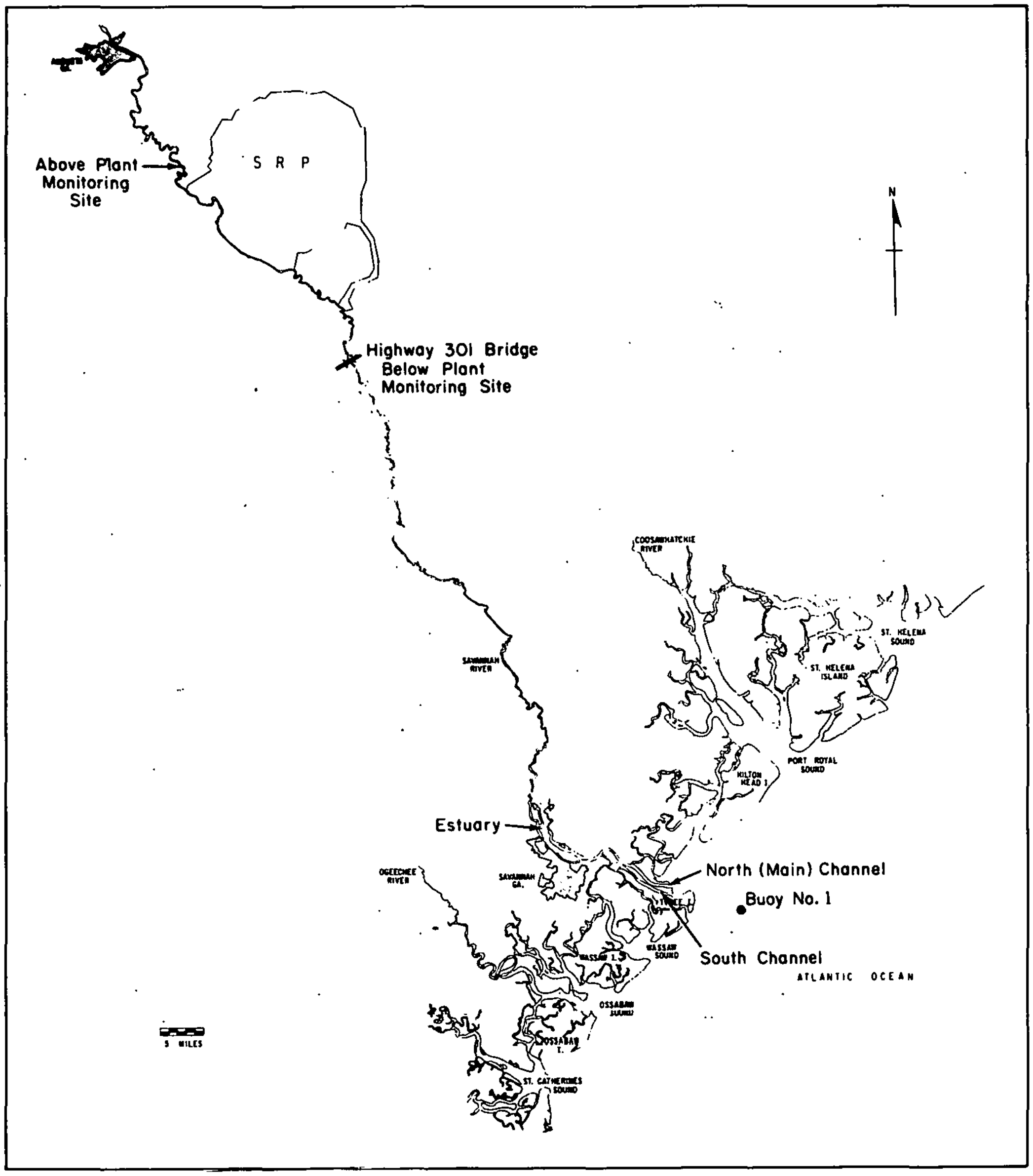

Fig. 1. Savannah River, Estuary, and Adjacent Marine Waters

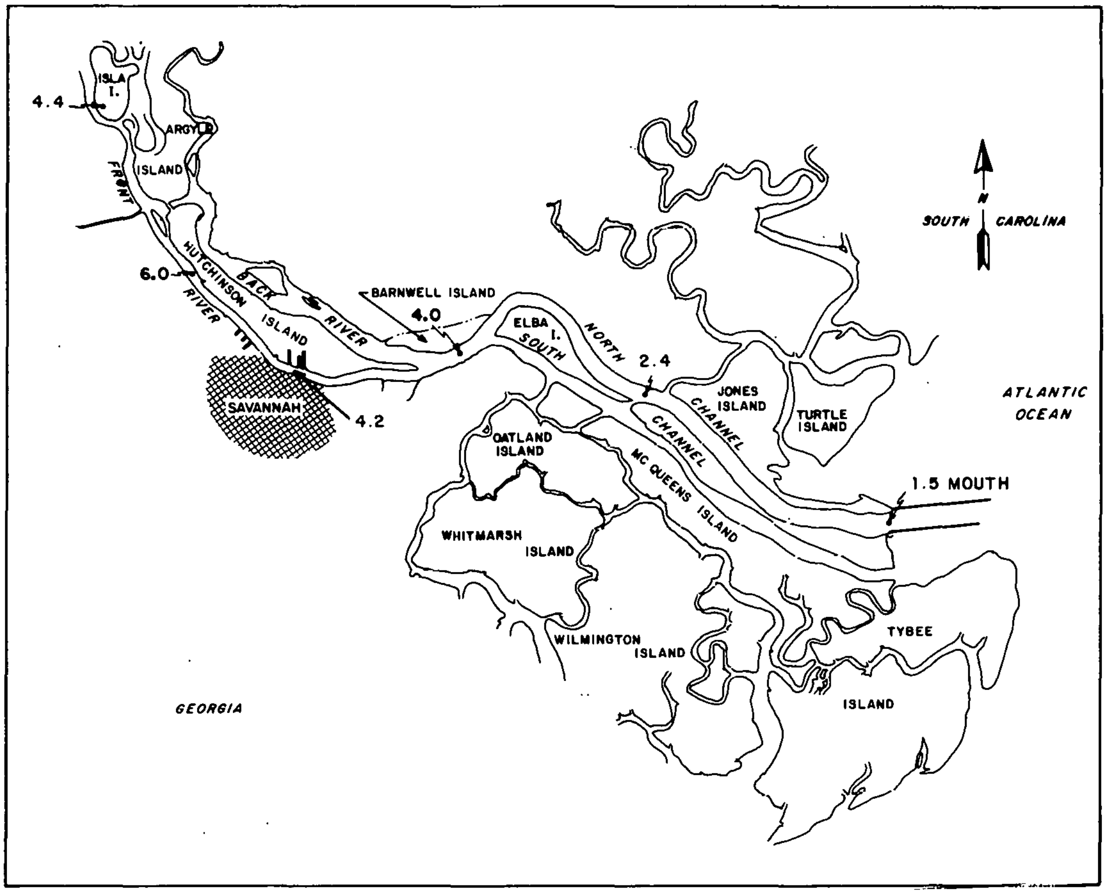

Fig. 2. Tritium Concentration in the Savannah River Estuary (pCi/mL)

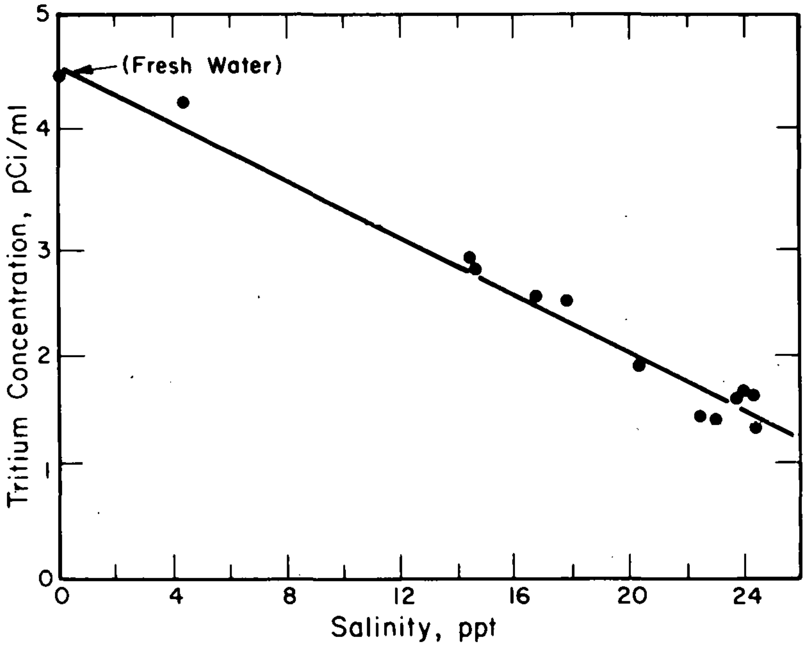

Fig. 3. Tritium-Salinity Relationship for Savannah River Water

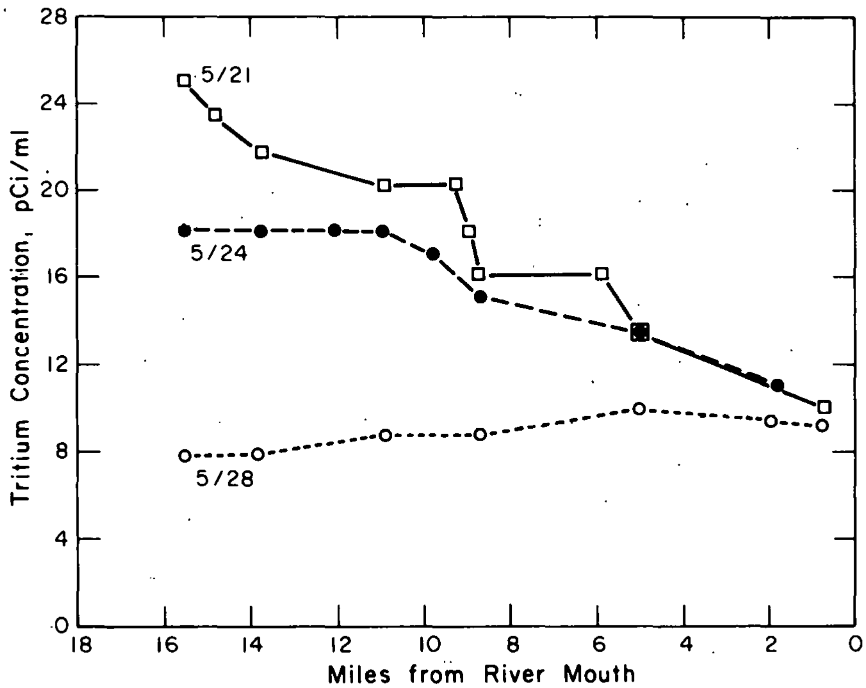

Fig. 4. Tritium Distribution in the Savannah River Estuary

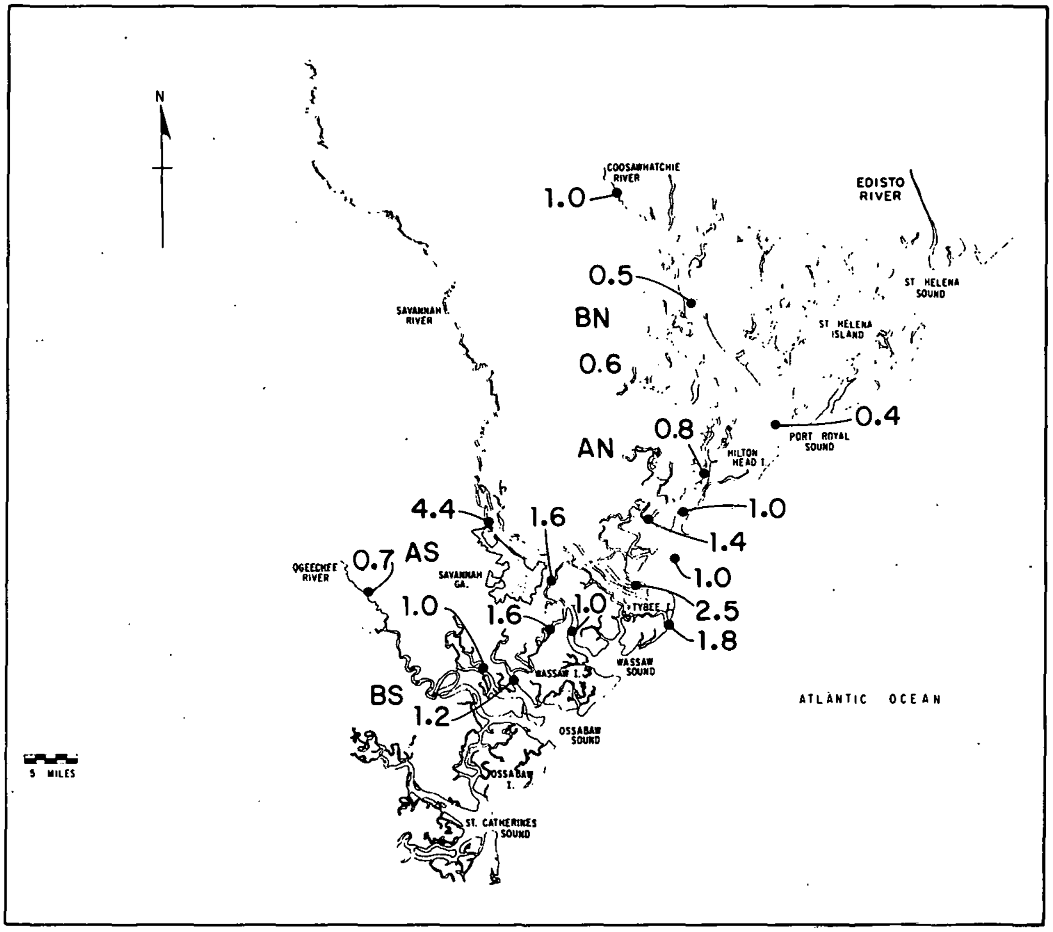

Fig. 5. Tritium Concentration in Tidal Waters (pCi/mL)

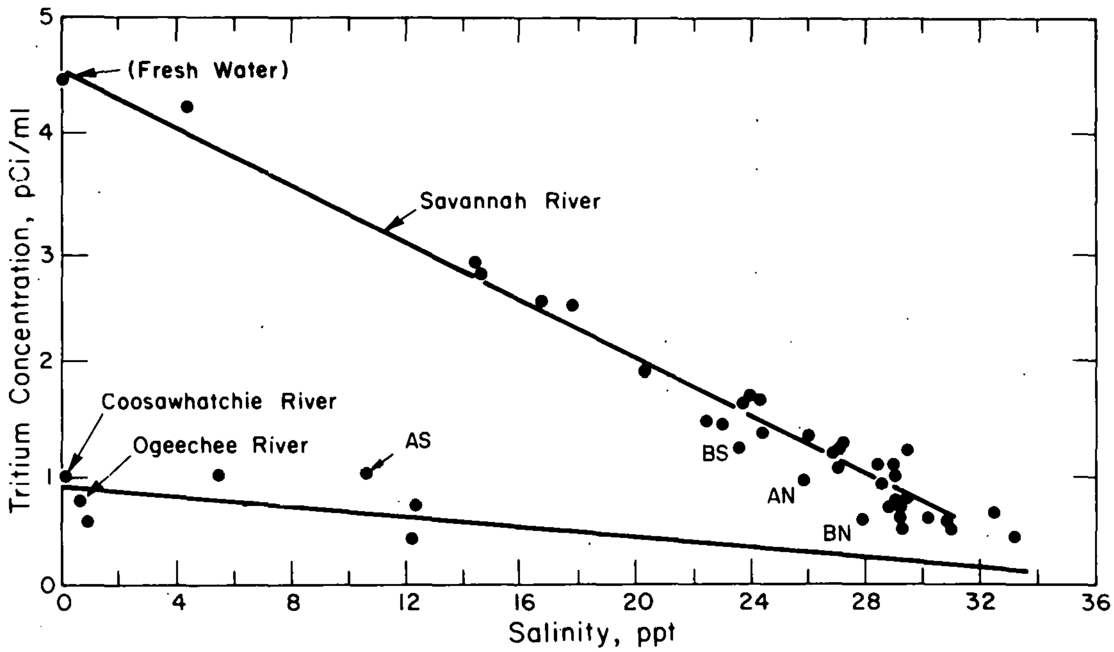

Fig. 6. Tritium-Salinity Relationship of Inland Waters in the Savannah Area