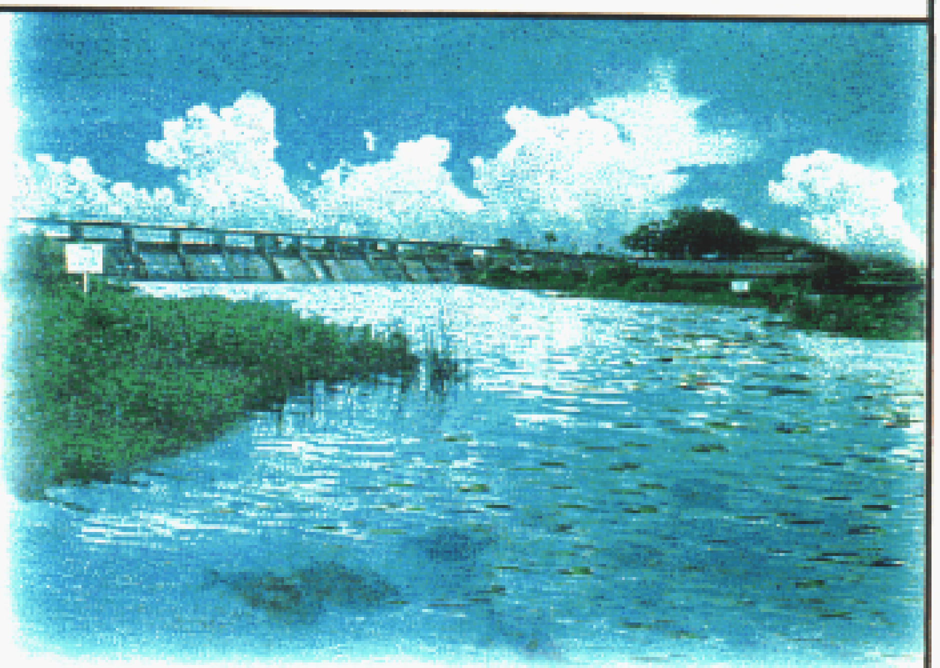
An Analysis of Hydrologic and Ecological Factors Related to the Establishment of Minimum Flows for the Hillsborough River



Southwest Florida
Water Management District

Peer Review FINAL DRAFT
June 15, 1999

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1. MINIMUM FLOWS APPROACH FOR THE LOWER HILLSBOROUGH RIVER

1.1 Background regarding development of a minimum flow for Lower Hillsborough River

Due to environmental stress to the water resources in the Northern Tampa Bay area. Section 373.042 Florida Statutes (F.S.), as amended by the Florida Legislature in 1996, directed the District to establish minimum flows and levels for priority water bodies in the region before October 1, 1997. The Northern Tampa Bay area is comprised of the counties of Pinellas, Pasco and the northern portion of Hillsborough. These counties are located in southwest Florida and surround the northern half of Tampa Bay.

Section 373.042, F.S. defines the minimum flow for a surface watercourse as "*the limit at which further withdrawals would be significantly harmful to water resources or ecology of the area*". Section 373.042, F.S. defines the minimum level of an aquifer or surface water body to be "*the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area*". The 1996 amendments to the statute required the District to adopt minimum flows and levels in Hillsborough, Pasco, and Pinellas County for priority waters that are experiencing or may be expected to experience adverse impacts. In response to this legislative direction, the District established minimum levels and flows, one of those minimum flows being for the Lower Hillsborough River.

Section 373.042, F.S. requires the District to use the best data available to set minimum flows and levels. The legislative requirement to set the levels by October 1, 1997 was absolute, that is, there was a limited time to collect additional information. Because of the time deadline, and the associated requirement to use the best information available, the District was constrained to use existing data despite any associated limitations of that data.

The process to develop the methods for determination of minimum flows and levels was an open public process with all interested parties invited to participate in the development of methodologies for determining the limit at which significant harm occurs. For the Lower Hillsborough River, the Tampa Bay National Estuary Program facilitated a technical advisory group which represented the various interests concerned with the Lower Hillsborough River. The purpose of this advisory group was to make recommendations to District staff for identifying and evaluating water resources and ecological criteria necessary to establish minimum flows for the Lower Hillsborough River.

Following this process the District staff finalized methodologies and the minimum levels and flows for approval by the Governing Board. However, effective July 1, 1997, paragraph 373.0421(l), F.S. was added. Therefore, at the Board's direction, staff reviewed the previous work, additional data as appropriate, continued meetings and workshops with affected parties and held public workshops with the Governing Board to ensure that the changes to the statute had been taken into account. On February 23, 1999, the Governing Board approved the subject minimum flow for the Hillsborough River.

As permitted under subsection 373.042(4), F.S., substantially affected persons may request Scientific Peer Review of the scientific and technical data and methodologies used to determine the minimum flow for the Lower Hillsborough River. The purpose of this report is to document for Scientific Peer Review the scientific and technical data and methodologies used to determine the minimum flow for the Lower Hillsborough River.

1.2 Boundaries and physical characteristics of the hydrologic system for the determination of minimum flows

This document describes the technical analyses that were conducted in support of the establishment of minimum flows for the Lower Hillsborough River. For the purposes of minimum flows, the Lower Hillsborough River is defined as the river downstream of Fletcher Avenue as this corresponds to the approximate upstream extent of the City of Tampa's water supply reservoir (Figure 2.1, page 2.2). Withdrawals from and operation of this reservoir affect flows to the tidal, ten-mile reach of the river that extends below the dam. The District's ecological analyses for the determination of minimum flows for the Lower Hillsborough River concentrated on the effects of various rates of flow on the tidal reach of the river.

The determination of minimum flows for both the Lower Hillsborough River accounted for the fact that this system has experienced extensive changes and structural alterations. The Hillsborough River near the City of Tampa has been impounded in one form or another since before the turn of the century. The present impoundment was built in the 1940's at the site of a previous hydroelectric dam. The Hillsborough River below the dam is a highly modified system which has experienced considerable shoreline hardening, filling of wetlands, sediment deposition, and impacts to water quality from stormwater runoff. The alterations to the Lower Hillsborough River have been so extensive that hydrologic functions associated with floodplain and estuarine wetlands have essentially been lost.

1.3. Minimum flows technical approach

While accounting for the extensive changes and structural alterations to the Lower Hillsborough River, the District evaluated the beneficial effects of various rates of flow of fresh and near-fresh water on the downstream ecosystems. The existing flow regime of the Lower Hillsborough River is characterized by prolonged periods when there is no discharge at the reservoir spillway other than dam leakage. The District's analysis concentrated on minimum flows that might be released during periods when there would otherwise be no discharge at the reservoir spillway. The evaluation of potential hydrologic and ecological benefits below the dam emphasized the relationships of flows with salinity distributions, dissolved oxygen concentrations, and the distribution of biological habitats.

The District requested that the Tampa Bay National Estuary Program facilitate a minimum flow advisory group to provide technically sound recommendations to District staff for evaluating water resource and ecological criteria necessary to establish minimum flows on the Lower Hillsborough River and Tampa Bypass Canal. The District held several meetings with this group and received their technical input which is presented in the Appendices to this report.

To a large extent, minimum flows for the Lower Hillsborough River were evaluated simultaneously with minimum flows for the Tampa Bypass Canal. *Ecological findings for the* Lower Hillsborough River are presented in this report. A separate minimum flows report was prepared for the Tampa Bypass Canal. However, because the Hillsborough River and the Tampa Bypass Canal are connected systems, some information concerning the Tampa Bypass Canal is presented in this report as it pertains to the connected hydrology of these two systems.

1.4. Organization of the document

This general introduction is followed by five chapters that describe the technical information that was used by the District to establish the minimum flow for the Lower Hillsborough River. Chapter Two describes the physical and hydrologic characteristics of the Lower Hillsborough River. Chapter Three presents the findings of the minimum flows advisory group facilitated by the Tampa Bay National Estuary Program . Chapter Four describes the sources of ecological information the District evaluated to establish the minimum flow. Chapter Five presents the results of a hydrodynamic model that was used to simulate the effects of various minimum flows on the salinity regime of the Lower Hillsborough River. The adopted minimum flow is presented in Chapter Six and the Literature Cited is listed at the end of the report.

2. PHYSICAL AND HYDROLOGIC CHARACTERISTICS OF THE HILLSBOROUGH RIVER SYSTEM

2.1 Physical Characteristics

The following describes the physical and hydrologic characteristics of the Hillsborough River System . A map of the Hillsborough River watershed is shown in Figure 2.1. A location map for the Hillsborough River Reservoir and Tampa Bypass Canal is shown in Figure 2.2. While the subject of this minimum flows determination is the Lower Hillsborough River, some consideration of the entire system is necessary to appreciate the factors affecting flows to the Lower Hillsborough River.

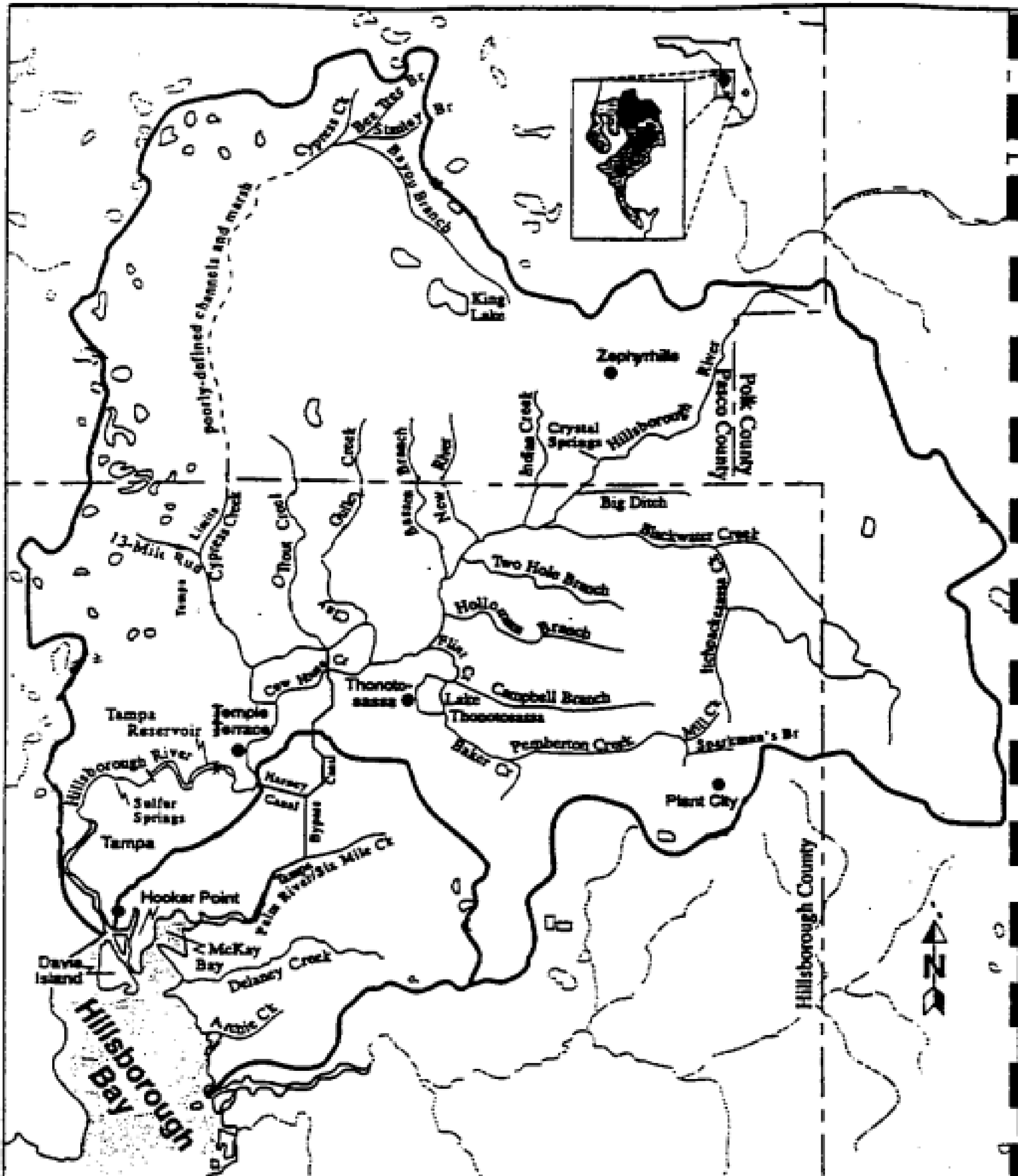
2.1.1 Hillsborough River. The Hillsborough River begins in the Green Swamp area of southeastern Pasco and northwestern Polk Counties. The river flows southwesterly 54 miles to upper Hillsborough Bay and drains approximately 675 square miles. Flows in both the upper and lower reaches of the Hillsborough River are partially derived from spring discharges. Crystal Springs, located near the city of Zephyrhills, discharges an average of 58 cubic feet per second (cfs) in the upper watershed, while Sulphur Springs in the Tampa area discharges an average of 40 cfs.

2.1.2 Hillsborough River Reservoir. The Hillsborough River was first dammed in 1898. This dam was destroyed in 1899 and rebuilt the following year. A hydroelectric dam was built in 1924 and the resultant reservoir served as a water supply for the City of Tampa Water Department. This dam was destroyed in 1933 by a hurricane. The present structure was built in the same location and completed in 1945. The Hillsborough River Dam is located about 10 miles above the mouth of the river and impounds a drainage area of approximately 650 square miles.

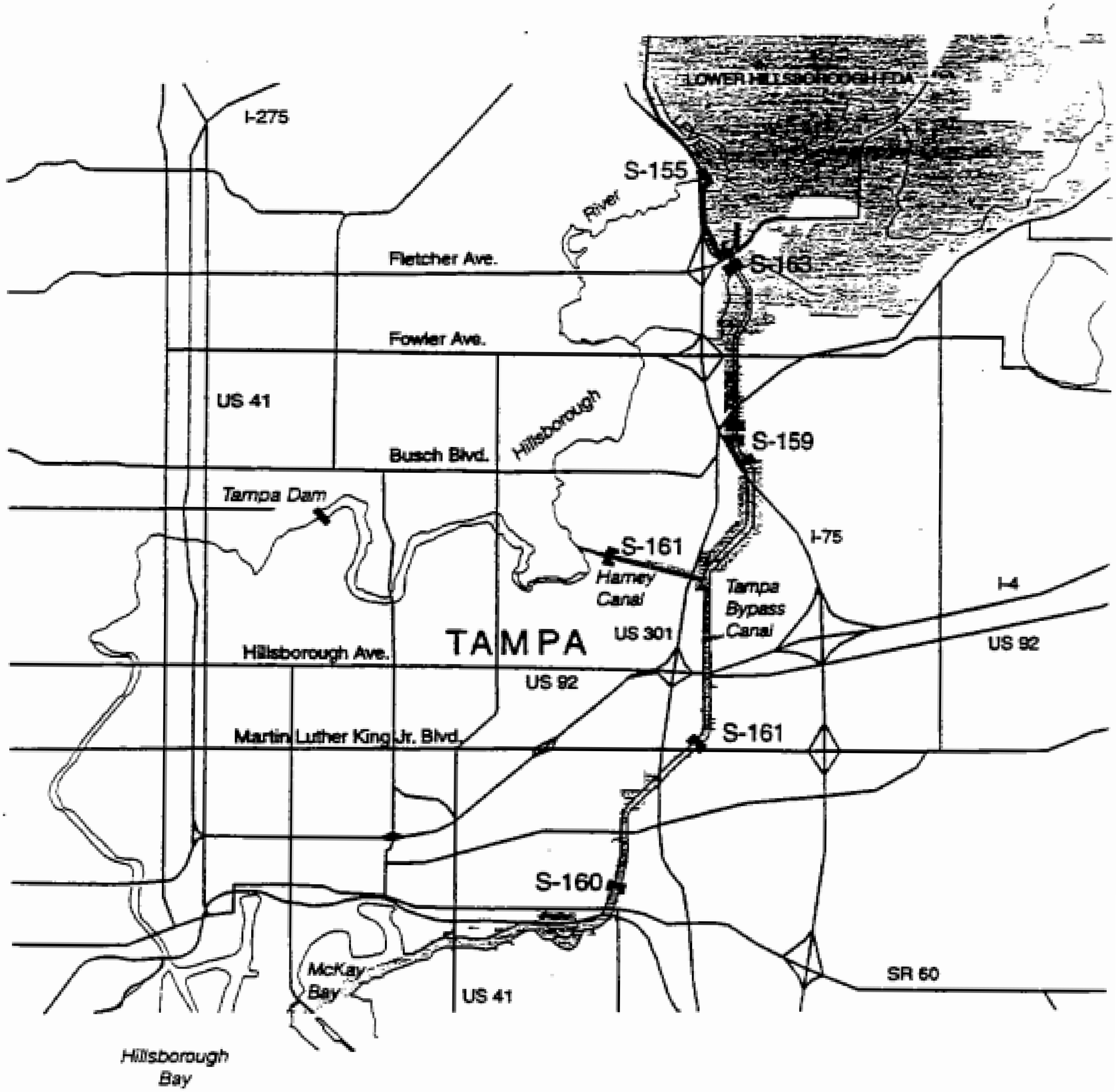
The reservoir created by the dam consists of 12.5 miles of natural river channel. The meandering, v-shaped channel and flood plain averages 15 feet in depth. Within the channel, there are many sinkholes, ledges, and sandbars. At a maximum stage of 22.5 feet NGVD, the reservoir has a capacity of nearly two billion gallons (Goetz, et al., 1978). The storage for the minimum observed stage of 14.9 feet, which occurred in 1977, is about 540 million gallons (Goetz, et al., 1978) .

2.1.3 Tampa Bypass Canal. The Tampa Bypass Canal (TBC), located east of the City of Tampa, was constructed during the period 1966 to 1982 (refer to Figure 2.2). The canal was excavated in the channels of the former Six Mile Creek/Palm River drainage systems. The purpose of the TBC was to divert Hillsborough River flood waters to McKay Bay, bypassing the cities of Temple Terrace and Tampa. The TBC extends about 14 miles south from Cow House Creek in the Lower Hillsborough Flood Detention Area (LHFDA) to McKay Bay at the mouth of the Palm River. The canal is subdivided into three principal reaches: the upper, middle and lower pools (Figure 2.2) which are separated by flow control structures. A structure (S-160) at the downstream end of the lower pool controls flow into the remains of the Palm River and finally into McKay Bay. Structure 160 also acts as a physical barrier that prevents the upstream migration of saline water from the bay.

Figure 2.1



Hillsborough River and Tampa Bypass Canal drainage basins.



Tampa Bypass Canal and Lower Hillsborough Flood Detention Area (FDA)

Figure 2.2

The 9,000 feet long Harney Canal connects the TBC middle pool and the Hillsborough River Reservoir (Figure 2.2). A structure (S-161) controls flow from the reservoir to the canal. Up to 4,000 cfs of flow can be diverted from the reservoir to the TBC through the Harney Canal during flooding. The TBC can also carry convey cfs from the LHFDA, while the TBC lower pool is designed to pass a total maximum flow of 26,700 cfs.

Since 1985, the TBC via the Harney Canal has been used to periodically augment water supplies in the Hillsborough Reservoir. During time of low water levels in the Hillsborough River Reservoir, waters are pumped from the Harney Canal over Structure 161 into the reservoir. Greater details regarding reservoir augmentation from the TBC are presented in a later section of this report.

2.1.4 Lower Hillsborough River. The Lower Hillsborough extends approximately 10 miles downstream of the Hillsborough Reservoir Dam. This section of the river is tidally-affected. The watershed of the Hillsborough River downstream of the dam is 11,400 acres and is highly urbanized, with residential and commercial land uses comprising 93 percent of the river's watershed below the dam. Nearly all of this land is drained by storm sewers, and 114 major stormwater outfalls enter the river below the dam. For over a century there has been extensive filling of fresh and saltwater wetlands associated with the lower river so that very little of these wetlands remain. Similarly, the shoreline of the lower river has been highly modified, as approximately 76 percent of the river shoreline is either bulkhead, riprap, or fill. Natural shorelines comprise 26 percent of the lower river shoreline and most are near the dam. There are no natural shoreline covers downstream of the I-275 bridge. Descriptions of the shorelines of the river are presented in the 1995 report by Water & Air Research and SDI Environmental Services, Inc., which for brevity is abbreviated as WAR/SDI (1995) in this report.

Sulphur Springs flows into the river approximately 2.2 below the Hillsborough River Dam, or about 7.8 miles upstream of the river mouth. The long-term average discharge for this second-order spring is 40 cfs, but a declining trend in flow from the spring has been reported by Stoker et al. (1996). Average springflow in recent years has been about 31 cfs. Spring flow is regulated by a control structure at the spring boil and by a structure near the river. Flow from the spring is periodically diverted by the City of Tampa and used to augment the Hillsborough River Reservoir .

2.2 Hydrologic Characteristics of the Hillsborough River Reservoir

This section summarizes the historic hydrologic conditions observed at the Hillsborough River Reservoir, particularly as they relate to discharge to the lower Hillsborough River. The period of record for stage and discharge measurements for the Hillsborough River Reservoir reported by the U.S. Geological Survey (USGS) is 1939 to present. This gaging station is designated by the USGS as the Hillsborough River near Tampa (# 02304500). During the period of record, water levels (stage) in the reservoir have ranged from 14.9 feet to 22.9 feet NGVD. In order to examine hydrologic conditions during a more recent time interval, a frequency distribution of water levels in the reservoir is presented for the period 1974-1996 in Table 2.2. During this time the median reservoir water level was 22.0 feet and 5 percent of all stage values were below 18.4 feet NGVD.

Since the 1980s, the Hillsborough River Reservoir has been augmented by water pumped from Sulphur Springs (1984 to present) and the Tampa Bypass Canal via the Harney Canal (1985 to present). Augmentation has enabled the City of Tampa to maintain higher reservoir stages than would be possible if only river inflows were available. For the period 1984 to 1996, the reservoir stage was below 20 feet NGVD only 8 percent of the time, compared to nearly 25 percent of the time during the pre-augmentation period of 1974 to 1983 (Table 2.2).

Table 2.2 Frequency Distribution of Hillsborough River Reservoir Stage

	Stage (feet, NGVD)		
Percentile	Combined Periods 1974 - 1996	Pre-augmentation Period 1974 - 1983	Augmentation Period 1984 - 1996
1	16.4	15.9	18.1
5	18.4	17.6	19.5
10	19.4	18.5	20.3
20	20.6	19.7	21.1
30	21.1	20.6	21.6
40	21.7	21.1	22.0
50	22.0	21.5	22.3
60	22.2	21.9	22.4
70	22.4	22.1	22.5
80	22.5	22.3	22.6
90	22.6	22.5	22.6
95	22.6	22.5	22.7
99	22.7	22.6	22.7

Daily records of streamflow that discharges from the Hillsborough River Reservoir at the reservoir spillway are available since 1939. The annual mean discharge at this site for 1939 to 1996 was 463 cfs. The median discharge for this same period was 152 cfs. Annual mean discharges for the 1939 to 1996 period of record range from less than 100 cfs to nearly 1700 cfs (Figure 2.3). The maximum daily discharge of 13,500 cfs was recorded on March 21, 1960. The U.S. Geological Survey (USGS) described the hydrologic records for the Hillsborough River Reservoir as "poor," indicating that differences between the actual and estimated values may exceed 15 percent (Stoker, et al., 1996). However, the data collected by the USGS represent the best available information for streamflow at this location.

Discharge from the dam depends on reservoir inflows, water supply withdrawals, and losses due to evaporation and seepage. Reservoir inflows can be estimated based on upstream watershed areas and gaged flows from Trout Creek, Cypress Creek, the Hillsborough River at Morris Bridge and Crystal Springs (see Figure 2.1). The period of record at the Morris Bridge gage goes back only to

1974, thus limiting the period for which inflows to the reservoir can be estimated. Daily estimates of reservoir inflows were developed for the period 1974 to 1996 and are presented in Figure 2.3.The frequency distribution of daily estimated reservoir inflows for the 1974 - 1996 time period is given in Table 2.3.

Table 2.3 Frequency Distribution for Estimated Daily Reservoir Inflow and Reservoir Outflow Records, 1974 - 1996. Flows rounded to the nearest integer. Leakage through the dam typically reported at less than 0.5 cfs.

Percentile	Reservoir Inflows (cfs)	Reservoir Outflows (cfs)
1	46	0
5	58	0
10	68	0
20	83	0
30	103	1
40	127	5
50	164	35
60	216	106
70	308	211
80	478	394
90	916	865
95	1379	1310
99	2565	2270

For the period 1939 to 1973, when only reservoir outflows were measured, it can be assumed that inflows to the reservoir equaled or exceeded outflows since water supply withdrawals were made from the reservoir. There were probably also seepage losses from the reservoir. A conservative estimate of reservoir inflows can therefore be made for 1939 to 1973 from the record of reservoir outflows for that period. No adjustments for yearly withdrawals from the reservoir were made to these estimates.

Figure 2.3 shows a hydrograph of yearly mean outflows from the reservoir (1939 - 1996) and estimated yearly mean inflows to the reservoir (1974 - 1996). Though the pre-1974 outflows represent conservative inflow estimates, there were many more high inflows years before the 1970s than after. Sixty percent of the years between 1939 and 1969 had average yearly flows greater than 500 cfs, whereas only 13 percent of the years after1974 had average yearly flows greater than that amount. This study did not evaluate any possible causes of this reduction in average yearly inflows, or impacts to other streamflow characteristics such as base flow.

Stoker et al. (1996) reported declining trends in reservoir outflows during 1939 to 1992. The rate of decline in the annual mean discharge was 7.7 cfs per year. They also identified decreases in 7-day and 30-day low flows and 7-day and 30-day high flows for the same time period. No attempt

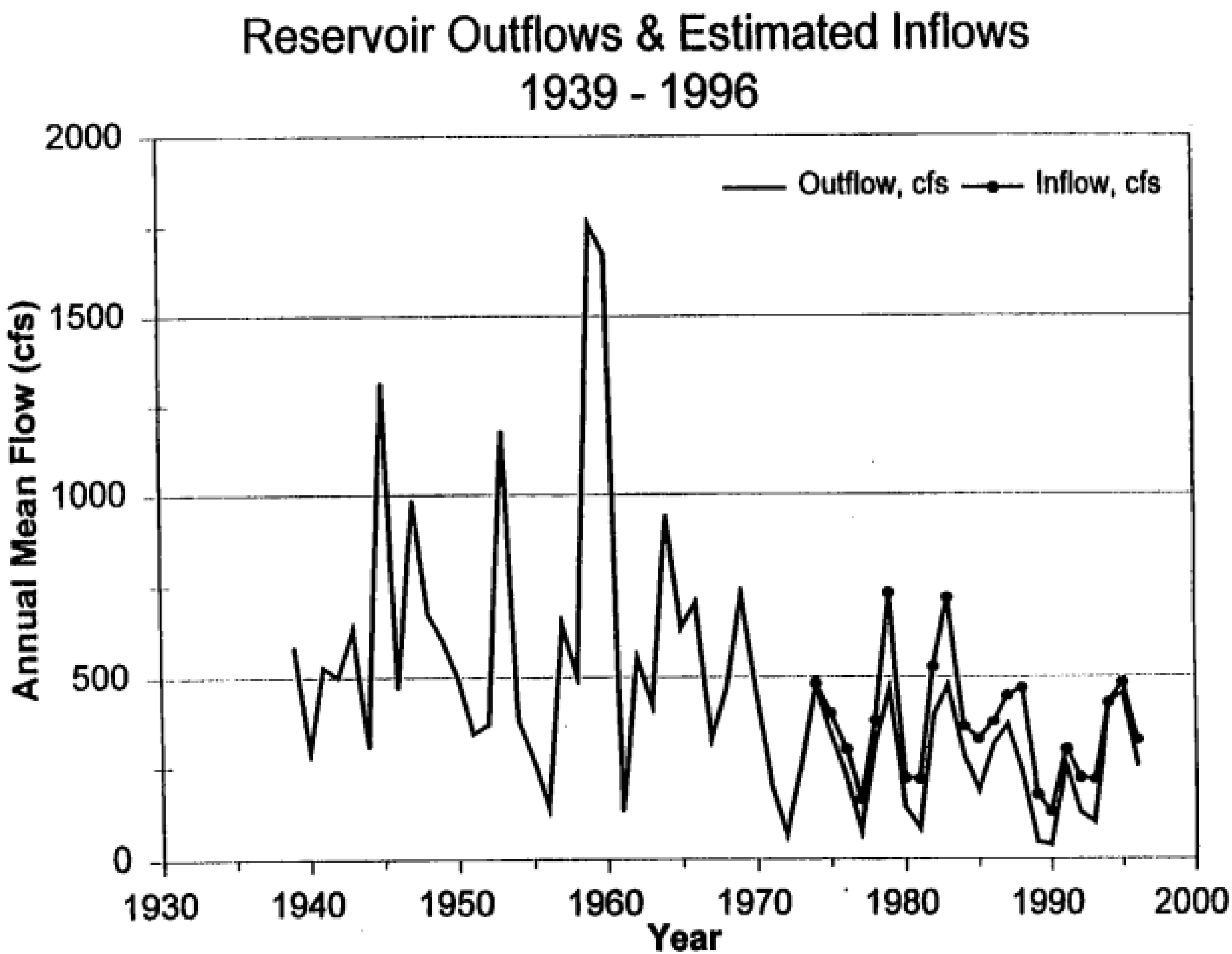

Reservoir Outflows & Estimated Inflows
1939 - 1996
Outflow, cfs
Inflow, cfs
Annual Mean Flow (cfs)
2000
1500
1000
500
0
1930
1940
1950
1960
1970
1980
1990
2000
Year

Figure 2.3

was made to identify the causes of streamflow declines. However, the authors cited deficit rainfall, alteration of drainage patterns, decreased base flows, and increased water use as possible factors. Table 2.2 on page 2.6 shows the frequency distribution of reservoir outflows at the Hillsborough River near Tampa gaging station for the period of 1974 to 1996. The median outflow for the reservoir was 35 cfs, while the outflow was less than one cubic foot per second about 30 percent of the time. Flows less than 1 cfs represent estimates of dam leakage.

Figure 2.4 shows hydrographs of daily flows from the Hillsborough River Reservoir for the years 1990 to 1997 to give the reader a sense of the daily fluctuation in discharge that occurs at the dam. Climatic patterns in southwest Florida produce a summer rainy season during which more than half of the yearly streamflow typically occurs in regional rivers. The hydrographs reflect this pattern, as high flows from the reservoir typically occur during the months of July through October. Low flows from the reservoir generally occur during the months of November through June, although exceptions to this pattern can occur such as the wet winters of 1993, 1996, and 1997.

The hydrographs show that during the dry season there are often prolonged periods when there is no discharge from the reservoir spillway. The number of zero-flow days (< 1 cfs) have shown dramatic increases beginning in the 1970s (Figure 2.5). In 1945 there were five zero flow days, which may have been associated with the completion of the dam. Between 1945 and 1968, there were no zero-flow days as withdrawals increased steadily, but there were 22 zero-flow days in 1968 as withdrawals reached 40 mgd. Zero-flow days increased substantially during the 1970s. From 1970 through 1995, only the years 1987 and 1988 experienced no zero-flow days. The number of zero-flow days have exceeded 200 days per year six times since 1972.

Withdrawals from the reservoir are reported to have begun in the 1920s, but records for withdrawals date from October, 1945. Average yearly withdrawals rates since 1946 are shown in Figure 2.5. Increasing water use has certainly played a role in the increased occurrence of zero-flow days at the reservoir dam. Declines in reservoir inflows discussed earlier have also probably had an effect. Construction of the Tampa Bypass Canal (TBC) may have affected ground-water inflows and outflows to the reservoir and the frequency of zero-discharge days. Construction breached the Upper Floridan aquifer and increased ground-water inflow to the canal by approximately 20 mgd (Knutilla and Corral, 1984). However, the fraction of this flow that originated in the vicinity of the Hillsborough River Reservoir has not been quantified. Augmentation of the reservoir with water from the TBC via the Harney Canal since the mid 1980s has returned some or all of the water lost by increased groundwater seepage from the reservoir.

Since 1979, outflows from the reservoir have also been periodically affected by the diversion of high flows from the Hillsborough River to the TBC flood control system. Operation of TBC structures allows diversion of upstream river flows through the Lower Hillsborough Flood Detention Area to TBC and reservoir inflows through the Harney Canal to the TBC. Records of these diversions have not been well-maintained, and generally the magnitudes of these diversions are unknown.

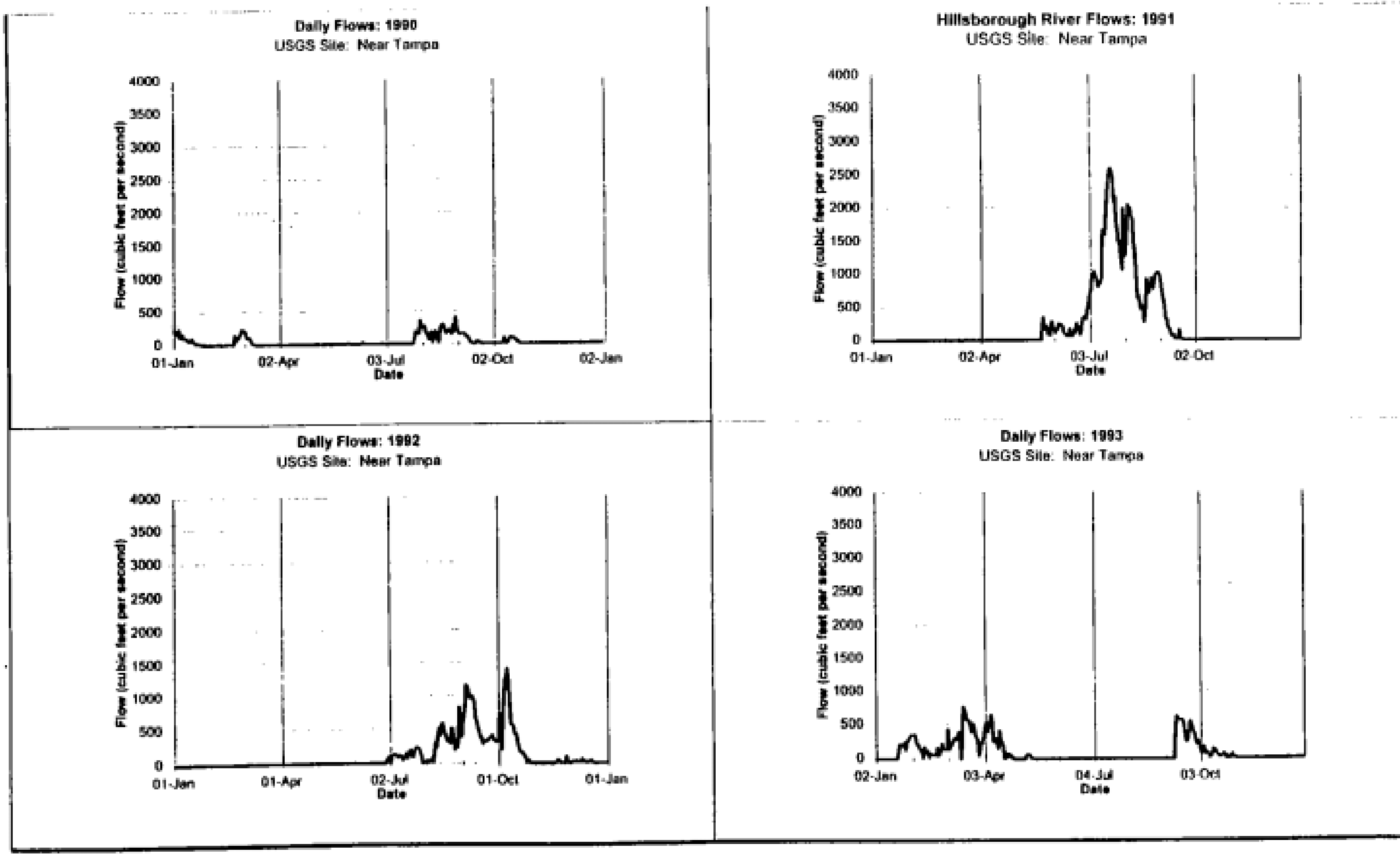
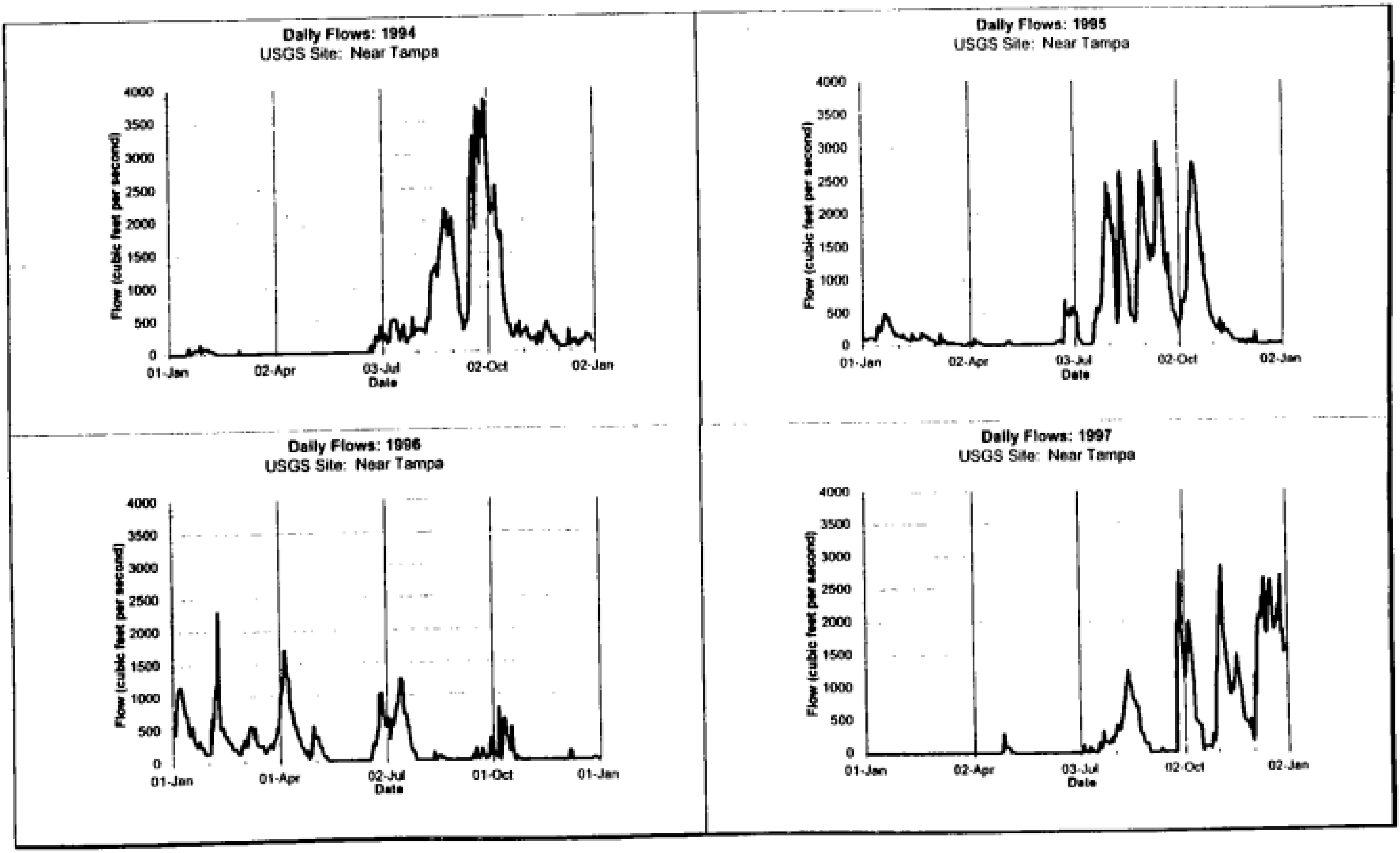

Daily Flows: 1990
USGS Site: Near Tampa
Flow (cubic feet per second)
4000
3500
3000
2500
2000
1500
1000
500
0
01-Jan
02-Apr
03-Jul
02-Oct
02-Jan
Date
Hillsborough River Flows: 1991
USGS Site: Near Tampa
Flow (cubic feet per second)
4000
3500
3000
2500
2000
1500
1000
500
0
01-Jan
02-Apr
03-Jul
02-Oct
Date
Daily Flows: 1992
USGS Site: Near Tampa
Flow (cubic feet per second)
4000
3500
3000
2500
2000
1500
1000
500
0
01-Jan
01-Apr
02-Jul
01-Oct
01-Jan
Date
Daily Flows: 1993
USGS Site: Near Tampa
Flow (cubic feet per second)
4000
3500
3000
2500
2000
1500
1000
500
0
02-Jan
03-Apr
04-Jul
03-Oct
Date

Figure 2.4 a-d



Daily Flows: 1994
USGS Site: Near Tampa
Flow (cubic feet per second)
4000
3500
3000
2500
2000
1500
1000
500
0
01-Jan
02-Apr
03-Jul
02-Oct
02-Jan
Date
Daily Flows: 1995
USGS Site: Near Tampa
Flow (cubic feet per second)
01-Jan
02-Apr
03-Jul
02-Oct
02-Jan
Date
Daily Flows: 1996
USGS Site: Near Tampa
Flow (cubic feet per second)
01-Jan
01-Apr
02-Jul
01-Oct
01-Jan
Date
Daily Flows: 1997
USGS Site: Near Tampa
Flow (cubic feet per second)
01-Jan
02-Apr
03-Jul
02-Oct
02-Jan
Date

Figure 2.4 e-h

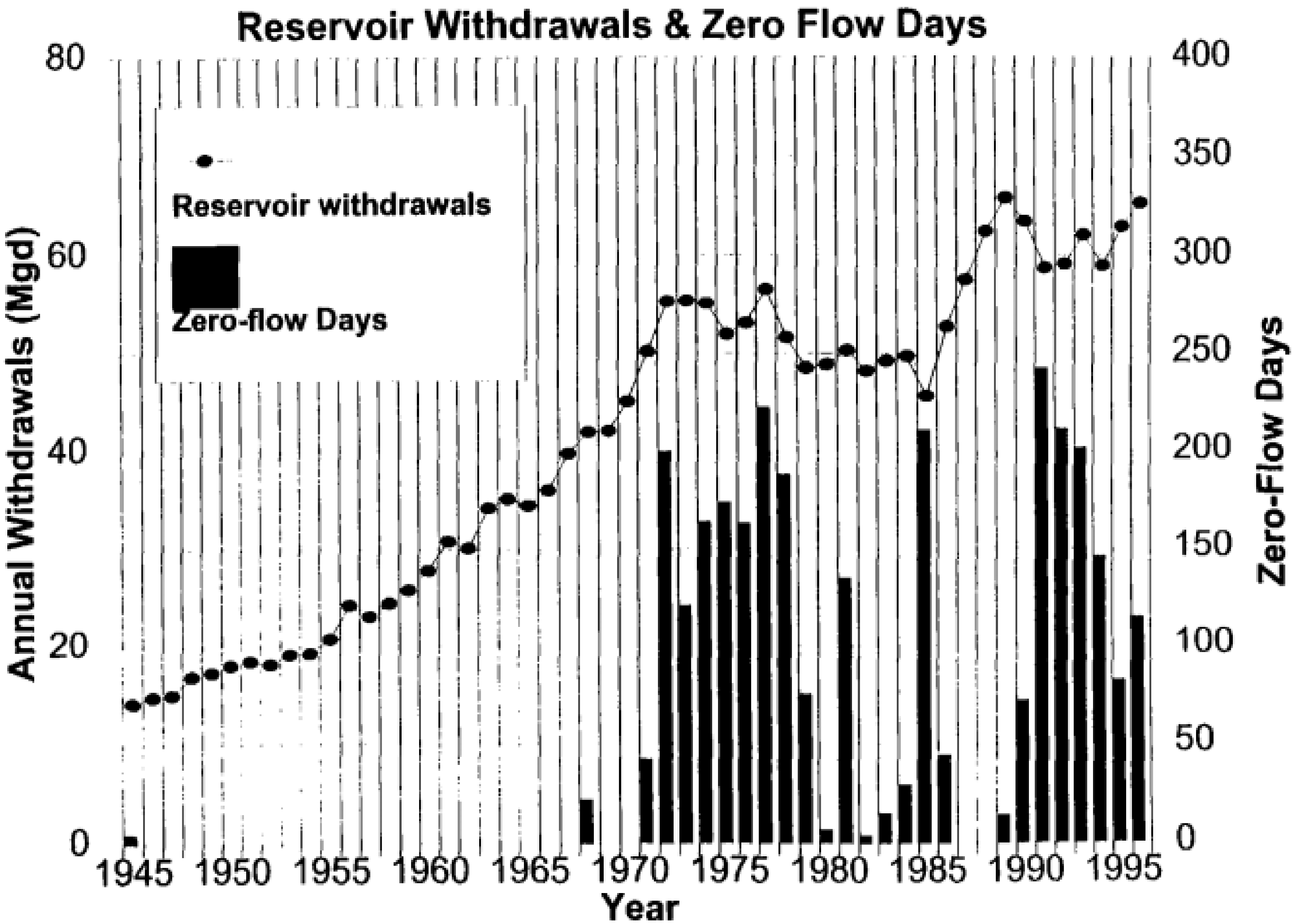

Reservoir Withdrawals & Zero Flow Days
Reservoir withdrawals
Zero-flow Days
Annual Withdrawals (Mgd)
Zero-Flow Days
Year
80
60
40
20
0
400
350
300
250
200
150
100
50
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Figure 2.5

2.3 Water Use in the Hillsborough River Watershed

The City of Tampa has historically depended on four sources to meet water supply demands: the Hillsborough River Reservoir, the Morris Bridge wellfield, the TBC and Sulphur Springs. Currently permitted quantities are shown in Table 2.3 in units of million gallons per day (mgd).

Table 2.3 Permitted withdrawal quantities (mgd) for the City of Tampa.

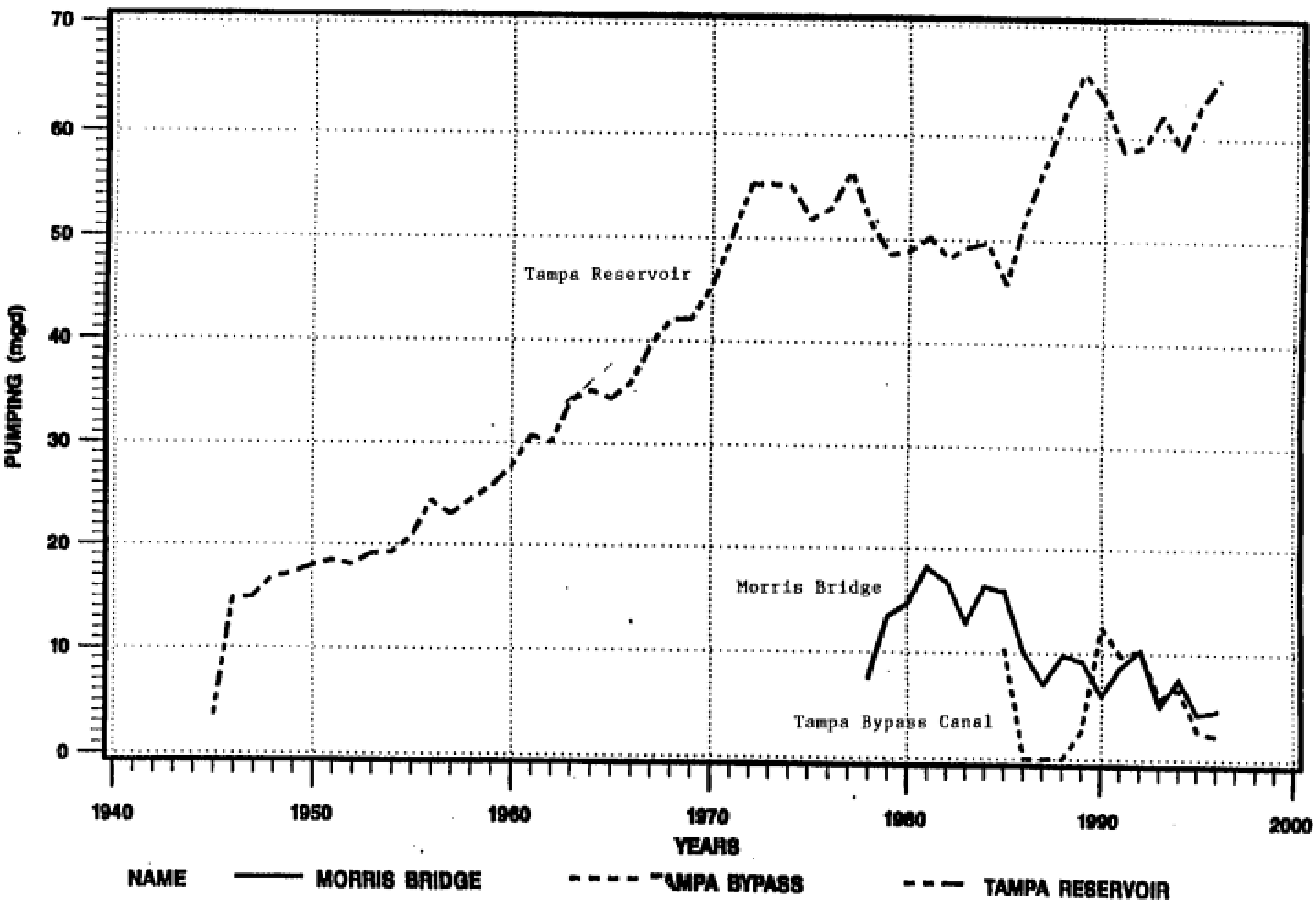
	Average Annual Day	Peak Month	Maximum Day
Hillsborough River	82	92	104
Tampa Bypass Canal	20	none specified	40
Sulphur Springs	5	10	20
Morris Bridge WF	15	27	30

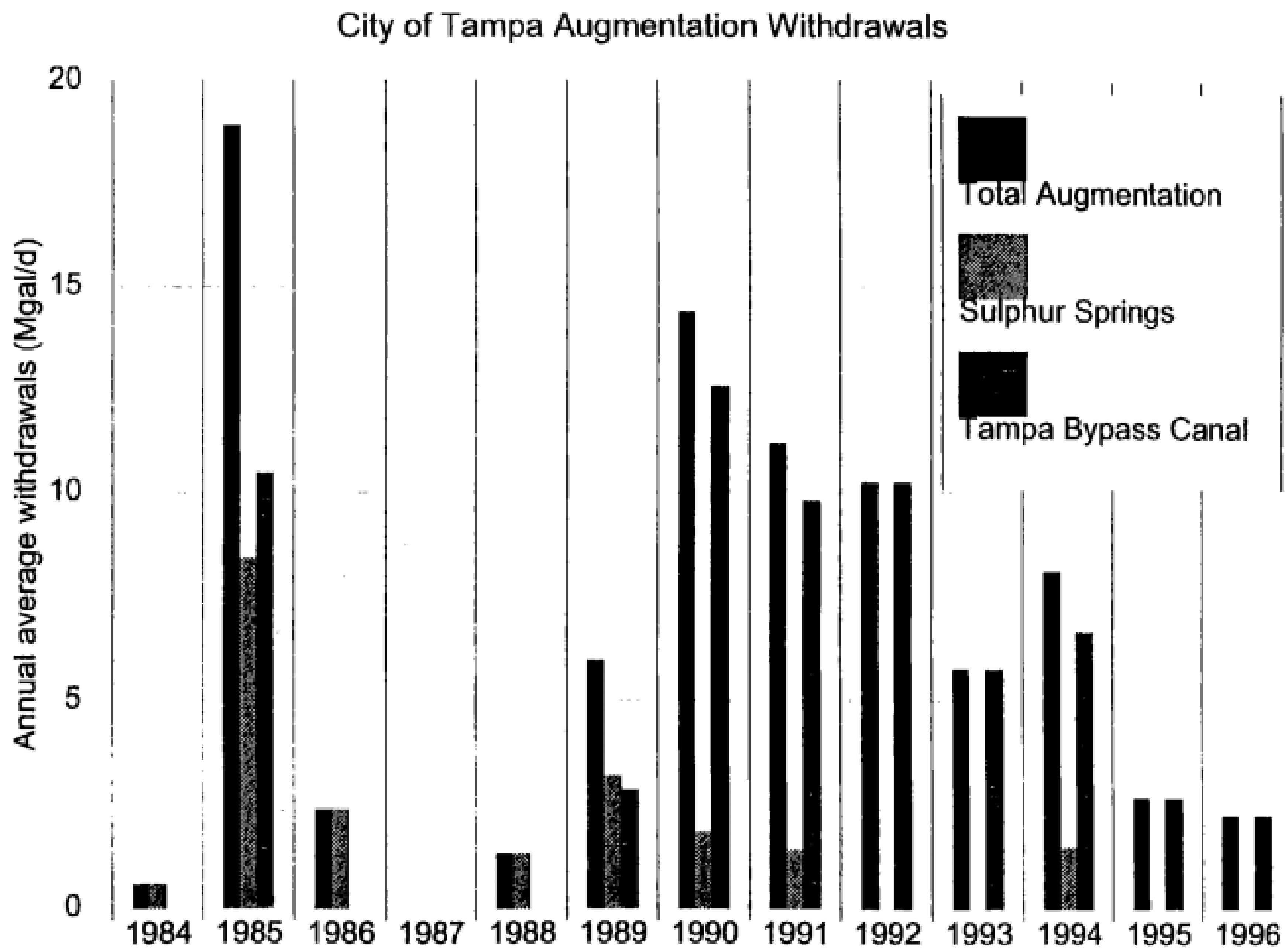
Continuous data of withdrawal quantities from the reservoir are available back to 1945. The first full year of withdrawals was 1946 when 15 mgd was withdrawn (Figure 2.5). Water demand increased steadily through 1972. Demand remained relatively constant from 1972 through 1977. The Hillsborough River was the sole source of water supply for the City of Tampa until 1978 when the Morris Bridge wellfield was brought on line. Total demand on the City's supply increased through 1981 but reservoir withdrawals remained about 50 mgd. In 1984 and 1985, the City of Tampa began to augment the reservoir from Sulphur Springs and the TBC, respectively (Figure 2.6). After 1985, withdrawals from Morris Bridge wellfield were reduced and withdrawals from the reservoir increased again. During the years 1976 to 1996, yearly average rates of 58 to 66 mgd have been withdrawn from the reservoir.

Withdrawals from the Tampa Bypass Canal and Sulphur Springs are considered augmentation to the reservoir, since they are pumped into the reservoir prior to withdrawal at the water treatment plant. Reported withdrawals from the reservoir include those waters augmented from the TBC and Sulphur Springs. Withdrawals from the TBC and Sulphur Springs are regulated by augmentation schedules that are based on water levels in the Hillsborough River Reservoir. From 1989 through 1996, the City has augmented every year from the TBC (Figure 2.7). Sulphur Springs has provided augmentation in only three of the seven years and generally provides 10 percent or less of the total augmentation quantity.

In March, 1999, the District issued a new water use permit to Tampa Bay Water Authority to divert water from the Hillsborough River Reservoir through the Harney Canal to a water supply facility to be built adjacent to the Tampa Bypass Canal. Withdrawals for this permit cannot begin until flows at the Hillsborough River Dam exceed 100 cfs. Withdrawals begin at 10 percent of flow measured at the dam and ramp up to 30 percent of flow beginning at 215 cfs. A maximum diversion capacity of 300 cfs is specified. The effects of these diversions, which will begin in 2001, were not included in the District's analysis of minimum flows for the Hillsborough River. The minium flows analysis, instead, concentrated on flows that could be provided at the dam in the dry season when there would otherwise be zero flow at the dam.

Figure 2.6 **ANNUAL PUMPING FROM CITY OF TAMPA SOURCES**





City of Tampa Augmentation Withdrawals
Annual average withdrawals (Mgal/d)
20
15
10
5
0
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
Total Augmentation
Sulphur Springs
Tampa Bypass Canal

Figure 2.7

3. RECOMMENDATIONS OF THE MINIMUM FLOWS ADVISORY GROUP AND SUBMITTAL OF ASSOCIATED REPORTS

3.1. Role of the minimum flows advisory group

In October, 1996, the Southwest Florida Water Management District requested that the Tampa Bay National Estuary Program (TBNEP) facilitate a technical advisory group for the establishment of minimum flows for the Lower Hillsborough River and the Tampa Bypass Canal/Palm River system. This advisory group met on approximately a monthly basis through May 1997. The advisory group included representatives of state, local and regional agencies, municipal and regional utilities, citizen environmental groups, and professionals from private firms and laboratories. The objective of the minimum flow advisory group was defined at the initial meeting and subsequently clarified as follows:

> Provide technically sound recommendations to SWFWMD staff for identifying and evaluating the water resources and ecological criteria necessary to establish minimum flows on the Hillsborough River downstream of the dam and on the Palm River/Tampa Bypass Canal downstream of Structure 160.

The advisory group's final recommendations to the District are listed in Section 3.3. It was determined that the role of the group did not include providing a definition of "significant harm" as that term is used in Sec. 373.042 Florida Statutes, nor would the group recommend a specific minimum flow rate for either the Lower Hillsborough River or the TBC. Instead, the advisory group recommended criteria the District should evaluate and consider in establishing minimum flows. A chronological summary of the committee meetings prepared by TBNEP staff (Appendix N-2) provides some background on how the recommendations were developed.

In support of the advisory group's activities, the TBNEP managed a contract with Coastal Environmental to consolidate previously collected data for the river and canal and develop statistical models for salinity distributions and dissolved oxygen concentrations as a function of freshwater inflow. Funding for this contract was equally shared by the City of Tampa and the Southwest Florida Water Management District. Also in support of advisory group activities, staff from the Florida Department of Environmental Protection Marine Research Institute (FMRI) performed new analyses of data collected from three tributaries as part of the fisheries independent monitoring program for Tampa Bay. The District reviewed and considered the findings of these studies in its minimum flows evaluation. The report by Coastal Environmental (1997) is discussed in Section 3.4 and that report is being provided to the scientific review panel for their use. The findings of the FMRI analysis are discussed in Section 3.5 of this report and presented in Appendix N-4.

3.2. Minimum flows technical approach

The minimum flows advisory group identified several points of agreement regarding criteria for establishing minimum flows. Two key points were that salinity and dissolved oxygen are critical water quality variables affecting the abundance and distribution of organisms in the Lower Hillsborough River. Accordingly, the determination of minimum flows evaluated how freshwater flows affect the distribution of salinity and dissolved oxygen concentrations in the lower river. The protection and enhancement of fish populations were identified as important ecological criteria and the relationships of freshwater flows to the abundance and distribution of potential fish habitat were evaluated. The relationships of other biological parameters (e.g., benthic invertebrates, shoreline plant communities) to freshwater inflows were evaluated as they affect the overall biological integrity and productivity of the systems.

Based on these considerations, the basic approach for minimum flows determination was to evaluate salinity and dissolved oxygen distributions in the Lower Hillsborough River as a function of freshwater inflows. Statistical models and a deterministic model were used to evaluate salinity distributions in the Lower Hillsborough River as a function of inflows of fresh and/or near-fresh water. Statistical analyses were used to predict dissolved oxygen concentrations and the probability of experiencing hypoxic (low dissolved oxygen) conditions in the Lower Hillsborough River under various minimum flow releases.

Salinity and dissolved oxygen distributions calculated by these methods were compared to potential habitats available for fish and other organisms. Physical habitat features that were compared to salinity and dissolved oxygen distributions included shoreline length, vegetated shoreline, river distance, surface area, bottom area, and river volume. Previous biological data for the river were used to evaluate species that could be expected to use potential habitats. Also, relationships of different species to salinity, dissolved oxygen, and physical riverine/estuarine habitats described in the technical literature and data from other tributaries to Tampa Bay were used to evaluate potential habitat use.

The amount of freshwater and low and medium salinity habitats in the river were quantified for various minimum flow releases. The probability of experiencing low dissolved oxygen concentrations was evaluated for the same releases. Starting with the existing flow condition, improvements in habitat quantity and quality were evaluated in a stepwise manner for incremental increases in minimum flows.

3.3 Recommendations of the minimum flows advisory group

The advisory group formulated and presented to the District the following recommendations regarding minimum flows for the Lower Hillsborough River (also see Appendix N-1).

1. Define ecological criteria or goals for dissolved oxygen concentrations in the Hillsborough River as a minimum of 4.0 mg/l and average 5.0 mg/l for optimizing fish utilization. If these criteria cannot be feasible met at all times and in all locations, minimize time and areas in the river where dissolved oxygen is less than 4.0 mg/l.

    Comment: Several members of the Advisory Group expressed concern that "optimizing fish utilization" misrepresented the intent of the statement, and that "enhancing" may be a more appropriate term. Others did not share the same concern.

2. Maintain a salinity gradient from the estuary to the dam ranging from polyhaline (>18 ppt) to fresh (<0.5 ppt), to optimize estuarine-dependent fish species utilization.

3. Maintain a freshwater segment below the dam to provide a refuge for freshwater biota.

    Comment: Some members of the Group questioned the ecological value of maintaining freshwater biota below the dam. Although many members agreed that maintaining freshwater biota below the dam could be of value to the ecological integrity of the system, the Group did not reach full consensus on this issue.

4. Evaluate other ecological issues and analytical tools related to freshwater flow management, including impacts on manatees and changes in water quality related to diverting a portion of the Sulfur Springs discharge.

5. Test the reliability of the management tools through a series of controlled releases of freshwater from the reservoir. Commencement of this work should be contingent upon a determination by SWFWMD and the City of Tampa of the need for a controlled release experiment.

    Additional information from the District: The District has initialed new data collection on the river, including three continuous salinity recorders operated by the USGS and periodic boat measurements above Sligh Avenue. These data are being used for additional verification runs of the District's deterministic model.

3.4 Minimum flow study by Coastal Environmental

The District and the City of Tampa interacted with the minimum flows advisory group to develop a scope of work for Coastal Environmental (a division of Post, Buckley, Schuh, and Jernigan, Inc.) to analyze data previously collected for the Lower Hillsborough River. This project involved statistical analysis of the data and development of empirical models to predict salinity distributions and dissolved oxygen concentrations in the Lower Hillsborough River (Coastal, 1997).

The summary of findings of the minimum flows advisory group included a comment prepared by the NEP staff and Coastal Environmental that stated "Due to the deficiency of low-flow data, the empirical model presented in the report cannot be used to reliably predict salinity levels in the river nor changes in salinity-based habitat due to dam releases when flows are greater than 0 cfs and less than 30 cfs" (Appendix N-1). The amount of salinity data just below the dam during low flows is given further discussion on pages 4.26 through 4.33. Also, a limitation of the WAR/SDI study was that there was not a station in the river channel in close proximity to Sulphur Springs. Data collected during no-discharge periods during 1996 (Table 4.2) show that shallow depths in the river near Sulphur Springs can be lower in salinity than at either the nearest upstream or downstream WAR/SDI stations (3 and 5). Since the empirical model (Coastal, 1997) uses data from these two stations to predict salinity values between them, the model probably slightly overestimates salinity at some shallow depths in this reach of the river.

In general, the empirical model provides very useful information regarding salinity distributions and salinity based habitat in the lower river, but the District concurs the model output should not be used to evaluate the effects of flows between 0 and 30 cfs. The District believes the results of the river-wide empirical model are best viewed along with the other analytical results that were generated for the lower river. In particular, the fixed station regression models presented in Coastal (1997) and the hydrodynamic model (Chapter 5) are good comparative tools for evaluating the effects of different quantities of fresh and near-freshwater inflows on salinity in the river.

The TBNEP staff and Coastal Environmental also suggested the empirical models presented in the report cannot be used to reliably dissolved oxygen concentrations at fixed stations in the river or the frequency at which specified dissolved oxygen concentrations will be achieved throughout the river. These suggestions were based the generally low r-square values for these regressions and the low number of observations recorded during low flows from the dam in the WAR/SDI data set. They also suggested the limitations of the various analytical tools, including the District's hydrodynamic model, be made clear to policy makers when presenting results and making presentations (Appendix N-1).

3.5 Analysis of salinity/fish relationships from other Tampa Bay tributaries by the Florida Marine Research Institute

Staff from the Florida Department of Environmental Protection Marine Research Institute (FMRI) participated on the minimum flows advisory group. In order to describe the use of tidal rivers by fish species present Tampa Bay, FMRI staff made a presentation to the group regarding fish distributions observed in studies of the Little Manatee River. Discussions were held about the relationships of the different life stages of estuarine dependent fishes to salinity distributions in the bay's tributaries. It was concluded that in order to offer maximum benefit to the most species of fish, the salinity gradient in the lower river should be complete (i.e. from fresh water to greater than 18 ppt). It was clarified that it would be suitable if the 18 ppt waters were located outside the mouth of the river since the estuary would still have a complete salinity gradient. It was concluded a complete salinity gradient would be valuable throughout the year, as there are always some species in the Lower Hillsborough River that could benefit from such a gradient.

Upon request by the advisory group, FMRI staff volunteered to perform new analyses of fish catch data from three tidal rivers monitored as part of the fisheries independent monitoring program. A summary of these analyses that was prepared by FMRI staff and presented to the group is included as Appendix N-4. The FMRI presented data from three tidal rivers on the bay; the Alafia, Little Manatee and Manatee. Sampling in each river was by a 21-m boat seine and a 6.1 m otter trawl. Sampling for each gear was based on a stratified random design in which sampling was randomized within designated geographic areas. Efforts were made to sample across the salinity gradient and the fish catch data were classified into salinity zones determined by the Venice system. Because the freshwater/saltwater mixing zone moves many miles in these rivers on a seasonal basis, there were many sampling dates when certain salinity zones were not sampled.

A summary of the number of samples taken in each salinity zone on each river is shown on page N4-8. The Little Manatee River had the most freshwater samples by seine, while the Manatee River had by far the most polyhaline (>18.0 ppt) seine samples. These differences in sampling effort per salinity zone were due to differences in the prevailing salinity regimes of these rivers, combined with navigational limits to areas the sampling boats could get to. The average (or median) salinity of sampling was very similar for the Alafia and Little Manatee Rivers (about 9 ppt), but was considerably higher (23 ppt) for the Manatee River (page N4-2). Due largely to the inclusion of the Manatee River in the analysis, more samples were collected in polyhaline waters than any other salinity zone.

Table 1 in the FMRI handout lists the number of fish caught in each salinity zone (pages N4-9 to N4-12). The density weighted mean salinity at capture (and standard error) for each species that was caught in ten or more samples is presented on page N4-16. These same statistics are plotted for 13 important species on page N4-17. The snook (*Centropus unidecimalis*) had a mean salinity at capture of 4.05 ppt, while three species had mean salinities at capture of about 9 parts per thousand. Seven species had mean salinities at capture between 12 and 17 ppt, while two species, the silver jenny (*Eucinostomus gula*) and the sand seatrout (*Cynoscion arenarius*), had salinities at capture of greater than 20 ppt. It should be noted the standard errors around the mean for each species are relatively large and many species were widely distributed during the study.

The lengths of fishes analyzed are presented with the salinity at capture statistics (page N4-16). The FMRI study largely captured fishes in the juvenile stage, although this varied between species. For some species, the mean salinity at capture varied with the length. For example, the mean salinity at capture for two seatrout (*Cynoscion*) species was lower at lengths between 40 and 70 mm than for lengths less than 30 (pages N4-19 and N4-20). This pattern occurred because these species tend to migrate into low salinity zones as juveniles. Many estuarine dependent species migrate into low salinity waters as they grow from larval to juvenile stages, then migrate back to higher salinity waters as they mature from juveniles to adults.

Another useful document for examining the salinity at capture for early life stages of estuarine dependent fish that was discussed by the advisory group is the ichthyoplankton study of the Little Manatee River by Peebles and Flannery (1992). This study used night-time plankton trawls with nets with a 505 micron mesh. Comparisons can be made of the salinity at capture for certain species between these two reports. For some species (e.g., *Anchoa mitchilli*), the salinity at capture is lower in the Peebles and Flannery report because earlier life stages and smaller lengths were captured.

The data presented by FMRI and included in Peebles and Flannery (1992) were used to assess general fish utilization and fish/salinity relationships in tributaries to Tampa Bay. This information was then compared to the fish data collected as part of the WAR/SDI study. Some members of the group suggested that potential fish utilization in the Hillsborough should be less than these other tributaries because of the highly urbanized nature of the river's shoreline. In essence, even if salinity and dissolved oxygen concentrations in the Hillsborough were suitable, fish populations would be smaller due to river's modified morphology and loss of tidal wetlands. In response in this issue, FMRI segregated their seine catch data into four shoreline classifications; unvegetated, emergent vegetation, overhanging vegetation, and hardened shoreline (N4-26 to N4-30). The results showed that substantial numbers of fishes were caught adjacent to hardened shorelines. For some notable species (*Anchoa mitchilli, Scienops ocellatus, Cynoscion nebulosus*) the shorelined class was ranked first or second with regard to average number caught.

FMRI staff pointed out that these results are partly related to the sampling gear. Seines can be more effective at capturing fish against a hard shoreline than when the fish can escape into marsh plants or roots. Also, the rivers analyzed by FMRI have substantial areas of natural shoreline and the functions of tidal wetlands in maintaining food-webs in those rivers are important. Overall, the WAR/SDI data for fishes in the Lower Hillsborough River and the FMRI data from other tributaries indicate that although the lower river has been substantially modified, it is capable of supporting valuable fish communities that warrant proper management.

4. ECOLOGICAL ASSESSMENT OF THE LOWER HILLSBOROUGH RIVER

4.1 Sources of Ecological Data and Information

To evaluate minimum flows for the Lower Hillsborough River the District principally relied on the six sources of ecological data and information that are listed below.

1. A hydrobiological study of the Lower Hillsborough River and the Tampa Bypass Canal required by special conditions of water use permits issued to the City of Tampa and the West Coast Regional Water Supply Authority (WAR/SDI, 1995).

2. Data for salinity, dissolved oxygen, and water quality parameters available from the Hillsborough County Environmental Protection Commission.

3. Data for salinity and dissolved oxygen concentrations in the Lower Hillsborough River measured by continuous recorders operated by the U.S. Geological Survey.

4. A report published by the Tampa Bay National Estuary Program (TBNEP) that was requested by its minimum flows advisory group to the District. This report, which was prepared by Coastal Environmental, Inc. (Coastal, 1997), analyzed data from the three sources listed above. Funds for this report were provided by the City of Tampa and the Southwest Florida Water Management District.

5. An analysis of salinity at capture and the abundance of juveniles for various fish species in other tributaries to Tampa Bay prepared by the Florida Marine Research Institute (FMRI).

6. A hydrodynamic model of the Lower Hillsborough River prepared by the District.

Results and conclusions from the first three of these data sources are summarized in this chapter. Results of the Coastal (1997) and FMRI studies are discussed in Chapter Three and the results of the hydrodynamic model of the Lower Hillsborough River are discussed in Chapter Five. Other studies the District considered in determining minimum flows for the Lower Hillsborough River are those by Ross (1980), Metcalf and Eddy (1983), Mote Marine Laboratory (1984), Peebles and Flannery (1992) and HSW Engineering (1992). Overall, these combined sources of data and studies comprise the best available information for establishing minimum flows on the Lower Hillsborough River.

4.2 Hydrobiological Study of Lower Hillsborough River and Tampa Bypass Canal

At the 1991 renewal of the water use permits required to withdraw water from the Hillsborough River Reservoir and the Tampa Bypass Canal, a hydrobiological study of the Lower Hillsborough

River and the Tampa Bypass Canal was required of the permittees (City of Tampa and West Coast Regional Water Supply Authority). With that renewal the average annual withdrawal quantity permitted from the Hillsborough River Reservoir was increased from 62 to 82 million gallons per day. The purpose and regulatory application of the hydrobiological study is described in special conditions contained in the water use permits issued to the City of Tampa and the West Coast Regional Water Supply Authority. Field data collection for the hydrobiological study was conducted between the years 1991 and 1994 by the firms of Water and Air Research and SDI Environmental Services, Inc., with the report published the following year (WAR/SDI, 1995).

The hydrobiological study included collection of a wide array of physical, chemical and biological variables including salinity, water quality, phytoplankton, benthic macroinvertebrates, fishes, and shoreline vegetation. Although the withdrawal/augmentation schedule and some of the corresponding ecological conclusions contained in Chapters 8, 9 and 10 of the WAR/SDI (1995) report are not necessarily endorsed by the District, the hydrobiological study is a principal source of data the District relied on to evaluate the biological characteristics of the Lower Hillsborough River and Tampa Bypass Canal and their relationships to freshwater inflows. Some general findings from the hydrobiological study relevant to the determination of minimum flows for the Lower Hillsborough River are summarized below. A map of the stations that were sampled as part of the hydrobiological study are shown in Figure 4.1.

4.2.1 Shoreline Habitat Inventory. The Lower Hillsborough River is a highly modified system. Most of the wetlands associated with the shoreline of the lower river have been filled and considerable sections of the shoreline have been hardened by seawalls, rip-rap or other material. Twenty-four percent of the total shoreline is presently in natural cover. River segments nearest the dam have the highest percentages of natural shoreline, with 89 percent of the shoreline above Rowlett Park bridge (22nd St.) in natural cover.

4.2.2 Salinity Mean surface salinity values in the Lower Hillsborough River ranged from 3.9 ppt at station 2 (0.5 miles below dam) to 15.7 ppt at station 10 near the river mouth. Salinity in the lower river was highly variable. Discharge from the reservoir resulted in a freshwater zone below the dam. The response of salinity to freshwater inflows in the Lower Hillsborough has been the subject of considerable analyses beyond that presented in the WAR/SDI hydrobiological study. The results of these analyses are presented later in this and the following chapters of this report.

4.2.3 Dissolved Oxygen. Surface dissolved oxygen (DO) values generally increased progressively downstream in the lower Hillsborough River. Low surface DO values were typically found at stations 3 and 5 during periods of no discharge from the dam. Surface DO concentrations at stations 2, 3, 5 and 6 were positively correlated with discharge from the dam. Depletion of DO with depth was common in the lower river, and there were frequent problems with hypoxia in bottom waters. In stations nearest the dam (2 and 3), bottom DO concentrations were closely related to the rate of freshwater inflows.

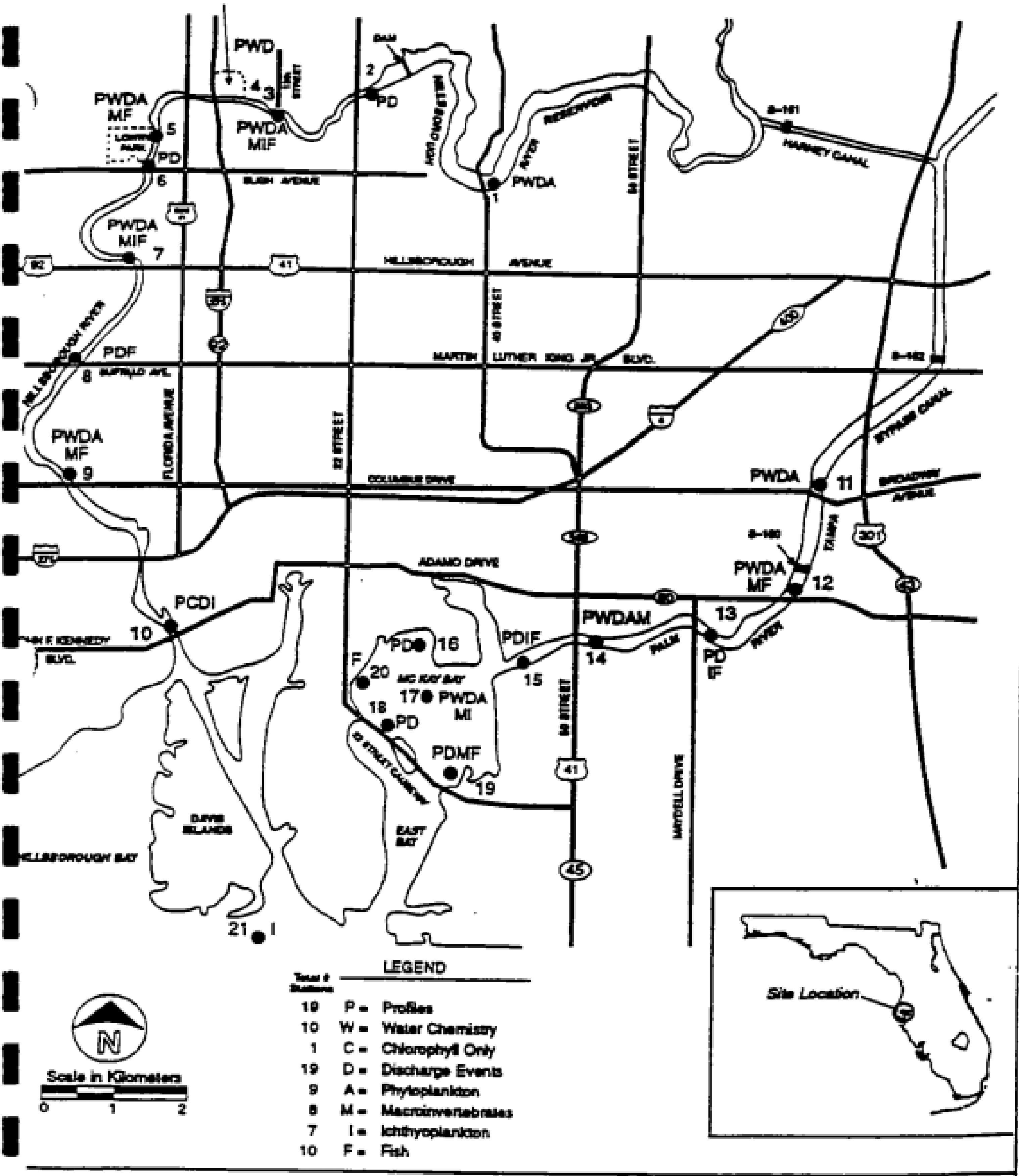


Figure 4.1 Location of WAR/SDI and USGS stations in the Lower Hillsborough River. Adapted from WAR/SDI (1995).

4.2.4 Water Chemistry Station means for total suspended solids (TSS) increased downstream in the Lower Hillsborough River and were negatively correlated with discharge at all river stations. Turbidity was also negatively correlated with discharge at two stations in the Lower Hillsborough River. Color and ortho phosphorus were positively correlated with discharge in the Lower Hillsborough, while Secchi disk values were negatively correlated with discharge.

4.2.4 Chlorophyll a and Phytoplankton. Median values of chlorophyll a in the lower river generally increased downstream toward the bay, ranging from 3.8 μg/l at station 3 to 17.3 μg/l at station 9. Mean values also generally followed this pattern but were heavily influenced by a phytoplankton bloom during December 1992. Chlorophyll a was negatively correlated with discharge from the dam at all stations in the lower river. Freshwater inflows resulted in shifts in phytoplankton group dominance in the lower river, reflecting the lower river's variable physico-chemical environment. During times of high reservoir discharge, freshwater taxa were found extending downstream from the dam.

4.2.6 Benthic Macroinvertebrates Many of the invertebrate collections in the Hillsborough River were indicative of stressed environments with low DO concentrations. Low values for population density, species richness, and diversity were common during the study, but were most frequent nearest the dam (Station 3). Communities collected from shallow waters at stations 3 and 5 during the second year of study generally had one to three orders of magnitude more organisms than collections from mid-channel areas, apparently due in large part to higher DO concentrations in the shallower waters.

Changes in salinity resulting from discharges from the Hillsborough River dam affected benthic communities primarily at stations 3 and 5. During periods of peak discharge, a shift in community compositions from estuarine species to freshwater species occurred at station 3. The freshwater populations rapidly decreased following termination of discharges from the dam and a return to more saline conditions.

4.2.7. Ichthyoplankton Ichthyoplankton captured in the Lower Hillsborough River were primarily the egg, larval, and juvenile stages of marine-derived fishes that tend to spawn in high salinity waters. These species migrate into lower salinity waters as juveniles and utilize these estuarine habitats. Compared to the Little Manatee River, which was sampled in another study (Peebles and Flannery, 1992), the Hillsborough River had lower taxonomic diversity, richness and evenness, which appeared to be related to poor representation of substrate associated fishes. A pronounced reduction in abundance of larval stages in the Lower Hillsborough River appeared related to benthic hypoxia.

4.2.8. Juvenile Fish. Fishes collected during the two year period were primarily adults and juveniles of small-sized resident species and the juveniles of seasonally abundant immigrant species. Juvenile fish abundance increased progressively downstream in the Lower Hillsborough River. The abundances of many taxa reflected responses to freshwater inflows and salinity regimes. Although numerically small, the freshwater resident community was an important

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component of the Lower Hillsborough River, where it was largely restricted to the two most upstream juvenile fish stations (WAR/SDI 1995; page 9.10). The transient fish communities in the lower river were important because most of the taxa represented juveniles of species of sport or commercial value. All transients were marine species that seasonally entered the study sites as young-of the year, using these systems as nursery areas.

4.3. Additional District Analyses of Salinity and DO Data from the Permit Required Hydrobiological Study

The District performed additional analyses of the salinity and DO data collected during the WAR/SDI hydrobiological study. Data from this study were also analyzed in the report published by the Tampa Bay National Estuary Program (Coastal, 1997), which is described in Chapter Three of this report. Plots and statistical summaries of WAR/SDI data prepared by District staff are presented in the following sections and compared to the findings of these other two studies (WAR/SDI, 1995: Coastal, 1997).

4.3.1 Salinity during discharge and no-discharge conditions from the Hillsborough River.

Summary statistics for salinity in surface and bottom waters are presented in WAR/SDI (1995) for periods when there was discharge and no discharge from the City of Tampa dam. Similar statistics are presented in Table 4.1 for the discrete depths measured in the in situ vertical profiles. The locations of the WAR/SDI stations are shown in Figure 4.1. Waters as deep as two meters were routinely measured at each station. However, the number of observations for 3 meters depth or greater were less due to differences in tide stage or the exact location of sampling between trips. No discharge is defined as days when three-day average flows at the dam were < 2 cfs.

Several points from Table 4.1 are worth noting. During discharge conditions there is typically fresh water at Station 2, while during periods of no discharge mean salinities ranged from 5.8 to 6.5 ppt at the different depths at that location. The quantity of water that is needed to produce freshwater conditions near station 2 has been the subject of considerable analyses which are presented later in this report. Mean salinity values of less than 1 ppt were also found at zero and one meter depths at station 3 during discharge conditions. Plots of salinity versus flow at station 3 and all other WAR/SDI stations in the river are presented in Appendix C.

Stations 5 and 6 are important because they were the closest WAR/SDI stations downstream from Sulphur Springs. During discharge conditions, vertical salinity gradients generally differed by 4 to 6 ppt over the top 3 meters of water. During no-discharge conditions, steep vertical salinity gradients were observed in the top meter of water. Differences in mean salinity between zero and one meter during no-discharge conditions was 5.7 and 5.0 ppt at stations 5 and 6, respectively (Table 4.1). Since the surface reading was actually taken at about 0.3 meters depth, steep salinity gradients were observed very near the surface during no-discharge conditions.

Table 4.1. Means and standard deviations for salinity values at the [illegible] stations for discharge and no-discharge conditions. Unless otherwise noted in parentheses for 3 m depth, the number of observations (N) is 18 for discharge and 24 for no-discharge conditions. All values expressed as parts per thousand.

	DISCHARGE (3-day flows > 2 cfs)	NO-DISCHARGE (3-day flows < 2 cfs)
<u>Station 2</u>		
Surface	0.2 ± 0.9	5.8 ± 3.1
1 M	0.2 ± 0.9	6.2 ± 3.0
2 M	0.2 ± 1.0	6.5 ± 3.2
3 M	0.0 (2)	3.5 ± 3.8 (3)
Bottom	0.3 ± 1.1	6.5 ± 3.1
<u>Station 3</u>		
Surface	0.4 ± 1.2	5.7 ± 2.9
1 M	0.6 ± 1.7	8.6 ± 4.5
2 M	1.9 ± 4.4	10.6 ± 5.6
3 M	2.2 ± 5.4 (12)	10.9 ± 5.4 (15)
Bottom	2.0 ± 4.6	11.4 ± 5.7
<u>Station 5</u>		
Surface	0.9 ± 1.5	5.6 ± 2.2
1 M	2.5 ± 3.9	11.3 ± 5.3
2 M	5.3 ± 6.8	14.4 ± 5.8
3 M	4.9 ± 7.4 (10)	14.3 ± 5.8 (19)
Bottom	5.7 ± 6.8	14.6 ± 5.4
<u>Station 6</u>		
Surface	1.3 ± 1.6	6.1 ± 2.4
1 M	3.7 ± 2.6	11.1 ± 4.8
2 M	6.5 ± 2.7	14.3 ± 5.5
3 M	7.1 ± 8.0 (10)	15.4 ± 5.2 (14)
Bottom	6.9 ±2.4	15.1 ± 5.5
<u>Station 7</u>		
Surface	2.5 ± 3.1	8.0 ± 2.9
1 M	3.8 ± 4.6	13.3 ± 5.1
2 M	7.6 ± 7.6	16.7 ± 5.3
3 M	8.5 ± 8.5 (11)	16.7 ± 5.3 (9)
Bottom	9.7 ± 7.7	17.0 ± 5.2
<u>Station 8</u>		
Surface	3.1 ± 3.4	11.2 ± 3.3
1 M	4.9 ± 5.5	14.7 ± 4.7
2 M	10.4 ± 8.9	17.9 ± 5.0
3 M	14.0 ± 8.8 (12)	18.9 ± 4.9 (14)
Bottom	13.3 ± 8.6	19.2 ± 4.1
<u>Station 9</u>		
Surface	5.3 ± 4.5	15.3 ± 3.7
1 M	9.0 ± 7.7	17.8 ± 3.9
2 M	14.5 ± 8.0	21.4 ± 3.1
3 M	18.8 ± 5.6 (15)	23.1 ± 2.6 (17)
Bottom	19.3 ± 3.7	22.4 ± 2.7
<u>Station 10</u>		
Surface	9.8 ± 6.0	20.0 ± 4.8
1 M	15.3 ± 7.7	22.1 ± 4.4
2 M	20.9 ± 5.1	23.8 ± 3.3
3 M	22.8 ± 2.2 (17)	24.6 ± 2.9
Bottom	22.8 ± 2.2	24.7 ± 2.8

Flows from Sulphur Springs contribute to the steep vertical salinity gradients in near-surface waters. The salinity of the spring water in recent years has typically ranged from about 0.8 to 1.5 ppt. The outlet from the spring is just over one meter deep and the less dense spring water tends to flow over the more saline water that occurs in the river during no-discharge conditions. When fresh or low salinity water is present in the river near Sulphur Springs outfall during high discharges from the dam, density gradients near the spring are not as great and the spring water mixes more readily with the river water.

The influence of Sulphur Springs on vertical salinity gradients is demonstrated by Table 4.2, which lists data recorded during a no-discharge period on November, 1996. In addition to three WAR/SDI stations (2,3, and 5), vertical profiles for salinity and DO are shown for five other stations in the three miles of river immediately below the dam. These data show that surface salinity was higher at stations near the dam (miles 0.54 and 0.92) than at stations further downstream, reflecting the influence of Sulphur Springs. For example, surface salinity recorded about one half mile below the dam (9.1 ppt) was about twice that recorded near the spring outfall. Vertical salinity gradients were non-existent or slight at stations near the dam (miles .54 and.92), but were most pronounced at stations just upstream and downstream of the spring outfall.

The differences in density stratification between discharge and no-discharge conditions were reverse at the stations near the bay - i.e., stratification was greater during discharge conditions. The mean values in Table 4.1 reflect that when there is discharge from the dam, fresh waters tend to flow over the deeper more saline waters in the downstream portions of the lower river. Plots presented in the next section are informative for examining how salinity at these stations responds to different quantities of flow. Also, plots and regression models presented in Coastal (1997) are valuable for evaluating salinity at different depths at the WAR/SDI stations as a function of freshwater inflow.

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Table 4.2. Salinity and dissolved oxygen concentrations at additional stations in the lower Hillsborough River sampled on November 21, 1996. Salinity units are ppt and units for dissolved oxygen are mg/l.

Station	Depth	Salinity	DO
MILE=0.54 (WAR/SDI 2)	0.3	9.1	7.5
	1.0	9.1	7.0
	1.5	9.1	6.0

Station	Depth	Salinity	DO
MILE=0.92	0.3	8.4	6.0
	1.0	9.3	6.3
	2.0	9.5	5.8
	2.5	9.6	5.5

Station	Depth	Salinity	DO
MILE=1.24	0.3	7.7	5.3
	1.0	9.4	5.6
	2.0	10.9	3.7
	3.0	13.2	0.8

Station	Depth	Salinity	DO
MILE=1.72 (WAR/SDI 3)	0.3	5.1	5.1
	1.0	11.8	3.0
	2.0	15.1	1.5
	3.0	16.1	0.5
	4.0	16.2	0.4

Station	Depth	Salinity	DO
Mile 2.03	0.3	4.5	5.2
	1.0	9.1	3.7
	2.0	16.4	1.4

Sulphur Springs outfall at mile 2.2

Station	Depth	Salinity	DO
Mile 2.45	0.3	4.6	4.7
	1.0	10.8	2.9
	2.0	17.1	1.4
	2.5	17.5	1.2

Station	Depth	Salinity	DO
Mile 2.75	0.3	6.8	6.5
	1.0	10.0	3.5
	2.0	17.4	1.4
	3.0	17.9	0.9
	4.0	18.0	0.7

Station	Depth	Salinity	DO
Mile 3.1 (WAR/SDI 5)	0.3	6.7	5.4
	1.0	10.2	2.9
	2.0	18.0	1.1
	3.0	18.3	0.9

4.3.2 Flow terms used for graphic analysis. In the following sections, salinity and DO concentrations are plotted vs. discharge from the Hillsborough River Dam. Discharge quantities calculated over different time periods can be used to examine the response of salinity and DO to freshwater inflows. For example, in their correlation analysis of water quality variables and flow, WAR/SDI used the preceding 14-day average flow from the Hillsborough River Dam. In developing least squares regressions to predict salinity as a function of flow at discrete depths at these stations, Coastal (1997) found that best fit resulted from using either the preceding 3-day average flow or the same-day flow depending on the station and depth (see pages 6-2 and 6-3 in Coastal, 1997).

Due to varying effects of antecedent conditions, the District suggests there is not a single flow term that consistently provides the best answer and the response of salinity and DO to various flow terms should be examined. The effect of using different length time periods to calculate average flows is illustrated in Table 4.3, where different preceding average flow terms are listed for days when salinity was measured at Rowlett Park Drive by either the USGS, HCEPC, or WAR/SDI. The values in Table 4.3 indicate that same-day flow terms should be used with caution, as flow can be very low on a particular sampling day but high just two or three-days prior (see ranked observations 17 and 34). This effect can be even more pronounced if flows are examined back one or two weeks (e.g., observations 15 and 25), when the residual effects of a flow event on salinity could be expected in at least some portions of the lower river. Conversely, using longer flow averages may not characterize an important flow event that occurred near the time of sampling (e.g. observation 33) which may have an effect on a reactive constituent such as DO.

A notable factor in this study is that there tended to be more salinity and DO observations available at low flows if longer flow terms are used. As shown in the plots presented in Appendices C and D, there is only one observation with a 3-day flow between 2 and 30 cfs in the WAR/SDI data set (42 total sampling trips). However, there are 5 and 6 observations in that range for 8-day and 14-day flows, respectively. Similarly, for the HCEPC data at Columbus Ave. (207 total sampling trips) there are 16 observations with 3-day flows between 2 and 30 cfs, but there are 26 and 24 observations in that range for 8-day and 14-day flows. This does not mean that longer flow terms are necessarily more appropriate, ans the District suggests that comparisons between plots using various flow terms should be made to discern apparent patterns.

4.3.3. Plots of salinity vs. flow for WAR/SDI data. To examine the response of salinity to freshwater inflows, salinity measurements by WAR/SDI were plotted versus discharge at the Hillsborough River dam using four different flow terms (same-day, and preceding 3-day, 8-day and 14-day averages). All flow values were calculated from daily flow records published by the US Geological Survey for the dam, which is designated as the Hillsborough River near Tampa gage (# 02304500). Same-day flows are those flows recorded the day the salinity measurement was taken, while preceding 3-, 8- and 14-day average flows were calculated from the same-day flow plus flows from the corresponding number of preceding days (2, 7,or 13, respectively).

Table 4.3. List of four different flow terms for days when salinity was measured at Rowlett Park Drive and the corresponding 3-day flows were between 2 and 48 cfs. Values ranked by three-day flow. Source indicates agency/firm making salinity measurment. Table includes HCEPC readings taken after 1986.

RANK	DATE	3-DAY	SAME-DAY	8-DAY	14-DAY	SOURCE
1	30JAN90	2.1	1.3	5.2	17.6	HCEPC
2	14OCT81	3.3	0.4	23.6	97.9	USGS
3	15OCT81	3.3	0.4	23.6	76.4	USGS
4	06JUN82	4.3	9.8	35.2	20.7	USGS
5	13FEB82	10.2	9.0	20.0	40.2	USGS
6	14FEB82	10.5	16.0	17.2	33.6	USGS
7	11FEB82	13.2	15.0	29.1	61.3	USGS
8	12FEB82	13.9	6.6	24.0	50.5	USGS
9	09JUN82	15.0	1.5	24.2	23.6	USGS
10	15DEC92	15.8	18.0	26.6	26.8	HCEPC
11	10FEB82	17.6	20.0	31.8	71.8	USGS
12	07JUN82	17.8	42.0	40.2	23.6	USGS
13	08JUN82	17.8	1.5	40.2	23.6	USGS
14	21FEB89	23.0	23.0	23.0	23.0	HCEPC
15	09FEB82	23.6	4.7	38.7	82.1	USGS
16	15FEB82	25.0	50.0	18.7	30.5	USGS
17	02MAY82	25.1	1.6	42.9	65.8	USGS
18	08DEC92	26.3	24.0	25.5	24.4	WAR/SDI
19	01JAN82	27.9	81.0	10.9	6.5	USGS
20	21MAR95	28.3	21.0	34.5	57.3	HCEPC
21	27OCT92	29.5	36.0	92.2	209.4	HCEPC
22	29APR82	30.3	88.0	56.2	121.4	USGS
23	08FEB82	35.0	28.0	49.9	97.1	USGS
24	28NOV95	37.3	59.0	52.6	87.8	HCEPC
25	28APR82	37.9	1.4	57.6	137.5	USGS
26	12OCT93	38.7	33.0	73.4	121.2	WAR/SDI
27	07FEB82	39.3	38.0	60.0	108.1	USGS
28	23OCT90	40.3	24.0	68.8	53.9	HCEPC
29	12JAN82	41.0	40.0	55.8	66.3	USGS
30	05FEB82	41.7	41.0	89.1	143.4	USGS
31	06FEB82	42.3	39.0	74.4	124.4	USGS
32	11MAY93	44.0	18.0	31.2	17.9	WAR/SDI
33	01JUN82	44.3	130.0	17.6	10.7	USGS
34	02JUN82	44.3	1.5	17.6	10.7	USGS
35	04JUN82	45.7	1.5	34.1	20.2	USGS
36	05JUN82	45.7	1.5	34.1	20.1	USGS
37	08FEB94	48.0	39.0	62.5	71.5	WAR/SDI

Plots of salinity vs. flow are presented for combined depths at each WAR/SDI station in Appendix C. Plots are presented separately for flows up to 600 cfs and flows less than 100 cfs, so that the response of salinity to low flows can be more closely examined. All depths are shown on the same plot, so several salinity values may be shown for a given flow rate corresponding to the gradient between surface and bottom values on that sampling date. Twenty-four of the WAR/SDI sampling dates occurred during no-discharge conditions. Therefore, many observations occur near 0 cfs, which may not be readily distinct due to the close proximity of the y axis.

For comparison, plots of surface and mean water column salinity vs. 14-day flow are presented in Appendices S and T of WAR/SDI (1995). Appendix B in the Coastal (1997) report includes plots of salinity at individual depths at the WAR/SDI stations vs. same-day or 3-day flows. Coastal also developed regressions to predict salinity at the WAR/SDI stations as a function of freshwater inflow, with the exception of station number 2 near Rowlett Park Drive. Appendix M in the Coastal report lists predicted salinity values at depths from surface to 2 meters at the WAR/SDI stations as a function of flow in 10 cfs increments between 0 and 100 cfs. Predicted salinities are also listed on the following page for WAR/SDI stations 3 and 6.

The plots of the raw data and the regressions fitted by Coastal demonstrate that salinity in the river responds in a curvilinear manner, i.e., the response to flow is very steep at low flows and changes to a more gradual response at high flows. In many cases, particularly in the upper parts of the lower river (station 3 through 7), the salinity/flow relationship has an inflection where the slope of the relationship rapidly changes. At stations near the mouth of the river (9 and 10) this change is more gradual and the inflection is less clear. Such progressions in salinity/flow curves are common in tidal river estuaries, where salinity is generally most responsive to low freshwater inflows in the upper regions of the system (pages 282 - 284 in Longley, 1994; Sklar and Browder, 1998).

The plots of the WAR/SDI data and the predictive equations developed by Coastal can be used to evaluate the response of the river to various rates of flow. These results indicate that relatively small flows can substantially reduce salinity in the upper part of the lower river compared to no discharge conditions. For example, the regression results presented in Table 4.4 indicate a discharge rate of 10 cfs reduces salinity at Station 3 by 1.7 to 3.8 ppt depending on the depth. A flow of 20 cfs is predicted to reduce salinity at this same station to about half that predicted for a no-discharge condition. Higher flows are predicted to reduce salinity further, but the relationship is curvilinear and the response of salinity to flow becomes more gradual as flow increases.

TEXT CONTINUED ON PAGE 4.13

STATION 3 - RIVER MILE 1.6

SALINITIES UNDER VARIOUS FLOW CONDITIONS AT VARIOUS DEPTHS

Sulfur Springs flow constant at 31 cfs

Dam Flow (cfs)	0	10	20	30	40	50	60	70	80	90	100
0 meter	5.80	4.06	3.01	2.32	1.84	1.50	1.24	1.05	0.90	0.78	0.68
1 meter	8.78	5.69	3.94	2.87	2.17	1.69	1.34	1.09	0.90	0.76	0.64
2 meters	11.70	8.49	6.48	5.12	4.16	3.46	2.93	2.51	2.18	1.91	1.70
Bottom	12.21	8.37	6.08	4.61	3.61	2.91	2.39	1.99	1.69	1.45	1.26

STATION 6 - RIVER MILE 3.5

SALINITIES UNDER VARIOUS FLOW CONDITIONS AT VARIOUS DEPTHS

Sulfur Springs flow constant at 31 cfs

Dam Flow (cfs)	0	10	20	30	40	50	60	70	80	90	100
0 meter	5.64	4.64	3.89	3.32	2.87	2.51	2.21	1.97	1.77	1.60	1.45
1 meter	10.58	8.51	7.00	5.86	4.99	4.30	3.74	3.29	2.92	2.61	2.34
2 meters	16.21	13.82	11.99	10.54	9.36	8.40	7.60	6.92	6.34	5.84	5.40
Bottom	17.22	14.81	12.93	11.44	10.23	9.23	8.39	7.68	7.07	6.53	6.07

Table 4.4 Predicted salinities at WAR/SDI stations 3 and 6 using regression equations from Coastal (1997).

4.3.4 Dissolved oxygen concentrations during discharge and no-discharge conditions from the Hillsborough River dam. The District generated plots and statistical analyses of dissolved oxygen (DO) data from the hydrobiological study in addition to those results presented in the other reports (WAR/SDI, 1995; Coastal, 1997). Statistical summaries of DO values for discrete depths at the various stations in the Lower Hillsborough River for discharge and no-discharge conditions at the Hillsborough River dam are presented in Table 4.5.

Mean DO concentrations at stations 2 through 6 were higher for discharge conditions than for no-discharge conditions. This corresponds to the findings of WAR/SDI (1995) and Coastal (1997), who both found significant positive relationships between DO and flow at these stations. Particularly striking are the low values at depth for the no-discharge conditions. Mean values less than 3 mg/l were found at 1 meter depth for stations 3, 5 and 6. Mean values were below 2 mg/l at 2 meters depth, while means for bottom waters ranged from 0.9 to 1.0 mg/l at these stations. These steep vertical gradients in DO concentrations are probably related to reduced circulation and vertical density gradients observed at these stations during no-discharge conditions. Although not as severe, low DO concentrations during no-discharge conditions were also observed at Station 2, whereas waters were typically well-oxygenated when there was flow at the dam. At the downstream stations (7, 8, 9, and 10), differences in DO concentrations between discharge and no-discharge conditions were very slight.

4.3.5 Plots of DO vs. flow for WAR/SDI stations Plots of DO vs. flow for WAR/SDI stations in the lower Hillsborough River are presented in Appendix D. The same flow terms (same-day, preceding 3, 8, and 14-day average flow) are used as for the plots of salinity vs. flow. Compared to salinity, there was considerably more scatter in the relationships of DO with freshwater inflow. This is not unexpected since DO is a reactive constituent that can be quickly affected by factors such as temperature, respiration, or photosynthesis.

There was a strong positive response of DO to flow at Station 2 for all four flow terms. Seventeen percent of the DO measurements at station 2 were below 2.0 mg/l during no-discharge conditions. However, values consistently above 2.8 mg/l were observed at flows above 8 cfs for 8-day flows, 18 cfs for same-day flows, and 26 cfs for 3-day flows. Values were consistently above 4 mg/l for same-day and 3-day flows above 33 and 44 cfs, respectively. Although the data are limited, breaks in the DO curves at station 3 appear to be near 40 cfs for same-day and 3-day flows. In general, longer flow terms appeared to produce results that are not clear-cut for stations near the dam, and shorter flow terms may be more appropriate for evaluating DO/flow relationships near the dam.

Although there was a positive response of DO to flow at Stations 5, 6 and 7, this relationship was only apparent at high flows and did not really apply for all depths at flows less than 130 cfs. The response of DO to flow at the lower stations (8, 9, and 10) was less clear. Longer flow terms (8- and 14-day) indicated a positive response to high flows (> 130 cfs) at station 8. Conversely, a high flow response was not clear at stations 9 and 10, but some positive response to low flows was possibly indicated. As discussed later, data from the USGS and the Hillsborough County Environmental Protection Commission from locations near the lower WAR/SDI stations provide more temporally extensive data for DO in the lower reaches of the river.

Table 4.5. Means and standard deviations for [illegible] WAR/SDI stations for discharge and no-discharge conditions. Unless noted in parentheses for 3 M depth, the number of observations (N) is 18 for discharge and 24 for no-discharge conditions. All values expressed as mg/l.

	DISCHARGE (3-day flows > 2 cfs)	NO-DISCHARGE (3-day flows < 2 cfs)
Station 2		
Surface	6.9 ± 2.2	4.7 ± 2.0
1 M	6.5 ± 2.4	3.8 ± 2.3
2 M	6.2 ± 2.4	3.4 ± 2.3
3M	6.1 2.1 (2)	1.9 ± 0.8 (3)
Bottom	6.1 ± 2.3	3.3 ± 2.3
Station 3		
Surface	6.0 ± 1.6	3.7 ± 2.0
1 M	5.6 ± 1.8	2.1 ± 1.7
2 M	4.9 ± 2.2	1.3 ± 1.5
3M	4.7 ± 2.5 (12)	1.0 ± 1.5 (15)
Bottom	4.8 ± 2.2	1.0 ± 1.4
Station 5		
Surface	5.4 ± 1.7	4.5 ± 2.2
1 M	4.4 ± 2.1	2.5 ± 1.6
2 M	3.2 ± 2.7	1.3 ± 1.3
3M	3.5 ± 2.9 (10)	1.0 ± 1.2 (19)
Bottom	2.9 ± 2.8	0.9 ± 1.0
Station 6		
Surface	5.6 ± 1.6	4.7 ± 2.4
1 M	4.2 ± 2.6	2.8 ± 2.2
2 M	3.0 ± 2.7	1.3 ± 1.1
3M	2.5 ± 2.5 (9)	0.9 ± 1.0 (14)
Bottom	2.6 ±2.4	1.1 ± 1.1
Station 7		
Surface	5.6 ± 1.9	5.6 ± 1.9
1 M	4.2 ± 1.9	3.6 ± 1.9
2 M	2.7 ± 2.2	2.4 ± 1.5
3 M	2.3 ± 2.0 (11)	1.3 ± 1.1 (9)
Bottom	2.2 ± 2.0	2.1 ± 1.5
Station 8		
Surface	6.6 ± 3.5	6.1 ± 2.1
1 M	4.7 ± 2.5	4.7 ± 1.9
2 M	3.2 ± 1.7	3.3 ± 1.4
3 M	2.4 ± 1.7 (12)	2.0 ± 1.7 (14)
Bottom	2.4 + 1.6	2.7 + 1.6
Station 9		
Surface	6.1 ± 2.5	6.2 ± 2.1
1 M	4.9 ± 1.8	5.1 ± 2.1
2 M	4.1 ± 1.9	4.2 ± 1.9
3 M	3.3 ± 1.5 (15)	3.6 ± 1.6
Bottom	3.3 ± 2.0	3.6 ± 1.6
Station 10		
Surface	6.2 ± 2.4	6.1 ± 1.7
1 M	5.3 ± 2.2	5.6 ± 1.6
2 M	4.8 ± 2.3	4.9 ± 1.6
3 M	4.2 ± 2.7 (17)	4.5 ± 1.9
Bottom	4.2 ± 2.6	4.5 ± 2.0

4.4. Salinity and Dissolved Oxygen Data from USGS continuous recorders on the Lower Hillsborough River

The USGS operated four continuous recorders on the Lower Hillsborough River during the early 1980s in support of studies associated with the National Urban Runoff Program (NURP) for the Lower Hillsborough River. These data were provided to District, who performed analyses of the data and also provided the data base to the TBNEP for additional analyses by Coastal Environmental (1997). The USGS recorders measured data in fifteen minute intervals for water level, water temperature, specific conductance, and DO concentration. The recorders were located at Rowlett Park Drive, Sligh Avenue, Columbus Avenue, and Platt Street (Figure 4.1). All values were recorded by fixed probes at approximately mid-depth. The period of record differed slightly at the various locations, but the recorders generally ran from October 1991 through September 1992 with some missing records due to periodic meter malfunction. The data were reviewed for quality control by the USGS before they were delivered to the District. Analyses of these data are also presented in the report by Metcalf and Eddy (1983).

Water temperature and specific conductance data from the USGS recorders were used to estimate salinity. Percent saturation values for DO were calculated from the temperature and DO values. Although the raw data measured in fifteen minute intervals were analyzed, most of the District's analyses of the relationships of salinity and DO to flow used daily mean, minimum, or maximum values.

4.4.1 Salinity. Means, standard deviations, and number of observations for mid-depth salinity values at the USGS recorders are listed in Table 4.5 for discharge and no-discharge conditions at the Hillsborough River dam. Statistics were calculated separately from populations of daily salinity averages and daily minima and maxima. Daily salinity ranges were calculated as the difference between the daily maximum and minimum. No-discharge conditions are categorized as three-day average flows of less than 2 cfs.

The USGS Rowlett Park Drive station is very close to the WAR/SDI station 2. The USGS results are very similar to the WAR/SDI results in that fresh water was observed at Rowlett Park during discharge conditions, whereas a mean salinity of 4.3 ppt was observed during no-discharge. The USGS probe was near 1 meter in depth and the salinity average at one meter at WAR/SDI station 2 was 6.2 ppt. The lower value for the USGS data may be due to the relatively wet conditions which occurred during that study. The total rainfall at Lowry Park during the year when most of the USGS data were collected (October 1981 - September 1982) was 81.7 inches. Even during periods of no-discharge, runoff to the lower river from the watershed below the dam can have a significant effect on salinity in the river. By comparison, the average yearly rainfall total for the three year period of the WAR study was 53.0 inches. In the USGS data set there were more salinity observations during discharge conditions, whereas in the WAR/SDI data set there were more observations during no-discharge conditions.

Table 4.6. Means plus or minus one standard deviation and number of observations (N) for daily mid-depth salinity at USGS continuous recorders for discharge and no-discharge conditions. All values except N are expressed as parts per thousand.

	Discharge Three-day flows > 2	N	No-discharge Three-day flows < 2	N
Rowlett Park Drive				
Daily salinity average	0.06 ± 0.1	(222)	4.3 ± 2.8	(120)
Daily salinity minimum	0.04 ± 0.1		3.6 ± 2.5	
Daily salinity maximum	0.09 ± 0.3		5.0 ± 3.1	
Daily salinity range	0.04 ± 0.2		1.7 ± 1.2	
Sligh Ave.				
Daily salinity average	2.0 ± 3.0	(203)	12.1 ± 4.7	(85)
Daily salinity minimum	1.4 ± 2.5		10.5 ± 4.1	
Daily salinity maximum	2.6 ± 3.8		13.1 ± 5.2	
Daily salinity range	1.2 ± 2.2		2.6 ± 2.7	
Columbus Ave.				
Daily salinity average	8.6 ± 5.1	(147)	17.0 ± 4.6	(118)
Daily salinity minimum	4.1 ± 3.9		14.2 ± 5.7	
Daily salinity maximum	15.5 ± 7.0		19.9 ± 4.1	
Daily salinity range	11.4 ± 5.8		5.7 ± 3.6	
Platt St.				
Daily salinity average	14.8 ± 6.3	(261)	22.0 ± 2.9	(120)
Daily salinity minimum	8.6 ± 6.1		19.0 ± 4.5	
Daily salinity maximum	19.7 ± 5.6		23.9 ± 2.4	
Daily salinity range	11.2 ± 4.2		4.9 ± 3.7	

Comparisons between the Sligh Avenue station for the USGS and the nearby WAR/SDI station 6 are more difficult because of the steep vertical gradients for salinity at the WAR/SDI station. Since salinity can vary considerably over relatively small depths, error could result comparing the fixed probe data to a specific depth measured by WAR/SDI. Regardless, the results are somewhat similar. Mean salinity for the USGS recorder during discharge conditions was 2.0 ppt compared to an average of 3.9 ppt in the top two meters at WAR/SDI station 6. Mean salinity during no-discharge conditions was 12.1 ppt for the USGS recorder, while the WAR/SDI average during no-discharge conditions was 10.5 ppt.

The USGS recorder at Columbus Avenue is very near WAR/SDI station 9. Again, comparison of the fixed probe USGS data to a specific depth in the WAR/SDI data set is difficult. The daily salinity average at the USGS recorder was 8.6 ppt during discharge conditions and 17.0 ppt during no-discharge conditions. Mean salinity at the USGS recorder at Platt St. was 14.8 ppt during discharge conditions, which is 6.2 ppt greater than the corresponding mean value at Columbus Ave. This relatively large difference indicates an increased role of Hillsborough Bay on salinity in the river near its mouth.

An interesting pattern is seen in the daily salinity ranges during discharge and no-discharge conditions. At Sligh Avenue, there are relatively small daily variations in salinity during discharge conditions, as this station was either fresh or had very low salinity. Conversely, the mean range in daily salinity becomes much greater at Columbus Ave. and Platt St. during discharge conditions, as the freshwater/saltwater mixing zone is located in this zone of the river and moves back and forth with the tides. During periods of no discharge, salinity values at these stations were higher and more stable.

<u>4.4.2 Plots of salinity vs. flow at USGS recorders</u> Daily values of mean and maximum salinity at the four USGS recorders are plotted separately vs. discharge at the Hillsborough River dam in Appendix E. The same four flow variables are used as for the WAR/SDI data (same-day, prior 3-day, 8-day, and 14-day average flow). Plots are presented separately for low flows and an expanded flow range. The upper flow limit of the expanded flow range was based on when a station became consistently fresh (there were additional observations at high flows).

The USGS plots show an interesting progression downstream that is characteristic of tidal rivers. The plots at Rowlett Park are nearly "L" shaped, exhibiting a wide range of salinity values during no-discharge conditions that quickly change to fresh water at low flows. Curves at Sligh Avenue are strongly curvilinear with a rapid decrease in salinity at low flows changing to a more gradual slope as flow increases. The plots at Columbus Avenue are hampered by a lack of observations in the 400 to 700 cfs range, but a more gradual curve is exhibited compared to Sligh Avenue. The relationship of salinity to flow at Platt St. is more linear, but very weak at flows between 0 and 100 cfs.

With the exception of Platt St., all the plots show a much wider range of salinity at zero flow compared to the range of values at even small reservoir releases. For example, daily average salinity values above 14 ppt. at Sligh Ave. and values above 20 ppt at Columbus Ave. were restricted to no-discharge periods. This may indicate that relatively small reservoir releases help prevent high-end salinities from occurring at these stations. Conversely, these high values during no-discharge periods may reflect a lack of recent rainfall. As discussed later, the highest salinity values during no-discharge periods occurred after prolonged dry periods when direct runoff to the lower river from the drainage basin below the dam had been low for quite sometime. Similarly, Metcalf and Eddy (1983) found that stormwater runoff below the dam reduced salinity in the river during times of low freshwater inflows.

Because of differences in the frequencies of measurement, caution should be used in comparing plots of salinity versus flow from the USGS recorders to plots generated from data collected by the other sources (WAR/SDI and Hillsborough County EPC). The USGS data are recorded at 15 minute intervals which were reduced for this report to produce daily mean and maximum values. In many cases these daily values are serially correlated, as salinity values on a number of successive days were related to what were largely the same antecedent conditions. In this regard, the USGS data are in effect not as numerous as they might first appear. For example, the plot of salinity versus 3-day flows on Appendix page E-2 shows there were eleven salinity values with corresponding flows between 3 and 20 cfs. However, as shown in Table 4.7 below, these eleven data points were recorded during only three sets of successive days during that study year.

Table 4.7. Dates, flows, and mid-depth salinity values for days with 3-day flows between 3 and 20 cfs during operation of the USGS recorder at Rowlett Park Drive. Flows are cubic feet per second (cfs) and salinity is parts per thousand (ppt).

Date	Salinity	3-Day Flow	Same-Day Flow
14OCT81	0.2	3.3	0.4
15OCT81	0.3	3.3	0.4
10FEB82	0.1	17.6	20.0
11FEB82	0.1	13.2	15.0
12FEB82	0.1	13.9	6.6
13FEB82	0.1	10.2	9.0
14FEB82	0.1	10.5	16.0
06JUN82	0.4	4.3	9.8
07JUN82	0.2	17.8	42.0
08JUN82	0.1	17.8	1.5
09JUN82	0.2	15.0	1.5

Examination of the daily flow records indicate that for each of these sets, low salinity values were probably related to high flow events that occurred sometime prior. For example, the low salinity values listed for June 6th to 9th, 1982 were probably related to daily flows of 130 and 134 cfs that occurred at the beginning of that month. The daily USGS data are valuable, but the number of independent observations is considerably less than what is indicated by the plots. This situation is not so pronounced in the WAR/SDI and HCEPC data sets, as salinity readings were recorded approximately one month apart, thus reducing the serial correlation between observations.

4.4.3 Regression models of salinity and flow The USGS recorder data were provided to Coastal Environmental who developed regression equations to predict salinity at the Sligh and Columbus locations. Those results are presented in Appendix M in Coastal (1997) and in Table 4.8. Similar to the WAR/SDI data, the regressions show a rapid response of salinity to flow at low rates of reservoir discharge. Although there is serial correlation in the daily USGS values, we do not believe this contributed to any bias in the regression equations developed for the Sligh Ave. and Columbus Ave. stations.

The USGS data at Rowlett Park did not lend itself to model development due to the unique L-shaped nature of the salinity flow relationship. The amount of water that is needed to maintain fresh water at Rowlett Park is discussed further in Section 4.6, where the USGS data are combined with the WAR/SDI and Hillsborough County data at that site.

4.4.4 Dissolved oxygen Means, standard deviations, and number of observations for mid-depth DO values at the USGS recorders are listed below for discharge and no-discharge conditions at the Hillsborough River dam (Table 4.9). Statistics were calculated separately from daily average, minimum, maximum, and range values. Daily ranges in DO were calculated as the difference between the daily maximum and minimum.

The results for Rowlett Park and Sligh Avenue are similar to the WAR/SDI data for those sites (stations 2 and 6) in that DO concentrations were markedly higher during discharge conditions. Mean values for daily averages and daily minima were between 4 and 6 mg/l at these stations during periods of dam discharge. During no-discharge conditions, however, mean values for daily averages were 3.5 mg/l at Rowlett Park and 2.5 mg/l at Sligh Avenue. Means of daily minima during no-discharge conditions were 2.7 mg/l at Rowlett Park and 1.1 mg/l at Sligh Avenue. The means of daily ranges in DO were also higher during no-discharge conditions, indicating large diurnal swings in DO during periods of no discharge. Flow from the dam diminishes these swings by increasing turbulence and aeration in the river. As discussed in Section 4.8, HCEPC water quality data indicate that large chlorophyll a and biochemical oxygen demand concentrations at Rowlett Park are limited to periods of no discharge at the dam.

The mean for average daily DO values was greater for discharge than for no-discharge conditions at the USGS Columbus Avenue recorder- a pattern that was not observed for nearby WAR/SDI station 9. Mean DO values at the Platt St. recorder were slightly lower for discharge conditions than for no-discharge - a pattern that was observed at the nearby WAR/SDI station at Kennedy Blvd. Overall, these results indicate that the effect of flow on DO are greatest in the upper portions of the Lower Hillsborough River.

Continuous Monitoring Station Models
Flow from Dam + 31 cfs from Sulphur Springs

STREET Columbus Dr.	FLOWVAL										
	0	10	20	30	40	50	60	70	80	90	100
	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)
	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM
DEPTH											
Mid-depth	21.56	18.53	16.19	14.32	12.80	11.55	10.50	9.60	8.84	8.17	7.59

STREET Sligh Ave.	FLOWVAL										
	0	10	20	30	40	50	60	70	80	90	100
	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)	Predicted Salinity (ppt)
	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM	SUM
DEPTH											
Mid-depth	11.64	9.39	7.74	6.51	5.55	4.79	4.19	3.69	3.28	2.93	2.64

Table 4.8. Predicted salinities at USGS recorders at Sligh Avenue and Columbus Drive. Reprinted from Coastal (1997).

Table 4.9. Mean plus or minus one standard deviation and number of observations (N) for daily mid-depth dissolved oxygen values at the continuous USGS recorders for discharge and no-discharge conditions. All values except N are expressed in milligrams per liter.

	Discharge Three-day flows > 2		No-Discharge Three -day flows < 2	
Rowlett Park Dr.				
Daily D.O. averages	6.0 ± 1.2	(192)	3.7 ± 1.6	(96)
Daily D.O. minima	5.4 ± 1.2		2.7 ± 1.5	
Daily D.O. maxima	6.6 ± 1.4		5.4 ± 1.9	
Daily D.O. ranges	1.2 ± 0.9		2.8 ± 1.5	
Sligh Ave.				
Daily D.O. averages	4.8 ± 1.1	(175)	2.5 ± 1.4	(43)
Daily D.O. minima	4.1 ± 1.3		1.1 ± 1.1	
Daily D.O. maxima	5.9 ± 1.6		4.6 ± 2.3	
Daily D.O. ranges	1.8 ± 1.5		3.5 ± 2.1	
Columbus Ave.				
Daily D.O. averages	4.4 ± 1.2	(142)	3.4 ± 1.7	(70)
Daily D.O. minima	3.1 ± 1.3		1.5 ± 1.5	
Daily D.O. maxima	5.6 ± 1.3		5.8 ± 2.0	
Daily salinity ranges	2.5 ± 1.5		4.2 ± 1.5	
Platt St.				
Daily D.O. averages	3.0 ± 1.4	(241)	3.7 ± 1.5	(91)
Daily D.O. minima	1.5 ± 1.4		1.8 ± 1.7	
Daily D.O. maxima	4.7 ± 1.9		6.3 ± 1.5	
Daily D.O. ranges	3.2 ± 1.5		4.5 + 1.8	

4.4.5 Plots of dissolved oxygen vs. flow at the USGS stations   Plots of mean and minimum DO concentration vs. flow for the four USGS recorders are presented in Appendix F. Like salinity, plots of daily average DO vs. flow at Rowlett Park are L-shaped but are in reverse - relatively small flows at the dam result in higher DO concentrations. The same-day and 3-day plots at this site are limited to few observations at low flows (2 to 30 cfs), but the plot with 8-day flows shows an almost linear increase in DO between 10 and 100 cfs. Similar to the WAR/SDI plots, the 14-day flow seems to be too long to be meaningful at this station since the results do not closely agree with the other flow terms. Plots of minimum daily DO show that values above 4 mg/l were almost consistently observed at flows above 40 to 50 cfs for 3-day and 8-day flows.

Plots at Sligh Avenue similarly showed a strong L-shaped response to flow, but not quite as distinct or with as low a breakpoint as Rowlett Park. Same-day flows showed the most immediate response to discharge as flow rates near 10 cfs resulted in values near 4 mg/l. Plots of daily average and minimum DO showed a generally positive response to flows in the 0 to 300 cfs range for all four flow terms examined.

Plots of daily average DO vs flow at Columbus Avenue showed an interesting pattern in that the variability in DO decreased with flow to form somewhat of a wedge shaped figure. Marked improvements in DO at low flows were observed around 6 cfs for same-day flows and 25 cfs for 14-day flows. Minimum daily DO values generally increased with flow, with possible break-points around 6 cfs for same-day flow and 25 cfs for 14-day flows. Because of the distance from the dam, longer flow terms may be more meaningful at Columbus Avenue and other downstream stations compared to the upper stations (Rowlett Park and Sligh).

Relationships of DO to flow were not as pronounced at Platt St. compared to the other stations. Average values of less than 2 mg/l persisted at flows as high as 800 to 900 cfs. However, there did seem to be some general positive response at flows above 500 cfs. Minimum daily values less than 1.0 mg/l persisted up to flows of 1000 to 1300 cfs. As with salinity, the differences between Platt St. and Columbus Avenue are striking and demonstrate markedly different responses to discharge at the dam, presumably due to the greater influence of Hillsborough Bay at Platt St.

4.5. Salinity and Dissolved Oxygen Data from the Hillsborough County Environmental Protection Commission.

As part of their regular monitoring network, the Hillsborough County Environmental Protection Commission (HCEPC) measures water quality at three locations on the Lower Hillsborough River (Rowlett Park Drive, Columbus Avenue, and Platt St). Sampling is on a monthly basis. In situ water quality measurements are taken with portable meters and water samples are taken to the laboratory for chemical analysis. Salinity and DO concentrations for surface (0.5 m depth), mid-depth and bottom waters (1 m from bottom) from the HCEPC data base were analyzed for the District's minimum flows evaluation. Salinity and DO data from the HCEPC analyzed for this study generally ranged from 1974 to 1995. Monthly data for mid-depth measurements began in 1974, while data for surface and bottom water measurements began on a regular monthly basis in 1987.

4.5.1. Salinity Means, standard deviations and the number of observations for top and bottom water salinity values from the HCEPC data base are listed below for discharge and no-discharge conditions at the Hillsborough River Dam. The HCEPC data are like the USGS data (and unlike WAR/SDI) in that there are more observations for discharge conditions than for no-discharge. The number of observations differ between stations for both discharge and no discharge, and there are more observations for mid-depth due to its longer period of record.

Table 4.10. Means plus or minus one standard deviation and number of observations (N) for surface, mid-depth and bottom salinity values from the HCEPC data base for discharge and no-discharge conditions. All values except N are expressed as parts per thousand.

	Discharge (3-day flows > 2 cfs)	No-Discharge (3-day flows < 2 cfs)
ROWLETT Park Dr.		
Salinity-surface	0.4 ± 0.4 (71)	5.0 ± 3.5 (47)
Salinity-middle	0.5 ± 1.0 (170)	4.7 ± 3.5 (102)
Salinity-bottom	0.5 ± 0.5	5.5 ± 3.5
Columbus Ave.		
Salinity-surface	4.0 ± 3.6 (68)	15.4 ± 3.7 (52)
Salinity-middle	8.7 ± 8.4 (129)	20.4 ± 4.2 (76)
Salinity-bottom	18.3 ± 8.9	24.7 ± 2.4
Platt St.		
Salinity-surface	15.2 ± 7.5 (122)	25.0 ± 4.8 (75)
Salinity- middle	18.6 ±7.7 (167)	26.6 ± 4.6 (98)
Salinity-bottom	22.4 ± 5.8	27.5 ± 3.0

Mean salinity values for the HCEPC station at Rowlett Park Drive are very similar to the results for WAR/SDI and USGS data for both discharge and no-discharge conditions. Freshwater typically occurs at Rowlett Park when there is discharge from the dam, but salinity averages 5 ppt during times of no discharge. The HCEPC mean salinity values for surface and bottom waters at Columbus Avenue are very similar to the mean surface and 3 meter values at nearby WAR/SDI station 9. The HCEPC mid-depth means at Columbus are similar to means for the USGS recorder, although the HCEPC data represents a much longer period of record. Like the WAR/SDI data, HCEPC salinity values at Platt Street show reduced surface salinities and some vertical stratification during discharge periods, and more vertically homogeneous salinity values during no discharge.

Surface, mid-depth, and bottom salinity values from the HCEPC stations are plotted separately vs. flow at the Hillsborough River dam in Appendix G. There are considerably more salinity data at low flows for mid-depth, compared to surface and bottom. The Rowlett Park station is shallow and the data indicate that pronounced vertical stratification is not common. Therefore, mid-depth salinity values may be fairly representative of the entire water column at that site.

Similar to the USGS data, the salinity response at Rowlett Park is quite abrupt, as freshwater conditions are fairly consistent at flows above 20 to 30 cfs depending on the flow term that is used. Below that range salinity values showed some variation, probably due to different tide stage and antecedent rainfall conditions at time of sampling. It also appears that some rounding of values occurred in the HCEPC data base, as salinity values of 1.0 ppt were reported in excess of 500 cfs.

The response of surface and mid-depth salinity at Columbus Ave. is strongly curvilinear. Surface salinity values above 16 ppt were restricted to periods of no discharge, and relatively small flows (10 to 30 cfs) seem to prevent high surface salinity values from occurring at this station. Mid-depth salinity also has a curvilinear response, but the response at low flows is more subdued as values above 20 ppt up to about 80 to 90 cfs. Salinity in bottom waters is not as responsive, and salinity generally remained above 20 ppt at flows up to 100 cfs

Plots of surface salinity vs. flow at Platt St. are more curvilinear than plots using the USGS mid-depth probe, indicating that salinity in the surface layer at Platt St. is more responsive to flow than slightly deeper waters. Plots of same-day and 3-day flows indicate that flows in the range of 10 to 20 cfs should keep surface salinity below 25 ppt most of the time. Plots of mid-depth salinity show that values above 30 ppt can occur during no discharge, but values are more stable without the high values at small rate of dam discharge. Plots of bottom salinity vs. flow at Platt St. have considerable scatter and a generally weaker response to flow. There were more observations with salinity greater than 30 ppt for mid-depth than bottom, probably due to the longer period of record.

4.5.2 Dissolved oxygen Means, standard deviations, and number of observations for DO concentrations from the HCEPC data base are listed on the following page for discharge and no-discharge conditions at the Hillsborough River Dam.

The HCEPC data for DO at Rowlett Park are similar to the other two data sets as there are substantial differences in mean DO concentrations between discharge and no-discharge conditions. However, there are only slight differences (< 0.3 mg/l) in means between discharge and no-discharge conditions at Columbus Ave., whereas the means for no-discharge at Platt St. are 0.6 to 0.9 mg/l higher than the corresponding discharge means. In general, these results plus other sources of information for the river (Metcalf and Eddy, 1983; WAR/SDI, 1995; Coastal, 1997) indicate that the response of DO to discharge from the reservoir is more pronounced the closer one gets to the dam.

Table 4.11. Means plus or minus one standard deviation and number of observations (N) for surface, mid-depth, and bottom water DO concentrations from the HCEPC data base for discharge and no-discharge conditions.

	Discharge (Three-days flows > 2 cfs)		No-discharge (Three-day flows < 2 cfs)	
Rowlett Park Dr.				
Dis. oxygen-surface	6.9 ± 1.6	(69)	3.6 ± 1.7	(49)
Dis. oxygen-middle	6.7 ± 1.8	(170)	4.0 ± 2.8	(104)
Dis. oxygen-bottom	6.8 ± 1.8		2.5 ± 1.8	
Columbus Ave.				
Dis. oxygen-surface	5.0 ± 1.7	(69)	5.2 ± 1.8	(42)
Dis. oxygen-middle	4.2 ± 2.1	(133)	3.9 ± 1.7	(78)
Dis. oxygen-bottom	3.2 ± 2.0		3.4 ± 1.6	
Platt St.				
Dis. oxygen-surface	5.2 ± 1.8	(101)	6.1 ± 1.8	(70)
Dis. oxygen-middle	4.8 ± 1.9	(167)	5.4 ± 1.7	(98)
Dis. oxygen-bottom	4.0 ± 2.4		4.6 ± 1.9	

Surface, middle and bottom values of DO concentrations at the HCEPC stations are plotted separately vs. flow at the Hillsborough River dam in Appendix H. As with salinity, there are considerably more observations for mid-depth values at low flows. An L-shaped curve is again observed at Rowlett Park, with many low values recorded during no-discharge but DO showing a rapid positive response to small amounts of flow. The plots of mid-depth values with same-day and 3-day flows indicate that flows as low as 5 to 10 cfs are effective at raising DO above 3 to 4 mg/l. Plots of 8-day and 14-day flows indicate that flows of up to 40 cfs may be needed to raise DO above the 4/mg/l threshold, but the use of longer flow terms to assess the DO response at the Rowlett Park station may be questionable. Although the data are more limited, surface and bottom DO concentrations show similar flow relationships, indicating this site is well mixed during periods of discharge from the dam.

Plots of surface DO vs. flow at Columbus Avenue were roughly similar to the USGS data in that the variability of DO generally decreased with flow. Although the data are limited and there was considerable scatter, there was a general positive response of surface DO to flow with breakpoints in the 20 to 30 cfs range for same-day and 3-day flows, and 5 to 20 cfs range for 8-day and 14-day flows. Mid-depth values may also indicate a positive response to low flows, but like surface values the relative lack of data at low flow limits interpretation, as the greater number of values below 2.0 mg/l at no discharge might simply be due to the much larger number of total observations. Bottom DO values had a much weaker response to flow, as values less than 2 mg/l persisted up to flows of 800 to 1000 cfs. There was no clear response of DO to flow at Platt St., although there may be some indication that low flows (10 to 30 cfs) can result in some improvement of low (<4.0 mg/l) DO concentrations.

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4.6 District Analysis of Combined Data to Evaluate Flows that Result in Fresh Water at Rowlett Park Drive

A question that arose from the minimum flows evaluation was what quantity of flow from the Hillsborough River Reservoir is needed to maintain a freshwater or low salinity zone below the dam. To address this question, the relationship of salinity at Rowlett Park Drive to the rate of discharge from the dam was given further evaluation. The salinity data base at Rowlett Park Drive is extensive, as this site was sampled by all three groups that collected data for the lower river (USGS, HCEPC, and WAR/SDI).

The analyses presented below were conducted on the combined salinity data base for the Rowlett Park Drive location. Surface water salinity measurements from the HCEPC and WAR/SDI data sets were combined to produce a surface salinity variable. Similarly, bottom salinity measurements from these two data sets were combined to produce a bottom salinity variable. Daily mean salinity values from the USGS recorder, mid-depth values from the HCEPC, and the 1-meter depth measurements from the WAR/SDI data set were combined to produce a mid-depth salinity variable. Caution should be used in combining data from different agencies, as differences in field meters, sampling locations, and reporting procedures can introduce error into the analysis. However, due to the need to evaluate relationships of freshwater inflows to salinity at this site, combining data from the different agencies was determined to be valuable.

All totaled, there were 636 observations for mid-depth salinity and 140 observations for surface and bottom salinity at the Rowlett Park location in the combined data set. There are more observations for mid-depth salinity because it includes data from the USGS recorder and there is a longer period of record for mid-depth salinity in the HCEPC data than for surface or bottom. One factor that was discussed by the advisory group facilitated by the TBNEP was the number of observations for salinity and other variables during low flows from the dam (Appendix N_1, page 30. The TBNEP advisory group focused primarily on the WAR/SDI data, with some discussion of the USGS data and very little discussion of the HCEPC data. In the combined data set (which was not evaluated by the TBNEP) there are 36 total dates having mid-depth salinity measurements at Rowlett Park Drive with corresponding three-day flows between 2 and 30 cfs. However, if longer average flow terms are used there are more observations in the 2 to 30 cfs range. There are 56 dates with salinity measurements that have 8-day flows in the 2 to 30 cfs range, and 69 dates with salinity measurements that have 14-day flows in the 2 to 30 cfs range.

Plots of surface, mid-depth, and bottom salinity at Rowlett Park vs. same-day, 3-day, 8-day and 14-day flow are shown in Figures 4.2, 4.3 and 4.4, respectively. Plots are limited to flows less than 60 cfs so that the response to low flows can be more closely examined. These plots show there can be considerable variation in salinity at Rowlett Park during low flows. This may be partly due to tidal effects, as tide phase varied among sampling dates. On days during low reservoir discharge, salinity could have differed substantially between low and high tides. This source of variation is reduced in the USGS data because these values are daily averages. However, daily and seasonal variations in tides could still affect salinity during low flows. Also, there is a considerable catchment area below the dam that drains directly to the lower river (see

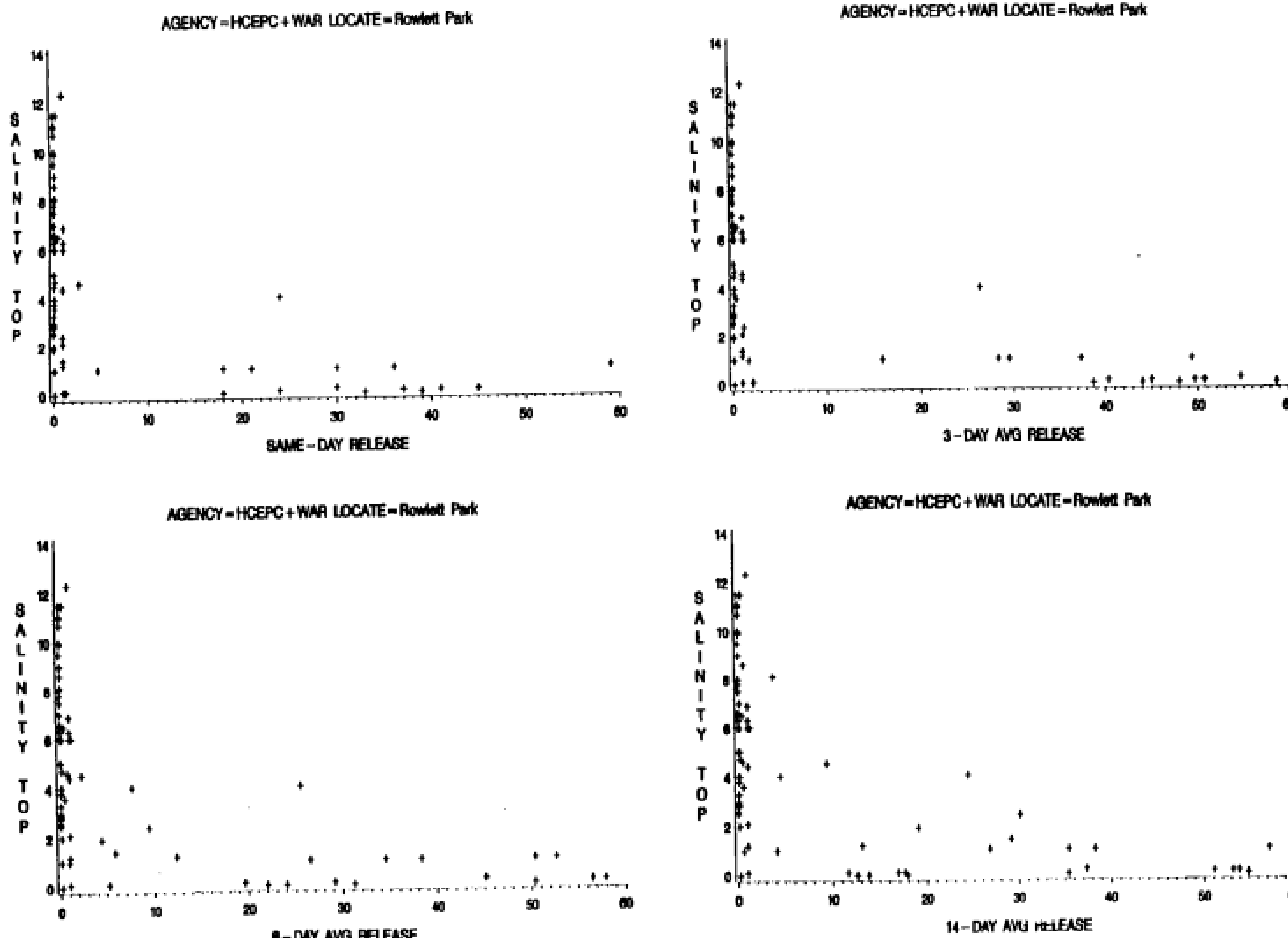
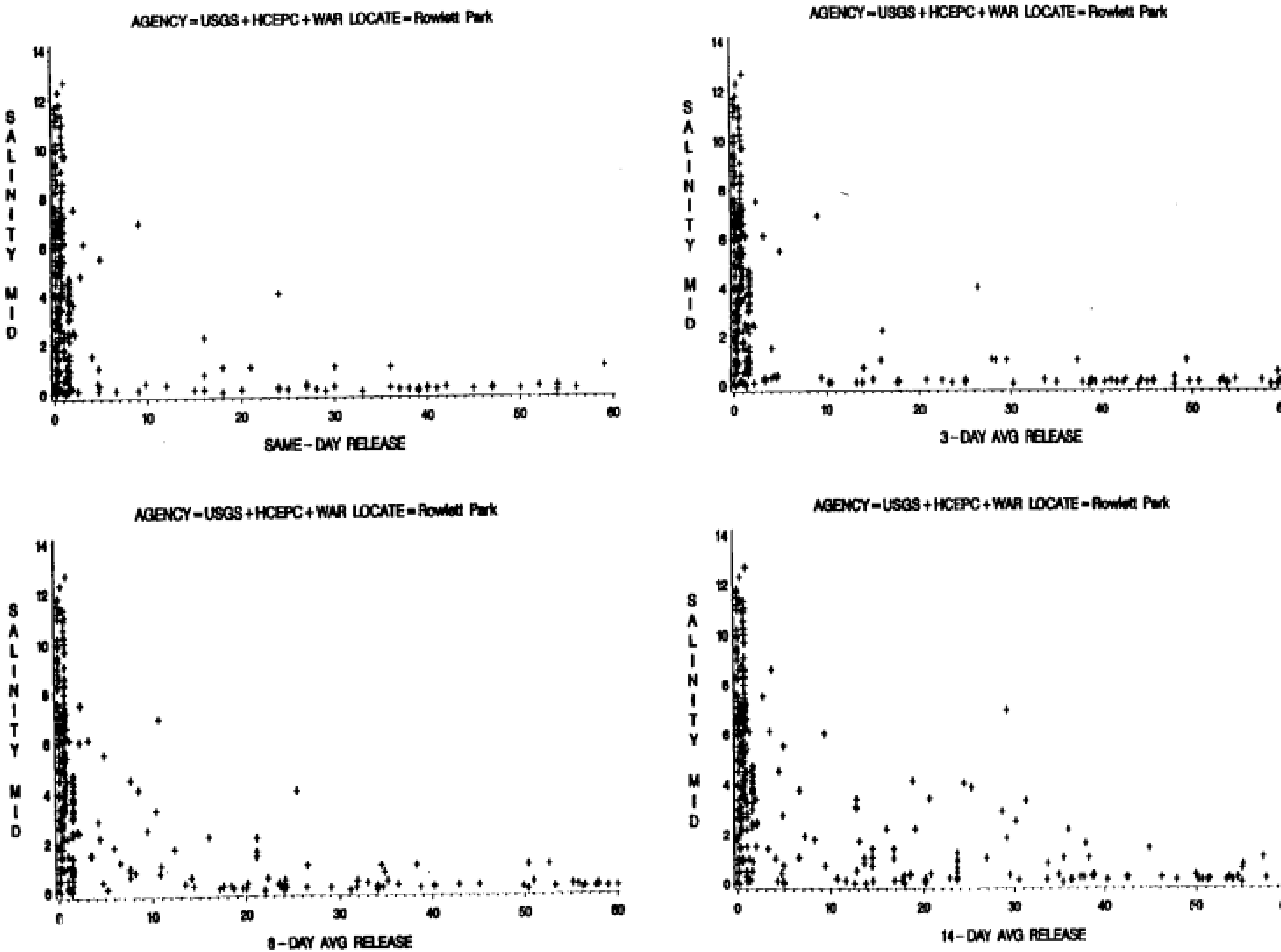


Figure 4.2. Surface salinity at Rowlett Park Drive vs. discharge from the Hillsborough River dam



[redacted] 4.[redacted] salinity at [redacted] Drive [redacted] discharge from the [redacted] River dam[redacted]

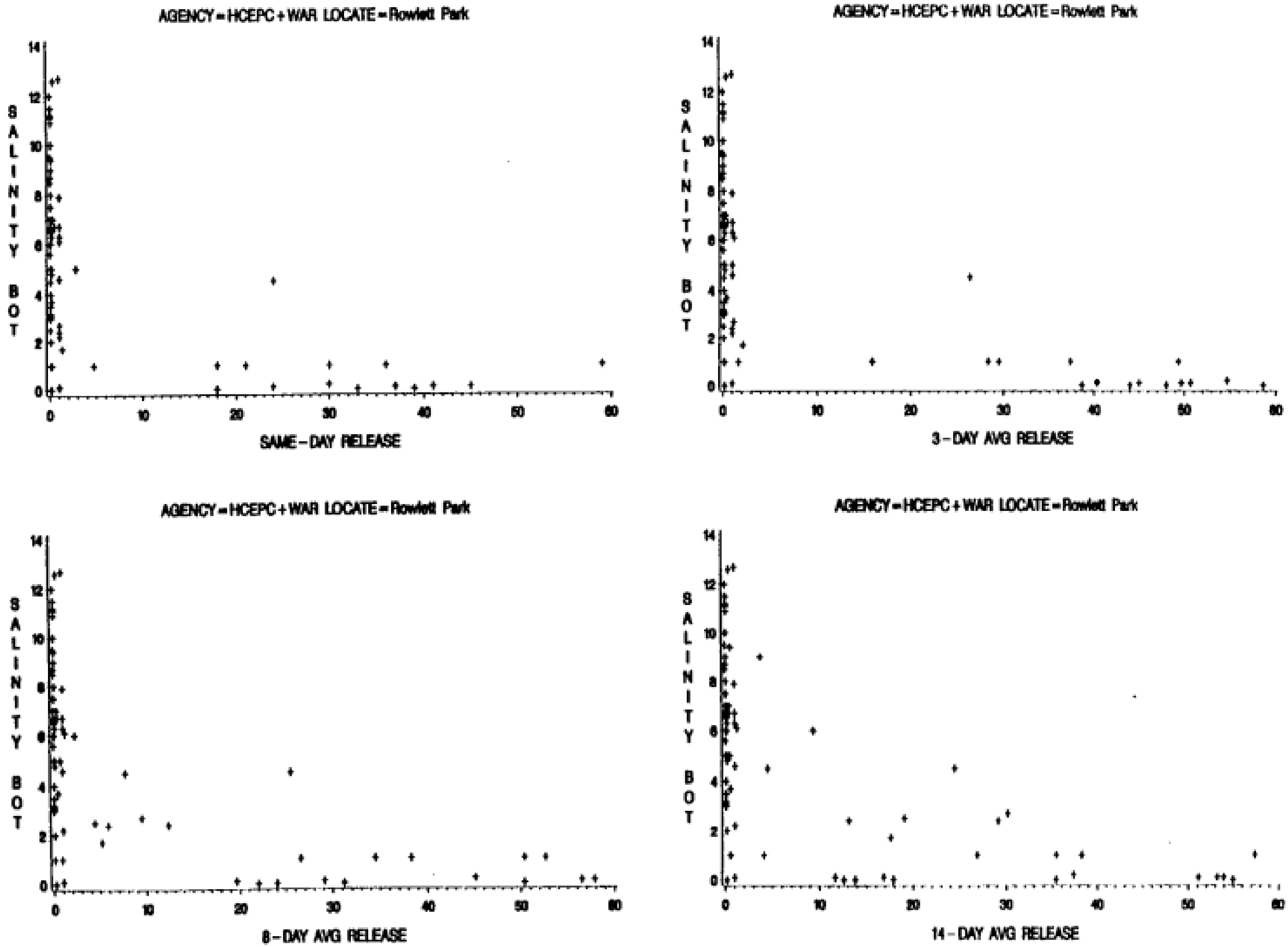


Figure 4.4. Bottom salinity at Rowlett Park Drive vs. discharge from the Hillsborough River dam

Appendix O and report by HSW, 1992). Portions of this catchment basin have high percentages of impervious surface area and well-developed storm drainage networks. Rainfall falling on the catchment area below the dam and the resulting stormwater runoff can have a pronounced effect on salinity in the lower river.

Plots of salinity at Rowlett Park Drive vs. rainfall are shown in Figure 4.5A and 4.5B, for two different flow categories: (1) 8-day flows less than 2 cfs and; (2) 8-day flows between 2 and 30 cfs. When 8-day flows were less than 2 cfs, salinity values greater than 8 ppt occurred only when the preceding 5-day rainfall total was less than 0.5 inches. Conversely, when 5-day rainfall was greater than 4.7 inches, fresh water was observed at Rowlett Park Drive even though there was very little flow at the dam. Similarly, when 8-day flows were between 2 and 30 cfs, salinity values greater than 3.0 ppt were observed only when rainfall for the preceding five days was zero.

The effects of rainfall should be considered when comparing the results of different studies. Salinity distributions in the Lower Hillsborough River predicted by a two-dimensional hydrodynamic model are presented in Chapter 5. During the calibration/verification phase of this modeling effort, it was found that good agreement between simulated salinity values and field data could only be obtained when the effects of rainfall and local runoff below the dam were included. Using the hydrodynamic model, minimum flow scenarios were evaluated assuming negligible rainfall in order to examine the effect of reservoir releases during dry periods (see Chapter 5 and Appendix O). Given negligible rainfall and a minimum flow of 10 cfs, the model predicted an average salinity of approximately 2 ppt at Rowlett Park Drive.

The salinity distributions predicted by Coastal (1997) assigned freshwater conditions (< 0.5 ppt) at the Rowlett Park station for any flow above zero cfs. The data shown in Figures 4.2 through 4.5 show this assumption is not always true, and at low flows, may not be the case most of the time. With the exception of the plots using 14-day flows, Figures 4.2 - 4.4 indicate that salinity values of 1.0 ppt or less should be fairly consistent at Rowlett Park at flows in the range of 15 to 30 cfs. There are some exceptions to this tendency, most notably a value of 4.2 ppt salinity that was recorded by WAR/SDI at flows between 24 and 27 ppt, depending on the flow term that is used.

Although the change in salinity at Rowlett Park is somewhat L-shaped, Figures 4.2 through 4.4 suggest a hyperbolic response of salinity to flow, which is the typical pattern observed in the upper reaches of estuaries (Longley, 1994; Sklar and Browder, 1998). In order to predict salinity as a function of flow, regression models were developed for the flow and combined salinity data at Rowlett Park. Models were developed separately for the relations of 3-day and 8-day flows to mid-depth salinity. Mid-depth salinity was used because of the larger number of observations compared to surface and bottom waters.

As discussed on page 4-20, the USGS data set contains many daily observations that may be serially correlated. Therefore, regressions fit to the combined salinity data at Rowlett Park could be strongly influenced by the large number of daily observations available from the USGS recorder. To limit this potential source of bias, the USGS data were reduced so that only one

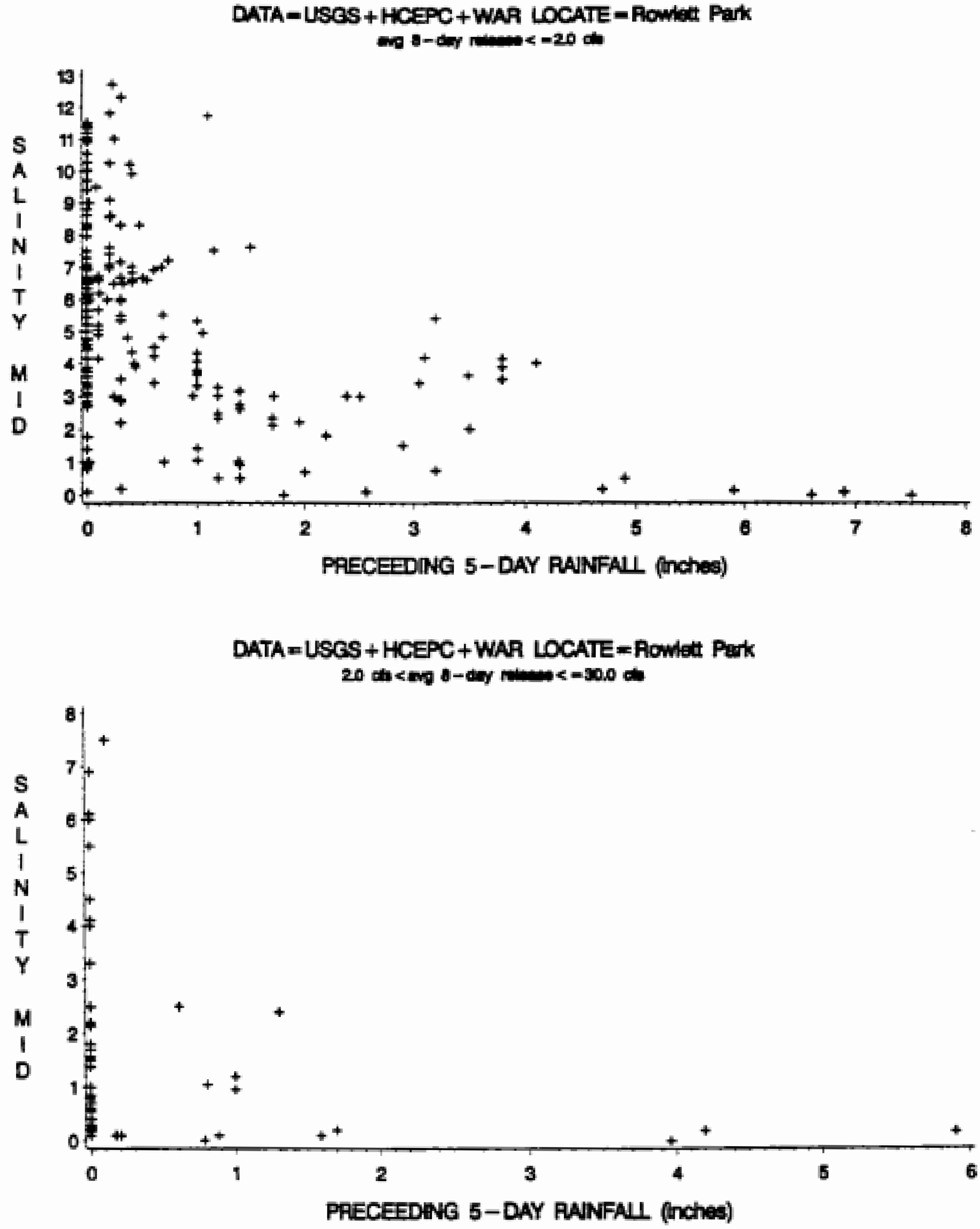


Figure 4.5 A and B. Plots of salinity vs. rainfall at Rowlett park for:(A) 8-day flows of less than 2 cfs and (B) 8-day flows of greater than 2 cfs and less than 30 cfs.

observation was included for each series of days that appeared interrelated with very similar values for salinity and flow. This was done only for days with flows between 1 and 50 cfs, since this is where the most dramatic change in salinity occurs. This reduced data set is referred to as the event-based USGS data, since only one observation is included for each flow event. The reductions of the daily USGS data to create the 8-day event-based data set are in Appendix I.

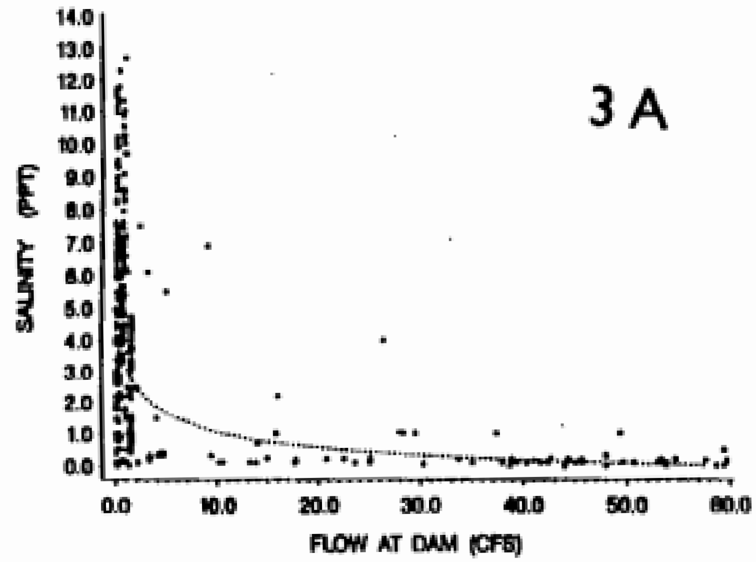
Regressions were then performed separately on the combined salinity data at Rowlett Park using both the event-based USGS data and data that included the complete USGS daily records. For all models, both salinity and flow were transformed to the natural logarithm after a constant of 1 was added to all values. The intercept and slope parameters were significant at $p < 0.001$ in all models tested. The coefficients of determination (r-square) for the regressions ranged between 0.40 and 0.49.

Plots of the data with the fitted regression lines are shown in Figure 4.6, while salinity values predicted from the four regressions are listed in Table 4.12. In general, there was very little difference between predicted values for the event-based and daily USGS data, although the event-based regressions predicted slightly higher salinities at low flows. Also, regressions using 3-day flows predicted slightly lower salinities at low flows than the regressions using 8-day flows, but the values were very close. Predicted salinity values at 10 cfs flow ranged from 1.0 to 1.3 ppt, while predicted salinity values at 25 cfs ranged from 0.4 to 0.6 ppt.

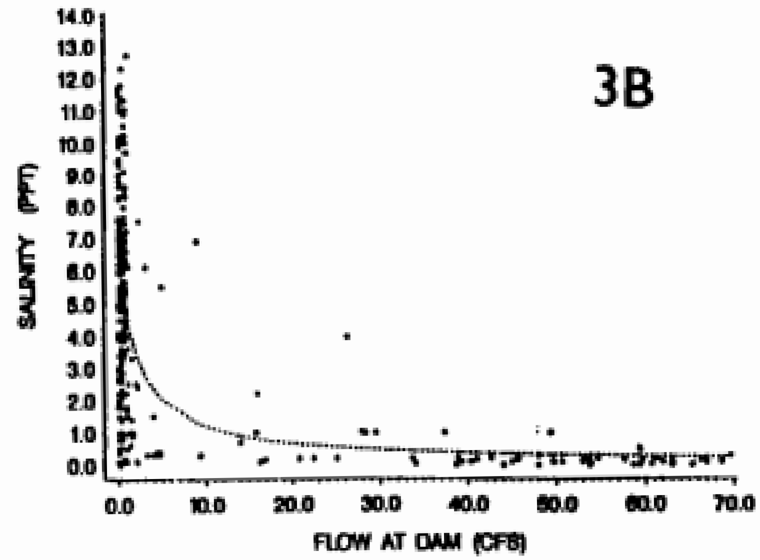
Table 4.12. Predicted mid-depth salinity values at Rowlett Park for the four regressions shown in Figure 4.6. Flows are in cubic feet per second and salinity is parts per thousand. Listed flows are either 3-day or 8-day flows depending on the regression that is used (3A, 3B, 8A or 8B in Figure 4.6.)

	Salinity (ppt) predicted by regressions shown in Figure 4.6			
Flow	3A	3B	8A	8B
0	4.6	4.8	5.1	5.3
1	3.2	3.4	3.5	3.7
5	1.6	1.8	1.8	1.9
10	1.0	1.2	1.2	1.3
15	0.7	0.9	0.9	0.9
20	0.6	0.7	0.6	0.7
25	0.4	0.5	0.5	0.6
30	0.3	0.4	0.4	0.5
35	0.2	0.4	0.3	0.4
40	0.2	0.3	0.2	0.3
45	0.1	0.2	0.2	0.2
50	0.1	0.2	0.1	0.2

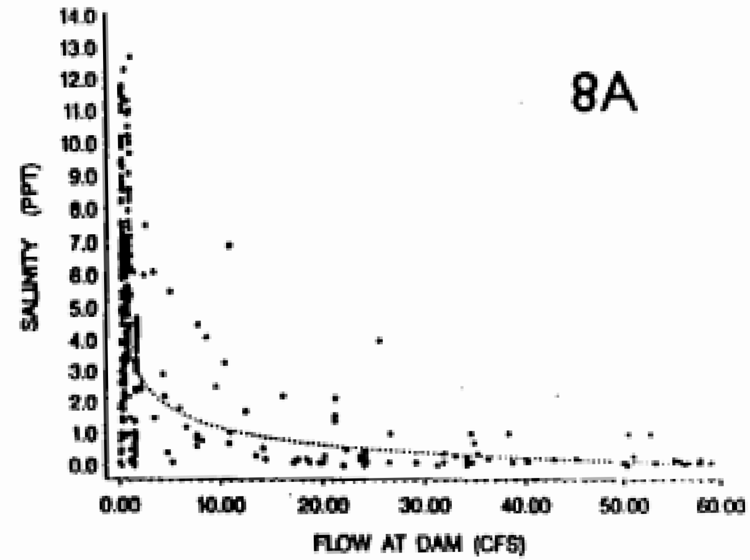
SALINITY VS. 3-DAY FLOW
COMBINED AGENCY DATA AT ROWLETT PARK DR.
WITH DAILY USGS DATA



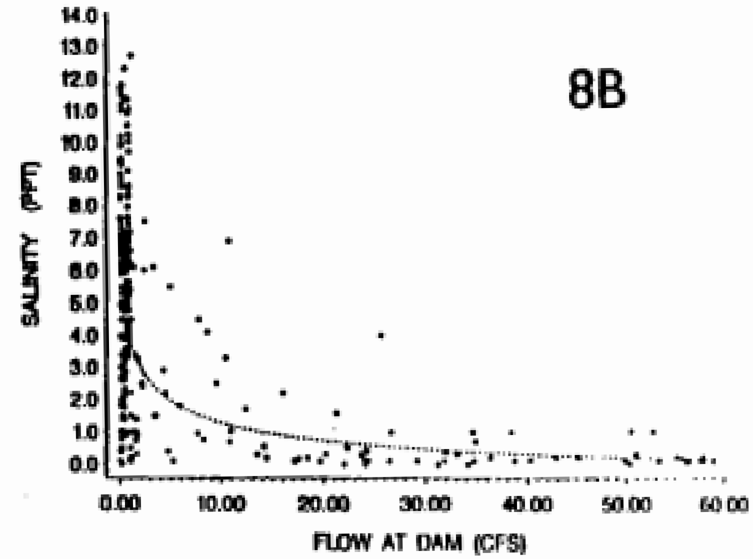
SALINITY VS. 3-DAY FLOW
COMBINED AGENCY DATA AT ROWLETT PARK DR.
WITH EVENT BASED USGS DATA



SALINITY VS. 8-DAY FLOW
COMBINED AGENCY DATA AT ROWLETT PARK DR.
WITH DAILY USGS DATA



SALINITY VS. 8-DAY FLOW
COMBINED AGENCY DATA AT ROWLETT PARK DR.
WITH EVENT-BASED USGS DATA



4.7 Ecological considerations for a freshwater zone

An objective of establishing a freshwater zone below the dam could be subject to certain qualifiers. The first is size - high discharge rates will create a larger freshwater zone than low discharge rates. Larger zones would result in a greater volume of suitable habitat for freshwater organisms, with corresponding increases in the abundance and productivity of those species. However, given the high salinity values that can occur near the dam during no discharge condition, even a small freshwater zone would represent a significant change from the existing condition.

Secondly, it is probably not necessary for an area to be consistently below a critical salinity value for freshwater organisms to survive there. Freshwater fishes differ in their salinity tolerances and many species can tolerate periodic exposures to brackish water (Peterson and Meador, 1994). Salinity tolerances of fishes can differ with size and age, however, and the reproduction or recruitment of certain species could possibly be affected before the growth and survivability of adults. The reproduction or survivability of freshwater fish species could be separate measures of success depending on the management criteria that are established.

Invertebrates also differ in salinity tolerances, as some freshwater invertebrates are often found in slightly brackish streams. A given minimum flow would probably result in a gradient of invertebrate communities, with the least salt-tolerant organisms oriented upstream toward the dam and more salt-tolerant organisms extending some distance downstream. By influencing salinity and the physical flow characteristics of the river below the dam, minimum flow releases could significantly improve both the biological diversity and stability of this region of the lower river. At present, fresh waters occur below the dam during the wet season. During the dry season, however, salinity can get high enough there to cause mortality of freshwater benthic communities and prevent them from becoming established year-round (WAR/SDI, 1995).

Minimum flow releases could be beneficial by creating a freshwater zone below the dam that supports reproducing populations of invertebrates that are characteristic of the tidal freshwater reaches of the bay's tributaries. Survival of these populations throughout the year would greatly enhance the stability of food webs below the dam and the production of higher trophic levels such as fish and wading birds. Furthermore, these resident freshwater populations could colonize areas further downstream when high flows return. At present, the initial recruitment of freshwater populations below the dam must be limited to organisms washed in from the reservoir or nearby storm drainage networks during high flows, or possibly reintroduced though the activities of birds.

The Rowlett Park station may be a good reference location to establish target salinity (or specific conductance) conditions for a minimum flow release. The station is located about one-half mile below the base of the dam, and salinity values just below the dam should be less than values measured at the Rowlett Park bridge. Since there is so much existing data at this location, and the station can be monitored with automated recorders, the effects of a minimum flow could be compared to previous conditions to assess improvements in water quality.

Minimum flow releases would affect the location of the zone of transition to estuarine communities and possibly enhance estuarine habitats by reducing the abnormally high seasonal variations in salinity now observed in many areas. As shown in the plots of data from all three sources (WAR/SDI, USGS.HCEPC), the highest salinity values are recorded during periods of no discharge from the dam. Regressions fitted to these data show that substantial reductions in salinity can occur at relatively low flows. At some locations, relatively small minimum flows could substantially reduce the high seasonal variability of salinity and other physicochemical characteristics that can cause stressful conditions for many organisms.

4.8 District Breakpoint Analysis of Streamflow/Dissolved Oxygen Relationships Using Combined Data Sets

Coastal Environmental (1997) found significant relationships between discharge from the Hillsborough River dam and the proportion of DO values in the lower river below 1, 2 and 3 mg/l. This relationship, however, was not evident for the proportion of DO values below 4 and 5 mg/l. This finding is supported by the plots presented in Appendices F, H and I-1, in that some quantities of flow are very effective at raising DO above very low values, but not as effective at raising them above 4 or 5 mg/l. It should be noted the regressions developed by Coastal (1997) relied solely on the WAR/SDI data set and analyzed data from all the stations together. As indicated by plots of DO vs. flow for the different agencies and the mid-day DO regressions developed by Coastal (page 6-7), the response of DO to flow can vary markedly between different stations and depths in the river. Therefore, it could be informative to examine the proportion of low DO concentrations as a function of flow at different stations separately.

Plots of DO vs. discharge from the three data sets (WAR/SDI, USGS, HCEPC) frequently showed similar relationships when a station was sampled by more than one group. In order to better evaluate DO/flow relationships at these stations, DO data were combined from the three data sets for stations at Rowlett Park Drive, Sligh Avenue, Columbus Ave. and Platt Street. Data from various depths were merged as described for the combined salinity data set for Rowlett Park, except that data for individual depths below 2 meters in the WAR/SDI data set were retained. Station 10 near Platt St. in the WAR/SDI data set was combined with the Platt St. data for the USGS and HCEPC due to the proximity of these stations.

DO data from the top 2 meters of water at these stations are plotted vs. discharge in Appendix I-1. As with the separate data sets, there is a strong positive relationship between flow and DO at Rowlett Park, with DO values consistently over 4.0 mg/l for same-day and 3-day flows greater than 33 and 45 cfs, respectively. Improvements in DO with increasing flow were also found for Sligh and Columbus Avenues, but at higher breakpoints. The data at Sligh and Columbus did indicate that flows in the range of 5 to 20 cfs were effective at raising DO values above 2 mg/l at those stations. However, the potential effects of stormwater runoff below the dam on these relationships were not examined.

Many plots from the combined data and separate data sets show that the variability of DO at several stations is a function of discharge. Generally, the variability of DO was greatest during no-discharge conditions, with a significant proportion of the DO values below 2 mg/l. To evaluate these patterns further, the District examined relationships between flow and the proportion of low DO concentrations at individual stations and sections of the lower river. This was accomplished by sorting the DO measurements by their corresponding rate of discharge and segregating the data into discharge classes of 10 cfs increments. Within each flow class, the percentage of DO values below 2 mg/l and greater than 4 mg/l were tallied and summarized in tables. The analysis was done twice. The first began with a flow class of 0 to 5 cfs and increased by ten (5 to 15 cfs, etc.), while the other began with a flow class of 0 to 10 cfs. The analysis proceeded in 10 cfs increments up 95 or 100 cfs, above which all observations were put into a single high flow class. The analysis was done for 3-day and 14-day flows, since these were the flow terms used by Coastal (1997) and WAR/SDI (1995) in their regression and correlation analyses, respectively.

The objective of the analysis was to determine if there were breakpoints in the data where the proportion of DO values in the two classes (<2 mg/l and > 4 mg/l) changed as flow increased. Judgement was used to determine when there was a fairly consistent pattern of higher flows resulting in a change in DO distributions. Breakpoints in the data were determined considering data for a given flow class and all flow classes above and below it. It is important to emphasize this analysis should be considered a coarse tool. Frequently, there were not numerous observations in the flow classes between which breakpoints were determined.

A summary of the breakpoint analysis is presented in Appendix I-2. The results are grouped by sections of the river. In some cases, data are combined from one or more adjacent stations to increase the number of observations and determine if there were consistent relationships in different sections of the river. The numbers shown under the headings < 2 and > 4 mg/l DO list the observed breakpoints. Two flow classes represented by a single number on either side of the slash are listed for each breakpoint (e.g. 15/15 cfs). The number on the left side of the slash (15) is the upper limit of the lower flow class where the break occurred. The number on the right hand side (15 cfs) is the lower limit of the upper flow class where the break occurred. In other words, a listing of 15/15 for the < 2 mg/l DO column means that the 15-25 flow class had markedly fewer DO observations less than 2 mg/l than did the 5 to 15 class. It does not mean the break necessarily occurred at 15 cfs.

If there were an insufficient number of observations in one or more intermediate classes the two listed numbers are different, such as 5/25. This means that the 25-35 class had markedly fewer observations of DO less than 2 mg/l than the 0 to 5 cfs class, but there were too few observations between those discharge classes to define a closer breakpoint. If no breakpoints were observed the symbol U was assigned. In most cases where U was assigned there was no clear relationship between flow and DO, at least in the flow classes examined. In some cases, however, U was assigned when there appeared to be a general positive relationship with flow but no clear breakpoints were observed.

The summary tables presented in Appendix I-2 show there were frequent breakpoints determined in the data. A 5/5 or 10/10 breakpoint was found for some stations and sections, meaning that flows as low as 5 to 15 cfs or 10 to 20 cfs resulted in a positive change in DO. In other cases, breakpoints ranging from 15 to 40 cfs were determined, indicating that additional flows continue to have a positive response on DO at those stations. Other breakpoints were observed at relatively high flows (65 to 95 cfs). Although those breakpoints may be relevant to high flow management on the river, minimum flows in that range would be impractical. In general, these analyses indicate that relatively small minimum flows could have a beneficial effect on DO concentrations in the river, with this effect being most pronounced in the upstream areas. This corresponds to the findings of Metcalf and Eddy (1983), who concluded that continual freshwater releases would improve in DO concentrations in the lower river, with the length of the river experiencing improvement dependent on the magnitude of the freshwater release (page 6-20).

4.8 Relationships of other water quality parameters to discharge from the Hillsborough River Reservoir

Minimum flow releases may affect water quality parameters in the Lower Hillsborough River other than salinity and DO. Such changes in water quality could potentially affect biological communities below the dam. The hydrobiological study by WAR/SDI (1995) examined the response of various water quality parameters to discharge from the Hillsborough River Reservoir. Also, the Hillsborough County Environmental Protection Commission (HCEPC) has three regular monthly monitoring sites in the Lower Hillsborough River at Rowlett Park, Columbus Avenue, and Platt St. Relationships of water quality at the HCEPC stations to discharge from the Hillsborough River Reservoir are evaluated below.

One factor that was raised during the minimum flows evaluation was the degree to which the Lower Hillsborough River has been affected by stormwater runoff below the dam. In response to these concerns, the permit required hydrobiological study included an assessment of nutrient loadings from local stormwater to the lower Hillsborough river and Palm River (HSW, 1992). In 1980, a modeling study of water quality in the Lower Hillsborough River was published by the University of South Florida for the City of Tampa (Ross, 1980). In the early 1980's, a major study of the effects of stormwater runoff on water quality in the Lower Hillsborough River was conducted by Metcalf and Eddy (1983) as part of the National Urban Runoff Program. This project included biological studies that examined the response of various organisms to stormwater runoff (Mote Marine Laboratory, 1984).

4.8.1 Water quality during discharge and no-discharge from the Hillsborough River Reservoir

Summary statistics for selected water quality parameters measured by the HCEPC are listed in Appendix J-1 for discharge and no-discharge conditions. At Rowlett Park, the mean value for chlorophyll a for no-discharge conditions (21.7 μg/l) is three times greater than the mean for discharge conditions (7.2 μg/l). This high value for no-discharge is influenced by several bloom occurrences, but the median for no-discharge (10.1 μg/l) is also greater than the median for discharge conditions my more than a factor of two. Both mean and median concentrations of biochemical oxygen demand (BOD) are higher for the no-discharge conditions, although these differences were not statistically tested. The high mean value for Total Suspended Solids (TSS) for no discharge conditions was influenced by several very high readings, but the median value for no-discharge (12 mg/l) was also considerably higher than the median for discharge conditions (5 mg/l). As expected, mean and median color values were considerably higher for discharge conditions at all three stations.

Similar to the Rowlett Park station, mean and median chlorophyll concentrations at Columbus Ave. were greater for no-discharge conditions. The difference is median concentrations was considerable - 18.1 vs. 4.9 μg/l, indicating that large algal populations are more common in the lower river when there is no flow from the dam. Means and medians for BOD and TSS were also higher for no-discharge conditions, while the median for nitrate was considerably lower. One difference from Rowlett Park is that bacteriological parameters are higher for discharge than no discharge conditions. Since discharge conditions occur during the wetter times of the year, it is not clear to what degree these bacterial counts are attributable to discharges from the reservoir or local inputs of urban stormwater below the dam.

At Platt St., means and medians for chlorophyll and BOD were close between discharge and no-discharge conditions, but TSS was still elevated during no discharge conditions. As discussed earlier in the summary of the WAR/SDI report, this probably reflects the influence of high TSS water from Tampa Bay. As at Columbus Ave., bacteriological parameters at Platt St. were higher during discharge conditions.

4.8.2 Plots of HCEPC water quality parameters vs. discharge and correlation analysis

The concentrations of 13 water quality parameters in surface waters at three HCEPC stations in the Lower Hillsborough River (Rowlett Park, Columbus Ave. and Platt St.) are plotted vs. 8-day discharge from the Hillsborough River Reservoir in Appendix J-2. Plots are presented separately for an expanded flow range and flows less than 200 cfs so that the response to low flows can be more closely examined. Pearson product-moment correlations of these parameters with discharge are presented in Appendix J-3. Correlations were tested for the entire flow range (all flows) and flows less than 100 cfs (low flows) using log-transformed and untransformed discharge data from the Hillsborough River Reservoir.

A significant negative correlation was found between pH and discharge at Platt St. This would be expected as river waters replace more buffered saline bay waters as flow from the dam increases. This pattern also appeared in the plot for Columbus Ave. but significant correlations were not found, possibly due to the effect of two outliers near 600 cfs. At Rowlett Park the untransformed data indicated a negative correlation of pH with discharge when all flows were analyzed, but significant positive correlations were found at low flows (< 100 cfs). Plots of the data, however, do not indicate a clear relationships between flow and pH, with the possible exception of a few values less than 7 occurring at no flows. Color was positively correlated with discharge for all stations and flow ranges.

Chlorophyll a and BOD were highly correlated with each other (r=0.79) at Rowlett Park, indicating that algal blooms may be a major source of oxygen demand in this part of the river. Both parameters were negatively correlated with discharge for both low flows and all flows. Plots of the data show that high values of both parameters were largely limited to periods of zero or very low discharge from the dam. For example, of 31 total observations of chlorophyll over 25 μg/l at Rowlett Park, 26 occurred during no-discharge conditions while the remaining five occurred at 8-day flows between 3 and 11 cfs. Similar results were found for BOD. Of thirty total observations of BOD over 3.5 mg/l, 27 were during no-discharge conditions while the remaining three observations occurred at flows between 2 and 11 cfs.

These relationships indicate that flows from the reservoir prevent high algal biomass in the region below the dam by increasing flushing in this part of the system. Based on 36 observations, WAR/SDI (1995) found chlorophyll a was negatively correlated with discharge at stations 2 through 7 and 9, but no significant correlations were found for BOD. In the HCEPC data for Columbus Ave., both chlorophyll and BOD are negatively correlated with discharge. Plots of these data indicate that relatively small discharges from the dam help reduce the occurrence of high chlorophyll concentrations at Columbus Ave. Similarly, high values of chlorophyll and BOD were infrequent at Columbus Ave. if flows are greater than 60 cfs. There was considerably more scatter in the flow/concentration plots for Platt St., and the correlations results for chlorophyll and BOD were inconclusive.

TSS were negatively correlated with discharge at the Columbus Ave. and Platt St. stations. Although significant ($p < .05$) correlations were not observed at Rowlett Park, (possibly due to one outlier near 400 cfs), plots indicated a general negative relationship between TSS and discharge at that station. Of twenty total observations of TSS values over 17 mg/l, seventeen occurred at flows less than 20 cfs. WAR/SDI found that TSS was negatively correlated with discharge at stations 2 through 7 and 9.

The relationships with nutrients were mixed. Nitrate was negatively correlated with discharge at Rowlett Park over the entire flow range, but was positively correlated with discharge at Columbus and Platt Street. These results at Columbus and Platt are not surprising, as discharge brings new inorganic nitrogen into the system while at the same increasing flushing and decreasing algal biomass, as evidenced by negative correlations with chlorophyll a. Large phytoplankton populations during no-discharge periods could result in low inorganic concentrations due to plant uptake. Total nitrogen was negatively correlated with discharge at Rowlett Park, which may be related to the negative correlations with chlorophyll and BOD at that site, but was positively correlated with discharge at Platt St. Ortho-phosphorus, but not total phosphorus, was positively correlated with discharge at Rowlett Park and Columbus Avenue.

The results for bacteriological parameters were mixed between stations and low and high flows. Although the large majority of very high counts of total coliforms (10,000 to 100,000 col./100 ml) at Rowlett Park occurred at zero discharge, there were no significant correlations with discharge. At Columbus Ave., high counts were also observed at zero flows with some drop-off at low flows (10 - 20 cfs). There was a general increase with discharge at flows above 20 cfs, however, resulting in significant positive correlations with discharge for all flows and low flow conditions (< 100 cfs). Total coliforms were positively correlated with discharge at Platt St.

Fecal coliform bacteria were negatively correlated with low flows at Rowlett Park, but not significantly correlated when all flows were analyzed. In contrast, both fecal coliform and fecal streptococci counts were positively correlated with all flows at Columbus Ave. and Platt St., but plots and correlation analysis found that this relationship did not exist at low flows (< 100 cfs).

Overall, the data indicate that minimum flow discharges will improve water quality in the upper reaches of the lower river by improving flushing and reducing high concentrations of chlorophyll a, BOD, and coliform bacteria. Even as far downstream as Columbus Ave., the data indicate that relatively small flows may help reduce chlorophyll concentrations. However, it is difficult to determine to what extent rainfall and local runoff influence these relationships. For some observations, local runoff below the dam may have a greater effect on flushing times and water chemistry in the river than relatively small flows at the reservoir dam. Regardless, the analysis of discharge/concentration relationships from both the HCEPC and WAR/SDI data bases indicate that minimum flow releases should not result in any water quality problems in the Lower Hillsborough River. This corresponds with the conclusion of Ross (1980), who stated that water quality in the Hillsborough River is especially vulnerable to nonpoint source runoff during periods when the dam is closed (page 11). Similarly, Metcalf and Eddy (1983) concluded that flows from the dam play a crucial role in the water quality of the river, and moderate to high flows from the dam act to diminish any impacts of stormwater runoff below the dam (pages 2-28, 2-29).

5. HYDRODYNAMIC SALINITY MODELING OF LOWER HILLSBOROUGH RIVER

5.1. Two-dimensional hydrodynamic model

A two-dimensional hydrodynamic model of the Lower Hillsborough River was developed by the District to further examine the response of salinity in the Lower Hillsborough River to inflows of fresh and near-fresh water. It is a laterally averaged model which includes both vertical and longitudinal components. The model was calibrated and verified using data recorded in 15 or 60 minute intervals by automated instruments operated by the USGS during 1981, 1982 and 1997. A report that describes the development, calibration, and verification of the model is presented in Appendix O.

The verified model was used to simulate the effects of different minimum flow scenarios on salinity distributions in the river. These scenarios included different combinations of discharges from the reservoir and flows from Sulphur Springs that could be diverted to the foot of the dam. Forty-five scenarios were run for the same simulation period of 18 days ending with spring tides to examine the effect of different flow scenarios on salinity distributions in the river.

Outputs from the scenario runs are presented in two forms. The first are color graphics that show two-dimensional salinity distributions in the river for each minimum flow scenario. The other is a table of salinity zone volumes predicted to occur for the different flow scenarios. This table and the complete set of two-dimensional salinity plots are presented in Appendix O. The table of water volumes is also shown in Table 5.1 (page 5-18), and selected two-dimensional salinity plots are presented in Figures 5.1 through 5.14.

The table of water volumes was produced by averaging the model output from the last 48 hours of the 18-day simulations, while the two-dimensional salinity plots are instantaneous distributions at different times during the tidal cycle. The simulations were run with negligible rainfall to determine the effect of discharges from the reservoir and Sulphur Springs on salinity distributions when there is no direct stormwater runoff below the dam. Although the results were taken from eighteen day simulations, model outputs examined for shorter time intervals indicate these results are indicative of salinity distributions after shorter periods of no rainfall (3 to 4 days).

The verified model was also used to examine the effects of a minimum flow of 10 cfs on salinity distribution during naturally occurring patterns of rainfall, dam discharges, and stormwater runoff. Three cases were studied: (1) 0 cfs minimum flow, (2) 10 cfs minimum flow from the reservoir, and (3) 10 cfs minimum flow with diversion from the Sulphur Springs. The simulation period for the three cases was a 9-month period from September 1981 through June 1982.

5.2 Salinity distribution graphics

The two-dimensional color graphics are valuable for they illustrate the effect of flows from Sulphur Springs on salinity distributions in the river near the spring outfall. Based on recent water chemistry data, the salinity of water discharging from the reservoir was set at 0.1 ppt in the model runs while the salinity of water discharging from Sulphur Springs was set at 1.2 ppt.

Under conditions of average springflow (31 cfs) and no discharge from the reservoir (Figure 5.1), the model shows lower surface salinity in the river near the spring outfall (4 to 5 ppt) than near the dam (5 to 6 ppt). The model also shows steep vertical salinity gradients in the river near the spring, which was confirmed by field measurements made during 1996 (Table 4.2) and measurements by WAR/SDI at stations 3 and 5 (Table 4.1).

Simulated salinity values at Rowlett Park Drive (0.8 kilometers downstream of dam), assuming average springflow and no discharge from the dam, range from less than 6 ppt at the surface to near 6 ppt at the bottom (Figure 5.1). These values compare very well with salinity measurements taken at Rowlett Park Drive during conditions of no discharge and low rainfall. For example, when the 14-day average flows were less than 2 cfs and the six-day rainfall was less than 0.5 inches, mean salinity at Rowlett Park was 6.5 ppt for the USGS data (n=54), 7.3 ppt for WAR/SDI data (n=15), and 7.6 ppt for the HCEPC data (n=13).

The graphs indicate that a release of 10 cfs from the reservoir will reduce salinity to between 1 and 2 ppt on the river bottom at the foot of the dam (Figure 5.2). At 15 cfs flow from the reservoir, the 1.0 ppt isohaline occurs on the bottom of the river on all tides, extending about 0.8 kilometers downstream of the dam on low tide (Figure 5.3). Higher flows push the salt concentrations further downstream. At a 40 cfs release from the reservoir the 1 ppt isohaline ranges from about 1.5 to 2.0 kilometers below the dam depending on the tide (Figure 5.5) At a 80 cfs release, the 1.0 ppt isohaline ranges from about 3 to 4 km below the dam, keeping the large deep area 2.5 kilometers from the dam fresh throughout the tidal cycle (Figure 5.6). For comparative purposes, the model was run for several minimum flows scenarios that assumed low (20 cfs) and high flows (40 cfs) from Sulphur Springs. Two-dimensional plots are shown in Figures 5.7 through 5.10 for minimum flow releases of 10 and 20 cfs assuming low and high flow rates from the spring.

A valuable attribute of the model was that it allowed the simulation of minimum flow scenarios that involve diverting a portion of flow from Sulphur Springs to the base of the dam. Figure 5.11 shows a minimum flow of 10 cfs spring water at the base of the dam, with the remaining 21 cfs of springflow entering the river at the spring outfall. This scenario results in a zone of salinity less than 3 ppt near the base of the dam, with the size of this zone varying with tidal conditions. Increasing the amount of diverted spring water to 15 cfs results in the 2 ppt isohaline appearing below the dam (Figure 5.12).

Figures 5.13 shows the effect of a minimum flow comprised of 10 cfs diverted spring water matched with 10 cfs of flow from the reservoir. This scenario results in the 2 ppt isohaline extending about one-half to one kilometer below the dam depending on the tide. A scenario of 15 cfs diverted spring water matched with an equal quantity of flow from the reservoir shows further downstream movement of the 1 ppt and 2ppt isohalines (Figure 5.14).

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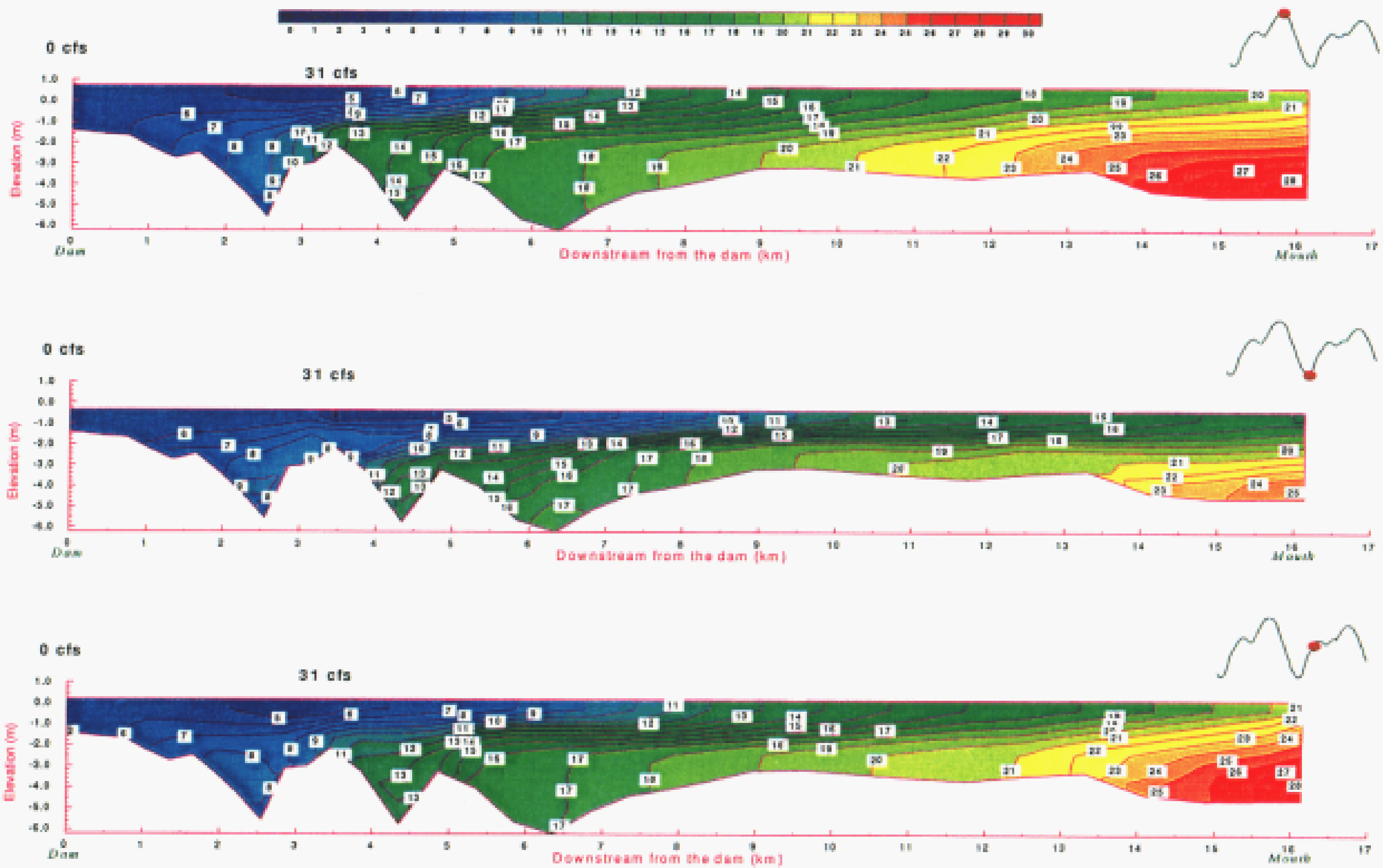

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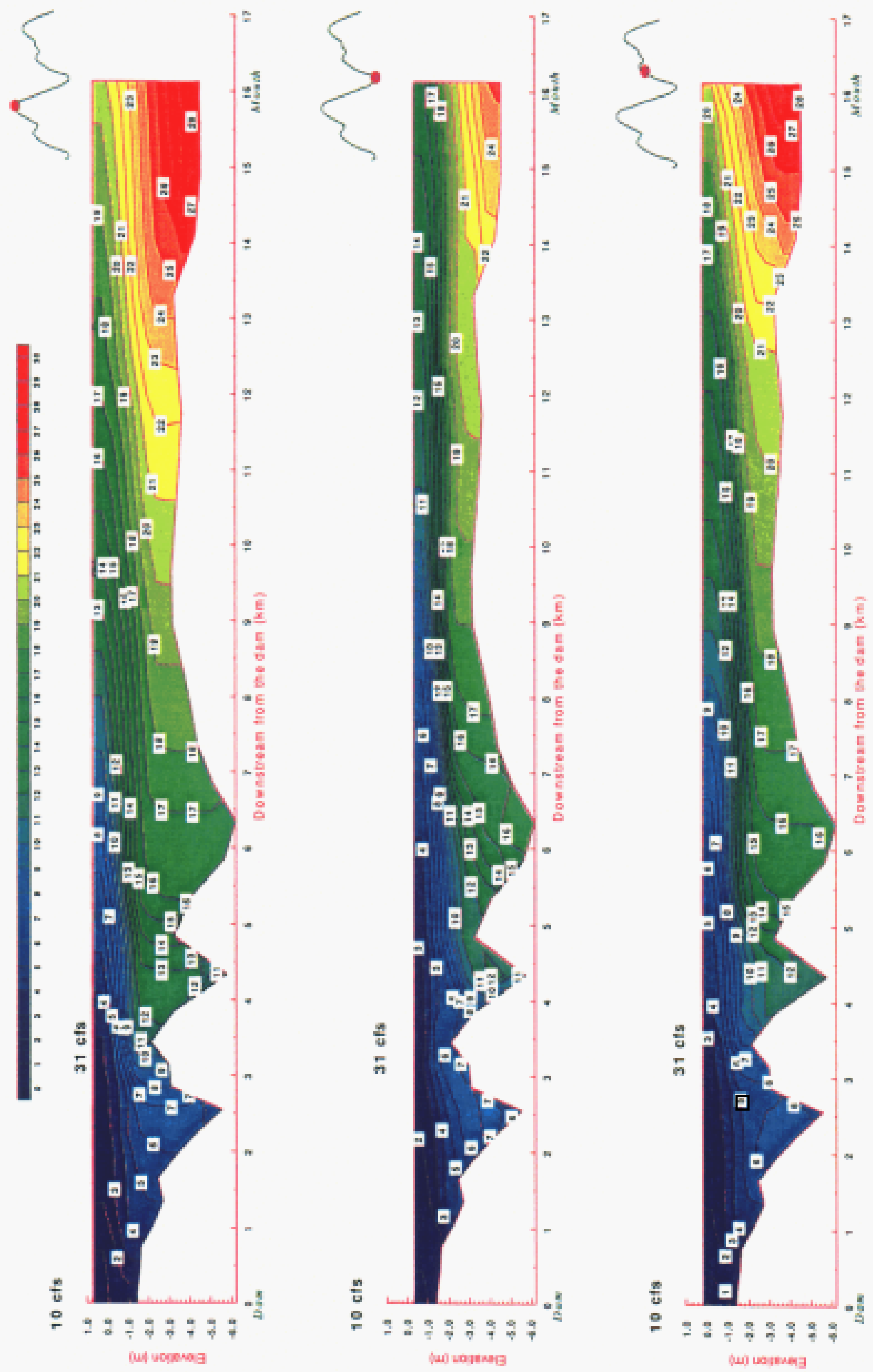

10 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)
10 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)
10 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)

Figure 5.2

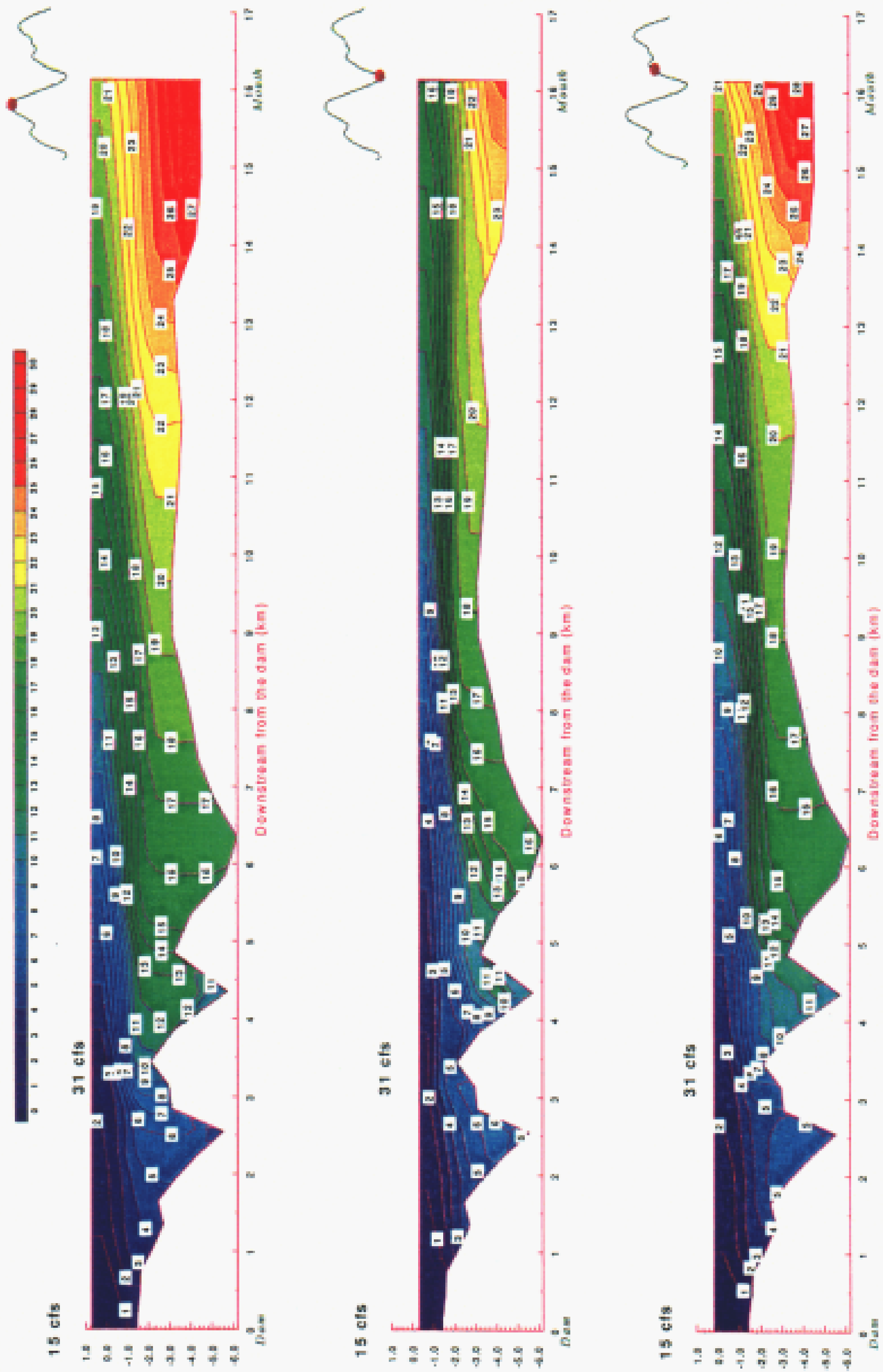

15 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.3

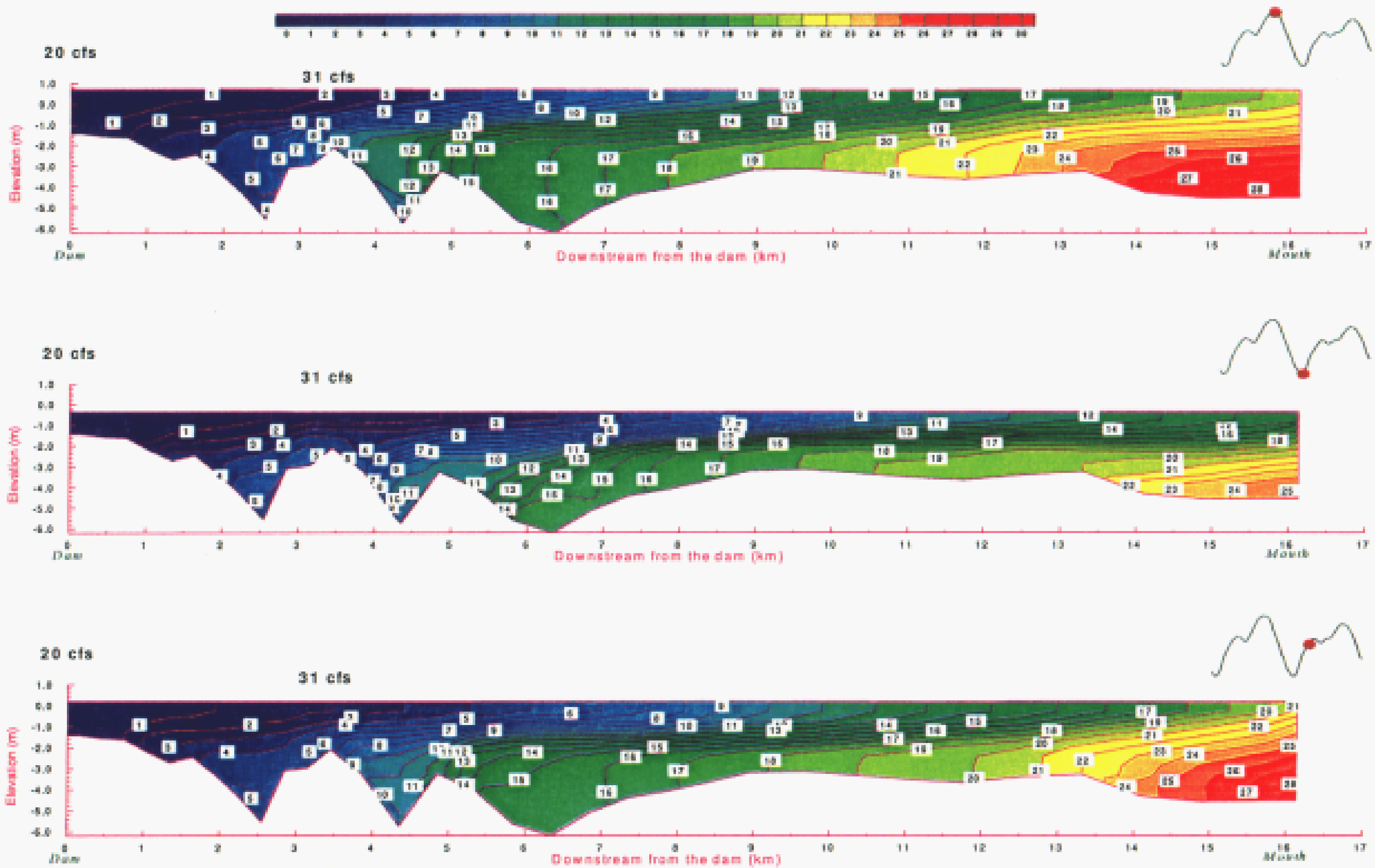

20 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.4

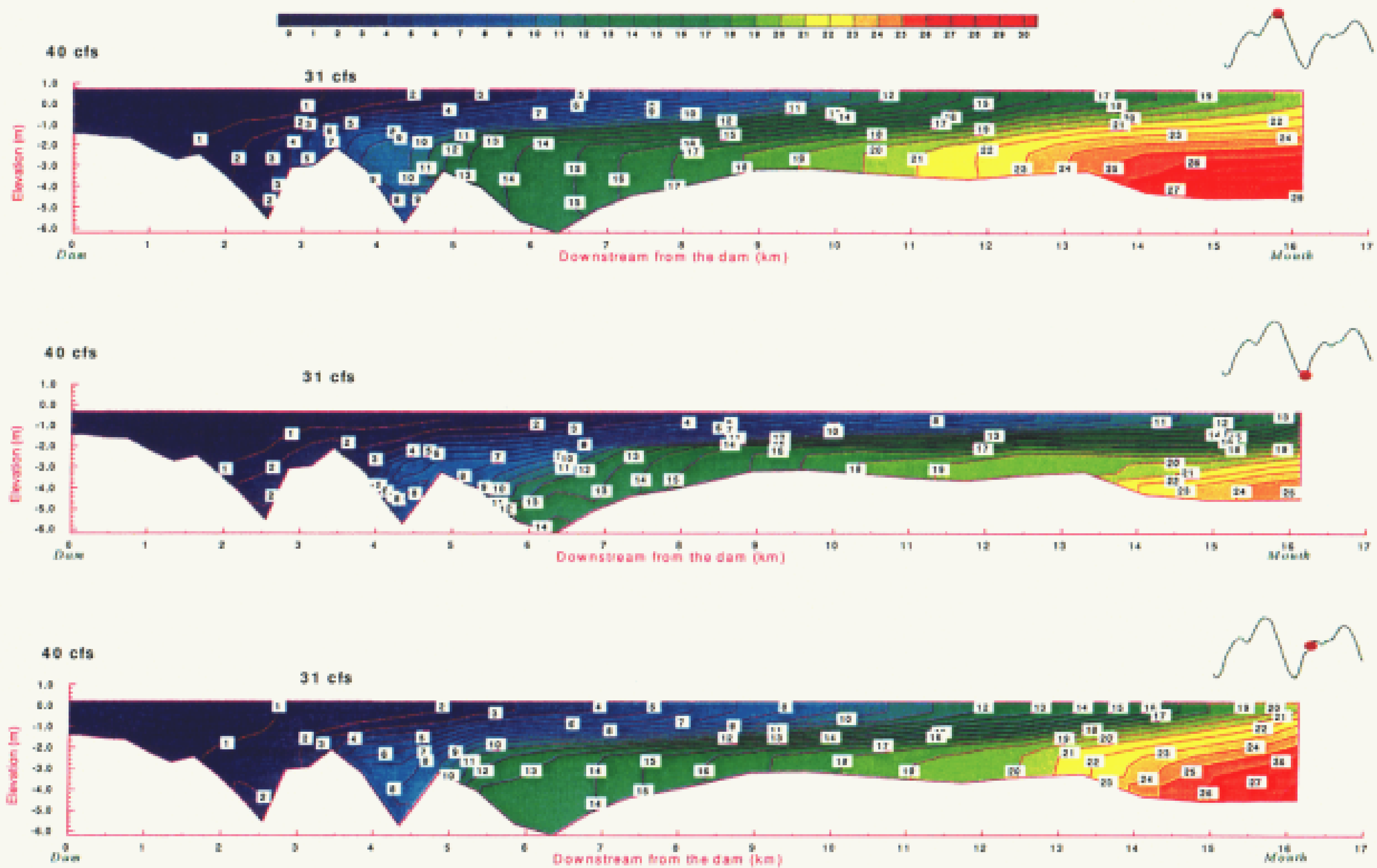
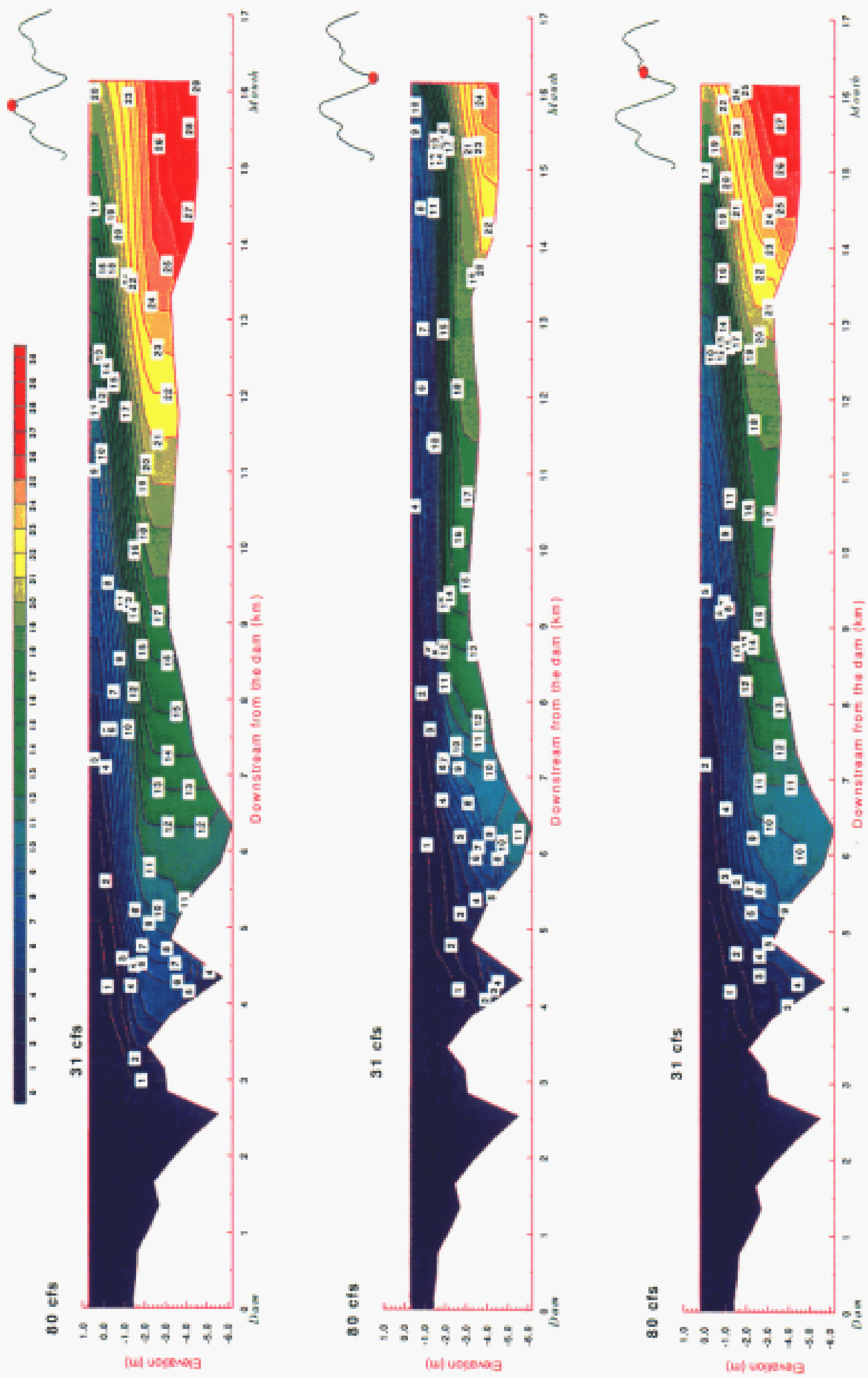

40 cfs
31 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.5



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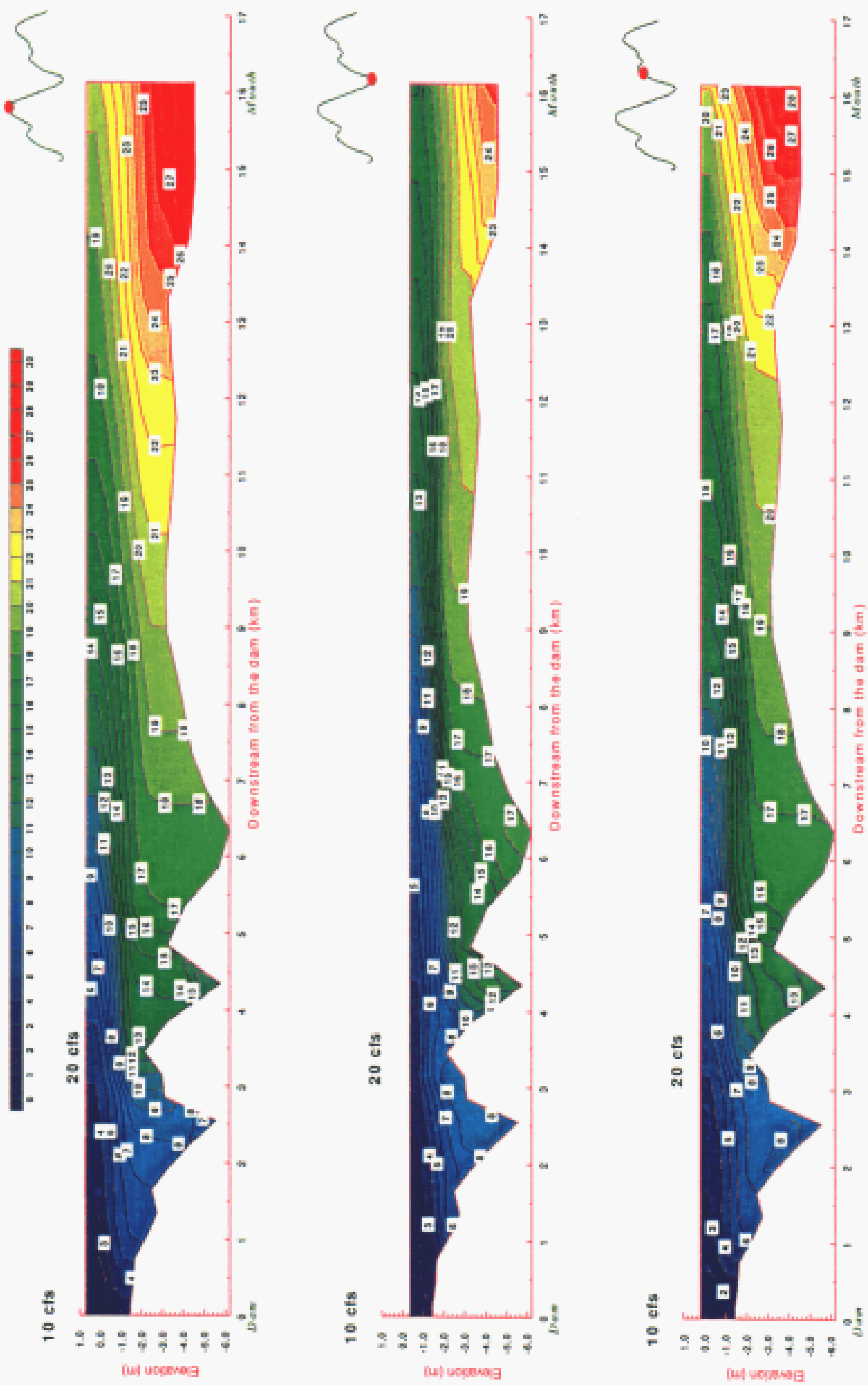
10 cfs
20 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Month
10 cfs
20 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Month
10 cfs
20 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Month

Figure 5.7

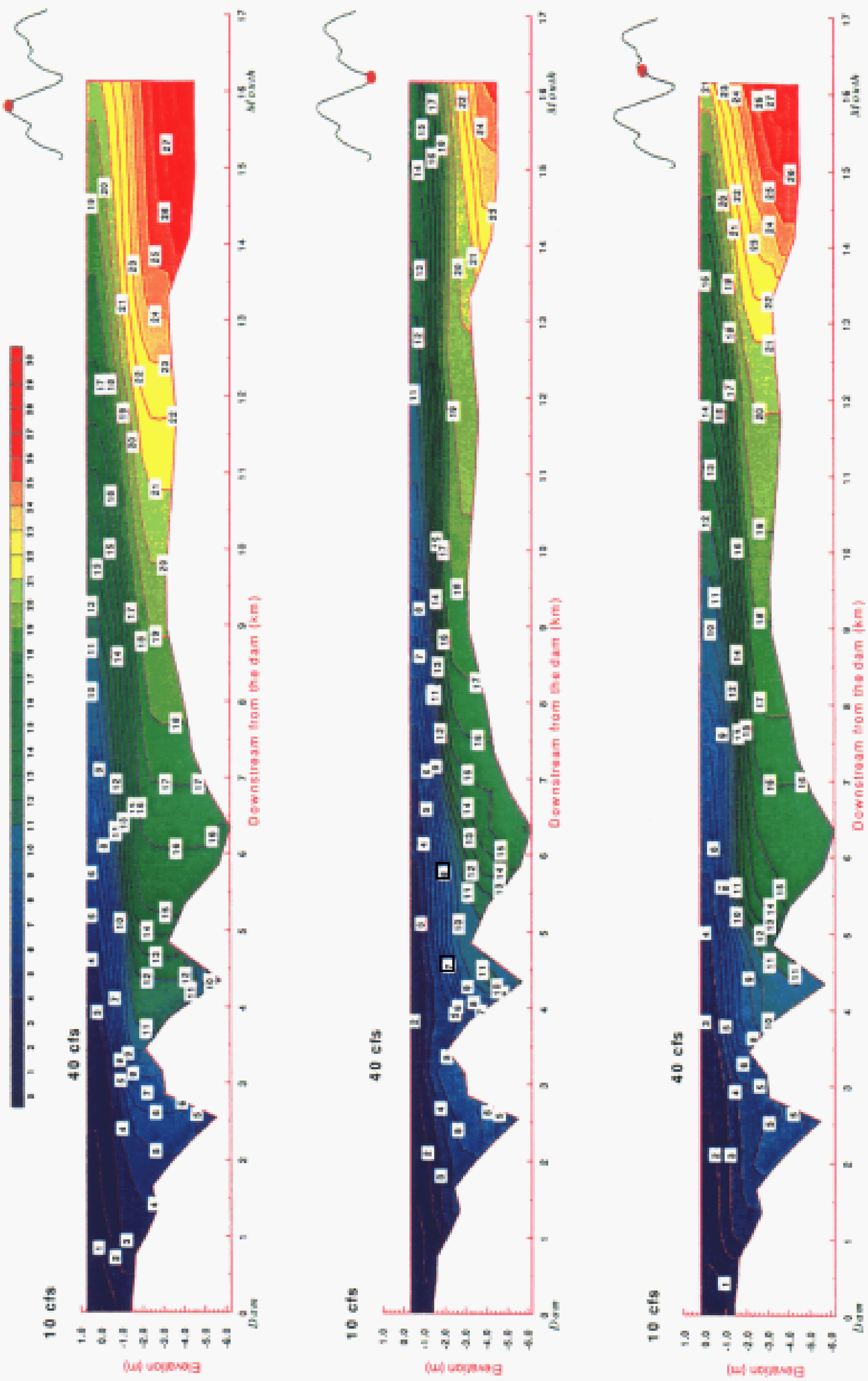

Figure 5.8

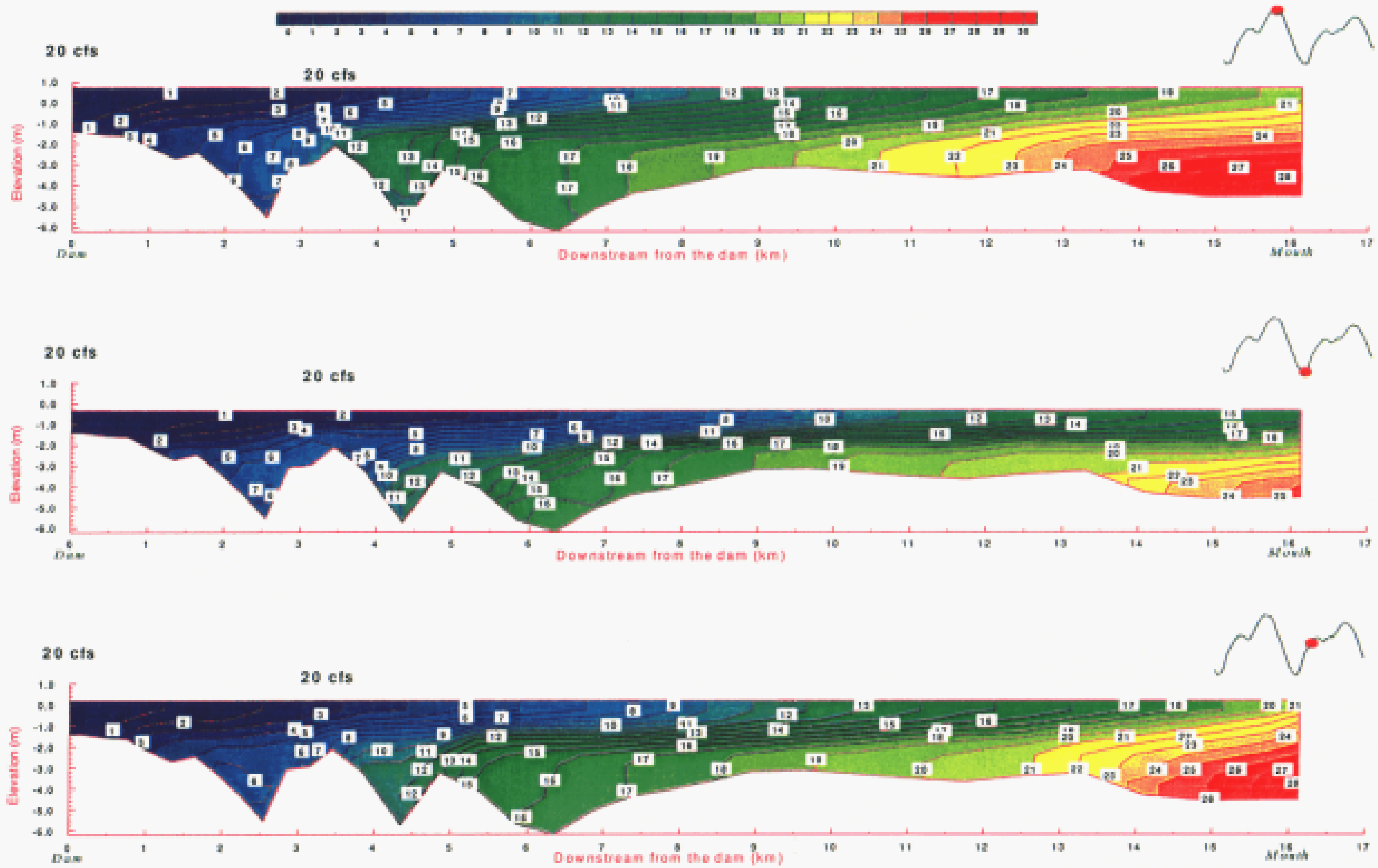
20 cfs
20 cfs
Elevation (m)
Dam
Downstream from the dam (km)
Mouth
20 cfs
20 cfs
Elevation (m)
Dam
Downstream from the dam (km)
Mouth
20 cfs
20 cfs
Elevation (m)
Dam
Downstream from the dam (km)
Mouth

Figure 5.9

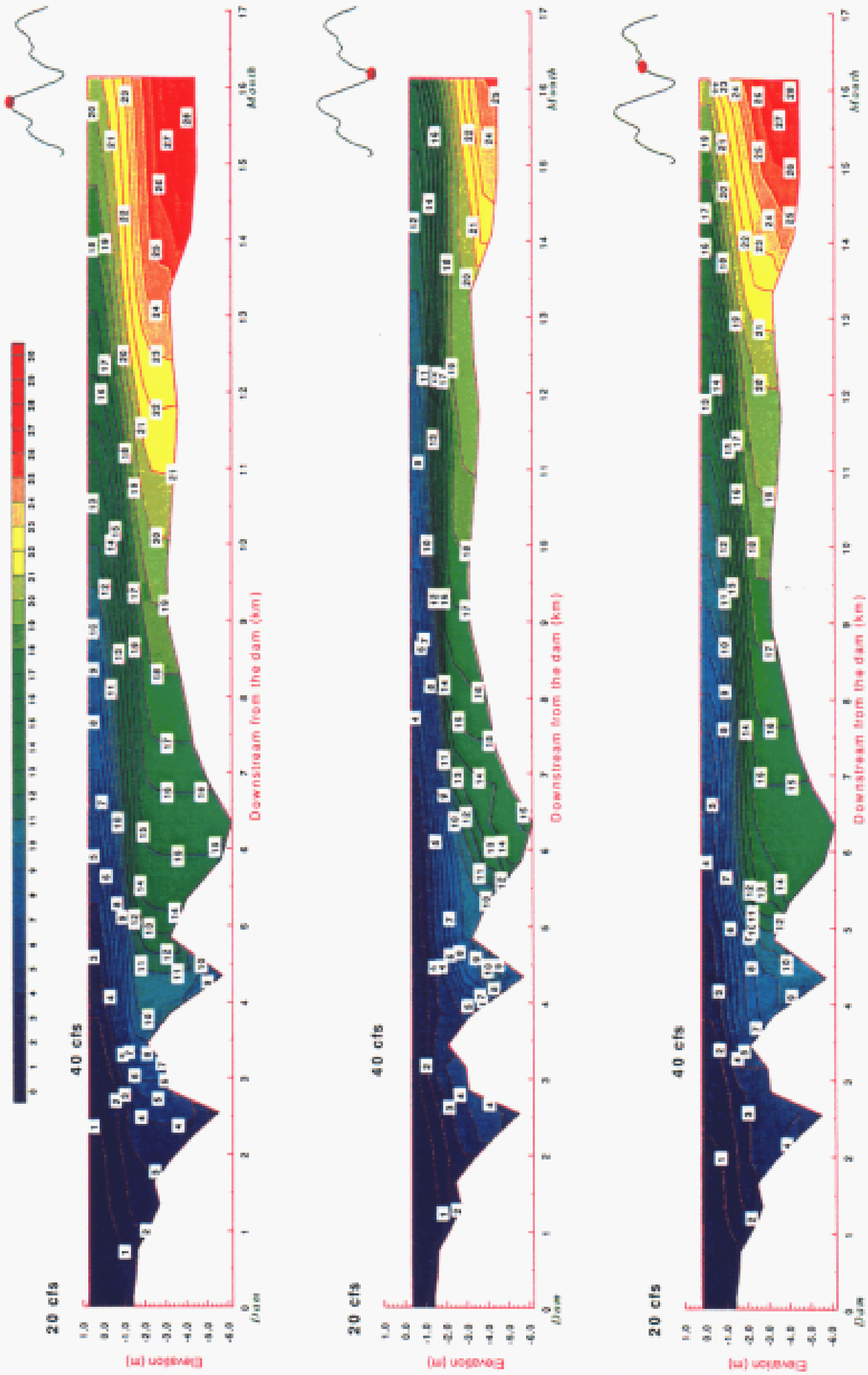
20 cfs
40 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.10

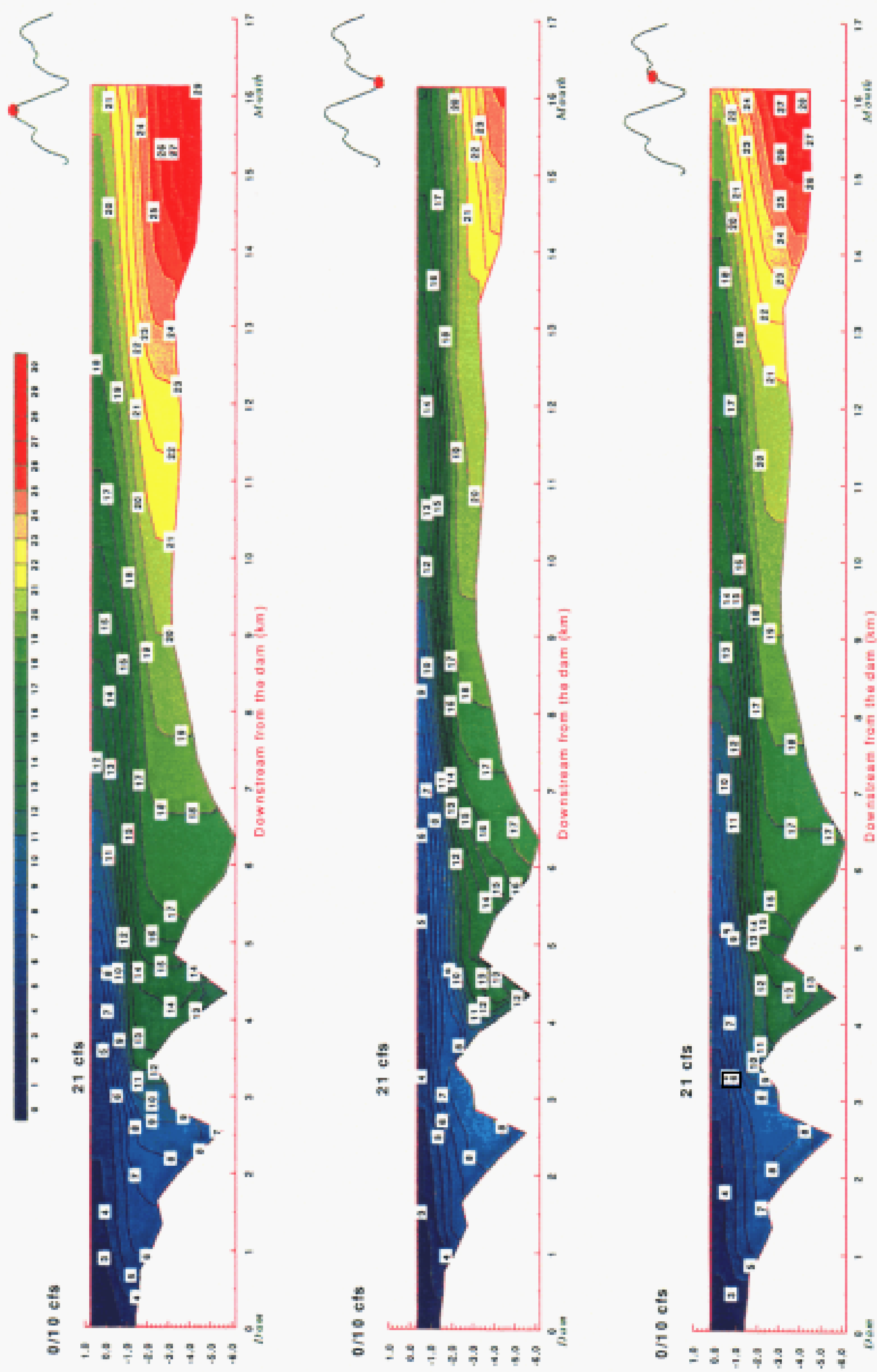
0/10 cfs
21 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.11

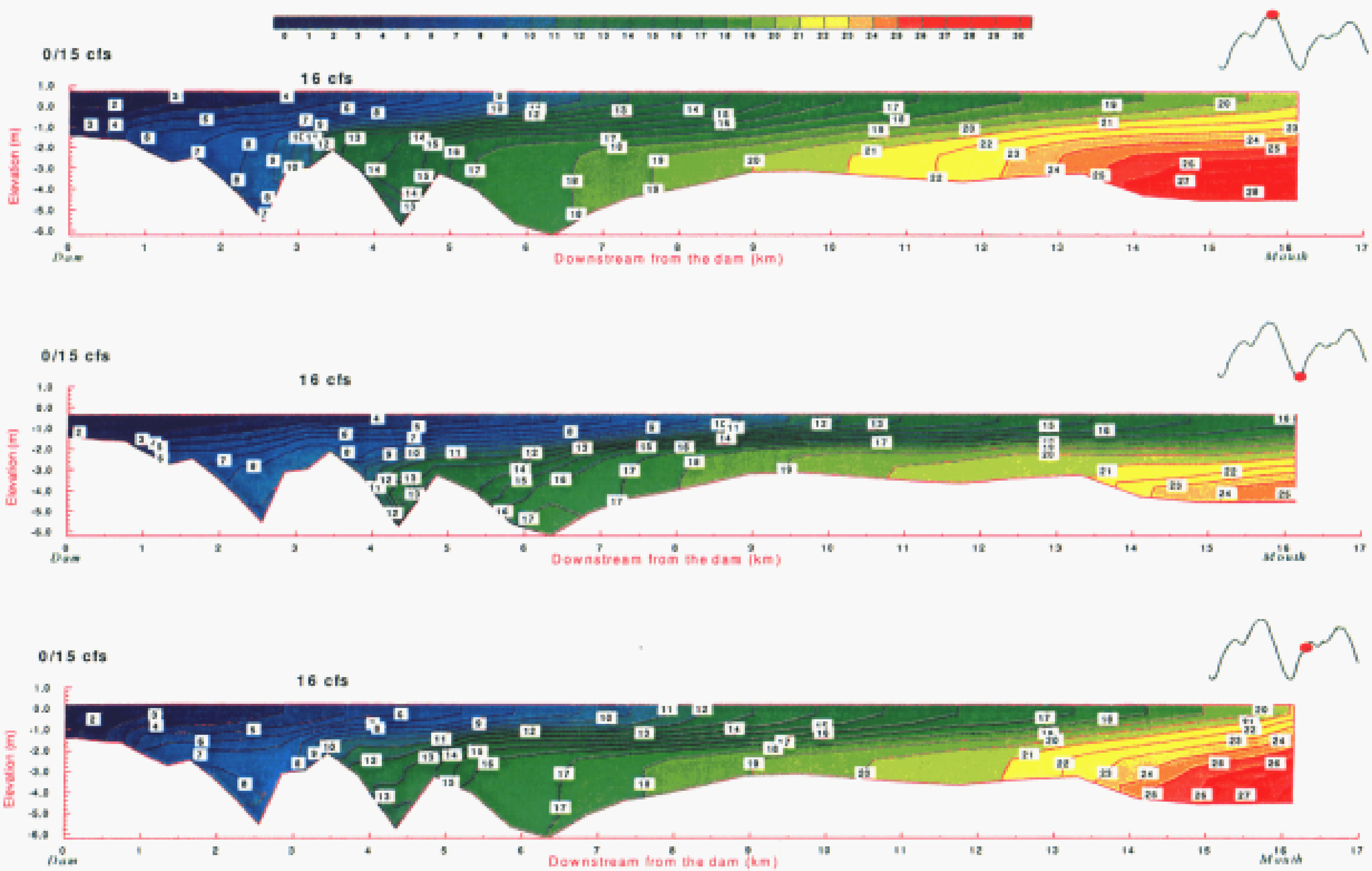
0/15 cfs
16 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.12

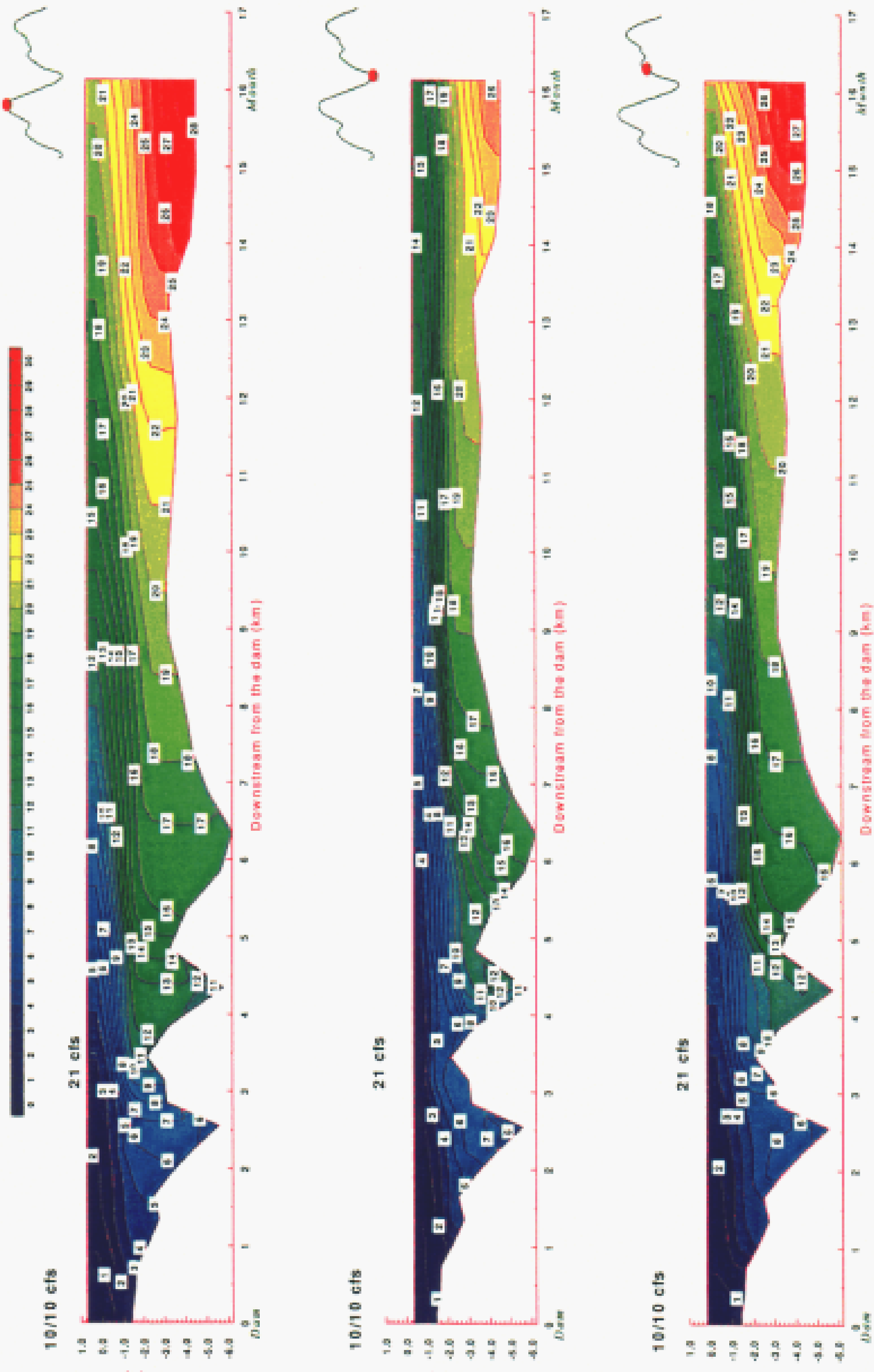
10/10 cfs
21 cfs
Downstream from the dam (km)
Elevation (m)
Dam
Mouth

Figure 5.13

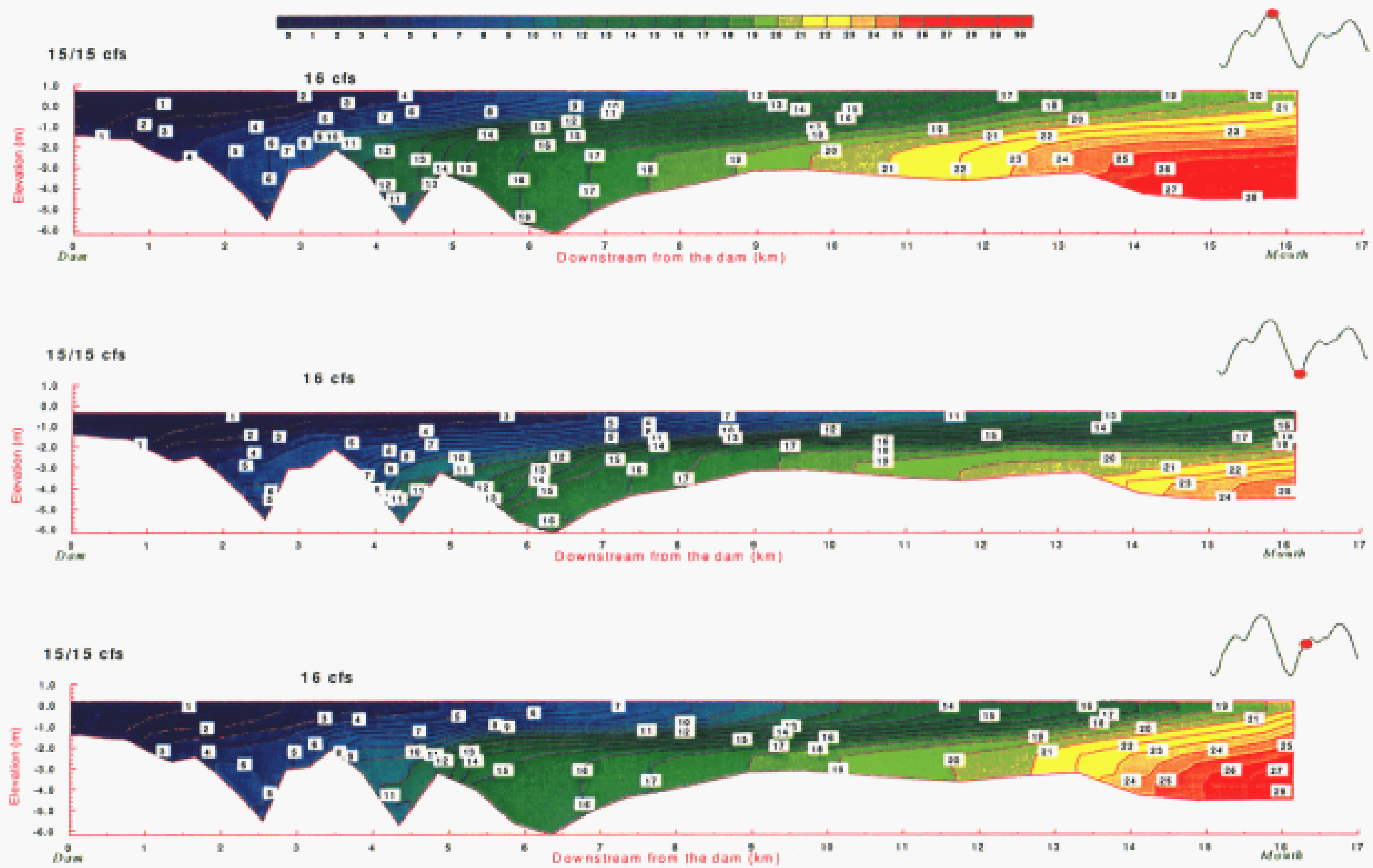
15/15 cfs
16 cfs
Elevation (m)
Downstream from the dam (km)
Dam
Mouth

Figure 5.14

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5.3 Predicted salinity zone volumes

Salinity zone volumes for thirty-eight scenarios are presented in Table 5.1. The response of ten different salinity zones were simulated so that comparisons could be made to the Venice System (Anonymous, 1959 as cited in Bulger et al., 1993) and the Bulger et al. (1993) salinity classification systems. The < 0.5 ppt zone was taken from the Venice System, which may be important to organisms with low salinity tolerances. The < 4.0 ppt zone corresponds to the freshwater to 4.0 ppt classification of Bulger et al. (1993), which was developed from principal component analysis of salinity ranges of fishes and invertebrates from the mid-Atlantic region.

Scenario numbers 21 through 30 in Table 5.1 list salinity zone volumes corresponding to different reservoir releases with an average flow of 31 cfs from Sulphur Springs. Using the model with its standard grid size, the < 1.0 ppt salinity zone does not occur below the dam until the reservoir release is 15 cfs. To investigate whether reducing the grid size would give better resolution of the occurrence of fresh water, the model was re-run with smaller grid sizes near the dam (see discussions on page 5.2 in Appendix O). That simulation (# 23A) resulted in a small zone (540 cubic meters) of <0.5 ppt salinity water below the dam with a 10 cfs minimum flow. The standard grid size was run for all other scenarios.

The volumes of low salinity waters rapidly increase with discharge from the reservoir. For example, the < 0.5 salinity zone increases from 540 to 20,300 cubic meters as flows at the dam increase from 10 to 15 cfs, then doubles again as flows increase to 20 cfs. Similarly, the < 1.0 ppt salinity zone increases by about a factor of five (from 14,000 to 73,400 cubic meters) when flows increase from 10 to 20 cfs. As flows increase from 20 to 30 cfs, the <0.5 ppt zone again doubles while the <1.0 ppt zone increases by 78 percent.

Table 5.1 also includes results for scenarios involving diversion of Sulphur Springs water to the base of the dam. A diversion of 10 cfs spring water with no reservoir release does not result in water less than 1.0 ppt below the dam, but a < 4.0 ppt zone of 82,710 cubic meters is established. Supplementing this springflow with 5 cfs from the reservoir nearly doubles the < 4.0 ppt zone, while it takes 10 cfs of reservoir water to establish a significant < 1.0 ppt zone. If 15 cfs is diverted from the spring, addition of 5 cfs reservoir water creates a small < 1.0 ppt zone.

The modeling results can be used to visualize what salinity distributions in the lower Hillsborough River would be under a different freshwater flow regime. For example, the median of estimated daily inflows to the Hillsborough River Reservoir for the period from 1974 to 1996 was 164 cfs, with only 5 percent of the values below 58 cfs (Table 2.4). Even if these inflows are reduced by seepage and evaporation losses from the reservoir, which have been estimated at between 33 and 53 cfs during very dry periods (Environmental Science and Engineering, 1987; page 6-3), the hydrodynamic modeling results indicate there would nearly always be freshwater zone below the dam in the absence of water withdrawals from the reservoir.

Run No.	River Flow	Spring Flow at Dam	Spring Flow	Salinity Range (ppt)									
				0 - 0.5	<1	< 4	< 5	1 - 10	5 - 11	4 - 11	11 - 18	10 - 20	> 20
	(cfs)	(cfs)	(cfs)										
1	0	0	20	0.0	0.0	0.0	0.1	315.1	381.6	381.7	1010.4	1696.4	804.2
2	10	0	20	0.0	0.8	116.4	168.6	455.6	347.3	399.4	1127.6	1663.4	698.6
3	20	0	20	28.7	48.3	212.9	272.0	519.0	374.5	433.7	1152.3	1615.5	638.0
4	40	0	20	112.5	155.3	374.1	430.4	651.9	484.7	540.9	1063.6	1466.1	551.5
5	80	0	20	262.0	337.5	588.9	678.9	858.6	636.0	726.0	835.4	1165.1	470.4
6	100	0	20	319.1	400.8	710.1	812.9	950.5	656.6	759.3	736.1	1036.6	446.8
7	0	0	40	0.0	0.0	58.5	204.9	533.0	404.2	550.5	1153.9	1633.0	653.8
8	10	0	40	3.8	30.2	254.8	327.5	618.9	418.3	491.0	1134.9	1572.8	600.2
9	20	0	40	51.6	95.0	348.2	408.6	675.8	472.1	532.4	1076.4	1493.4	559.9
10	40	0	40	154.3	217.4	461.6	525.7	779.5	584.4	648.5	956.9	1324.9	506.0
11	80	0	40	265.7	377.2	690.7	794.9	960.2	660.4	764.6	745.3	1048.9	447.8
12	100	0	40	307.0	447.9	809.0	920.7	1029.3	663.5	775.2	661.8	928.6	431.2
13	0	10	10	0.0	0.0	31.3	58.0	323.7	325.2	351.9	1002.1	1685.1	807.1
14	5	10	10	0.0	0.0	80.1	122.6	399.2	331.9	374.3	1086.3	1674.6	743.6
15	10	10	10	0.0	13.2	132.7	177.7	442.5	337.2	382.3	1127.5	1664.1	698.6
16	15	10	10	0.0	37.2	176.1	228.1	474.3	350.9	402.9	1149.2	1639.7	668.5
17	0	20	20	0.0	0.0	173.2	233.6	533.0	375.0	435.4	1153.1	1632.9	654.2
18	5	20	20	0.0	15.6	224.4	289.2	572.9	386.4	451.3	1154.5	1609.0	623.8
19	10	20	20	0.0	46.9	269.6	335.2	601.1	409.0	474.7	1137.3	1574.8	599.5
20	15	20	20	0.0	79.2	313.1	374.5	632.0	442.4	503.8	1106.6	1534.9	577.1
21	0	0	31	0.0	0.0	6.6	47.5	446.9	460.6	501.4	1129.3	1669.0	702.2
22	5	0	31	0.0	0.0	136.6	200.8	506.2	372.2	436.5	1149.2	1645.1	668.1
23	10	0	31	0.0	14.7	192.8	253.9	546.8	386.4	447.4	1154.1	1619.8	639.2
23A	10	0	31	0.5	14.0	190.4	251.7	544.7	385.6	446.9	1153.0	1618.7	642.9
24	15	0	31	20.3	42.4	240.2	309.5	577.6	399.5	468.7	1143.1	1587.9	613.7
25	20	0	31	41.9	73.4	289.2	357.1	606.1	419.8	487.8	1123.0	1550.8	592.4
26	30	0	31	86.4	130.6	367.7	425.4	669.0	483.5	541.1	1067.9	1472.7	552.4
27	40	0	31	134.1	186.0	424.2	482.1	727.2	546.3	604.1	1005.0	1386.9	526.5
28	60	0	31	220.5	293.3	527.7	606.0	818.7	618.2	696.6	889.4	1227.9	489.9
29	80	0	31	264.0	358.3	644.2	743.3	921.3	651.6	750.7	784.4	1096.2	457.1
30	100	0	31	318.7	425.3	762.3	868.8	1000.5	686.2	772.8	694.6	972.1	438.1
31	0	10	21	0.0	0.0	82.7	153.9	447.5	353.7	424.9	1128.1	1667.7	703.1
32	5	10	21	0.0	0.0	154.9	209.5	503.4	361.1	415.6	1149.5	1645.1	671.0
33	10	10	21	0.0	29.5	202.0	261.2	530.8	377.8	437.0	1154.6	1620.8	639.6
34	15	10	21	1.3	51.4	247.0	312.6	567.7	395.9	461.5	1142.5	1588.5	614.1
35	0	15	16	0.0	0.0	106.6	161.1	447.3	346.3	400.8	1126.5	1666.9	704.1
36	5	15	16	0.0	1.4	161.7	214.5	503.3	357.3	410.1	1149.6	1645.0	669.8
37	10	15	16	0.0	34.0	206.3	265.2	525.4	373.0	432.0	1154.7	1622.4	638.8
38	15	15	16	0.0	55.1	250.5	314.5	564.1	394.3	458.3	1144.0	1590.2	612.3

Table 5.1 Two-day average water salinity zone volumes (1000 m^3) for various minimum flows.

5.4 Extended simulations that include rainfall and reservoir discharge records

The minimum flow scenarios described above can be considered worst case scenarios since they were run assuming conditions of no rainfall. Even during periods of no discharge from the dam, periodic rainfall events and resulting stormwater runoff should reduce salinity below that predicted for the minimum flow alone. To evaluate how minimum flows would affect salinity under actual rainfall conditions, the model was run for a nine month period from September 1981 through June 1982 with an assumed 10 cfs minimum flow. Rainfall at a nearby site was used to calculate stormwater runoff to the Lower Hillsborough River which entered into the model along with discharges from the dam reported by the USGS. On days when flows from the dam were less than 10 cfs, a minimum flow of 10 cfs was input into the model. Greater details on the hydrologic variables that were used for 1981-1982 simulations are presented in Chapter 5 of Appendix O.

The model was run for three scenarios: (1) no minimum flow: (2) a 10 cfs minimum flow of water from the reservoir; and (3) a 10 cfs minimum flow with diversions from Sulphur Springs used to bring the total flow at the dam up to 10 cfs (small dam discharges were included in total 10 cfs). Salinity zone volumes were calculated for each of the 274 days in the nine month period. During this period there were periodic discharges from the dam that occurred between periods of no flow. In order to examine salinity distributions during periods of periodic rainfall events but low dam discharges, a subset of 135 days was examined when recorded flows from the dam were less than 10 cfs, including many no-discharge days when only small flows from dam leakage were reported.

Daily salinity zone volumes were calculated for each of three scenarios using both the 274-day and 135-day time periods. The results of these simulations are presented in Table 5.2 and 5.3 as frequency distributions of salinity zone volumes. With the 274-day record (Table 5.2), salinity zone volumes for the higher percentiles (60 to 100) show little difference between minimum flows, since periodic flows from the dam control the magnitude of the larger salinity volumes that occur. From the 50th percentile and lower, however, the salinity zone volumes differ for the minimum flows. For example, the 40th percentile value for the <1 ppt zone for the 10 cfs reservoir minimum flow is over 4 times greater than the volume calculated with a minimum flow from Sulphur Springs, due to the salinity of the spring water being simulated at 1.2 ppt. Differences in the higher salinity zones (<4 and 4-11 ppt) are not as pronounced.

Salinity zone volumes for the 135-day time period show greater differences between minimum flows, because the effects of dam discharges are greatly reduced (Table 5.3). For example, 70 percent of the time there is no $<$ 1ppt zone if Sulphur Springs is used to provide the minimum flow, but this zone is present most of the time if reservoir water is used. For the <1.5 ppt zone, however, the results are much more similar between the two minimum flow sources.

Percent \ Salinity	< 0.5	< 1	< 1.5	< 4	4 - 11
No Minimum Flow					
100	2604.96	2677.40	2707.85	2789.80	1220.93
90	1208.24	1454.70	1571.71	1883.36	819.53
80	857.58	1095.72	1245.36	1636.36	711.11
70	601.16	828.66	965.49	1357.80	639.16
60	371.24	583.56	683.19	1080.35	594.40
50	204.47	319.62	398.10	660.96	560.38
40	45.70	107.22	190.45	407.47	525.24
30	0.00	0.00	5.36	251.86	459.18
20	0.00	0.00	0.00	87.06	385.84
10	0.00	0.00	0.00	30.27	280.31
0	0.00	0.00	0.00	0.00	74.04
10 cfs Minimum Flow From the Reservoir					
100	2605.61	2677.43	2707.13	2789.83	1174.13
90	1239.28	1454.45	1577.15	1882.11	817.82
80	873.41	1114.55	1245.15	1636.76	712.95
70	601.91	828.43	969.63	1358.56	645.90
60	410.64	588.89	695.24	1097.56	599.78
50	209.66	343.18	413.62	688.88	562.67
40	95.70	163.49	242.82	454.59	510.40
30	27.13	54.27	104.19	335.97	448.35
20	2.13	25.30	43.71	249.99	398.78
10	0.00	8.57	23.69	183.68	306.43
0	0.00	0.00	0.00	35.42	74.04
10 cfs Minimum Flow from Sulphur Springs					
100	2583.69	2662.28	2694.22	2780.31	1223.09
90	1208.36	1456.23	1574.24	1879.41	816.89
80	878.96	1105.82	1249.04	1646.96	705.61
70	600.01	820.07	957.47	1363.89	632.77
60	372.78	586.34	697.04	1083.88	570.15
50	7.79	322.81	407.48	661.20	509.97
40	0.00	38.97	208.29	408.87	461.09
30	0.00	0.00	87.08	275.46	413.67
20	0.00	0.00	46.61	191.70	381.71
10	0.00	0.00	29.20	147.00	279.58
0	0.00	0.00	0.00	0.00	74.04

Table 5.2. Frequency distributions of daily average water volume (in $1000m^3$) for various salinity ranges in the Lower Hillsborough River with 0 cfs minimum. 10 cfs minimum flow from the reservoir. and 10 cfs minimum flow from Sulphur Springs (sample size:274 days).

Percent \ Salinity	< 0.5	< 1	< 1.5	< 4	4 - 11
No Minimum Flow					
100	1135.15	1567.90	1801.29	2480.09	1130.64
90	145.18	244.10	353.74	656.94	849.10
80	40.42	107.22	190.45	416.94	769.32
70	0.00	8.35	38.39	338.02	630.79
60	0.00	0.00	4.78	242.50	594.24
50	0.00	0.00	0.24	190.60	565.02
40	0.00	0.00	0.00	76.40	550.00
30	0.00	0.00	0.00	44.72	525.24
20	0.00	0.00	0.00	29.15	491.23
10	0.00	0.00	0.00	0.00	383.47
0	0.00	0.00	0.00	0.00	145.28
10 cfs Minimum Flow From the Reservoir					
100	1252.17	1654.49	1876.03	2518.25	1124.34
90	162.06	282.92	387.36	712.34	850.67
80	94.78	170.91	245.88	486.16	768.24
70	38.01	96.14	169.61	389.33	646.16
60	26.66	50.41	101.96	334.48	599.28
50	15.92	39.39	74.90	306.74	567.48
40	1.68	24.21	42.89	249.17	548.63
30	0.00	11.99	30.59	220.36	494.90
20	0.00	8.43	23.11	181.99	451.27
10	0.00	1.01	18.14	112.45	425.17
0	0.00	0.00	0.00	35.42	287.53
10 cfs Minimum Flow from Sulphur Springs					
100	1062.33	1564.92	1802.81	2466.64	1130.94
90	0.98	234.38	350.09	657.93	842.66
80	0.00	30.60	208.29	420.99	769.79
70	0.00	0.00	127.70	337.65	613.36
60	0.00	0.00	84.86	270.61	548.73
50	0.00	0.00	64.35	237.98	502.46
40	0.00	0.00	46.36	190.22	473.64
30	0.00	0.00	40.17	169.89	426.51
20	0.00	0.00	28.53	146.12	392.33
10	0.00	0.00	0.00	4.79	375.91
0	0.00	0.00	0.00	0.00	159.55

Table 5.3. Frequency distributions of daily average water volume (in $1000m^3$) for various salinity ranges in the river with 0 cfs minimum flow (MF), 10 cfs MF from the reservoir, and 10 cfs MF from Sulphur Springs (sample size: 135 days of < 10 cfs recorded flow).

6. SUMMARY AND DETERMINATION OF THE ADOPTED MINIMUM FLOW

6.1 Minimum flows approach for the Lower Hillsborough River

The watershed, channel, and natural systems of the Lower Hillsborough River have experienced extensive changes and structural alterations. Significant hydrologic functions of the resource, such as those provided by intertidal estuarine wetlands, have largely been lost due to the extensive urbanization of the river. The river has been impounded for many years, with the dam creating a barrier that prevents the upstream movement of fishes past that point in the river channel. There are, however, important ecological communities and natural resource values associated with the Lower Hillsborough River. Accordingly, the District's determination of minimum flows for the Lower Hillsborough River was based on the loss of historical hydrologic functions, the existing changes and alterations along the river and its watershed, and the dependence of viable ecological communities downstream of the dam on flows from the Hillsborough River and Sulphur Springs.

A limitation of the District's minimum flows evaluation is there are not abundant data available for periods of low flow (5 to 30 cfs) from the dam. As described in Section 6.5, implementation of a minimum flow and the subsequent ecological monitoring of the river will provide extensive new data to re-evaluate the minimum flow for the Lower Hillsborough River.

6.2 Ecological characteristics of concern

Although it is highly modified, the Lower Hillsborough River supports valuable communities of both freshwater and estuarine organisms. After reviewing data for the lower river, the minimum flows advisory group facilitated by the Tampa Bay National Estuary Program concluded that salinity and dissolved oxygen are critical water quality variables affecting the abundance and distributions of organisms in the Lower Hillsborough River. Accordingly, two of the group's recommendations dealt with salinity regimes needed to provide for both freshwater and estuarine dependent organisms below the dam (page 3.3). A key element of these recommendations was that a freshwater zone would help optimize utilization of the lower river by estuarine dependent fishes and also provide a refuge for freshwater organisms in the dry season. Freshwater was defined by the group as having salinity values below 0.5 ppt.

The District concurs that maintaining a freshwater zone is an important management objective for the lower river, but the salinity values needed to maintain biological use of a freshwater zone should be subject to further evaluation. Freshwater species differ in their salinity tolerances and many species can tolerate periodic exposures to slightly brackish water. Also, the size and location of the freshwater zone will be important, and additional information is needed on how different organisms respond to the distribution of fresh and low salinity waters in the lower river.

The advisory group also recommended that in order to optimize fish utilization of the lower river, goals for dissolved oxygen concentrations should be a minimum of 4.0 mg/l and a daily average of 5.0 mg/l. As described in this report, there are many locations in the river where flow releases are effective at raising DO concentrations above 2.0 or 3.0 mg/l, but not at raising them above 4.0 mg/l or 5.0 mg/l. The District suggests that where the 4.0 or 5.0 mg/l thresholds can not be feasiblely met, important ecological gains may be achieved by raising DO values at lower concentrations. Future studies of the lower river in support of the minimum flows re-evaluation will examine how the biota of the river respond to improvements in DO that result from implementation of a minimum flow.

The advisory group also recommended the District evaluate other ecological issues related to freshwater flow management, including impacts to manatees and changes in water quality related to diverting a portion of the Sulphur Springs discharge. Impacts to manatees will be evaluated as part of the establishment of minimum flows for Sulphur Springs, which is scheduled for 2001. Changes in water quality that could result from diversions of water from Sulphur Springs will be examined as part of the minimum flows evaluation for the spring and re-evaluation of the minimum flows for the Lower Hillsborough River.

6.2 Salinity summary

The results presented in this report and Coastal (1997) indicate the salinity regime of the Lower Hillsborough River is very responsive to freshwater inflows. Therefore, minimum flow releases could result in pronounced changes in the salinity regime of the lower river, especially the reach between the dam and Sulphur Springs. During periods of no flow from the reservoir spillway, salinity at the Rowlett Park station averages about 5 to 6 ppt with values occasionally reaching as high as 11 to 12 ppt. Salinity values this high are unsuitable for the freshwater organisms that become established below the dam in the wet season. On many days during no-flow conditions, the Rowlett Park site would not even be classified as oligohaline (0 to 5 ppt) using the Venice Estuarine Classification System.

Relatively small minimum flows could dramatically reduce salinity values at the Rowlett Park station. Regressions of flow on salinity at Rowlett Park presented in this report predict salinity values of 1.0 to 1.3 ppt at that station with a minimum flow of 10 cfs. Scatter plots of the data, however, indicate salinity would still vary at Rowlett Park with a 10 cfs minimum flow, due apparently to the effects of tides and antecedent rainfall. As flows from the dam increase, salinity at the Rowlett Park station becomes less variable and gradually approaches freshwater conditions. At flows of about 15 to 30 cfs, it appears waters released from the dam become more effective at displacing brackish waters at Rowlett Park that move upstream on incoming tides. Salinity values of 0.4 to 0.6 ppt are predicted at the Rowlett Park station at a flow of 25 cfs.

Flows in the range of 10 to 30 cfs are also effective at reducing salinity at stations further downstream. Coastal (1997) developed regressions for salinity at the WAR/SDI and USGS stations in the lower river as a function of flow and listed predicted salinity values at these stations for flows in increments of 10 cfs (Appendix M in Coastal, 1997). The response of salinity to flow is strongly curvilinear, with changes in salinity most responsive at low flows. For example, the average changes in predicted surface salinities at WAR/SDI Stations 3 thought 10 are: 1.25 ppt as flows increase from 0 to 10 cfs, 0.92 ppt as flows increase from 10 to 20 cfs, and 0.74 ppt as flows increase from 20 to 30 cfs. As described on page 4.12, these regression analyses indicate that minimum flows in the range of 10 to 20 cfs could substantially reduce salinity in the river reach above Sulphur Springs. By decreasing salinity in the brackish reaches of the river, minimum flows could result in the downstream expansion of ecologically important low and medium salinity zones thus making them more available for use by estuarine dependent fishes.

Examination of the relationships of salinity and flow from the three data sources (WAR/SDI, HCEPC, USGS) shows that wide ranges of salinity occur at different stations in the river during no-flow conditions, presumably due to variations in rainfall and stormwater runoff below the dam. These data indicate that flows as small as 10 to 20 cfs from the dam can markedly reduce the maximum salinity values that occur at these stations. By reducing the maximum salinity values that occur in the river, minimum flows could help alleviate the upstream movement of low and medium salinity zones that occur during prolonged dry periods.

The hydrodynamic model developed by the District also indicates that dramatic changes in the salinity regime of the lower river can occur at relatively low minimum flows (10 to 30 cfs). Minimum flows are particularly effective at increasing in the volumes of fresh (<0.5 ppt) and near-fresh (<1.5 ppt) waters below the dam (see discussion on page 5.17). The distribution and volumes of medium salinity waters (e.g., 4 - 11 ppt) are not as strongly affected (Table 5.1).

The hydrodynamic model allowed the assessment of minimum flow scenarios that involve diverting a portion of water from Sulphur Springs to the base of the dam. Compared to the release of river water from the reservoir, diversions from Sulphur Springs were not as effective at increasing the volumes of waters less than 1.0 ppt, due to the spring water having a salinity of 1.2 ppt. Differences between the two minimum flow sources are much less when volumes of water less than 1.5 or 4.0 ppt are considered (Table 5.2 and 5.3). The beneficial effects of Sulphur Springs diversions on reductions of salinity will be limited to above the spring outfall, since below the spring there will be no net gain of fresh or near-fresh water to the river. However, there may be some improvements in vertical DO gradients in the river near the spring outfall as a result of reduced density stratification, since spring waters diverted to the base of the dam should be well mixed with the tidal river water.

6.3 Dissolved Oxygen (DO) Summary

This report and other studies of the Lower Hillsborough River (Metcalf and Eddy, 1983; WAR/SDI, 1995; Coastal, 1997) have found positive relationships between flows from the dam and DO concentrations in at least some reaches of the lower river. Data presented in this report from all three available sources (WAR/SDI, HCEPC, USGS) show that different reaches of the Lower Hillsborough River can have problems with low DO concentrations during periods of no discharge from the dam. This is similar to the findings of Metcalf and Eddy (1983), who found that DO concentrations in the river were related to freshwater inflows and the absence of flows from the dam tend to reduce DO levels in the upper reaches of the river (page 1-2, 2-28,). They further suggested that the effects of sediment oxygen demand on DO concentrations are most pronounced during times of low freshwater inflows when the estuary is insufficiently flushed.

Overall, the studies conducted to date indicate that the implementation of minimum flows will have a beneficial effect on DO concentrations in at least some portions of the Lower Hillsborough River. Although positive relationships between DO concentrations in the lower river and flow from the dam are evident, estimating the improvement in DO concentrations that will result from incremental increases in freshwater inflows is difficult.

In general, the data analyzed in this report support the findings of Metcalf and Eddy (1983), who concluded that continual releases of water from the dam would improve DO concentrations in the lower river with the length of the river experiencing improvement dependent on the magnitude of the freshwater release. However, it is difficult with the existing data to determine over what length of river substantial improvements in DO can be expected. For example, Rowlett Park is the only station with extensive data in the first three miles of river below the dam. More limited data at WAR/SDI Station 3 (mile 1.6) indicate a positive response of DO to flow, but low DO concentrations may persist at that station at flows as high as 30 to 40 cfs. Although general improvements of DO in the lower river with increased flows are expected, it is difficult to determine the length of river where significant improvements in DO should occur at flows between 10 and 50 cfs.

At this juncture, the District suggests the further evaluation of the effects of minimum flows on DO concentrations in the lower river should involve the implementation of a minimum flow and monitoring of the response. Implementation of a minimum flow will allow examination of DO concentrations under a flow regime which has not yet been observed - a low but constant inflow of fresh or near-fresh water in the dry season. Also, the minimum flow waters will be fully aerated before discharge to the lower river, which might produce results not observed in the existing data. The sampling regime for the monitoring plan should have high spatial and temporal resolution in the reaches below the dam. Continuous recorders should be used to the greatest extent possible so that DO values are collected frequently over diurnal and seasonal cycles. Finally, test releases should be conducted so that different minimum flows can be evaluated. It is intended that the design and objectives of such a program will be carefully established before the monitoring plan is implemented so that the effects of the minimum flow can be most effectively evaluated.

6.4 Determination of the minimum flow

Based on the factors described above, the Governing Board adopted a minimum flow for the Lower Hillsborough River of 10 cubic feet per second (cfs) at the base of the Hillsborough River Reservoir dam as measured at the Rowlett Park Bridge station. This minimum flow should provide immediate improvements to the ecological characteristics of the Lower Hillsborough River, particularly in the reaches immediately below the dam.

Because the existing data base for the river during low flows is limited, the District and the City of Tampa shall commence a study to re-evaluate the minimum flow for the Lower Hillsborough River once it has been implemented. The work plan and study shall commence before October 1, 1999. The study is to be completed by December 31, 2005, unless a extension of time is mutually agreed to by the City and the District. If the study demonstrates the need for revisions to the minimum flow, the District shall revise the minimum flow.

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FINAL DRAFT

APPENDICES

for

An Analysis of Hydrologic and Ecological Factors Related to the Establishment of Minimum Flows for the Lower Hillsborough River

Southwest Florida Water Management District

June 15, 1999

List of Appendices

N-2 Chronological meeting summary of the Tampa Bay National Estuary Program Minimum Flows Advisory Group for the Lower Hillsborough River and the Tampa Bypass Canal.

N-4 Results of analyses of fish catch data conducted by the Florida Department of Environmental Protection Florida Marine Research Institute.

O. (Bound separately) Study of salt transport in the Lower Hillsborough River using a laterally averaged two-dimensional hydrodynamic model.

Appendix C
(Appendices begin with Appendix C)

Plots of salinity at the WAR/SDI stations vs. discharge from the Hillsborough River Reservoir. All depths are shown. Units are parts per thousand for salinity and cfs for discharge.

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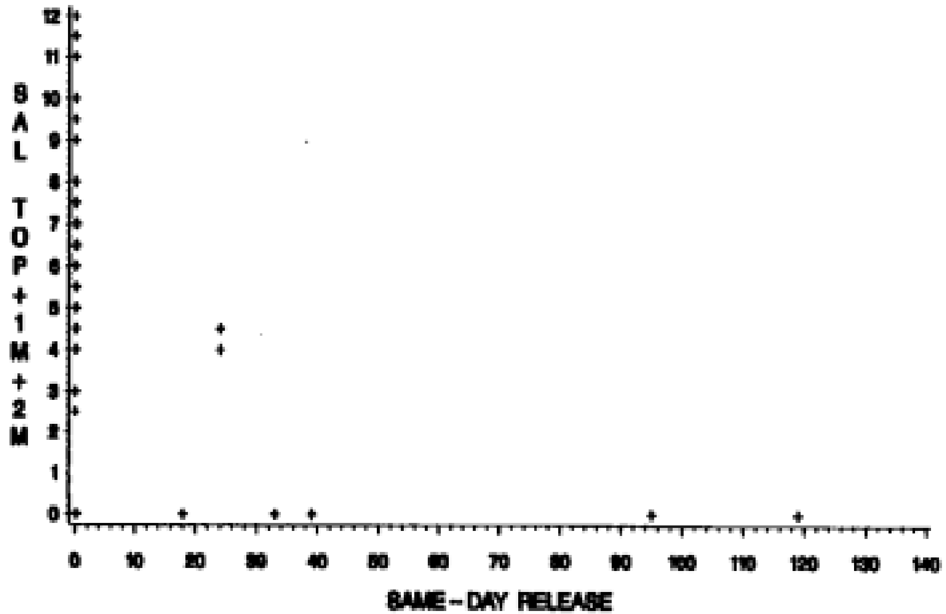

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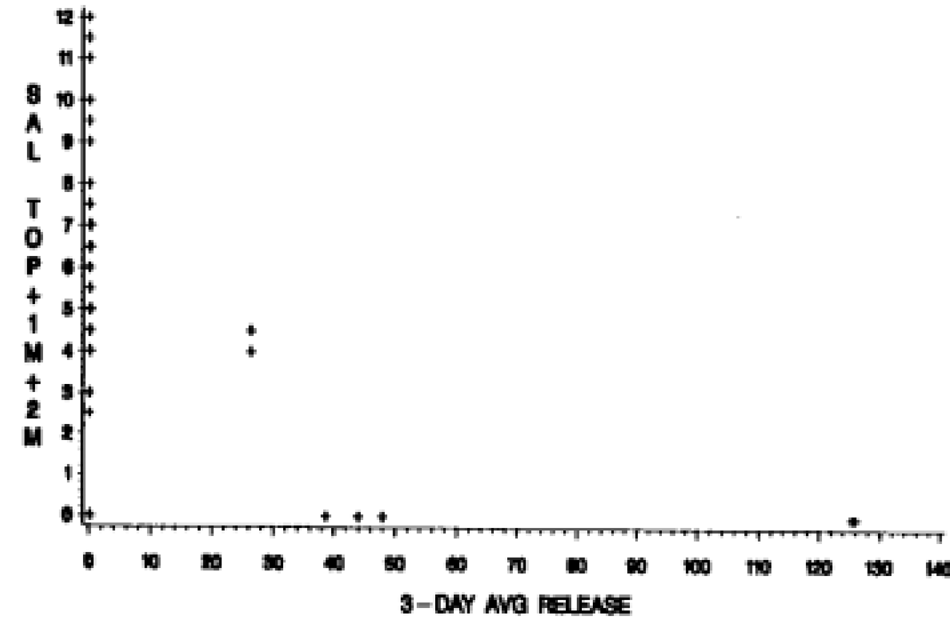

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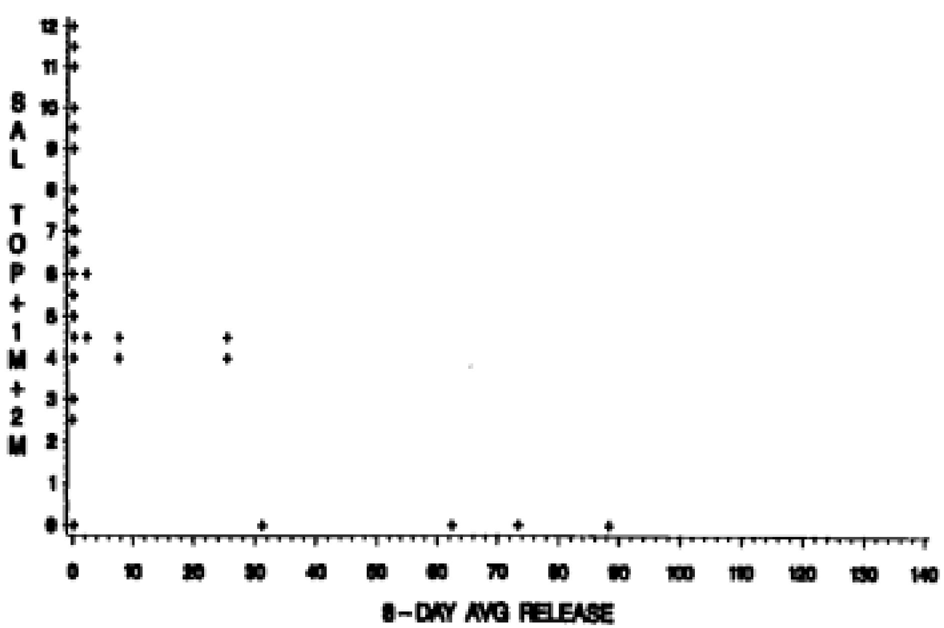

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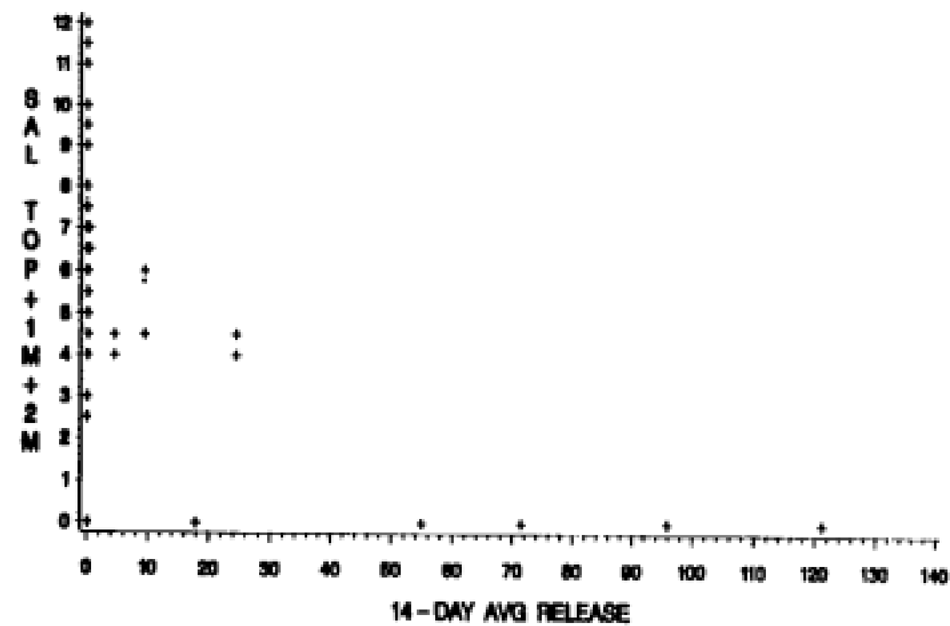

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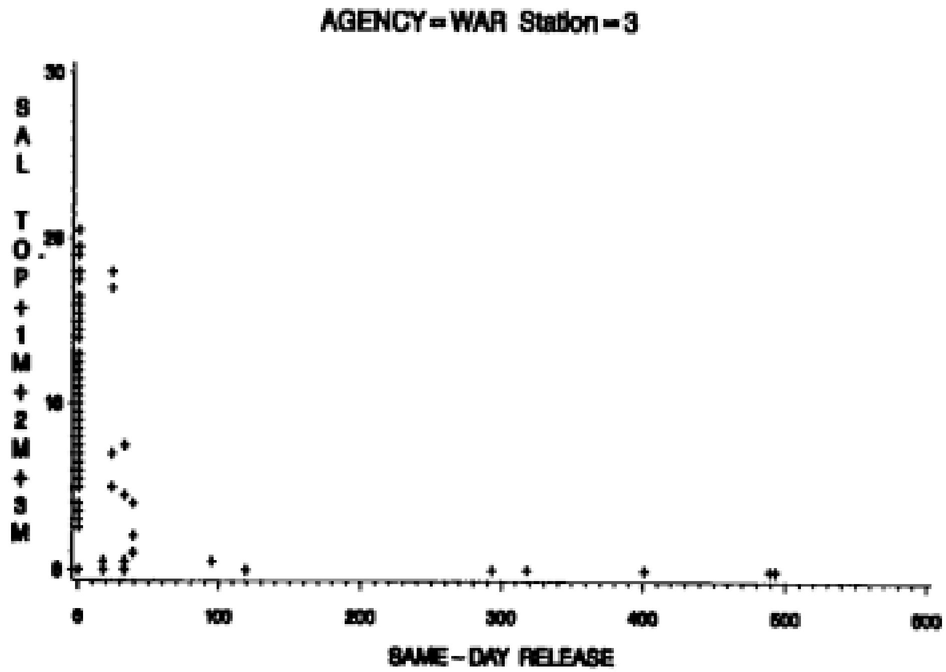
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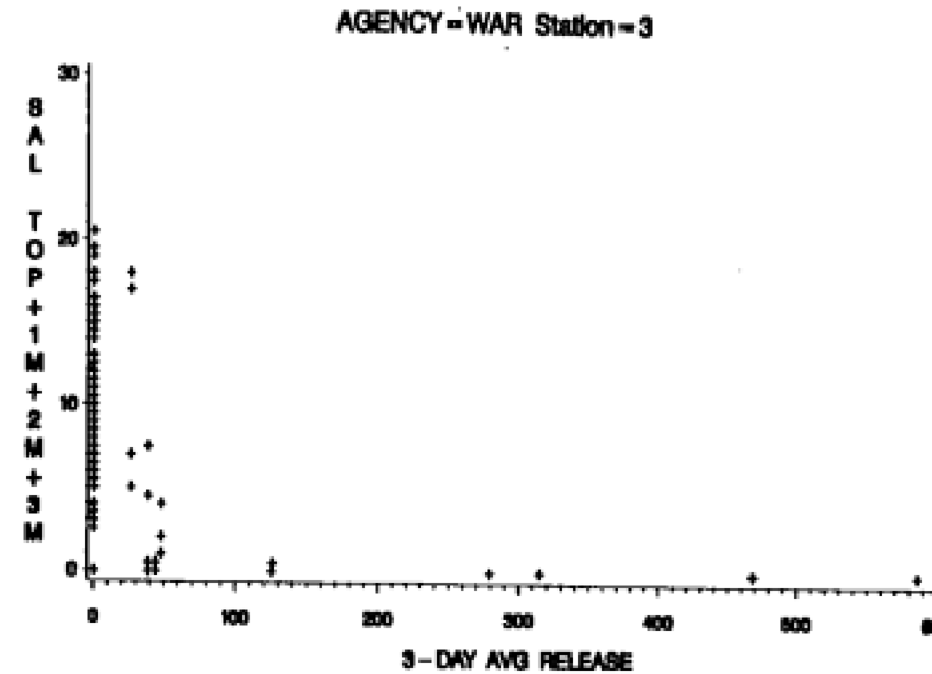
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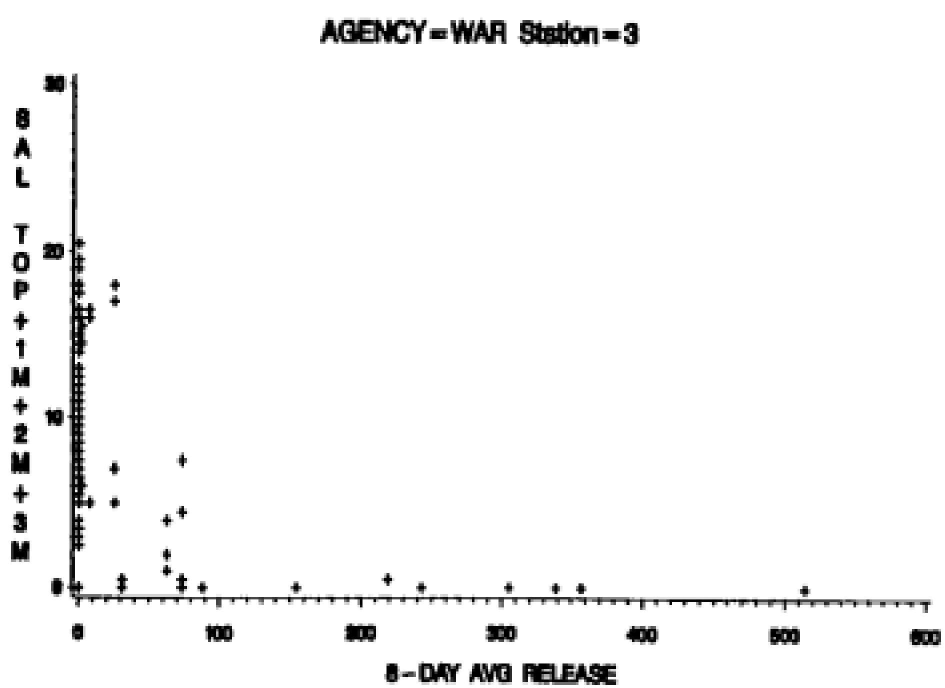
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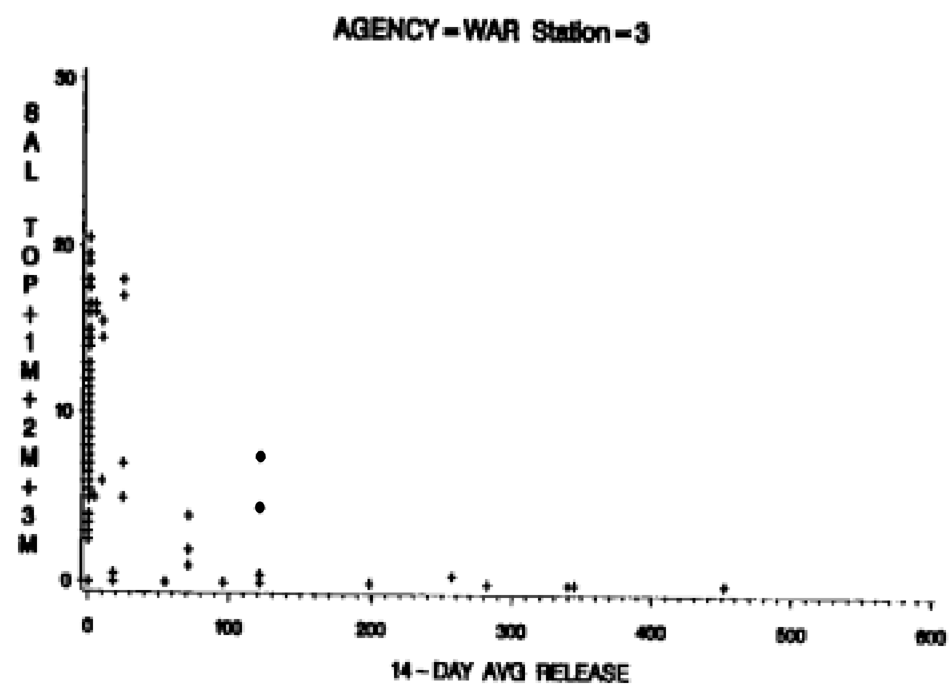
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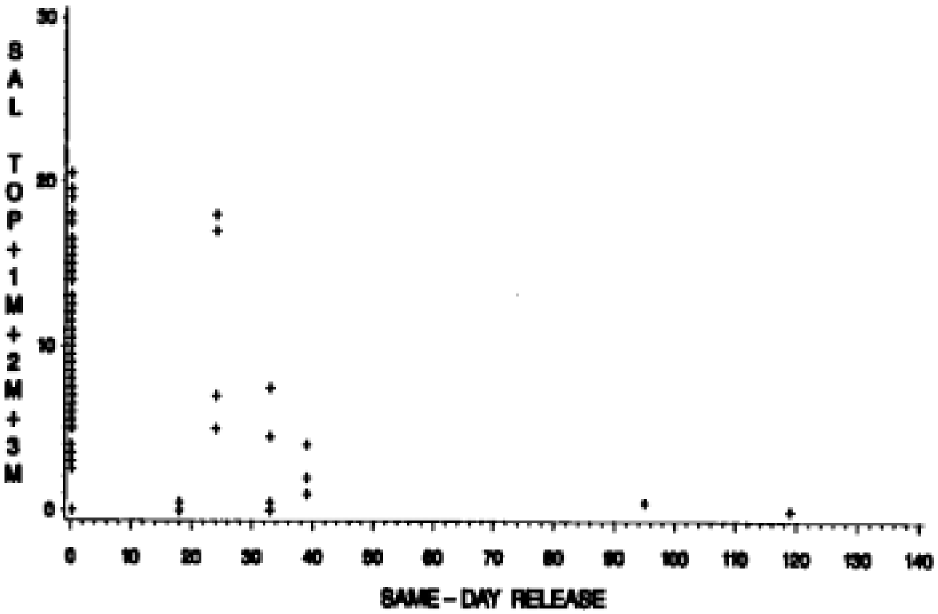

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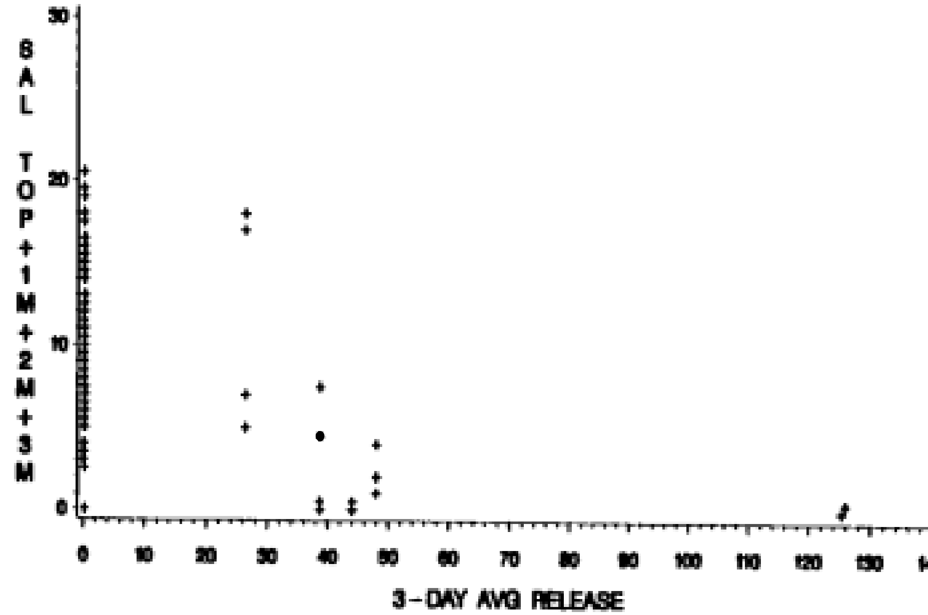

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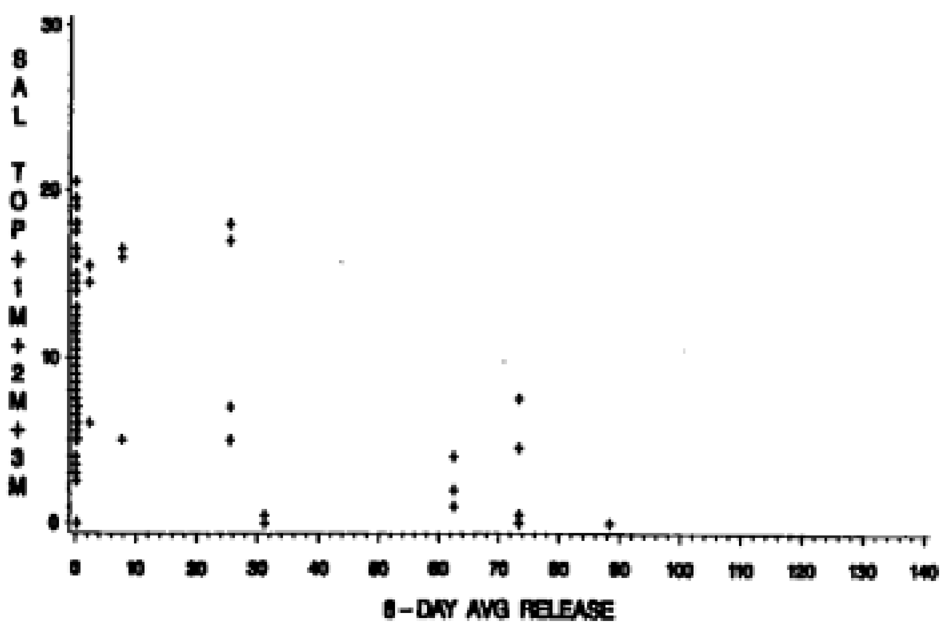

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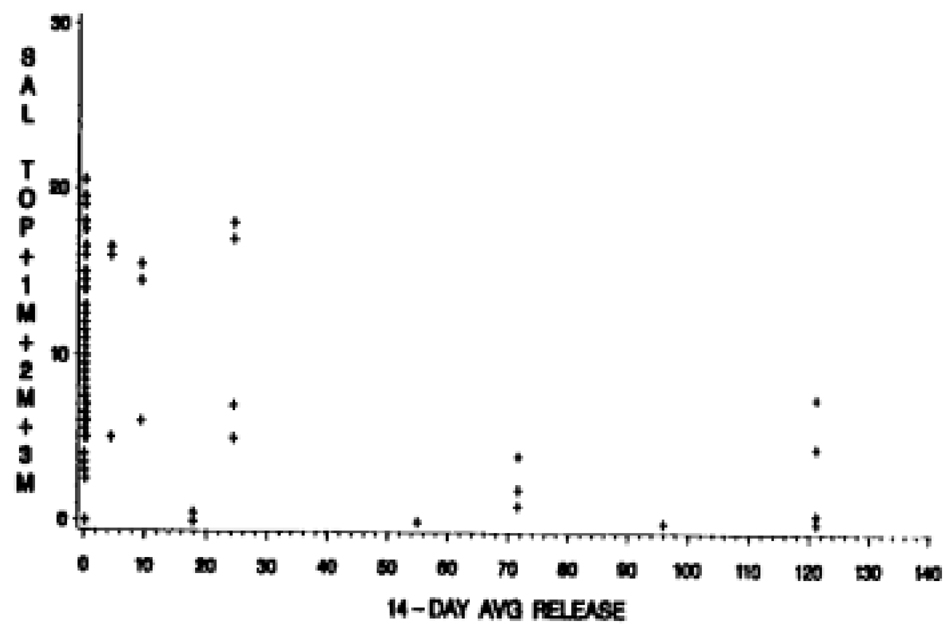

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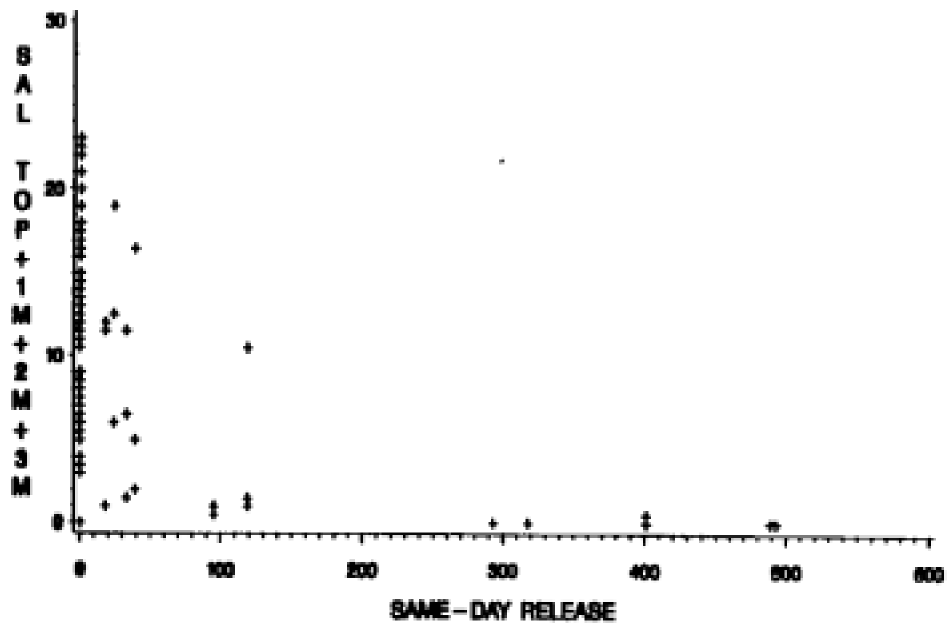

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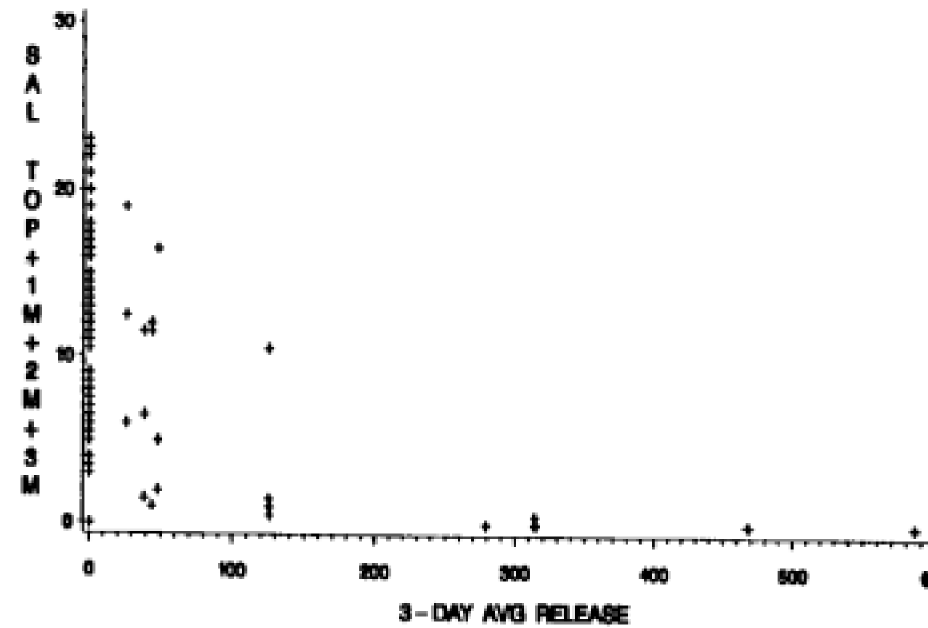

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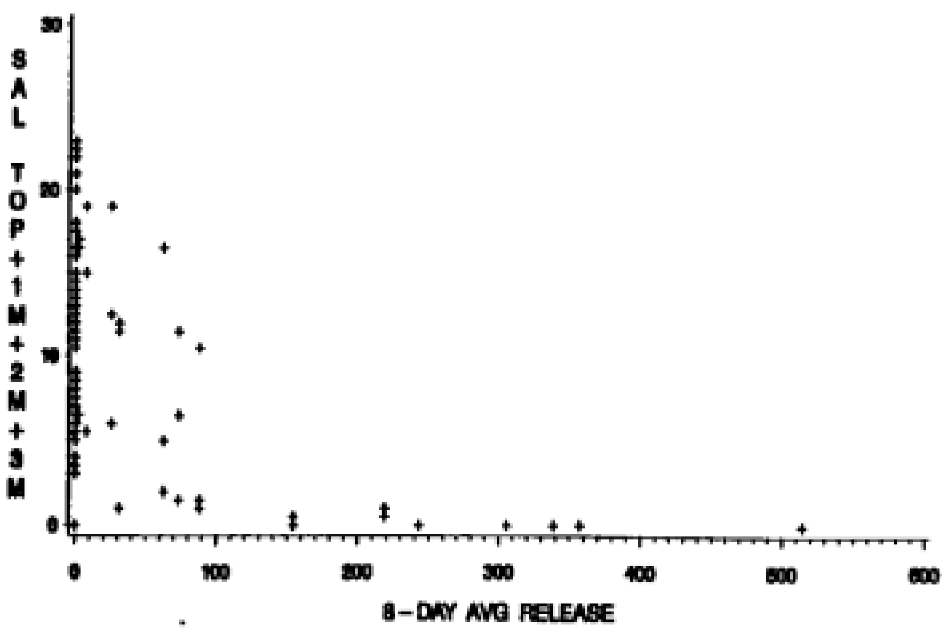

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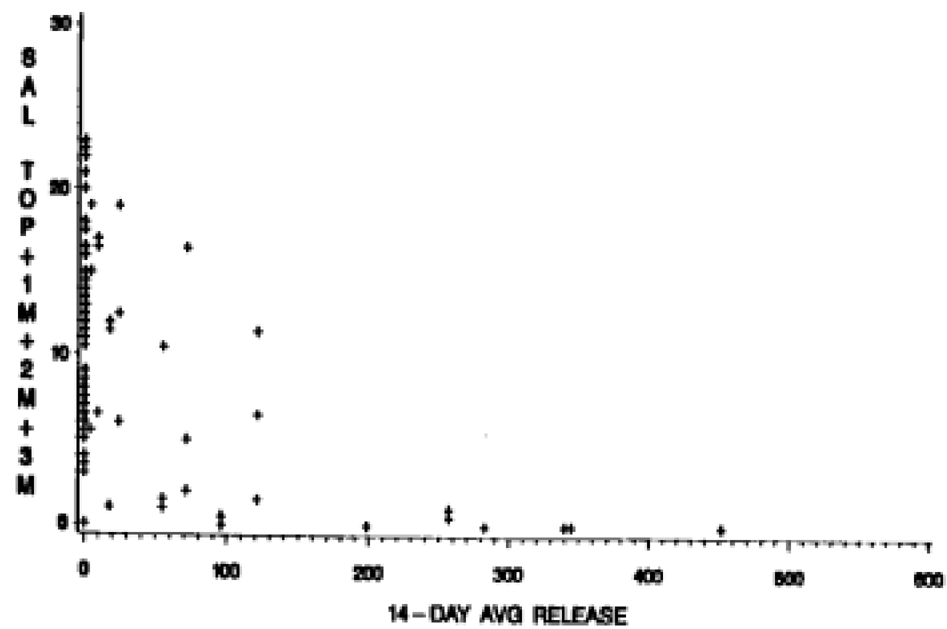

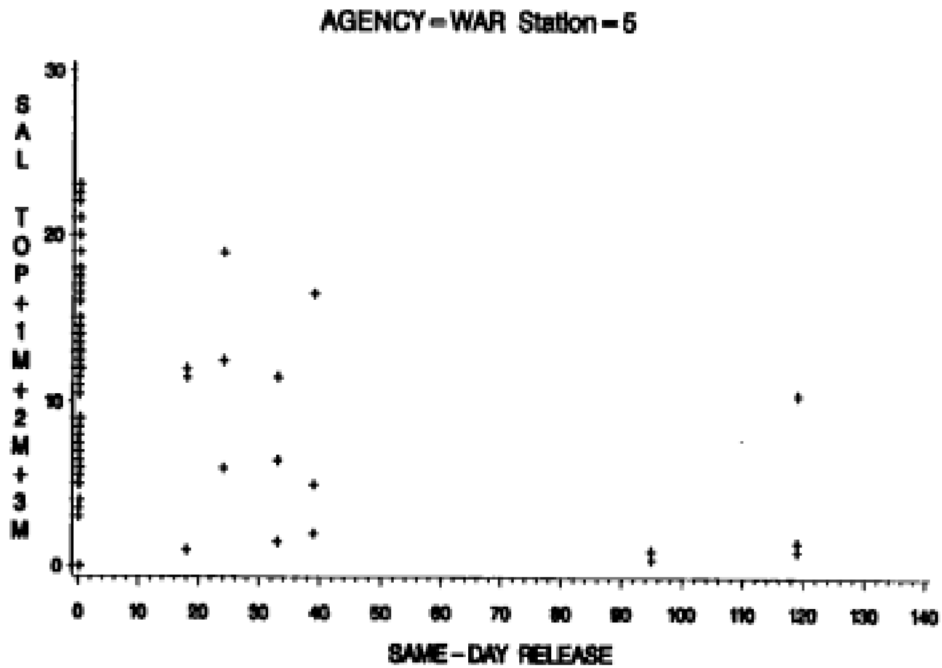
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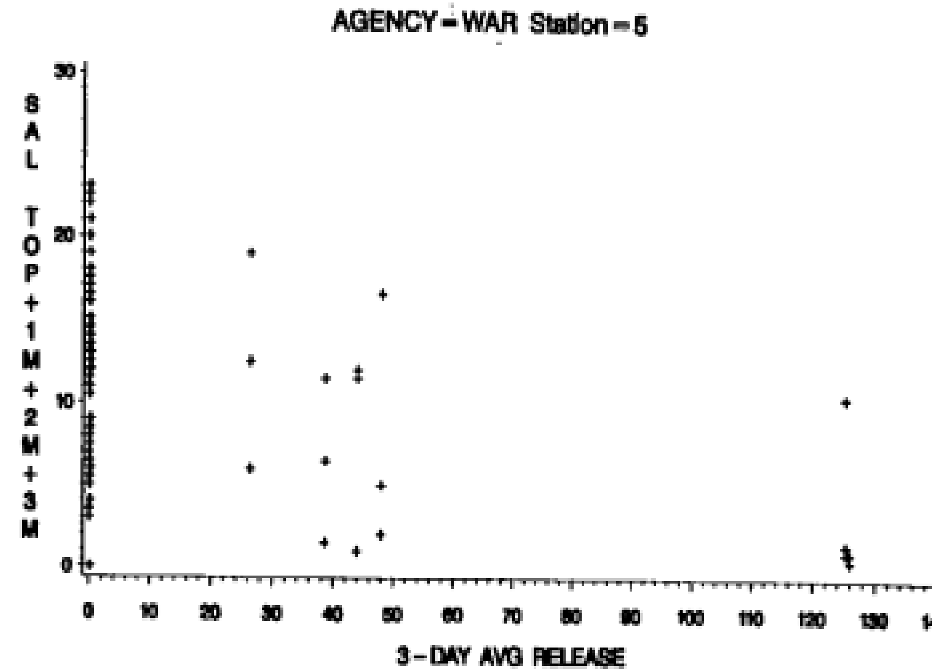
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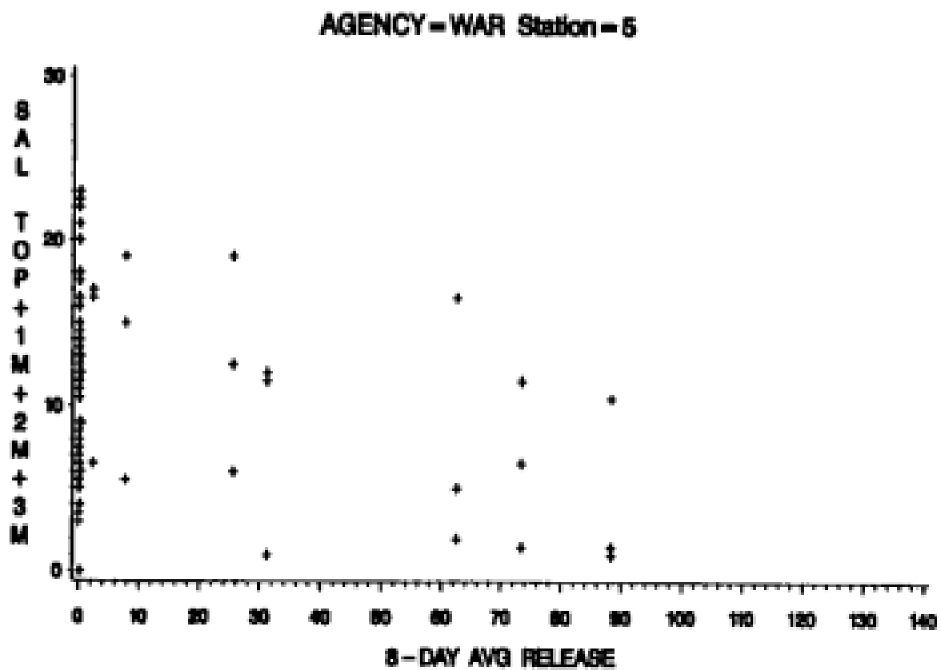
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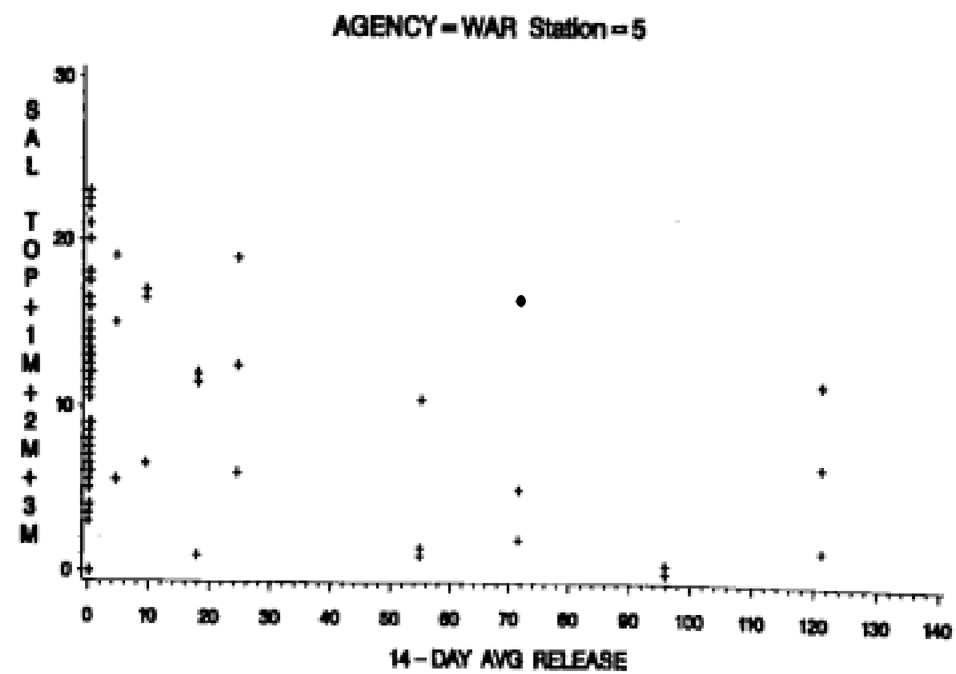
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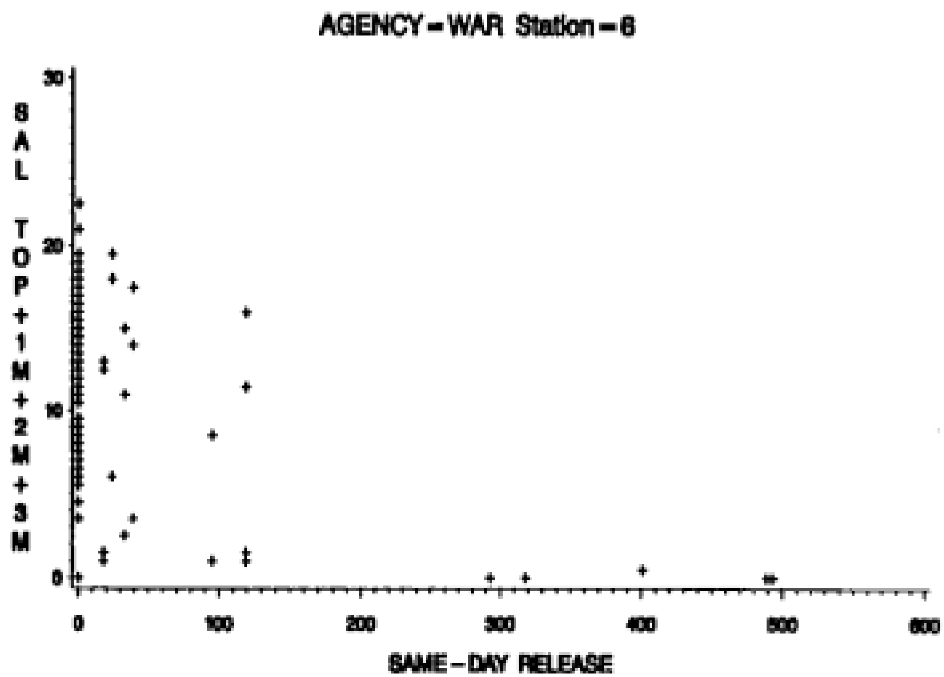
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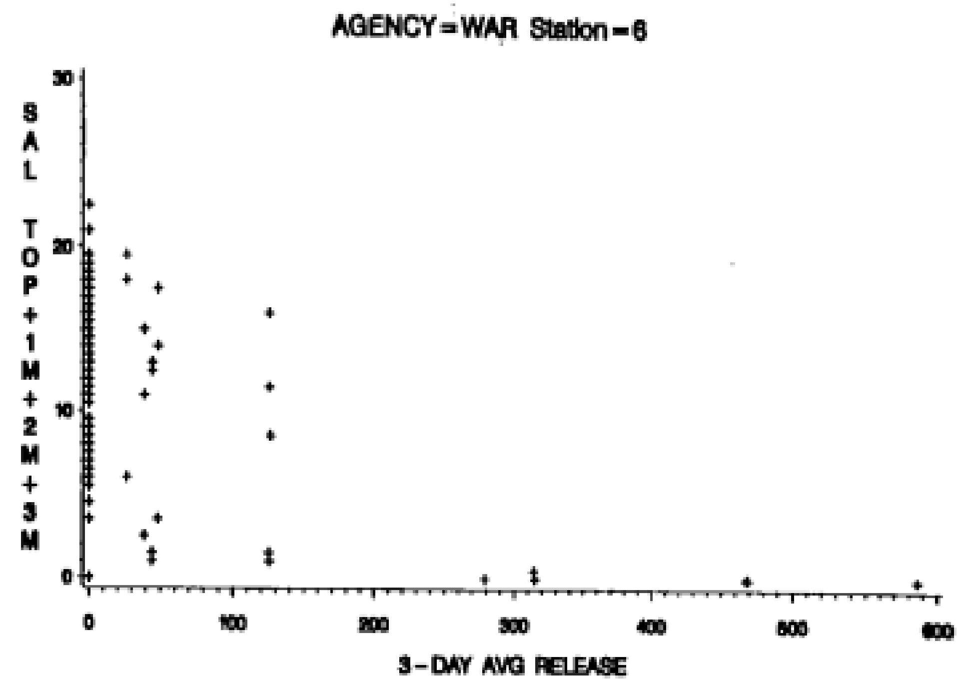
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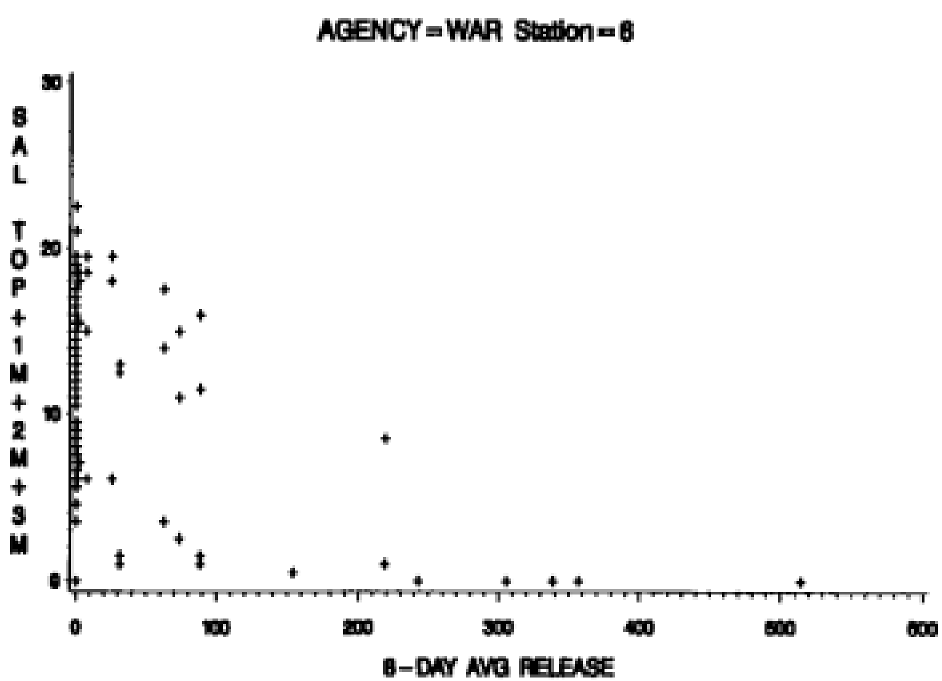
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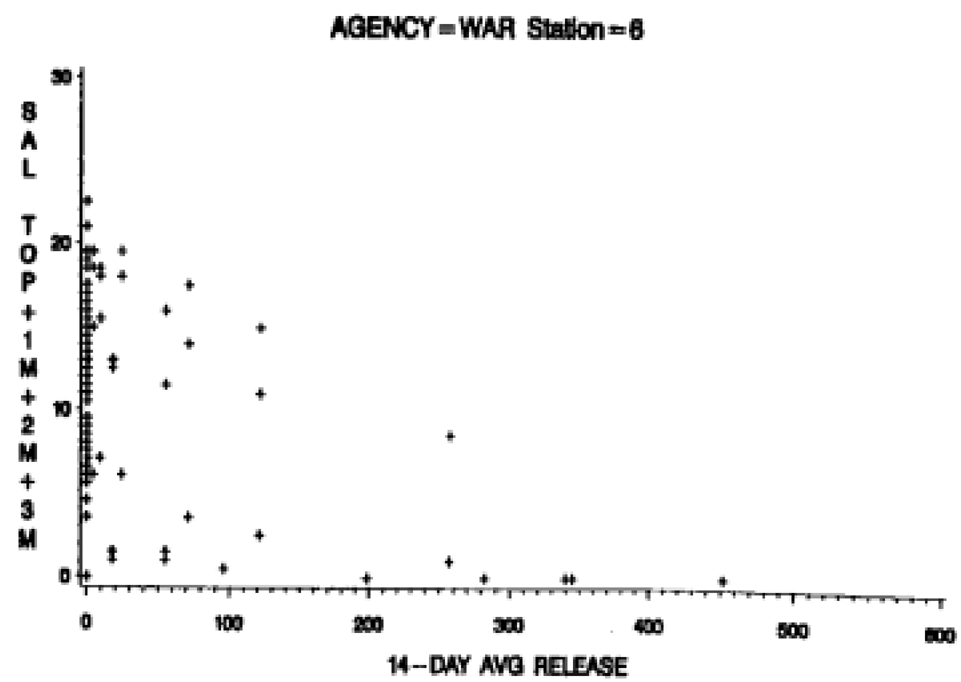
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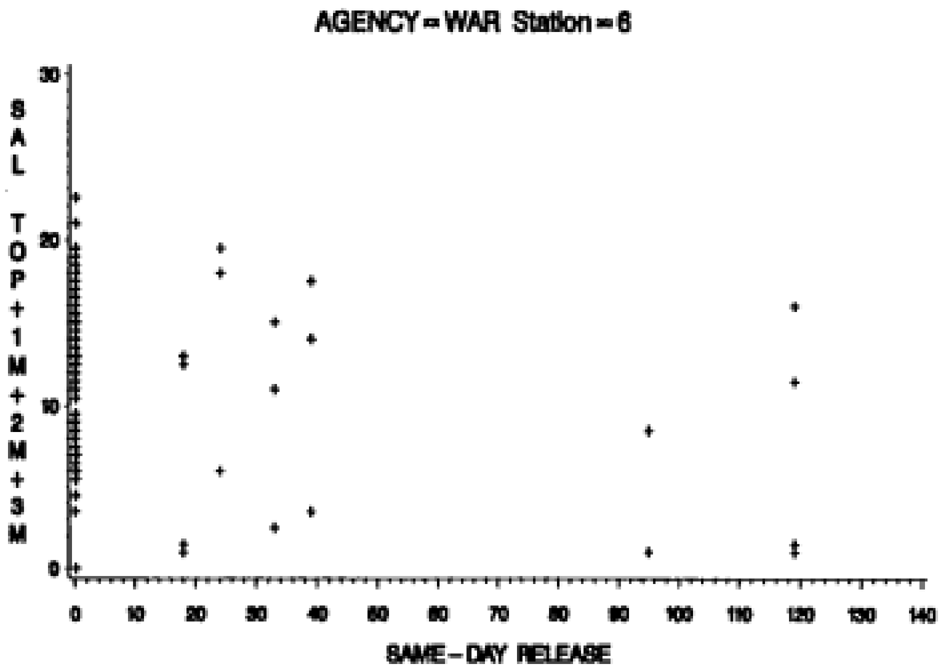
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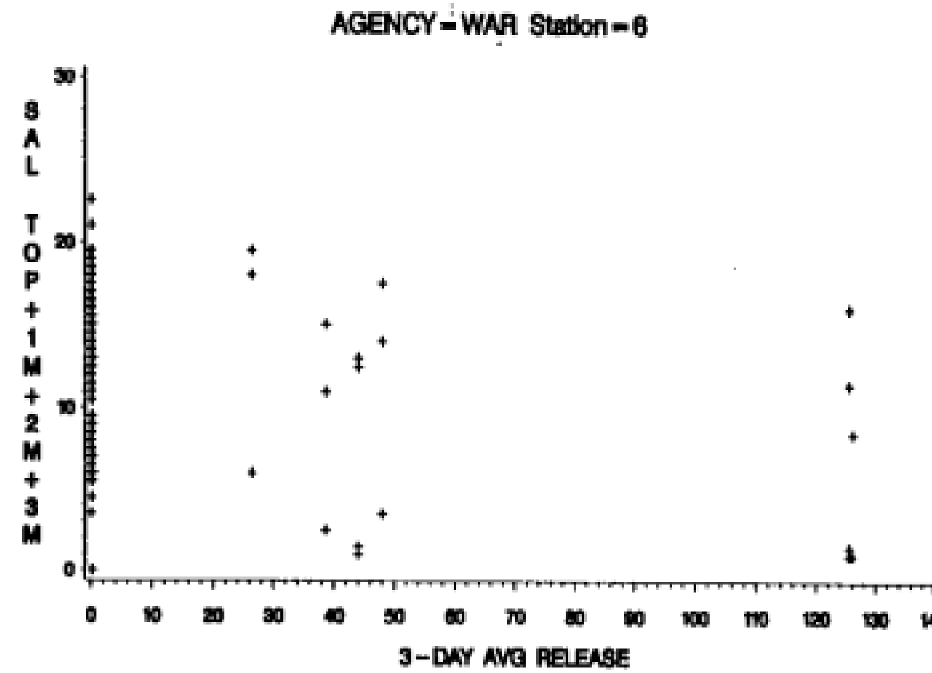
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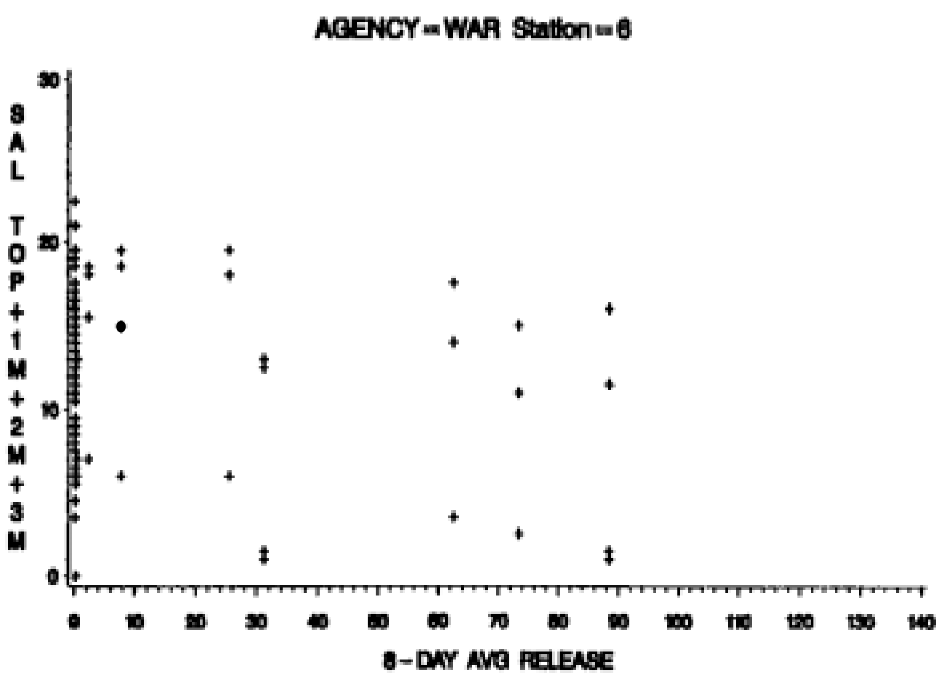
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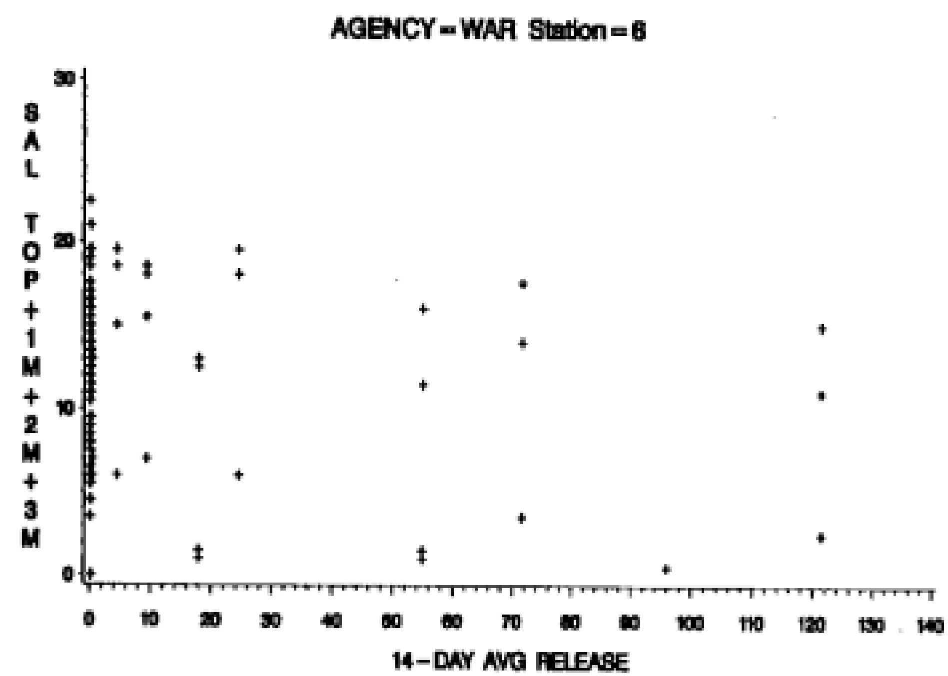
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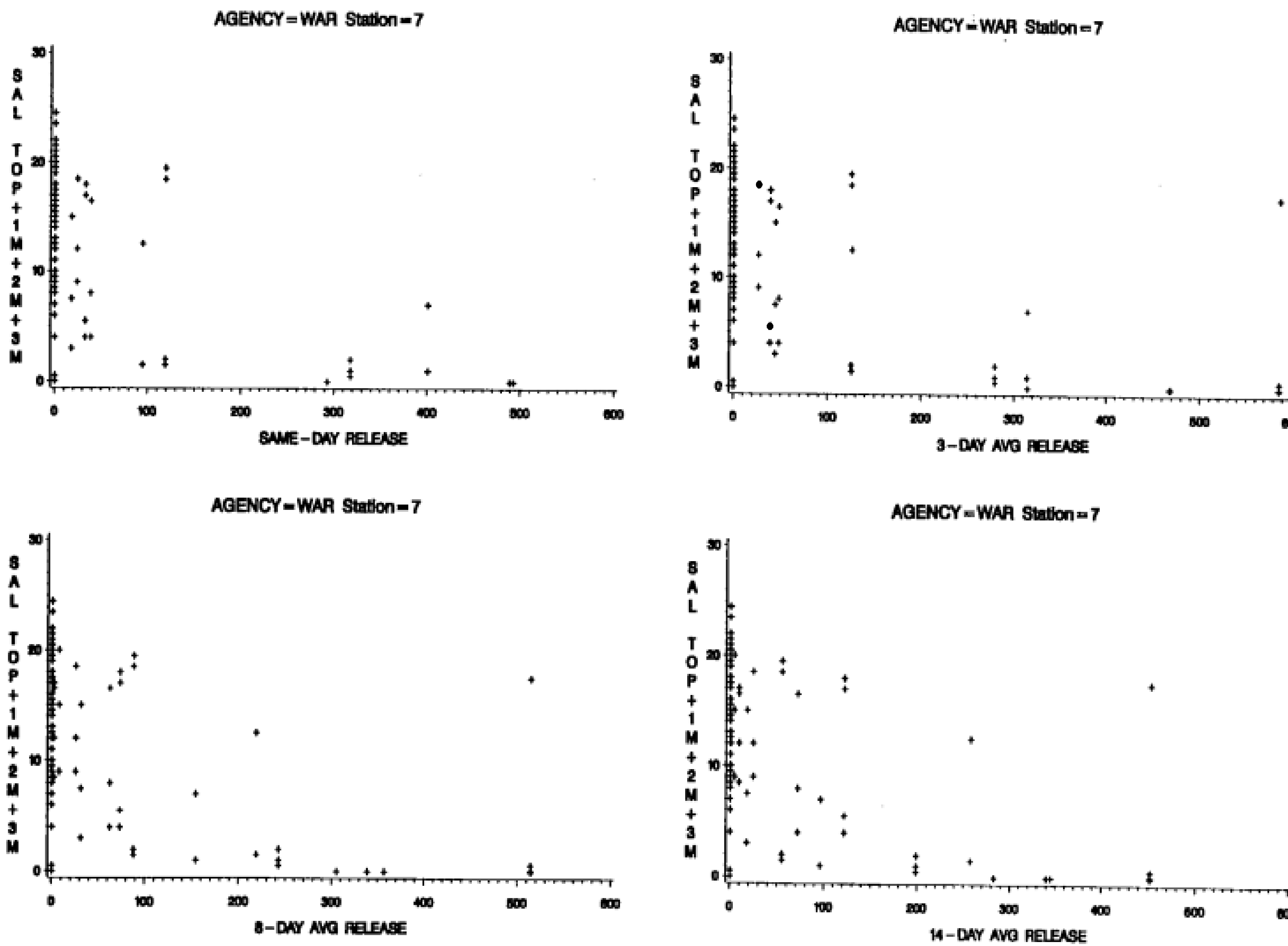
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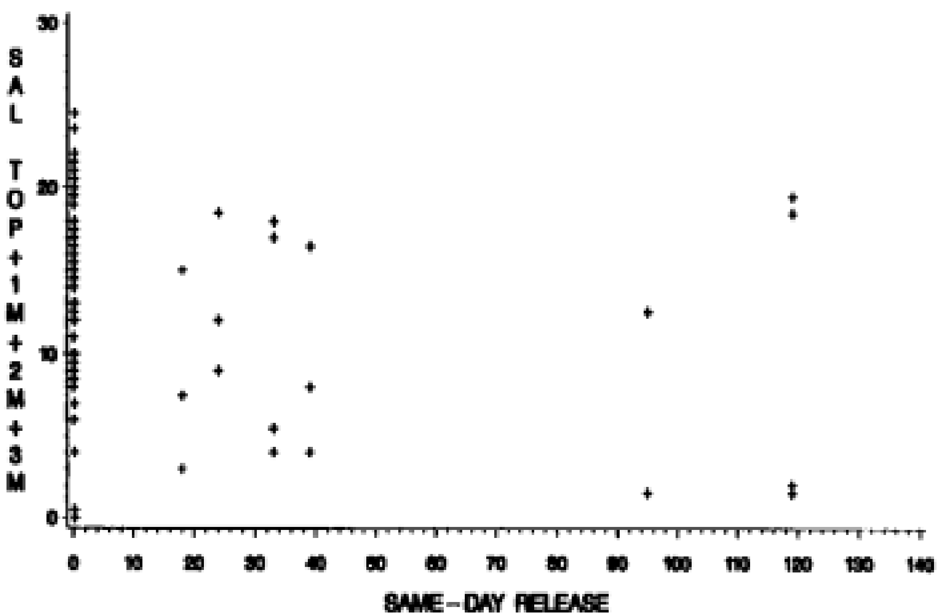

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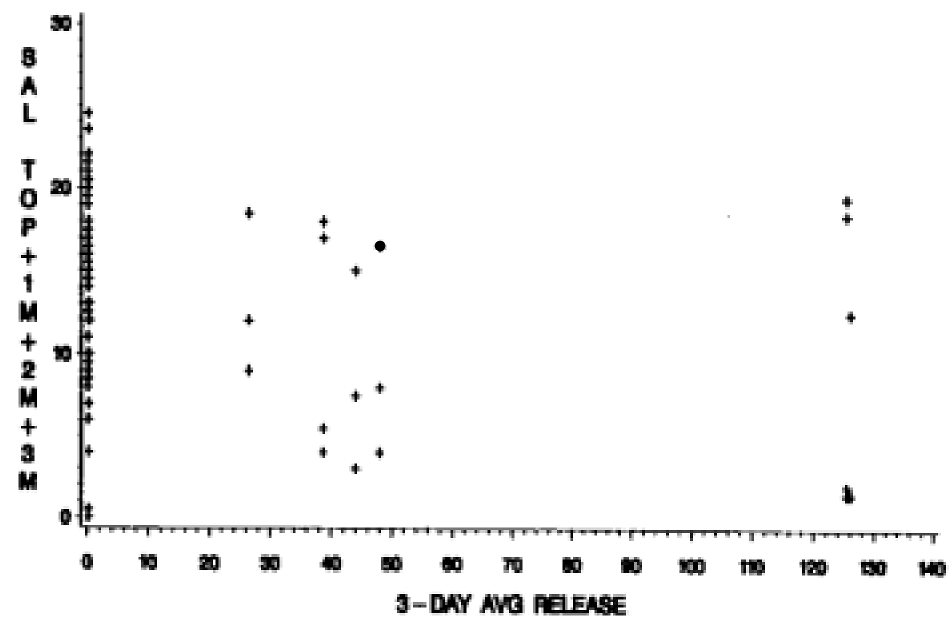

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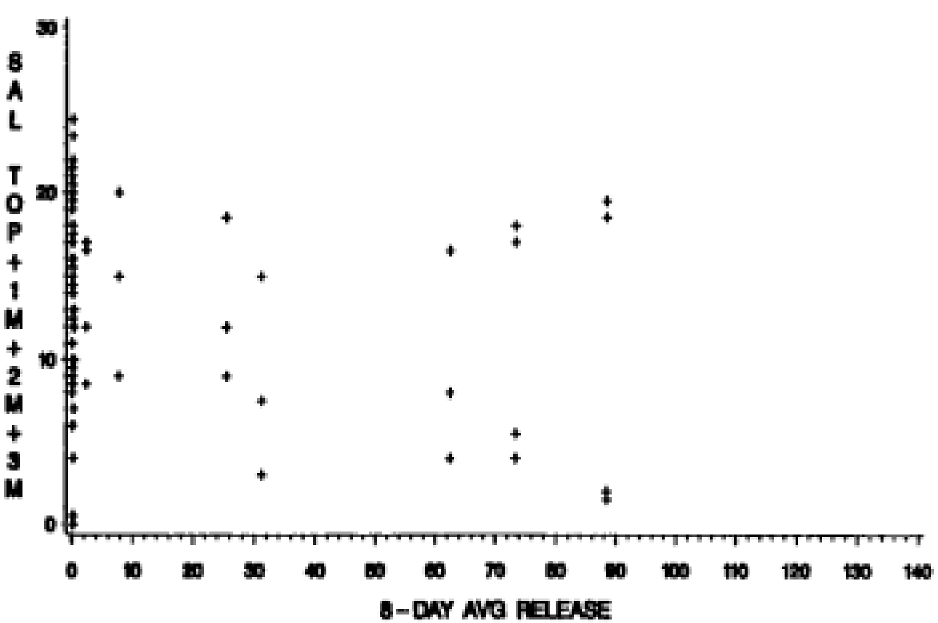

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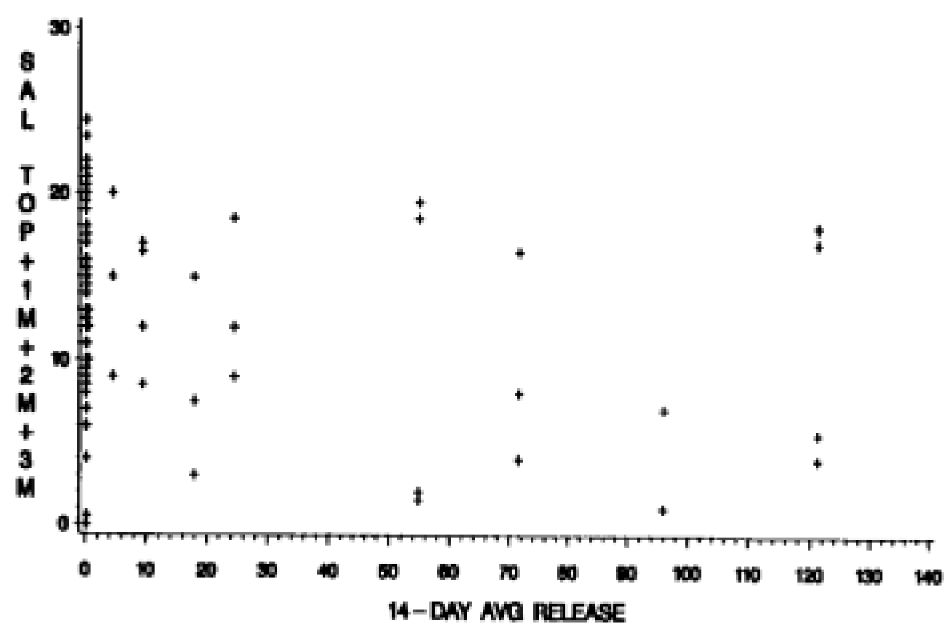

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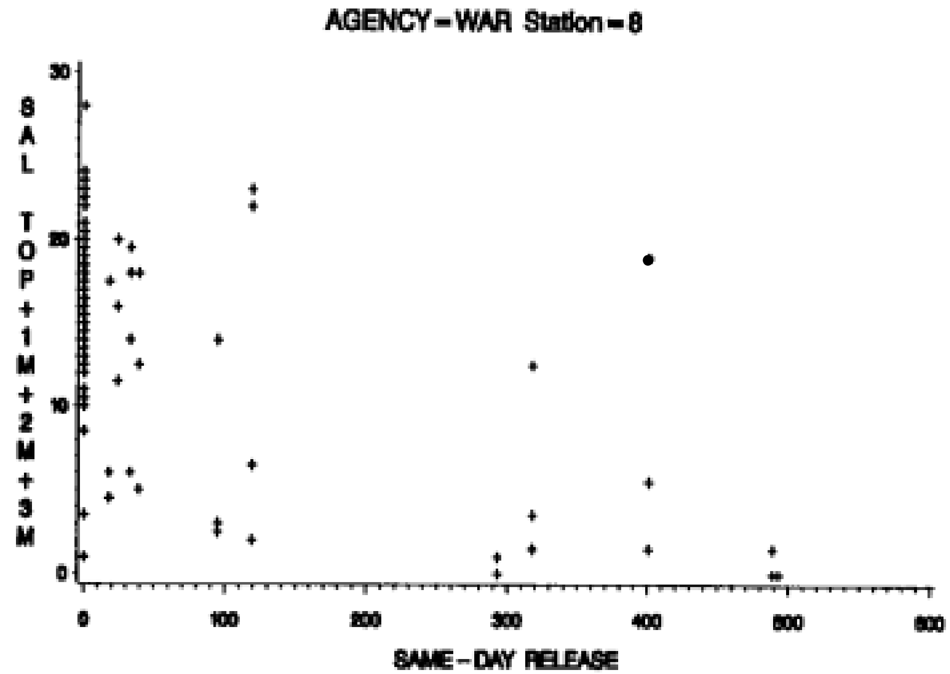
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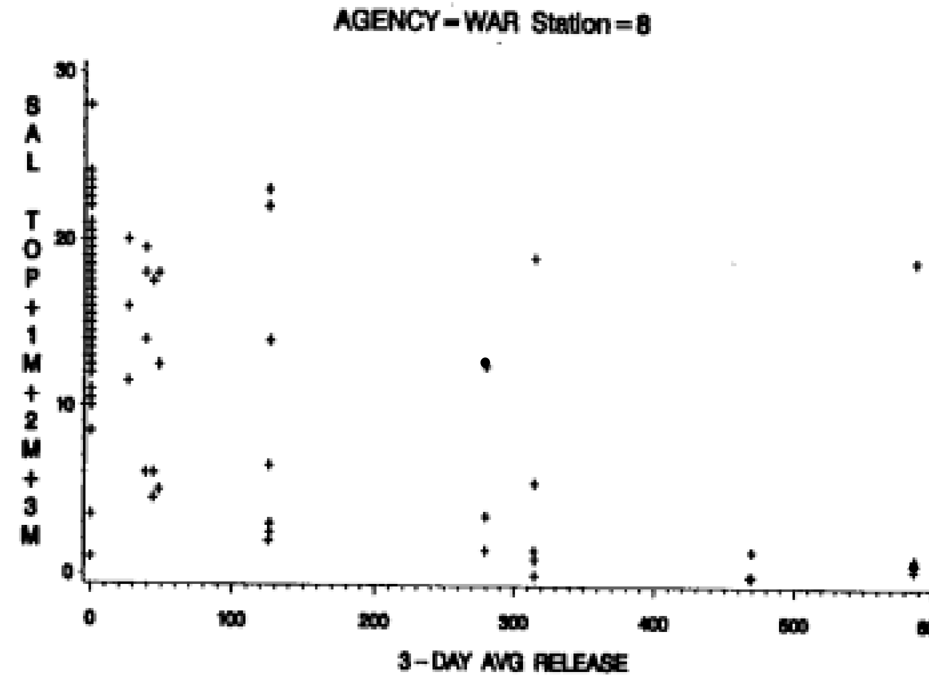
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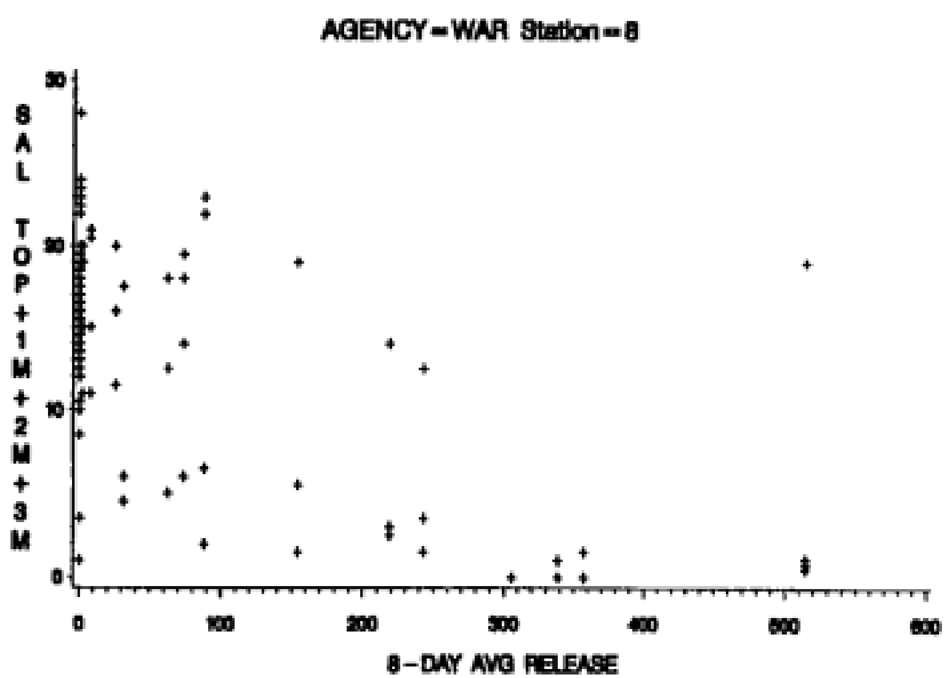
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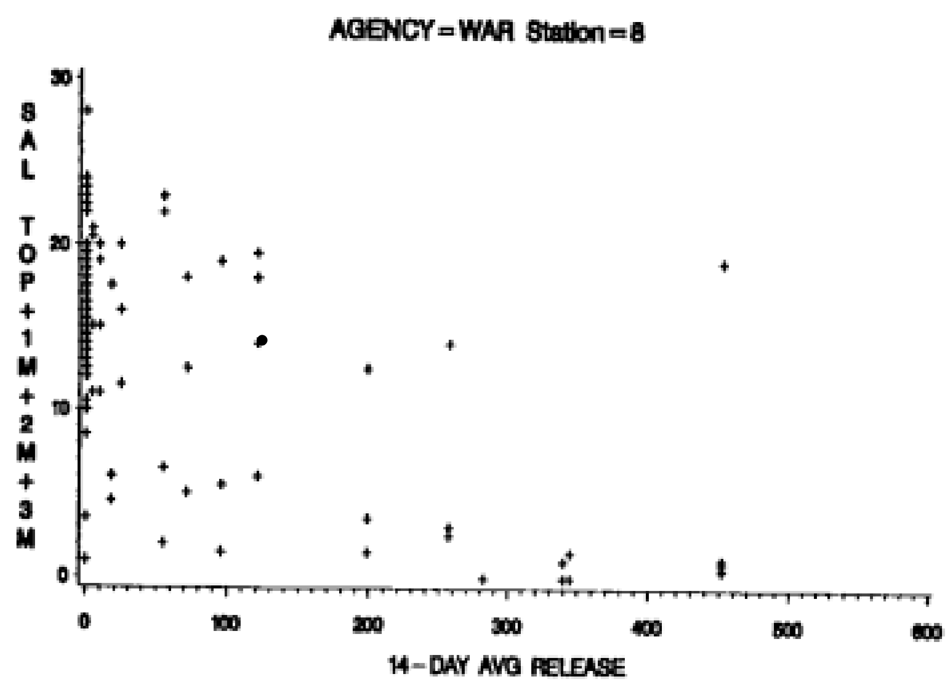
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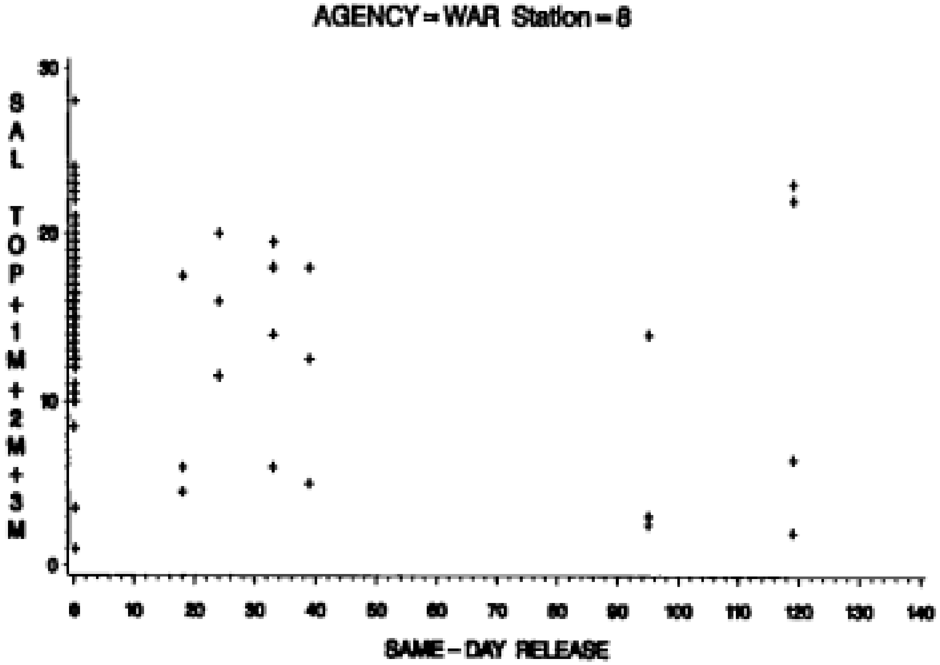
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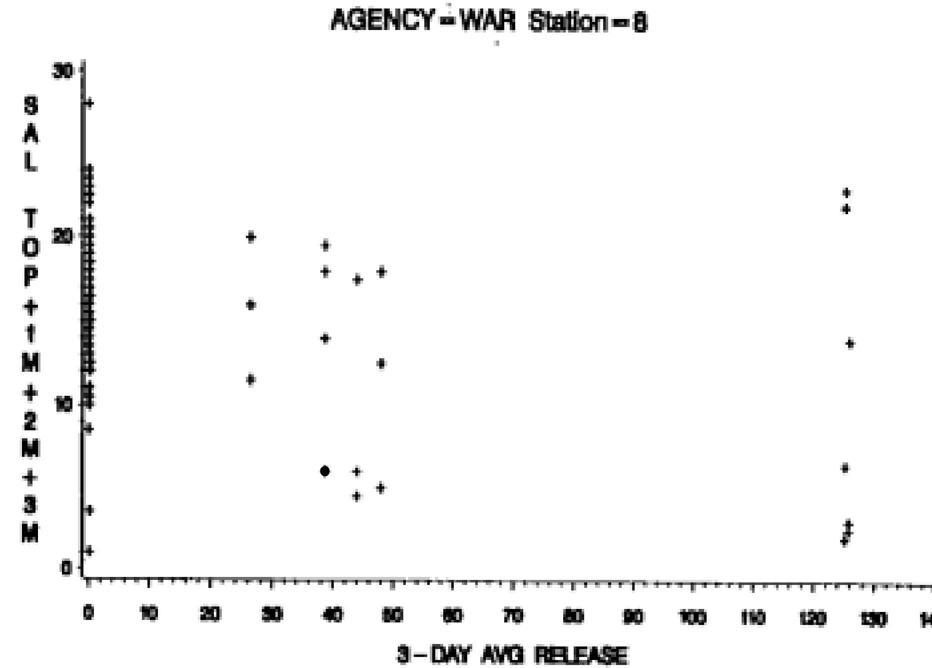
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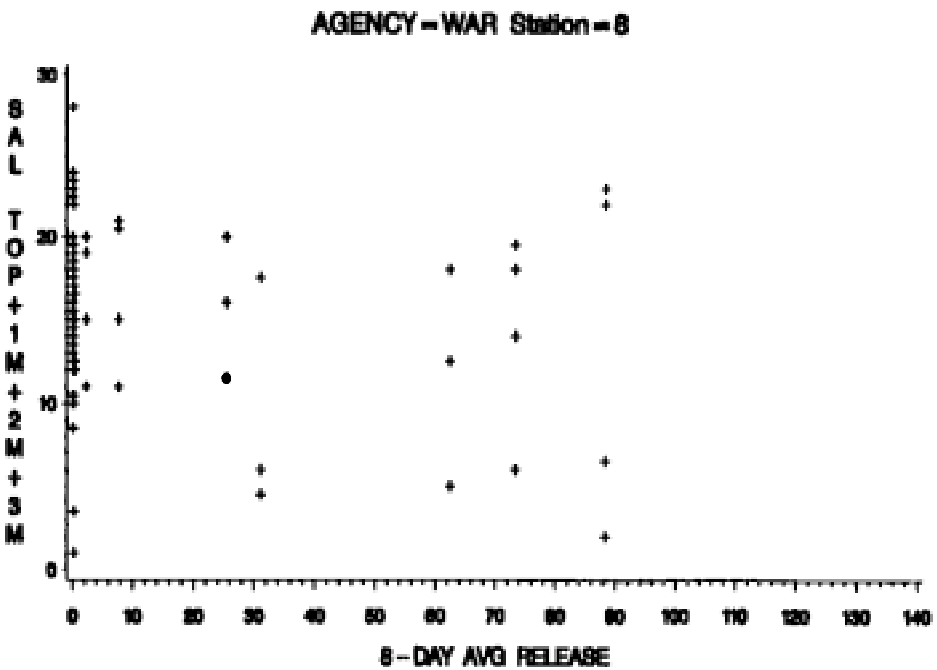
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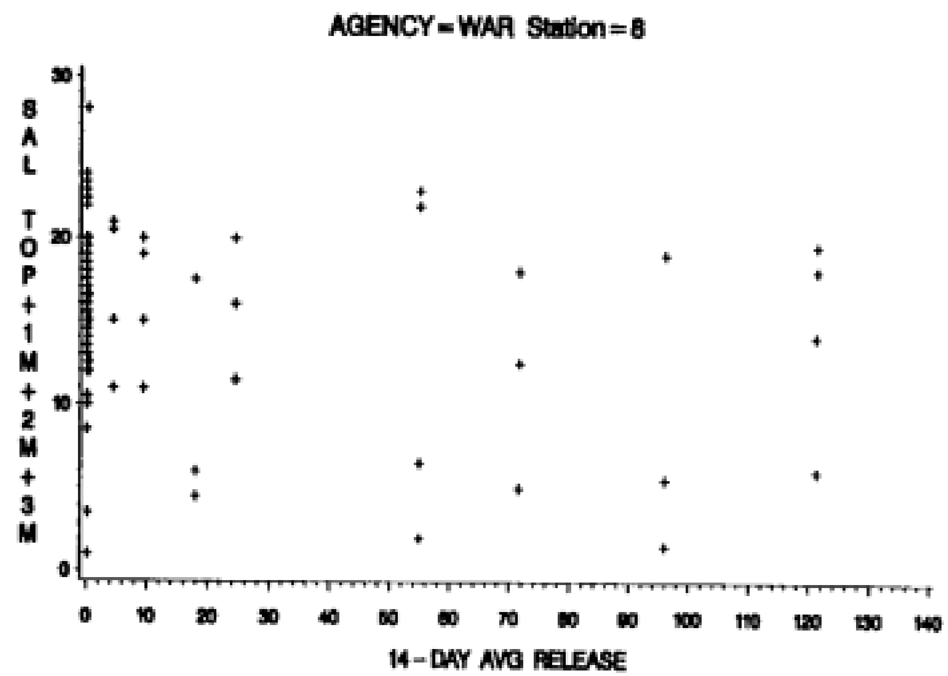
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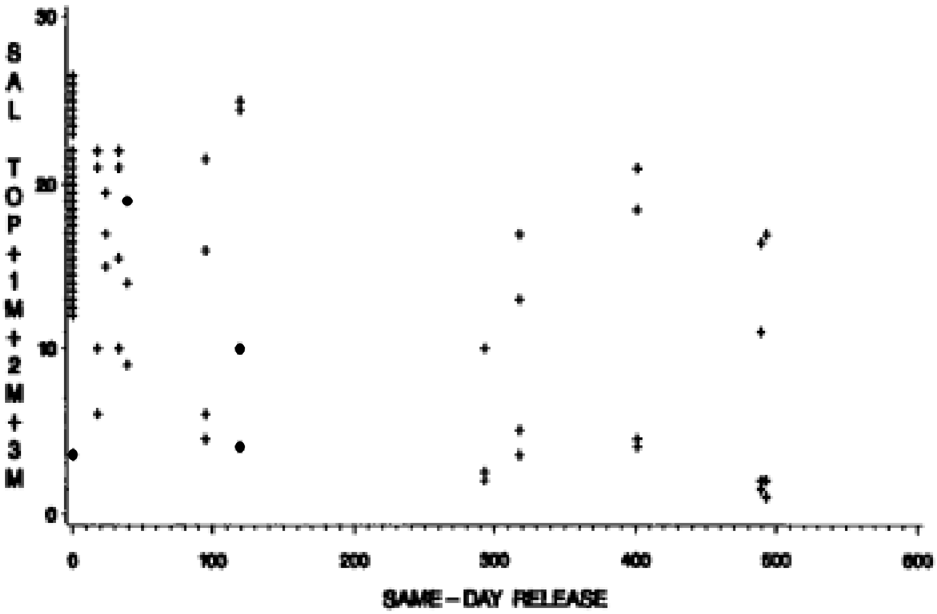

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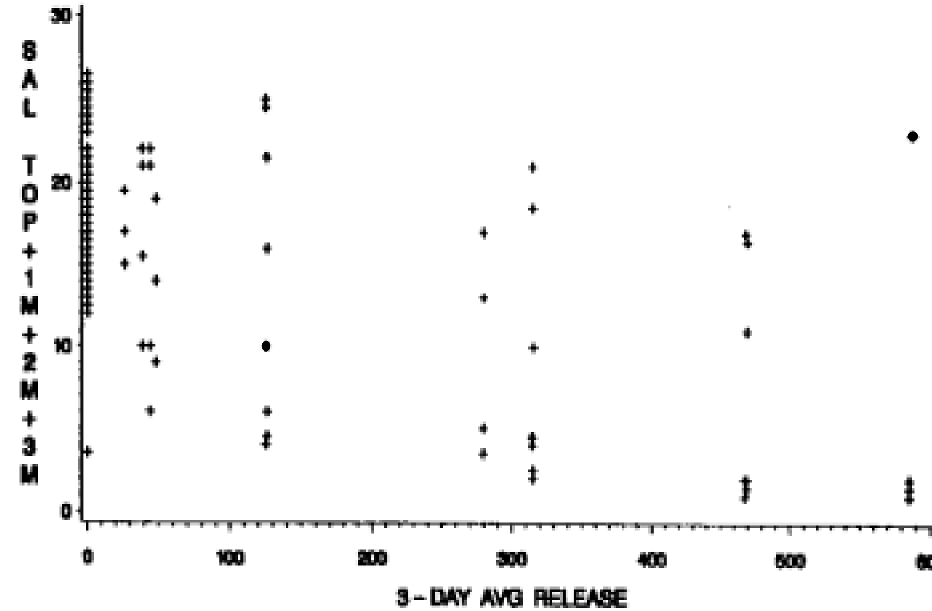

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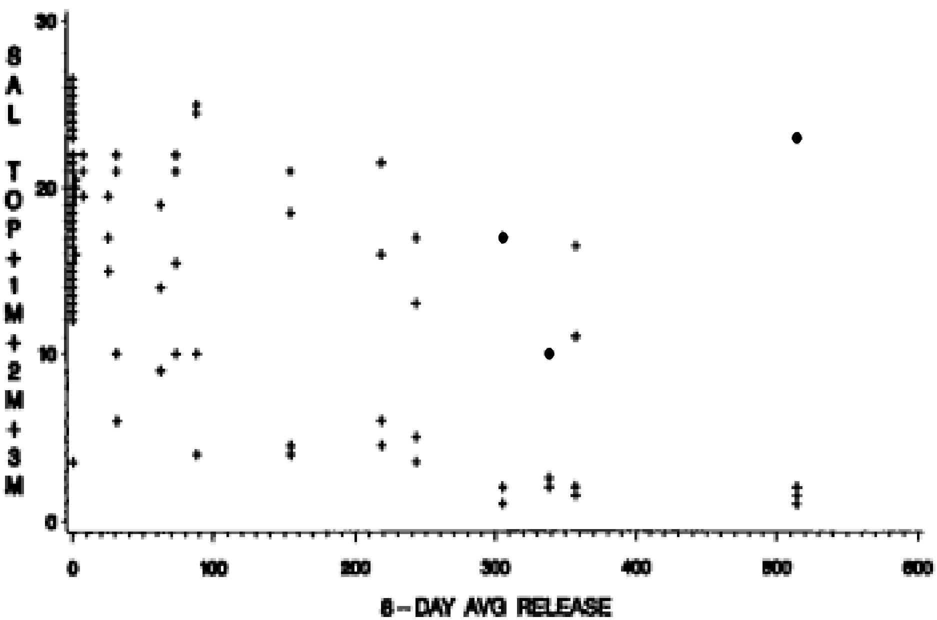

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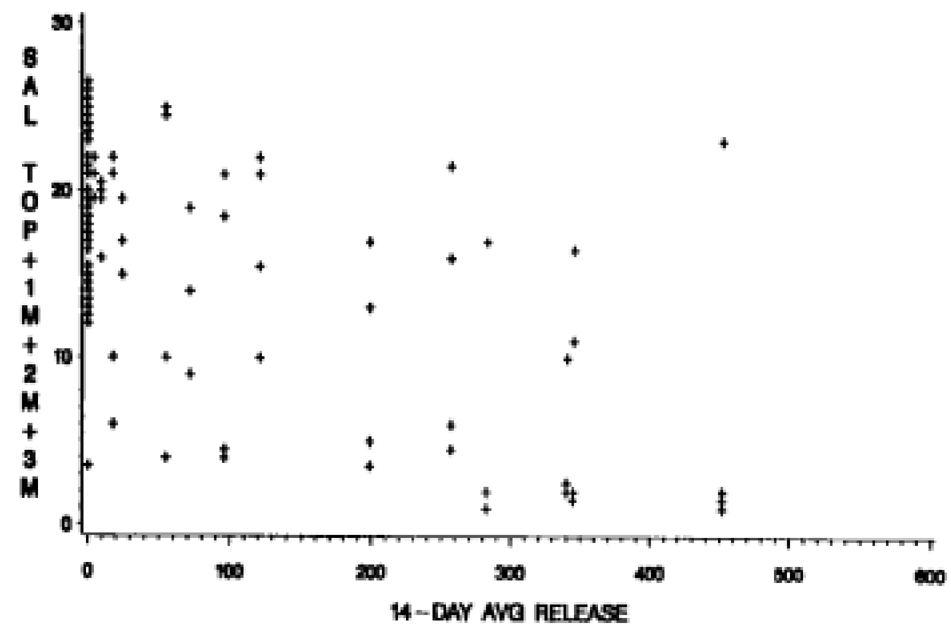

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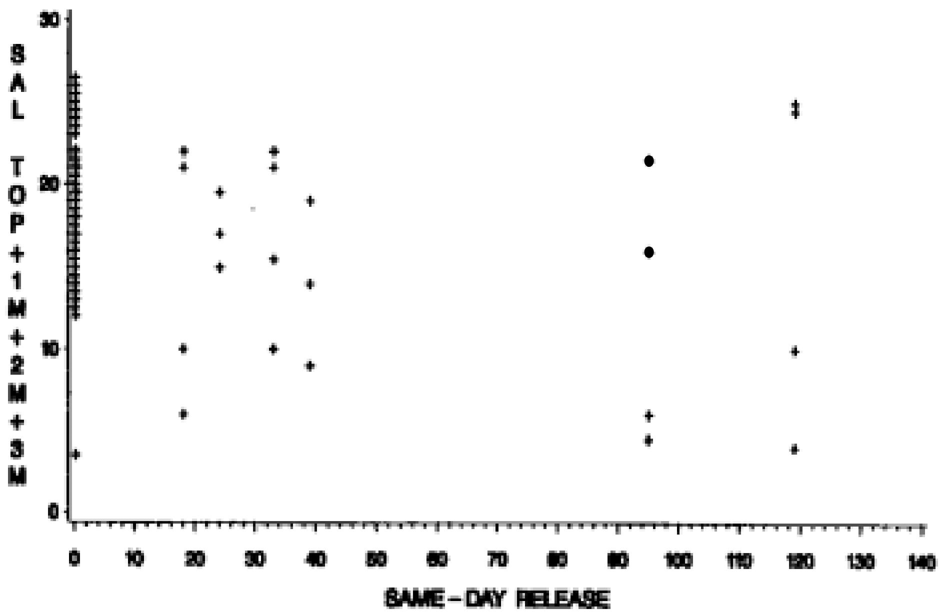

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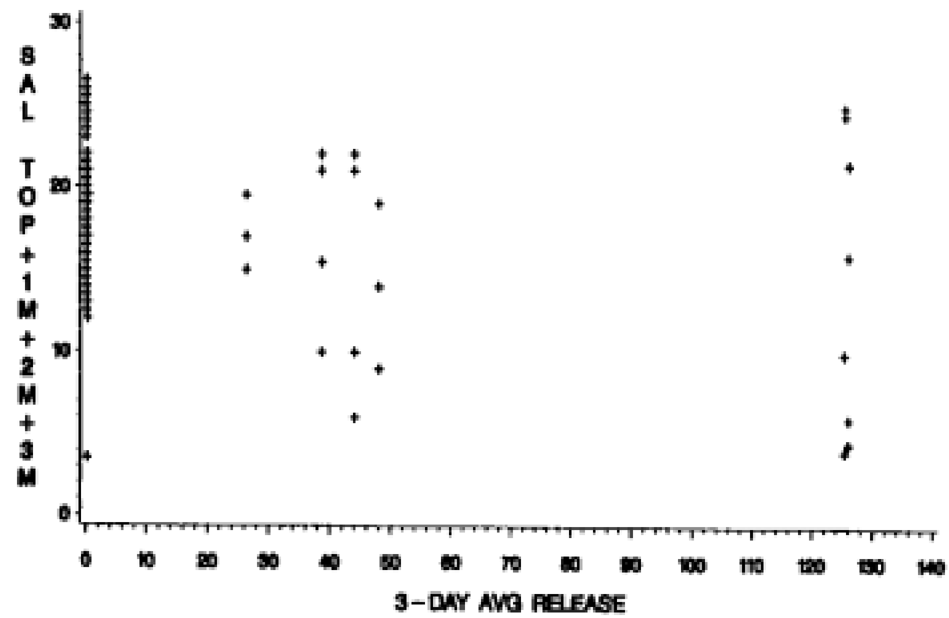

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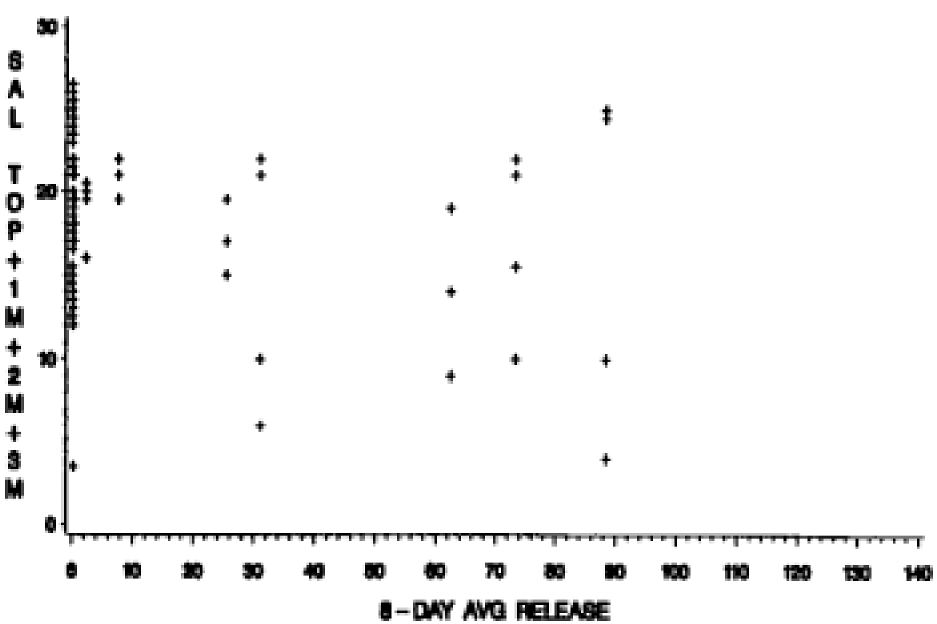

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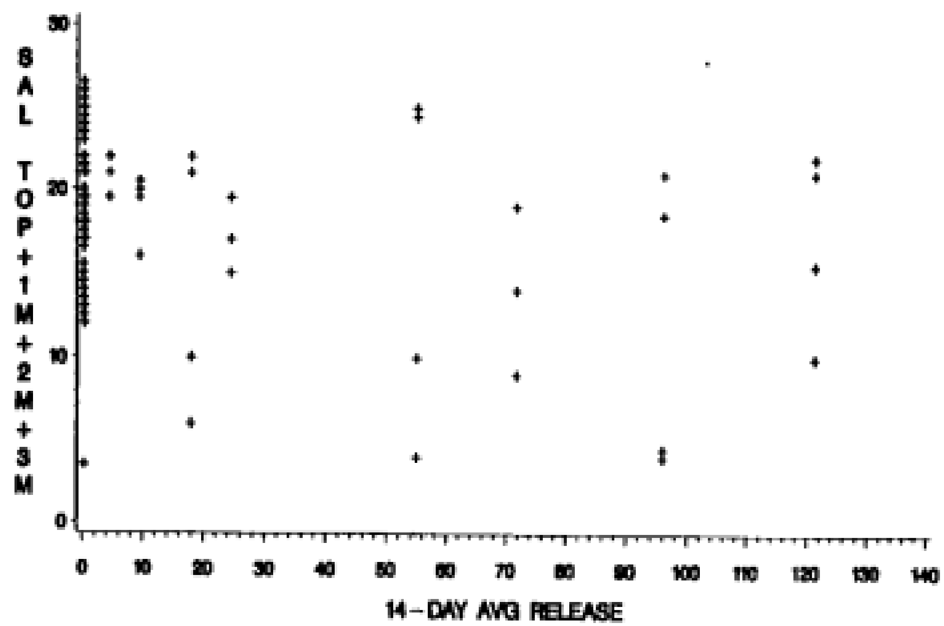

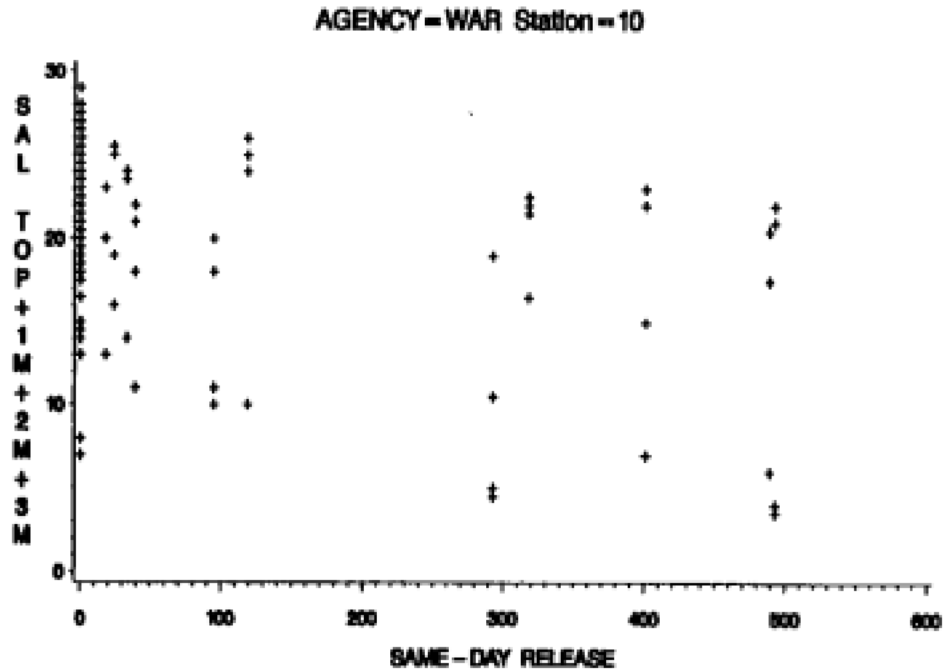
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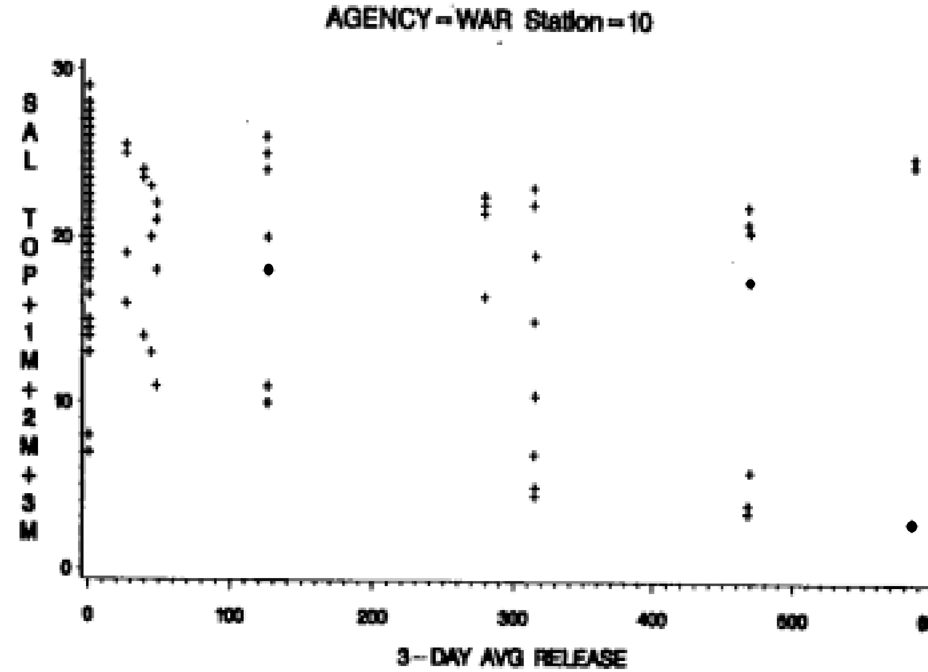
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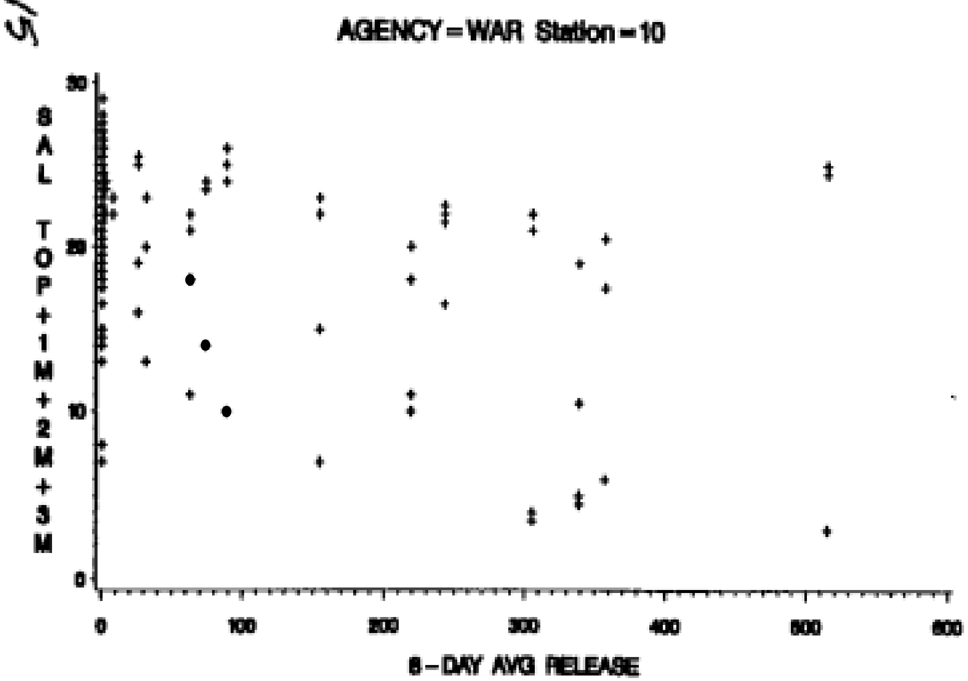
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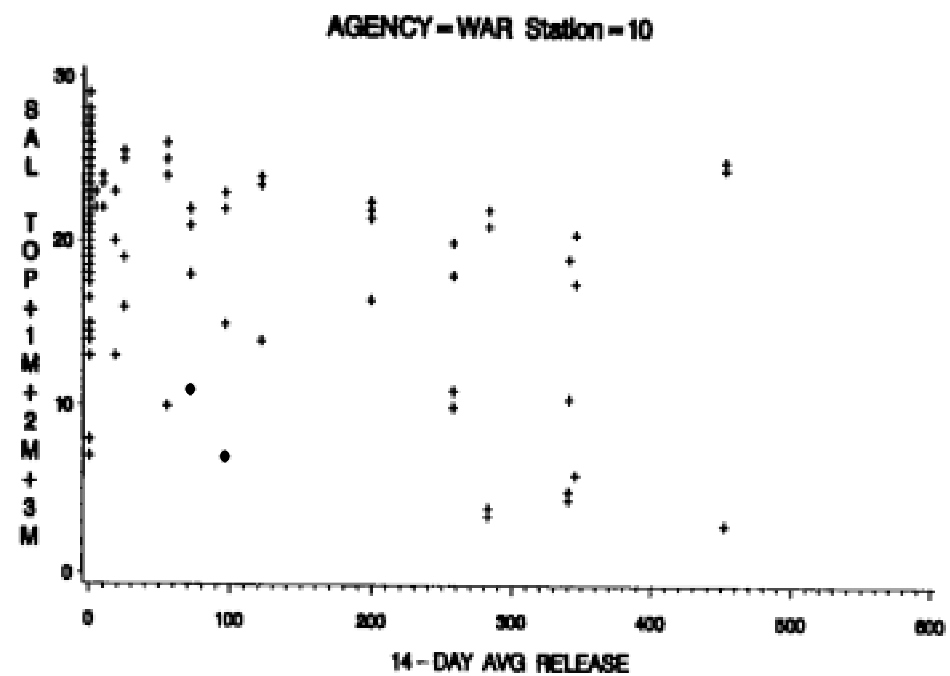
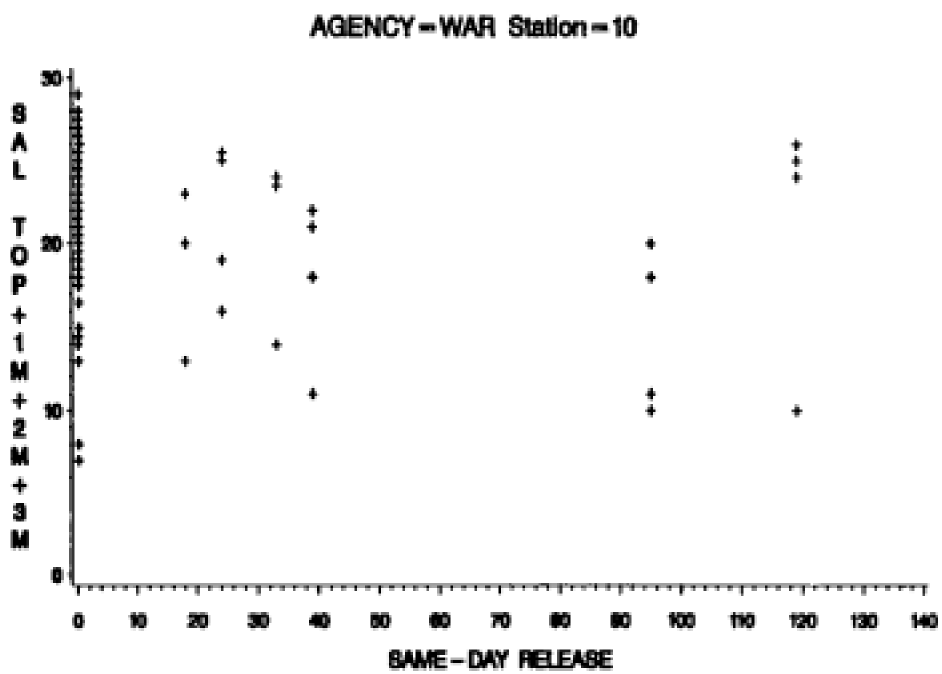
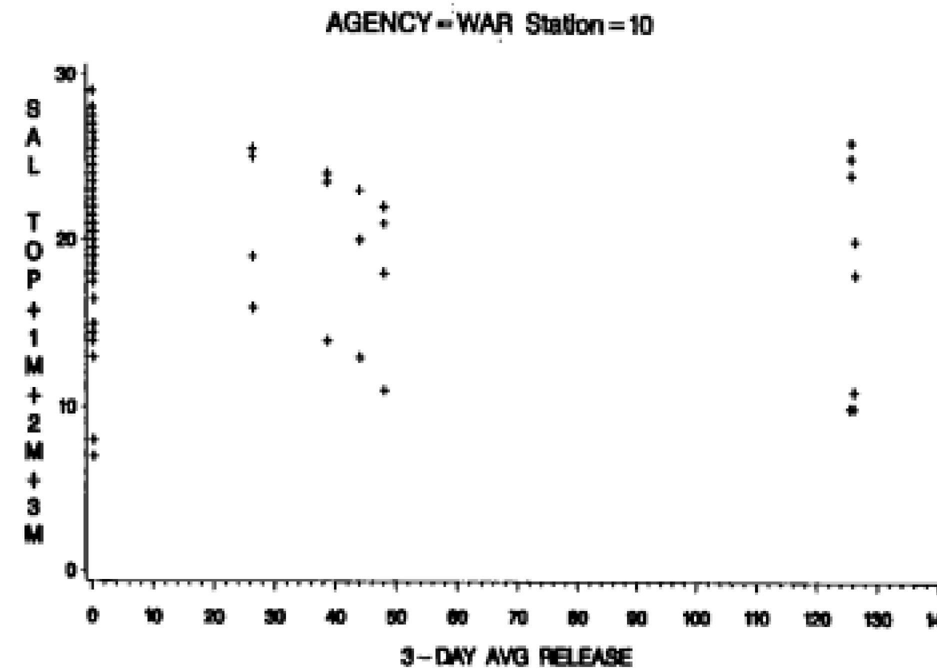
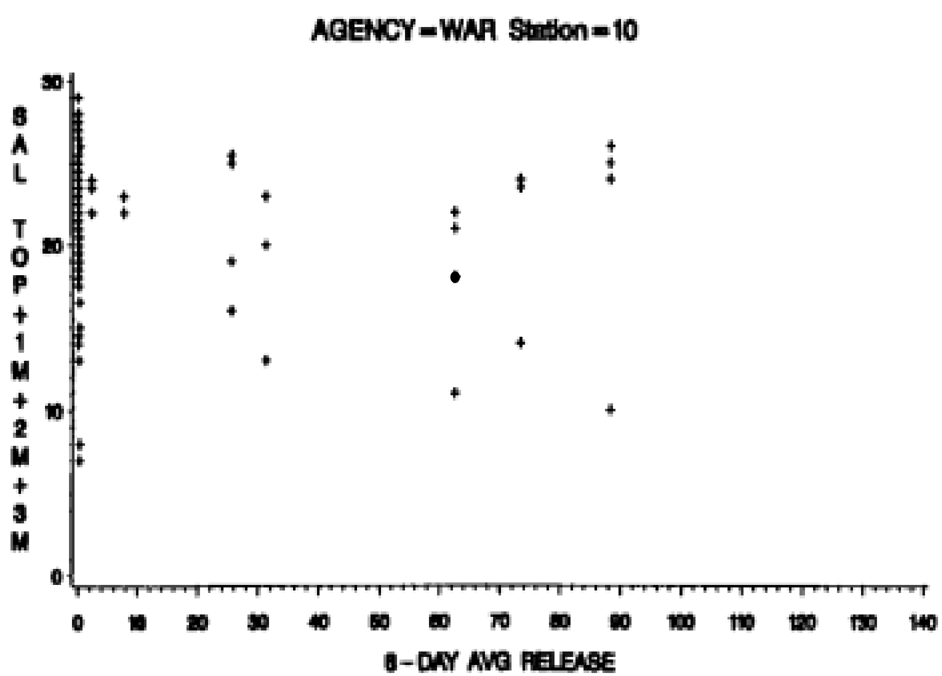
8-DAY AVG RELEASE

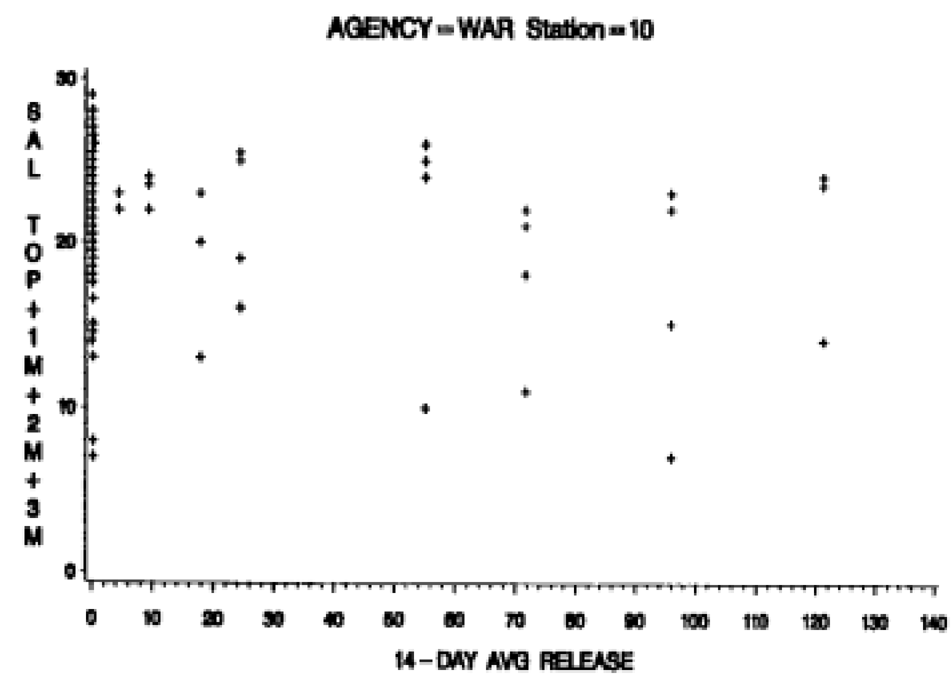

AGENCY=WAR Station=10
SAL TOP+1M+2M+3M
14-DAY AVG RELEASE


AGENCY=WAR Station=10
SAL TOP+1M+2M+3M
SAME-DAY RELEASE


AGENCY=WAR Station=10
SAL TOP+1M+2M+3M
3-DAY AVG RELEASE

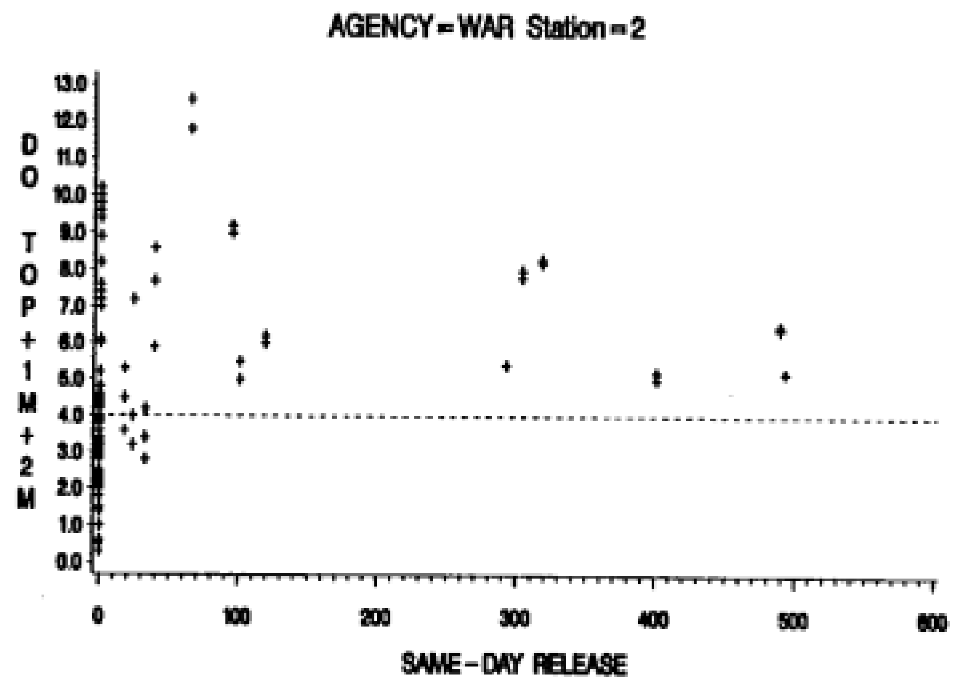
C16

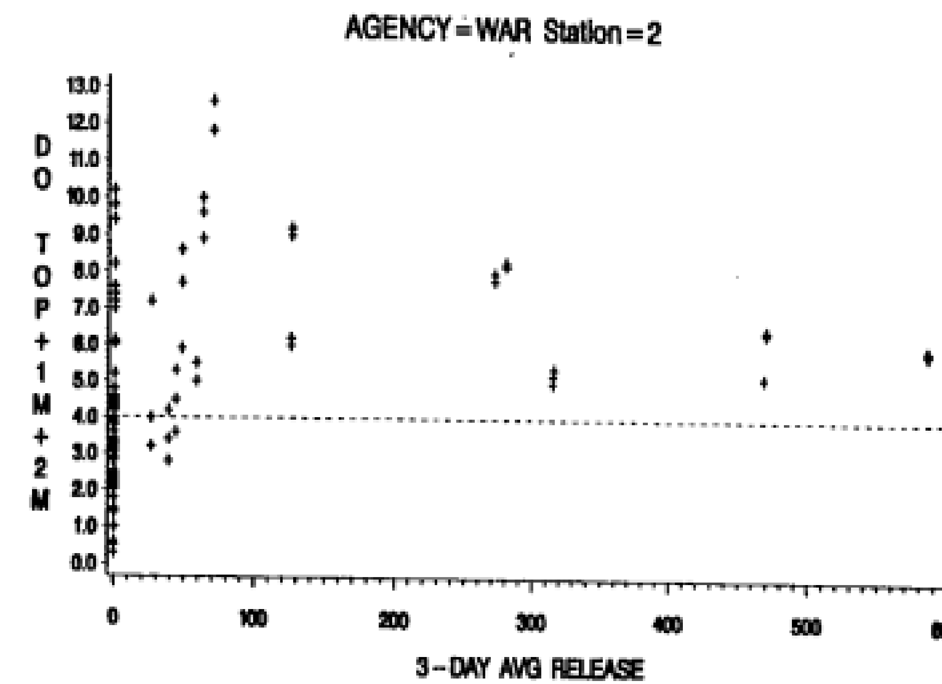

AGENCY=WAR Station=10
SAL TOP+1M+2M+3M
8-DAY AVG RELEASE


AGENCY=WAR Station=10
SAL TOP+1M+2M+3M
14-DAY AVG RELEASE

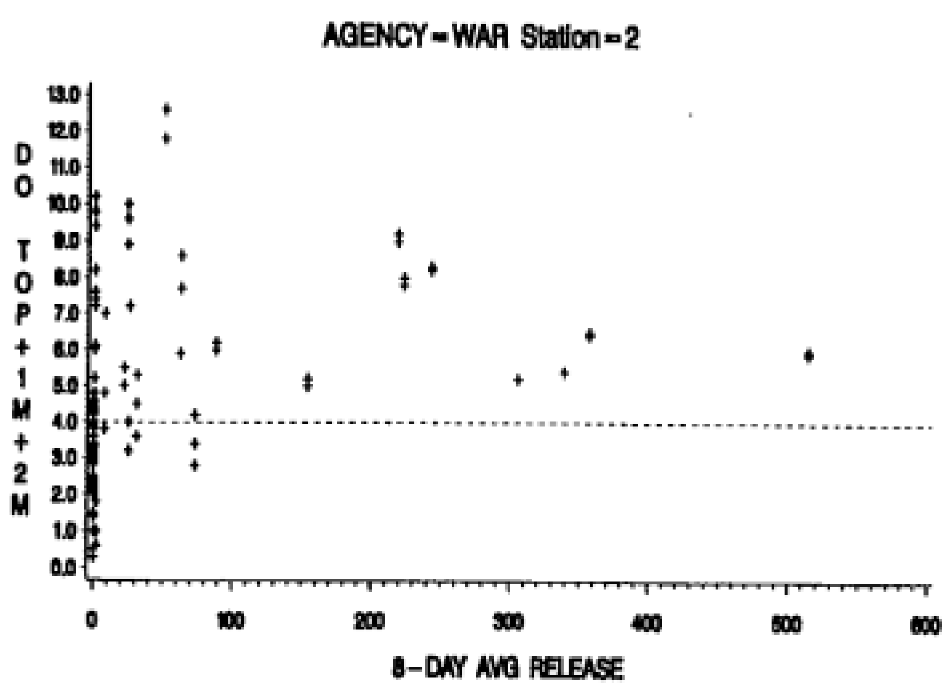
APPENDIX D

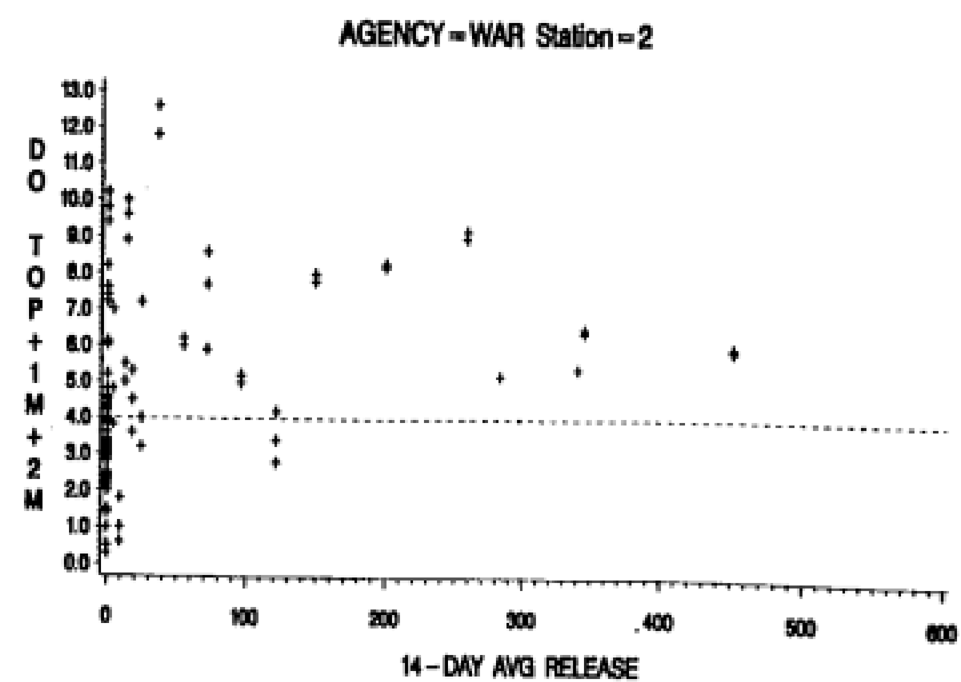
Plots of dissolved oxygen at the WAR/SDI stations vs. discharge from the Hillsborough River Reservoir. (All depths are shown. Units are mg/l for dissolved oxygen and cfs for discharge).


AGENCY=WAR Station=2
DO TOP+1M+2M
SAME-DAY RELEASE

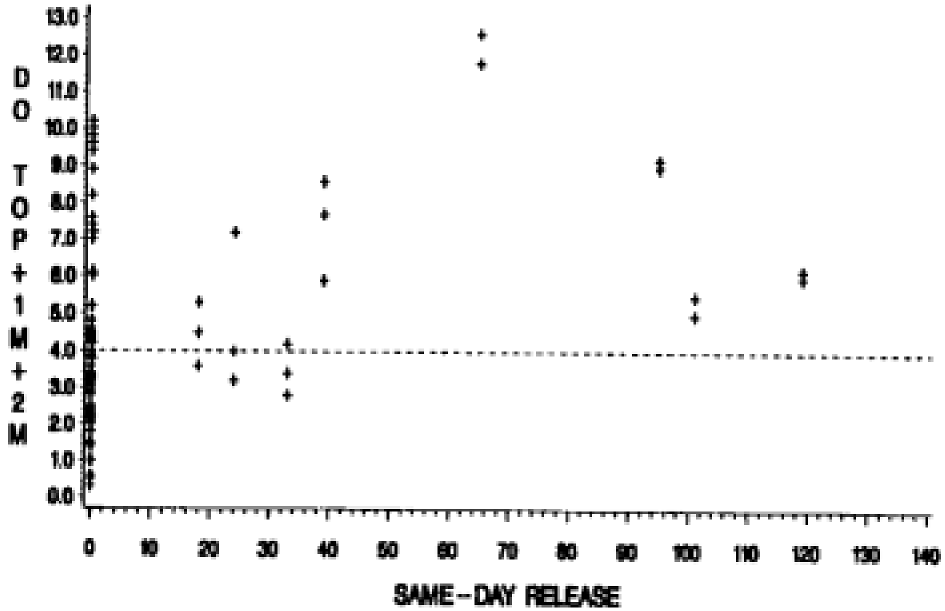

AGENCY=WAR Station=2
DO TOP+1M+2M
3-DAY AVG RELEASE

DI

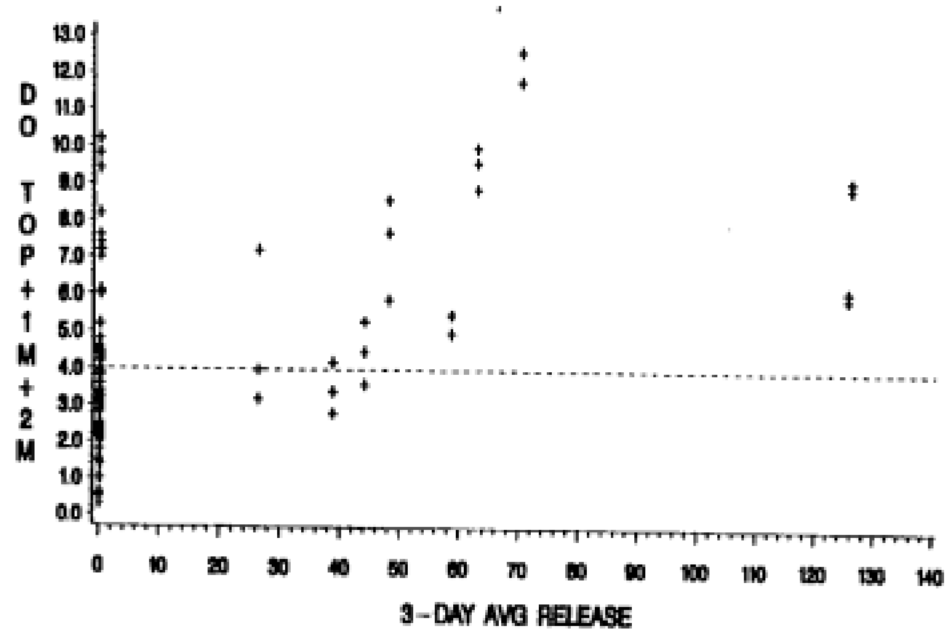

AGENCY=WAR Station=2
DO TOP+1M+2M
8-DAY AVG RELEASE


AGENCY=WAR Station=2
DO TOP+1M+2M
14-DAY AVG RELEASE

AGENCY=WAR Station=2

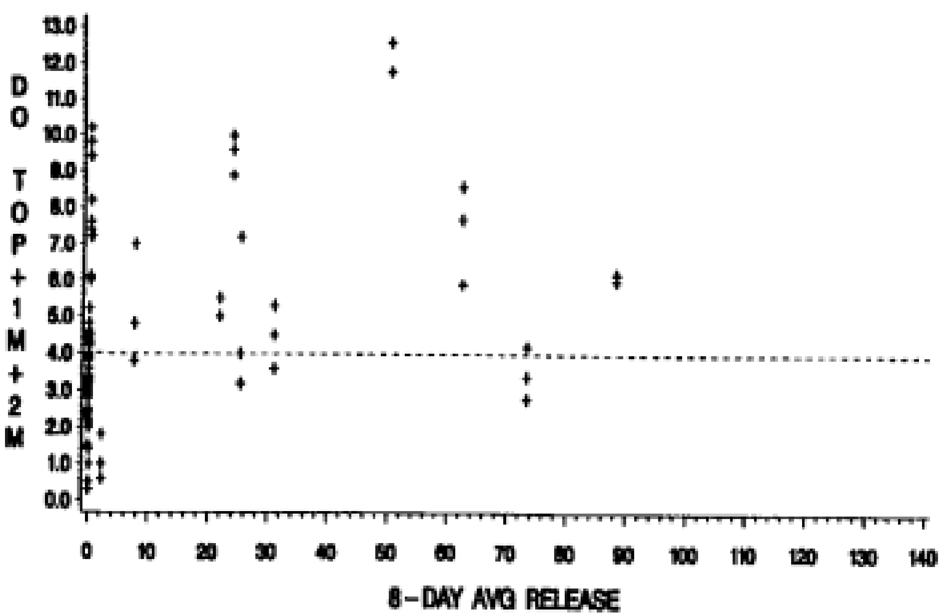


AGENCY=WAR Station=2

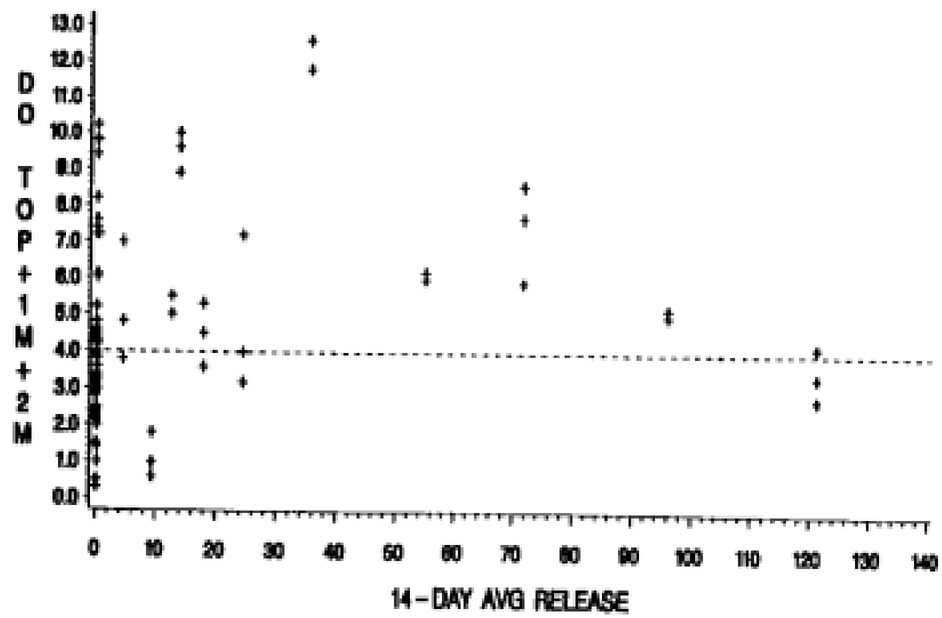


D2

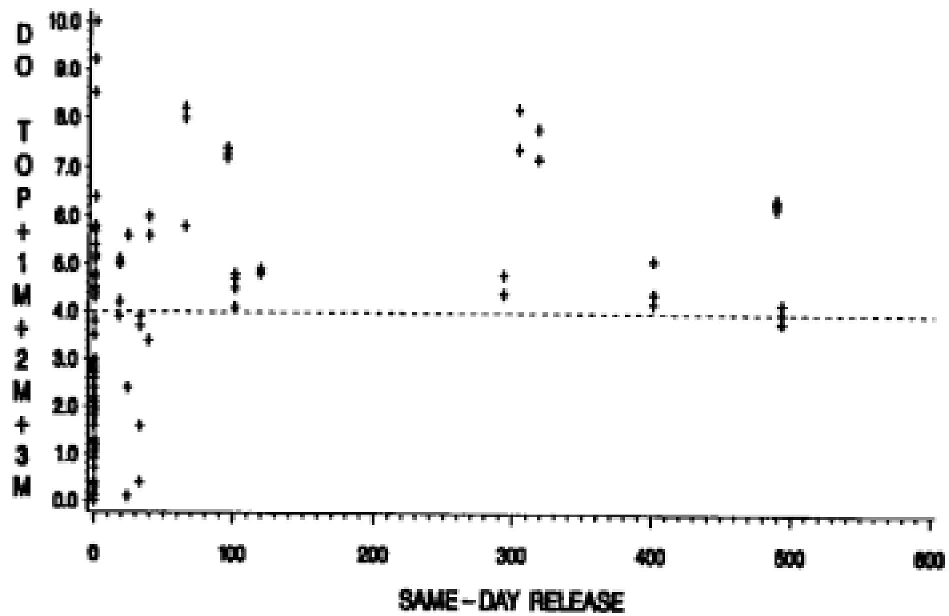
AGENCY=WAR Station=2



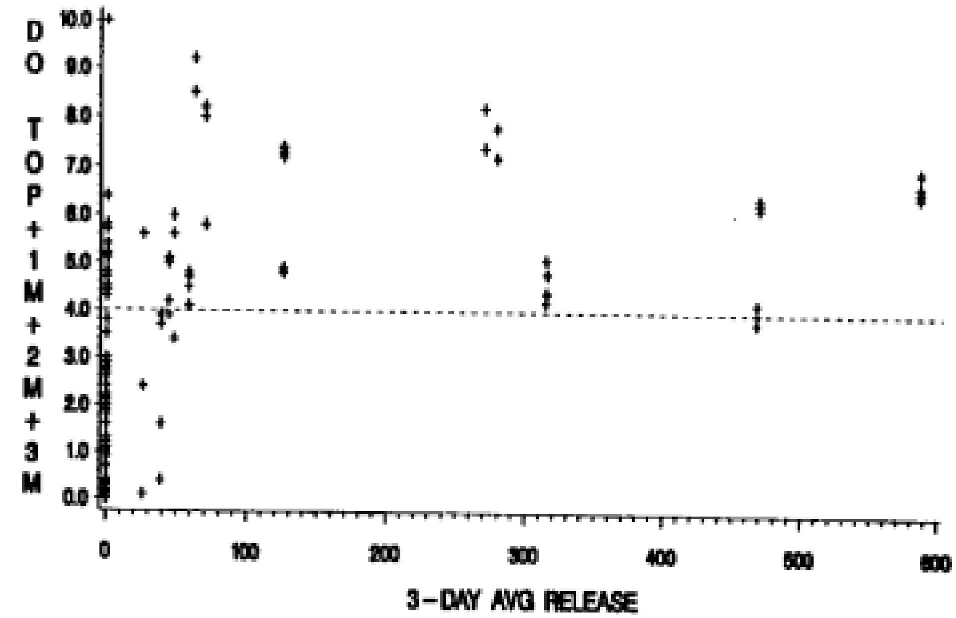
AGENCY=WAR Station=2



AGENCY=WAR Station=3

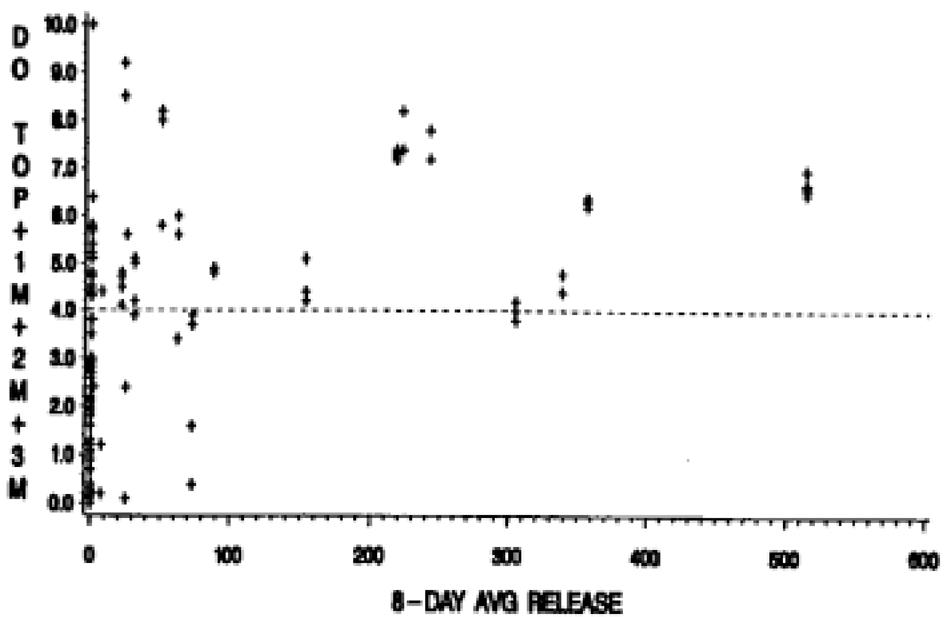


AGENCY=WAR Station=3

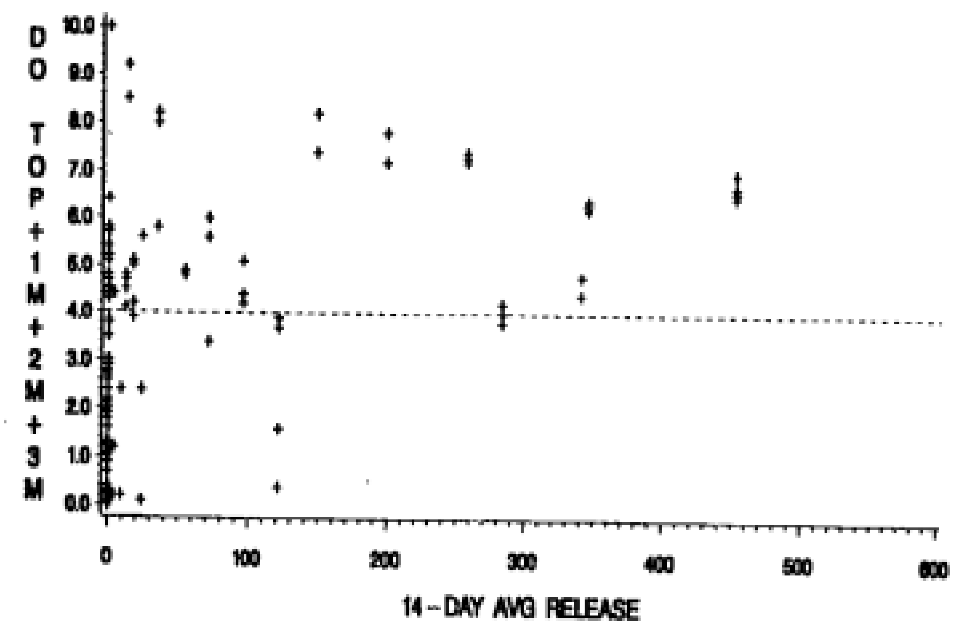


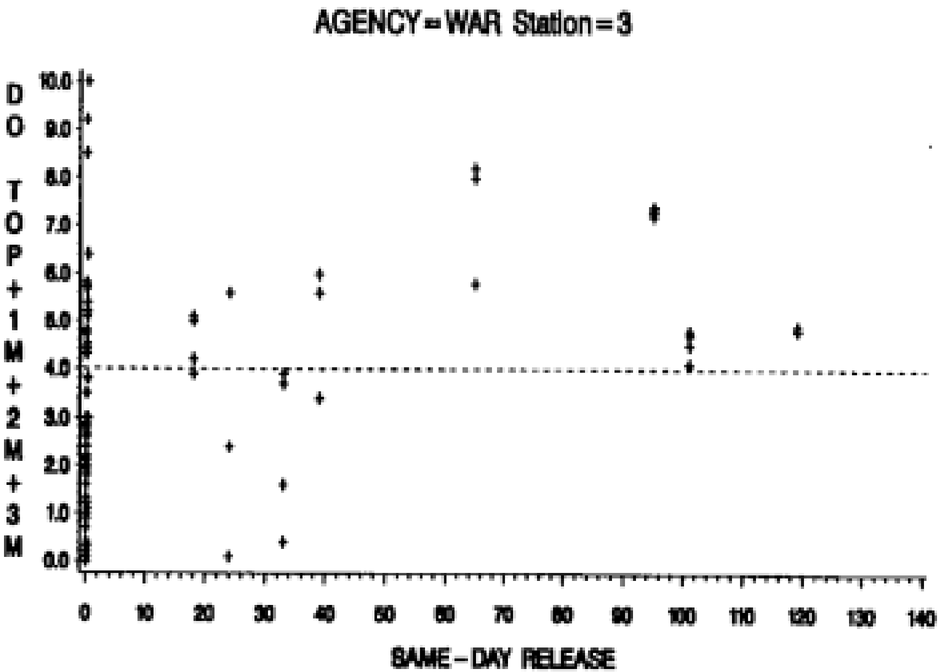
D3

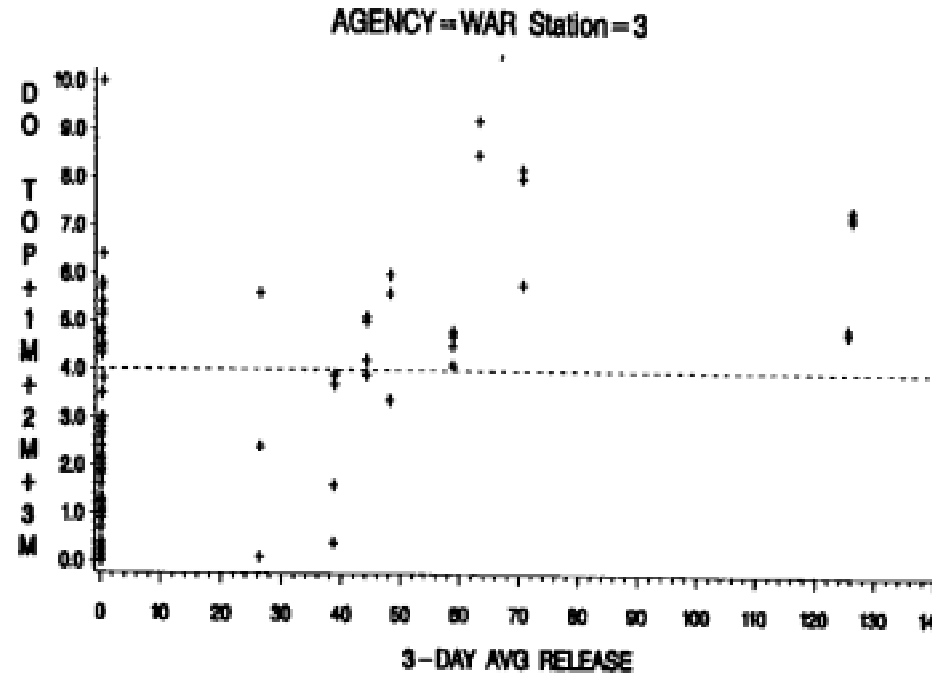
AGENCY=WAR Station=3



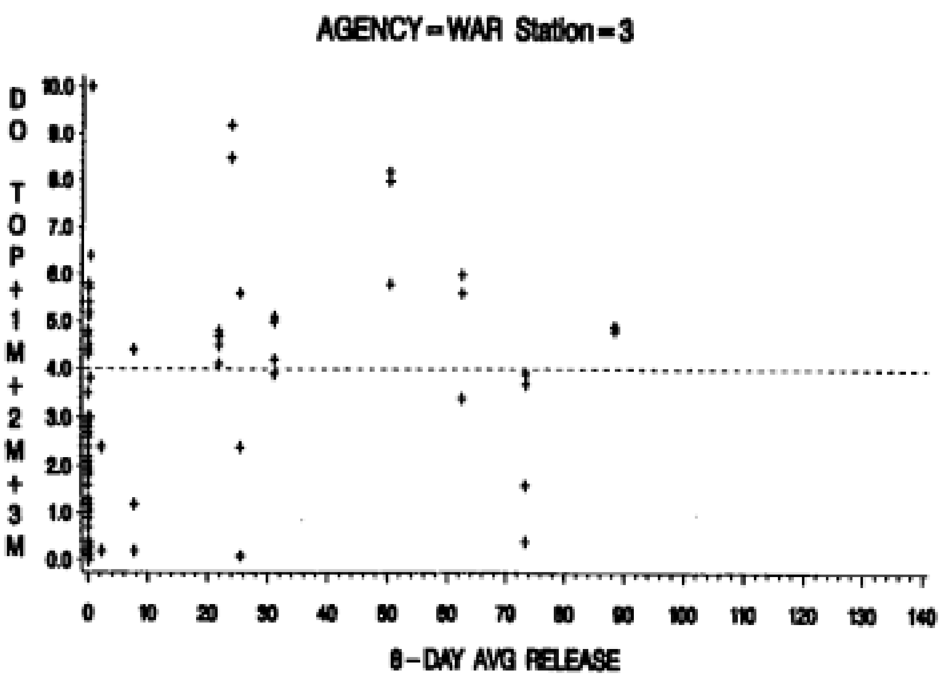
AGENCY=WAR Station=3

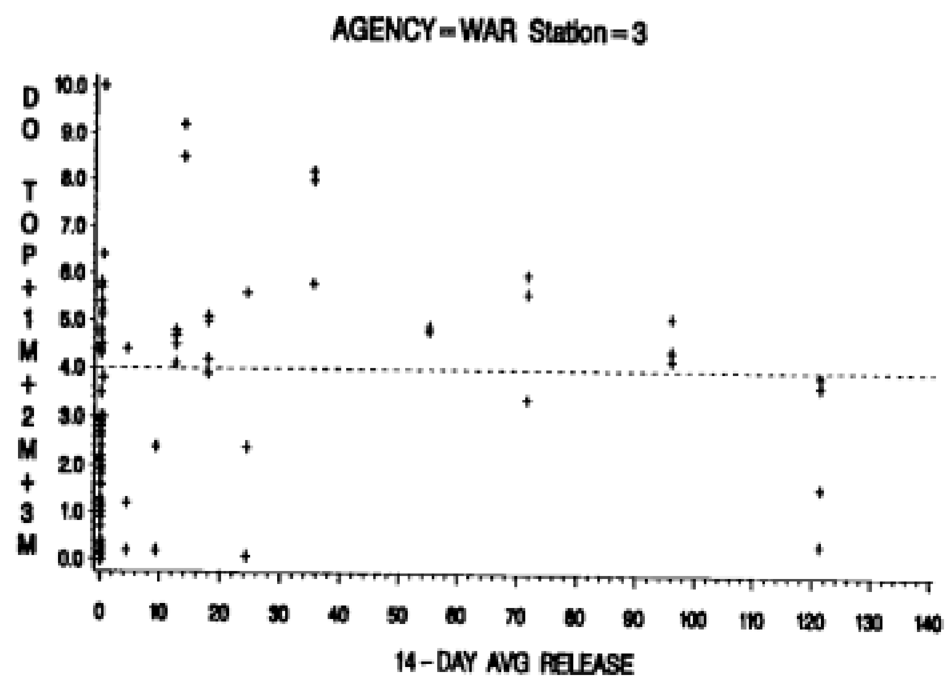


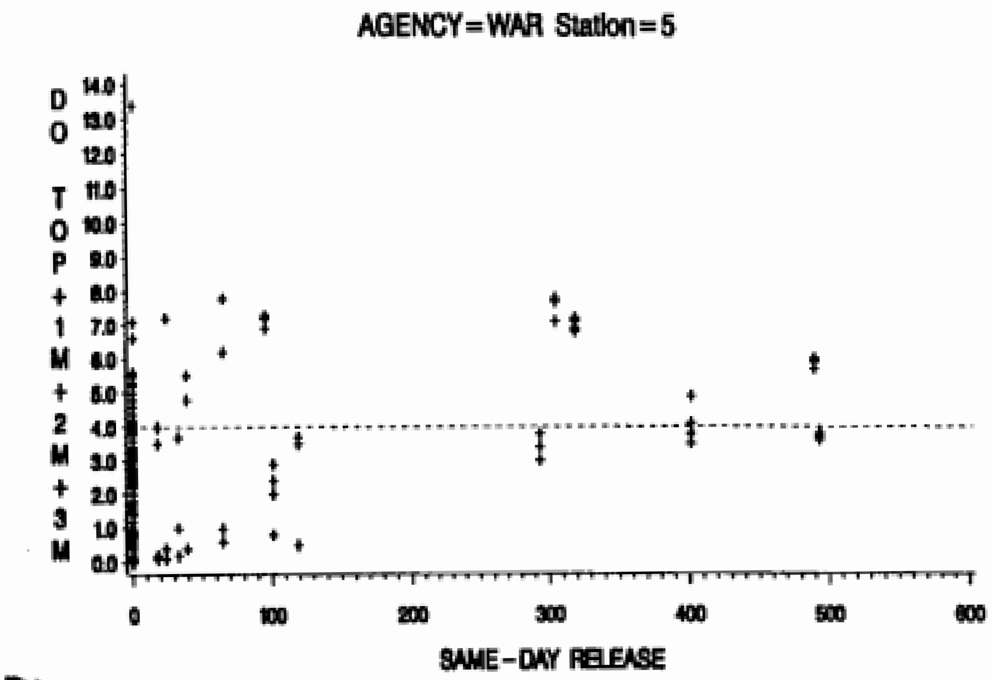

AGENCY=WAR Station=3
DO TOP+1M+2M+3M
SAME-DAY RELEASE

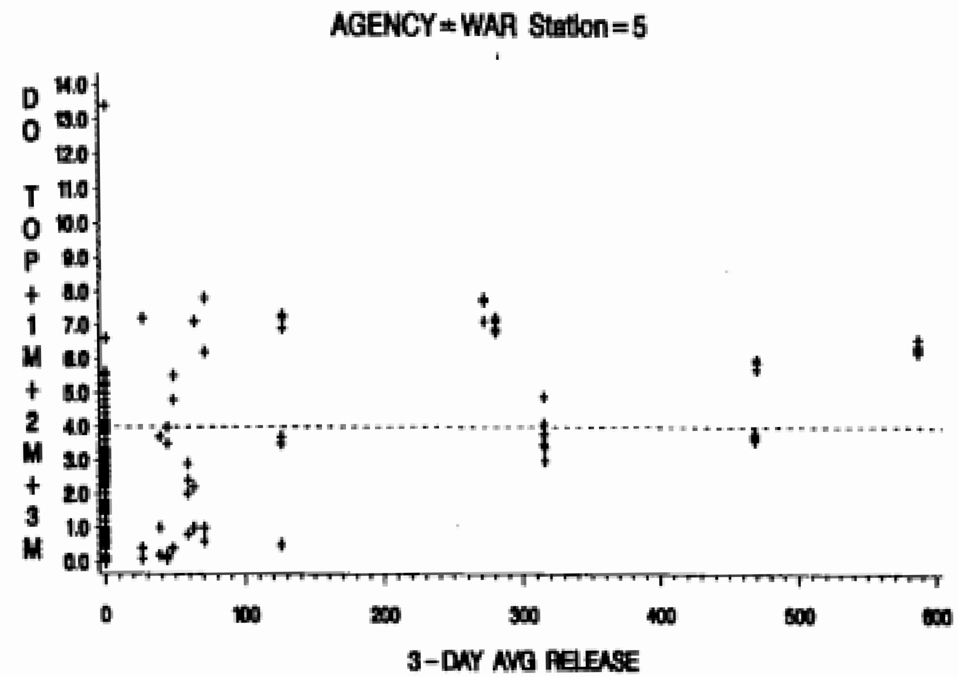

AGENCY=WAR Station=3
DO TOP+1M+2M+3M
3-DAY AVG RELEASE

D4

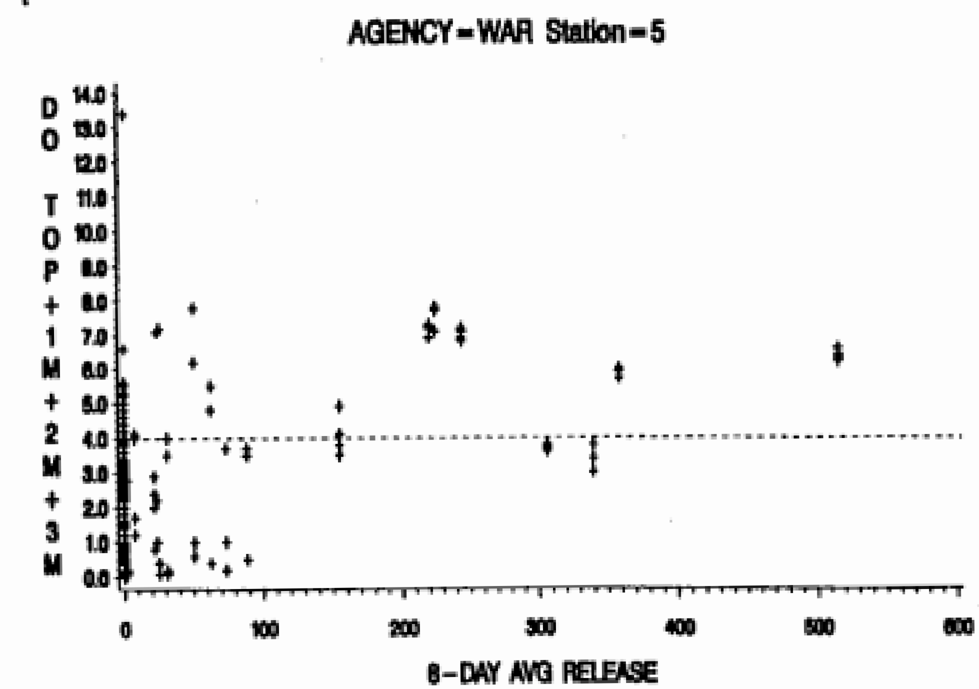

AGENCY=WAR Station=3
DO TOP+1M+2M+3M
8-DAY AVG RELEASE

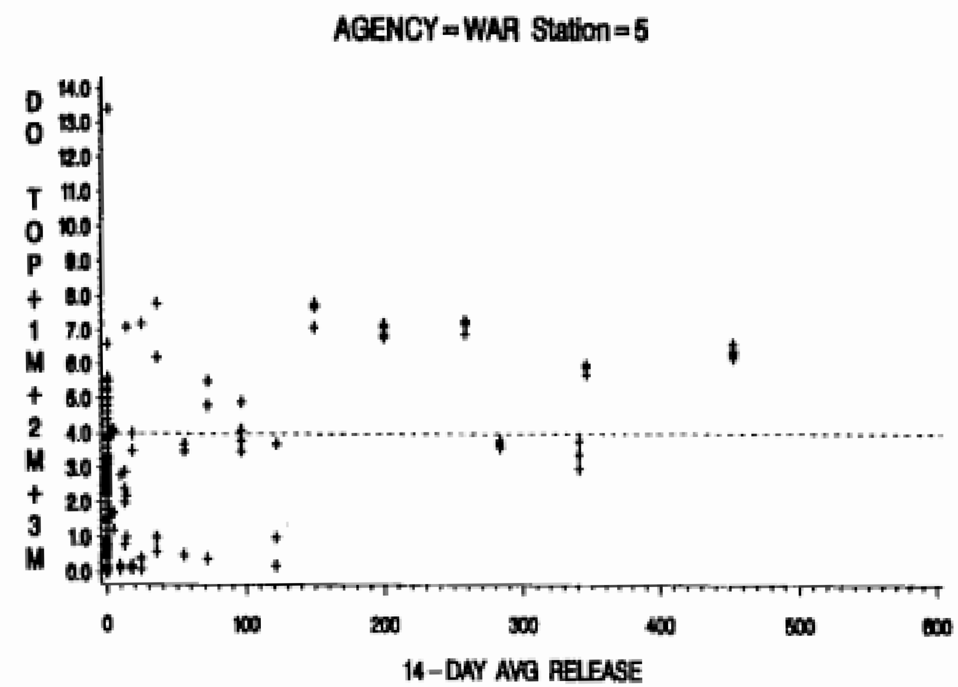

AGENCY=WAR Station=3
DO TOP+1M+2M+3M
14-DAY AVG RELEASE


AGENCY=WAR Station=5
D O TOP+1M+2M+3M
SAME-DAY RELEASE

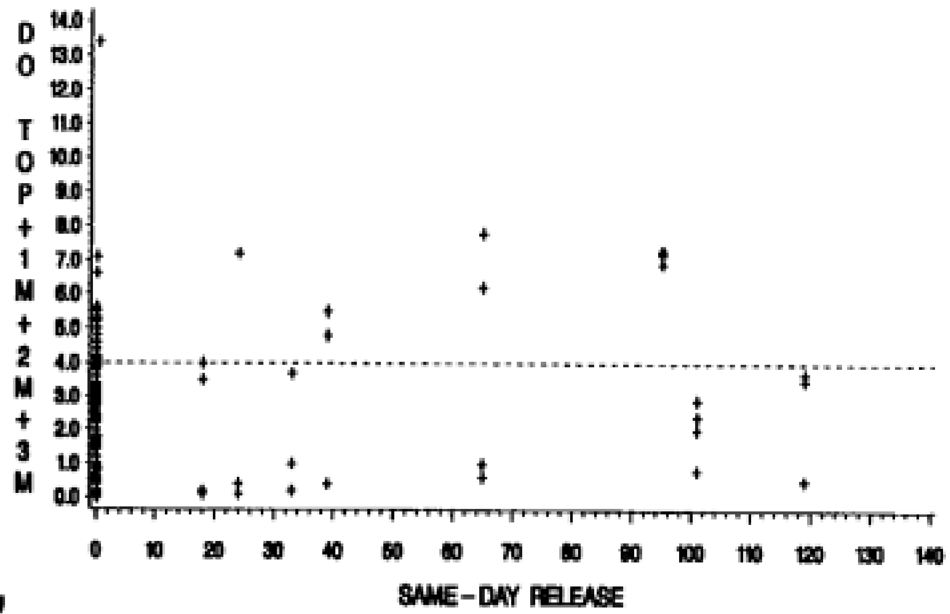

AGENCY=WAR Station=5
D O TOP+1M+2M+3M
3-DAY AVG RELEASE

D5

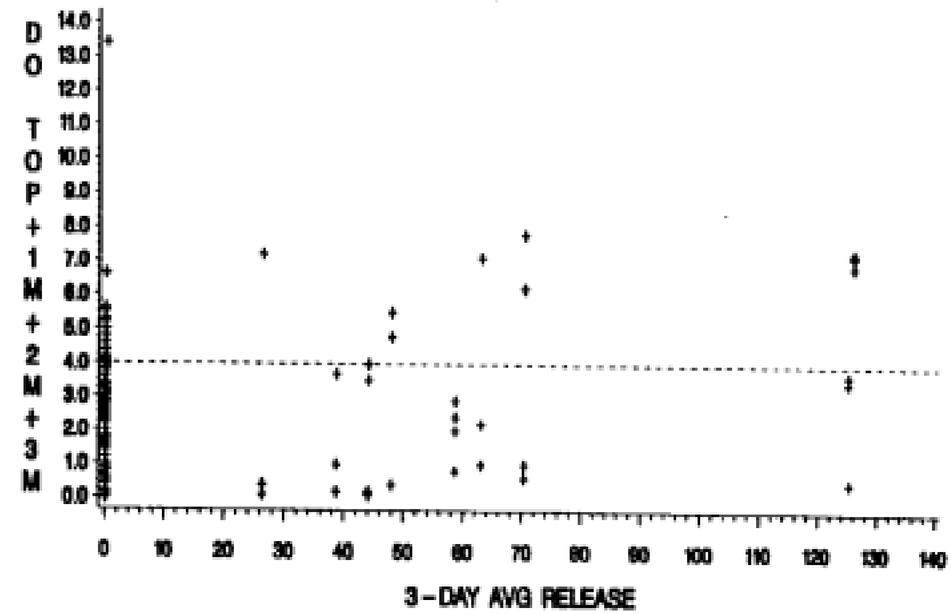

AGENCY=WAR Station=5
D O TOP+1M+2M+3M
6-DAY AVG RELEASE


AGENCY=WAR Station=5
D O TOP+1M+2M+3M
14-DAY AVG RELEASE

AGENCY=WAR Station=5

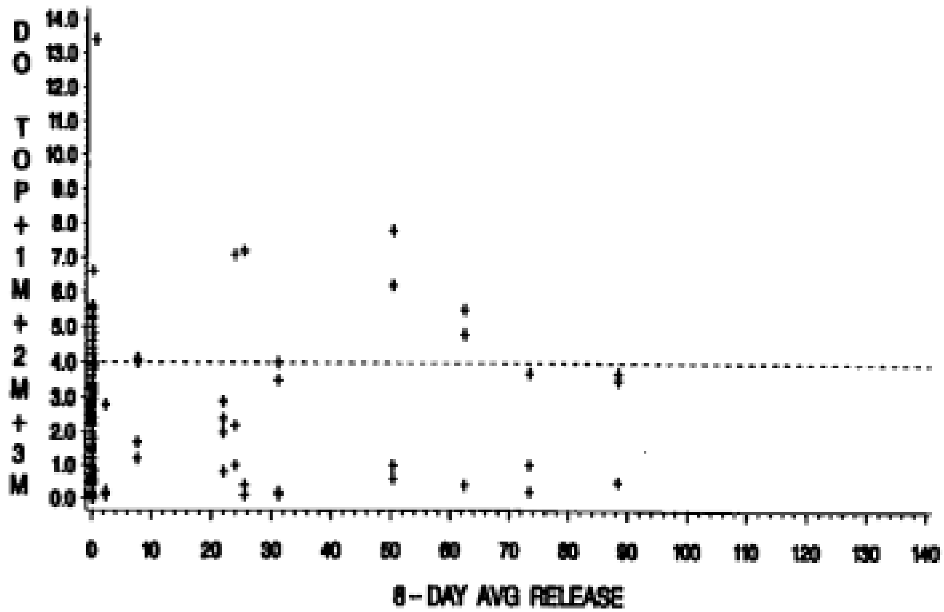


AGENCY=WAR Station=5

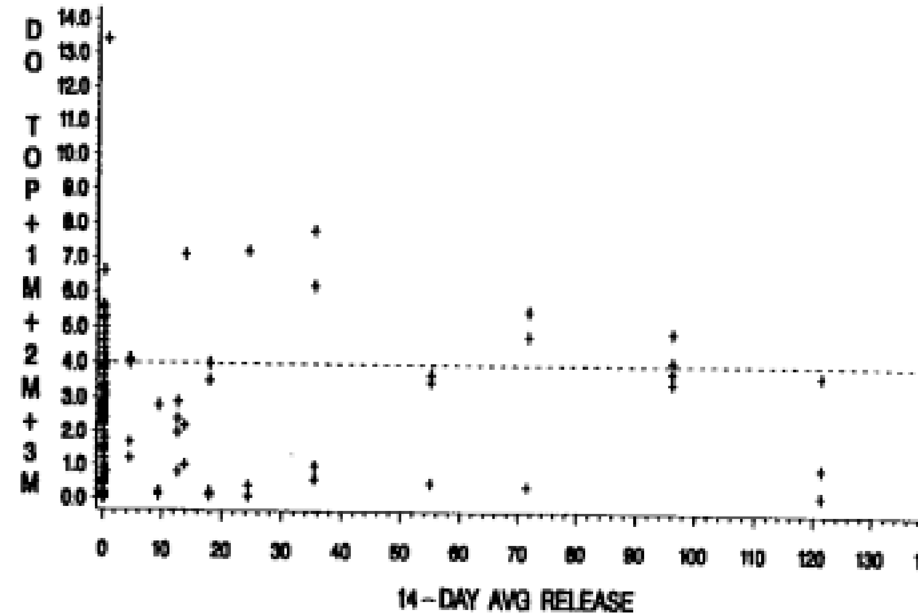


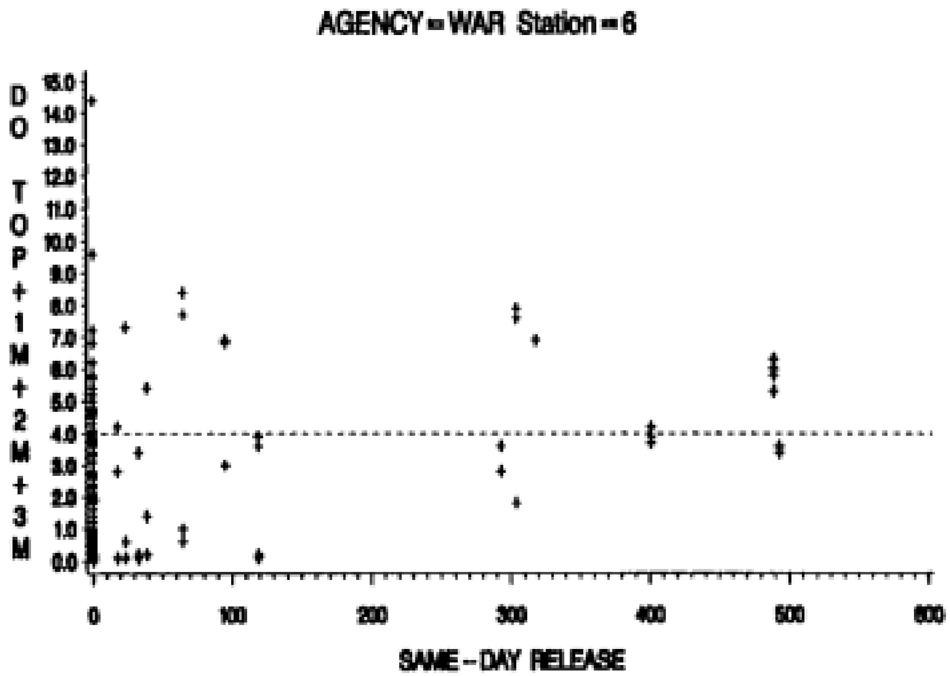
D6

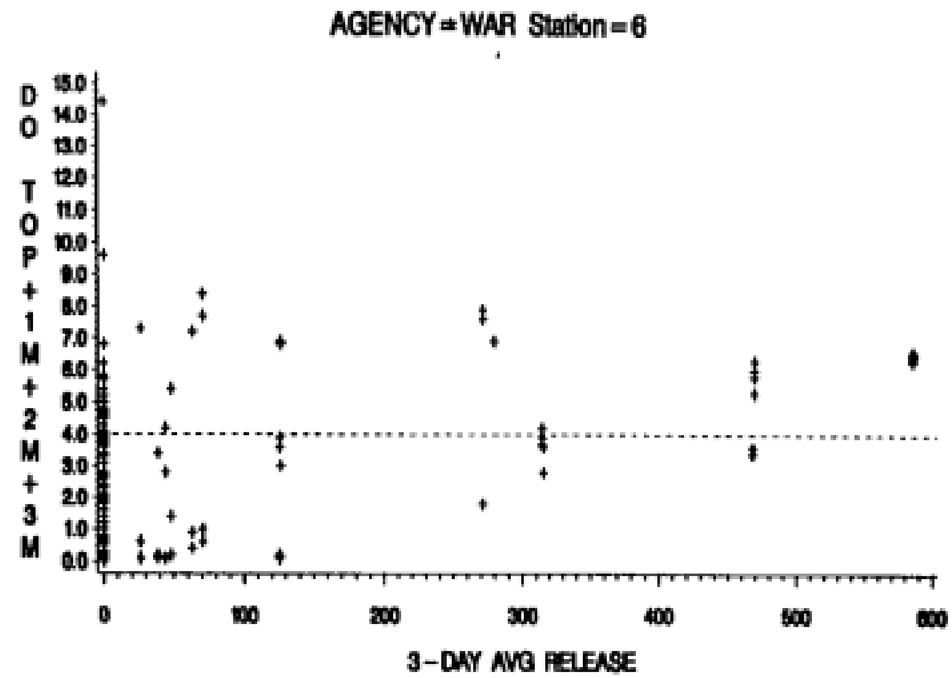
AGENCY=WAR Station=5



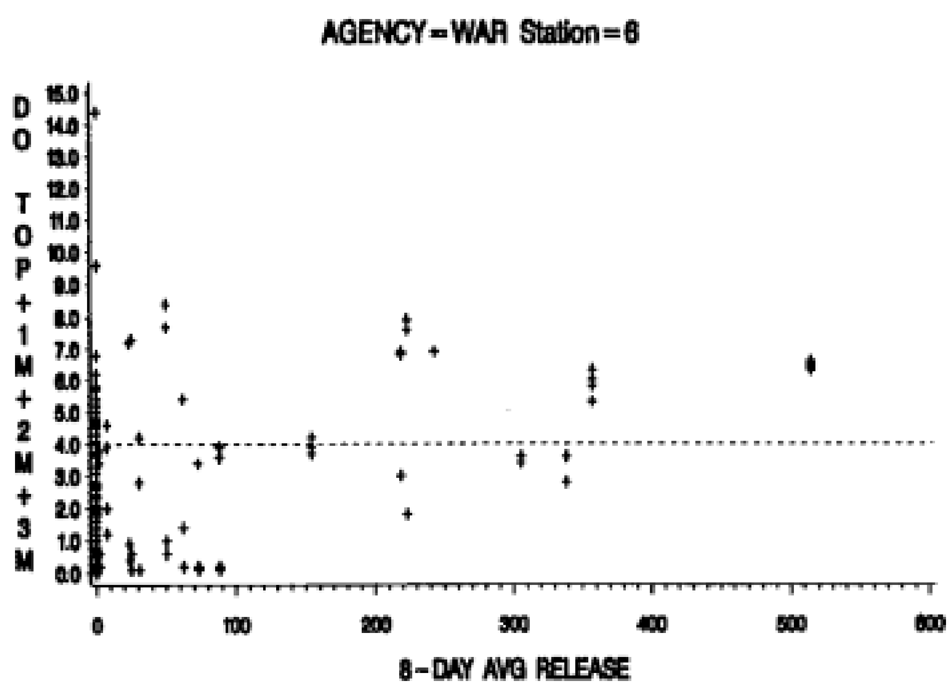
AGENCY=WAR Station=5

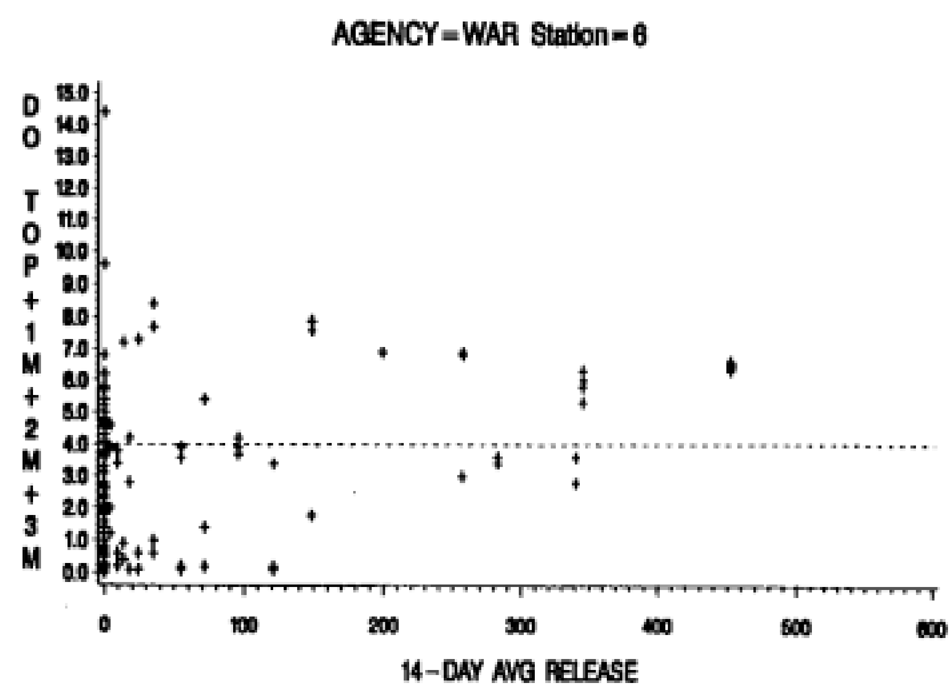



AGENCY=WAR Station=6
DO TOP+1M+2M+3M
SAME-DAY RELEASE

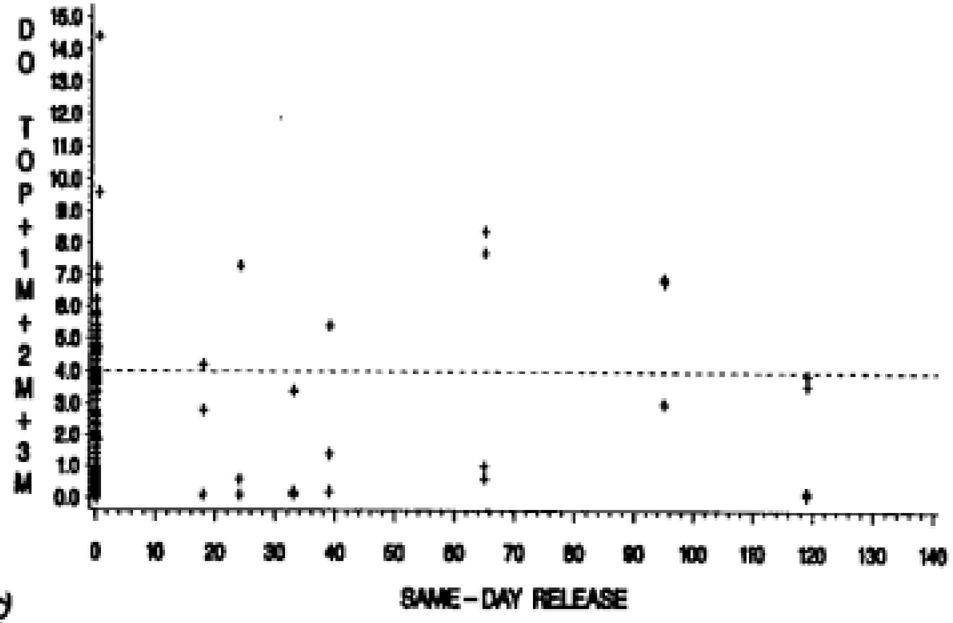

AGENCY=WAR Station=6
DO TOP+1M+2M+3M
3-DAY AVG RELEASE

07

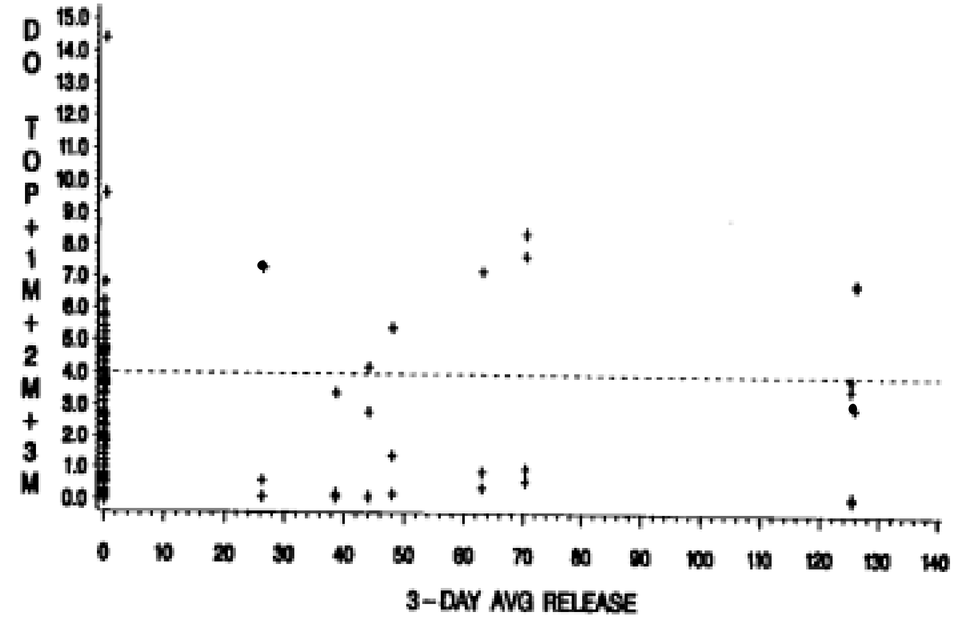

AGENCY=WAR Station=6
DO TOP+1M+2M+3M
8-DAY AVG RELEASE


AGENCY=WAR Station=6
DO TOP+1M+2M+3M
14-DAY AVG RELEASE

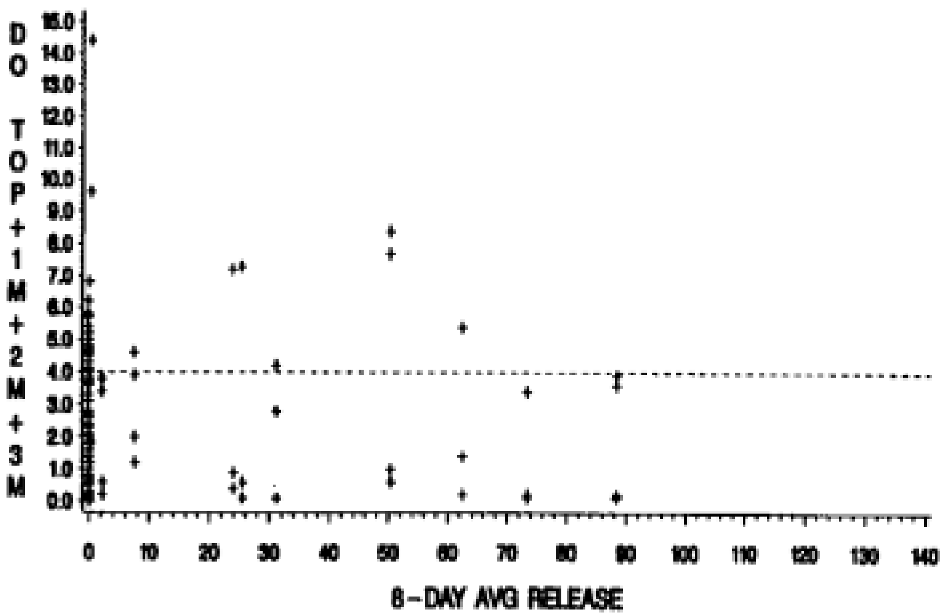
AGENCY=WAR Station=6



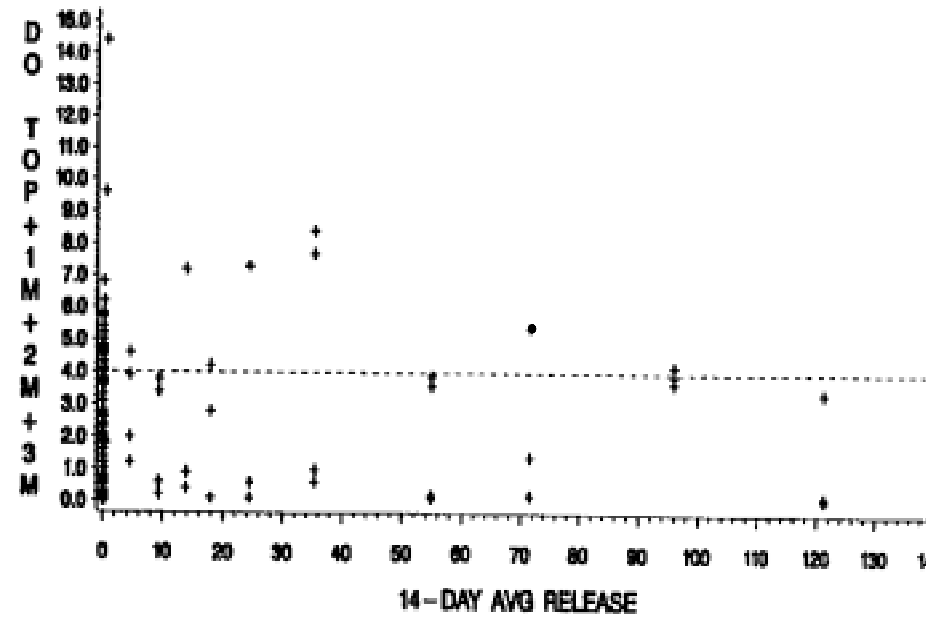
AGENCY=WAR Station=6

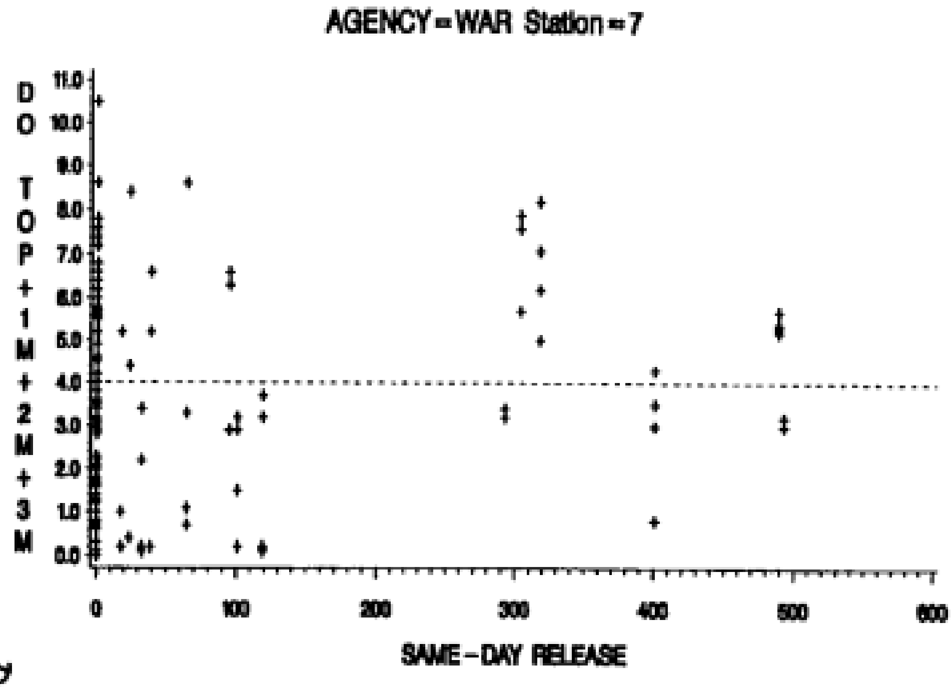


AGENCY=WAR Station=6

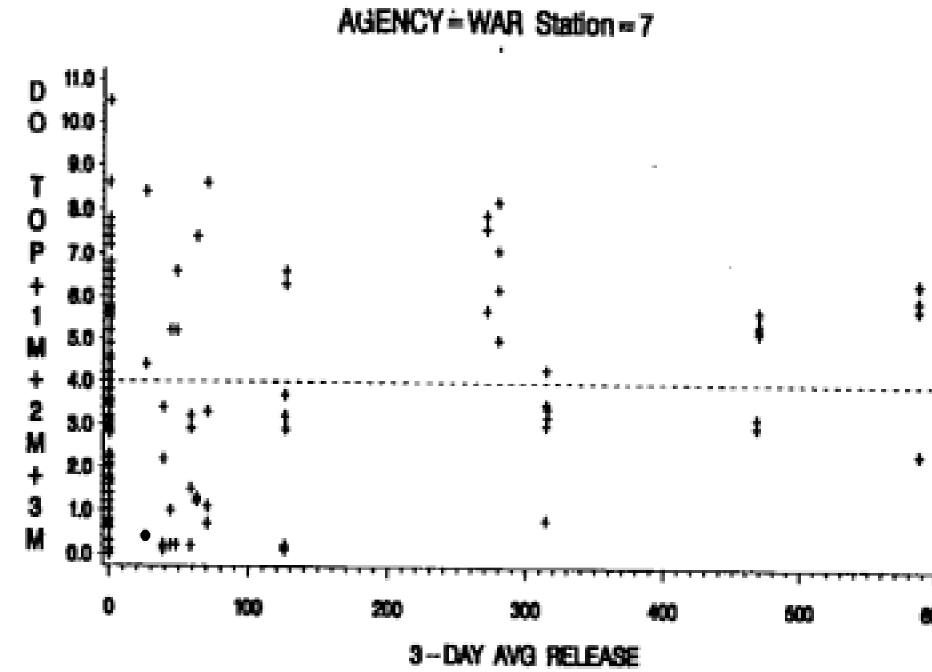


AGENCY=WAR Station=6



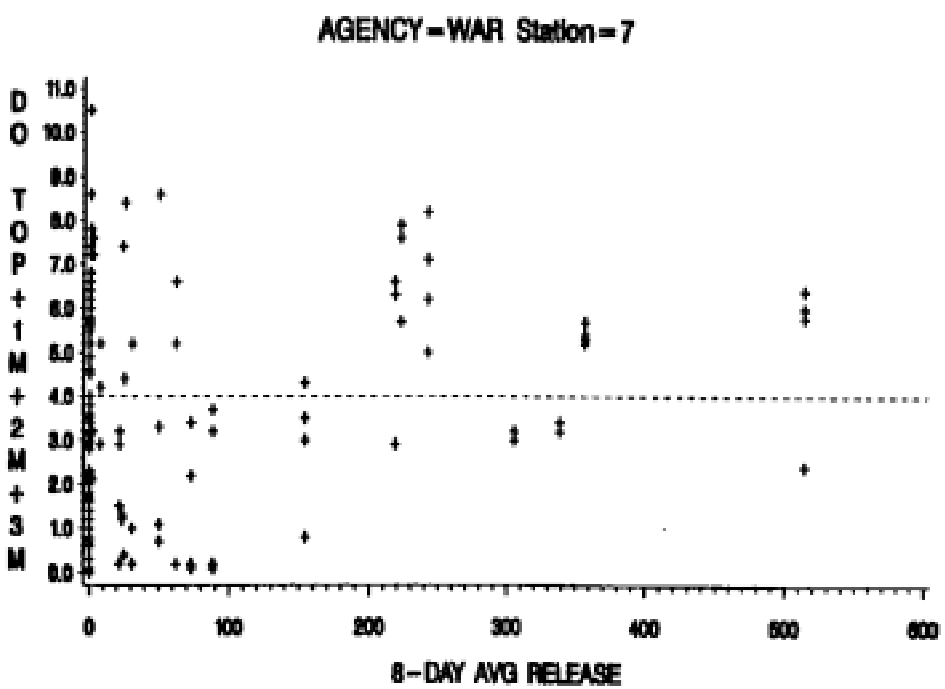


AGENCY=WAR Station=7
DO TOP+1M+2M+3M
SAME-DAY RELEASE

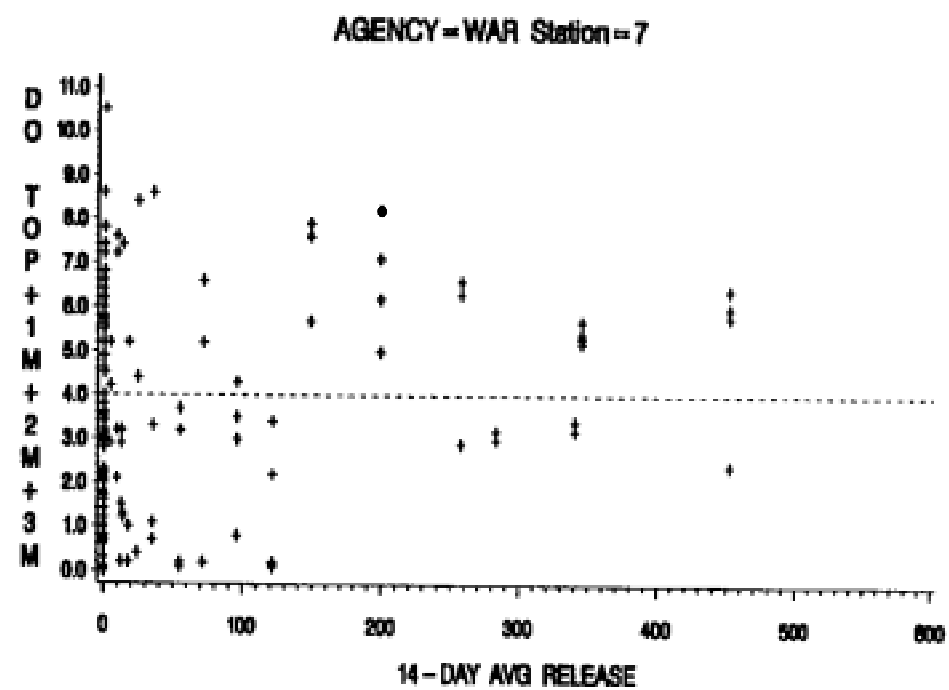


AGENCY=WAR Station=7
DO TOP+1M+2M+3M
3-DAY AVG RELEASE

D9

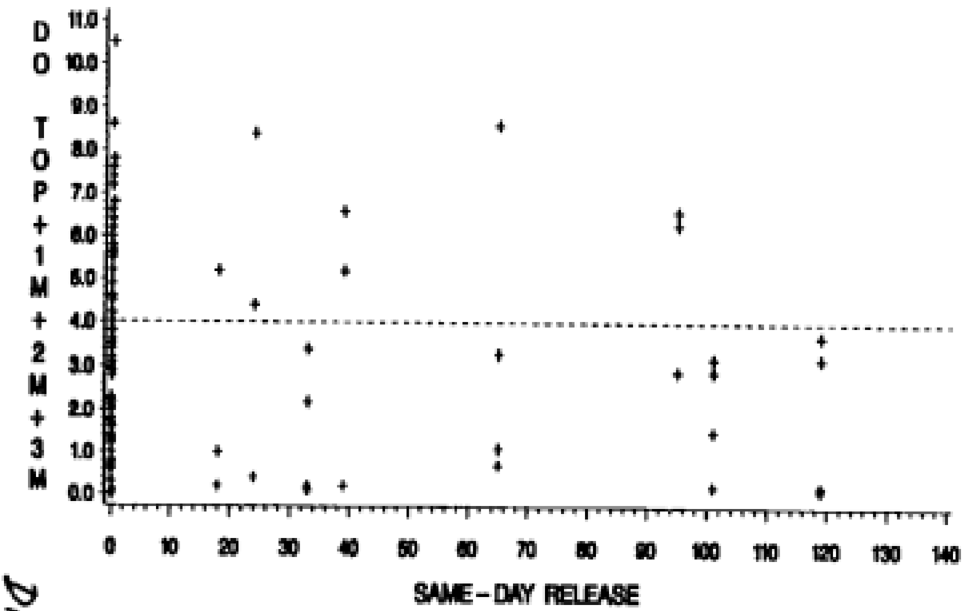


AGENCY=WAR Station=7
DO TOP+1M+2M+3M
8-DAY AVG RELEASE



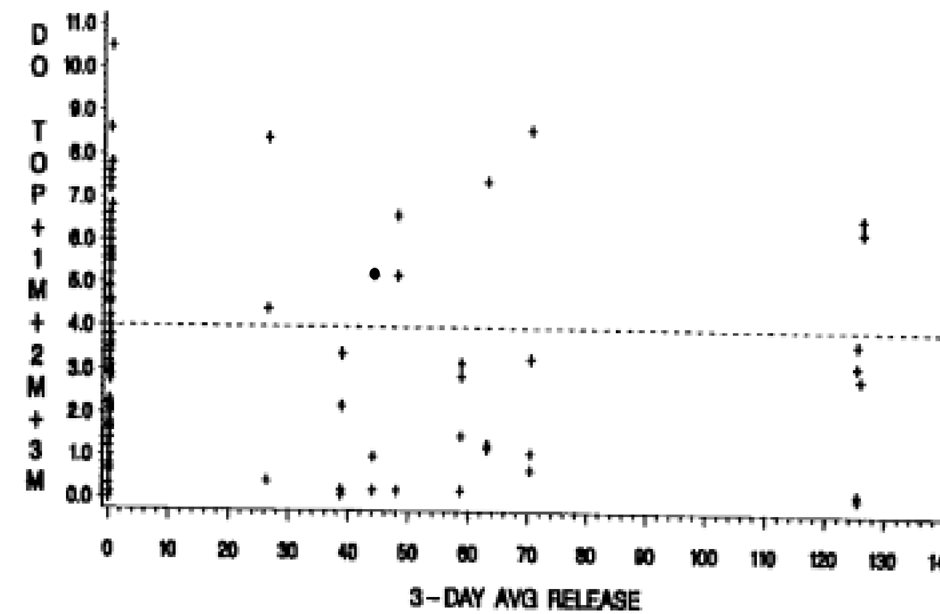
AGENCY=WAR Station=7
DO TOP+1M+2M+3M
14-DAY AVG RELEASE

AGENCY=WAR Station=7

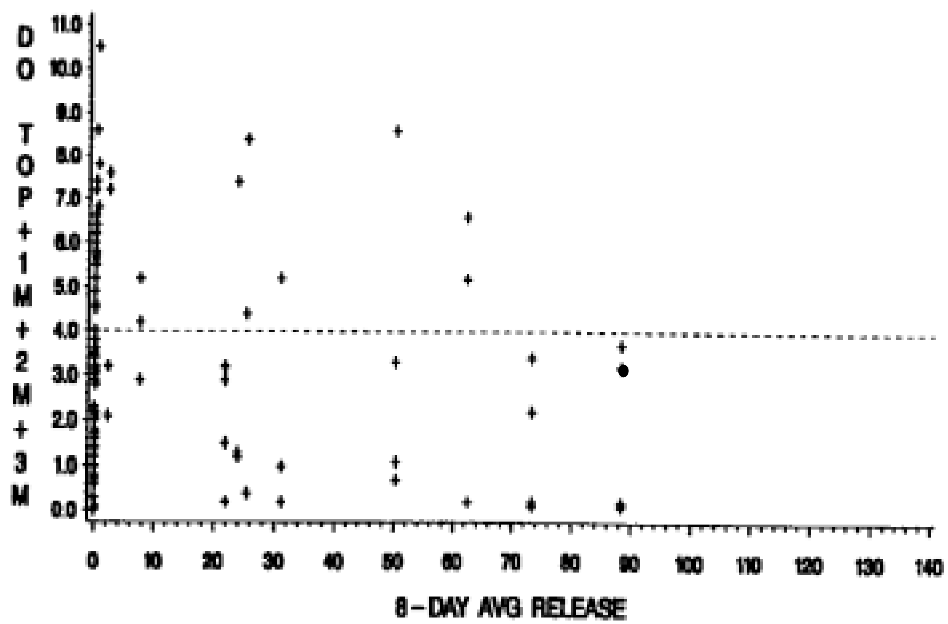


D10

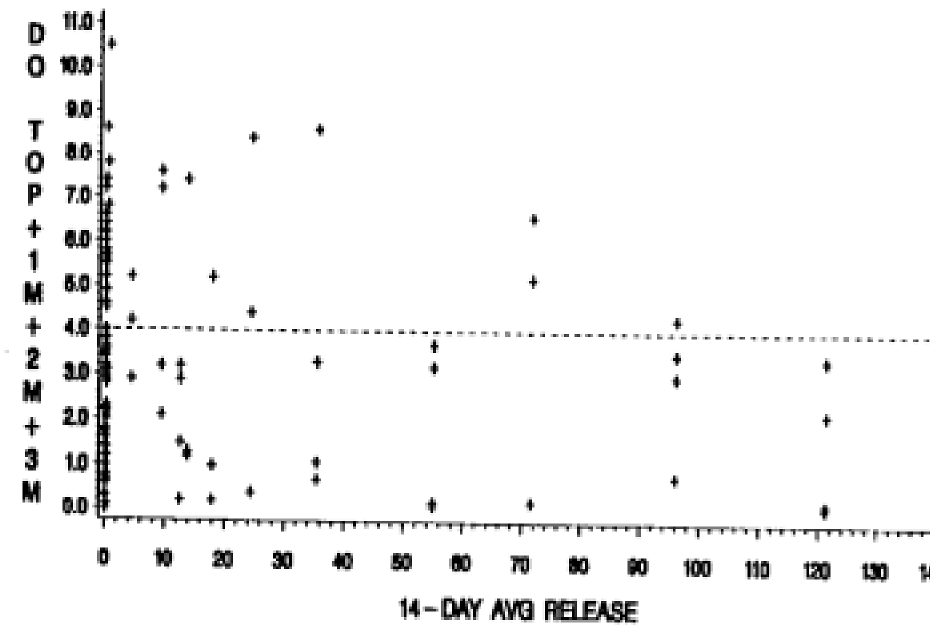
AGENCY=WAR Station=7



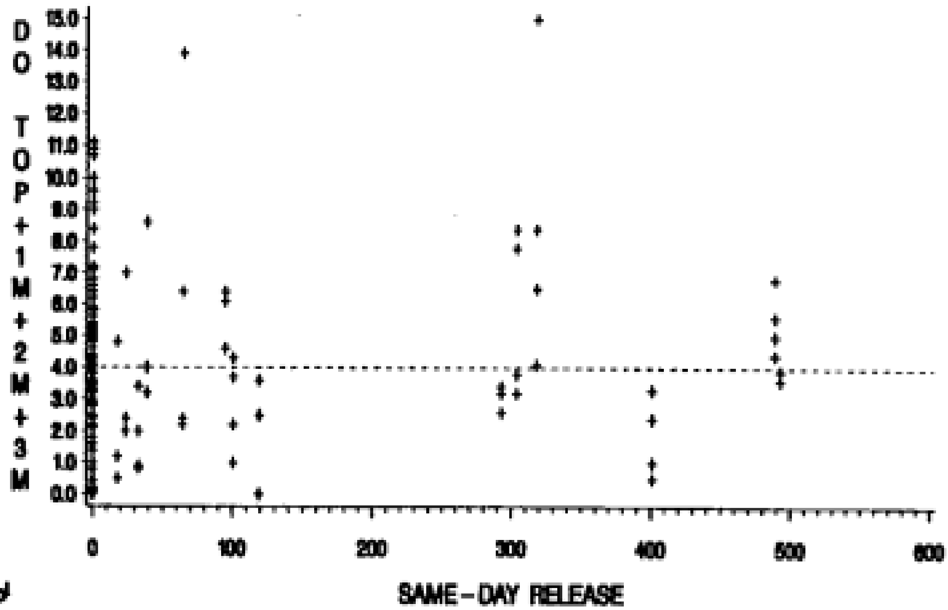
AGENCY=WAR Station=7



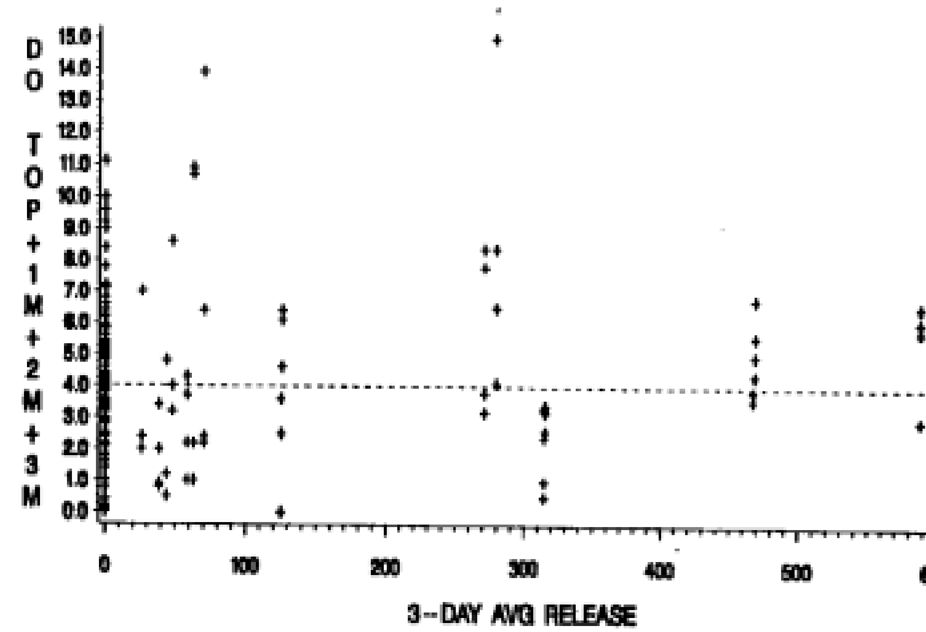
AGENCY=WAR Station=7



AGENCY=WAR Station=8

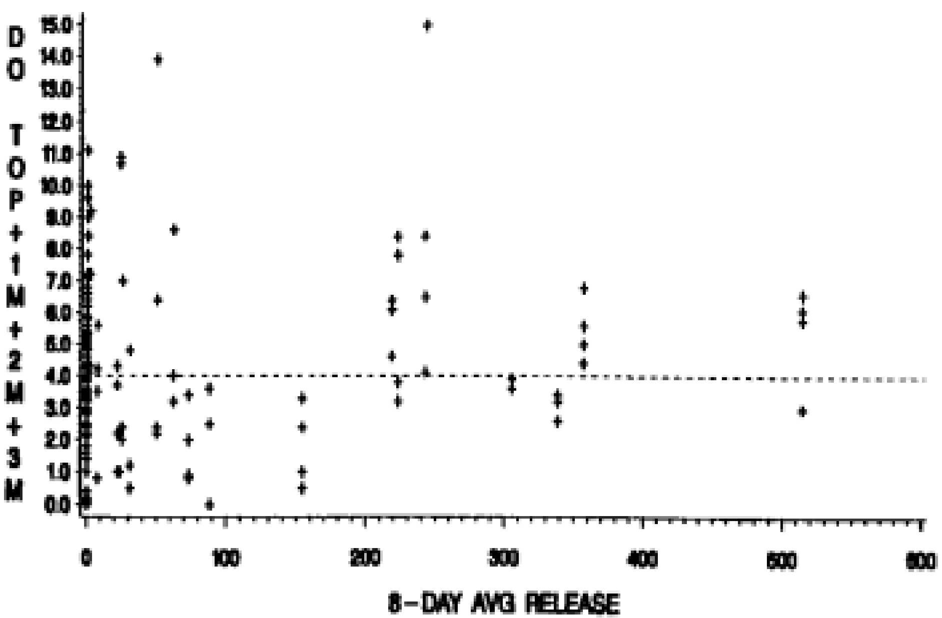


AGENCY=WAR Station=8

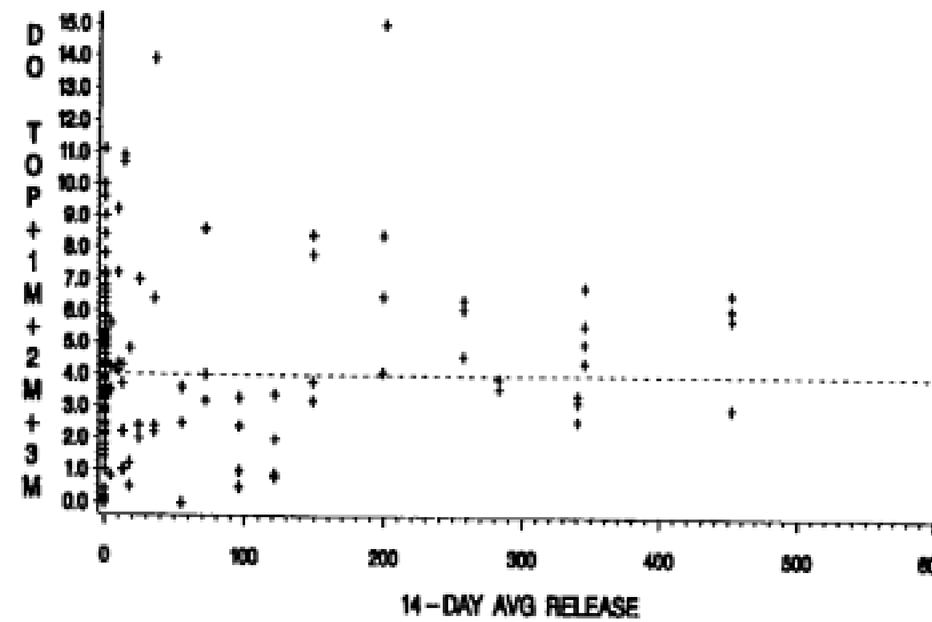


112

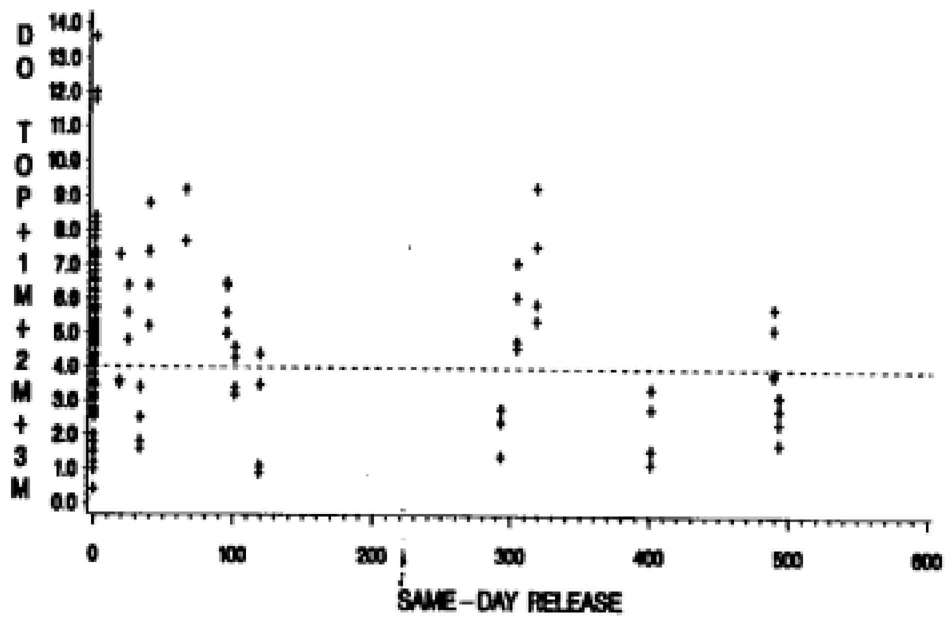
AGENCY=WAR Station=8



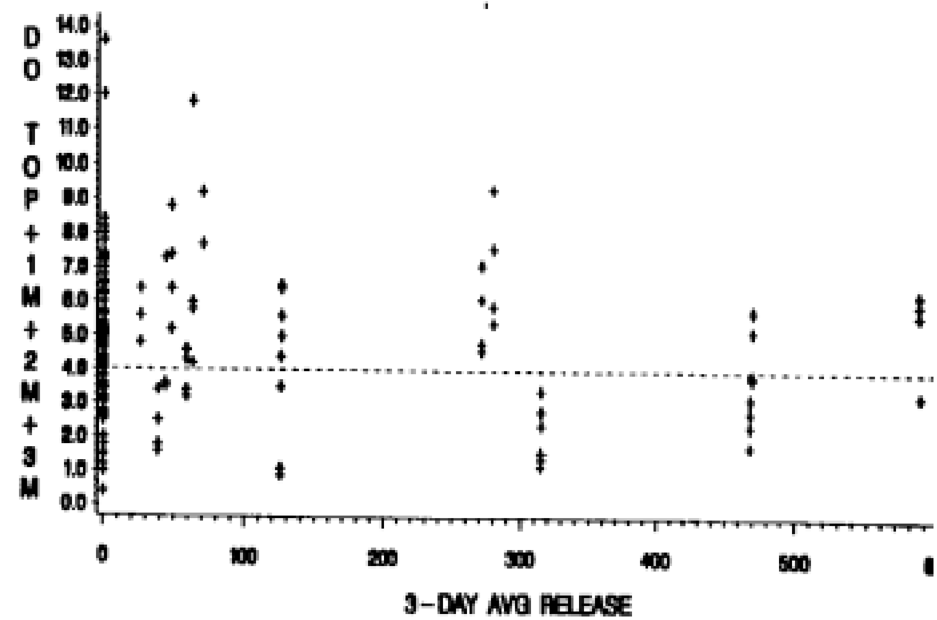
AGENCY=WAR Station=8



AGENCY=WAR Station=9

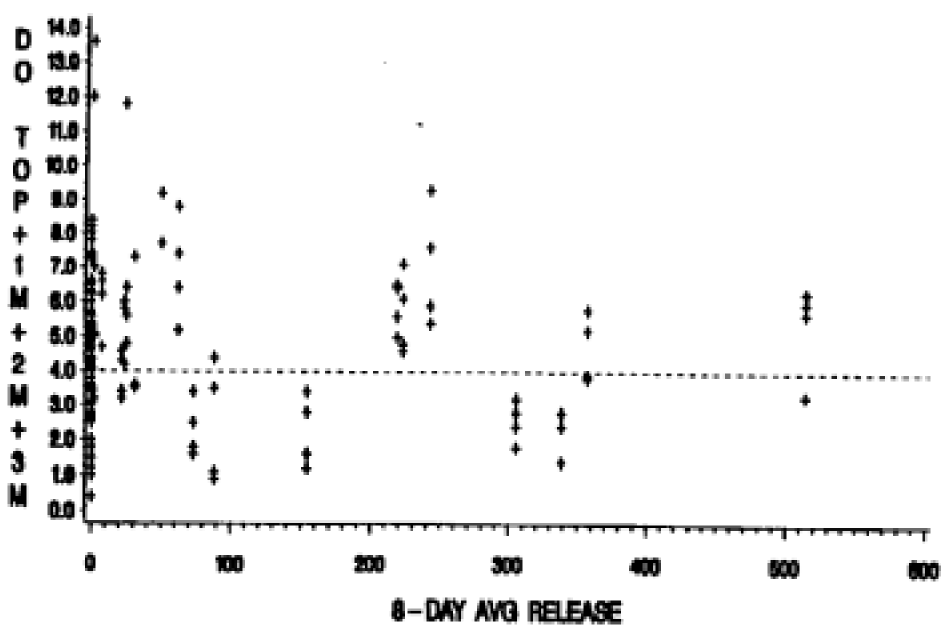


AGENCY=WAR Station=9

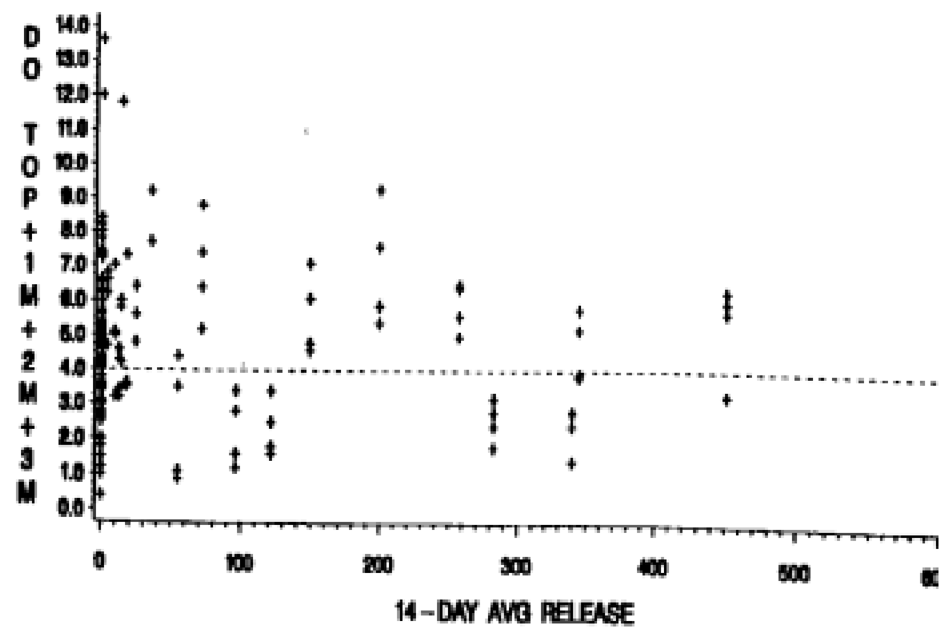


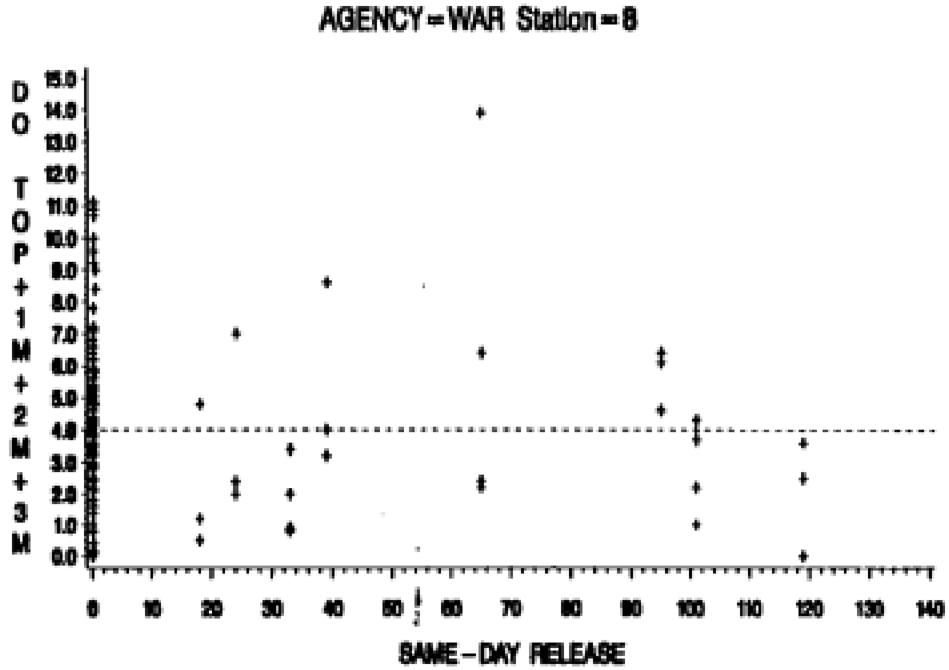
D12

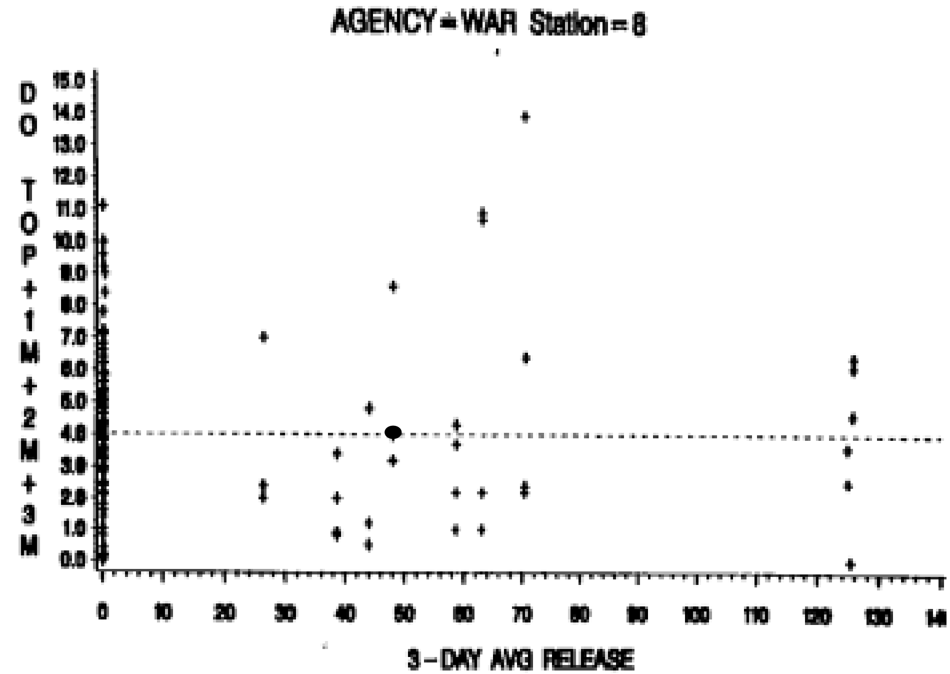
AGENCY=WAR Station=9



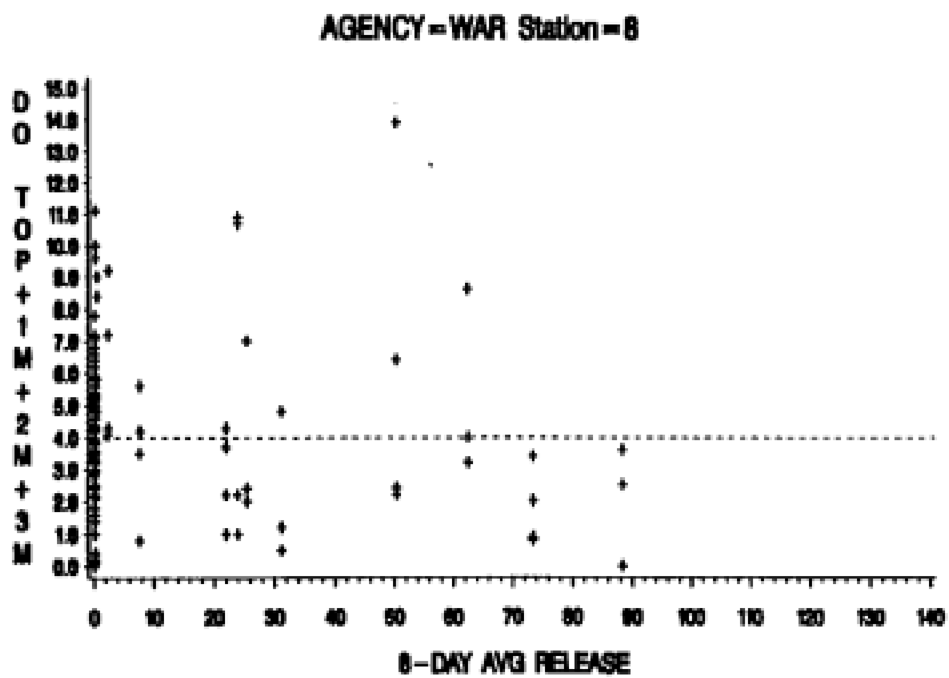
AGENCY=WAR Station=9

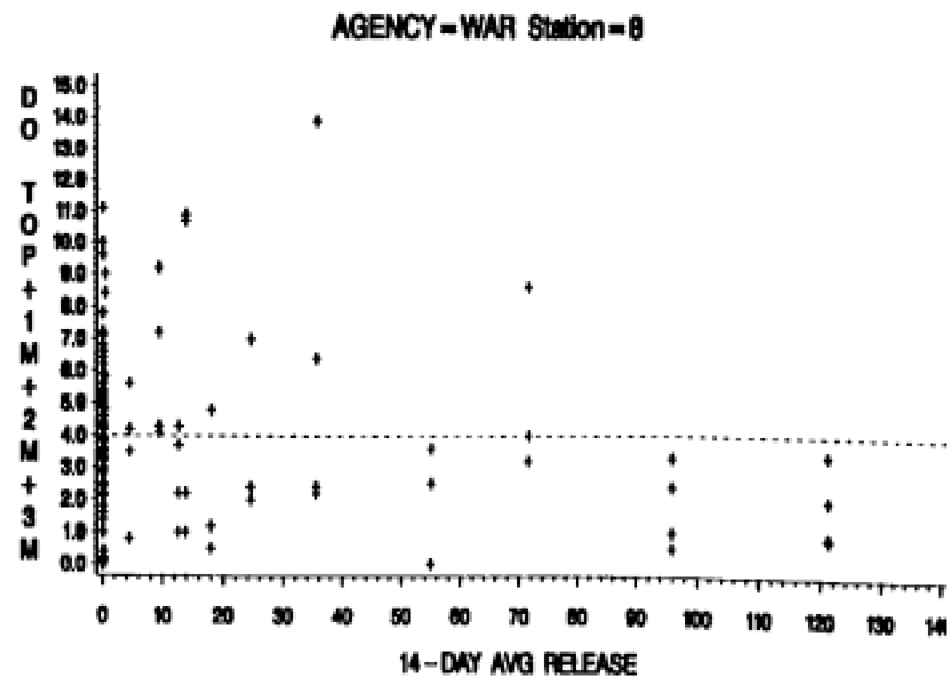



AGENCY=WAR Station=8
DO TOP +1M +2M +3M
SAME-DAY RELEASE

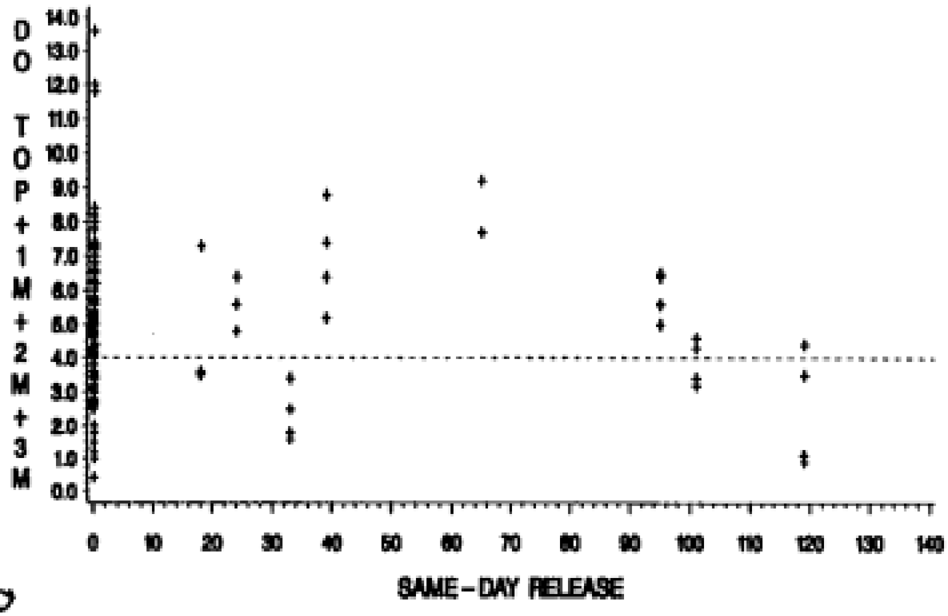

AGENCY=WAR Station=8
DO TOP +1M +2M +3M
3-DAY AVG RELEASE

D13

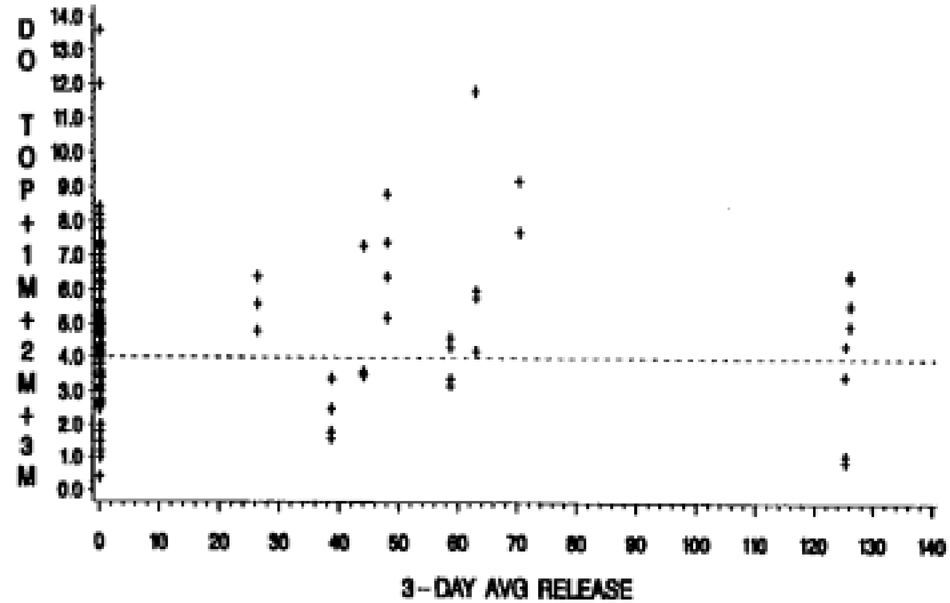

AGENCY=WAR Station=8
DO TOP +1M +2M +3M
8-DAY AVG RELEASE


AGENCY=WAR Station=8
DO TOP +1M +2M +3M
14-DAY AVG RELEASE

AGENCY=WAR Station=9

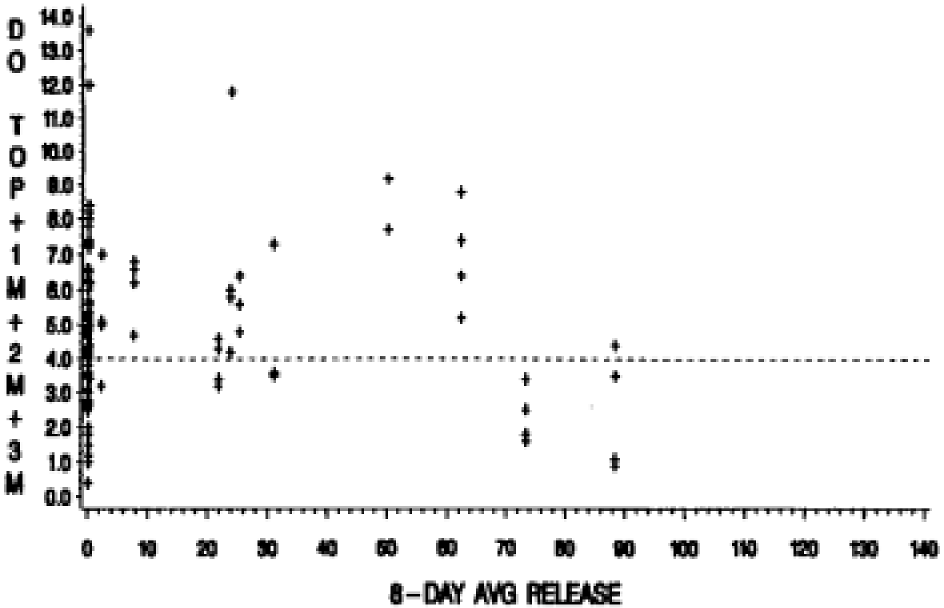


AGENCY=WAR Station=9

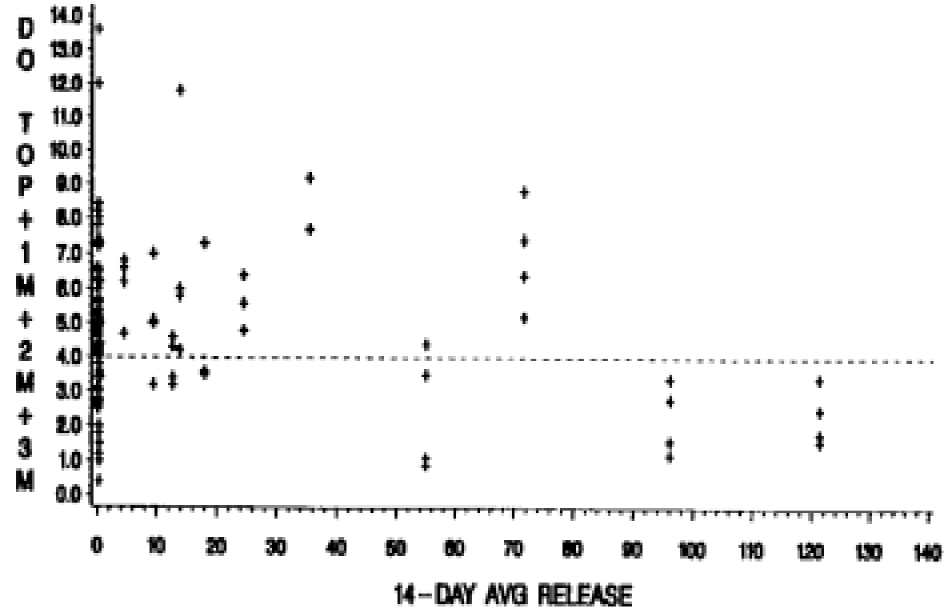


D14

AGENCY=WAR Station=9

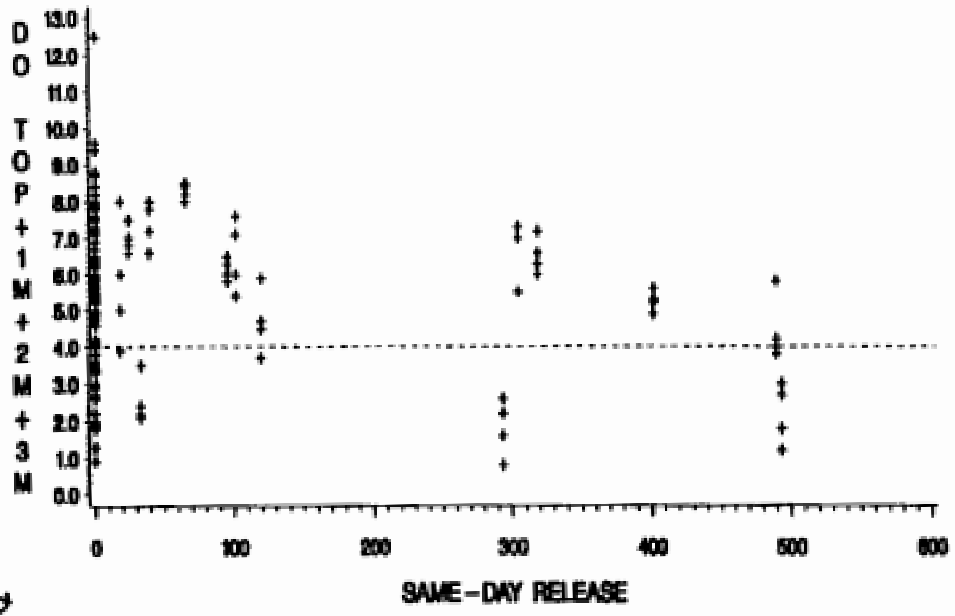


AGENCY=WAR Station=9

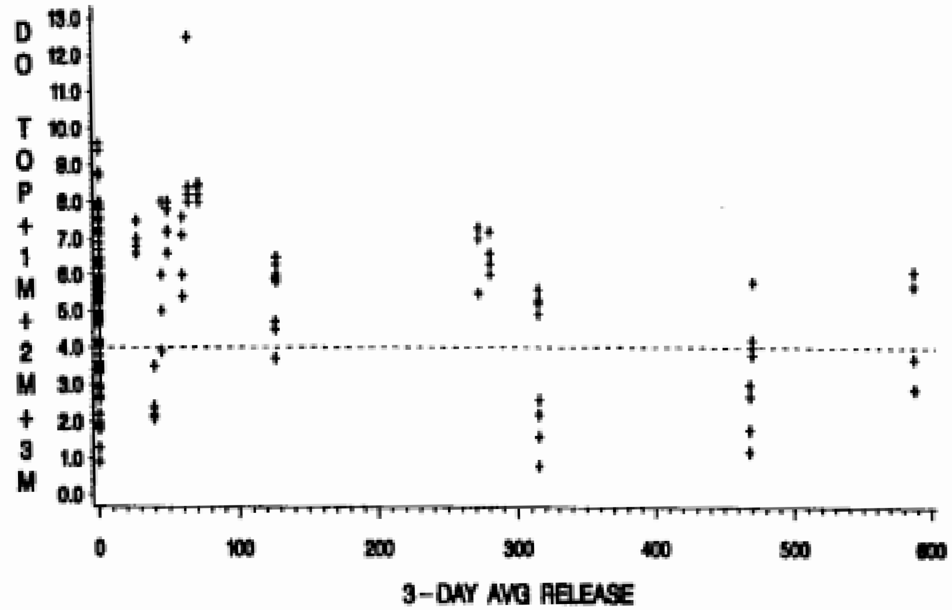


D15

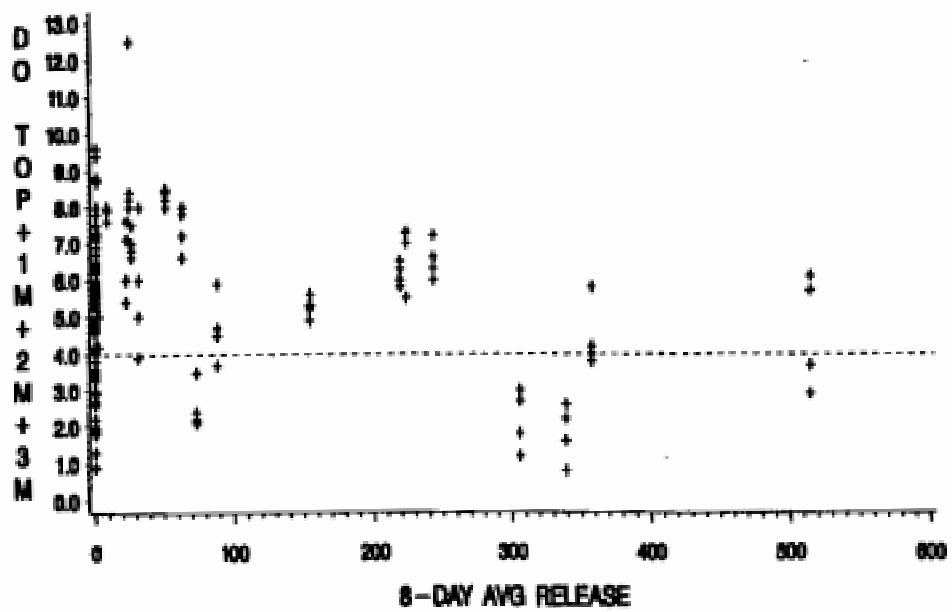
AGENCY=WAR Station=10



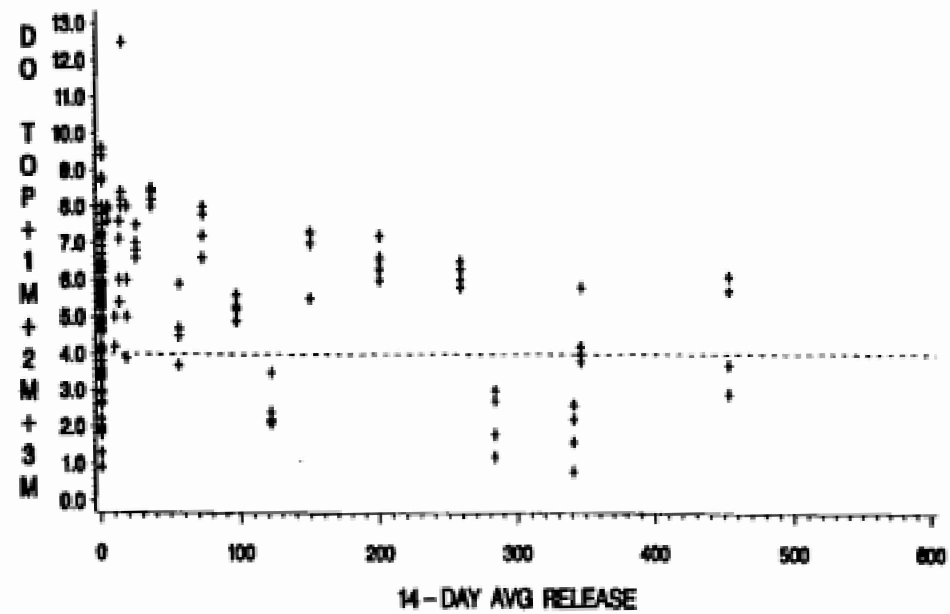
AGENCY=WAR Station=10



AGENCY=WAR Station=10



AGENCY=WAR Station=10



D16

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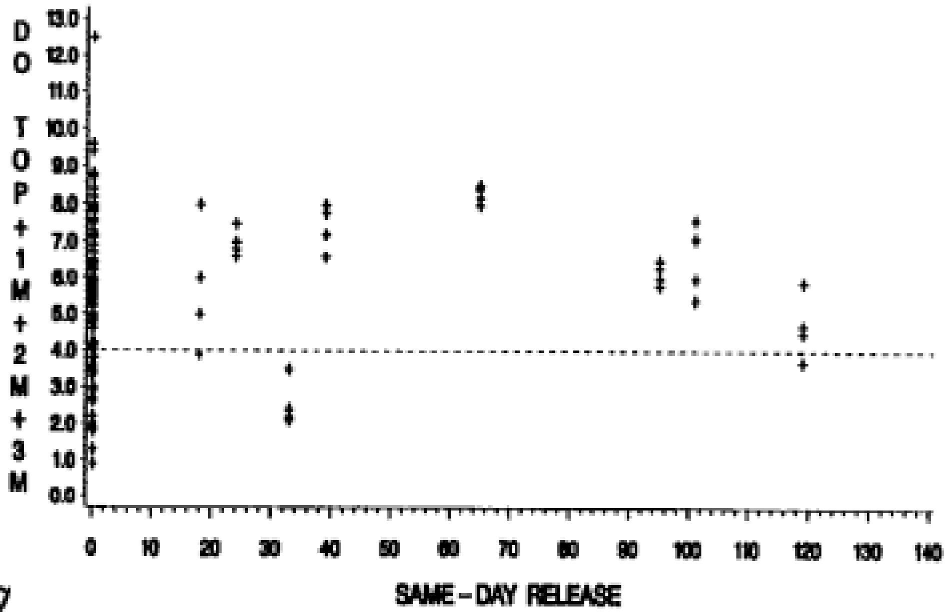

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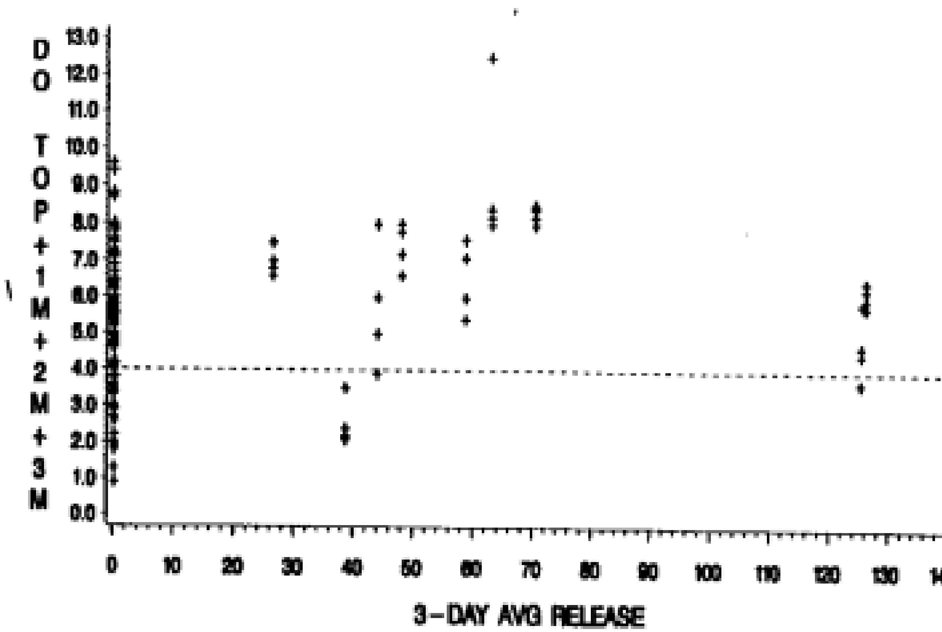

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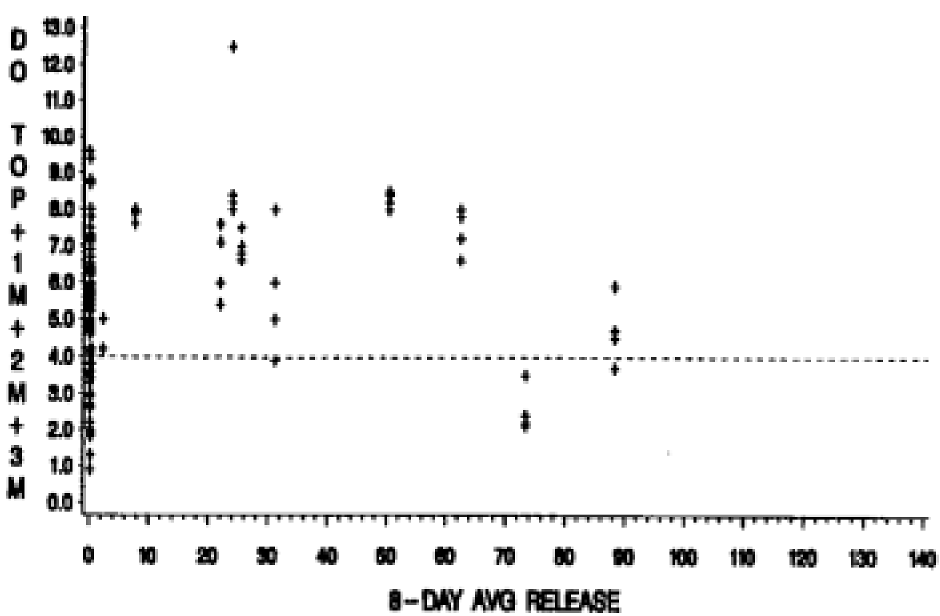

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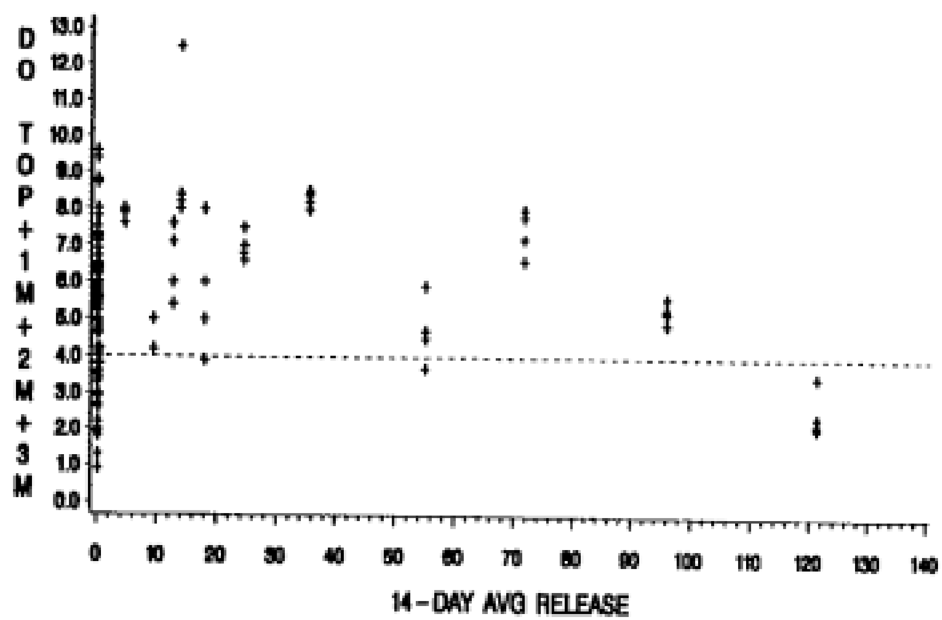
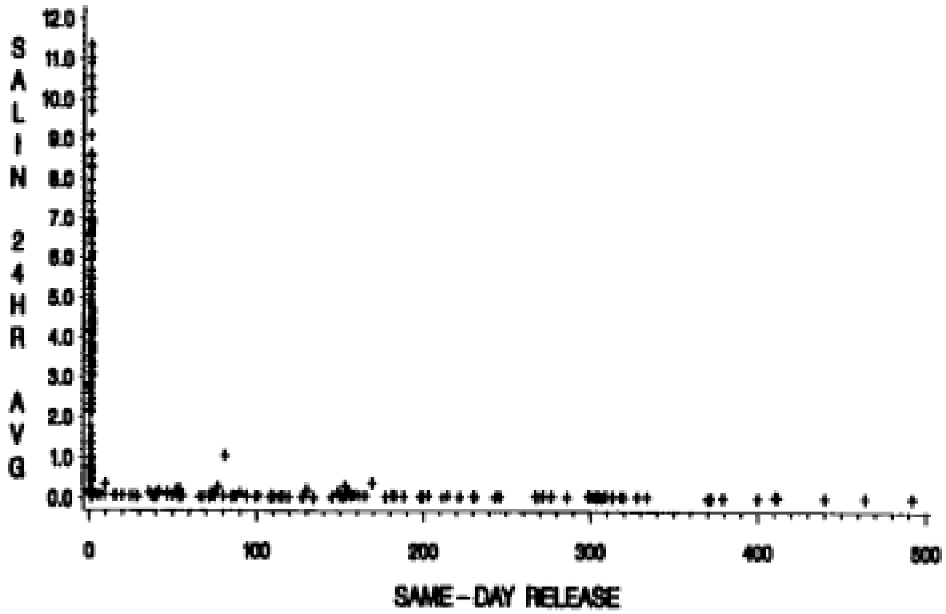


APPENDIX E

Plots of daily average and daily maximum salinity at the USGS recorders vs. discharge from the Hillsborough River Reservoir. (Recorders are mid-depth. Units are parts per thousand for salinity and cfs for discharge).

AGENCY=USGS LOCATE=Hills R at Rowlett Park



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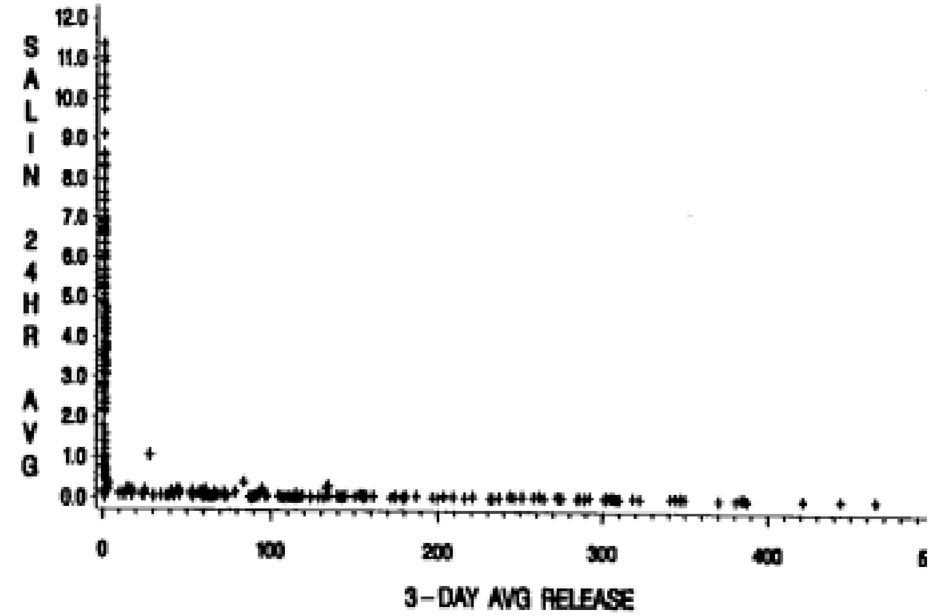

13

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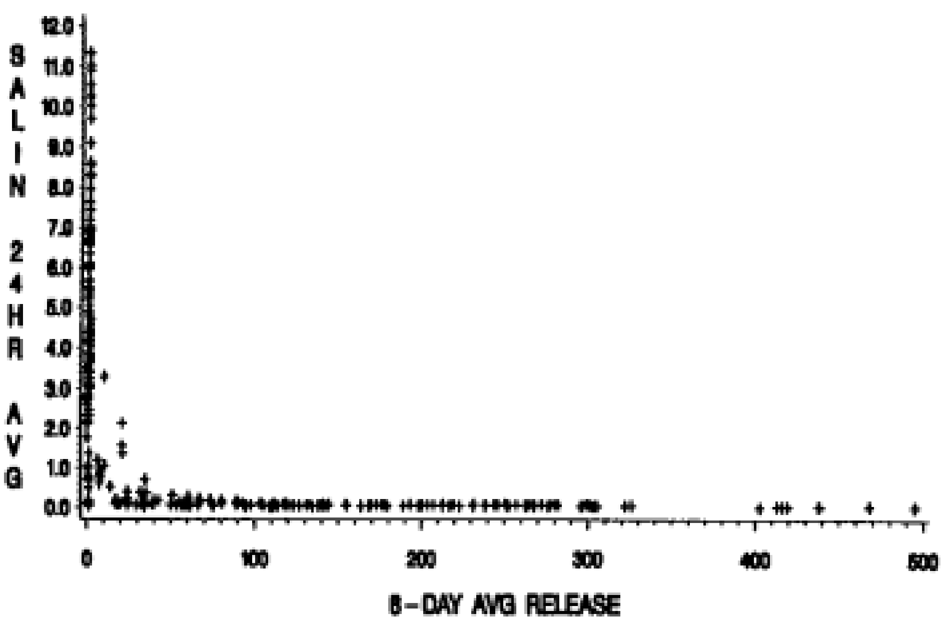

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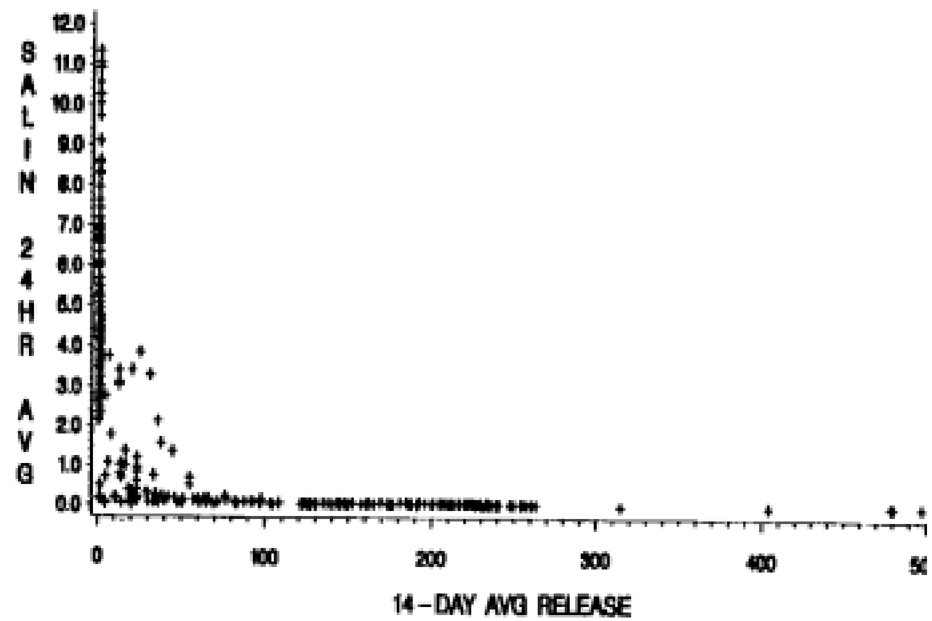

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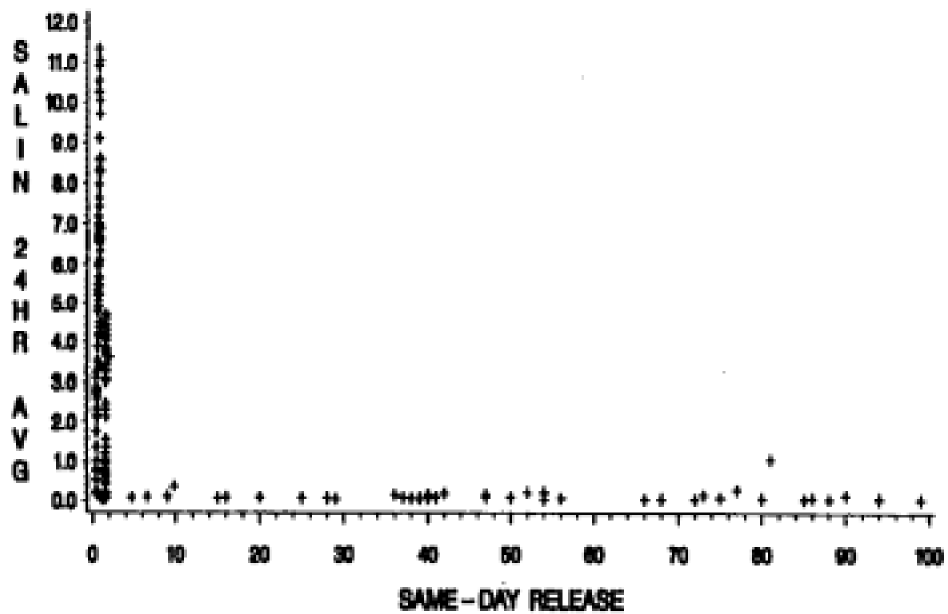

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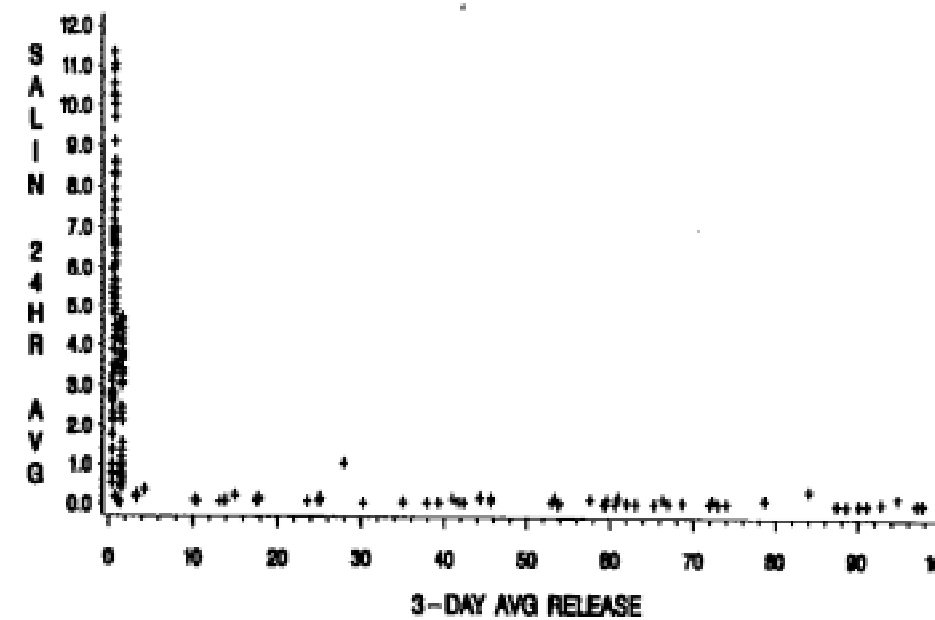

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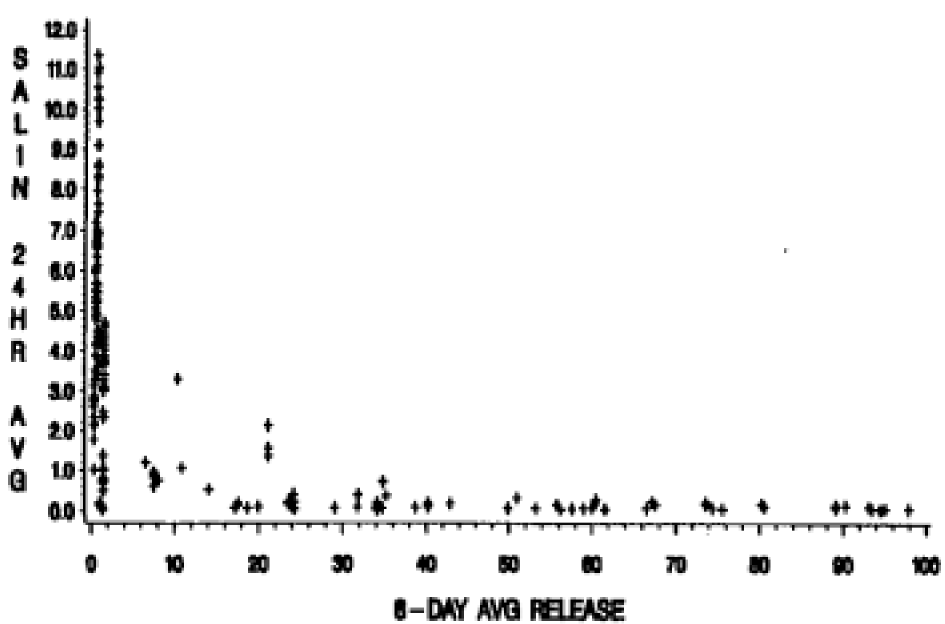

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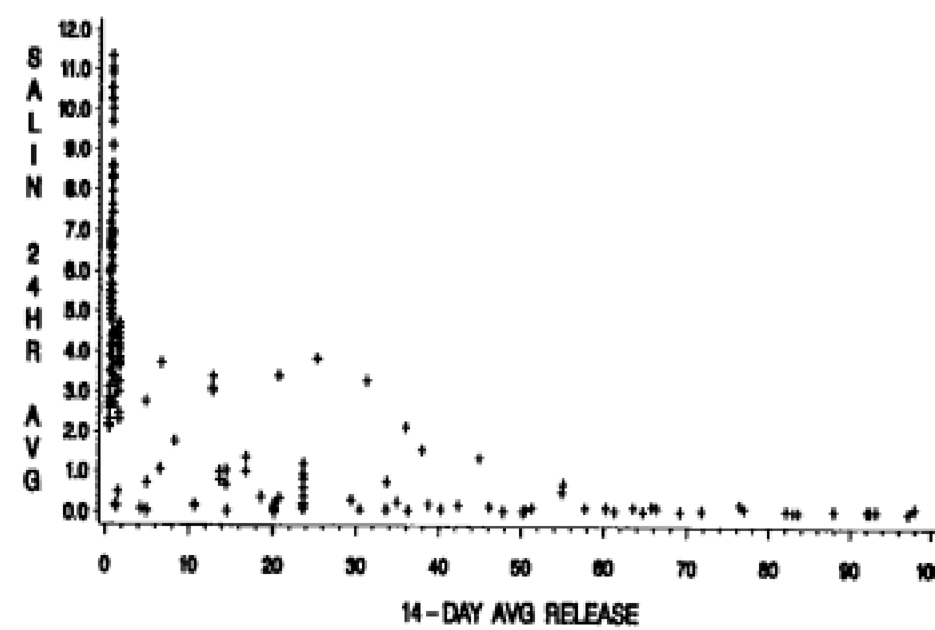

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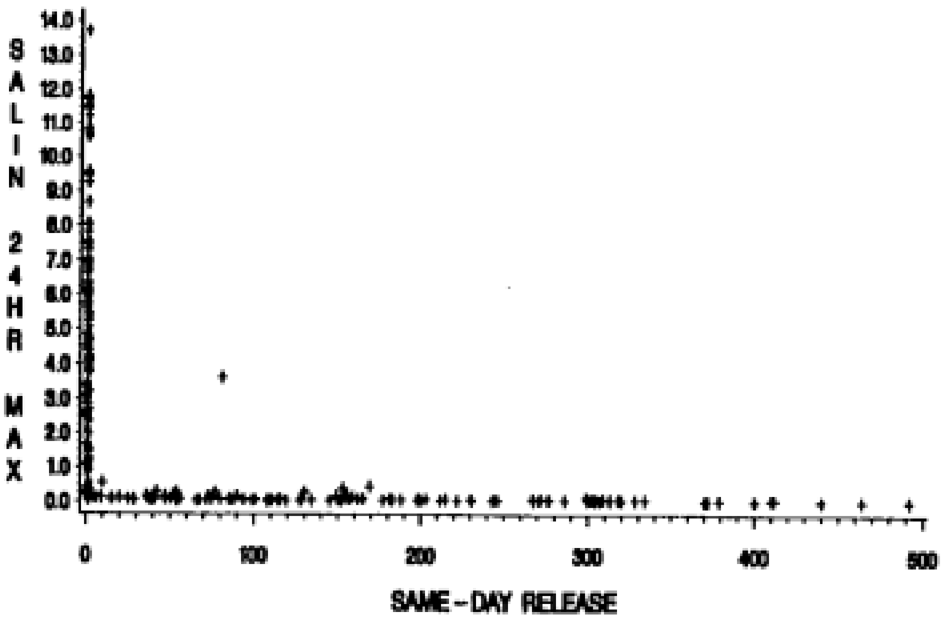

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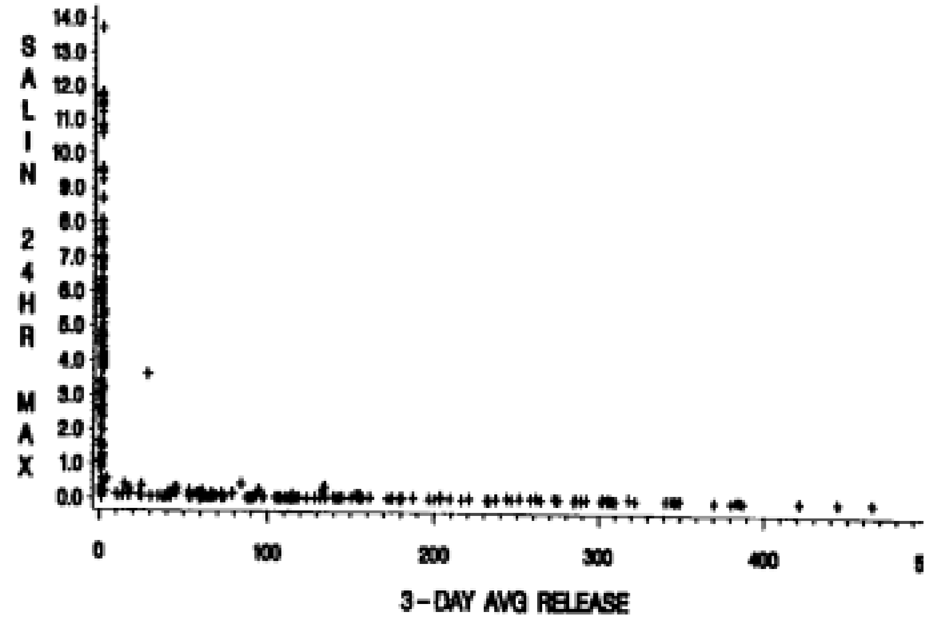

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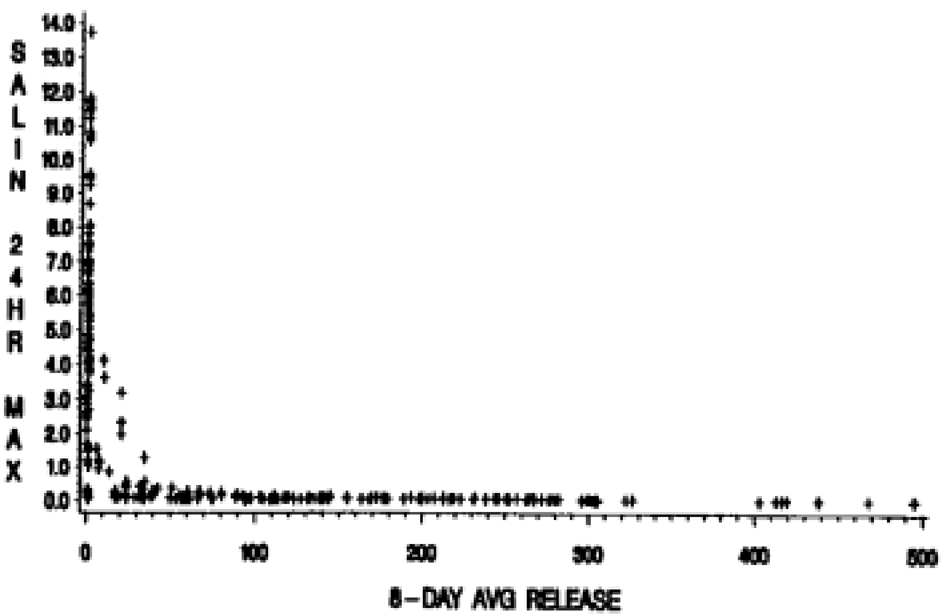

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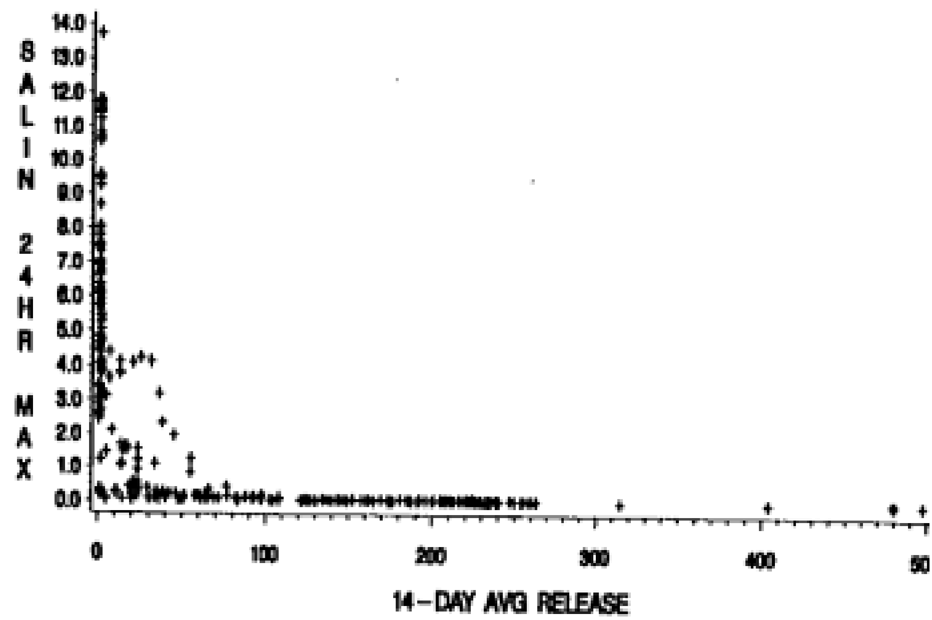

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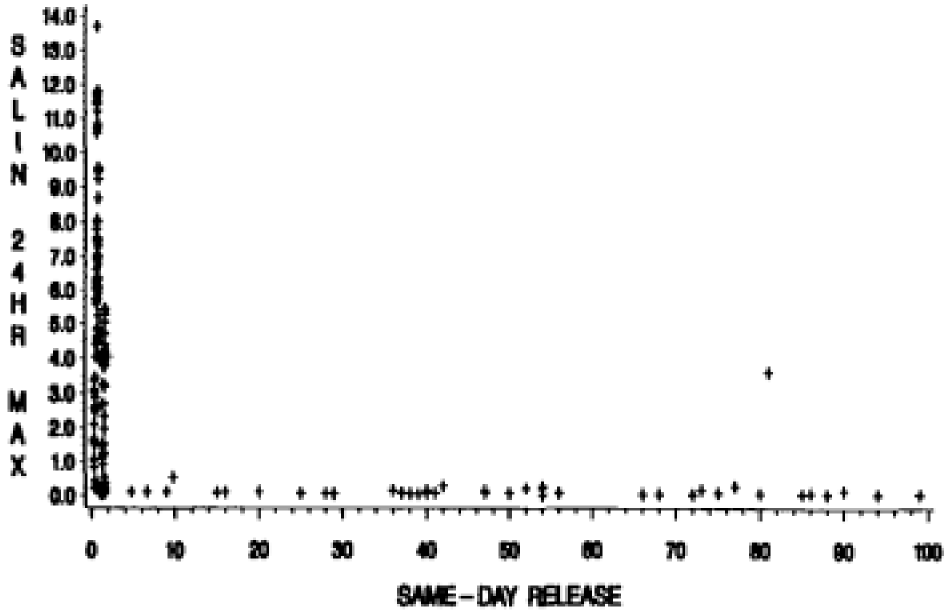

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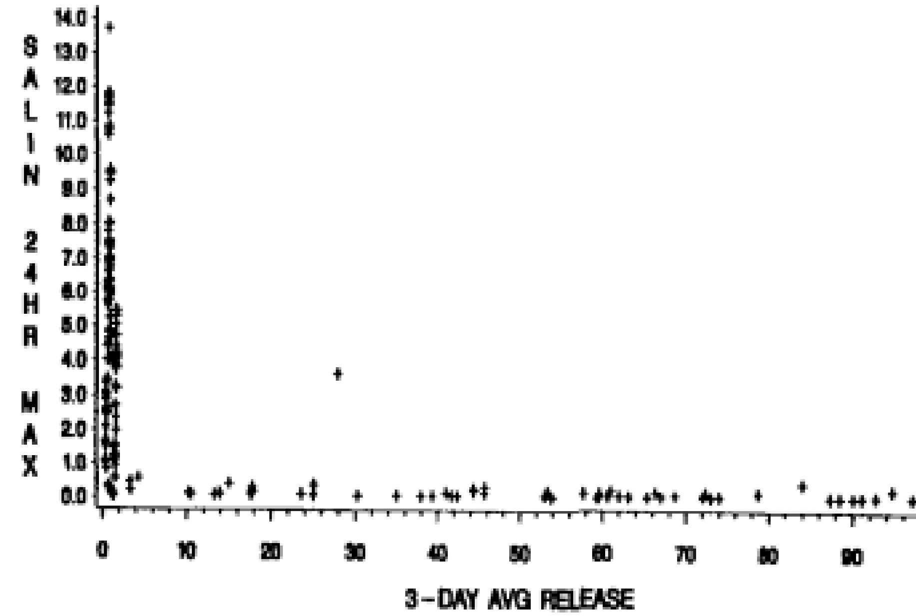

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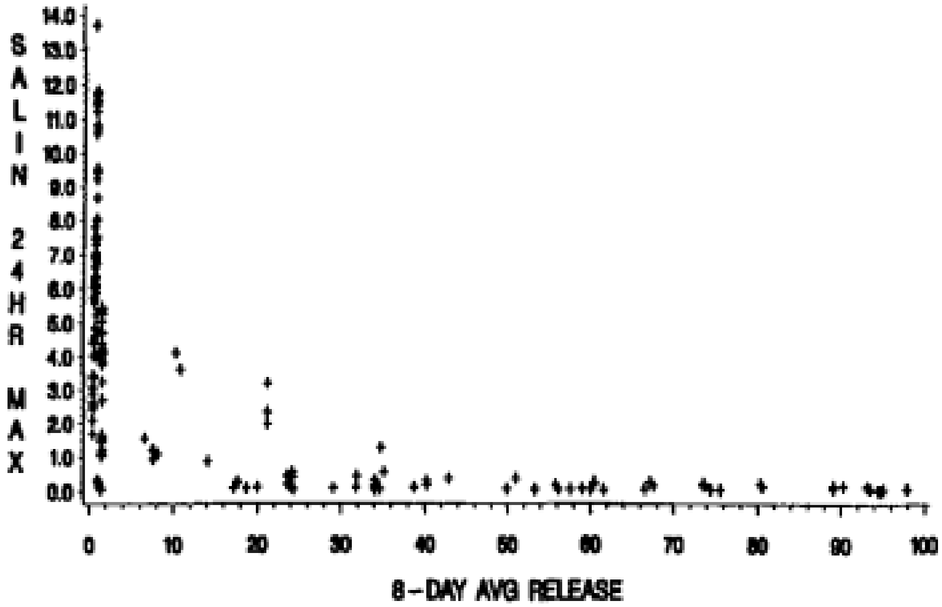

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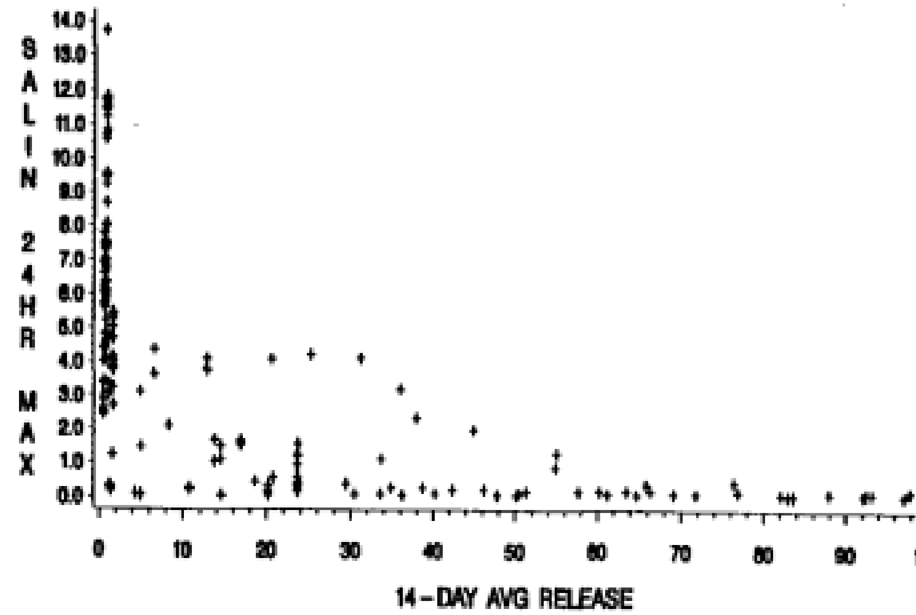

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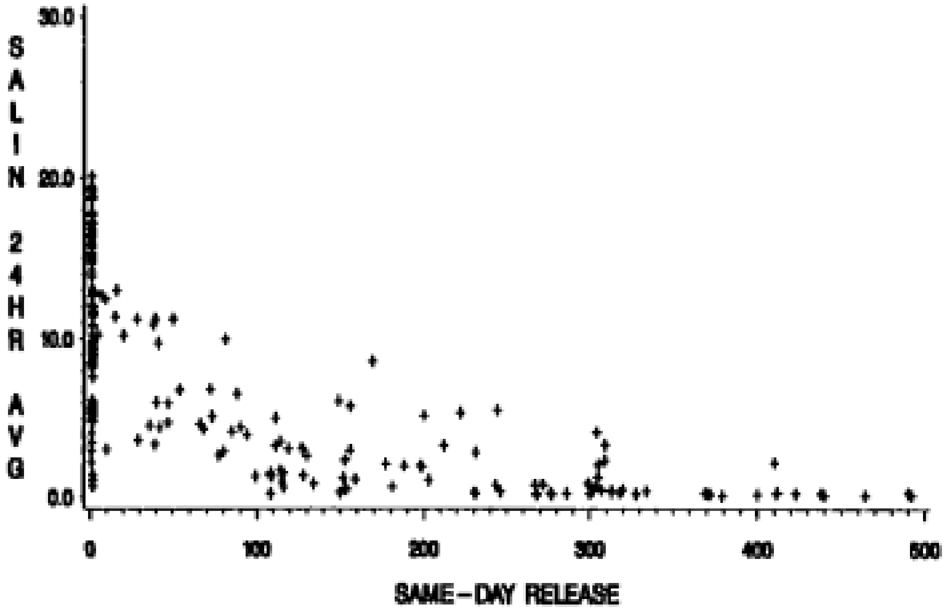

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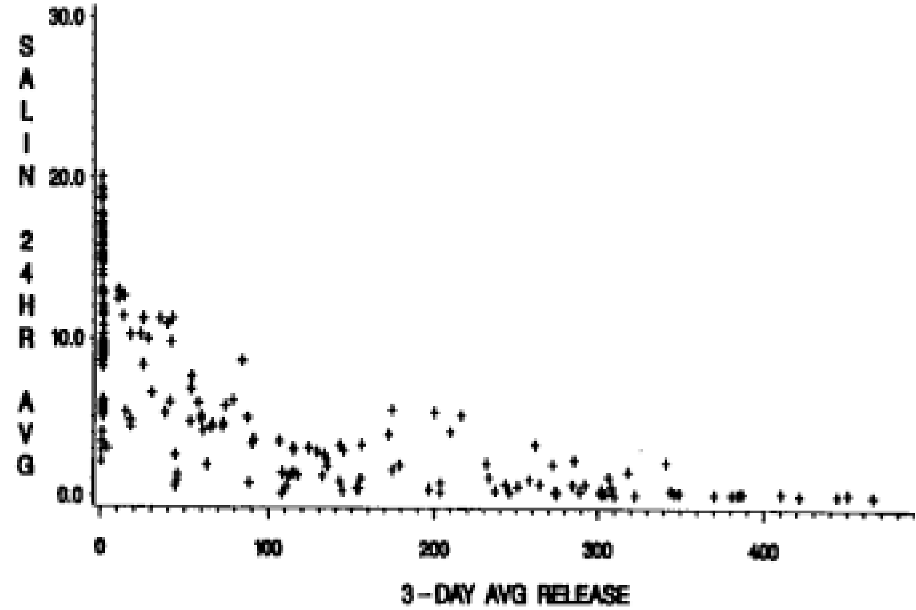

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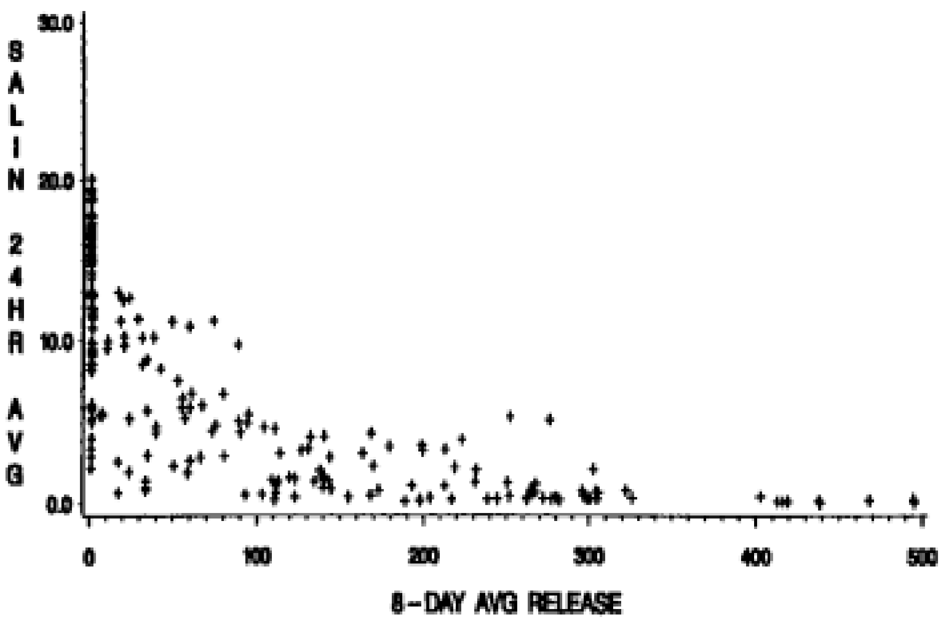

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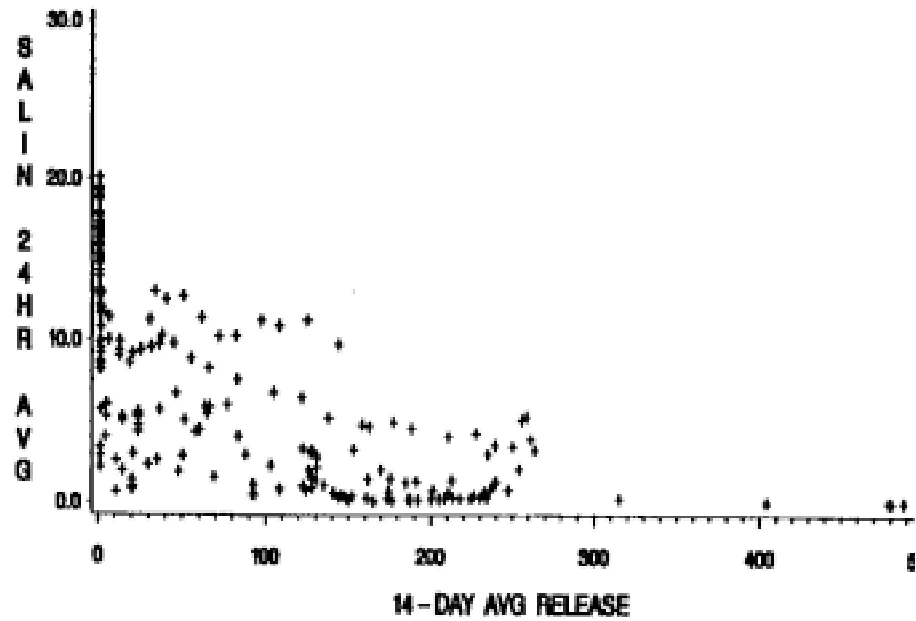

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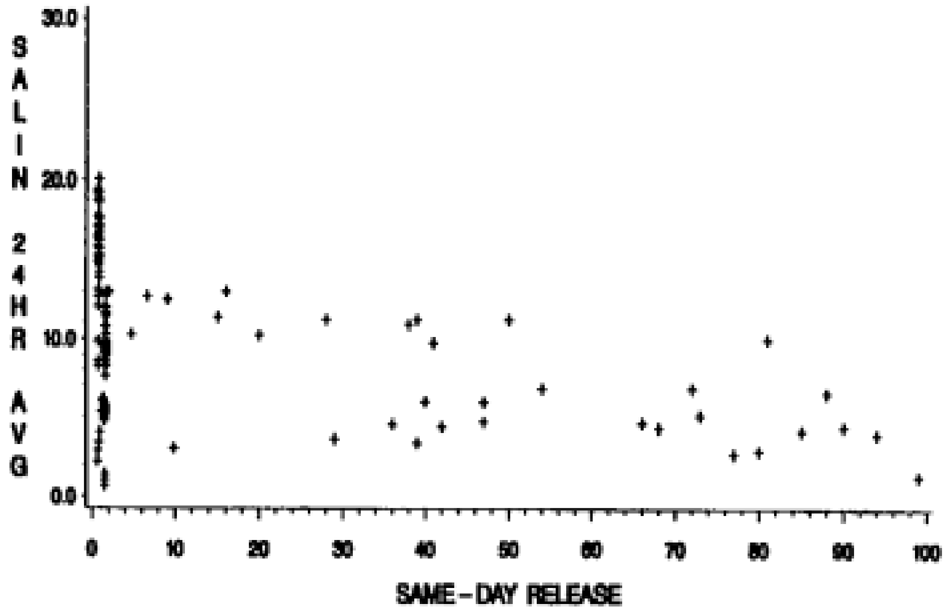

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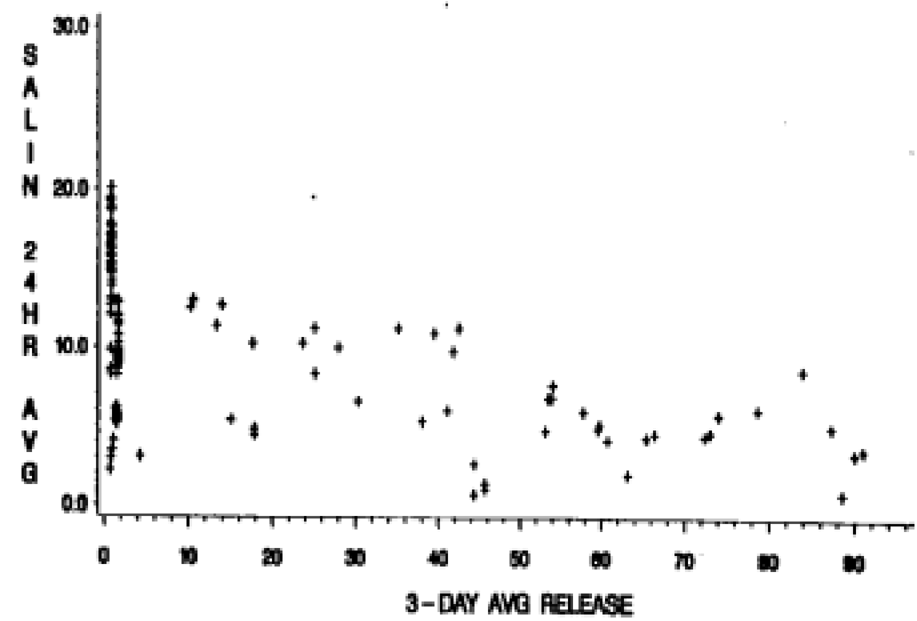

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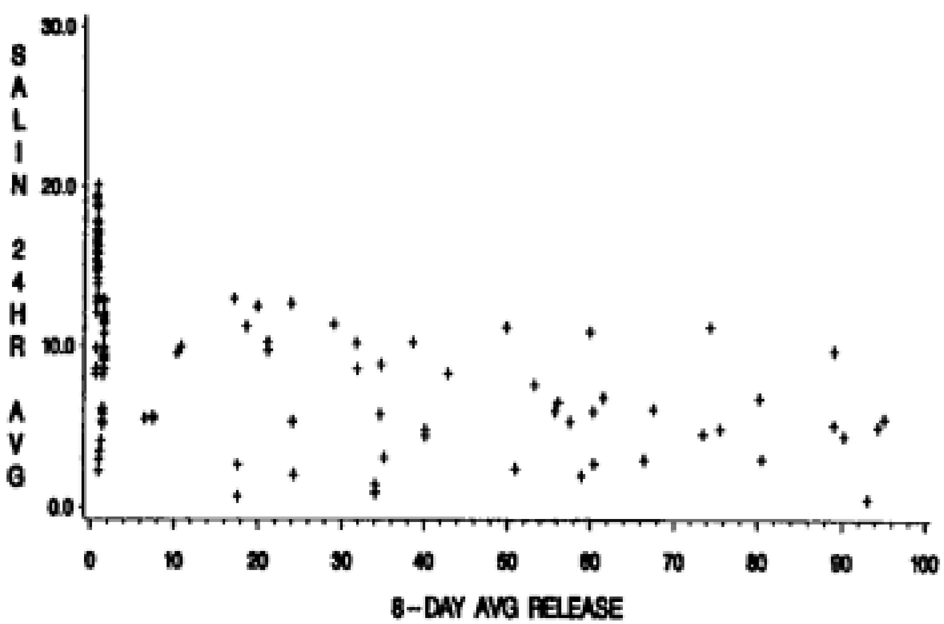

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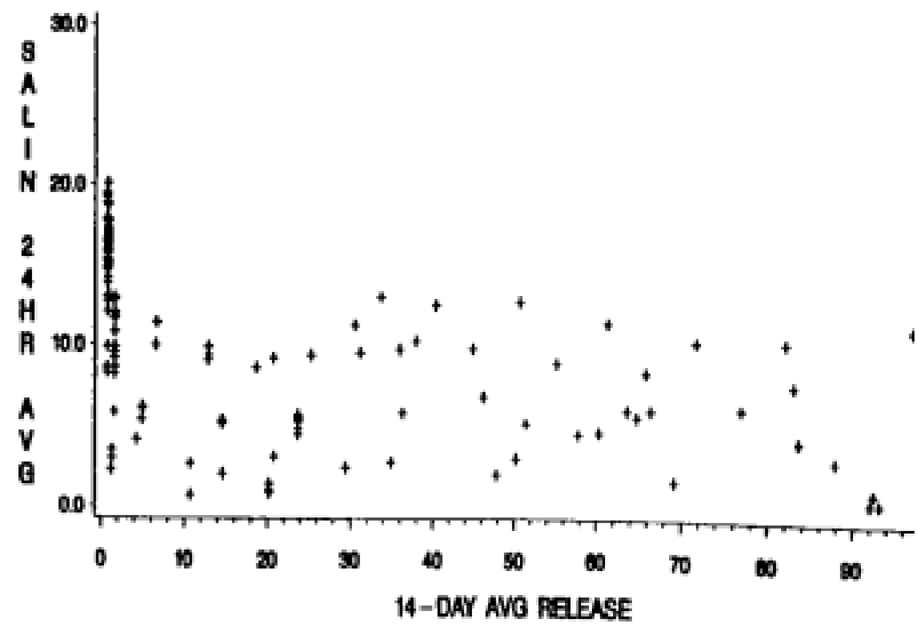

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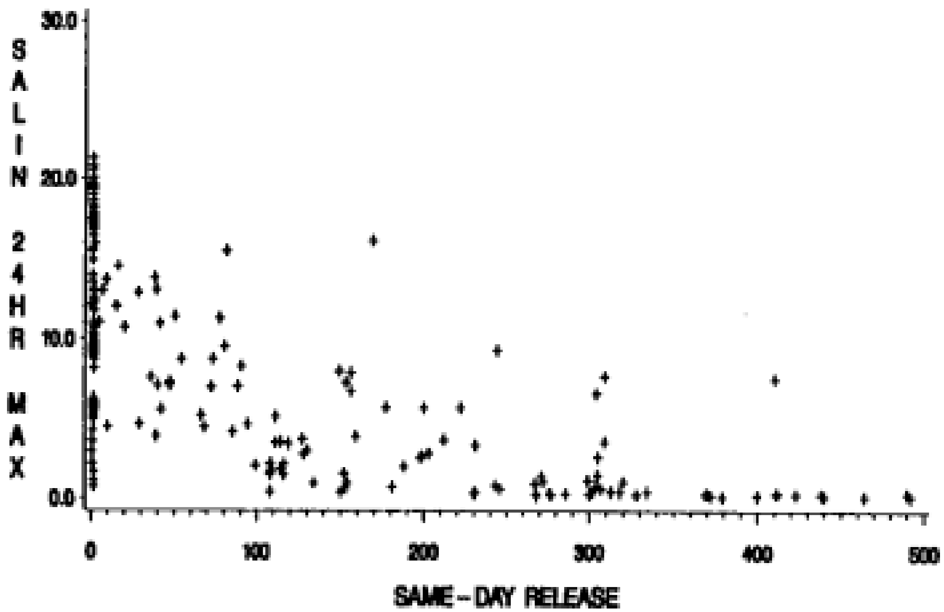

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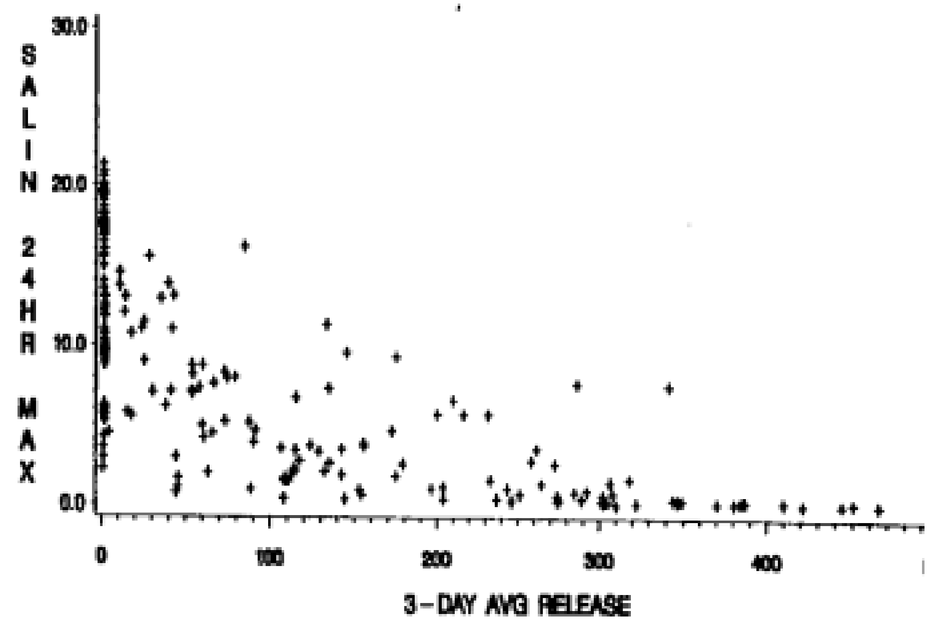

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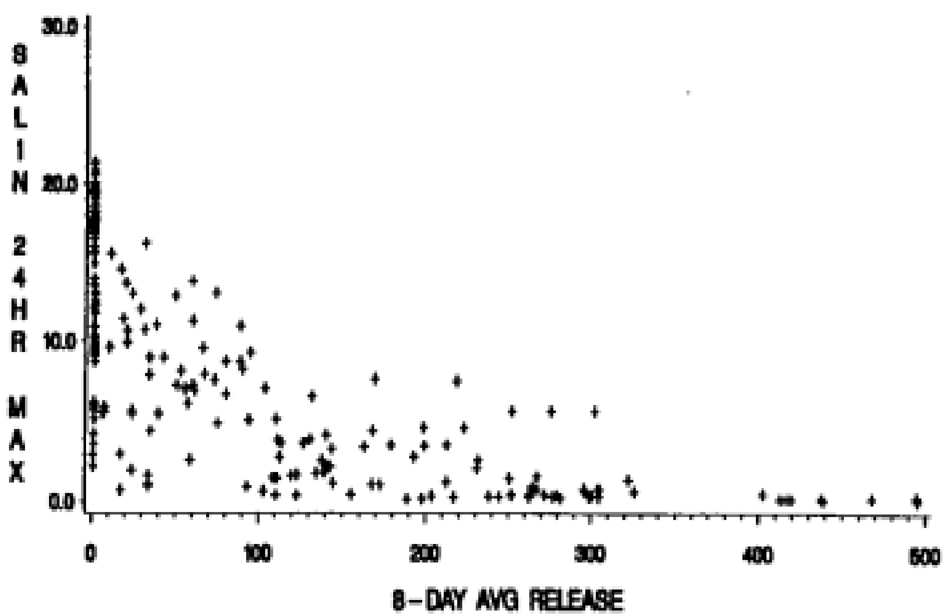

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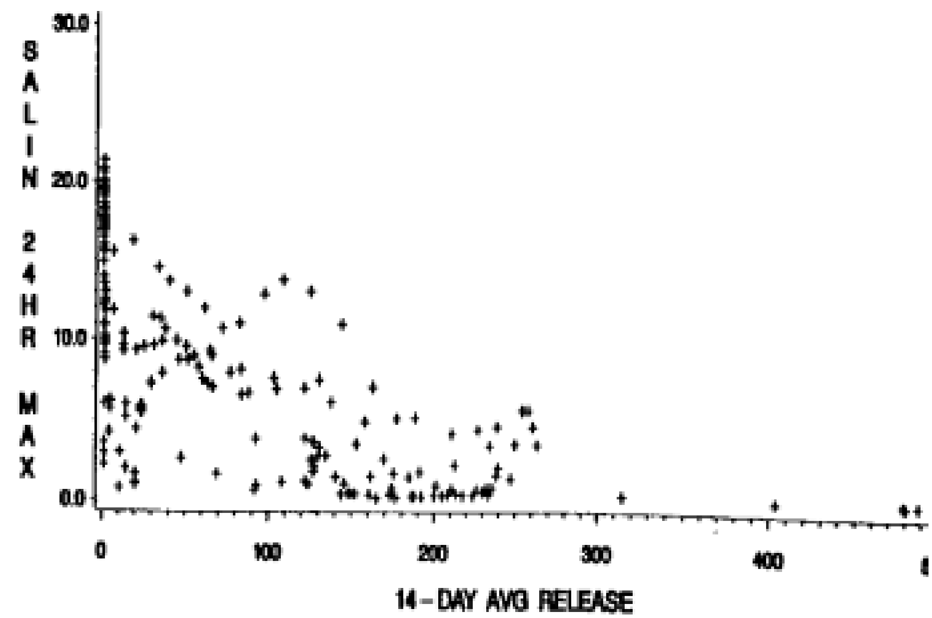

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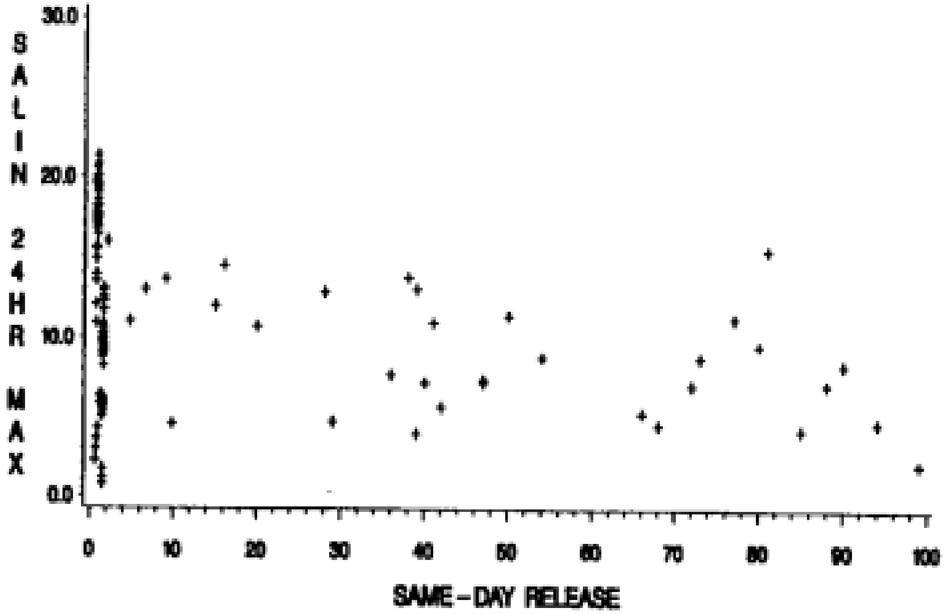

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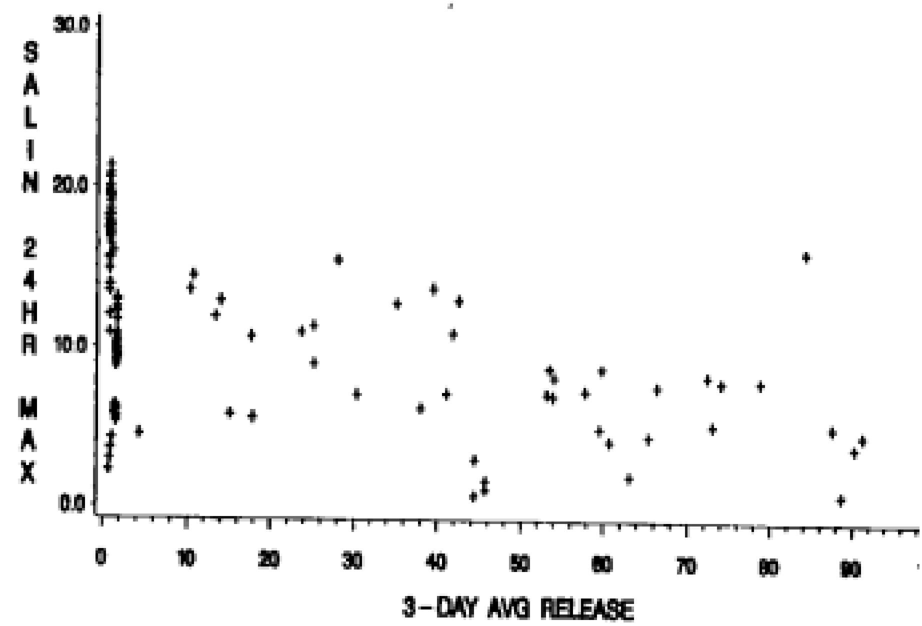

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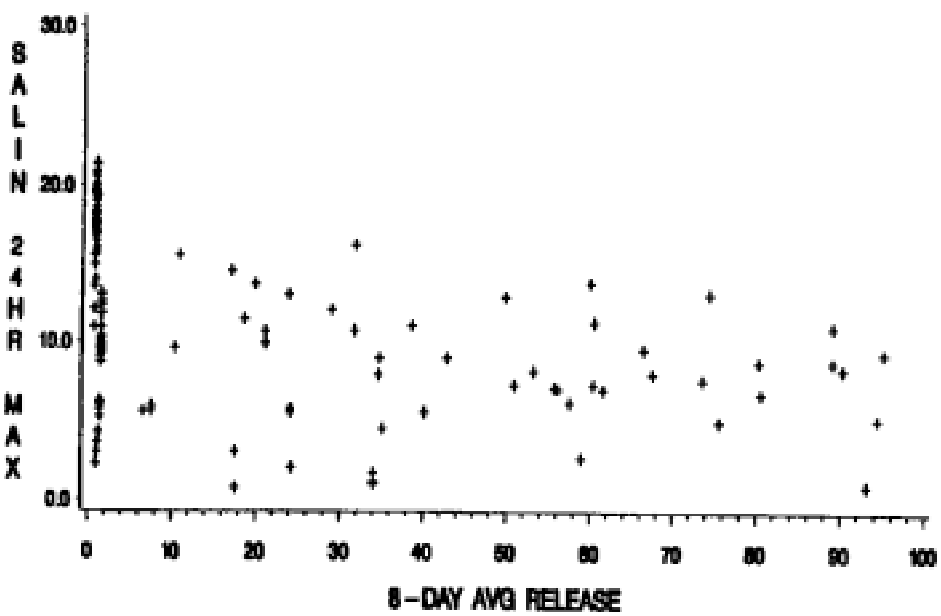

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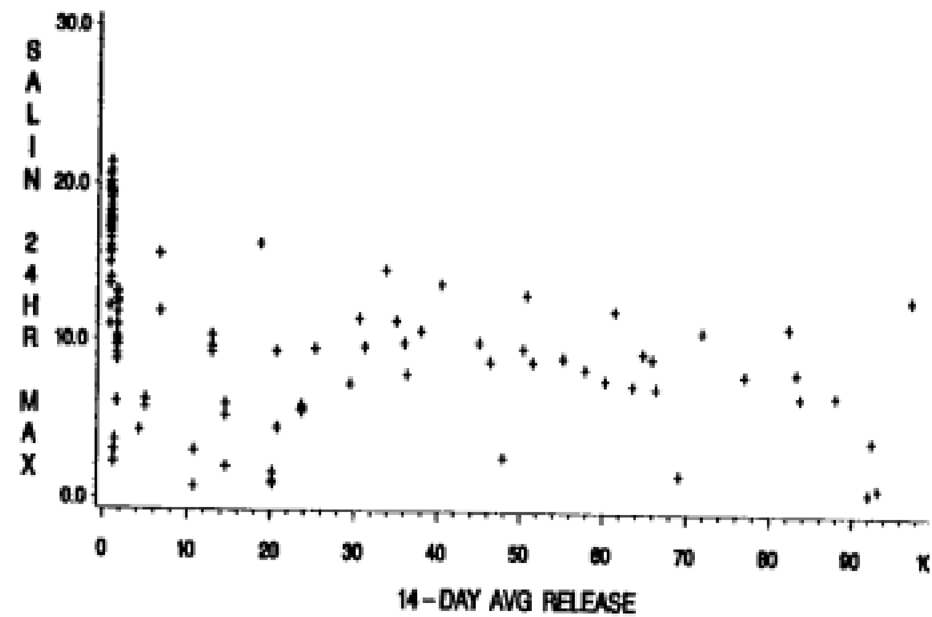

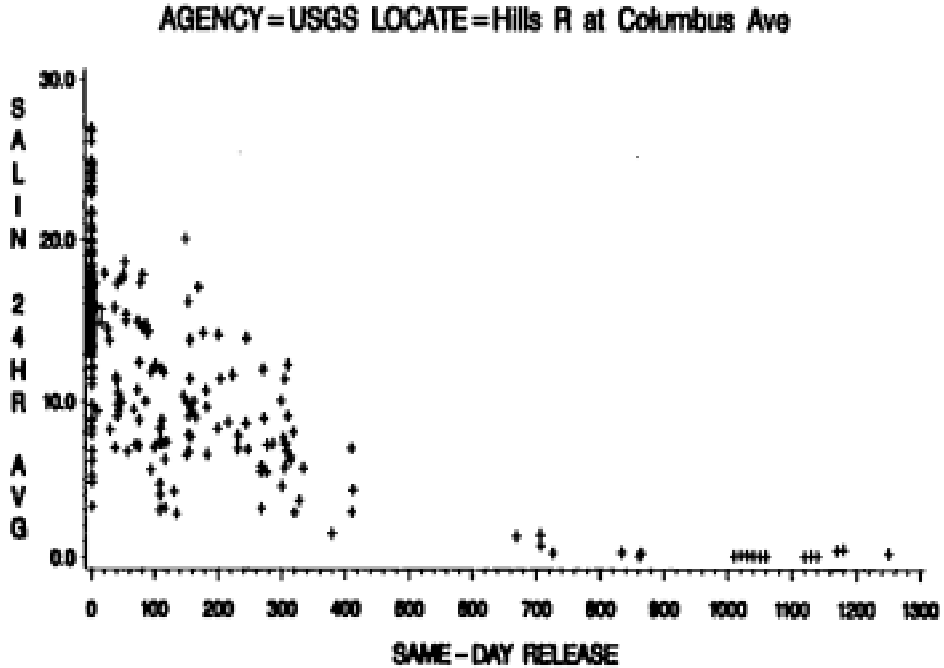
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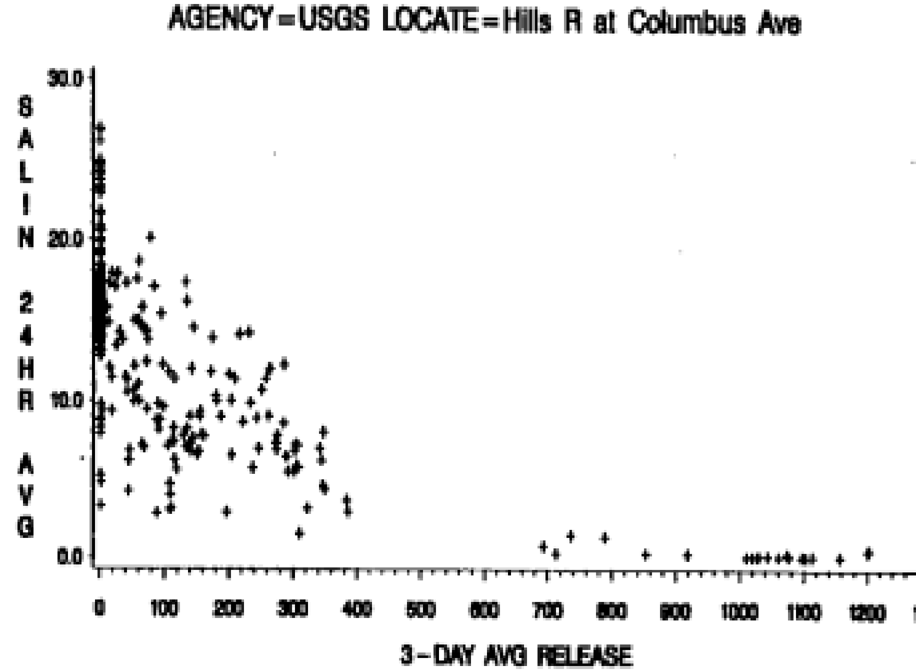
SAME-DAY RELEASE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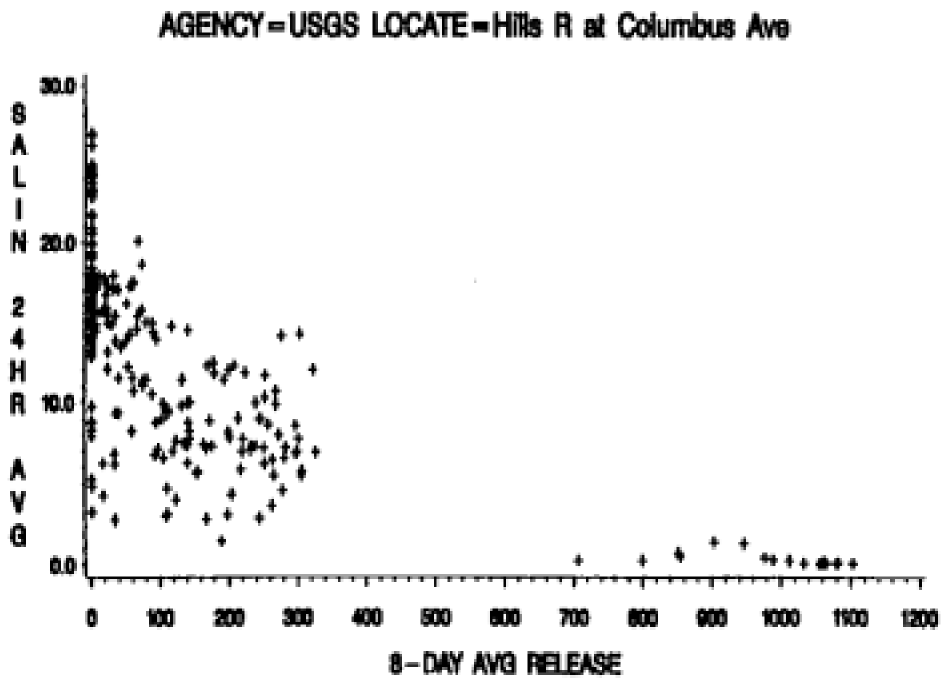
3-DAY AVG RELEASE

E9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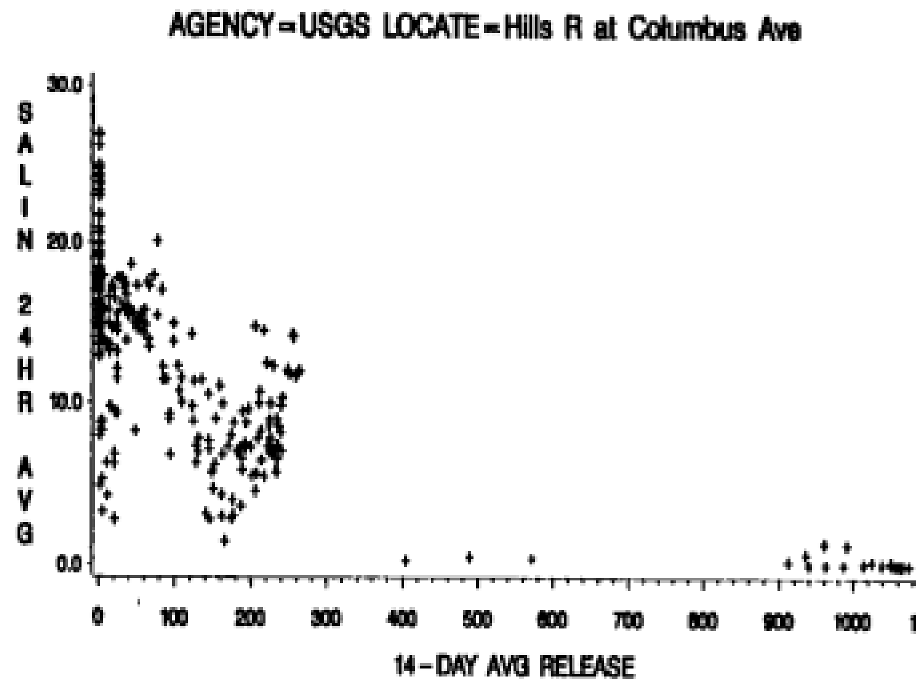
SALIN 24HR AVG
8-DAY AVG RELEASE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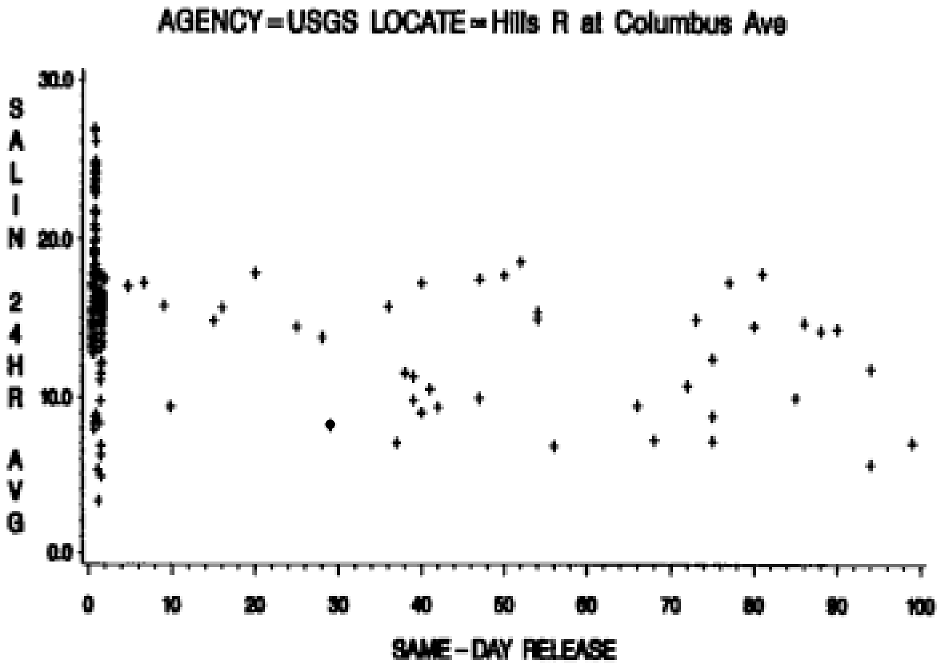
14-DAY AVG RELEASE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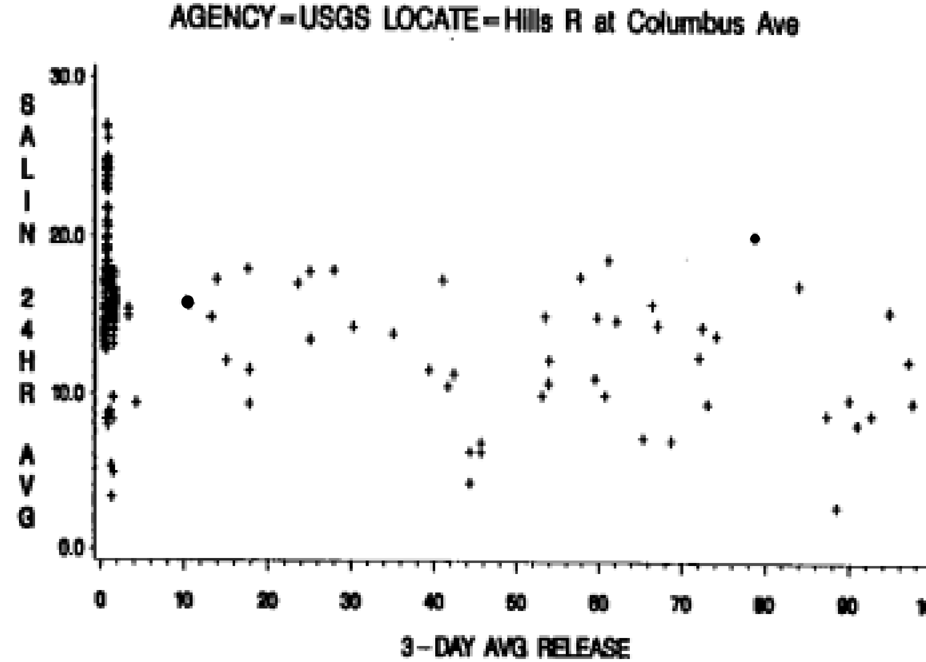
20.0
10.0
0.0
0 10 20 30 40 50 60 70 80 90 100
SAME-DAY RELEASE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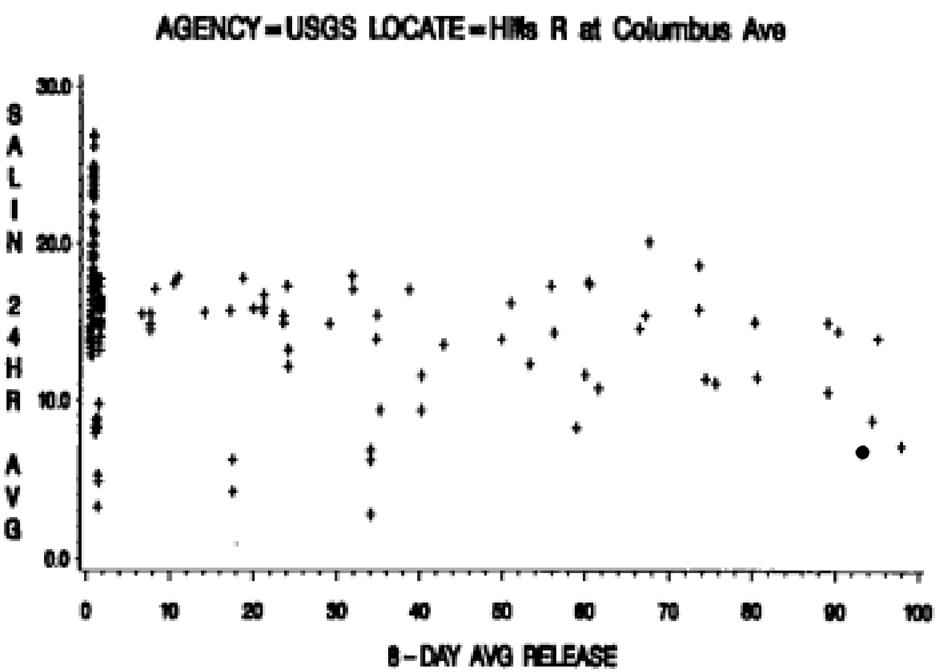
0.0
0 10 20 30 40 50 60 70 80 90
3-DAY AVG RELEASE

E10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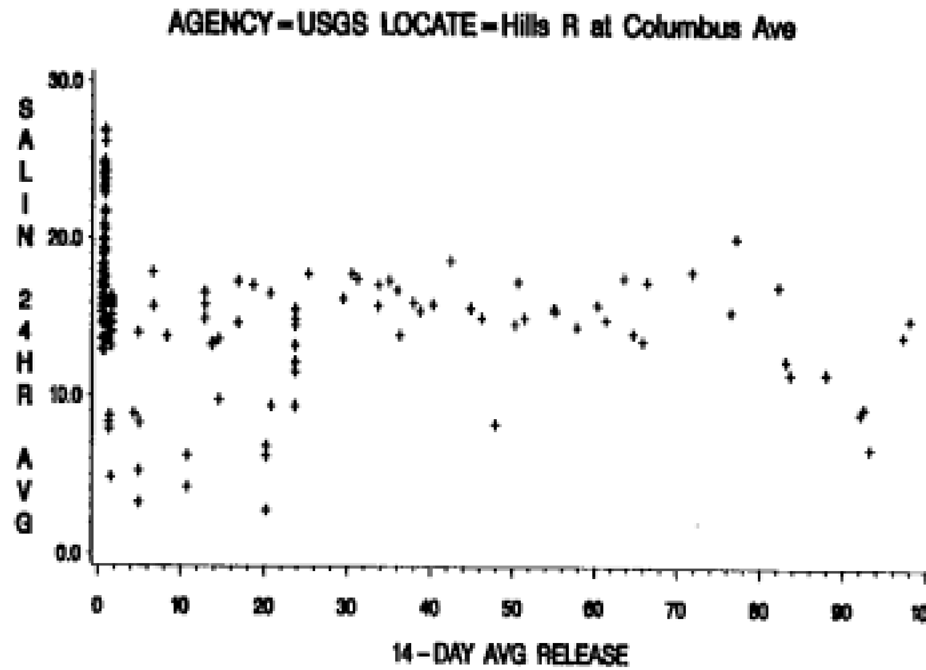
20.0
10.0
0.0
0 10 20 30 40 50 60 70 80 90 100
8-DAY AVG RELEASE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SALIN 24HR AVG
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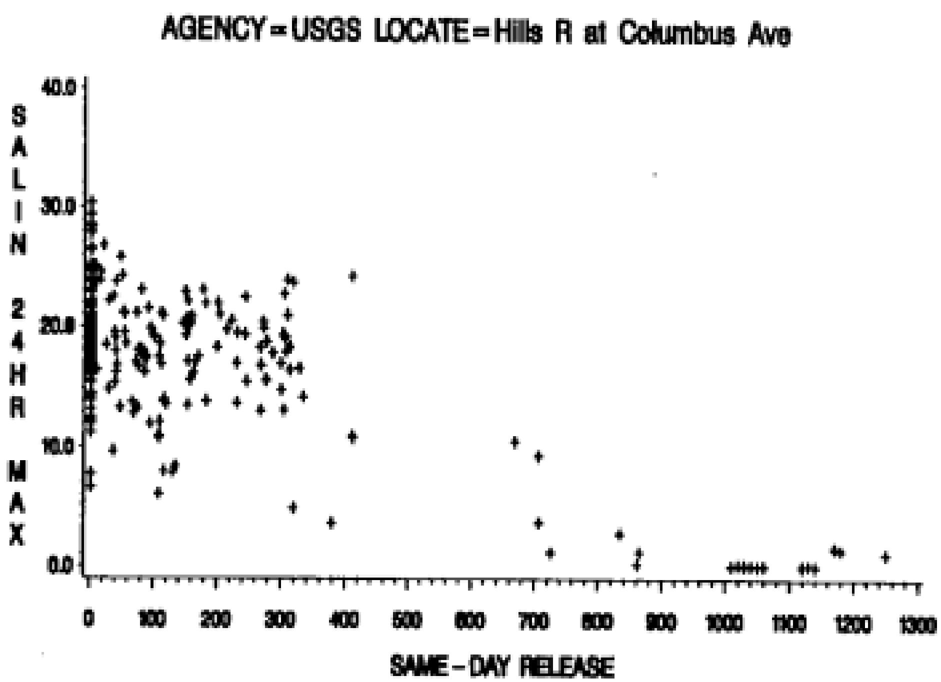
20.0
10.0
0.0
0 10 20 30 40 50 60 70 80 90
14-DAY AVG RELEASE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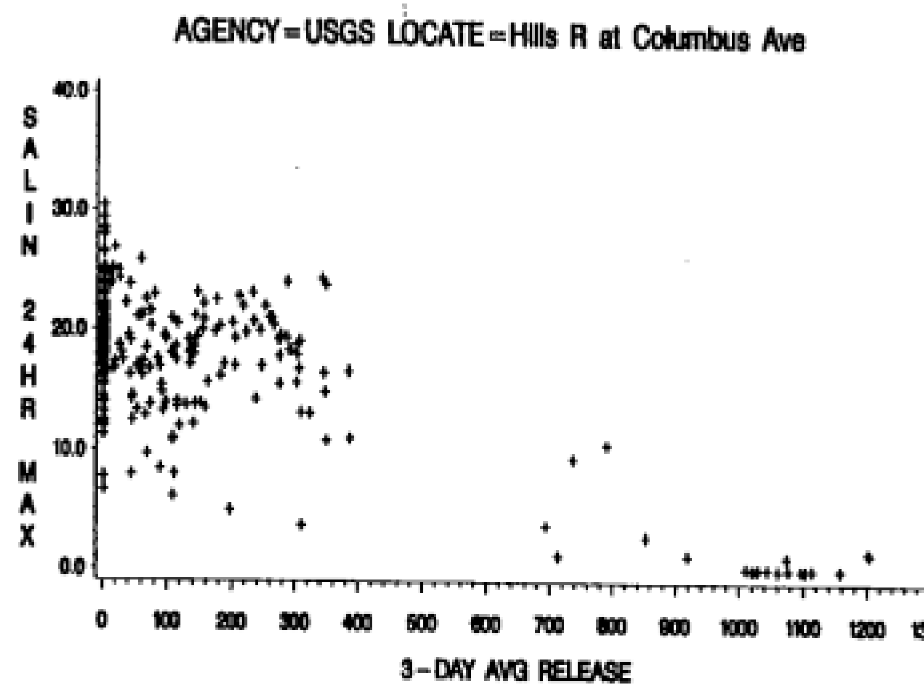
SALIN 24HR MAX
SAME-DAY RELEASE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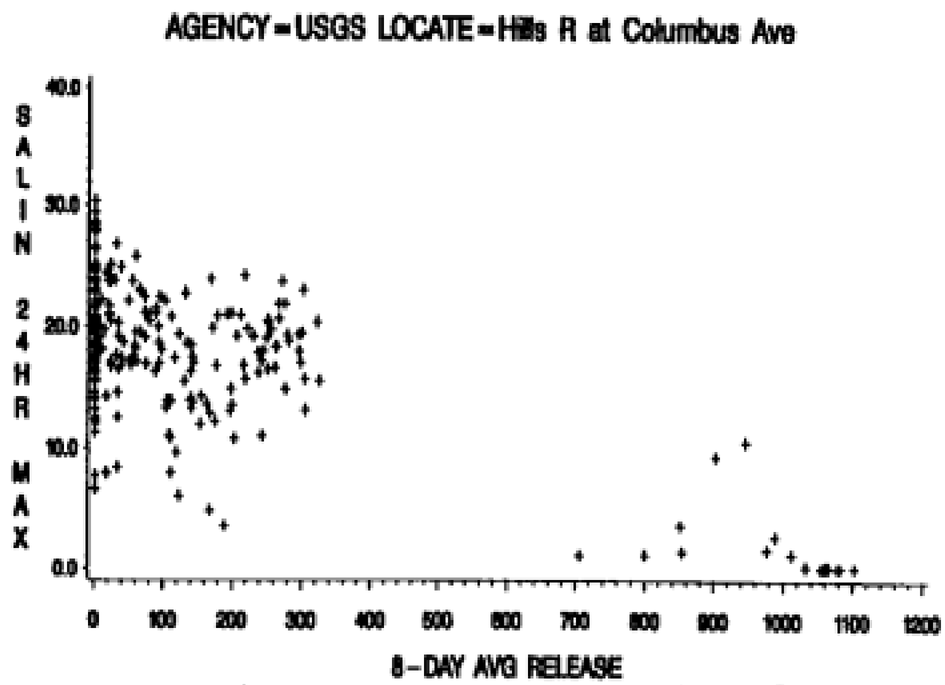
SALIN 24HR MAX
3-DAY AVG RELEASE

E11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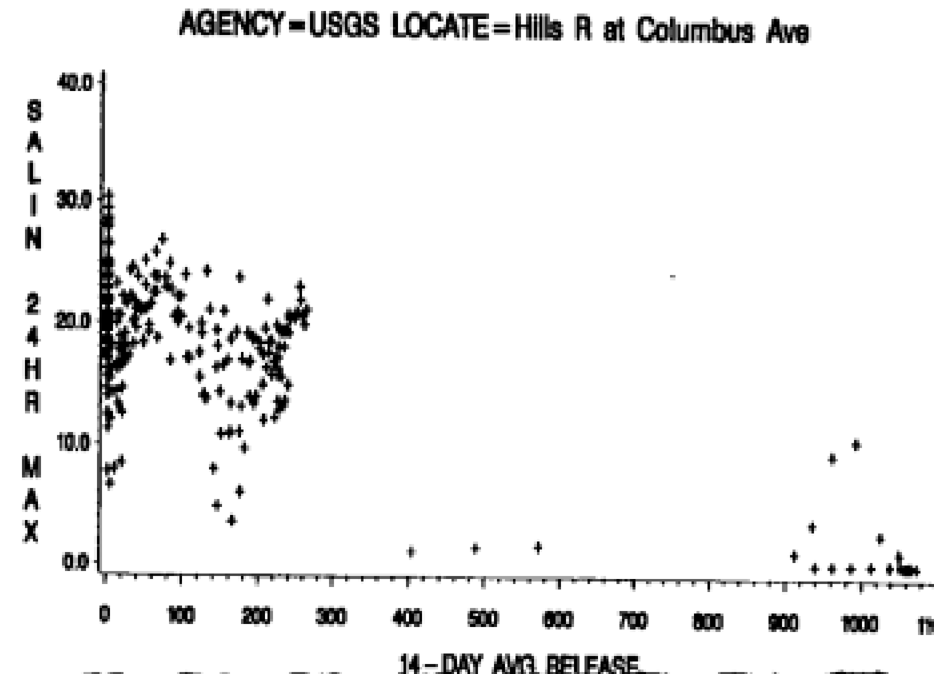
SALIN 24HR MAX
8-DAY AVG RELEASE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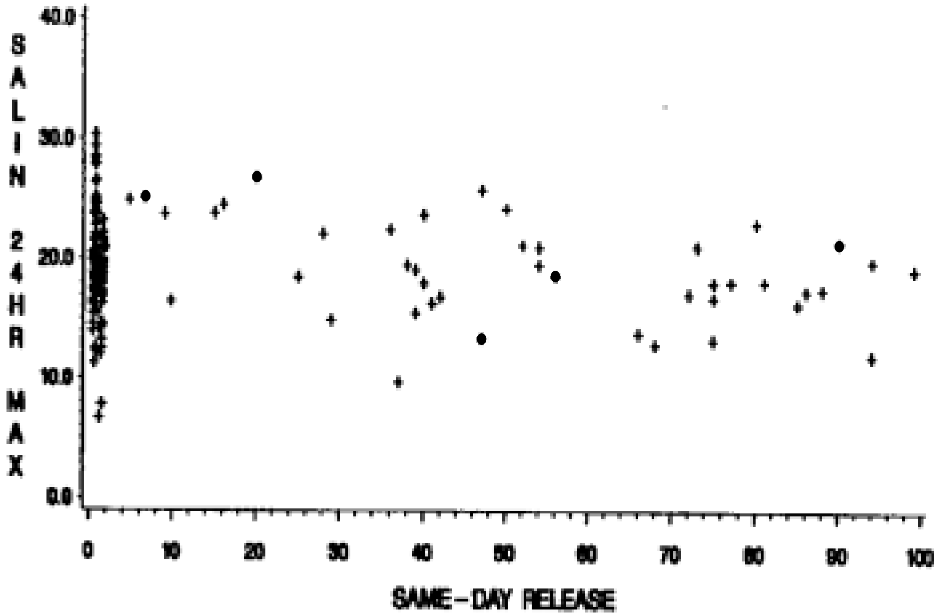
SALIN 24HR MAX
14-DAY AVG RELEASE

AGENCY=USGS LOCATE=Hills R at Columbus Ave



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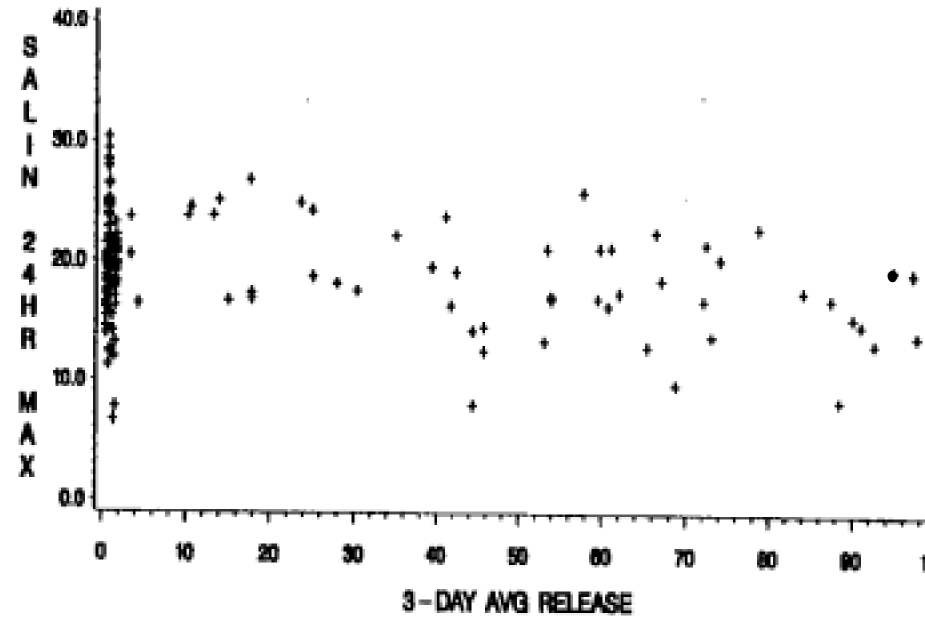

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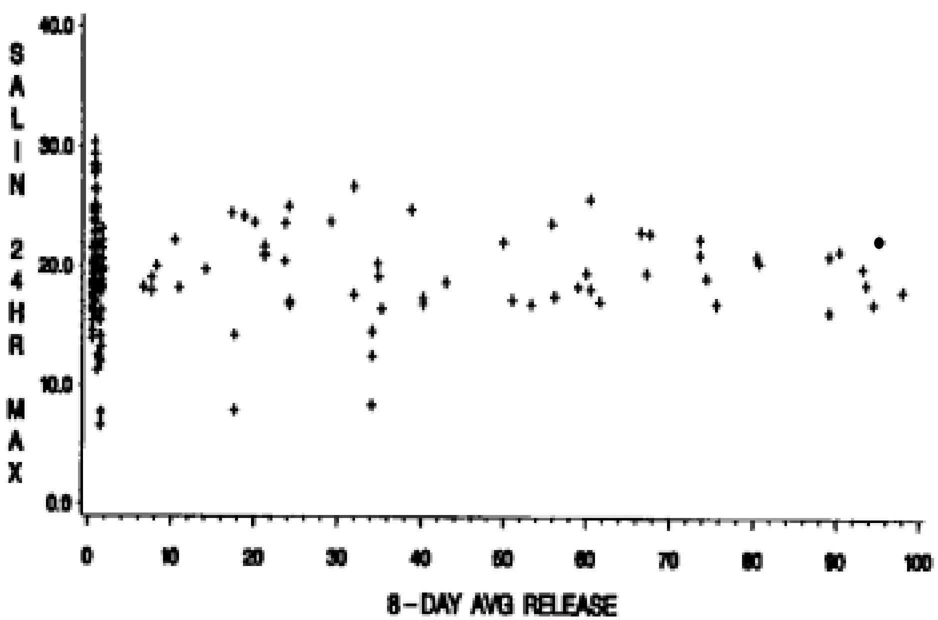

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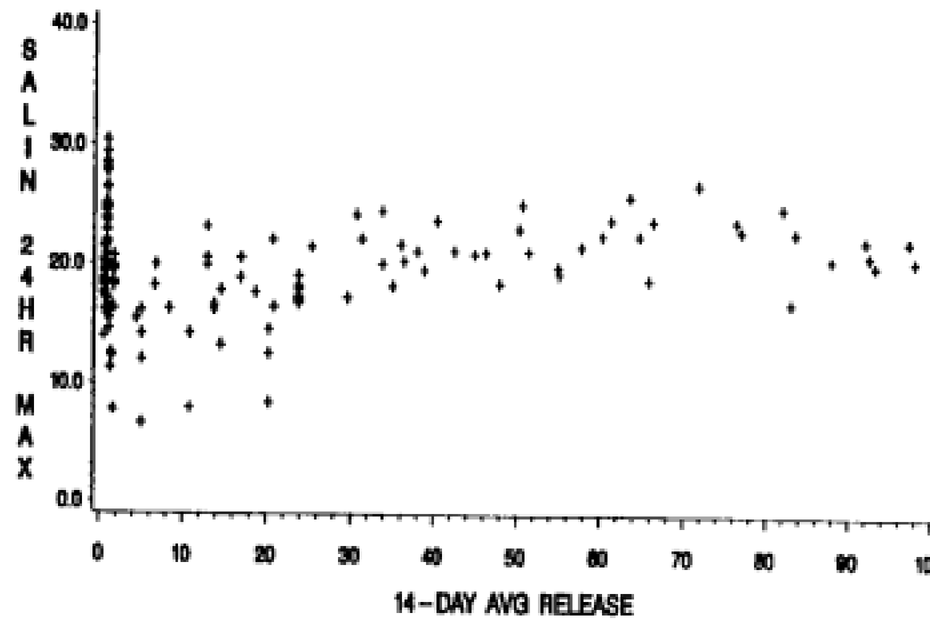

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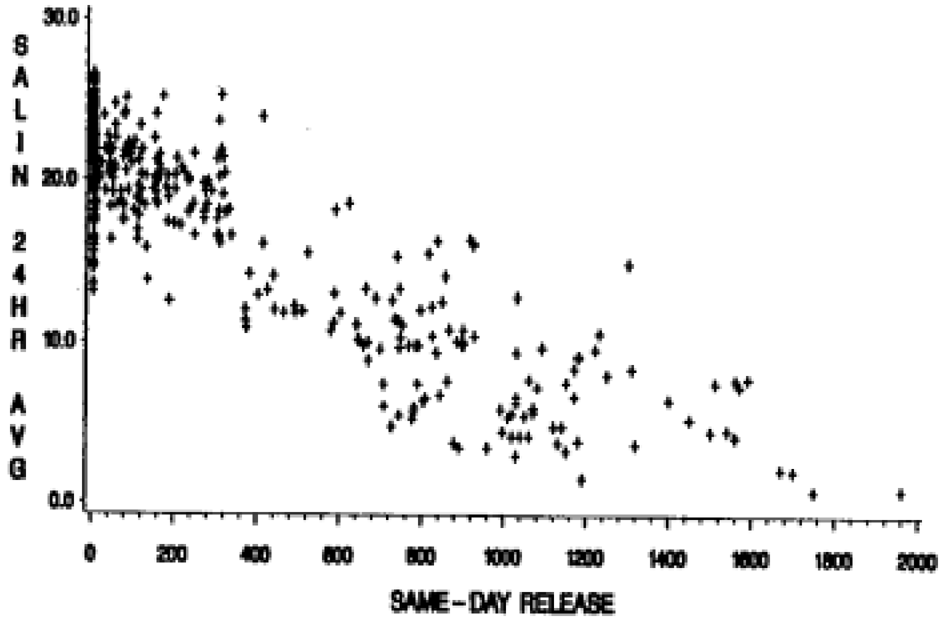

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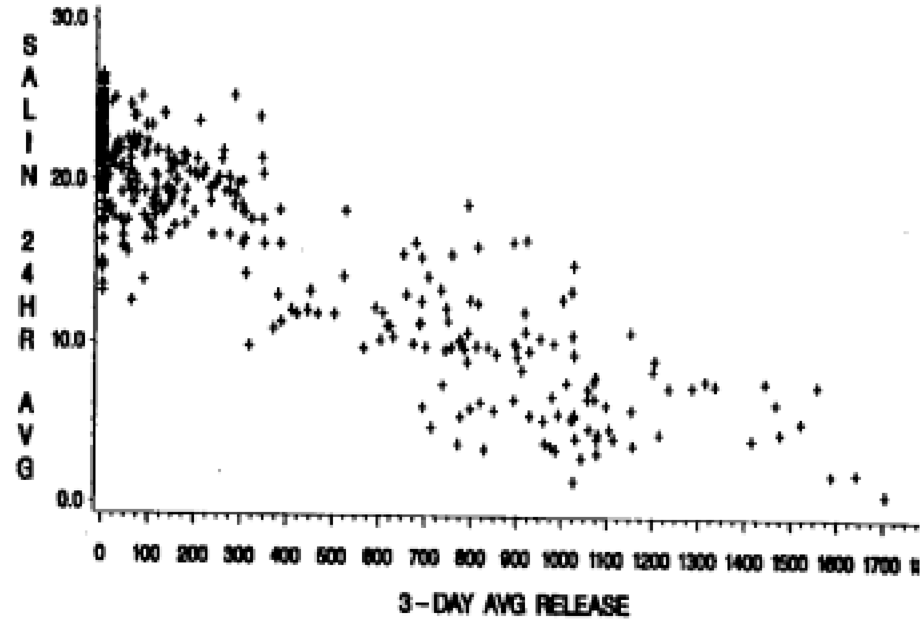

E13

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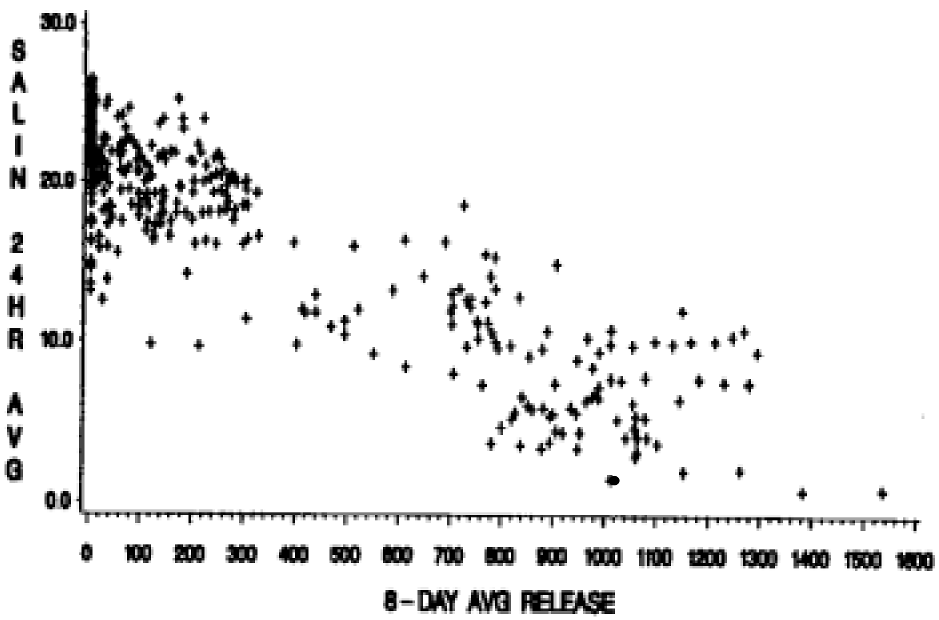
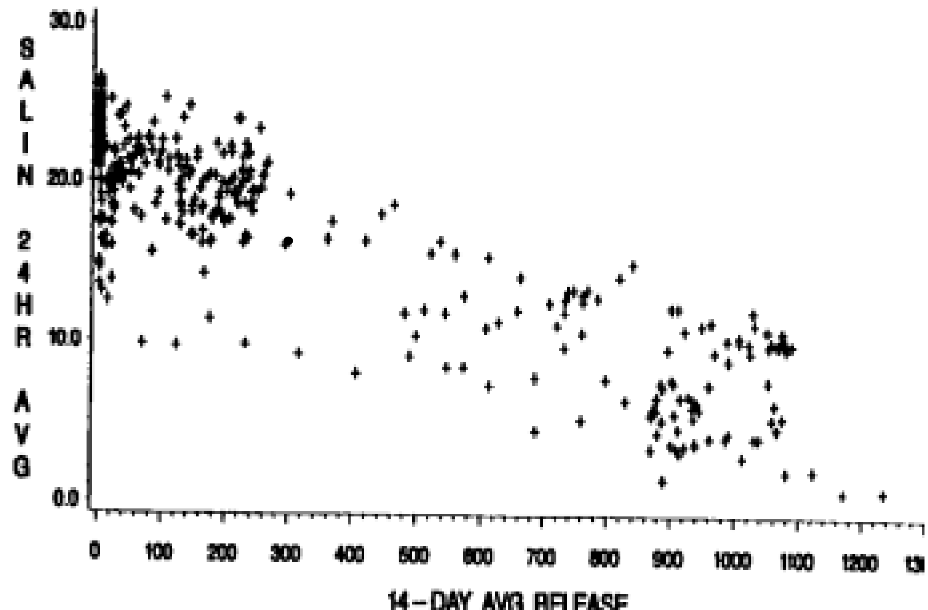


AGENCY=USGS LOCATE=Hills R at Platt St



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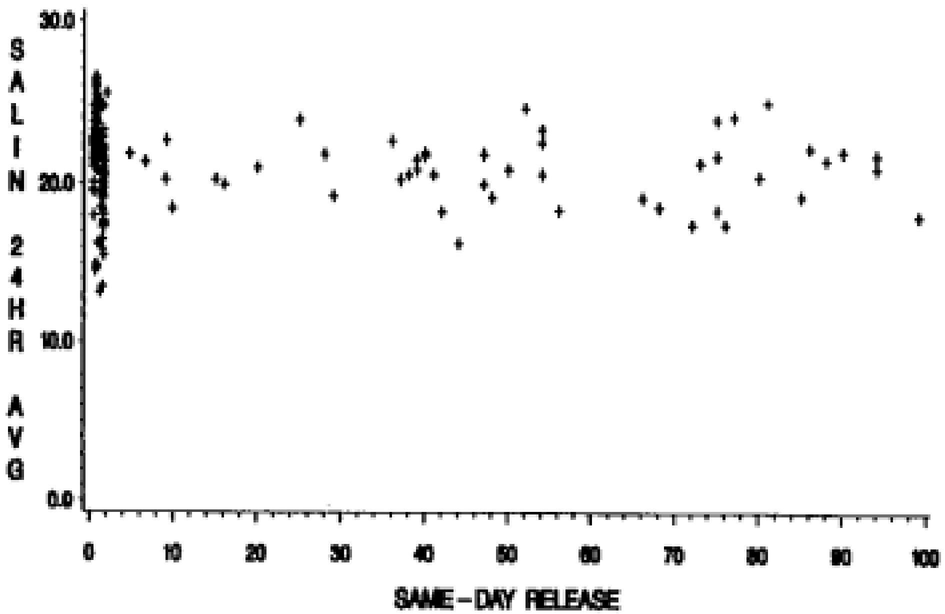

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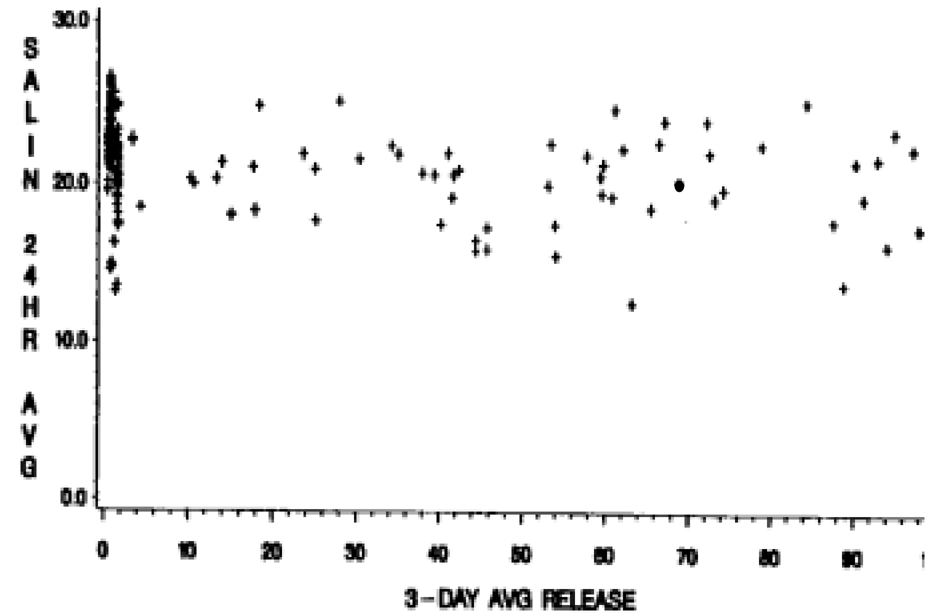

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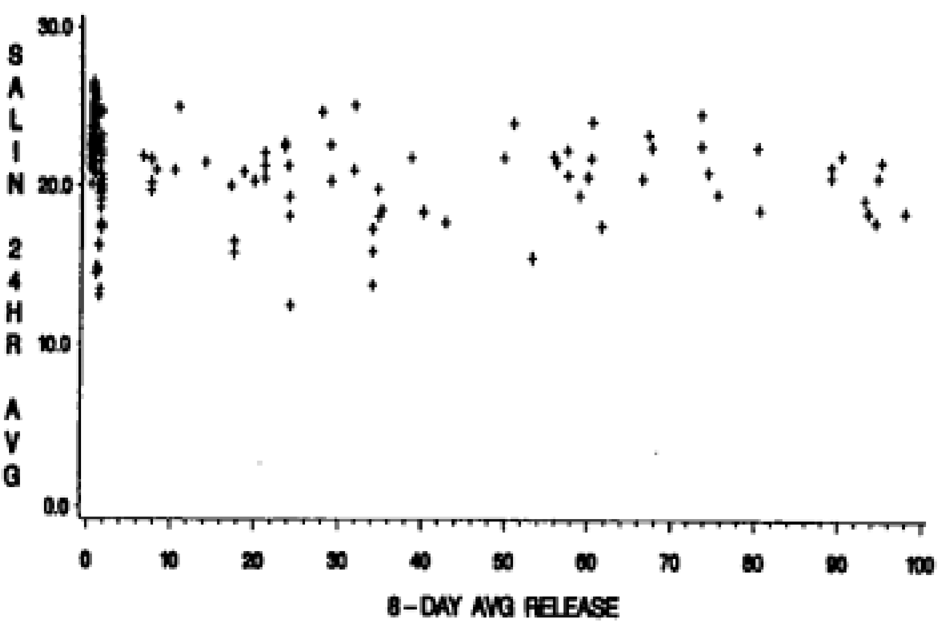
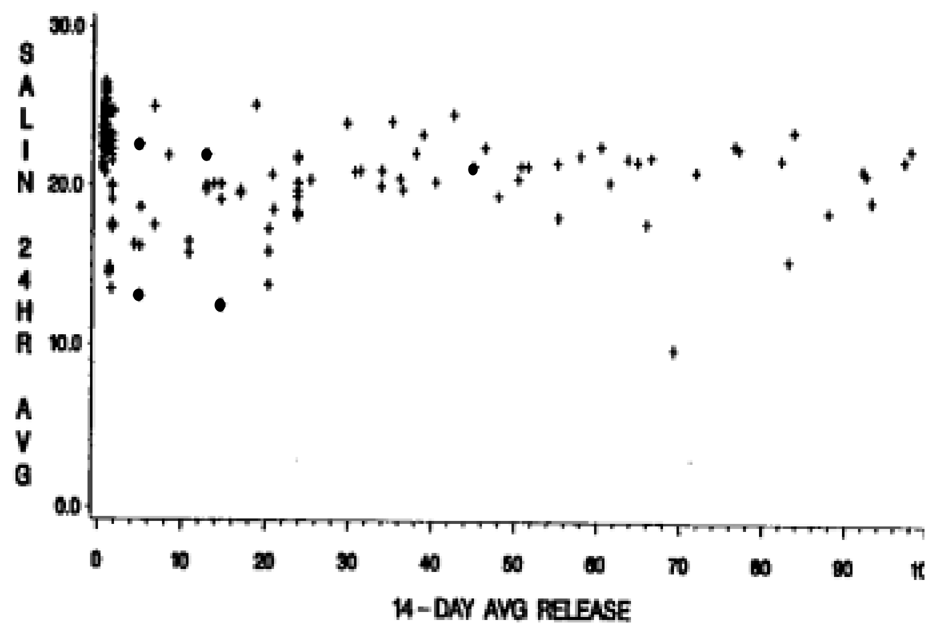
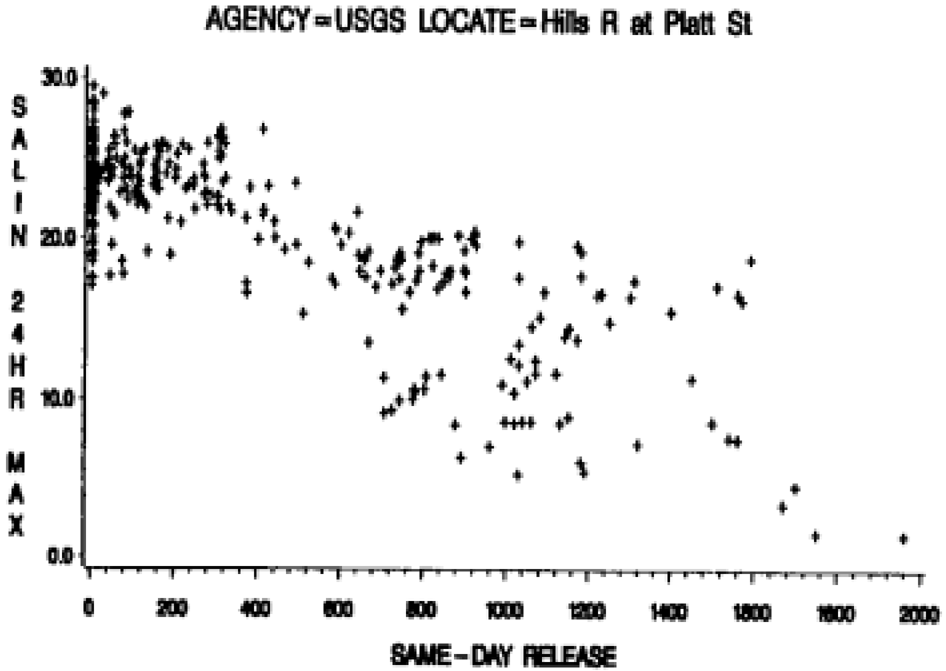
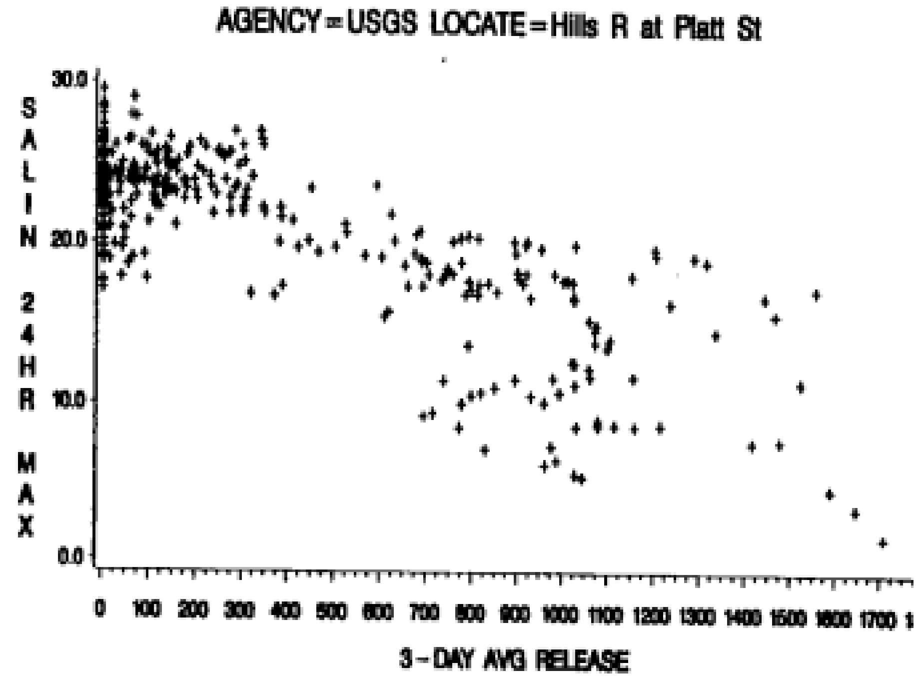


AGENCY=USGS LOCATE=Hills R at Platt St



E14


AGENCY=USGS LOCATE=Hills R at Platt St
SALIN 24HR MAX
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
SAME-DAY RELEASE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1100
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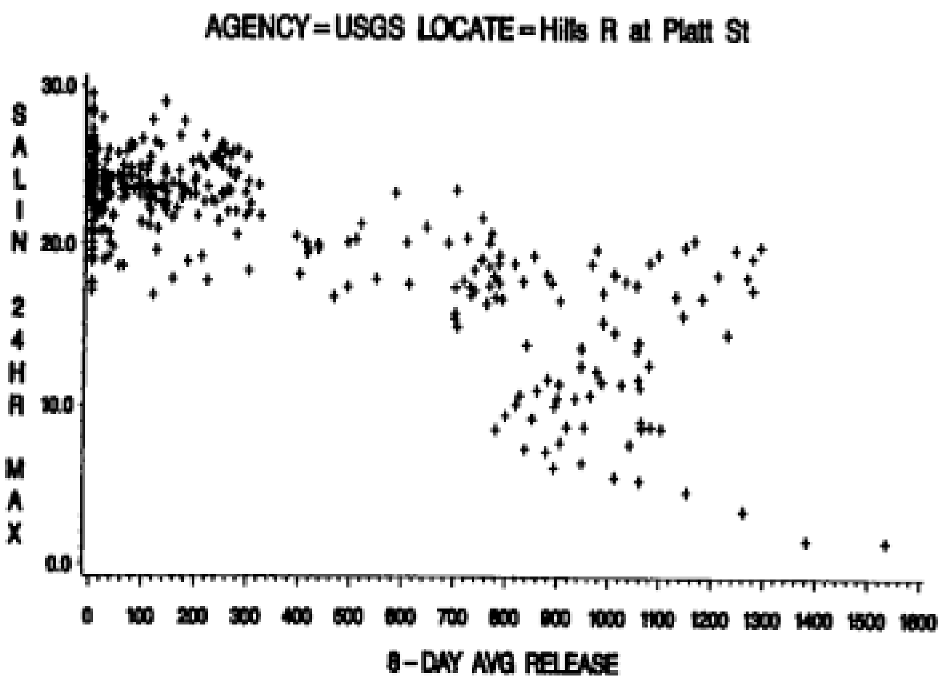
3-DAY AVG RELEASE

E15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10.0
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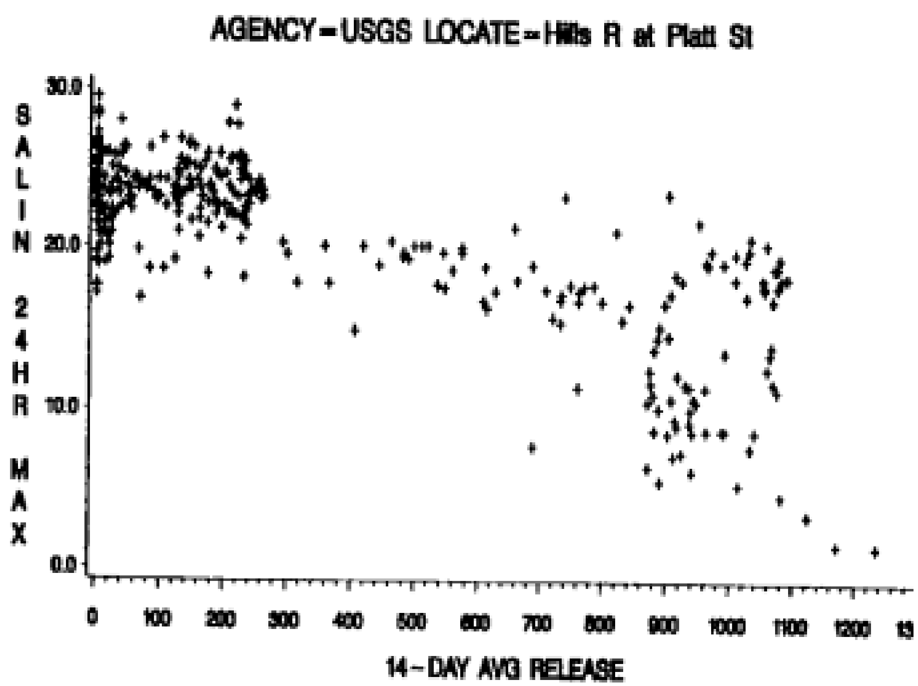
8-DAY AVG RELEASE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SALIN 24HR MAX
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900
1000
1100
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14-DAY AVG RELEASE

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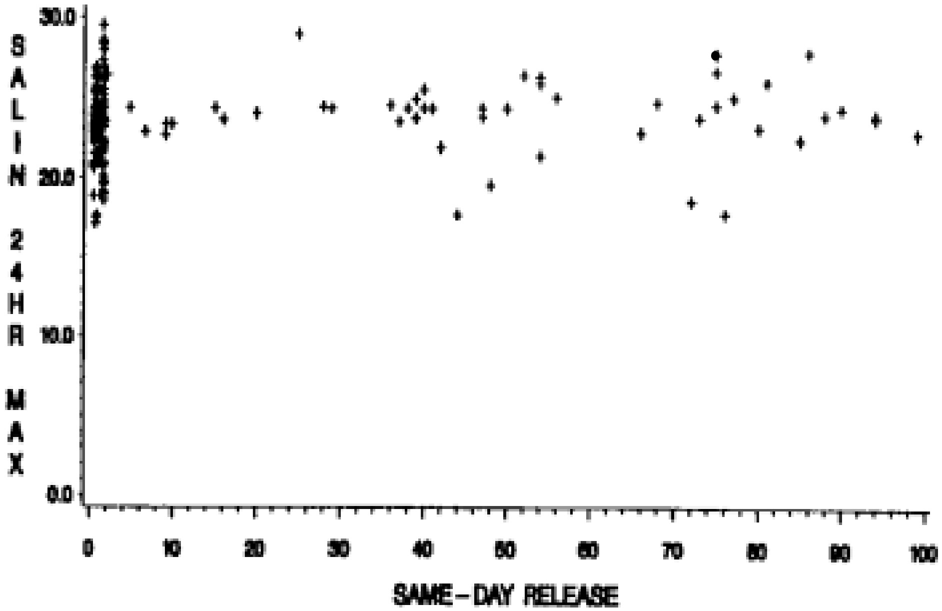

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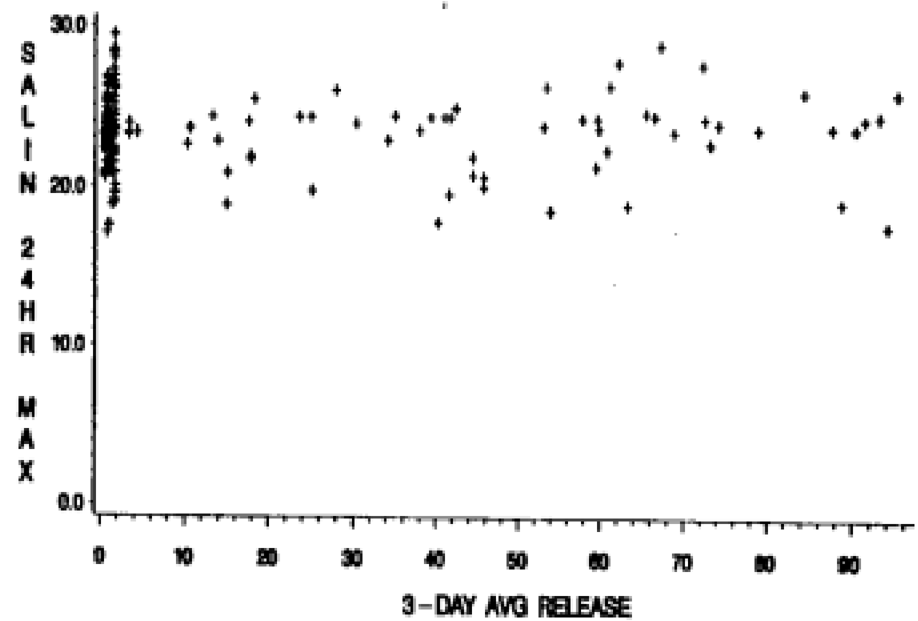

E16

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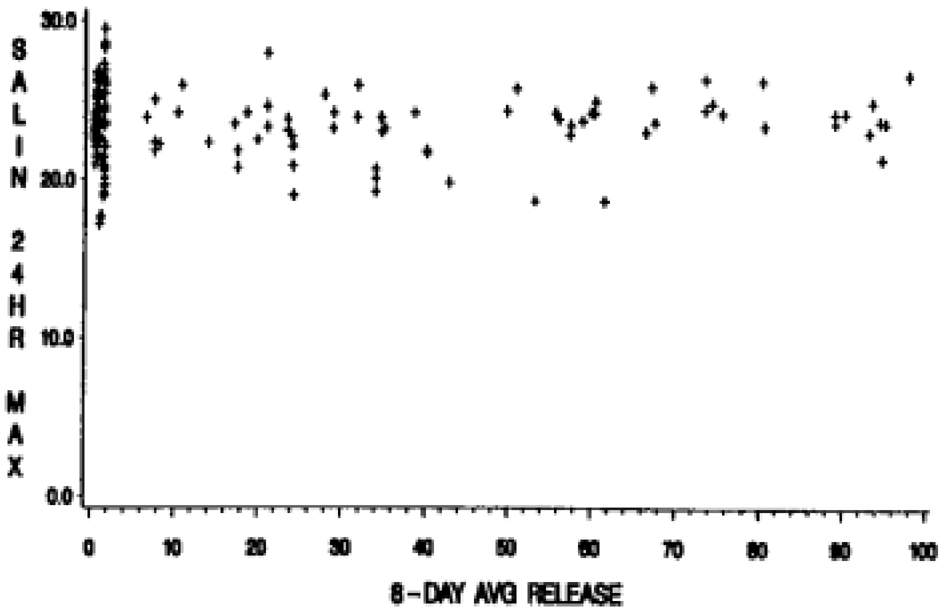

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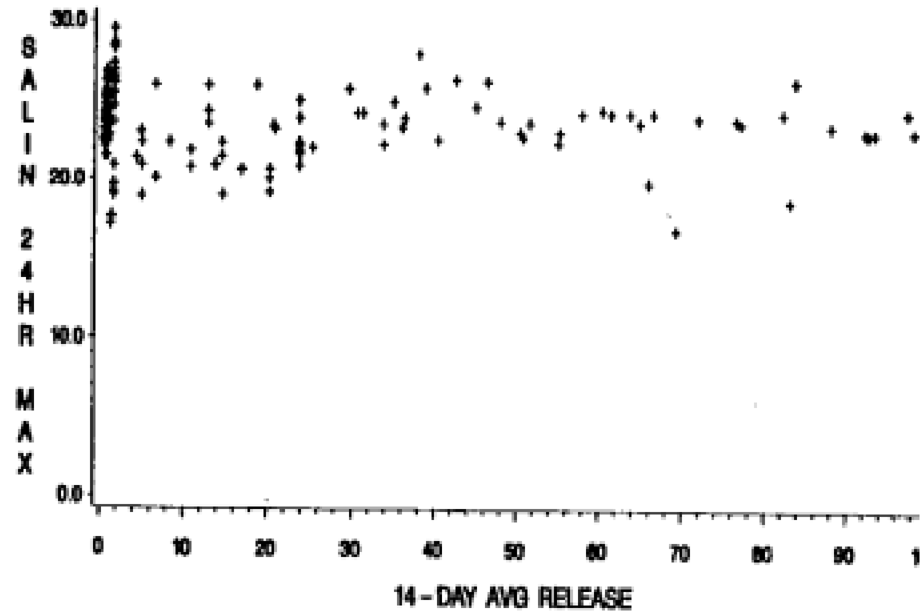

APPENDIX F.

Plots of daily average and daily minimum dissolved oxygen concentrations at the USGS recorders vs. discharge from the Hillsborough River Reservoir. (Recorders are mid-depth. Units are mg/l for dissolved oxygen and cfs for discharge).

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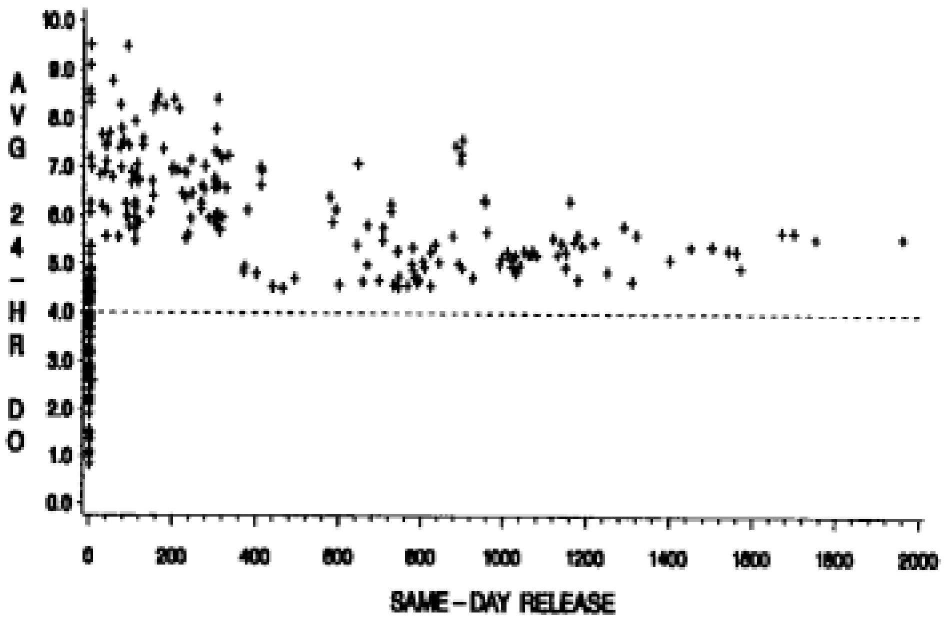

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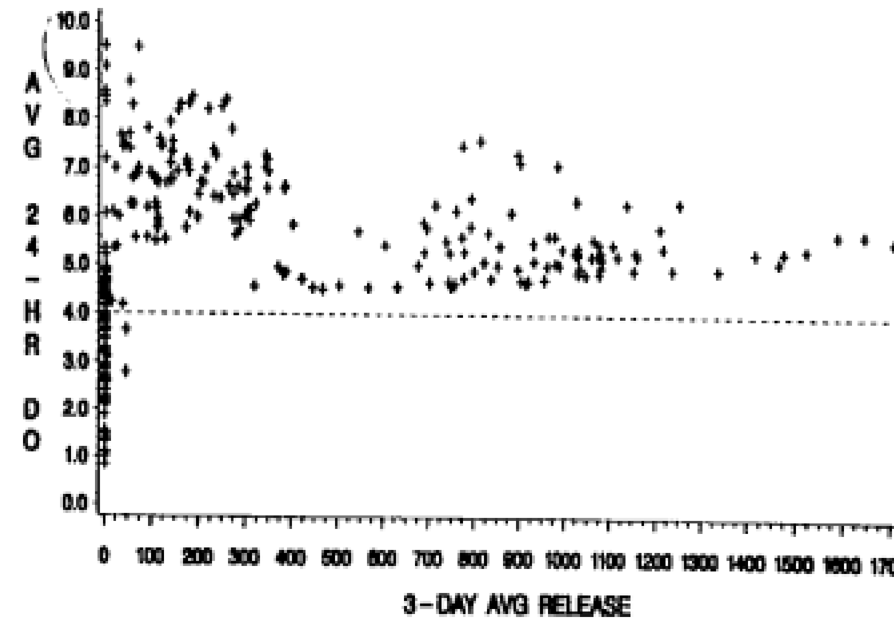

F1

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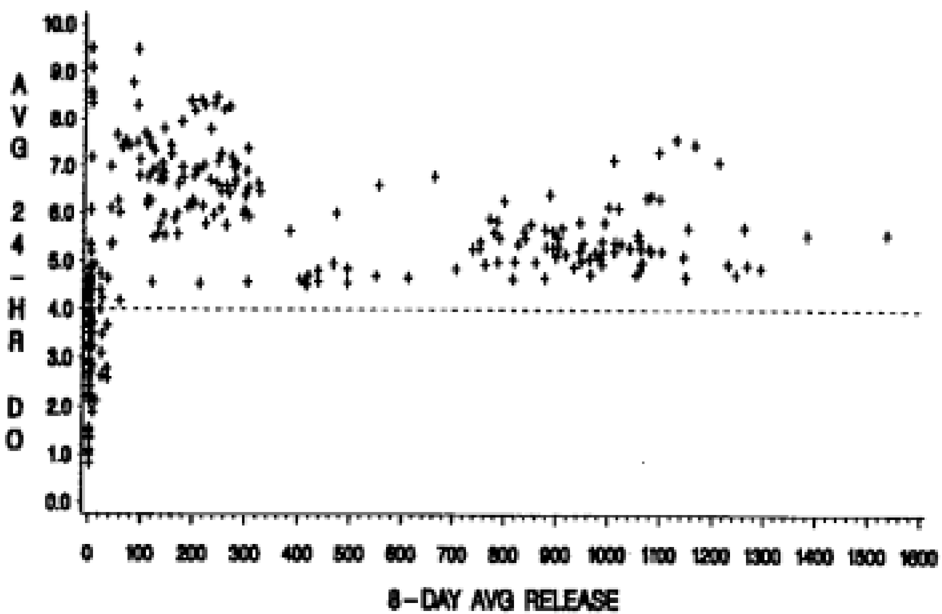

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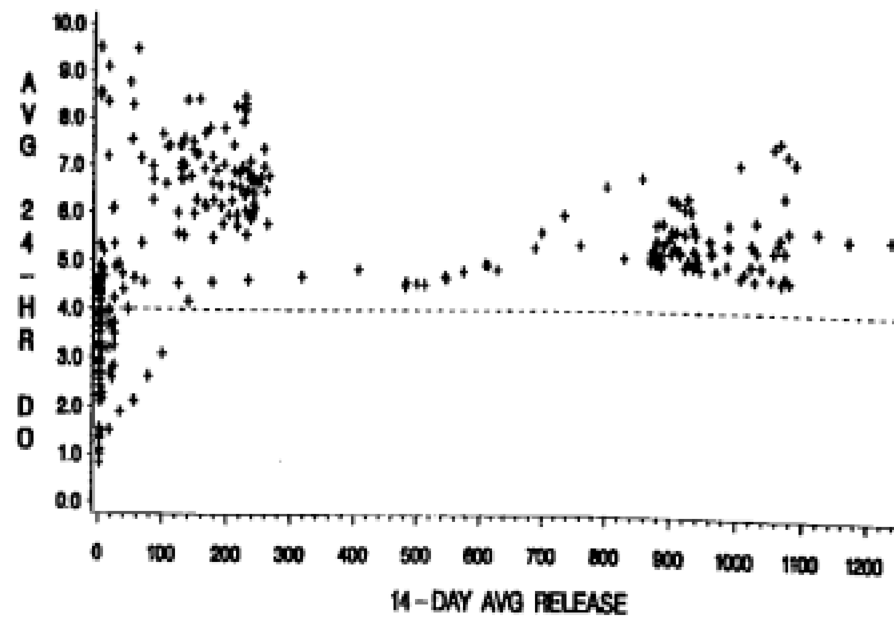

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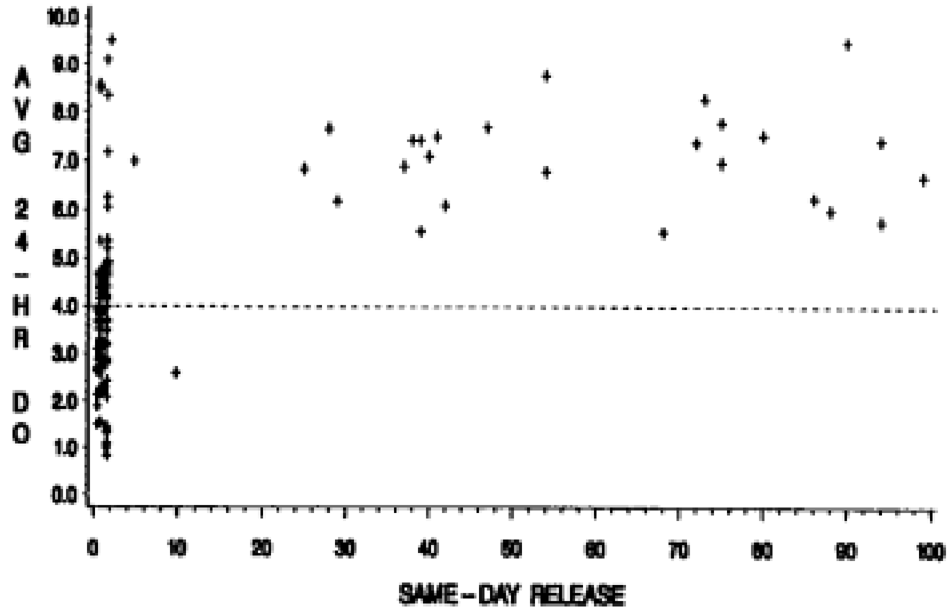

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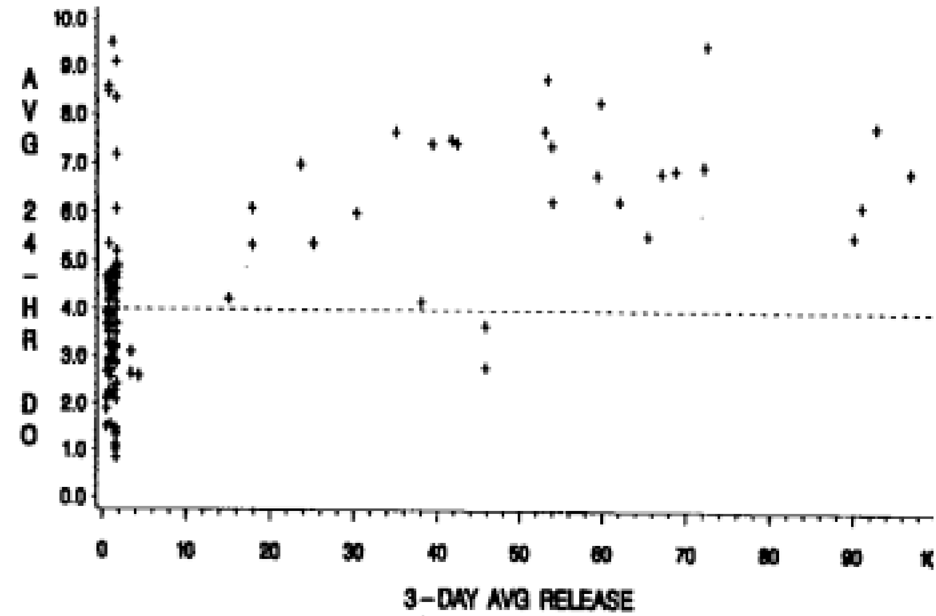

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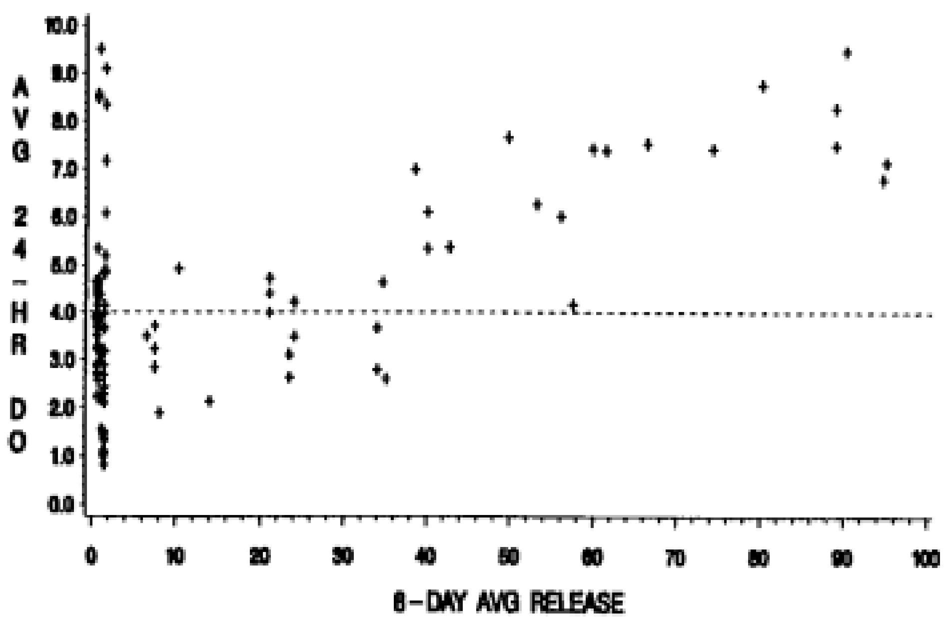

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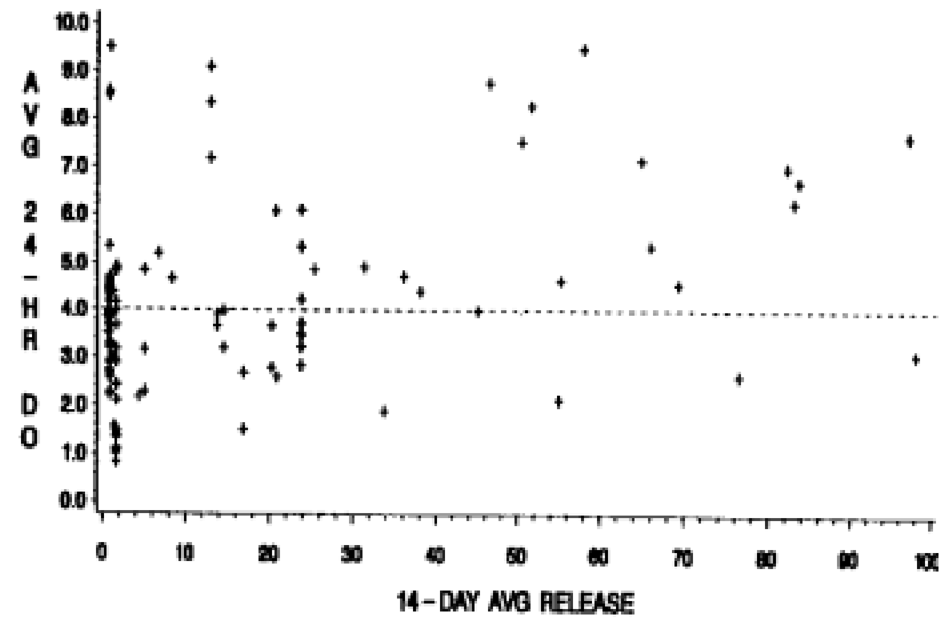

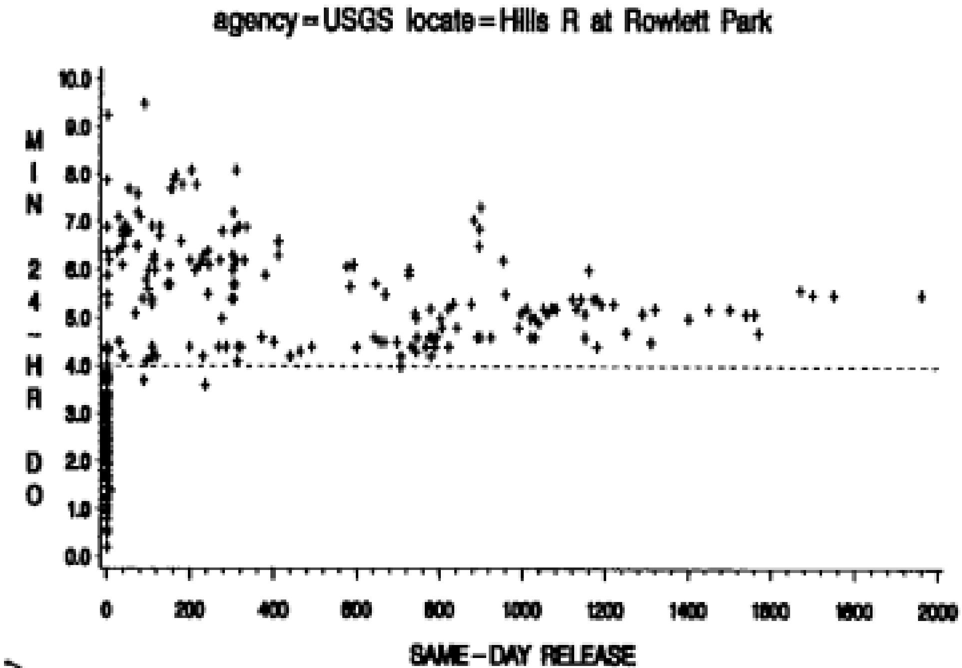
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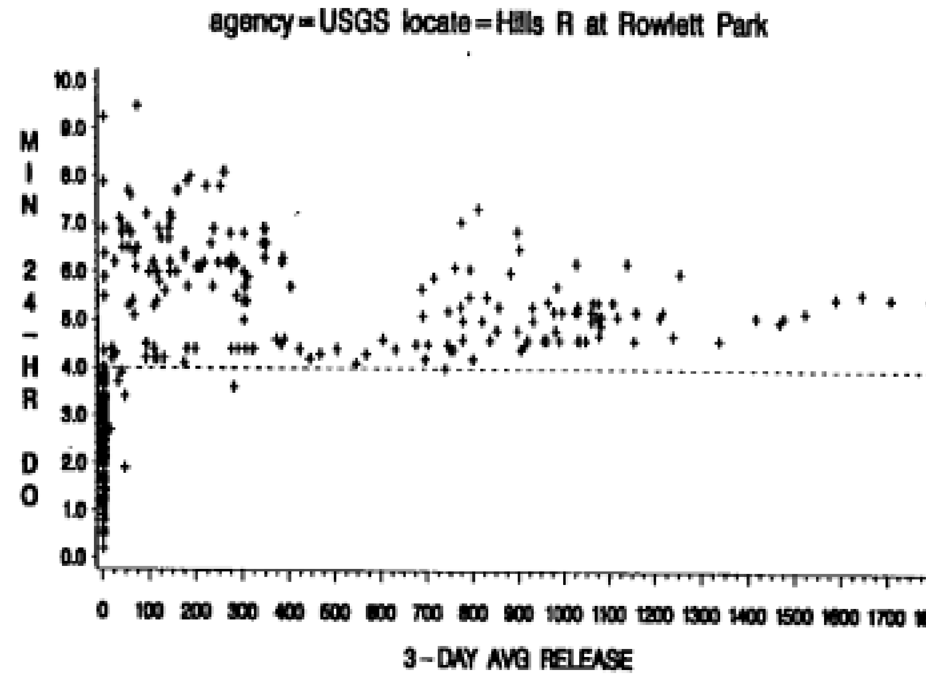
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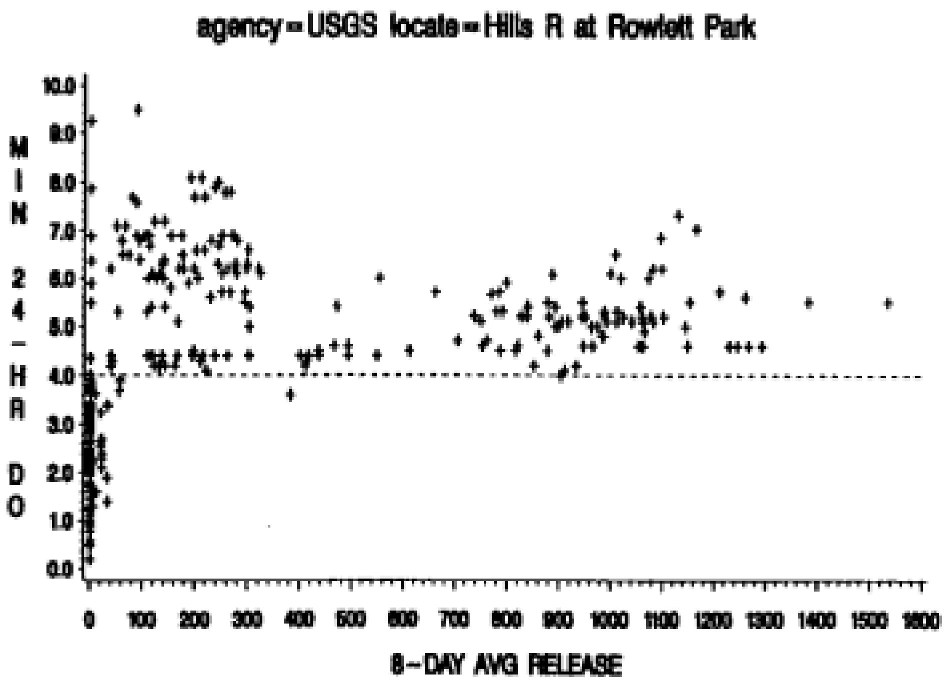
MIN 24-HR DO
3-DAY AVG RELEASE

F3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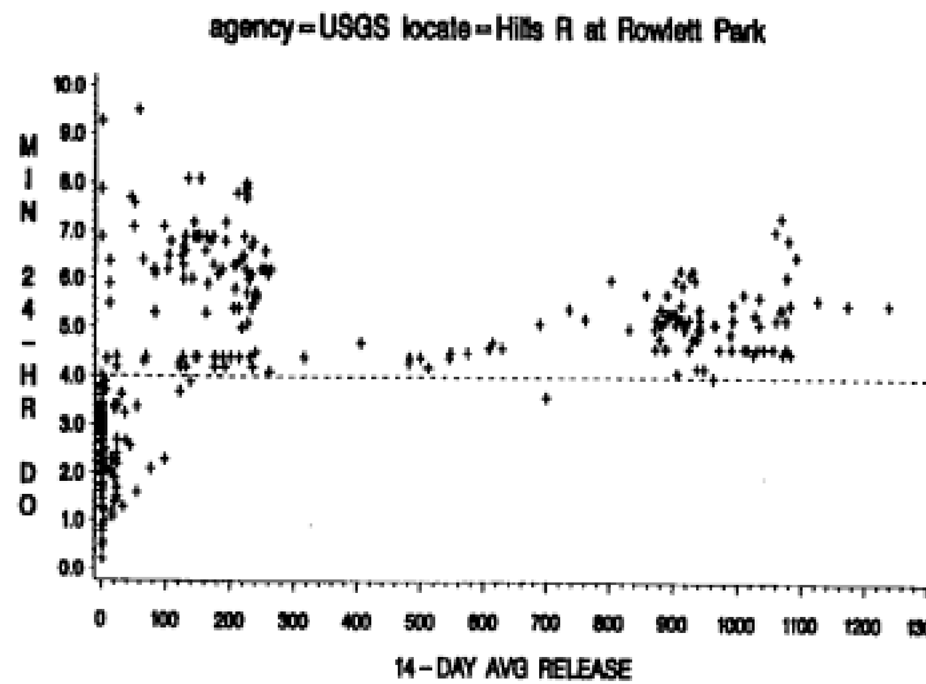
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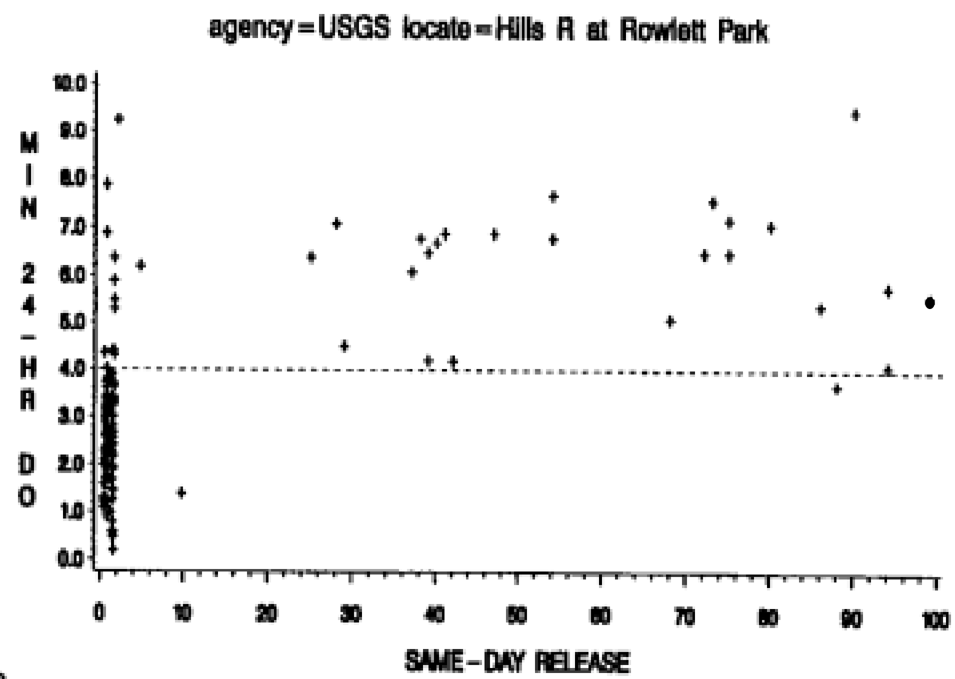
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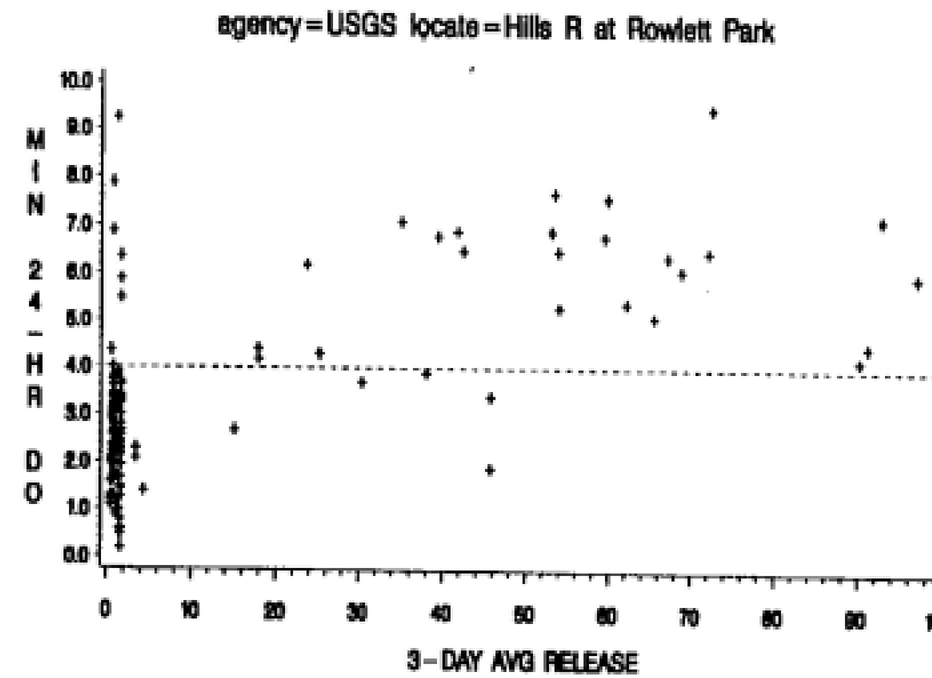
SAME-DAY RELEASE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MIN 24-HR DO
3-DAY AVG RELEASE

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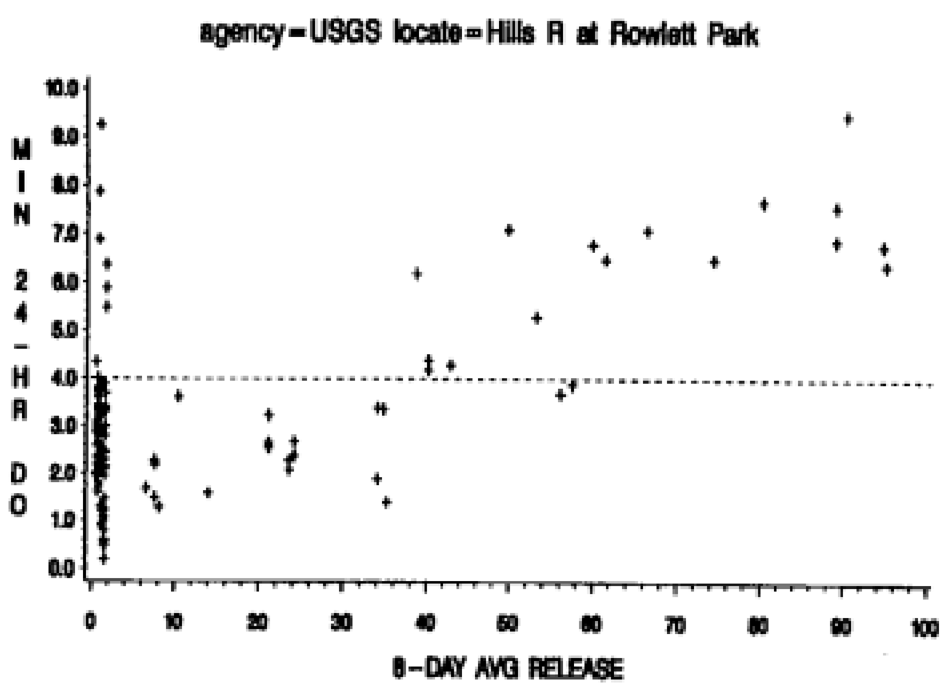
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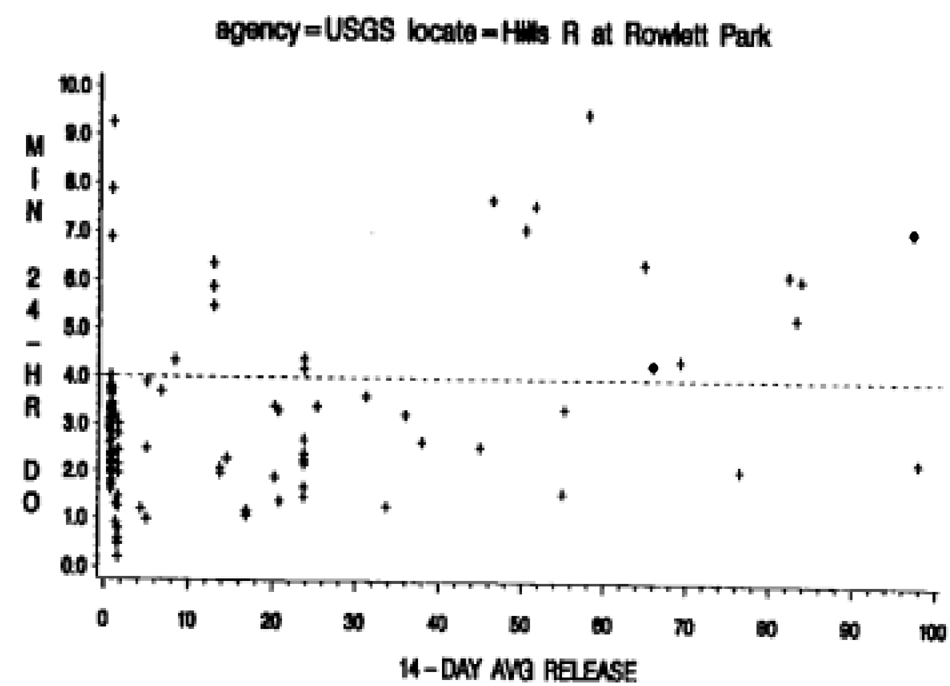
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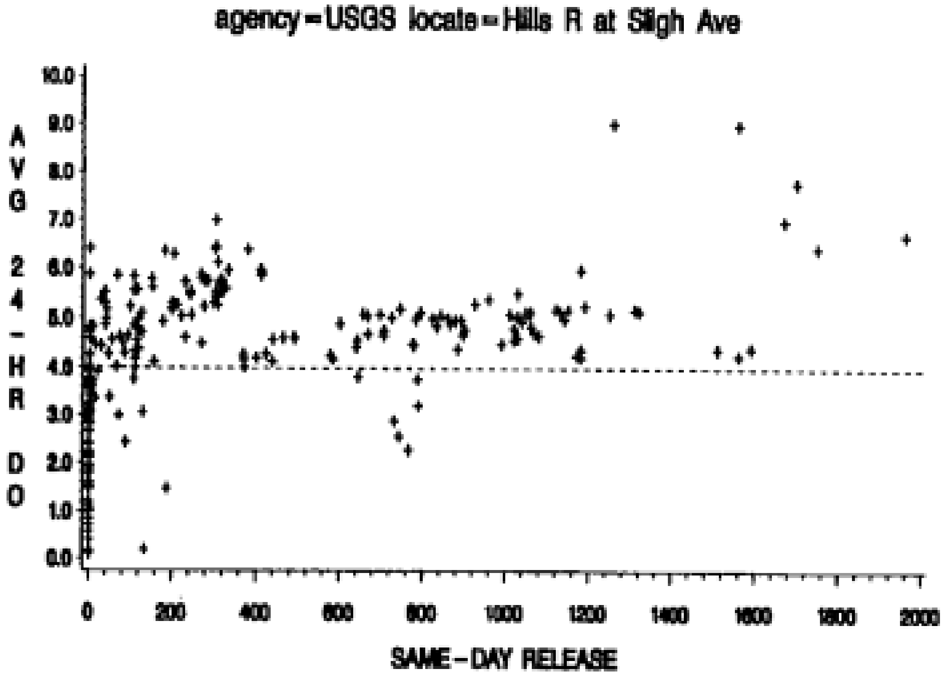
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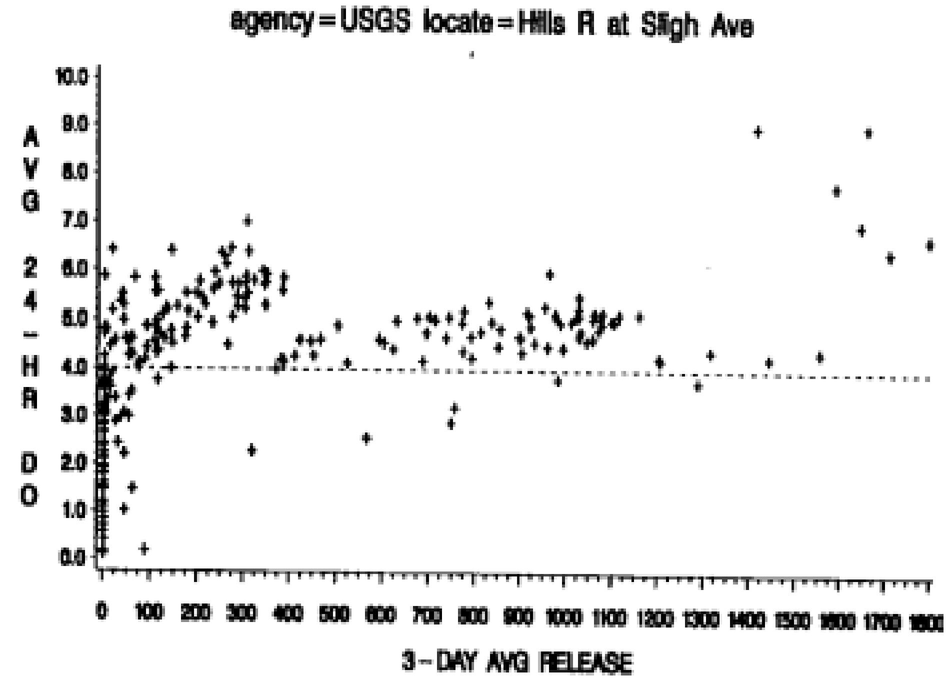
SAME-DAY RELEASE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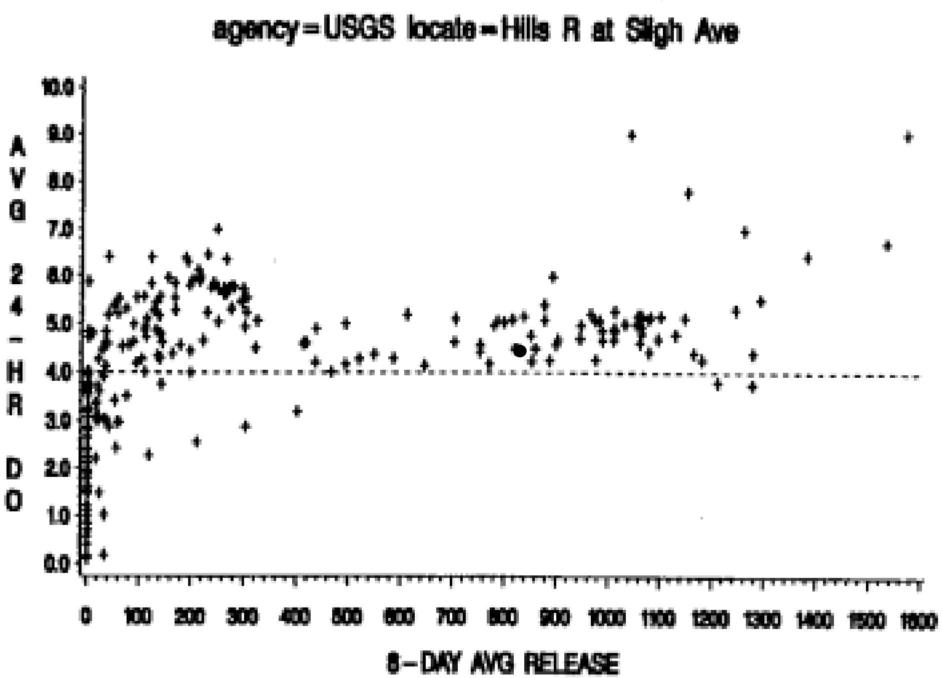
3-DAY AVG RELEASE

F5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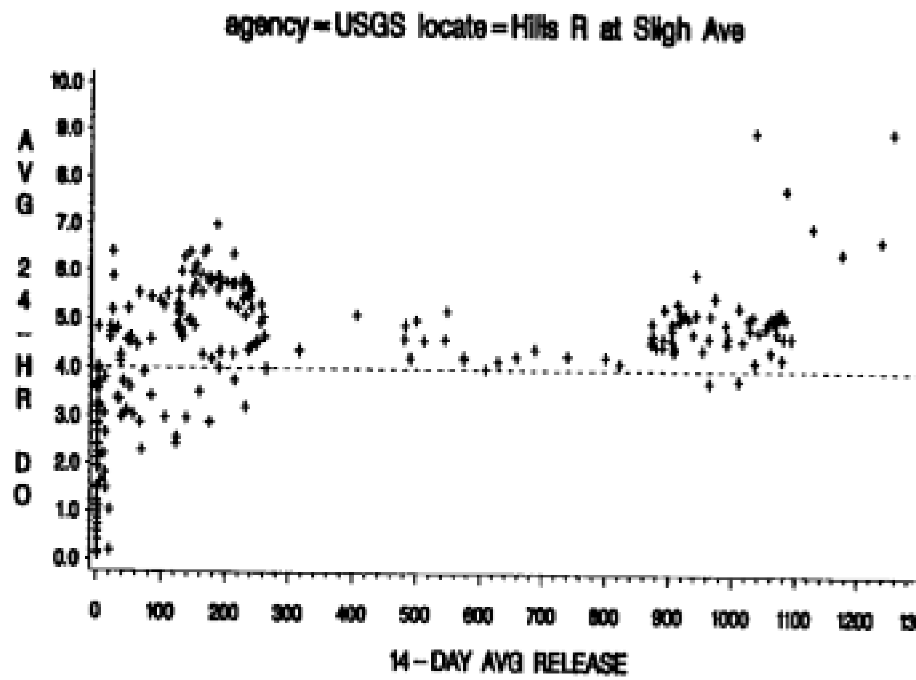
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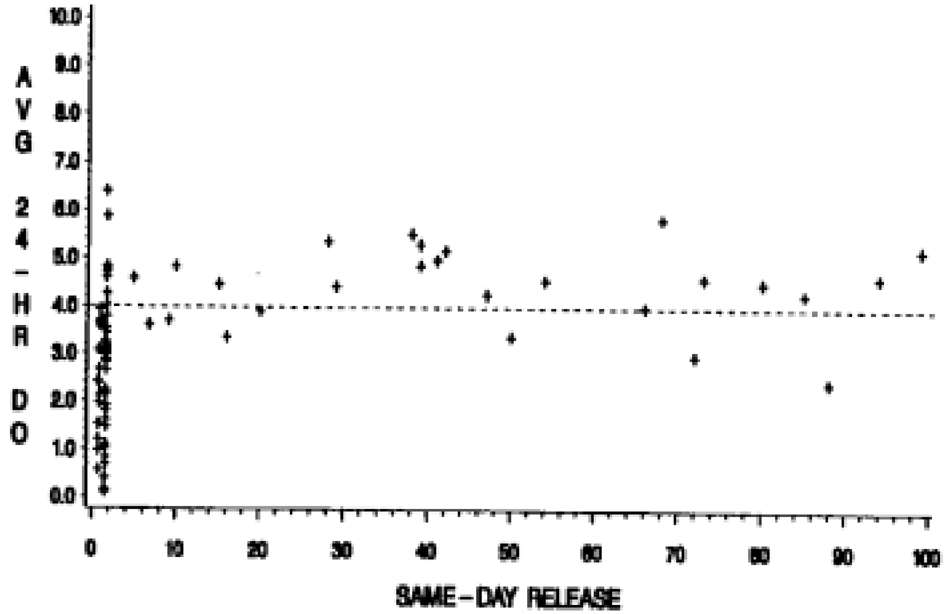

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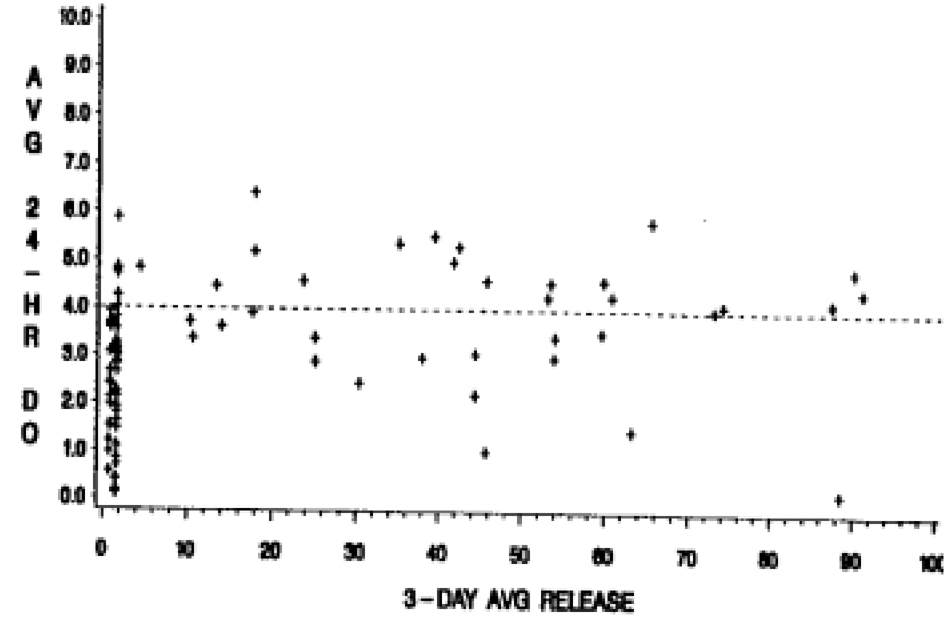

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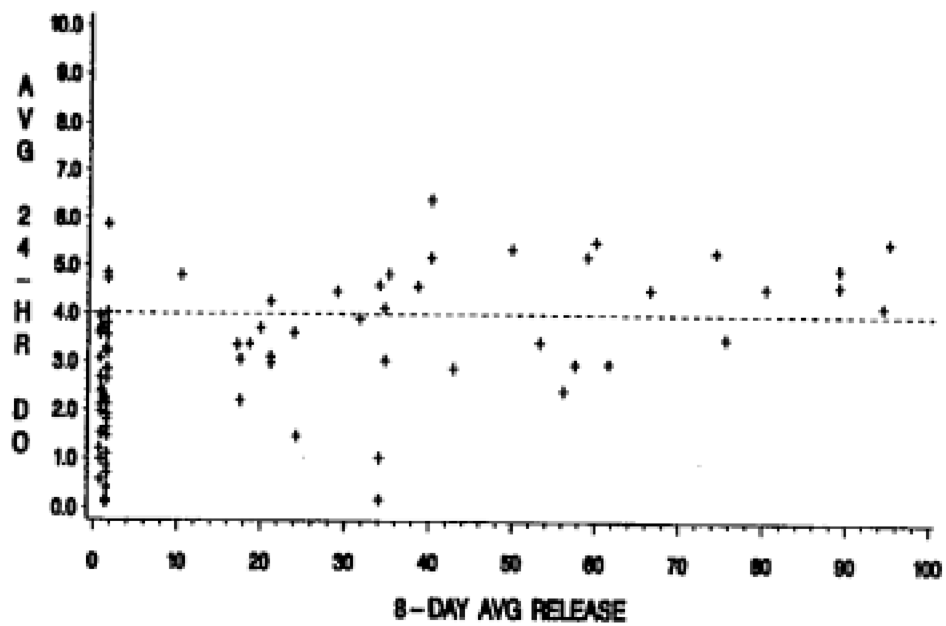

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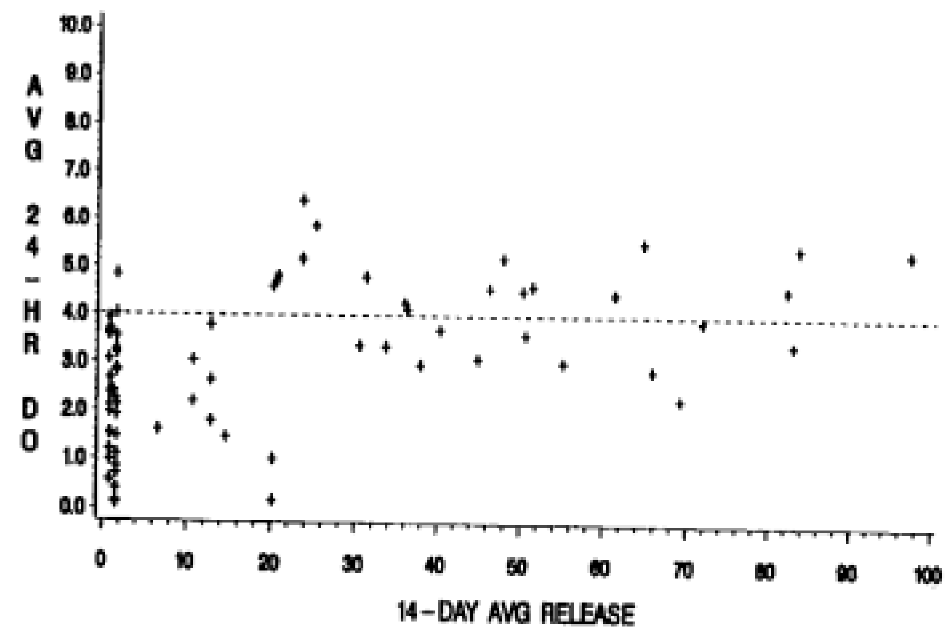

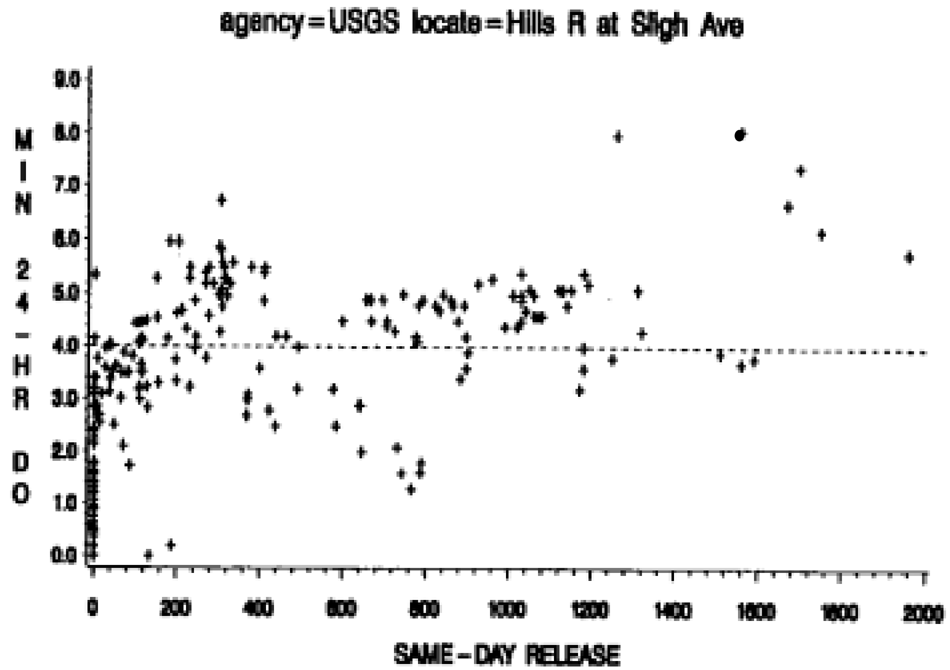
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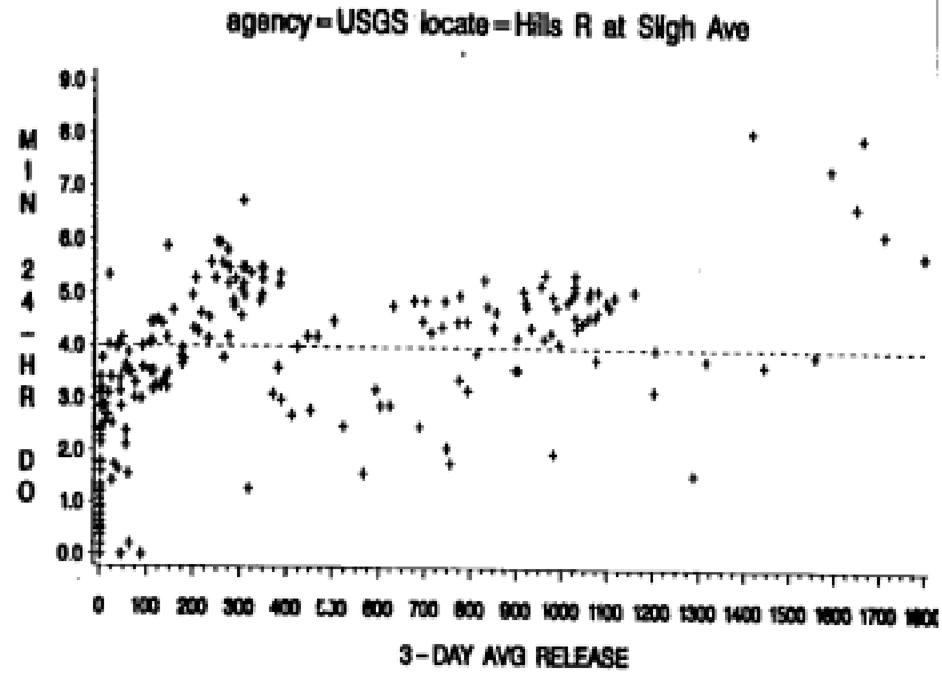
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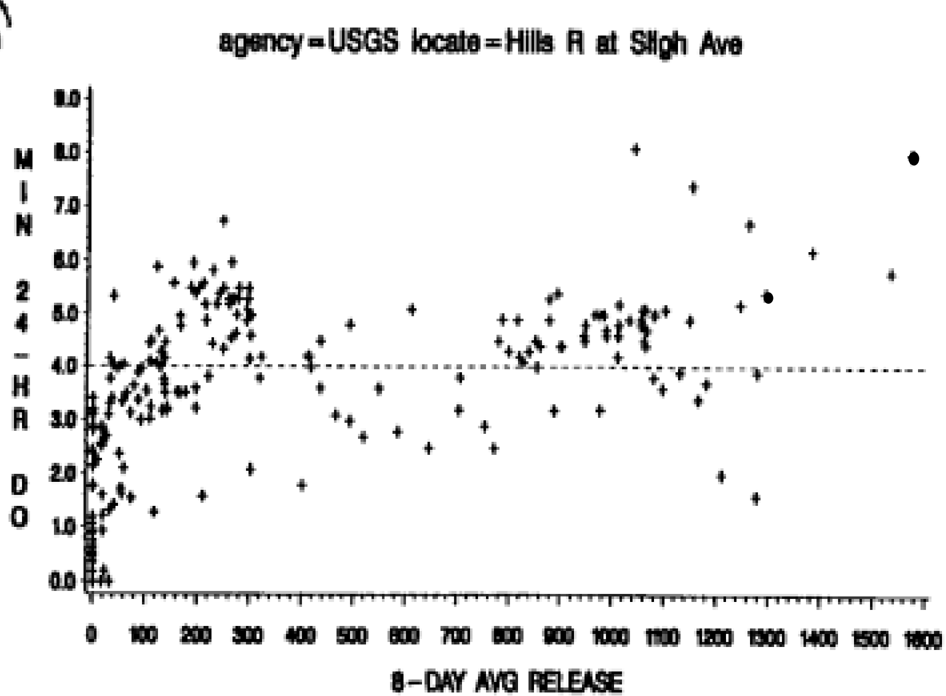
3-DAY AVG RELEASE

F7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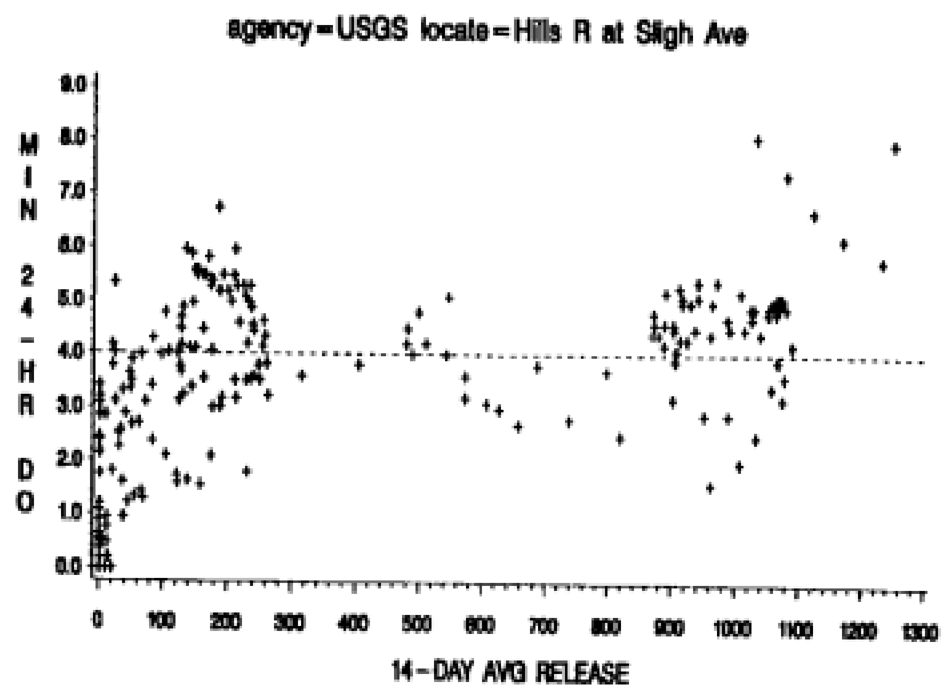
8-DAY AVG RELEASE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14-DAY AVG RELEASE

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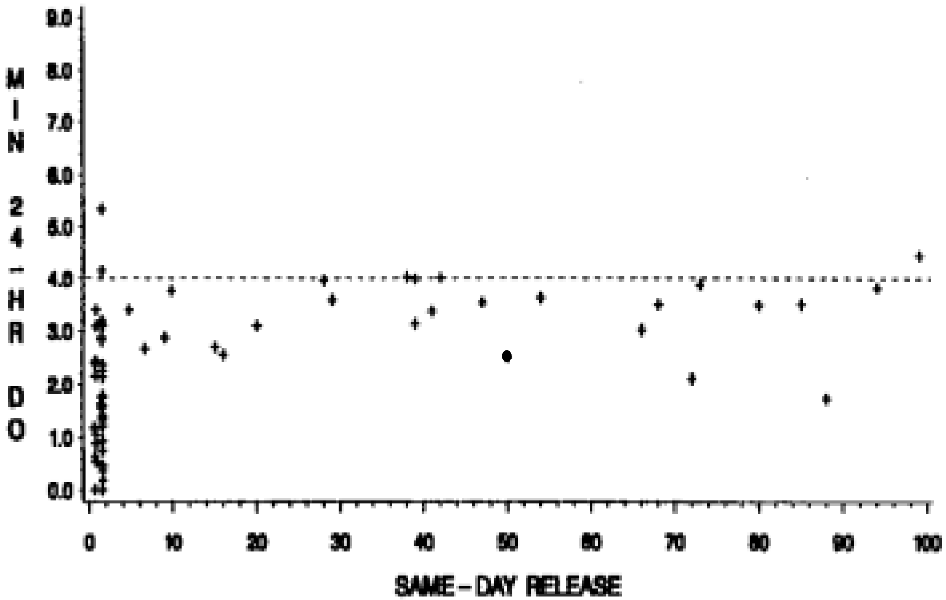

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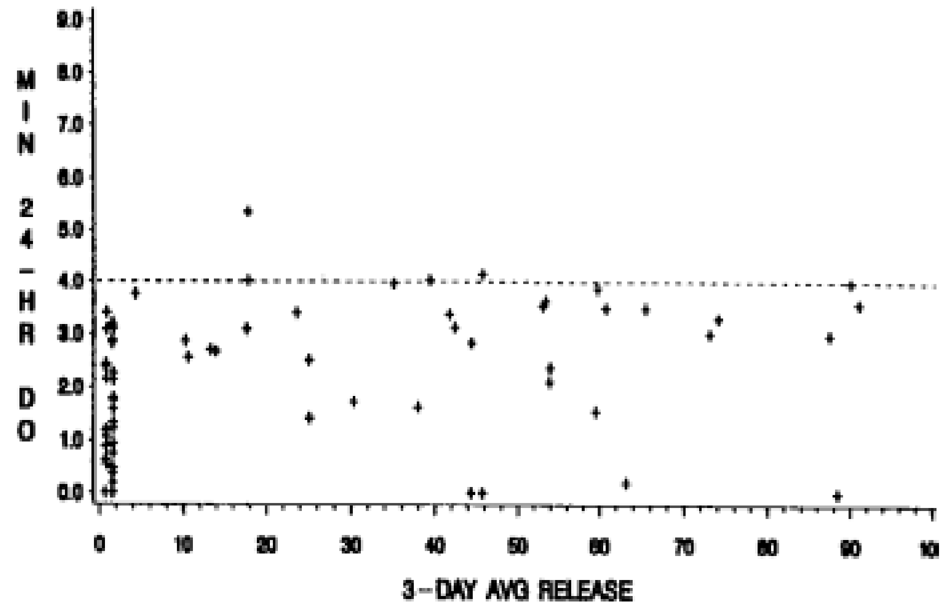

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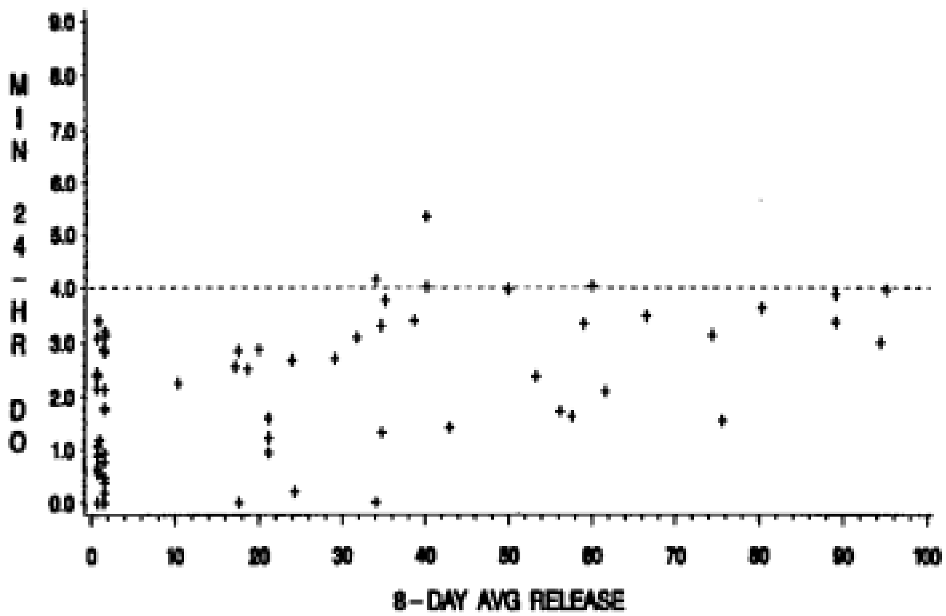

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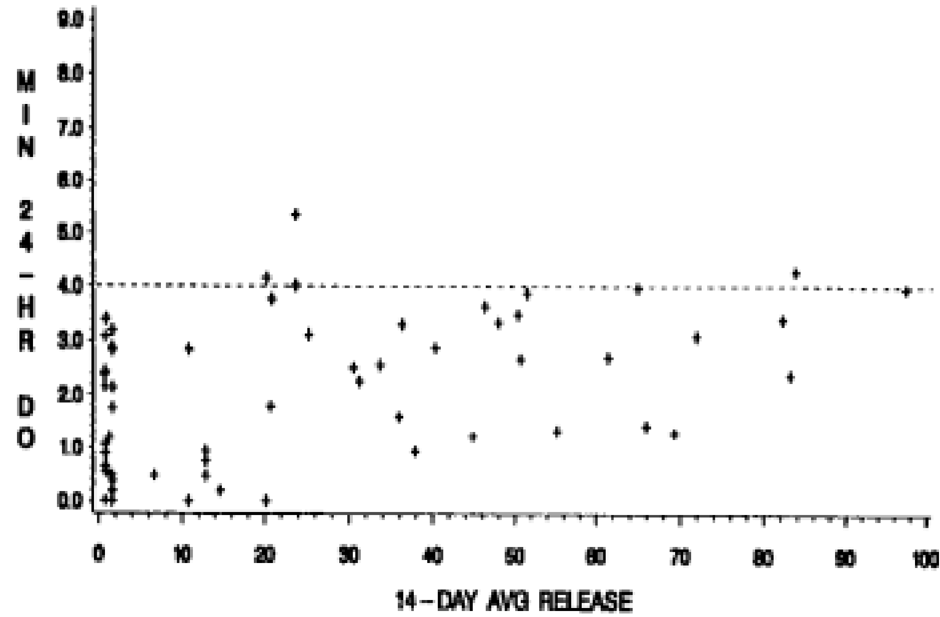

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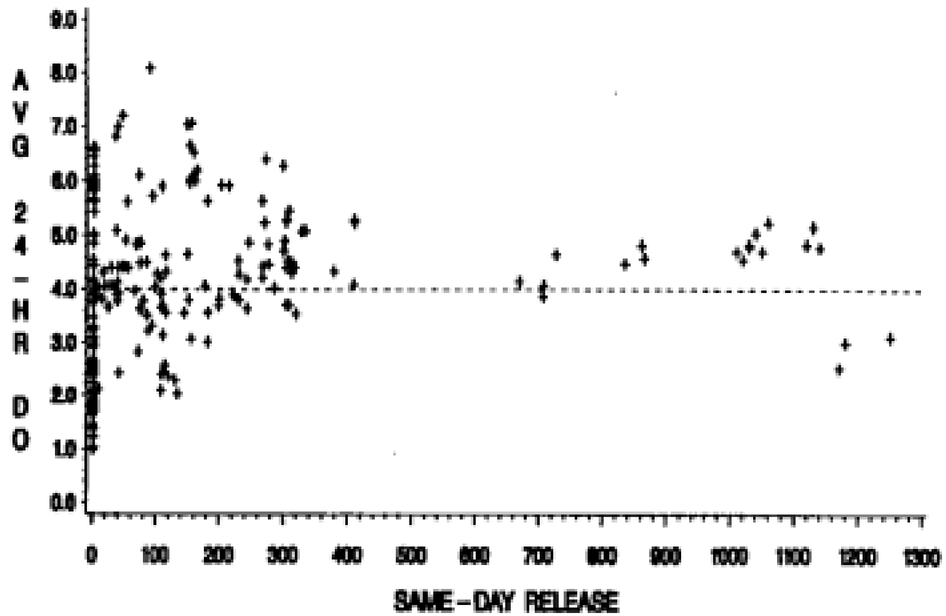

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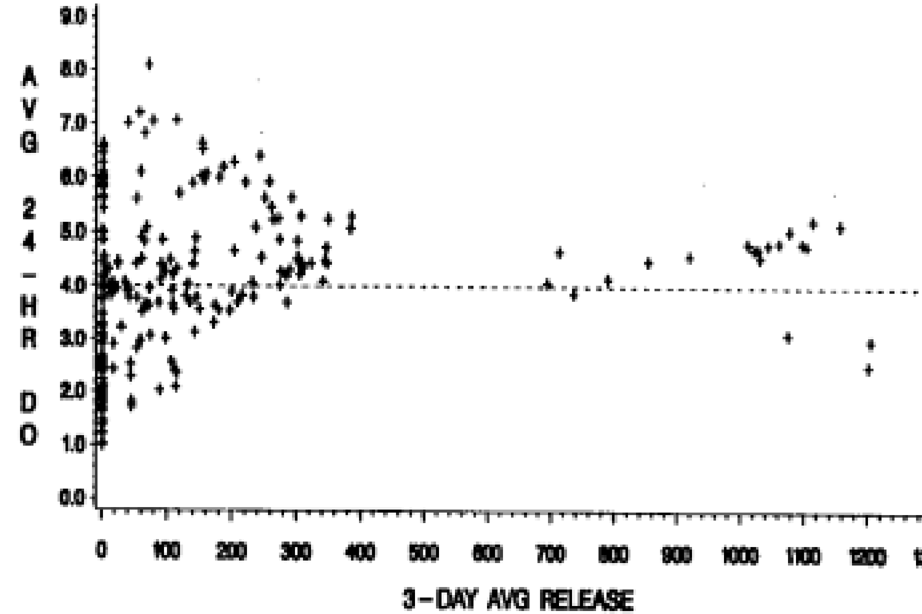

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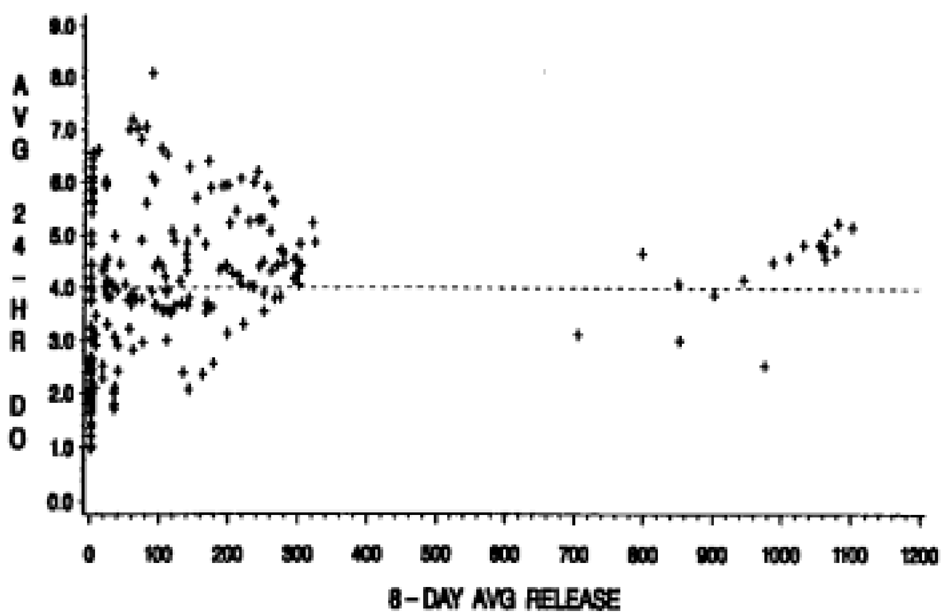

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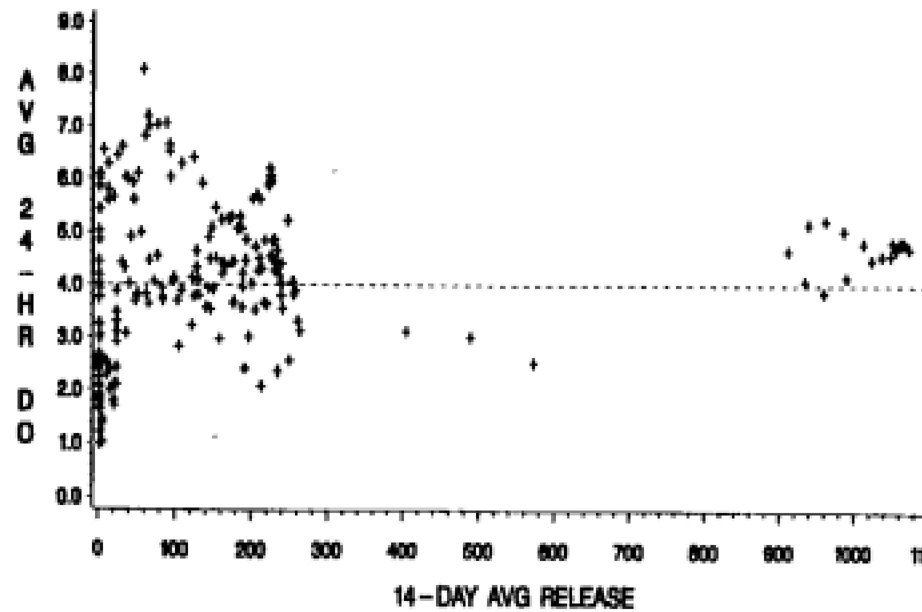

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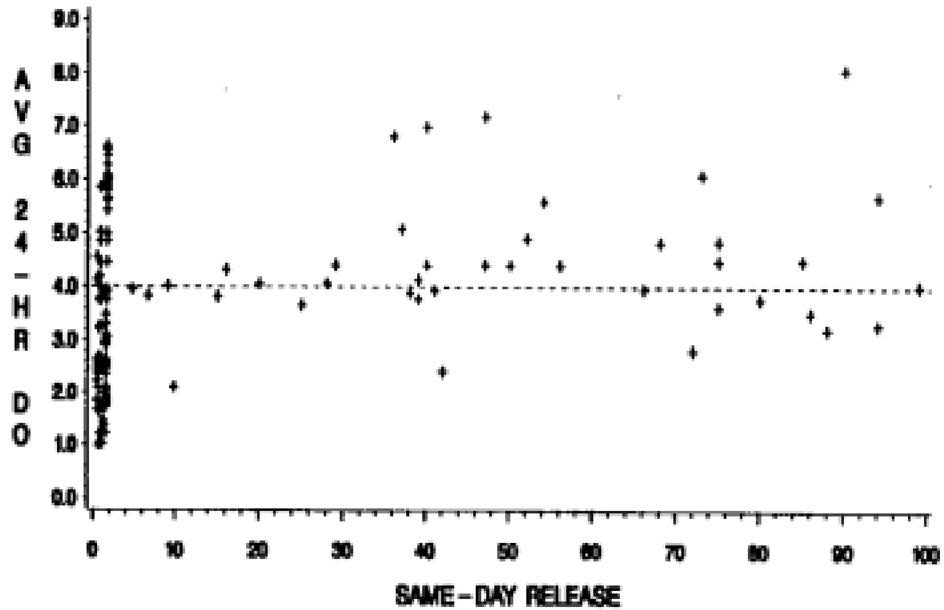

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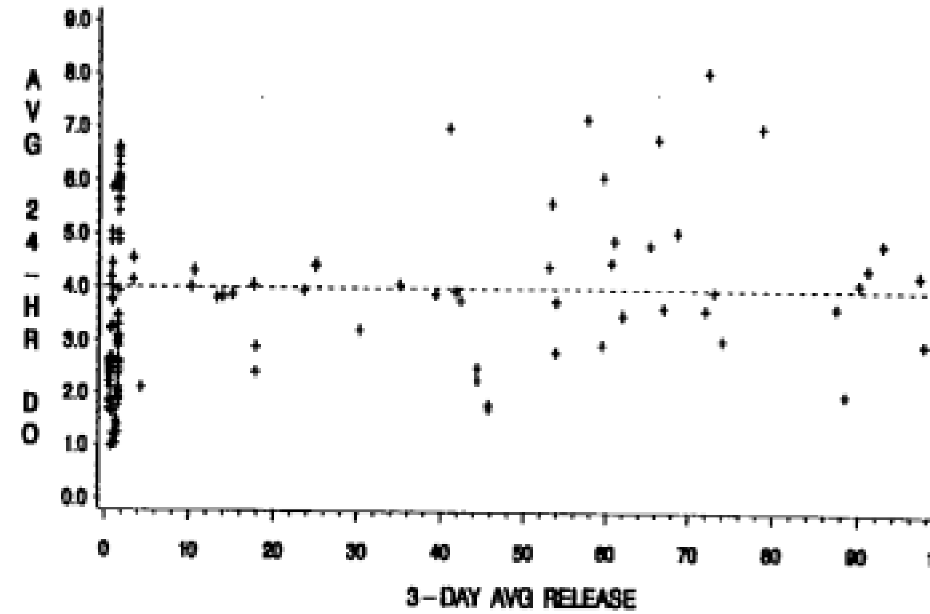

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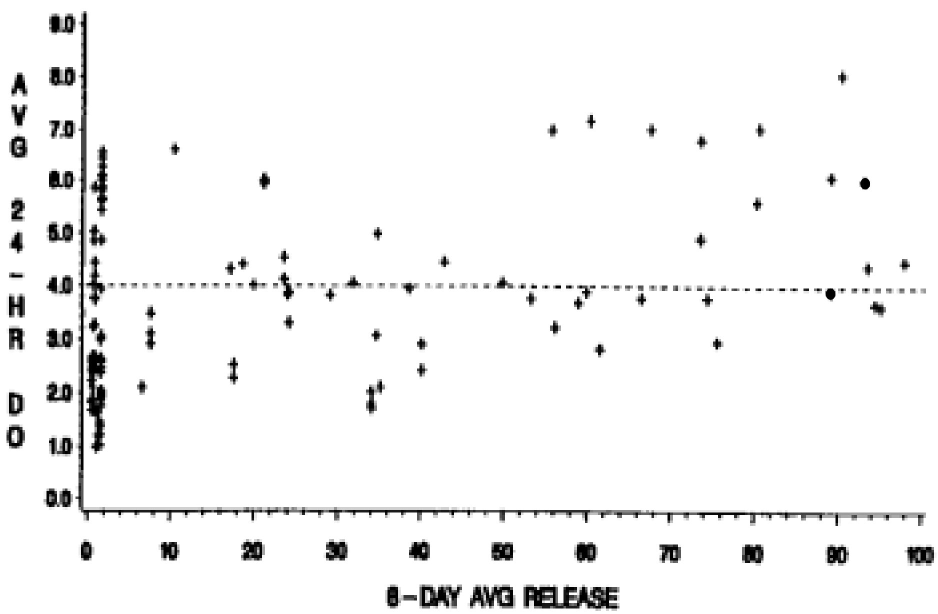

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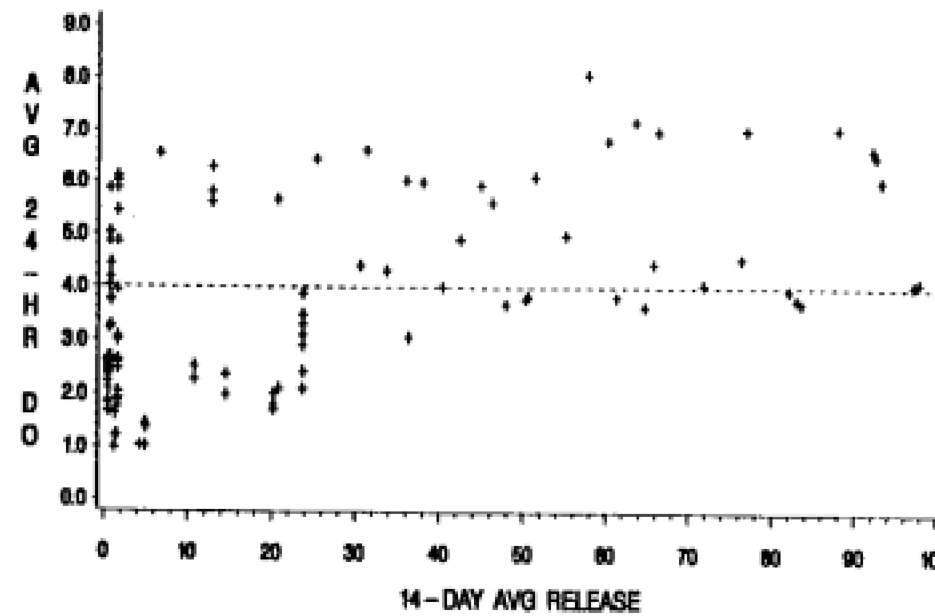

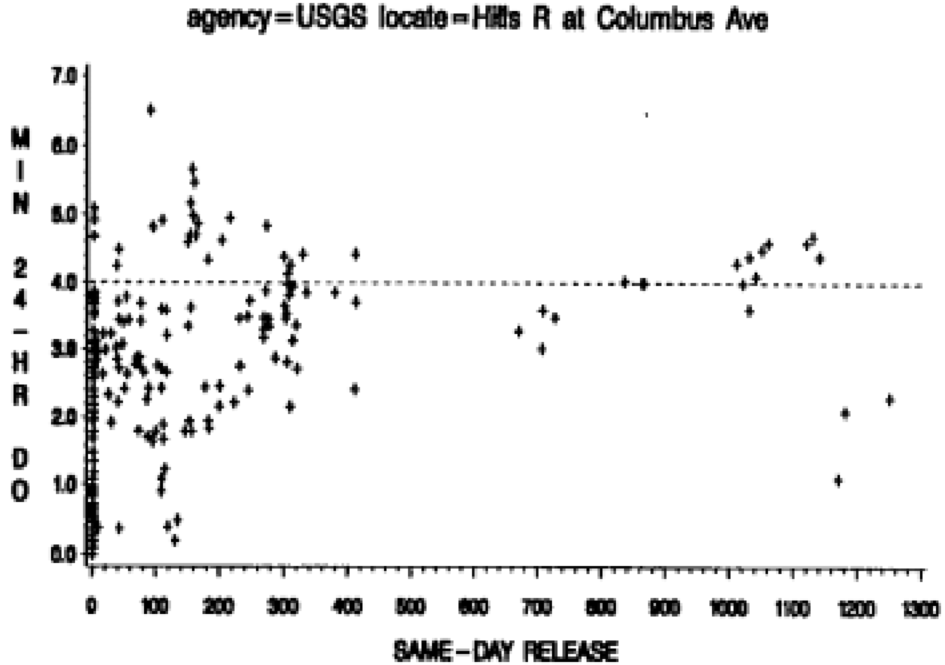
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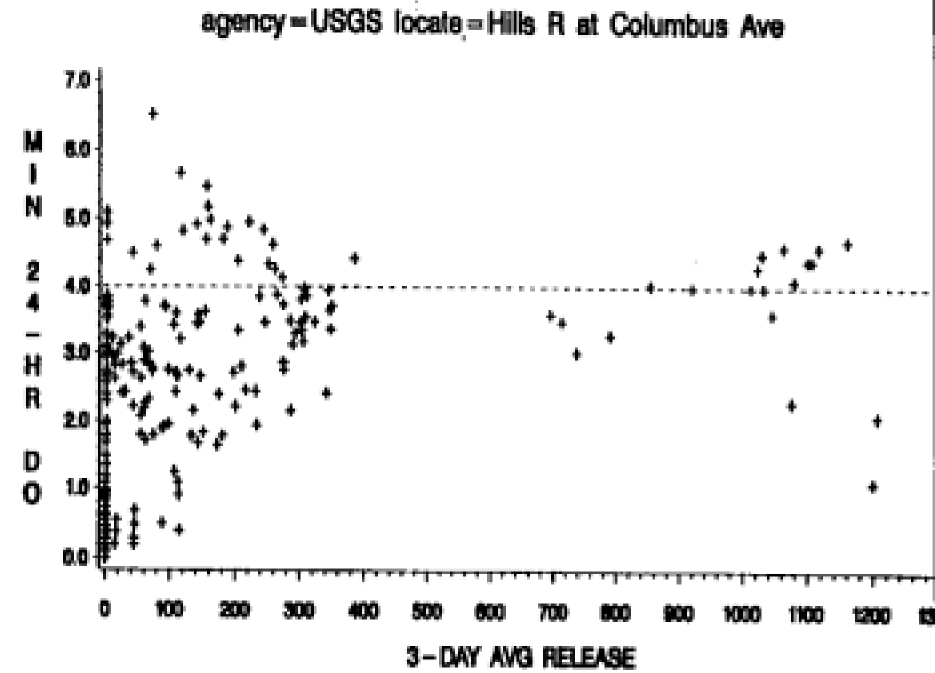
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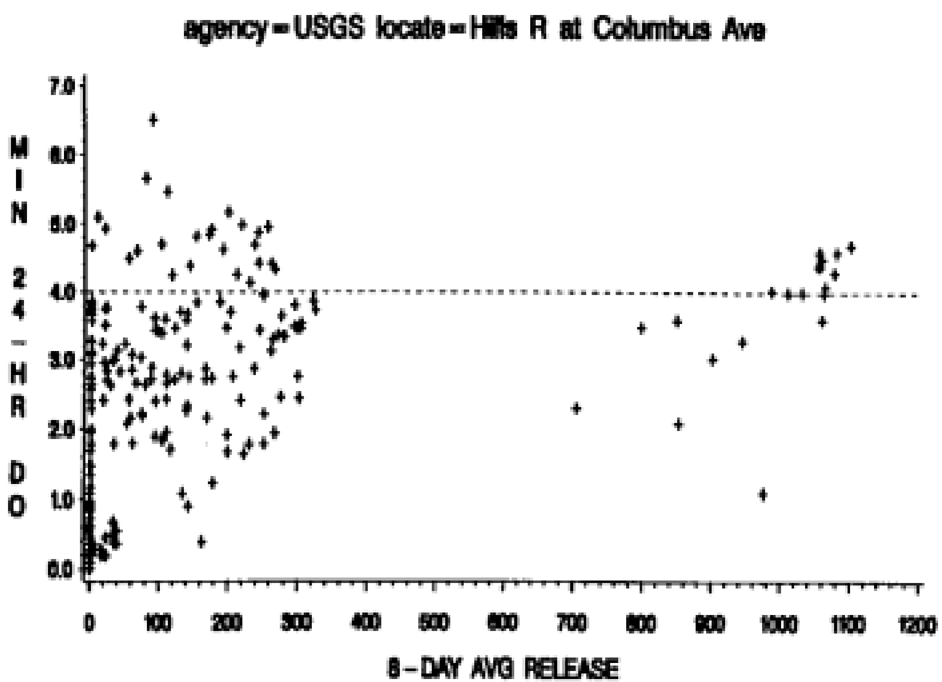
3-DAY AVG RELEASE

F11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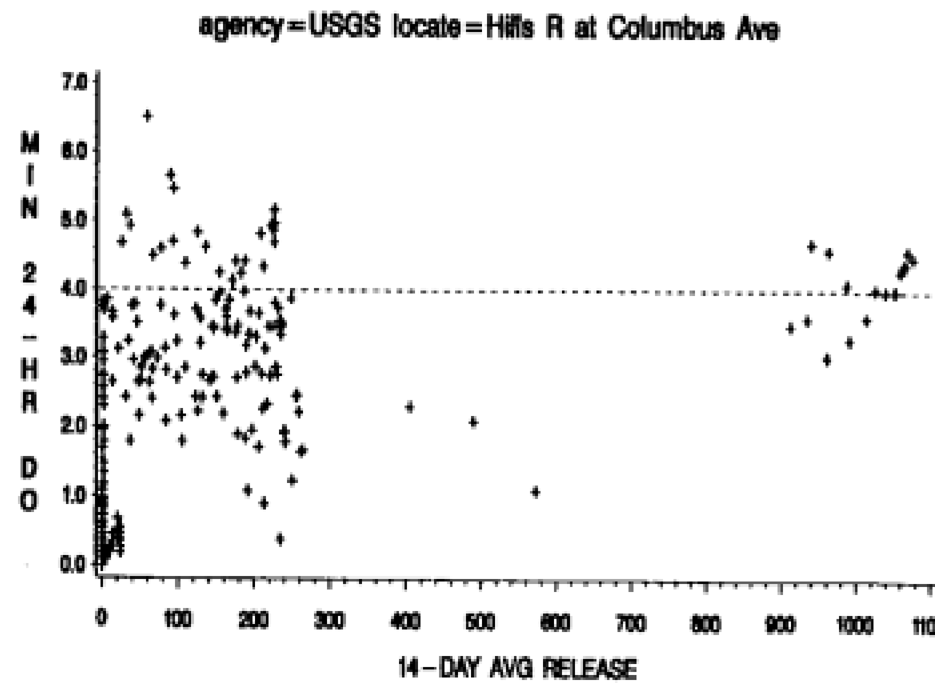
8-DAY AVG RELEASE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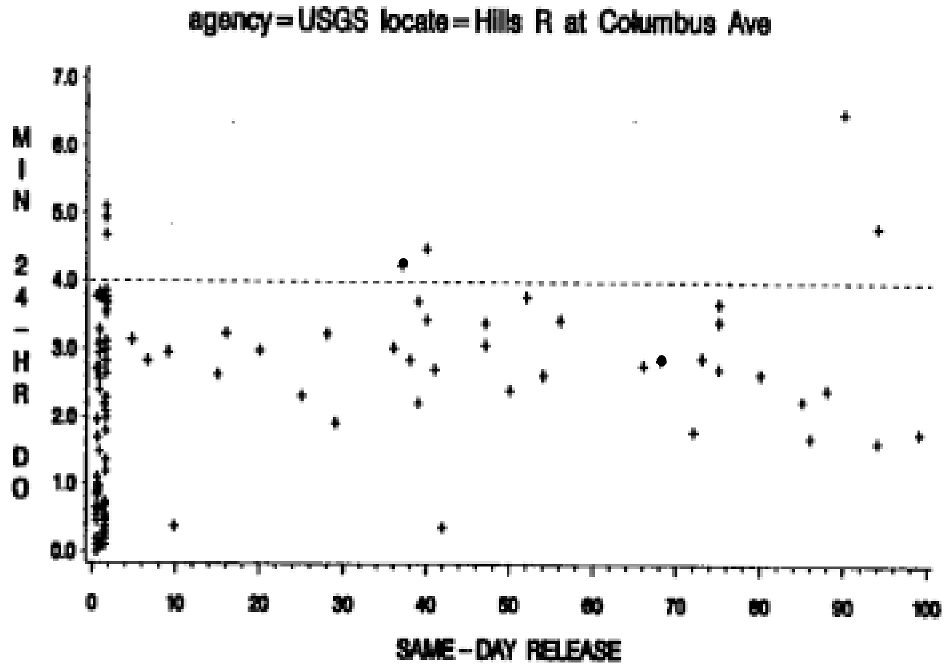
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4.0
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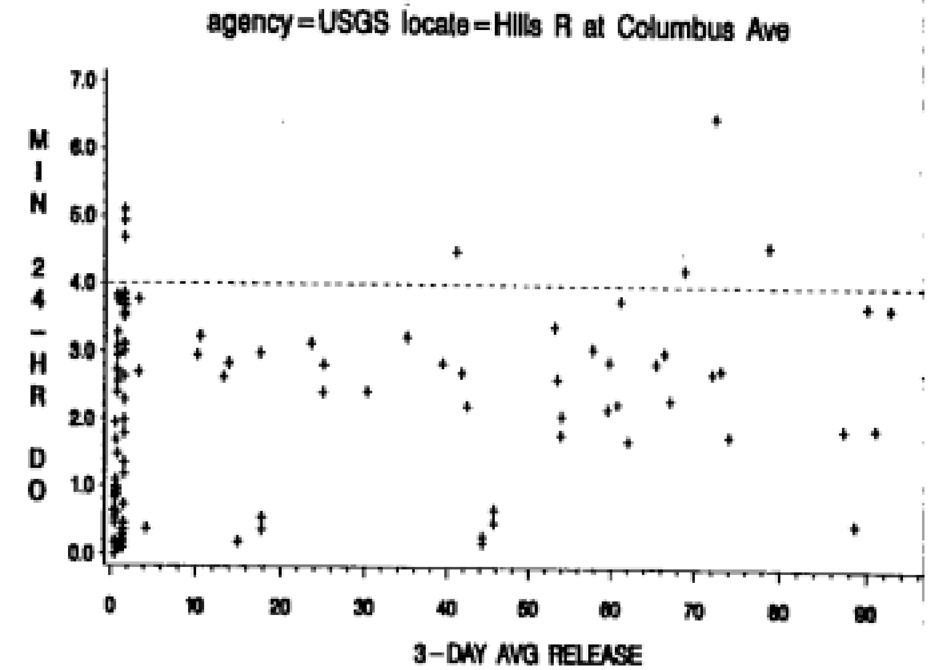
0
10
20
30
40
50
60
70
80
90
100
SAME-DAY RELEASE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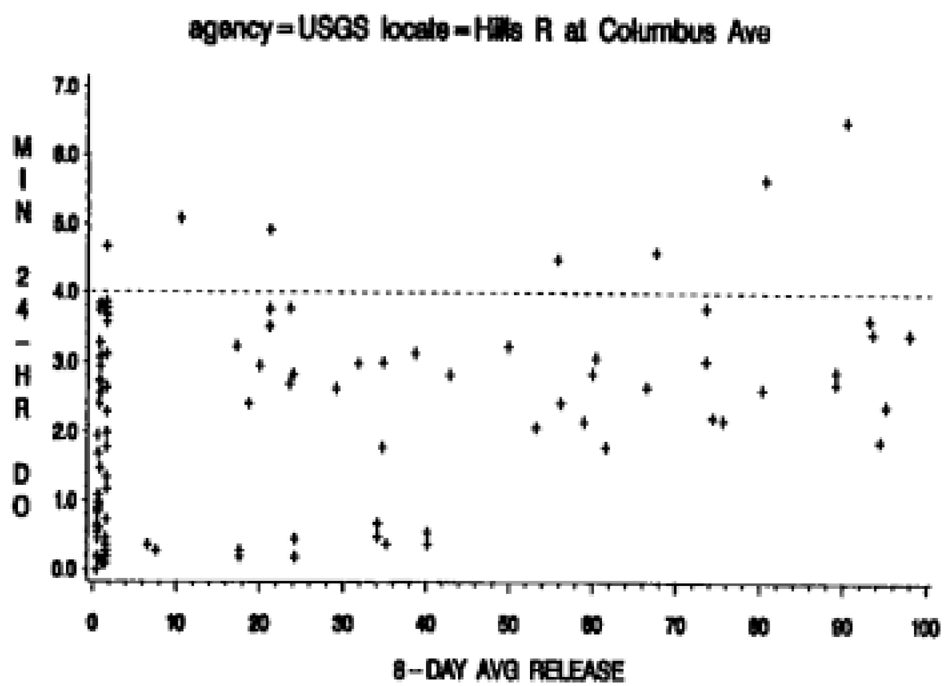
20
30
40
50
60
70
80
90
3-DAY AVG RELEASE

F12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4.0
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10
20
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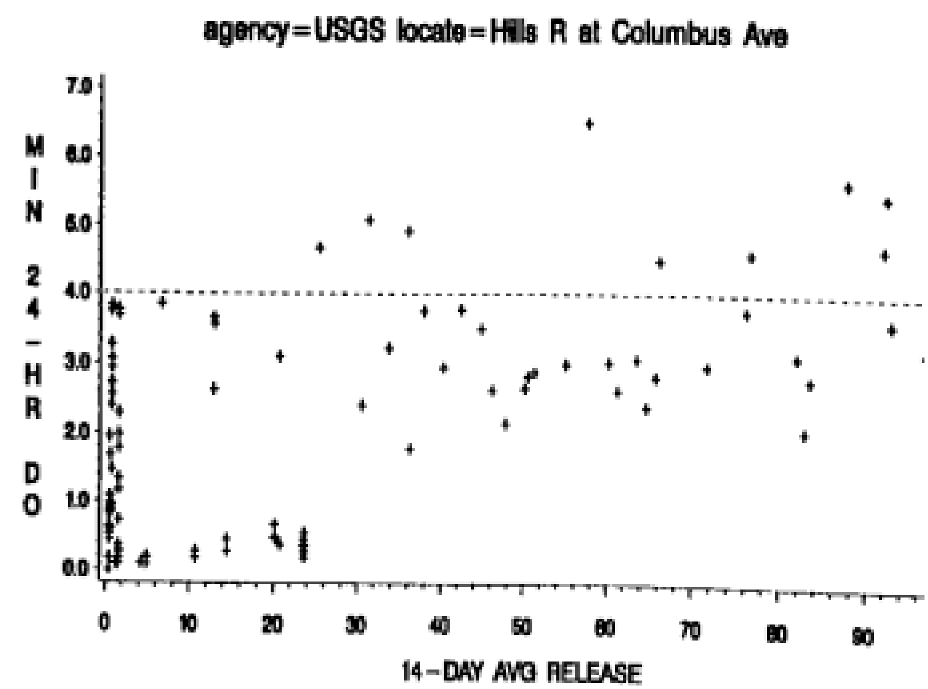
40
50
60
70
80
90
100
8-DAY AVG RELEASE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60
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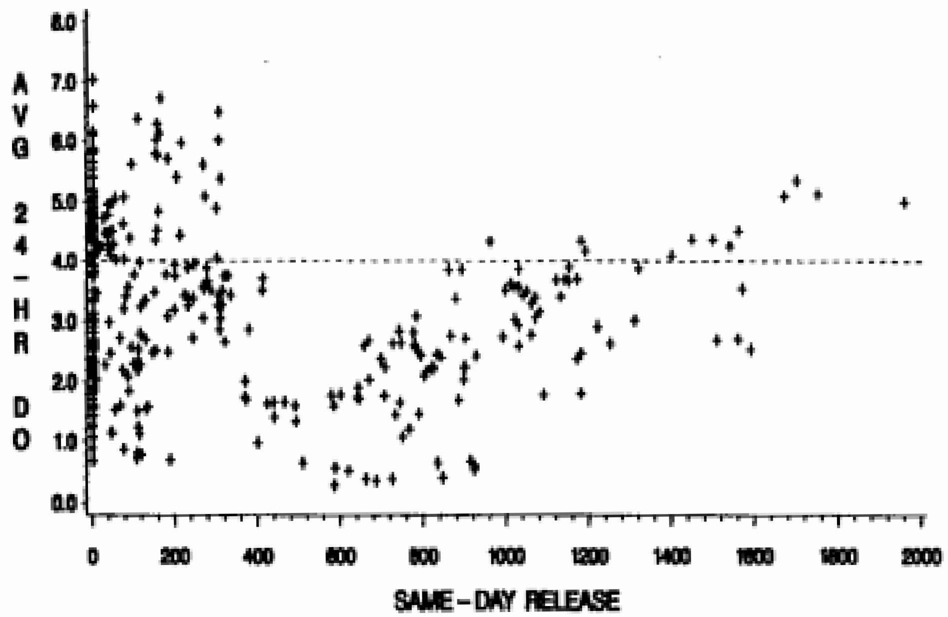
90
14-DAY AVG RELEASE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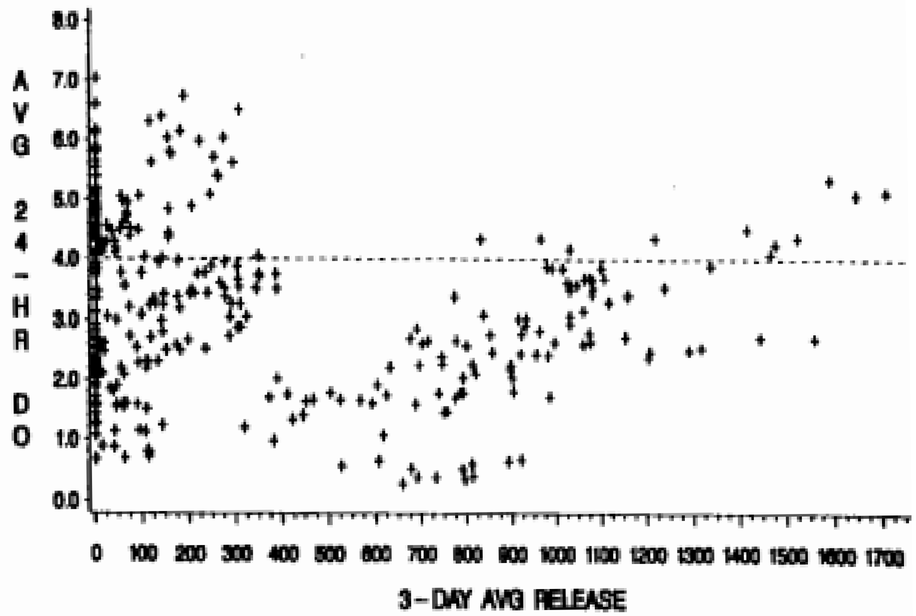
SAME-DAY RELEASE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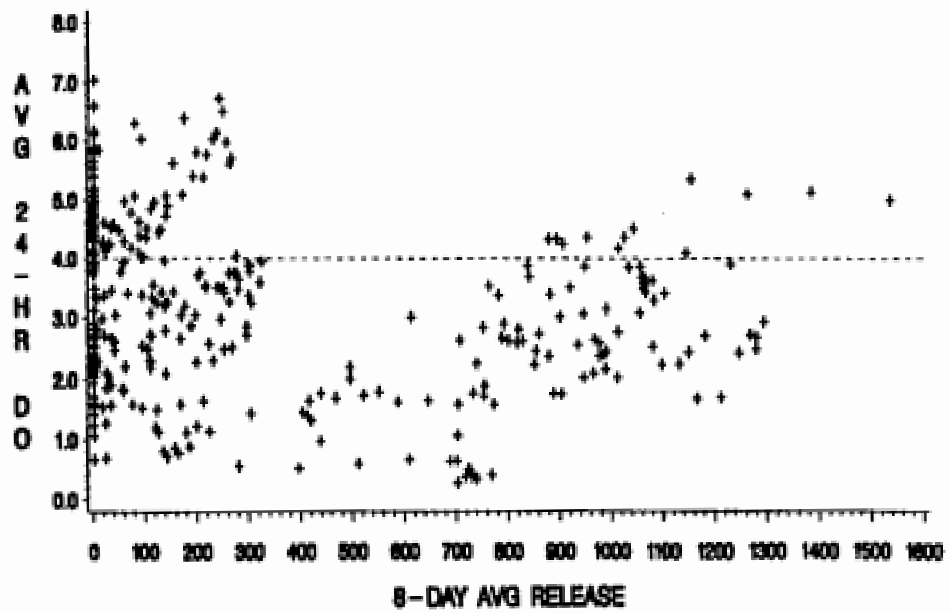
3-DAY AVG RELEASE

E13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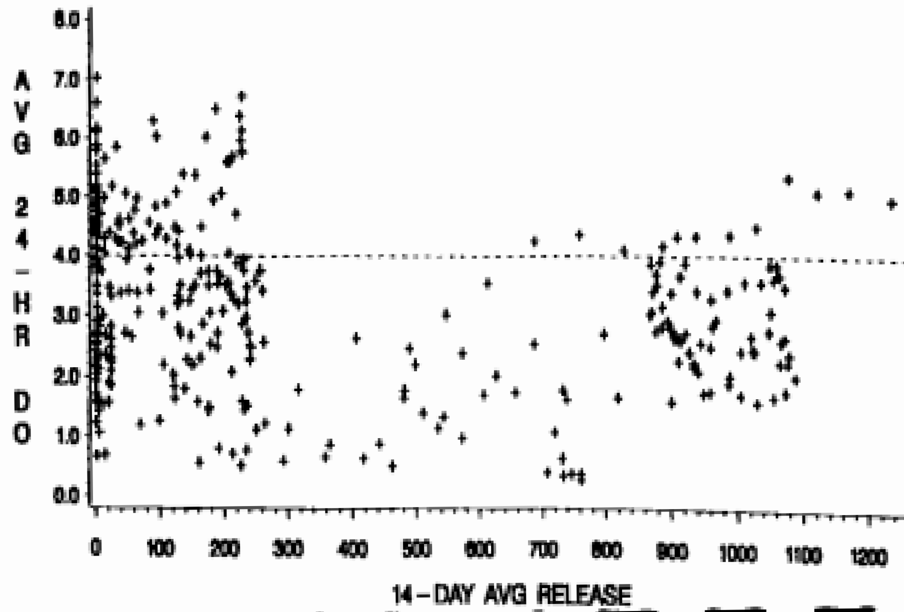
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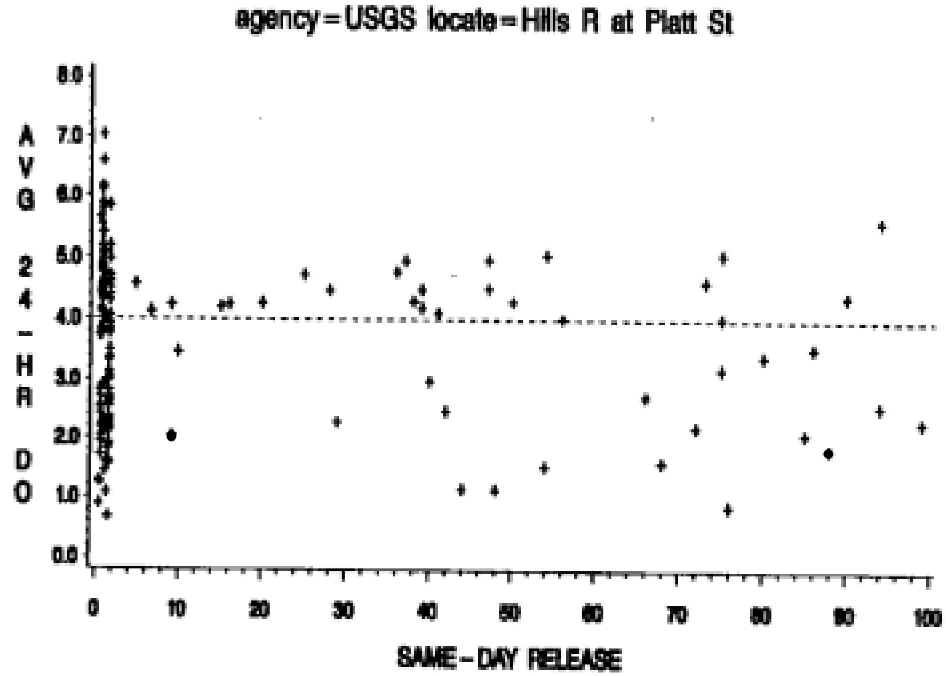
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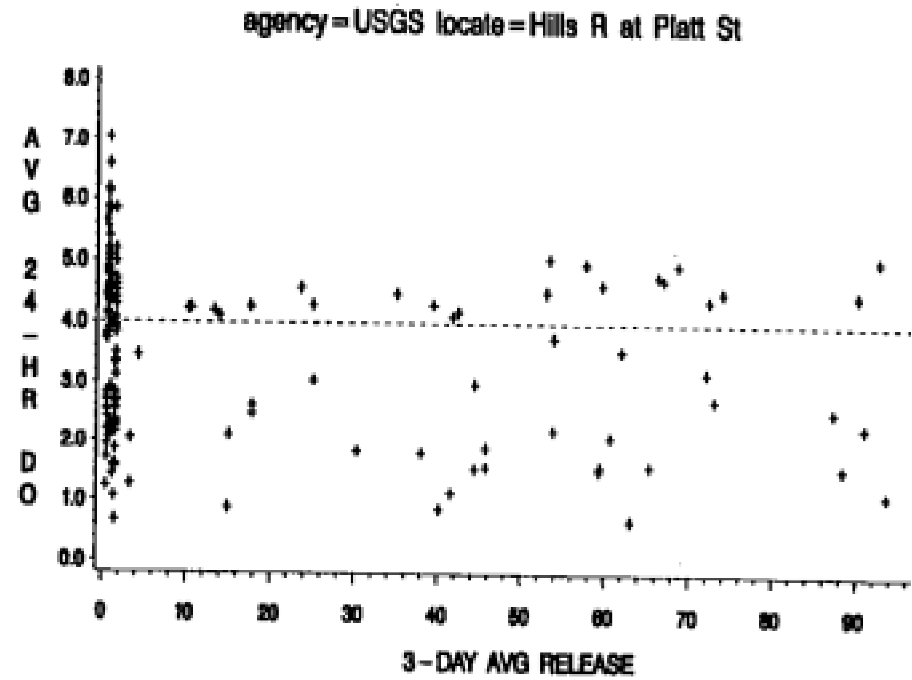
AVG 24-HR DO
SAME-DAY RELEASE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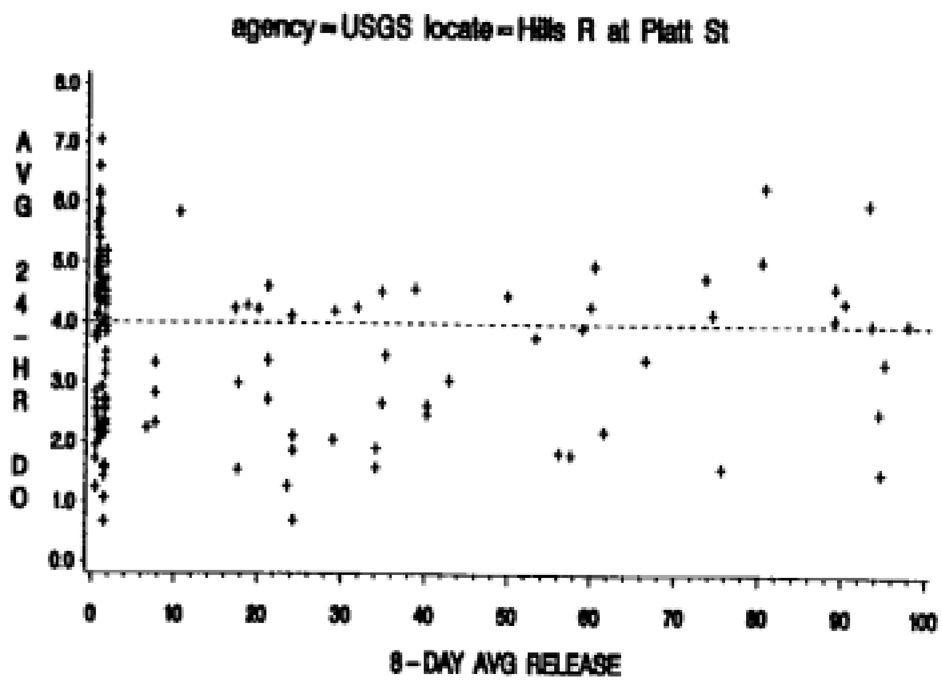
AVG 24-HR DO
3-DAY AVG RELEASE

F14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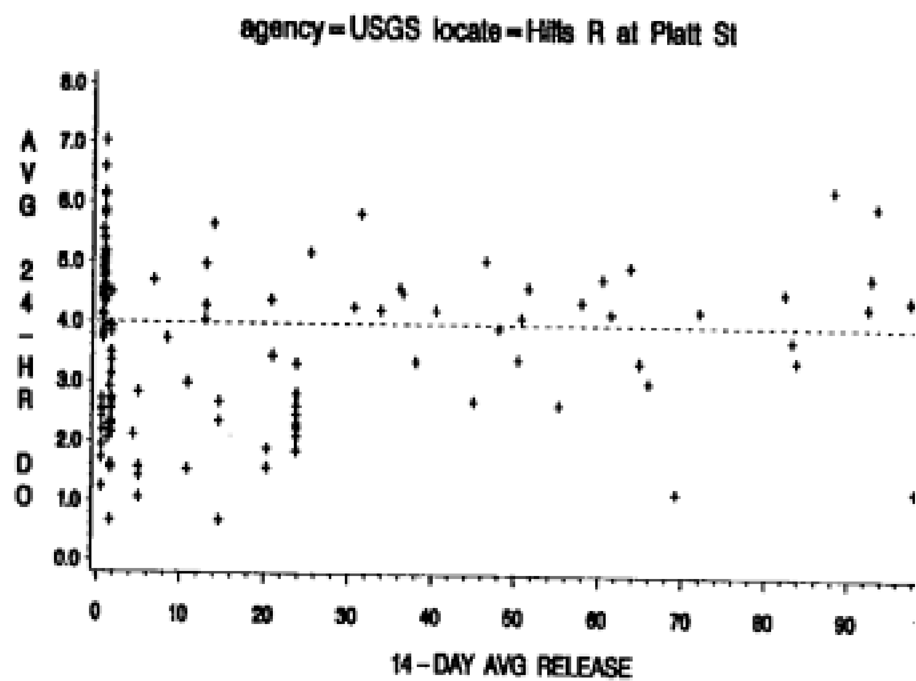
AVG 24-HR DO
8-DAY AVG RELEASE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AVG 24-HR DO
14-DAY AVG RELEASE

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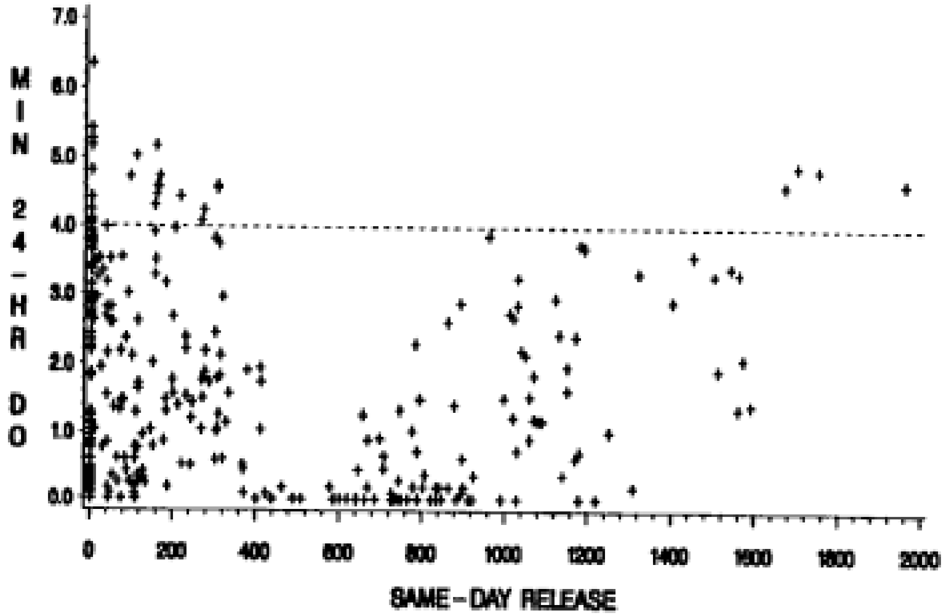

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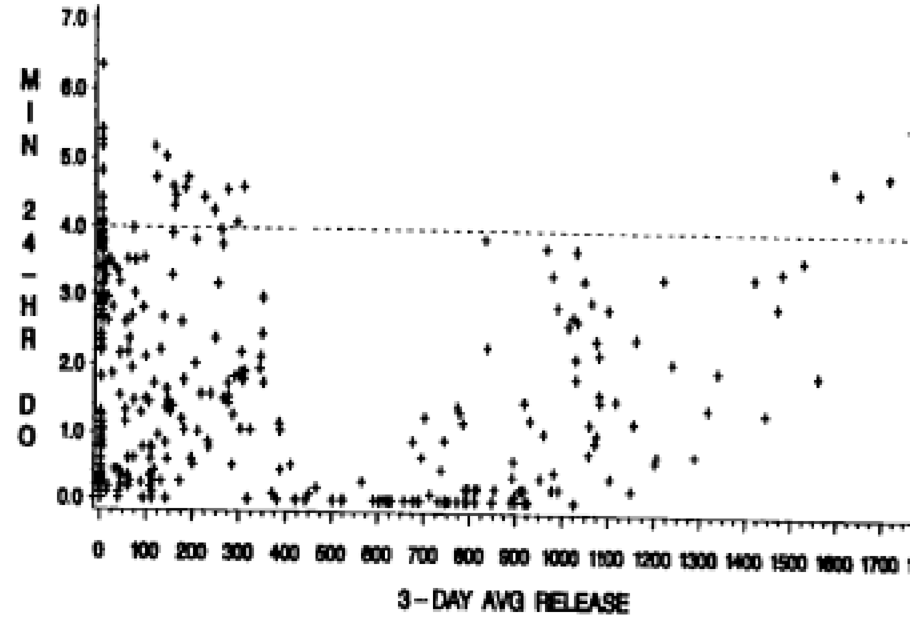

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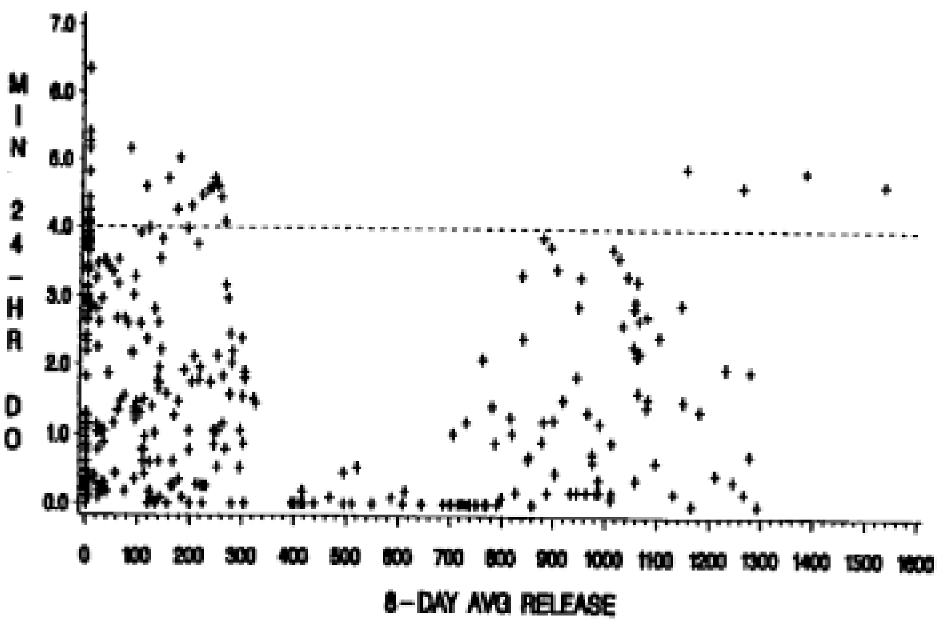

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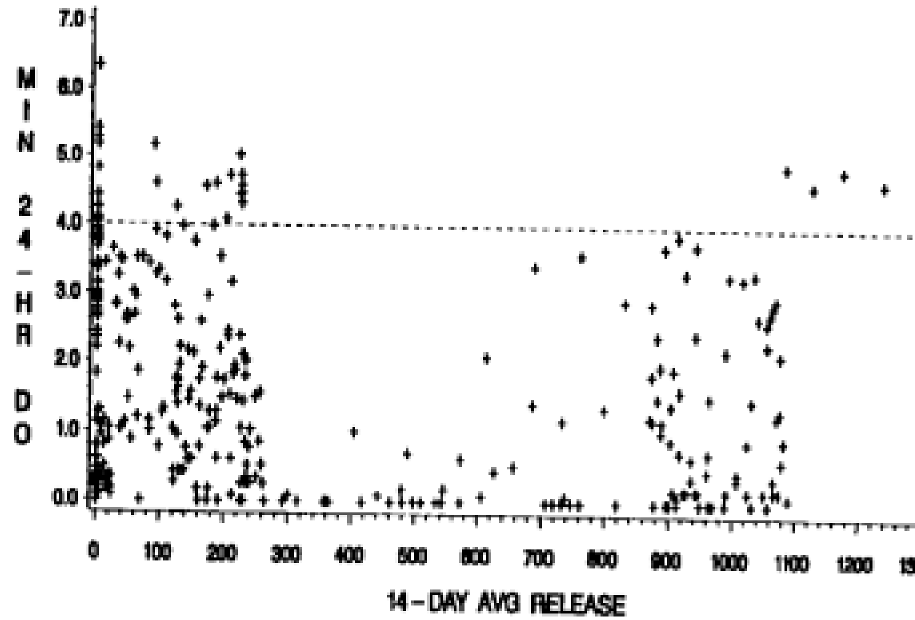

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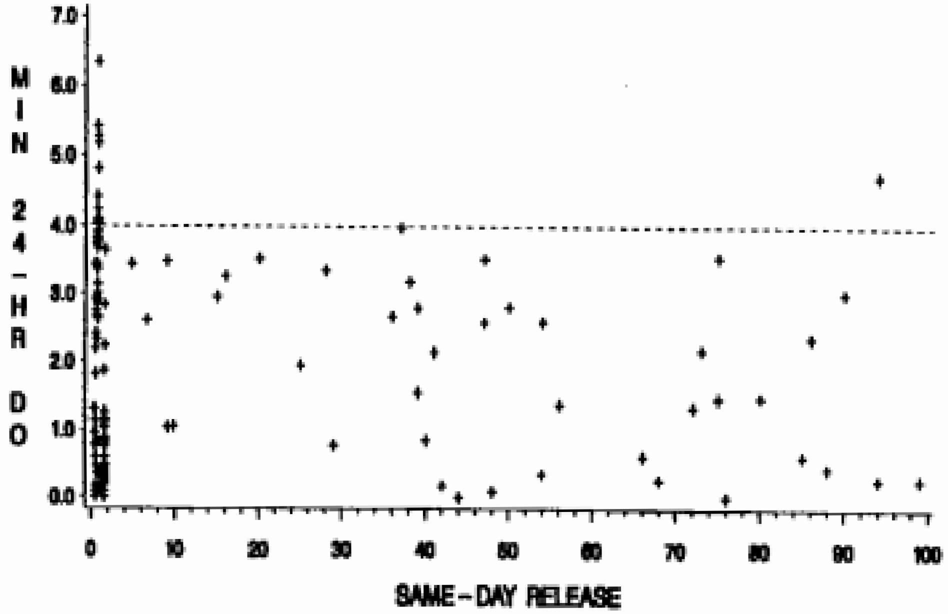

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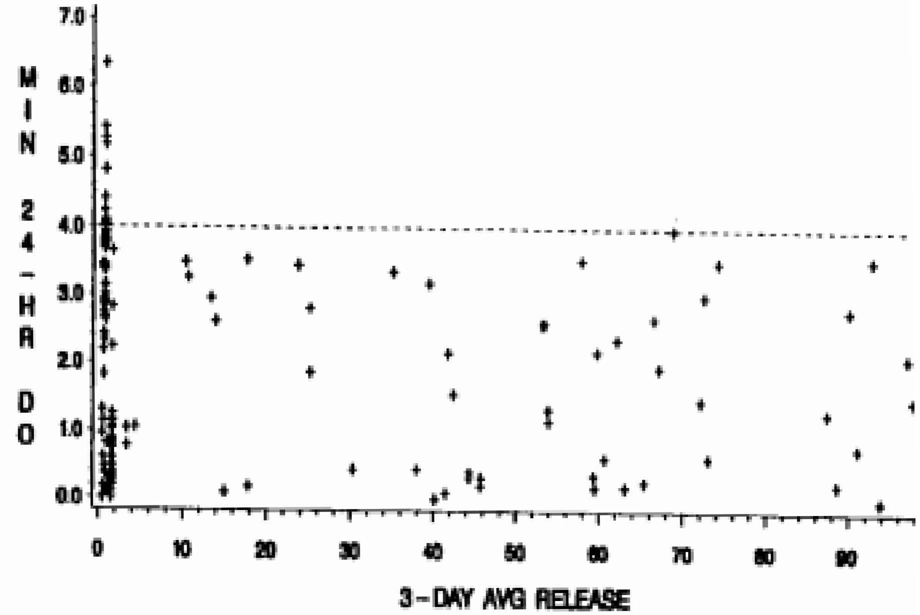

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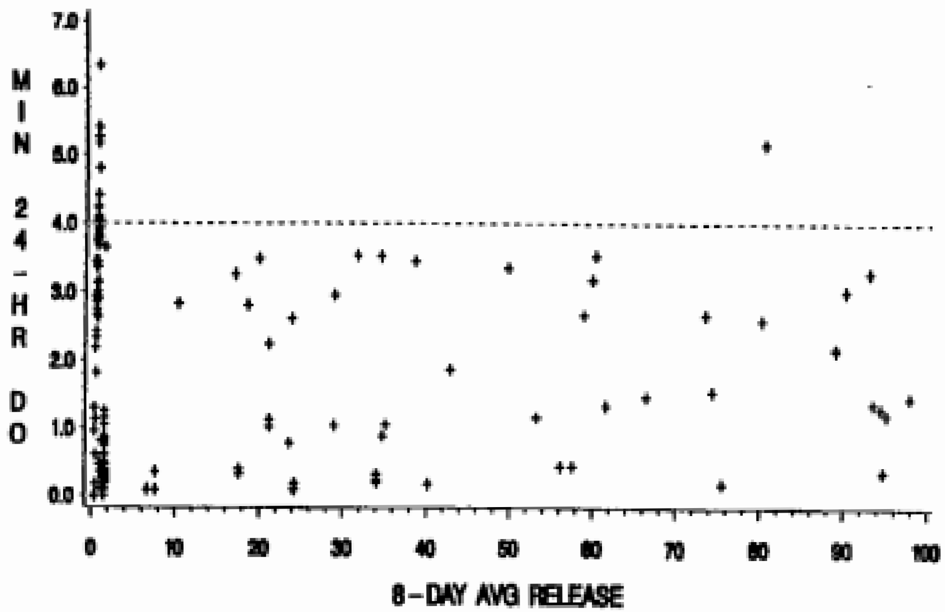

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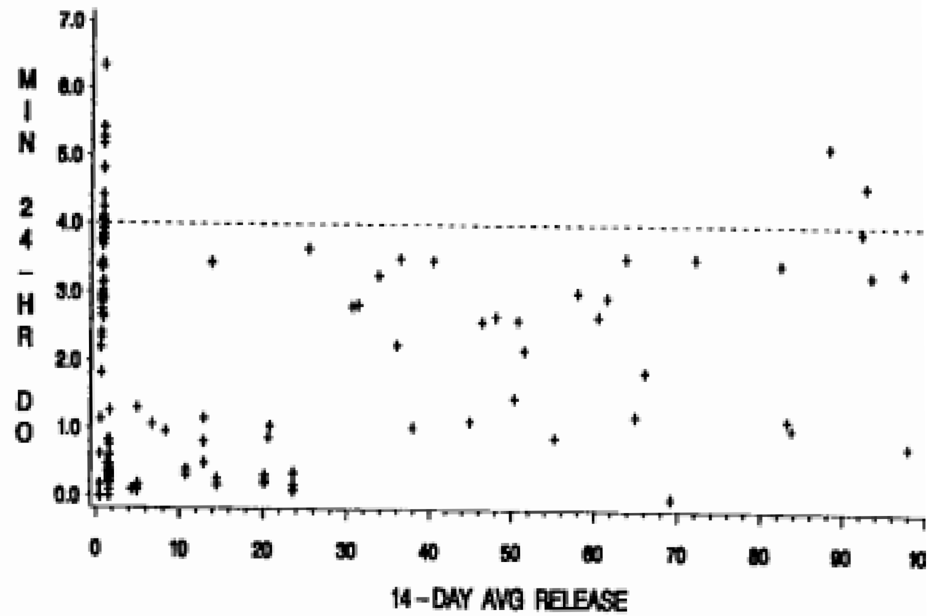
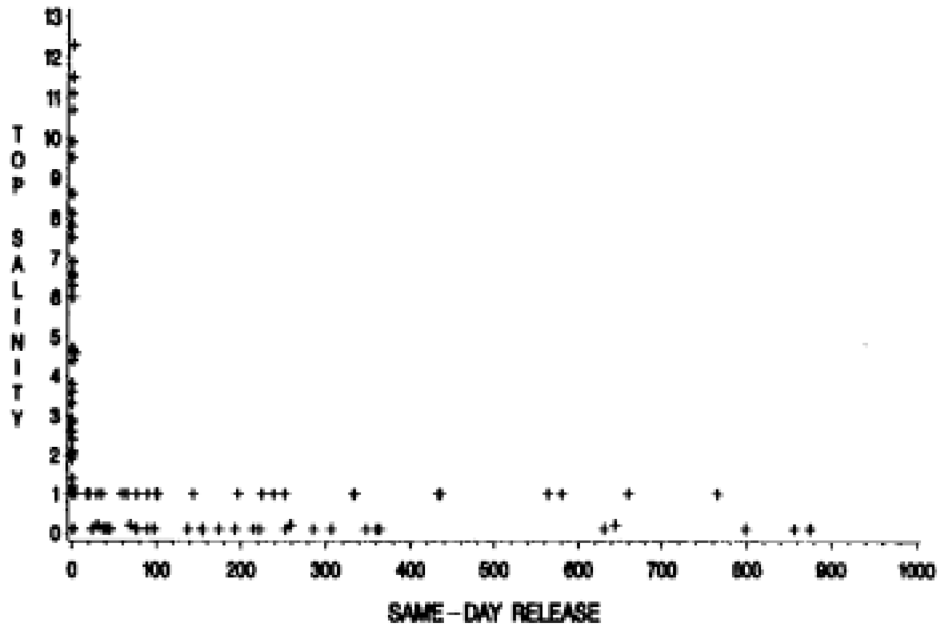


APPENDIX G

Plots of surface, mid-depth and bottom salinity at the HCEPC stations vs. discharge from the Hillsborough River Reservoir. (Units are parts per thousand for salinity and cfs for discharge).

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



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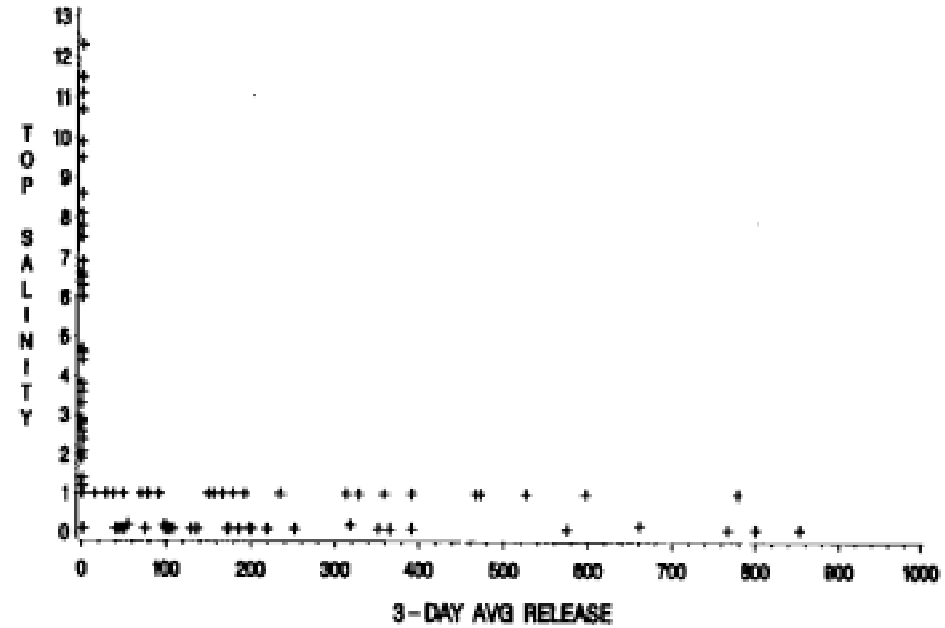
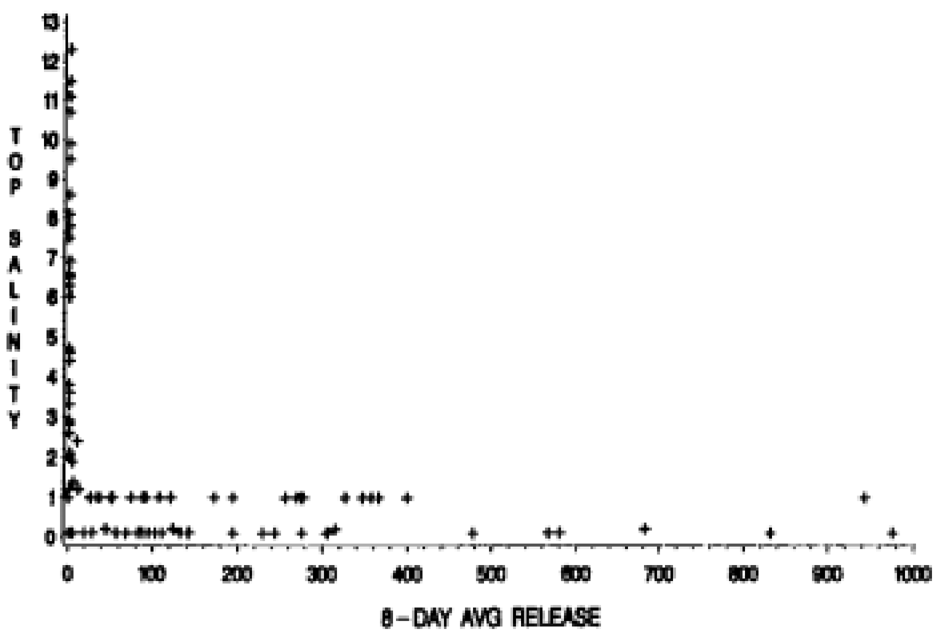


6-1

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



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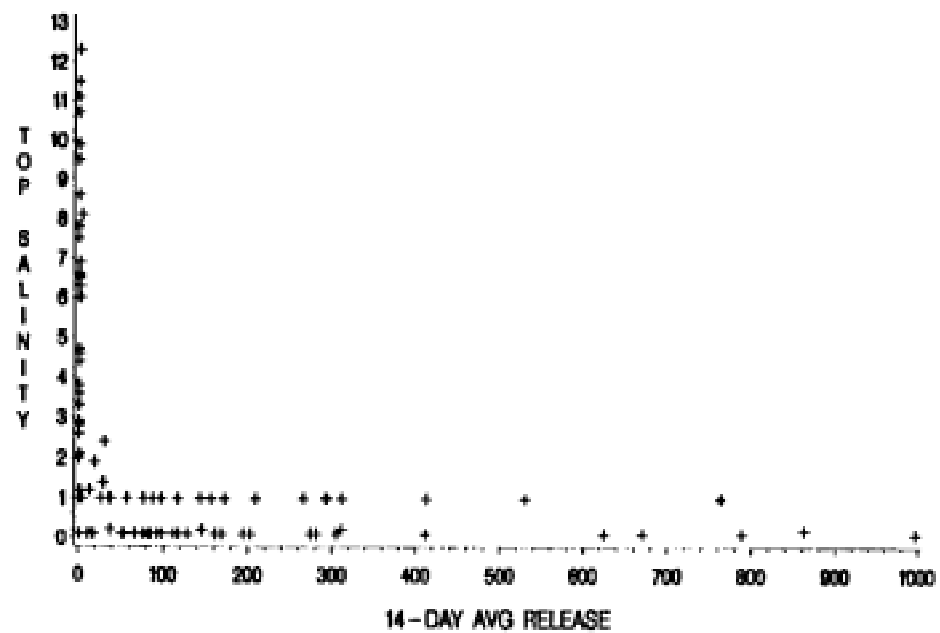

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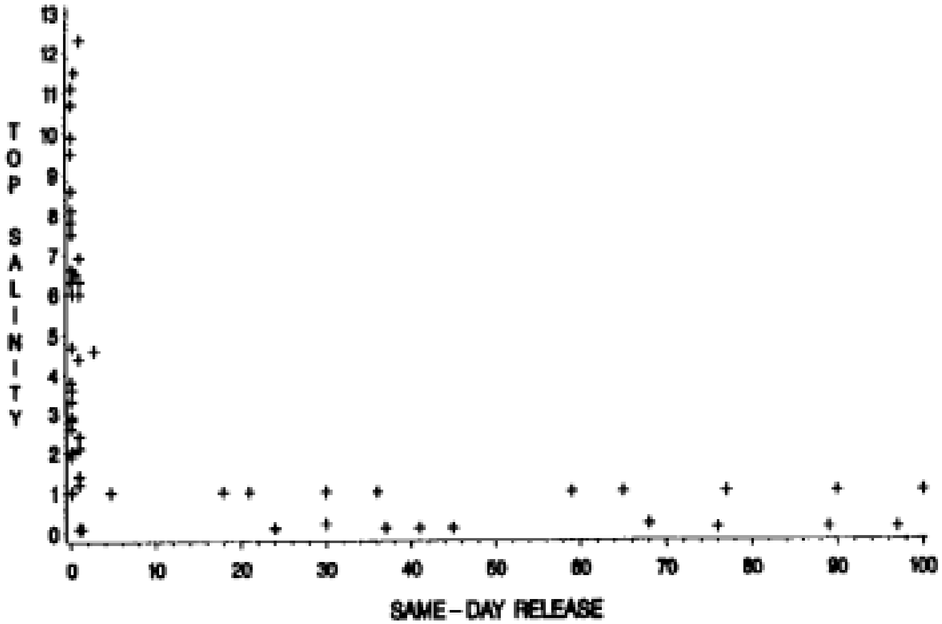

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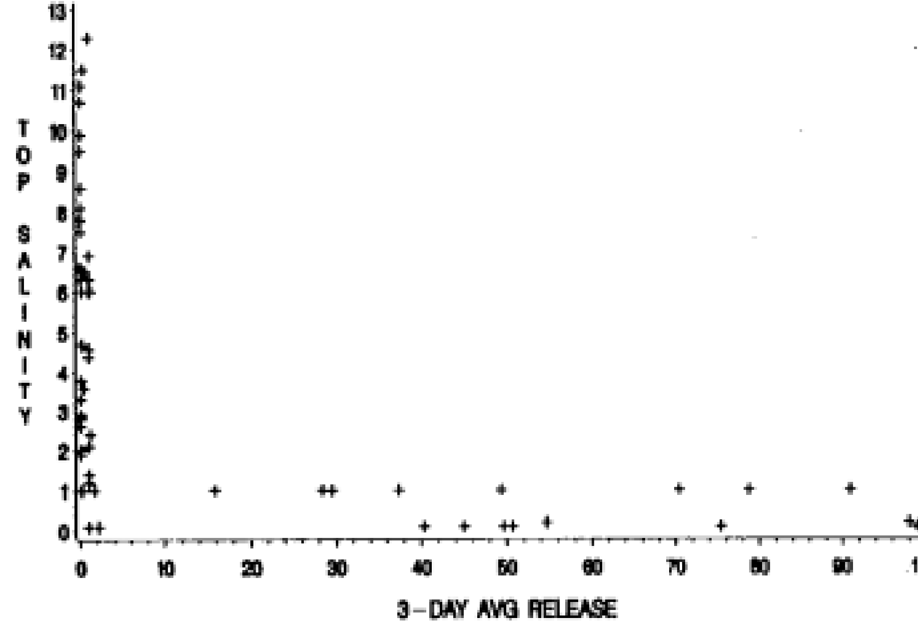

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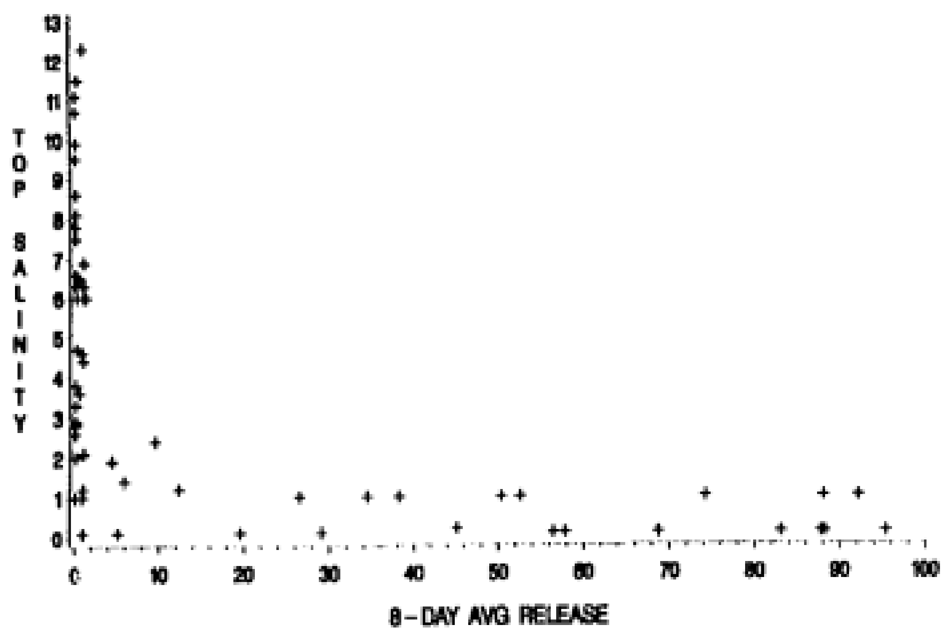

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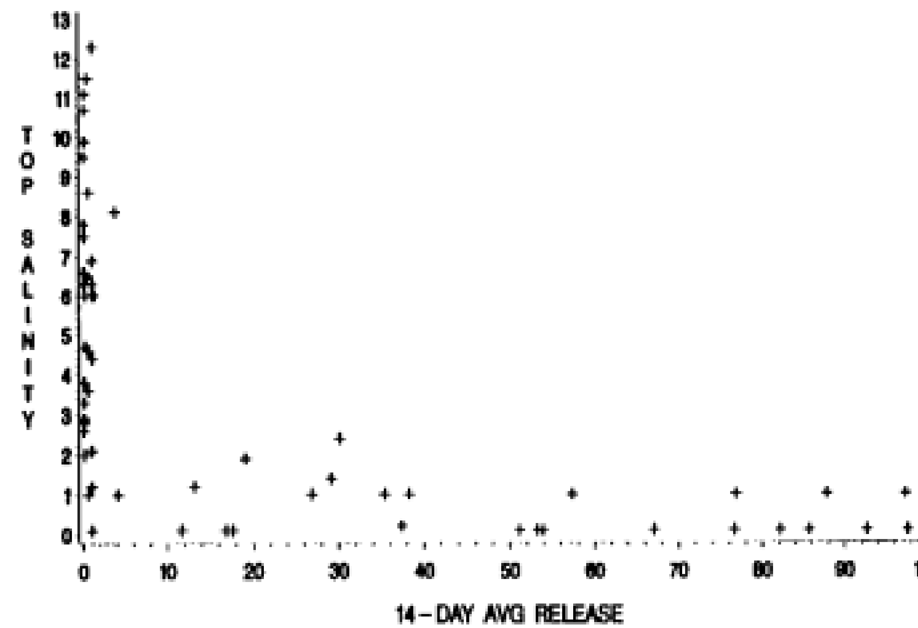

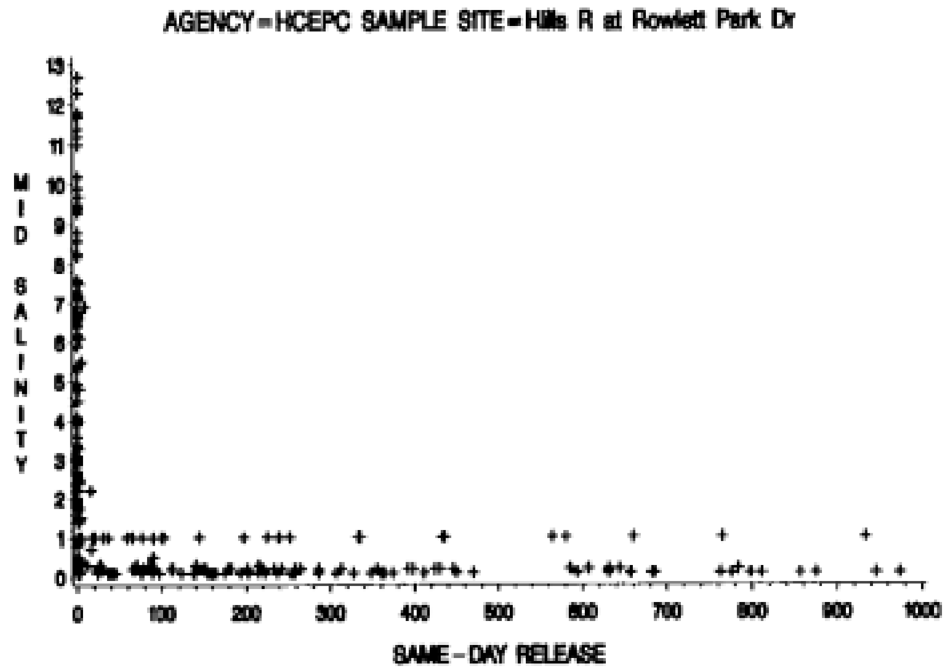
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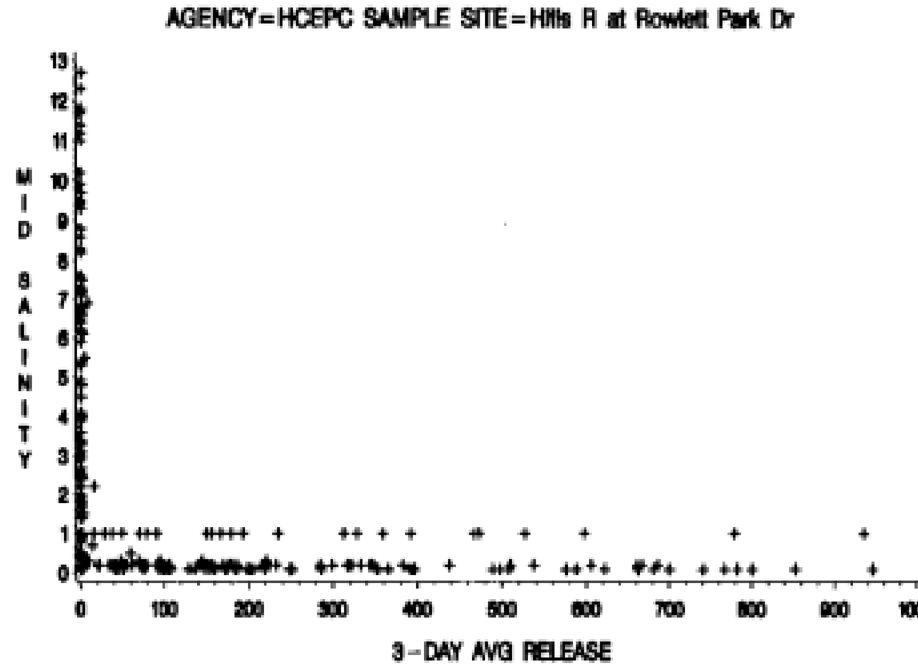
MID SALINITY
SAME-DAY RELEASE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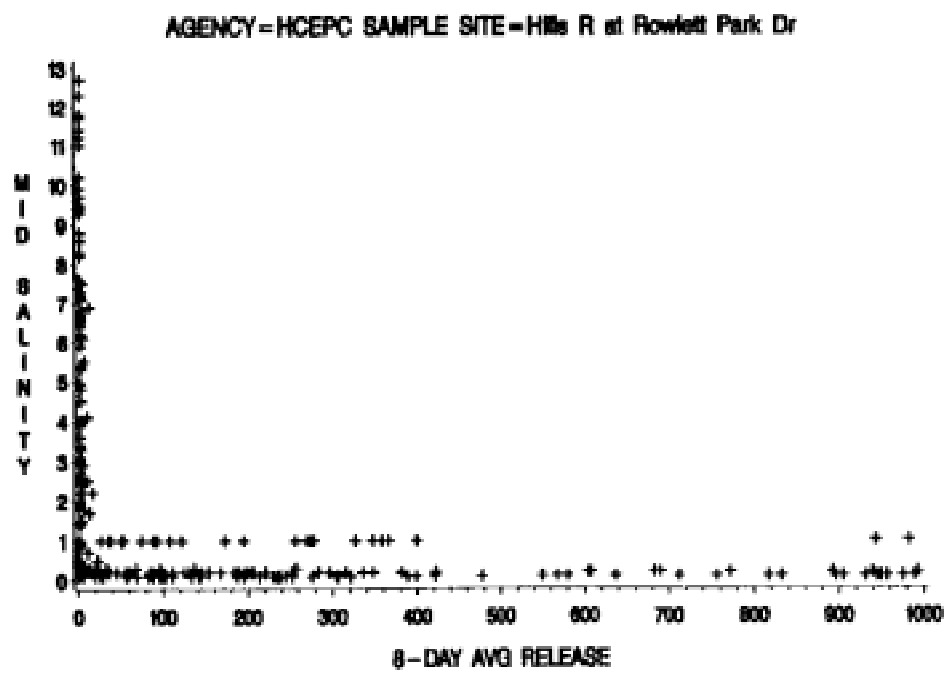
MID SALINITY
3-DAY AVG RELEASE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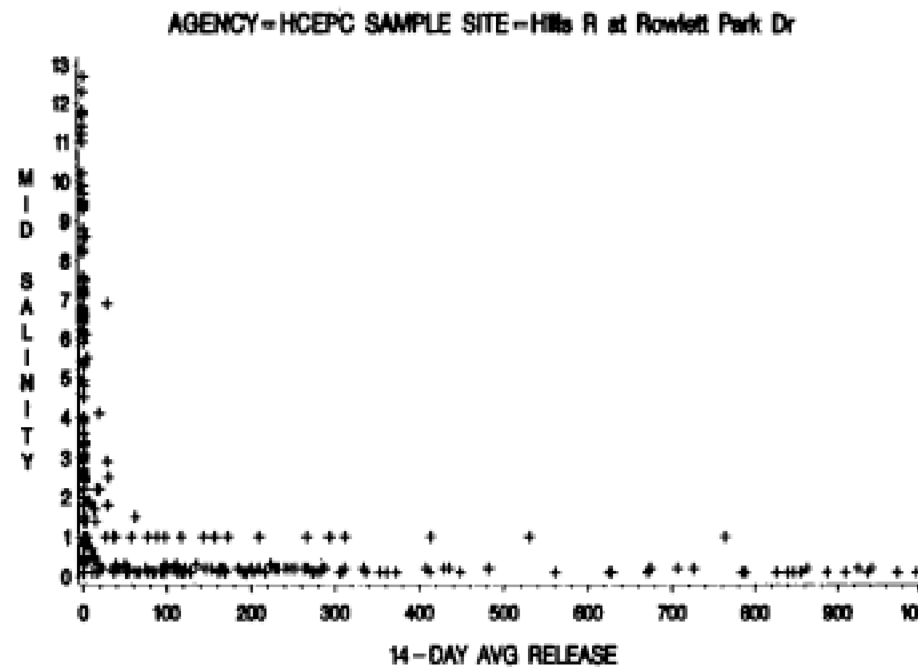
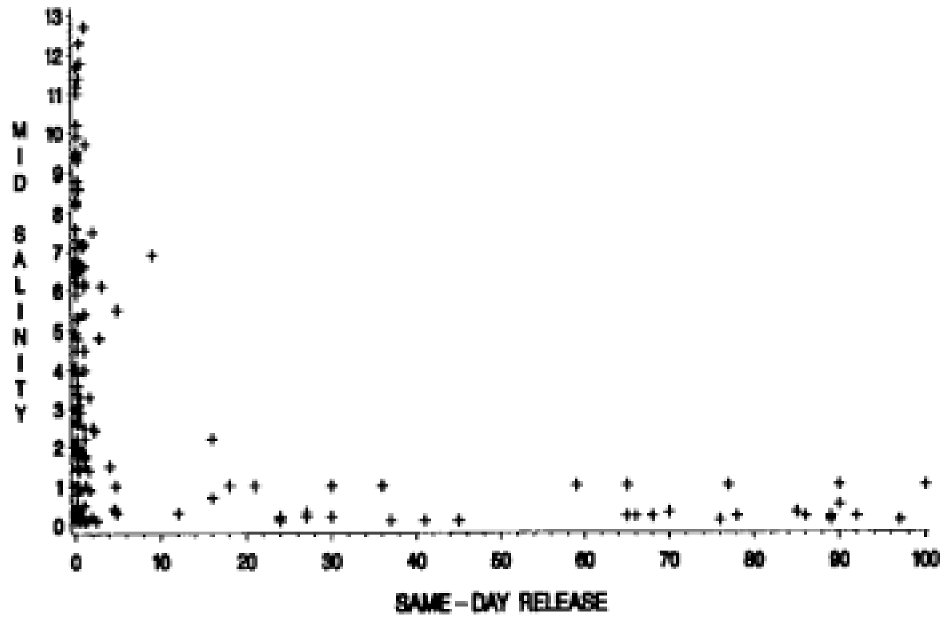
MID SALINITY
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
MID SALINITY
14-DAY AVG RELEASE

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



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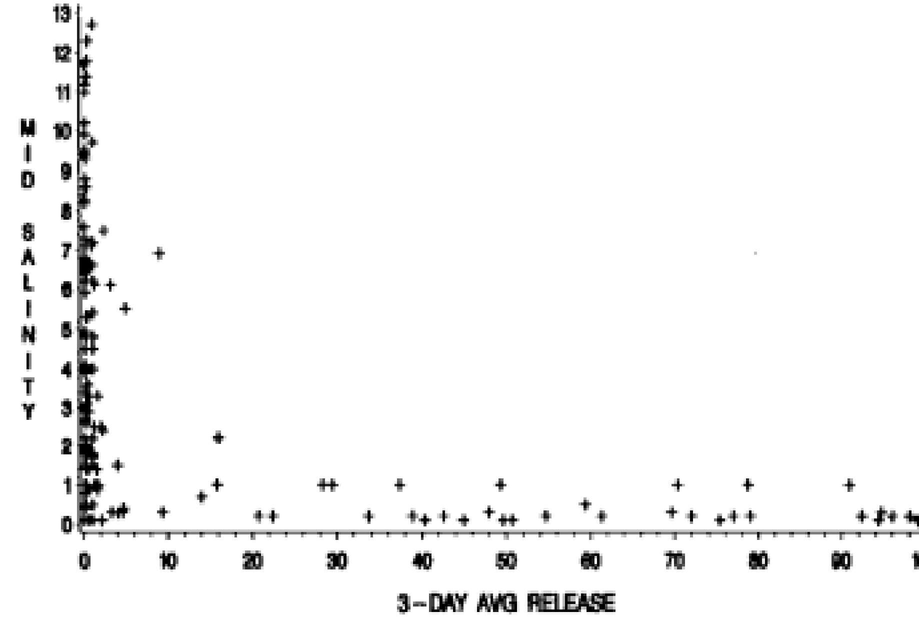

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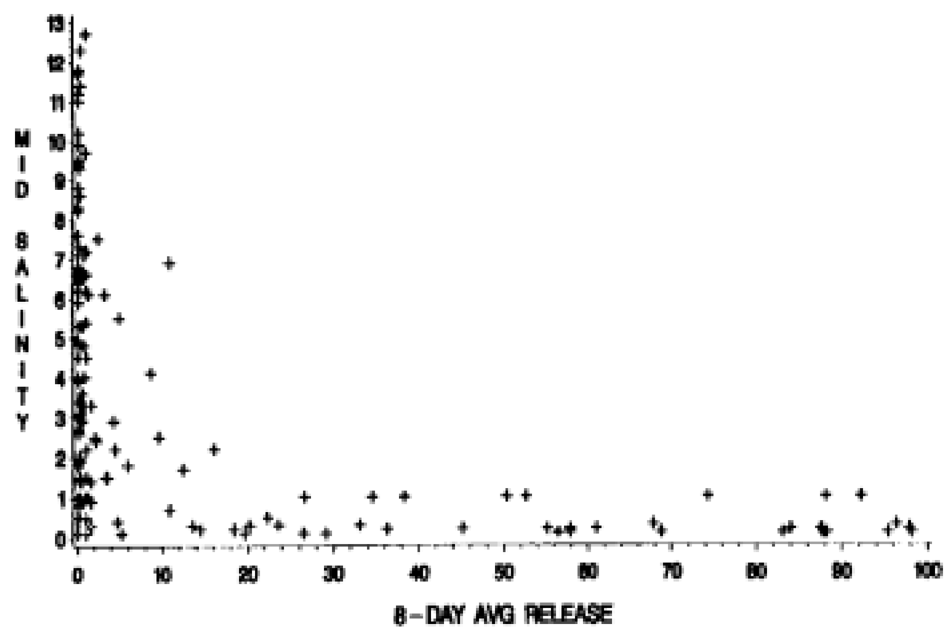

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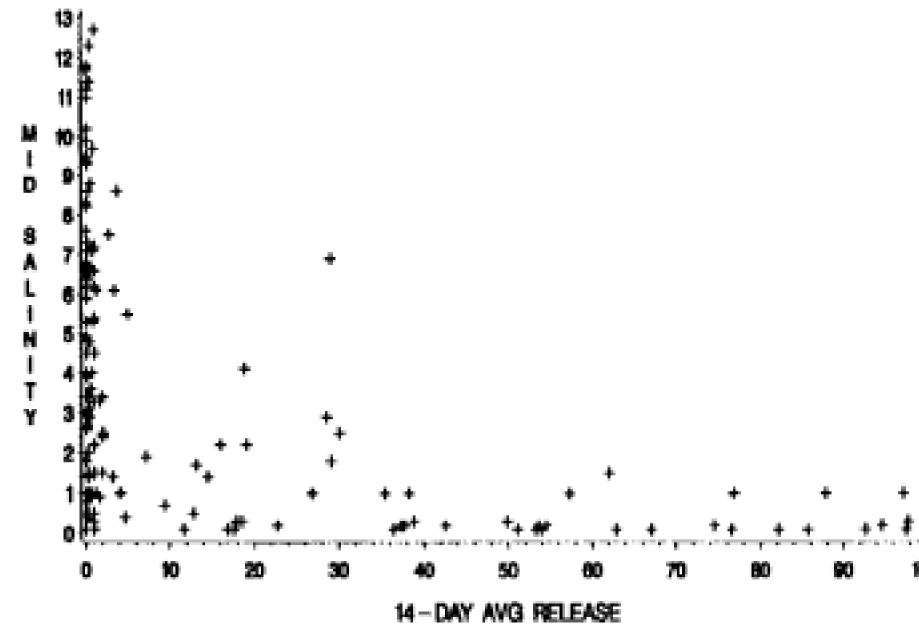

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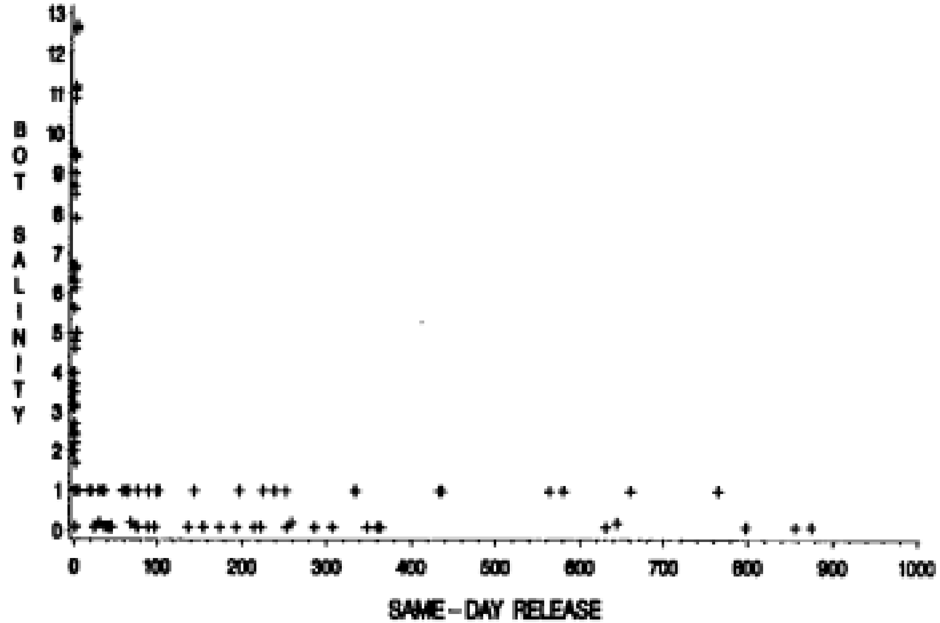

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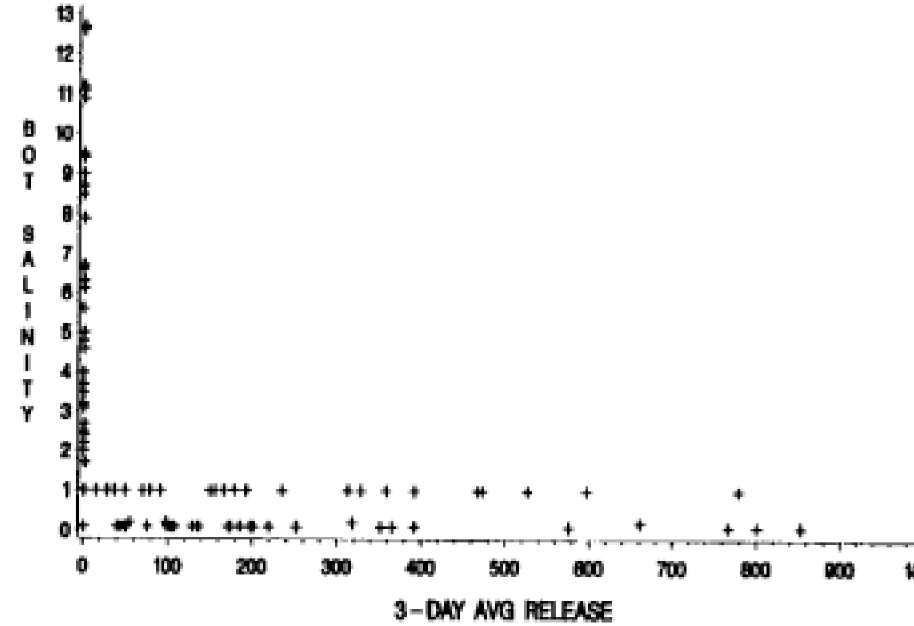

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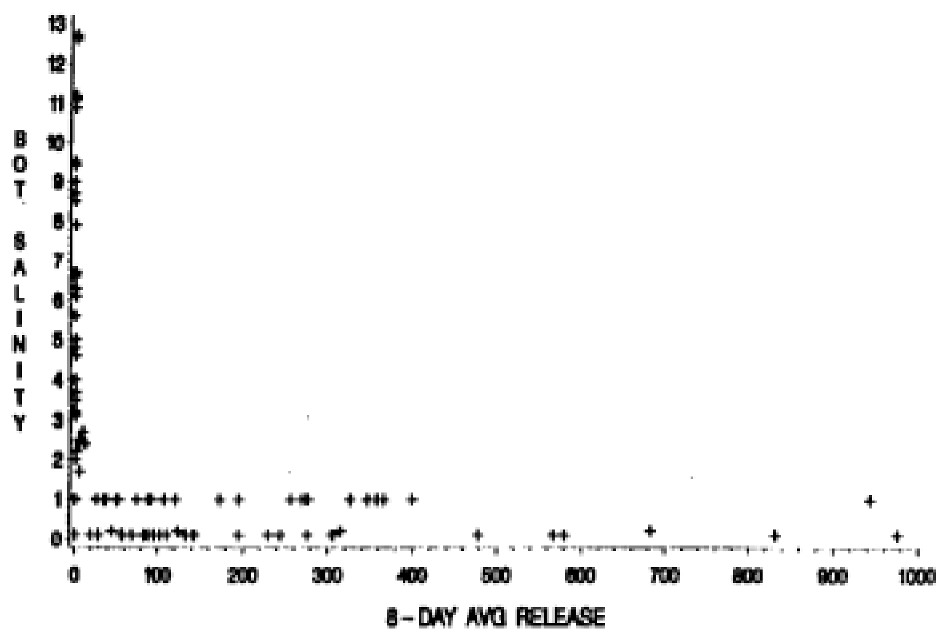

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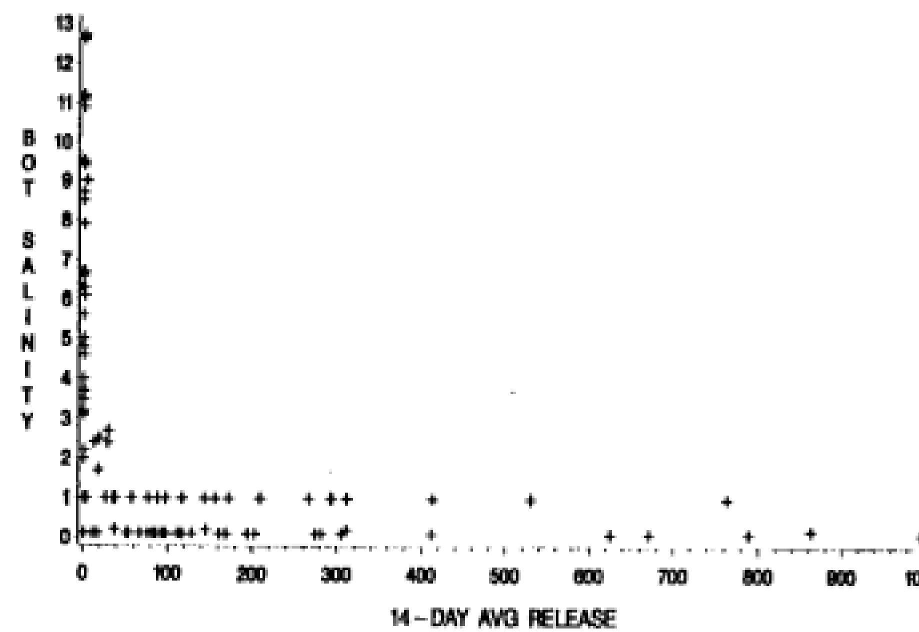

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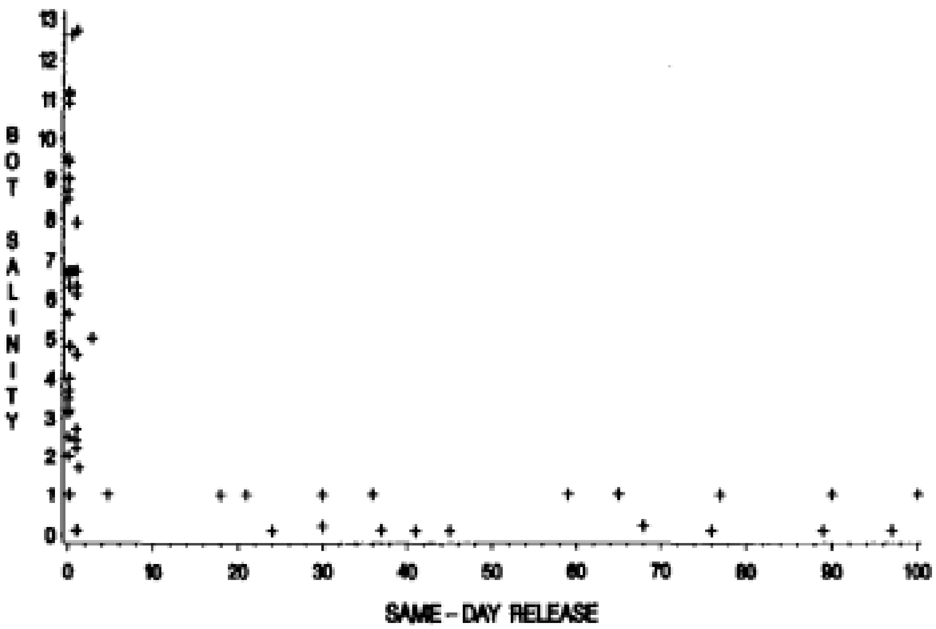

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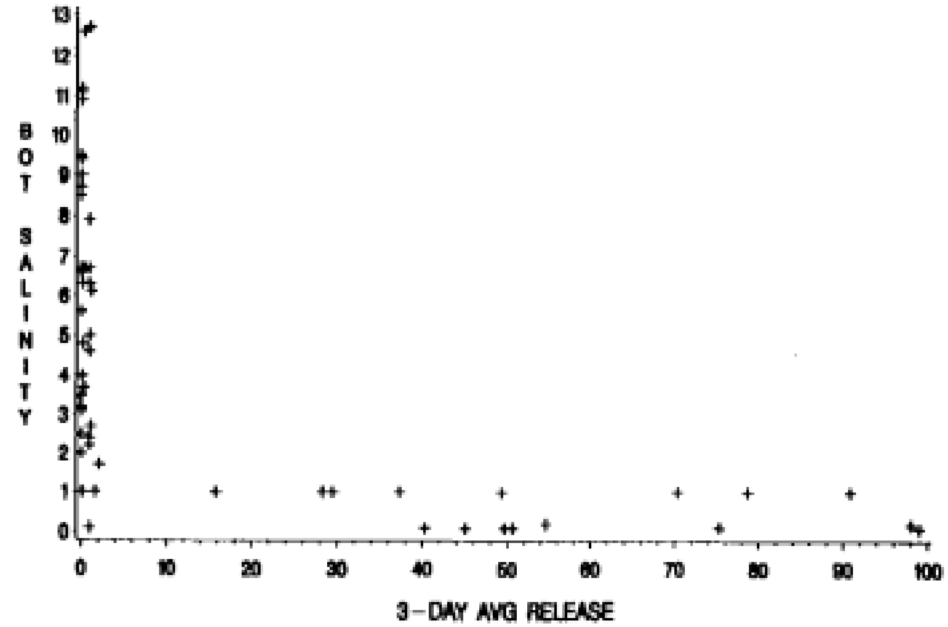

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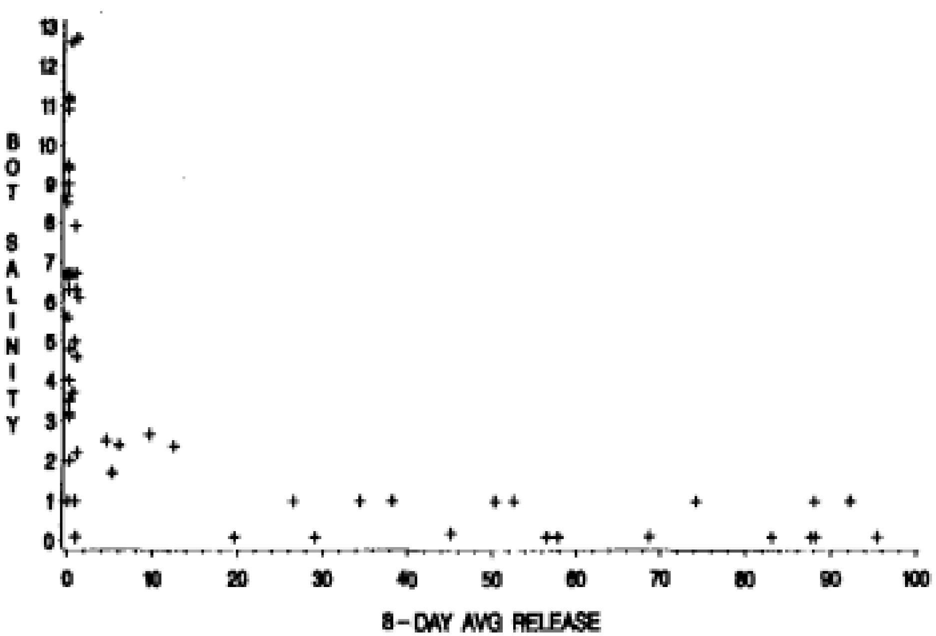

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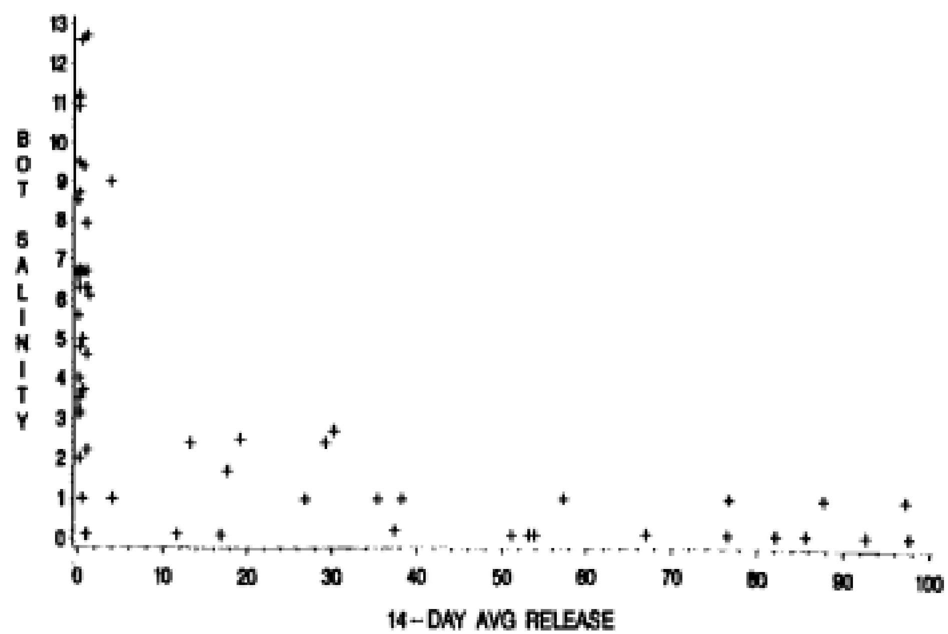

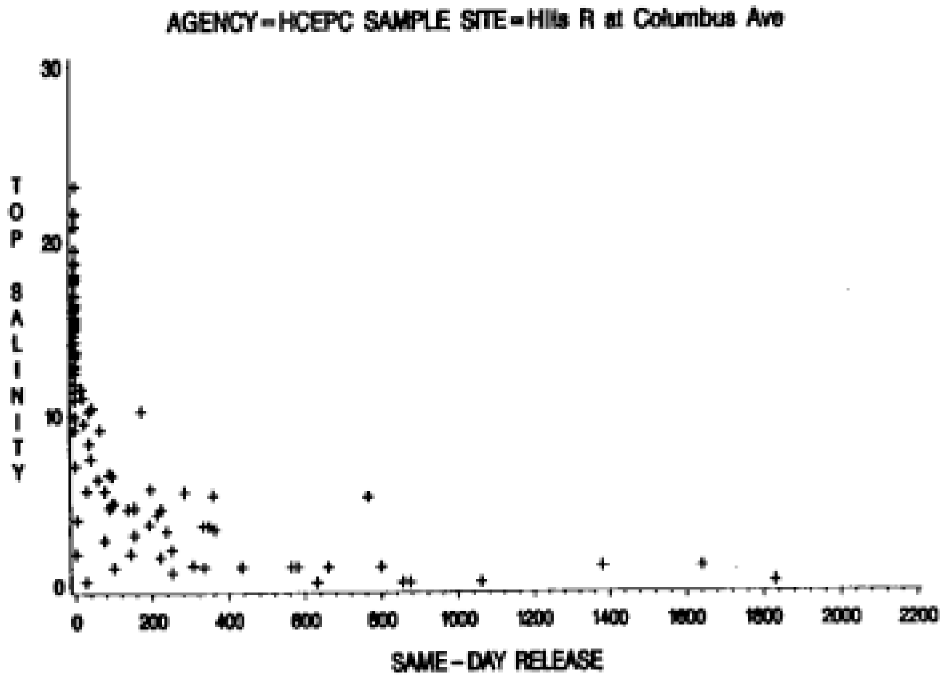
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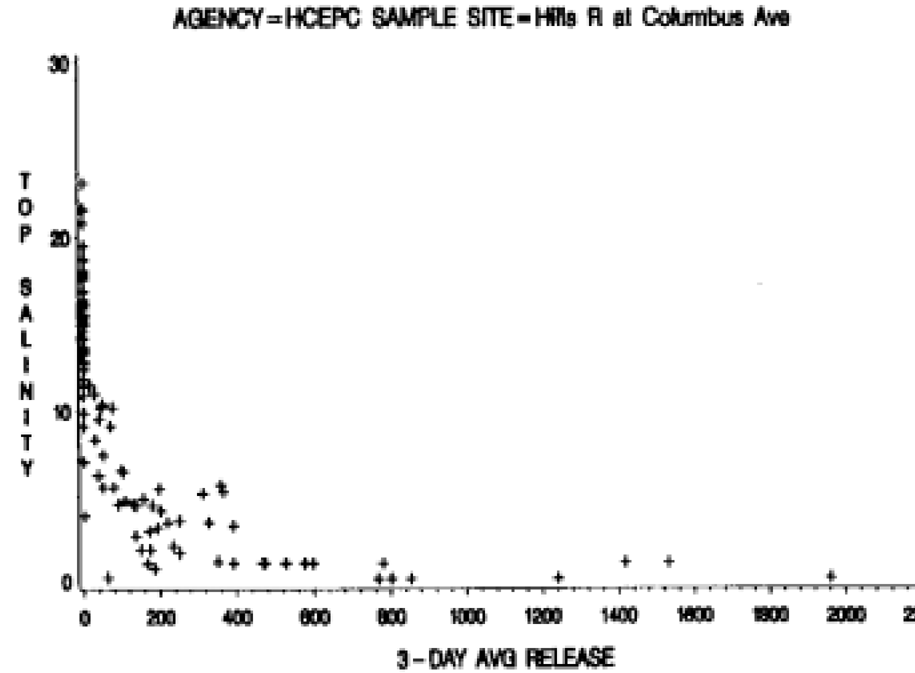
TOP SALINITY
SAME-DAY RELEASE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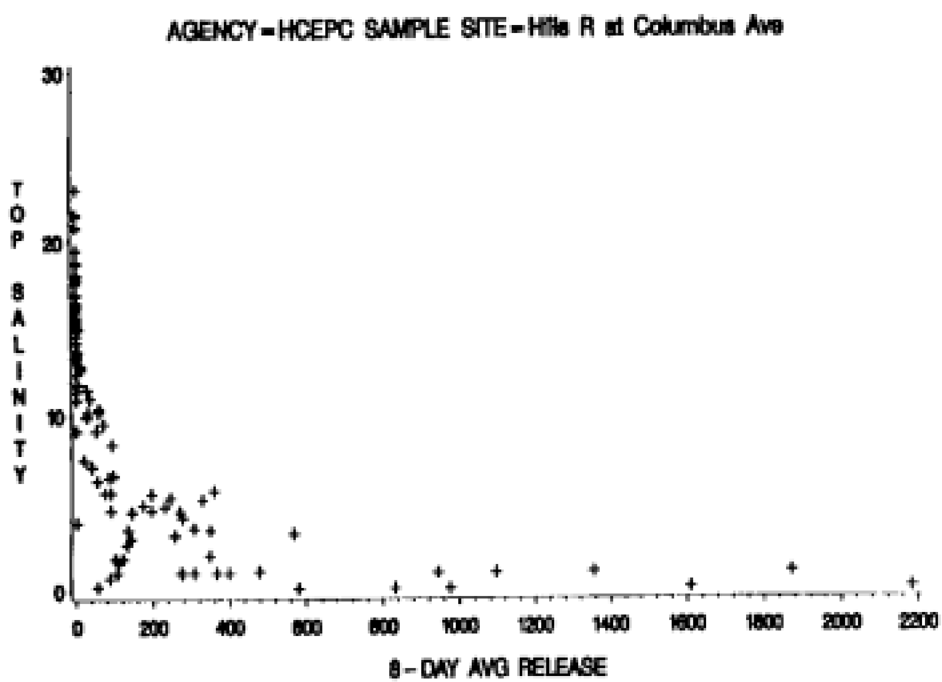
TOP SALINITY
3-DAY AVG RELEASE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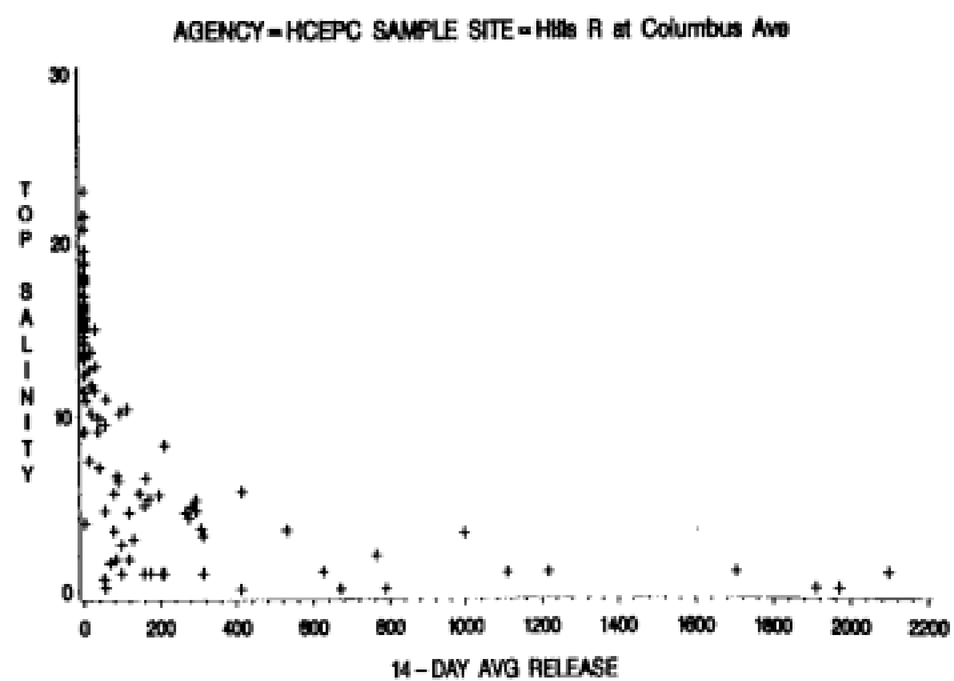
TOP SALINITY
8-DAY AVG RELEASE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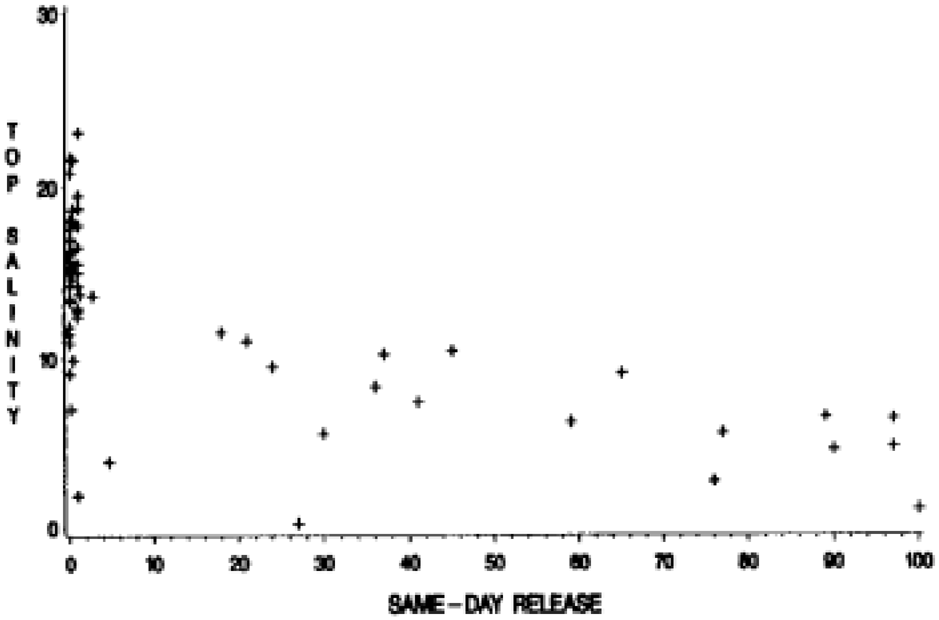
TOP SALINITY
14-DAY AVG RELEASE

G-7

AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



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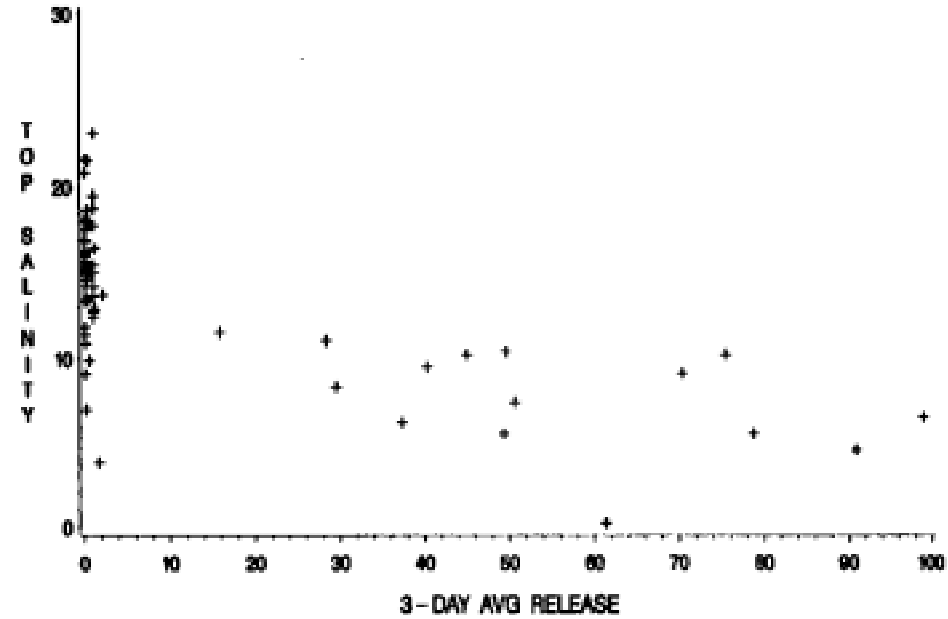

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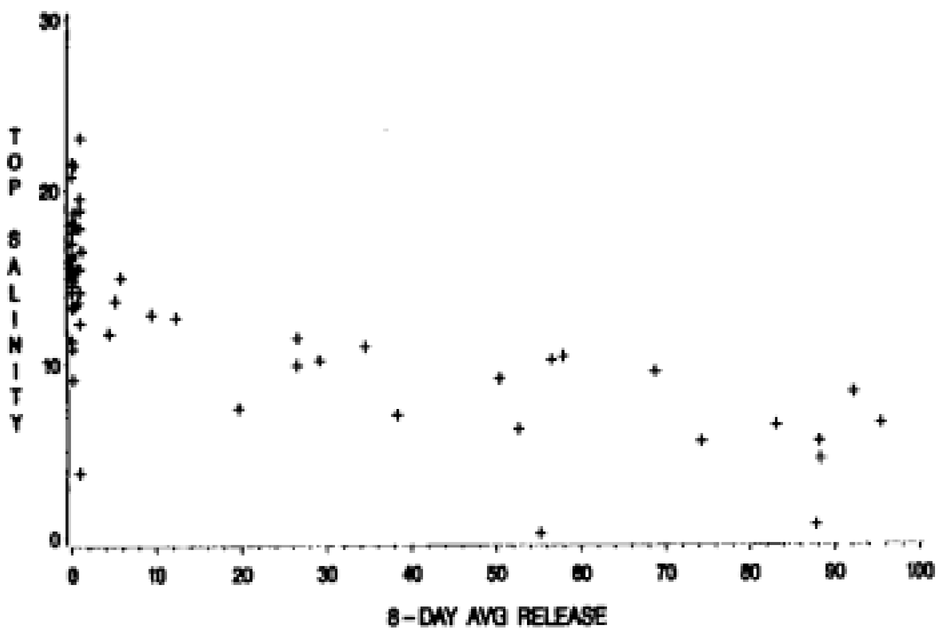

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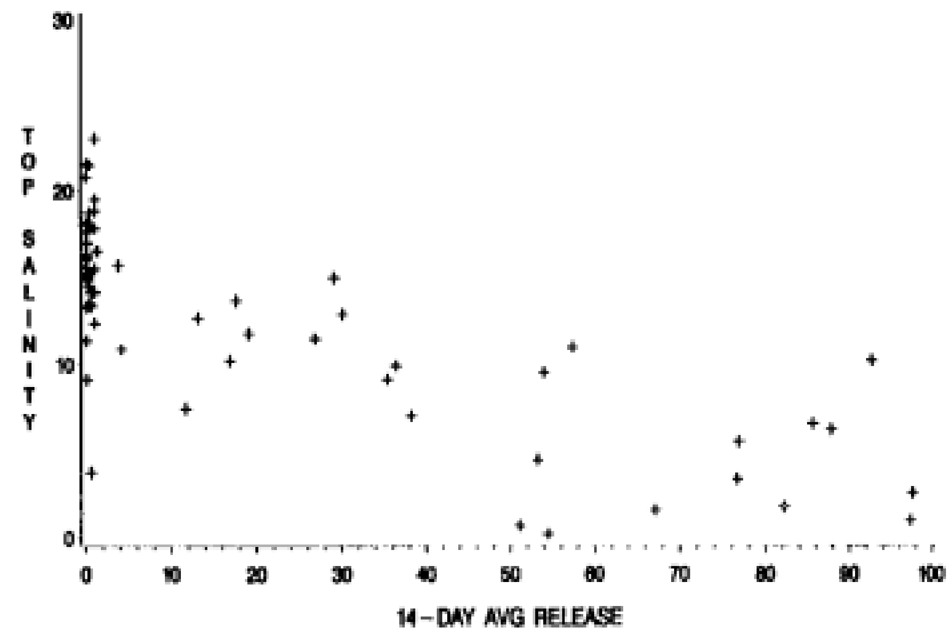

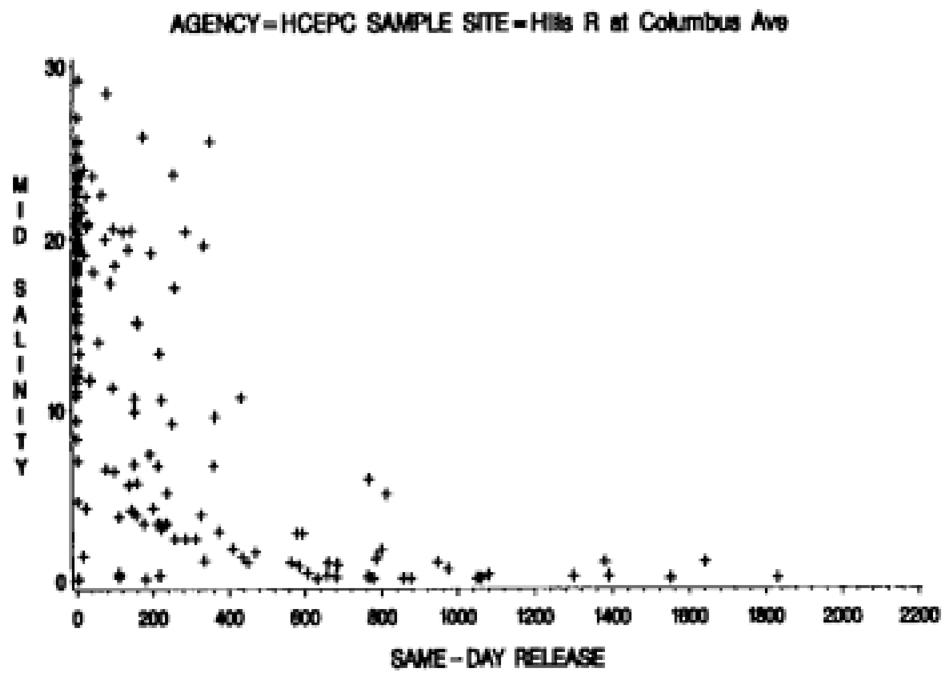
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MID SALINITY
SAME-DAY RELEASE
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20
30
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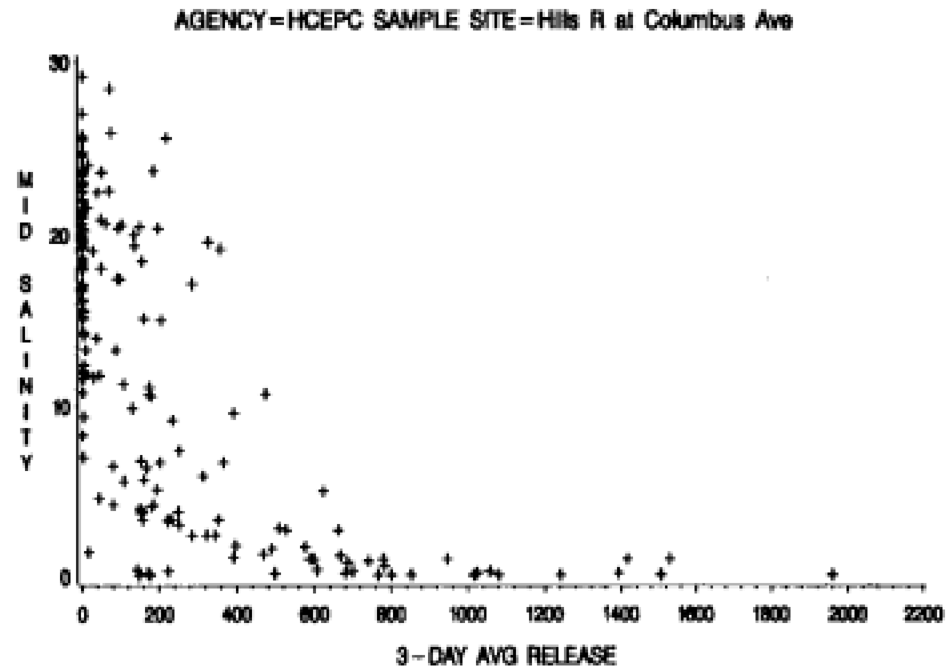
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MID SALINITY
3-DAY AVG RELEASE
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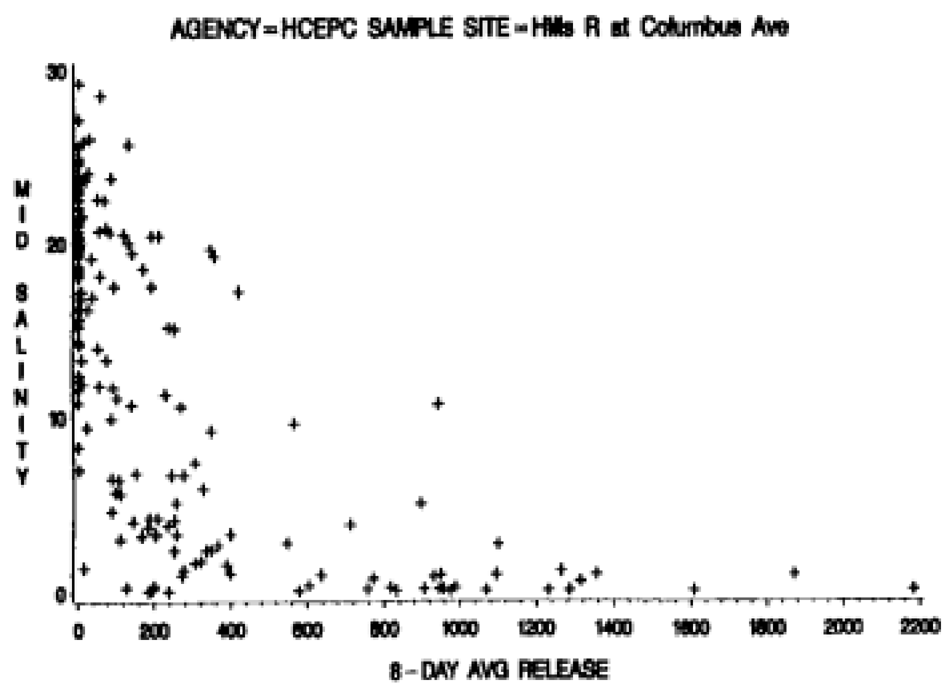
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MID SALINITY
8-DAY AVG RELEASE
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30
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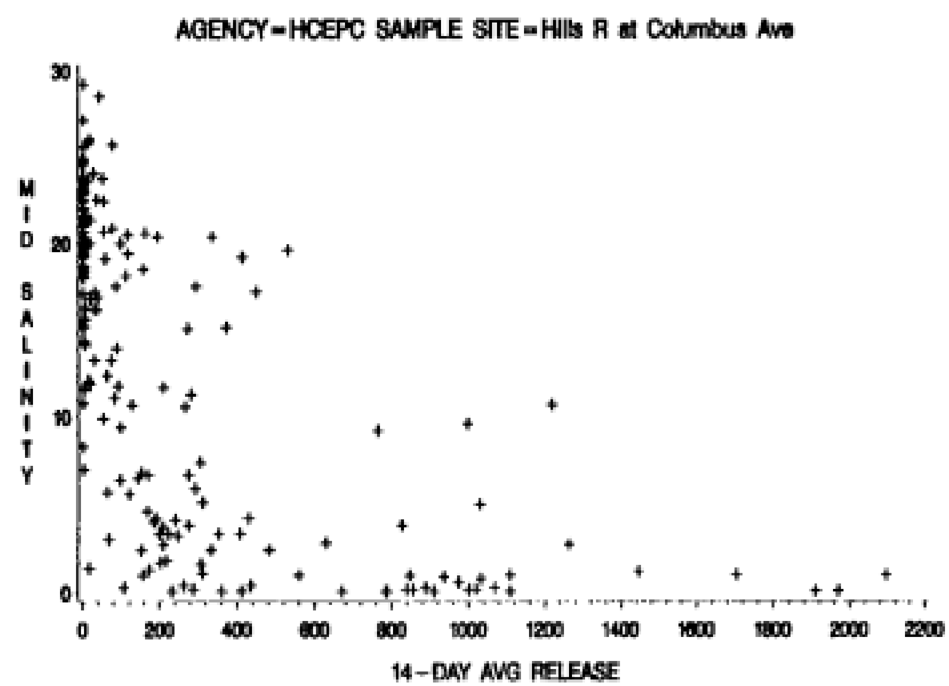
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MID SALINITY
14-DAY AVG RELEASE
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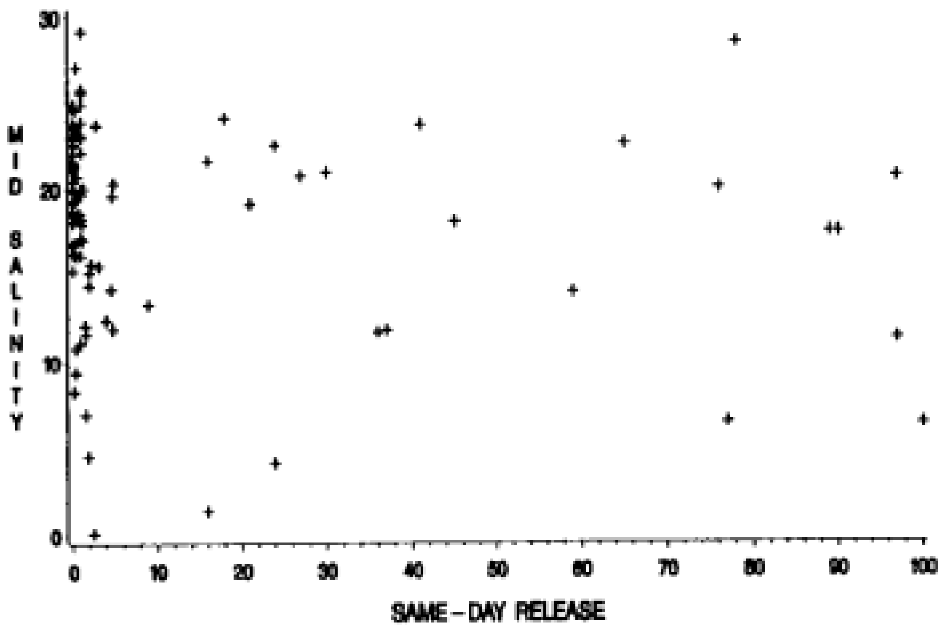

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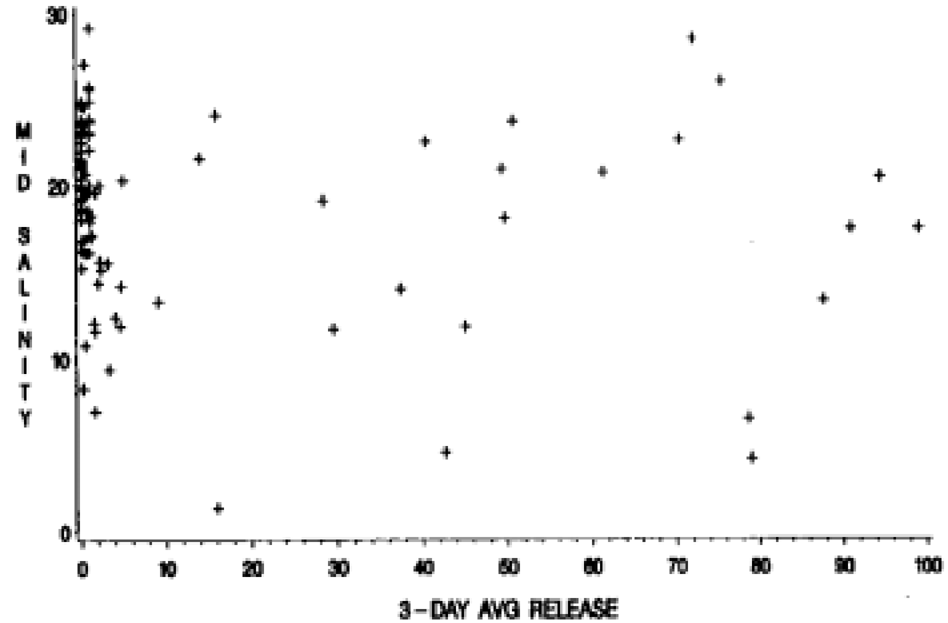

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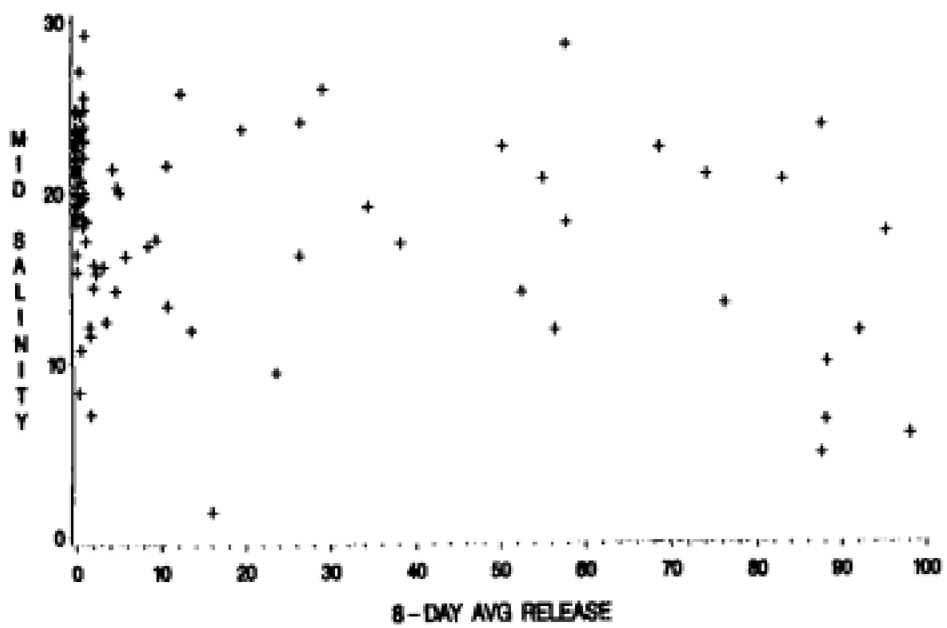

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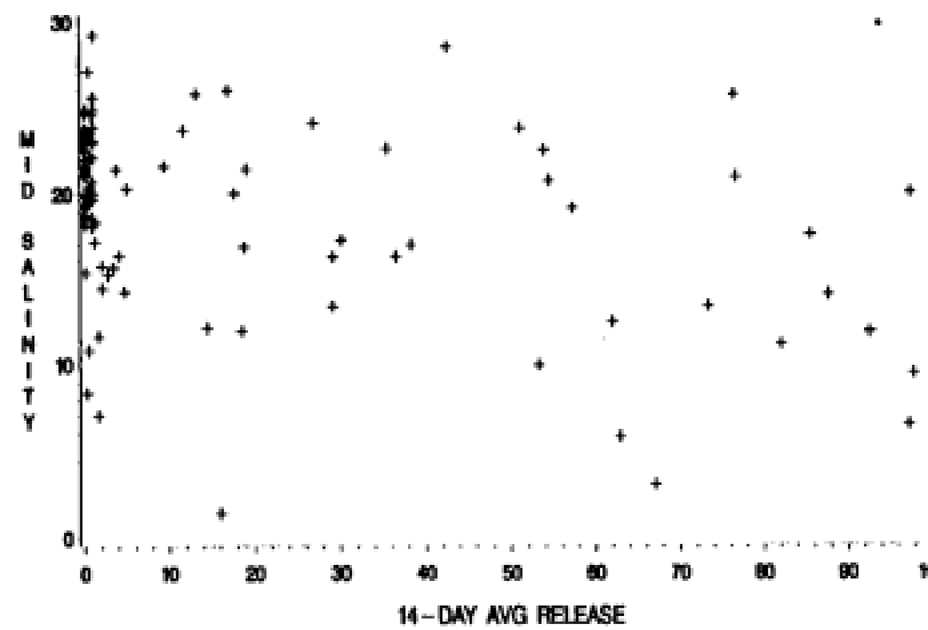

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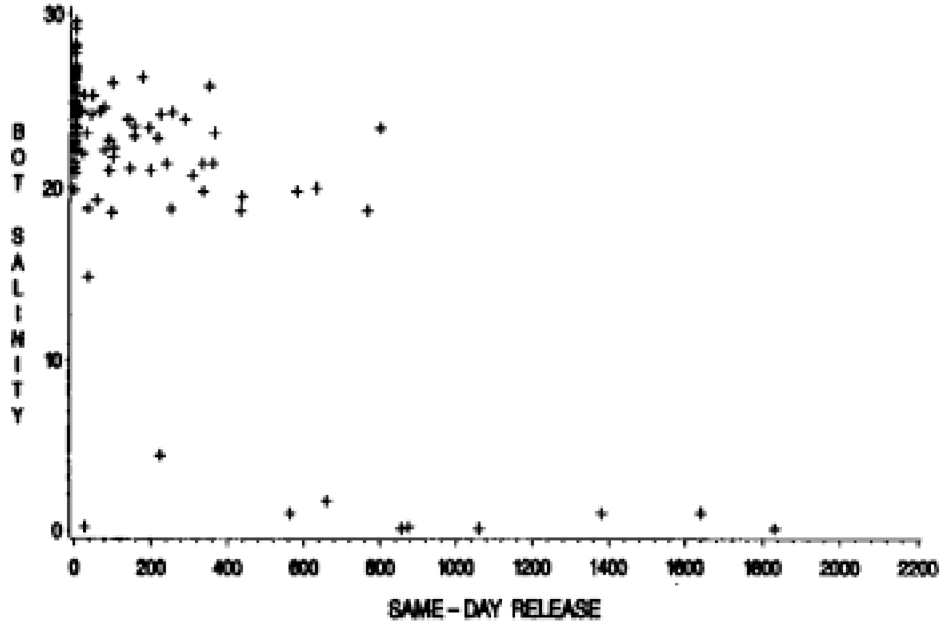

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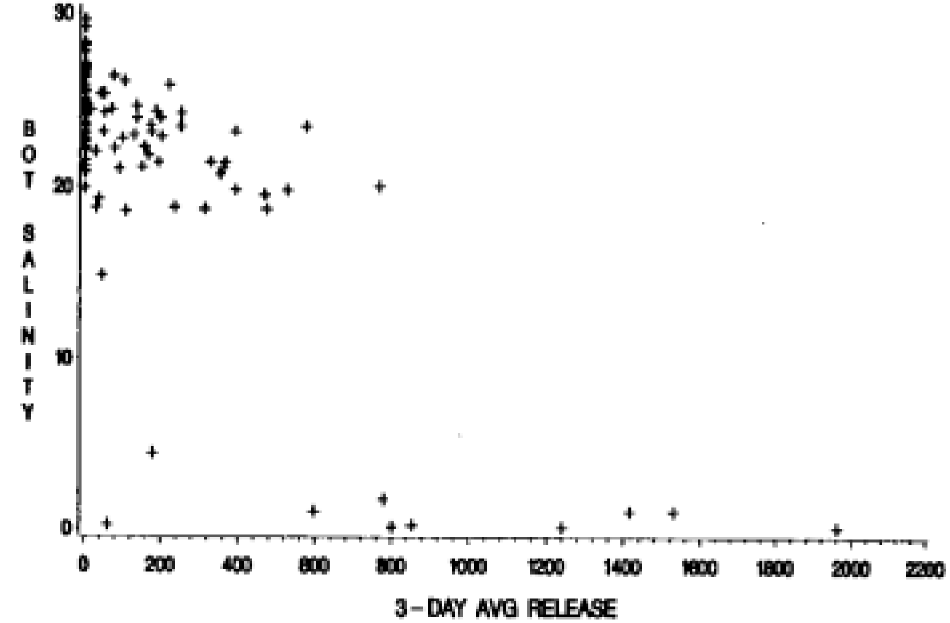

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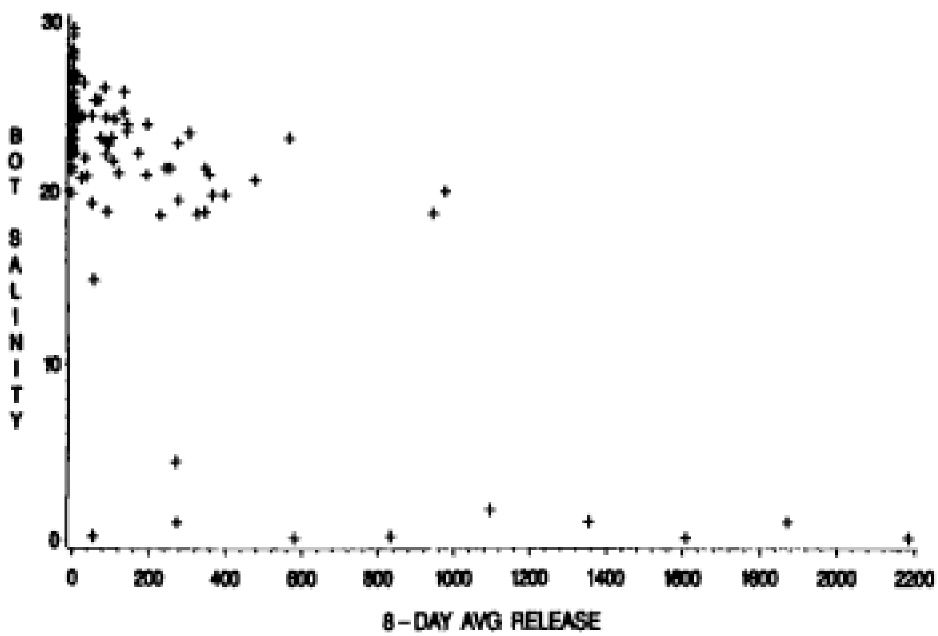

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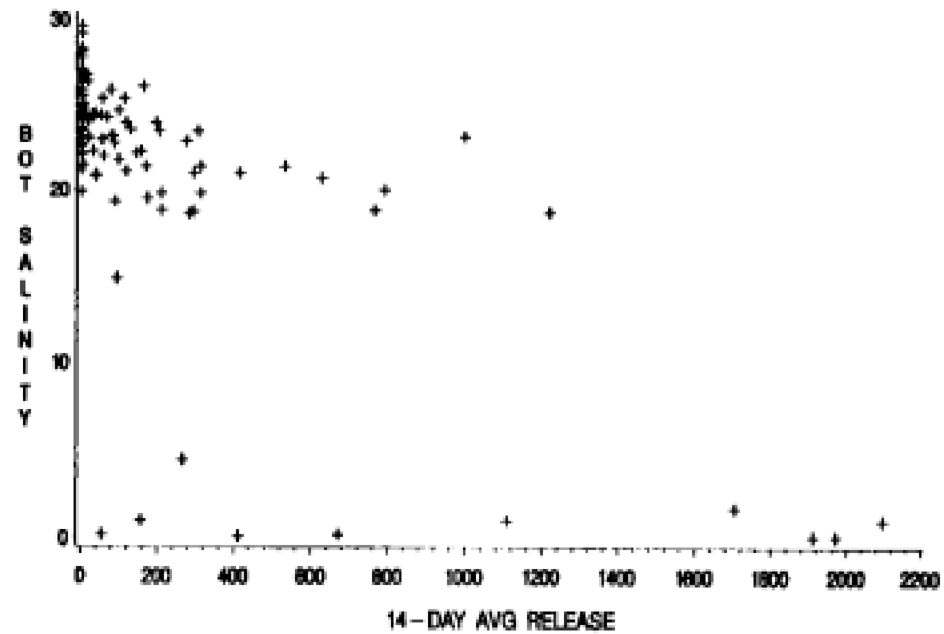

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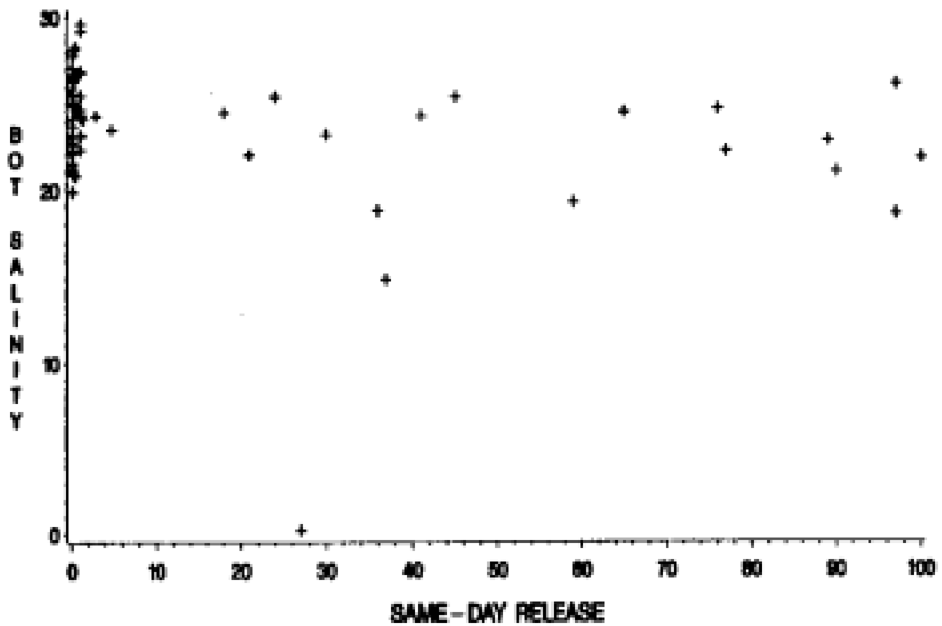

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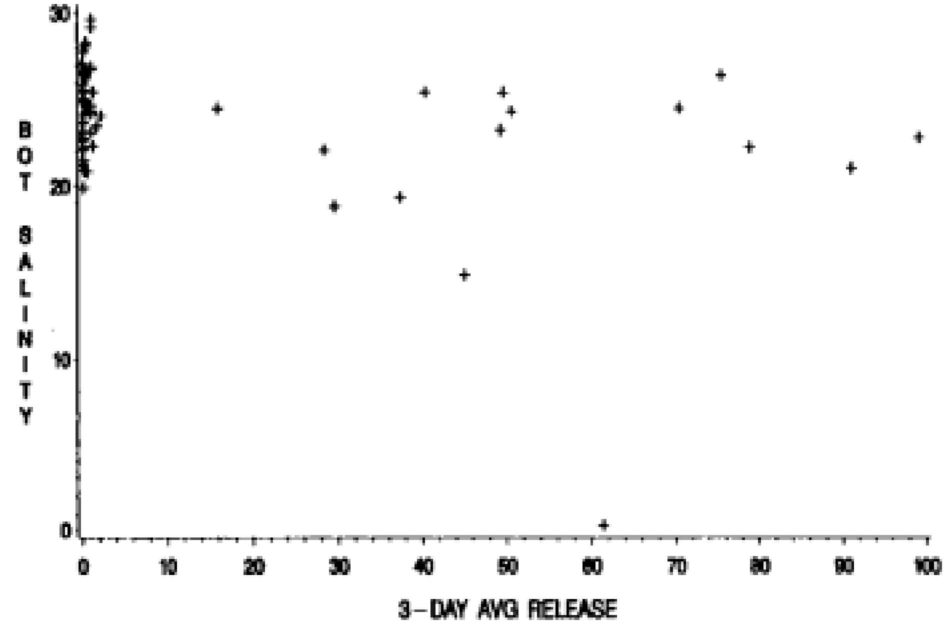

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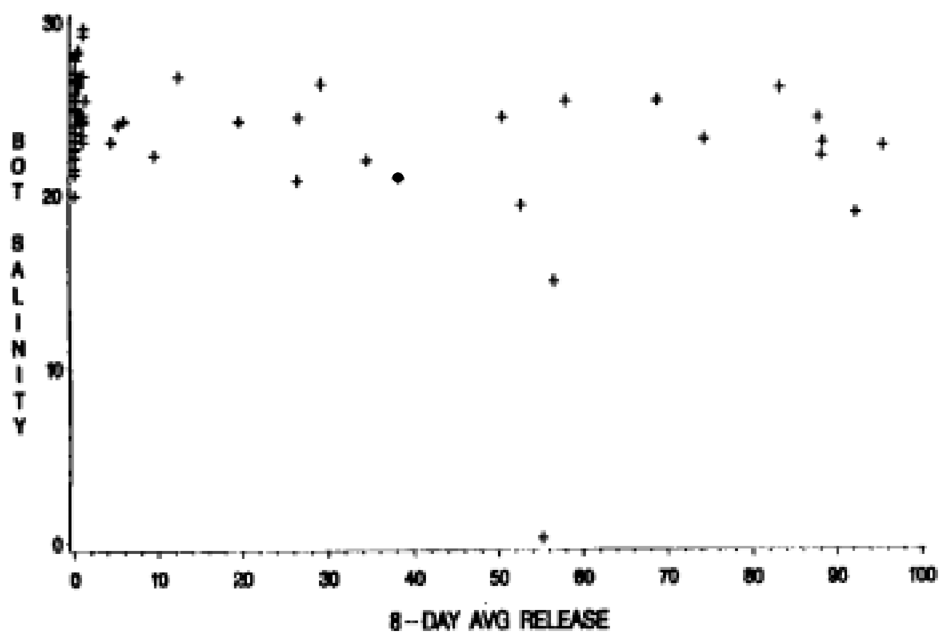

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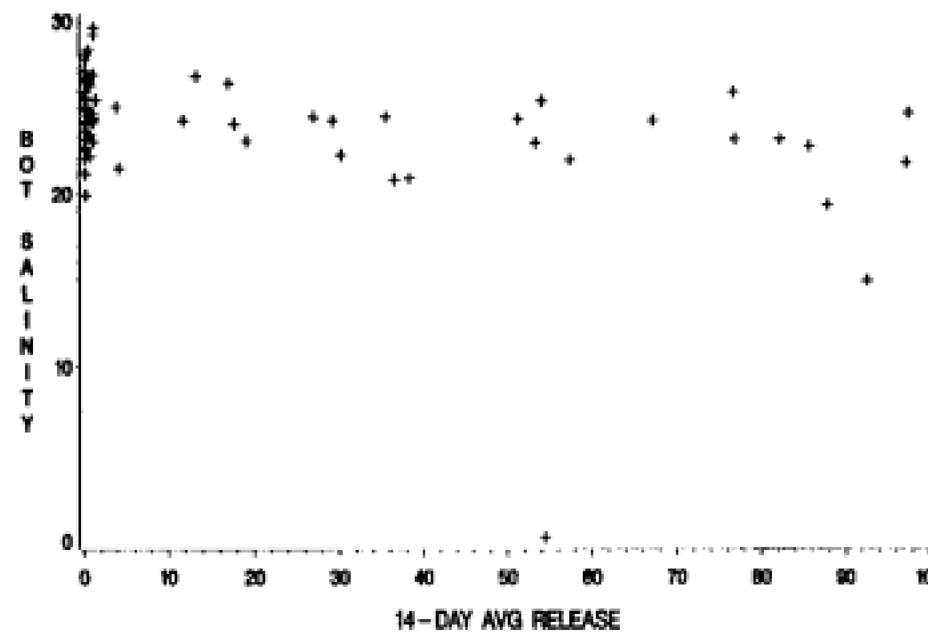
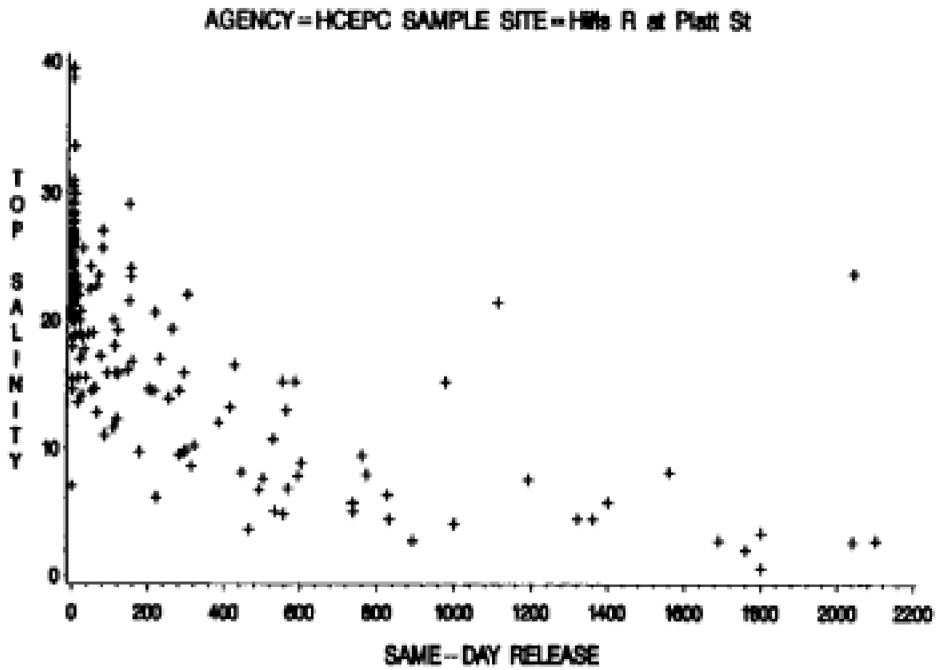
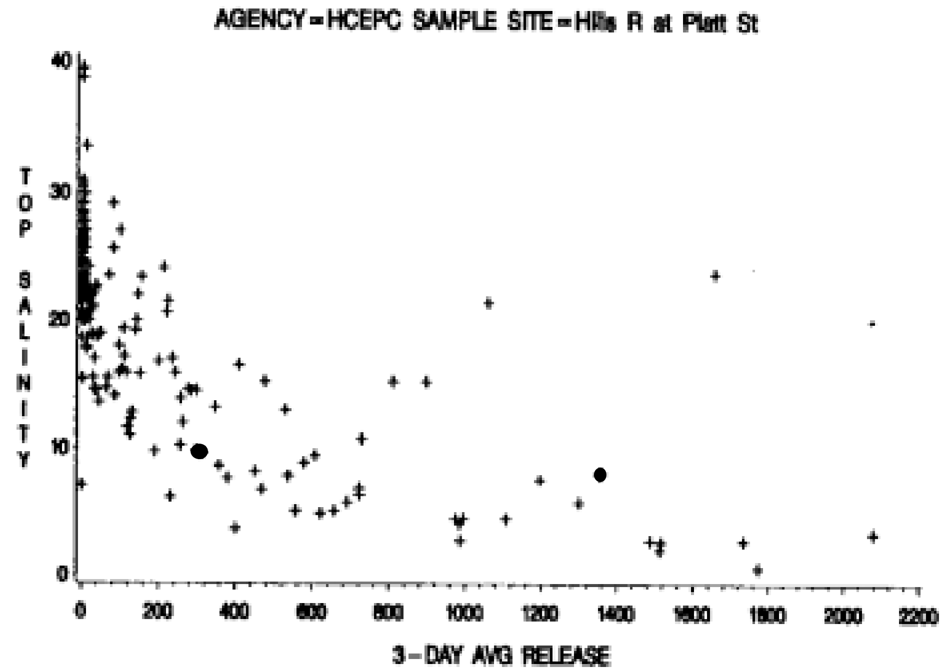
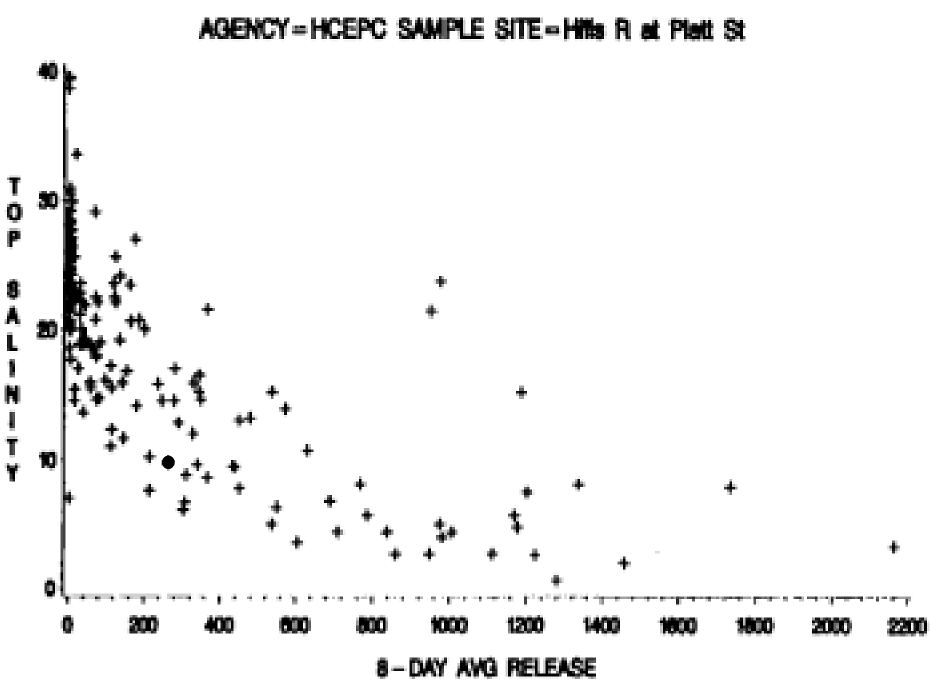



AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOP SALINITY
SAME-DAY RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOP SALINITY
3-DAY AVG RELEASE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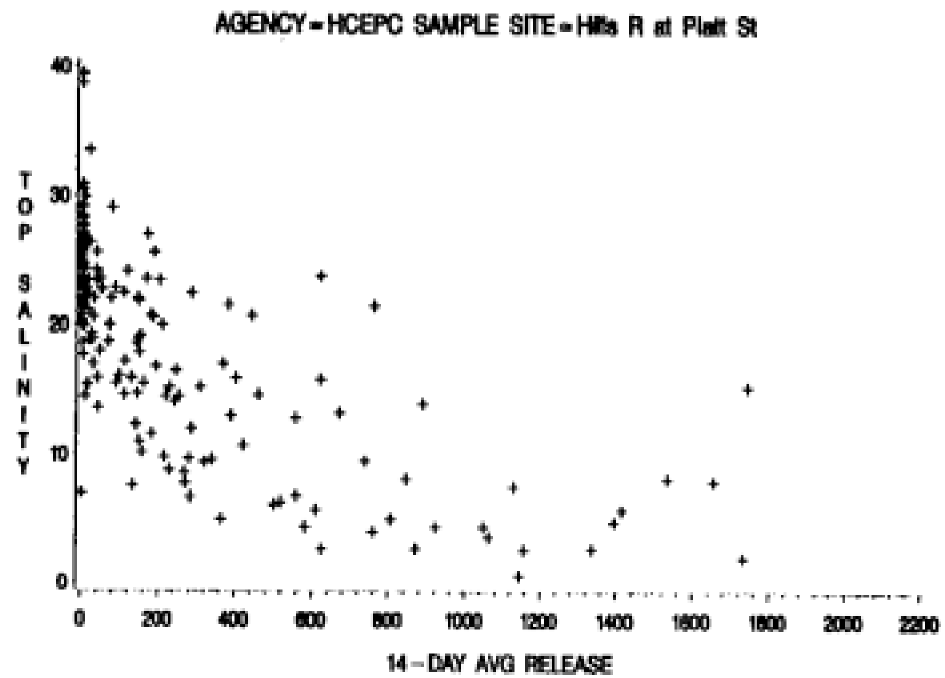
TOP SALINITY
8-DAY AVG RELEASE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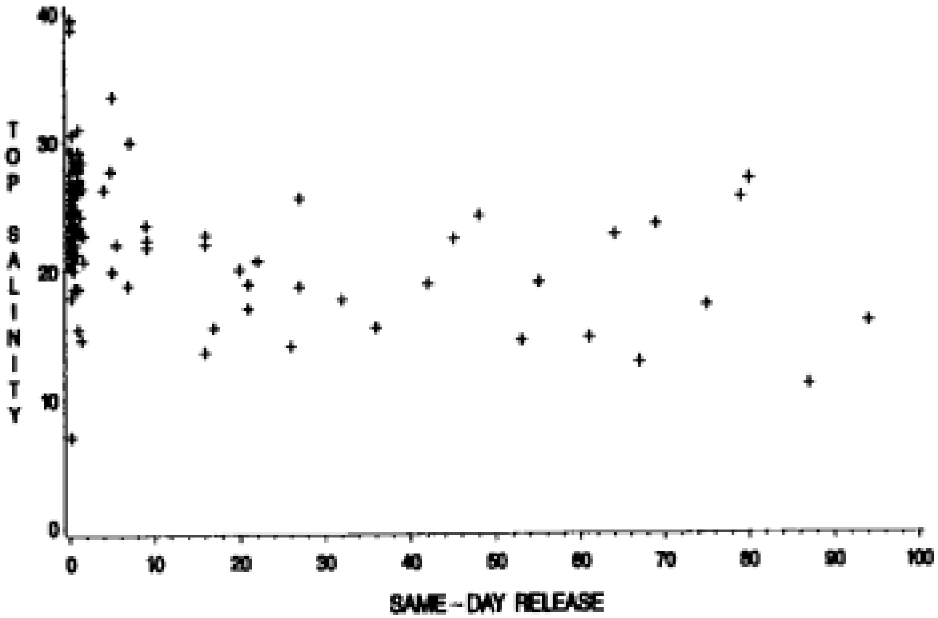

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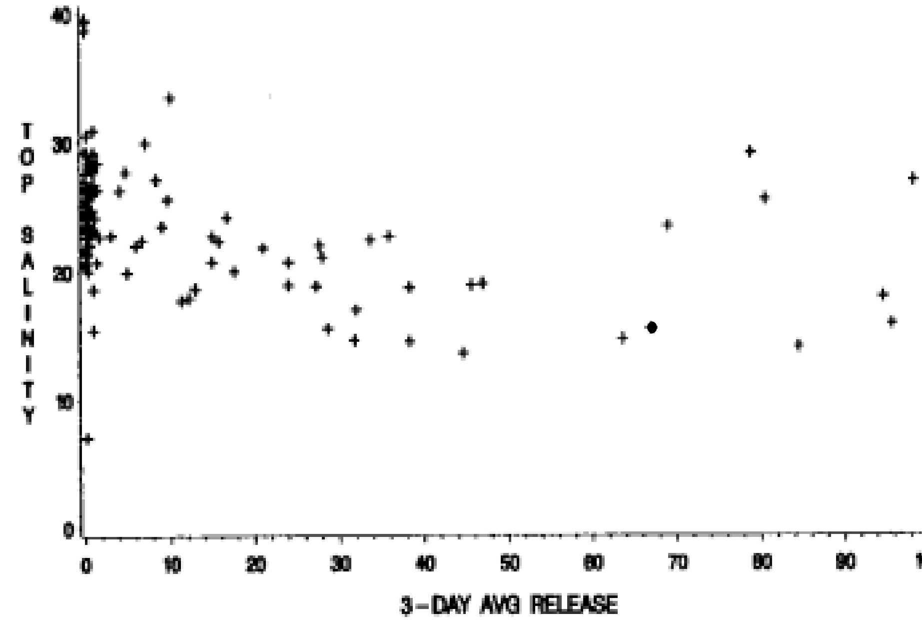

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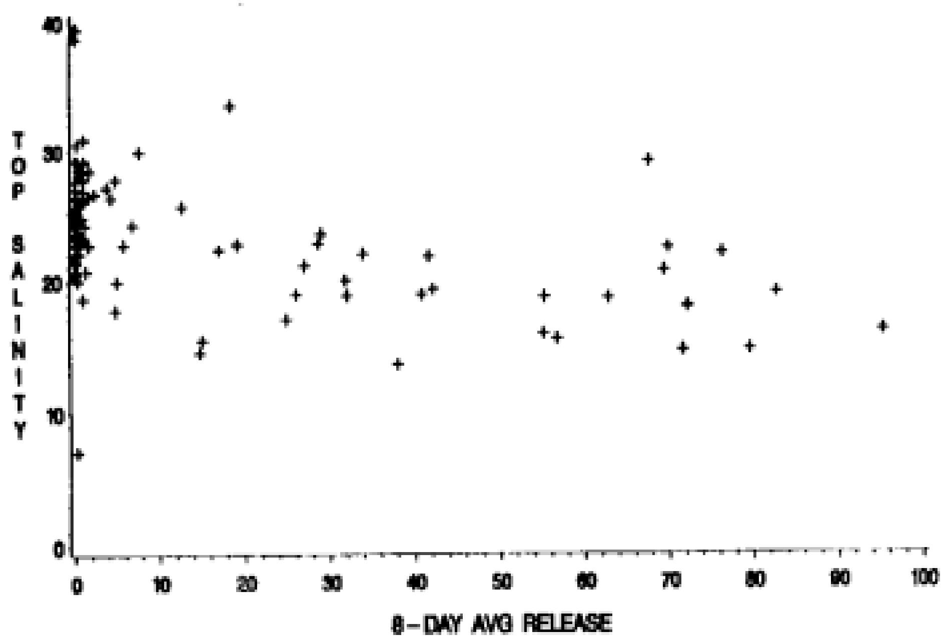

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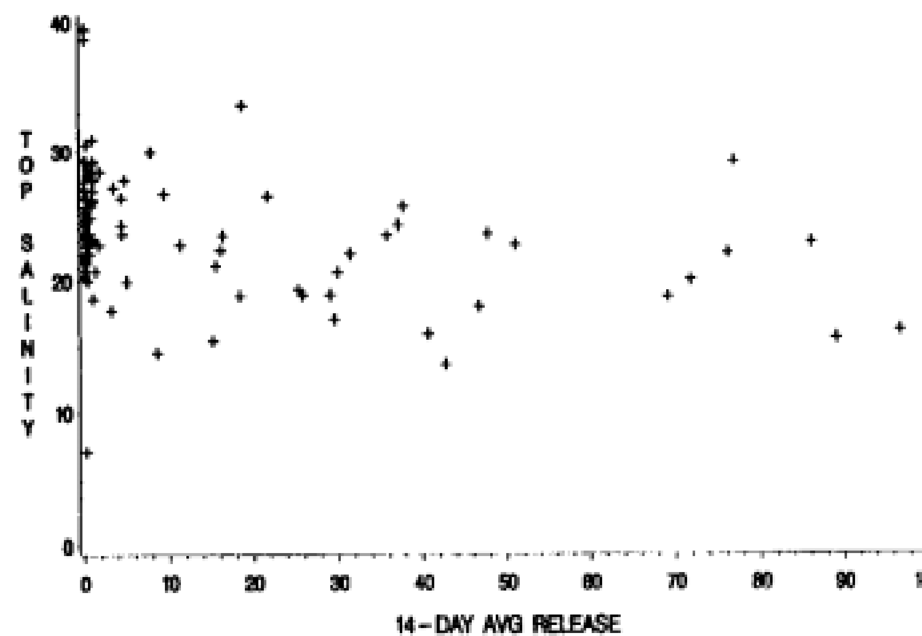

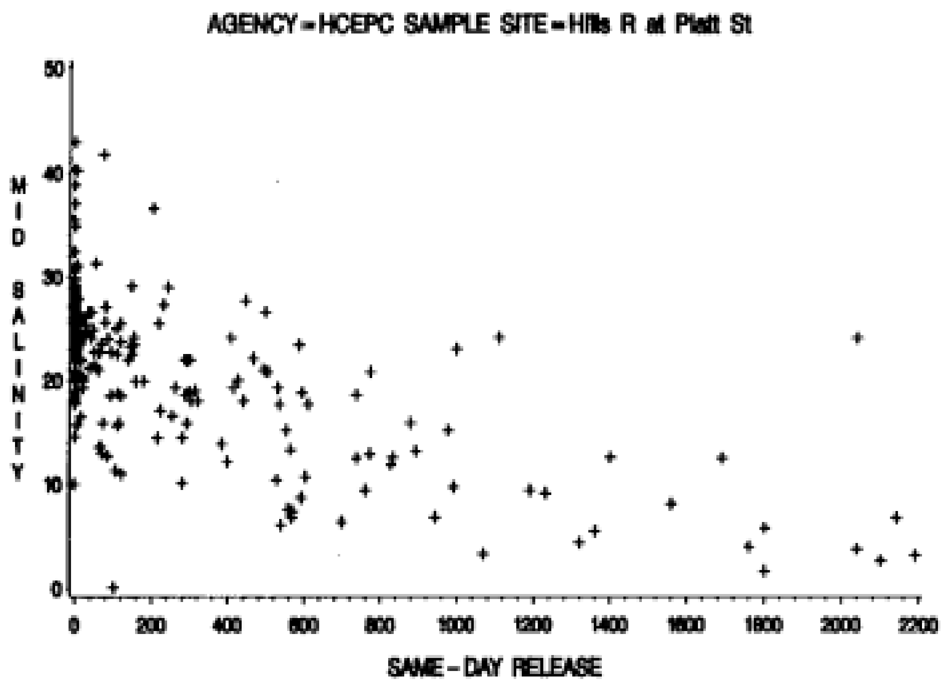
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800
1000
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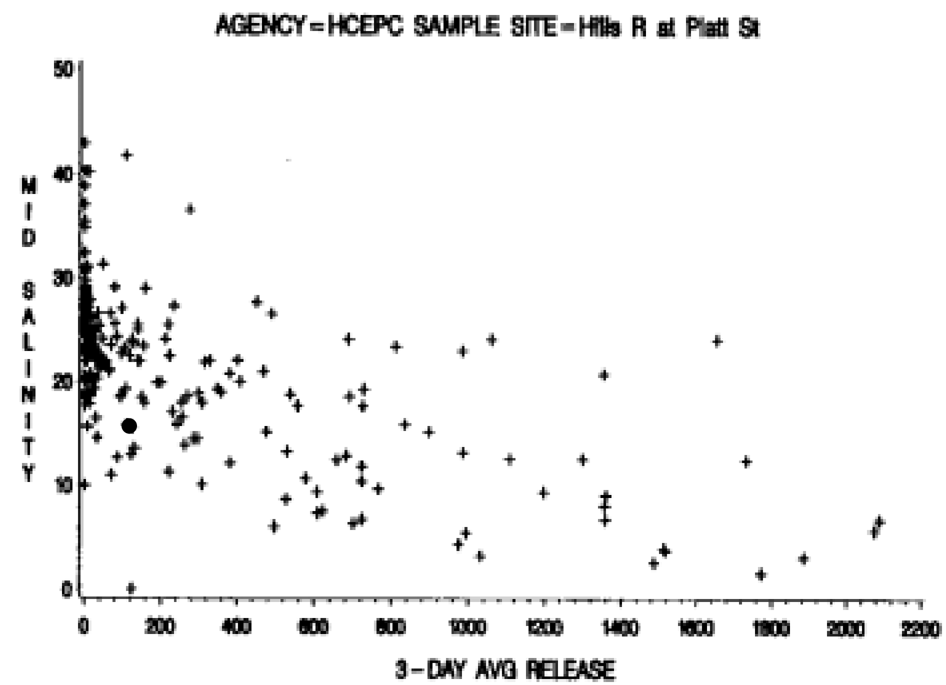
1400
1600
1800
2000
2200
SAME-DAY RELEASE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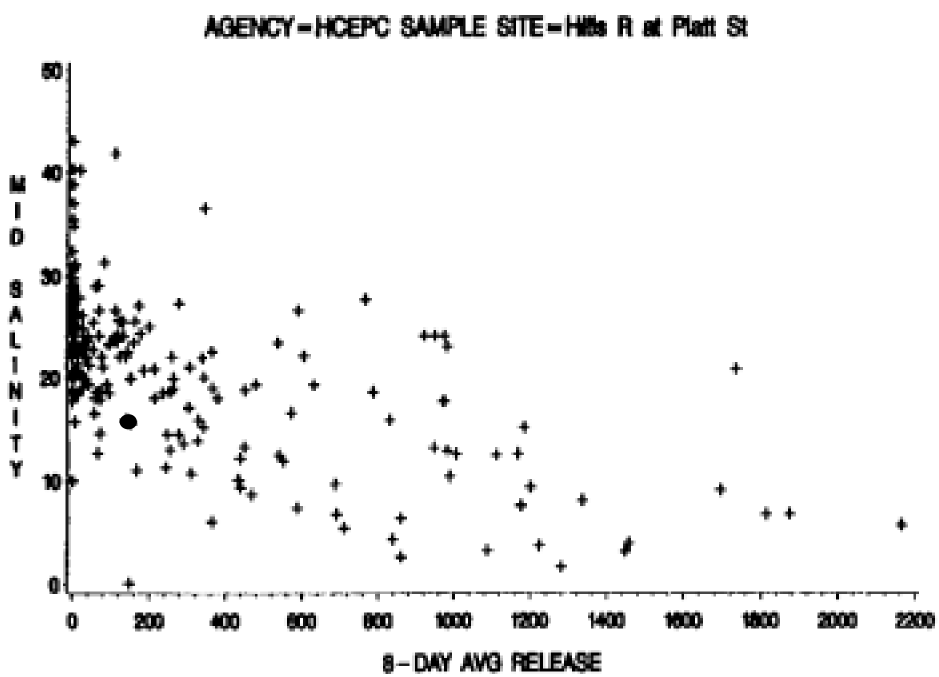
3-DAY AVG RELEASE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MID SALINITY
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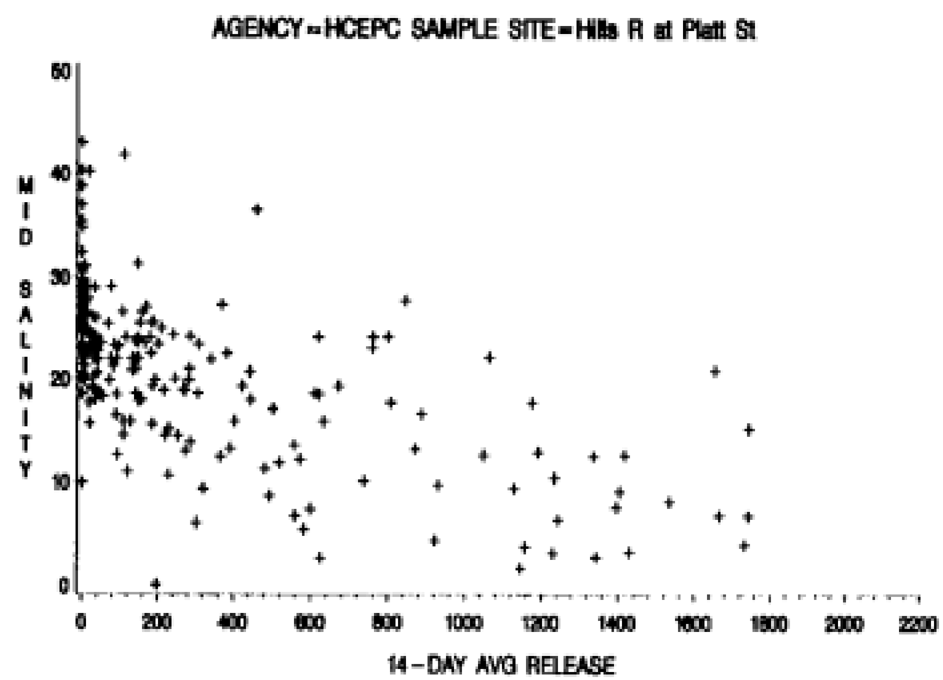
8-DAY AVG RELEASE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MID SALINITY
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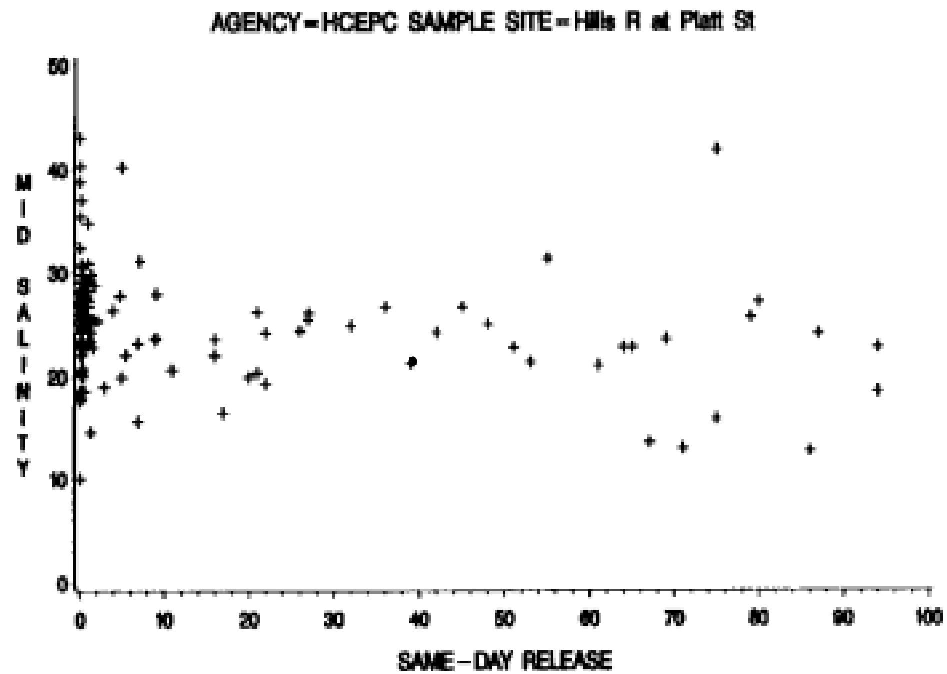
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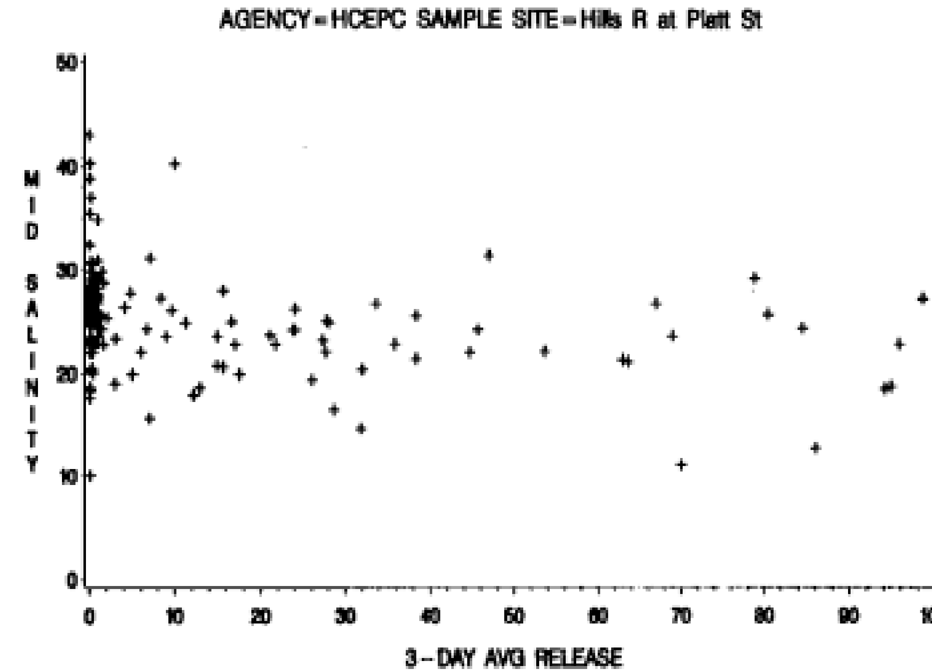
SAME-DAY RELEASE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MID SALINITY
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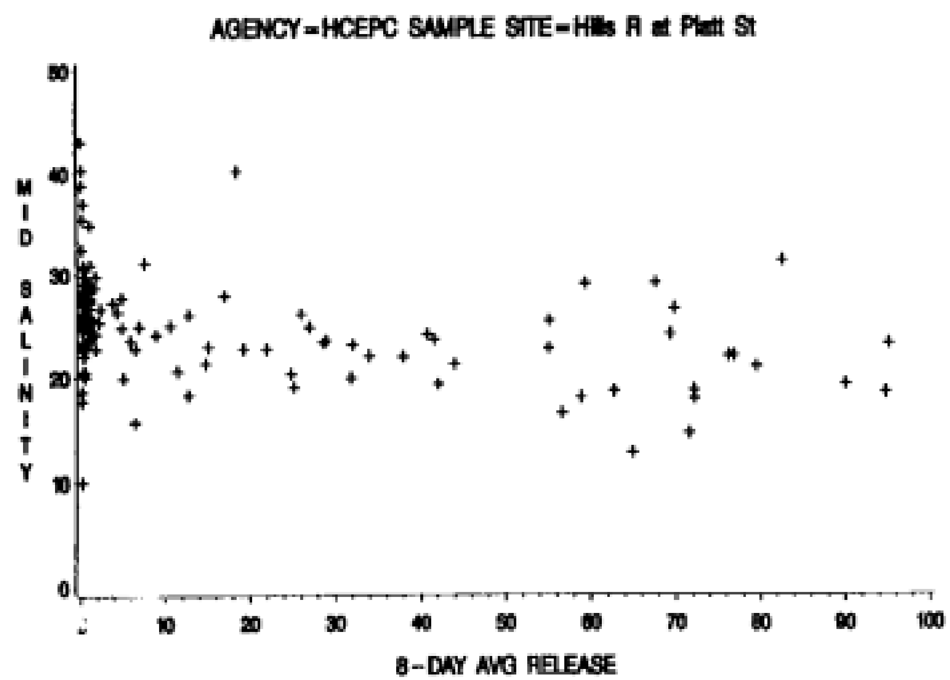
3-DAY AVG RELEASE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MID SALINITY
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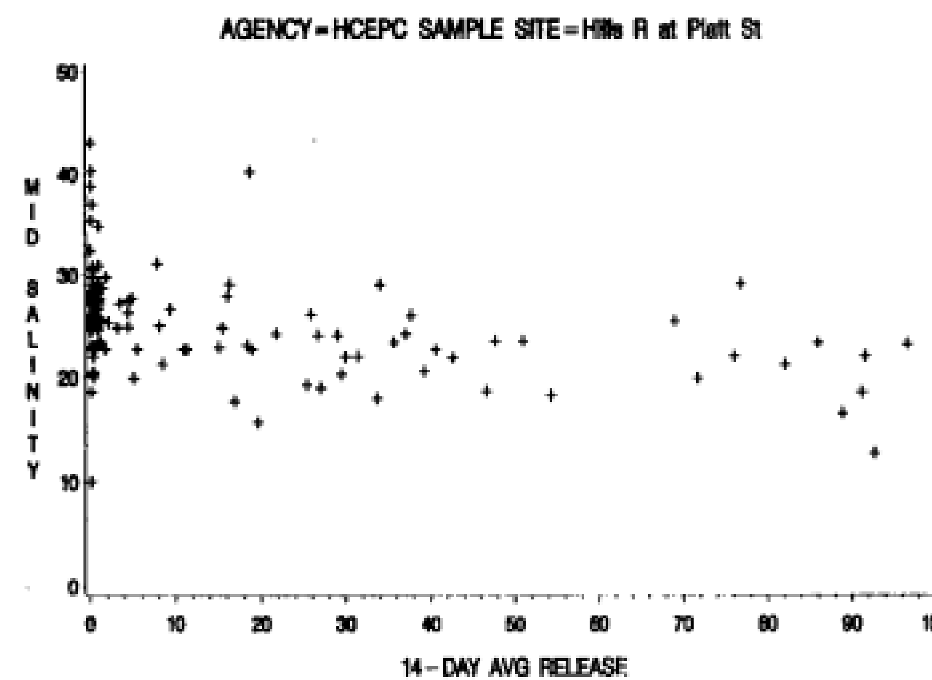
8-DAY AVG RELEASE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MID SALINITY
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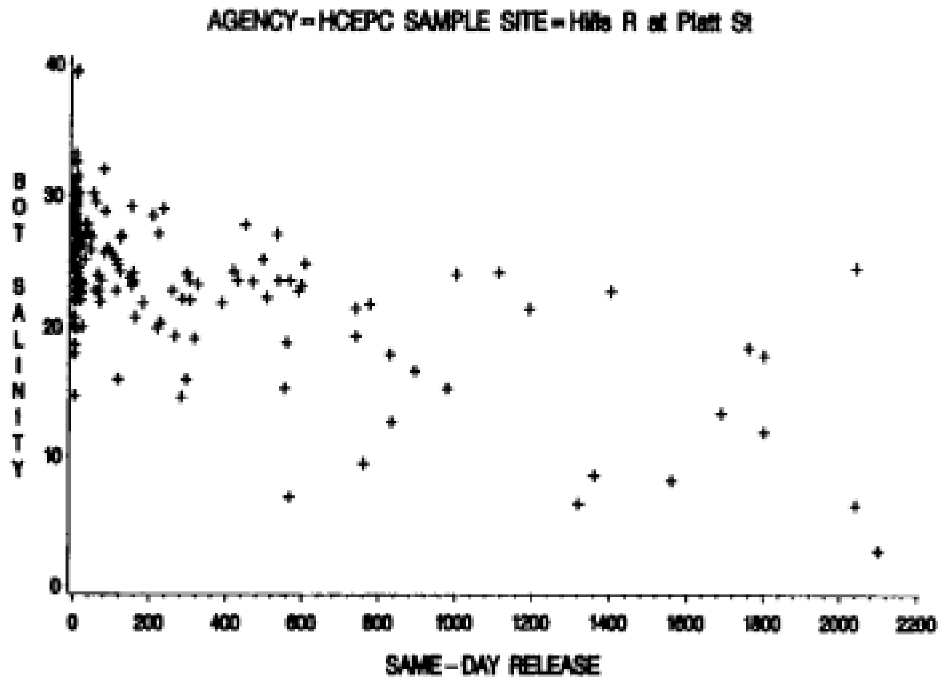
90
100
14-DAY AVG RELEASE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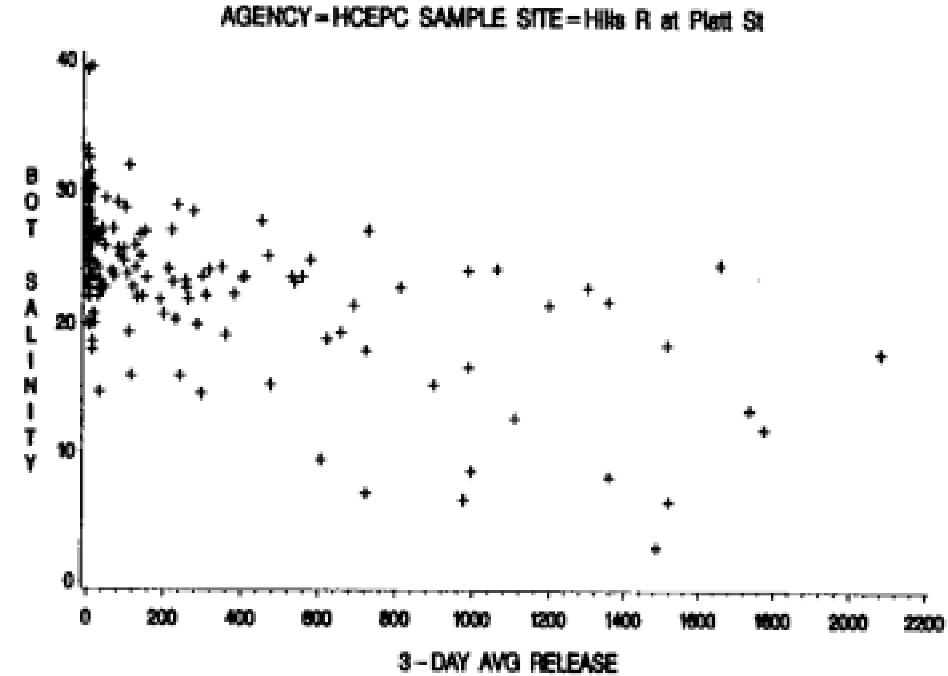
BOT SALINITY
SAME-DAY RELEASE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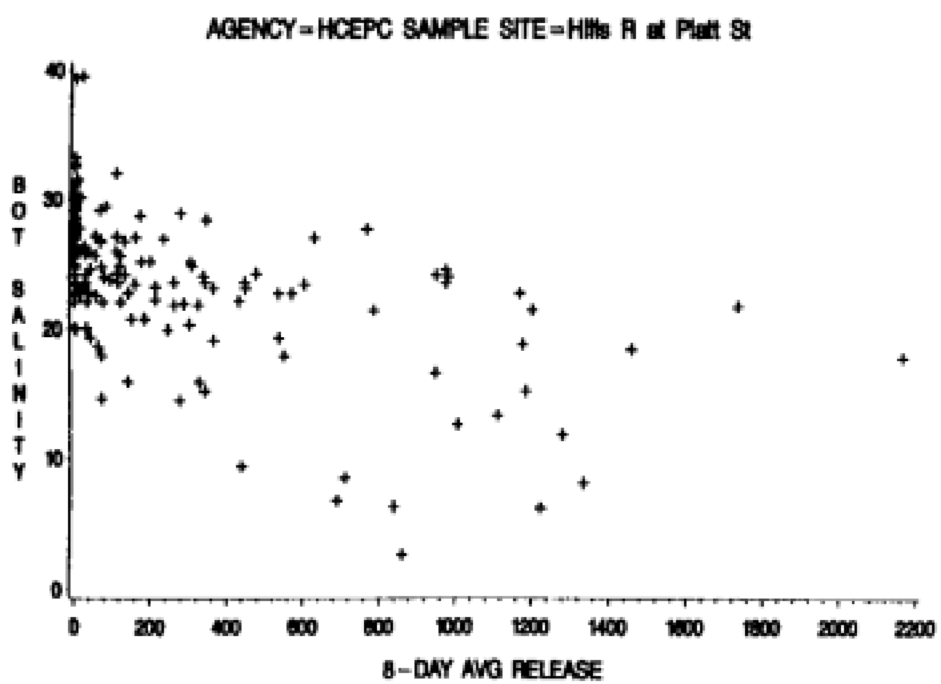
BOT SALINITY
3-DAY AVG RELEASE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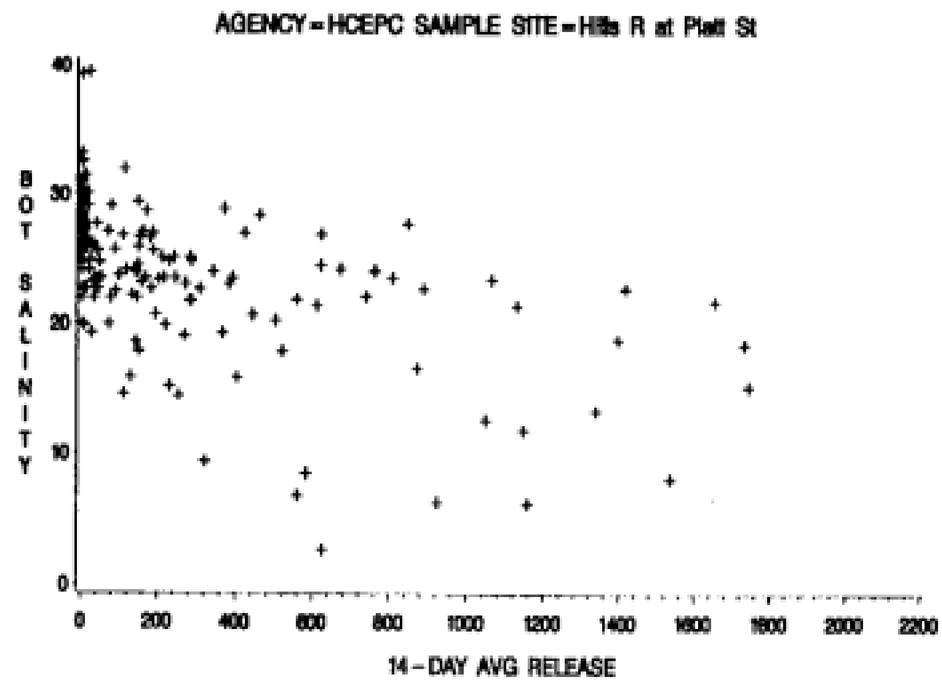
BOT SALINITY
8-DAY AVG RELEASE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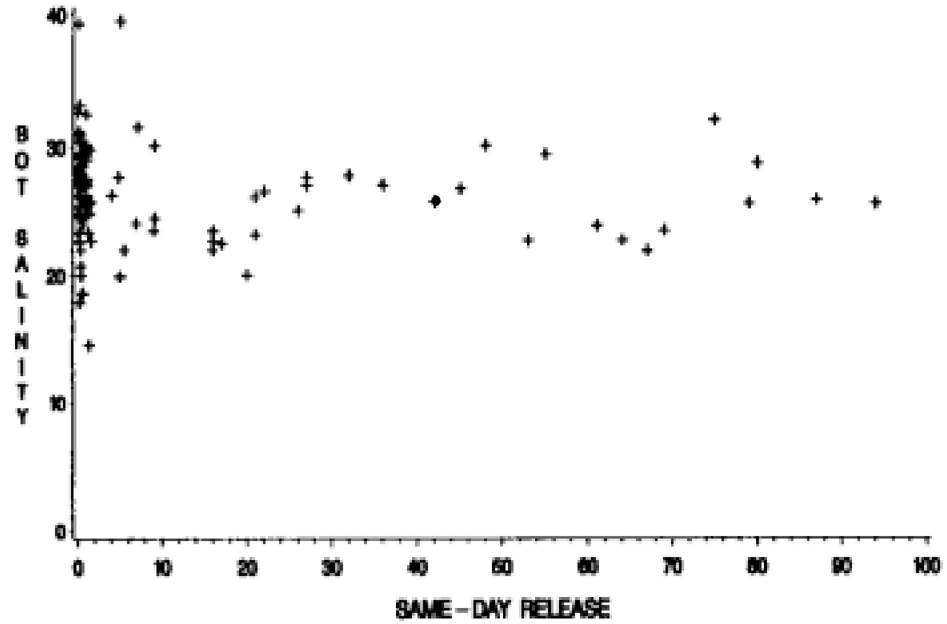
BOT SALINITY
14-DAY AVG RELEASE

AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St



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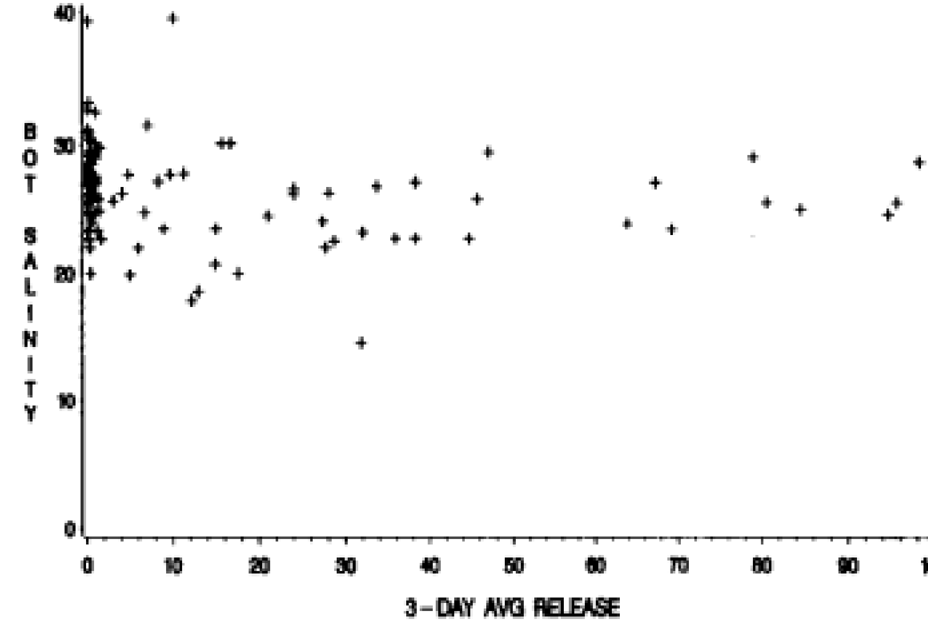

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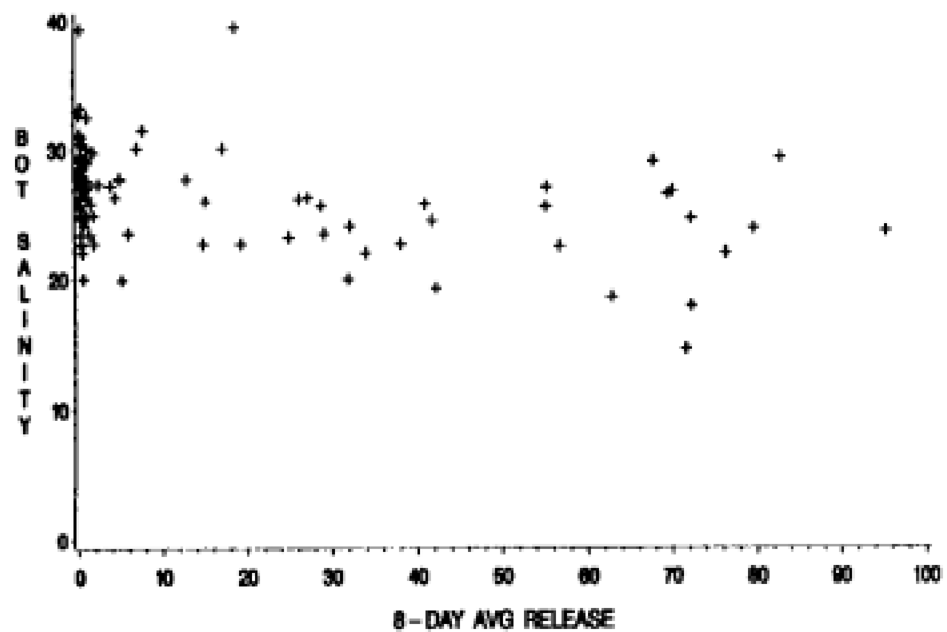

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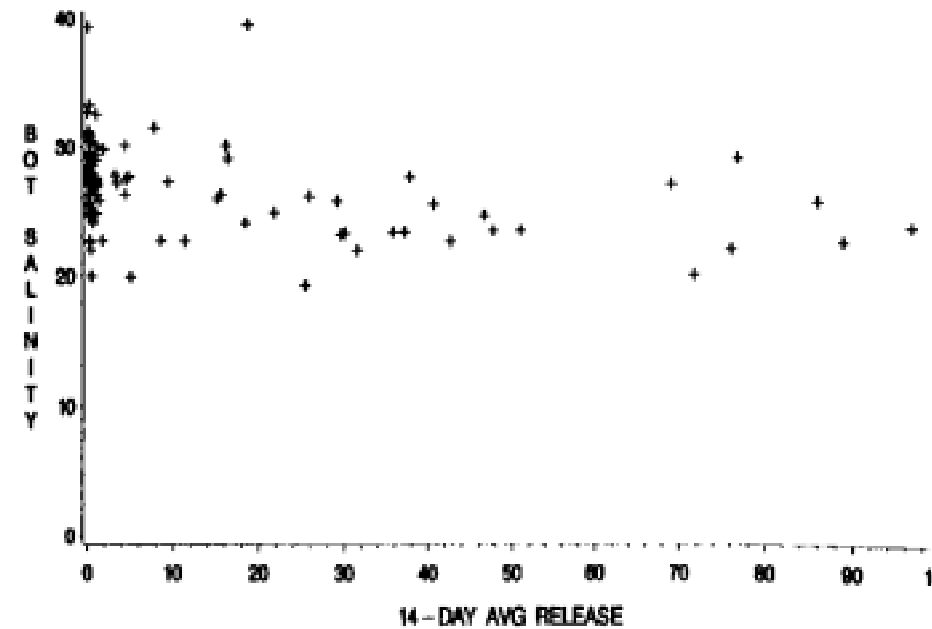
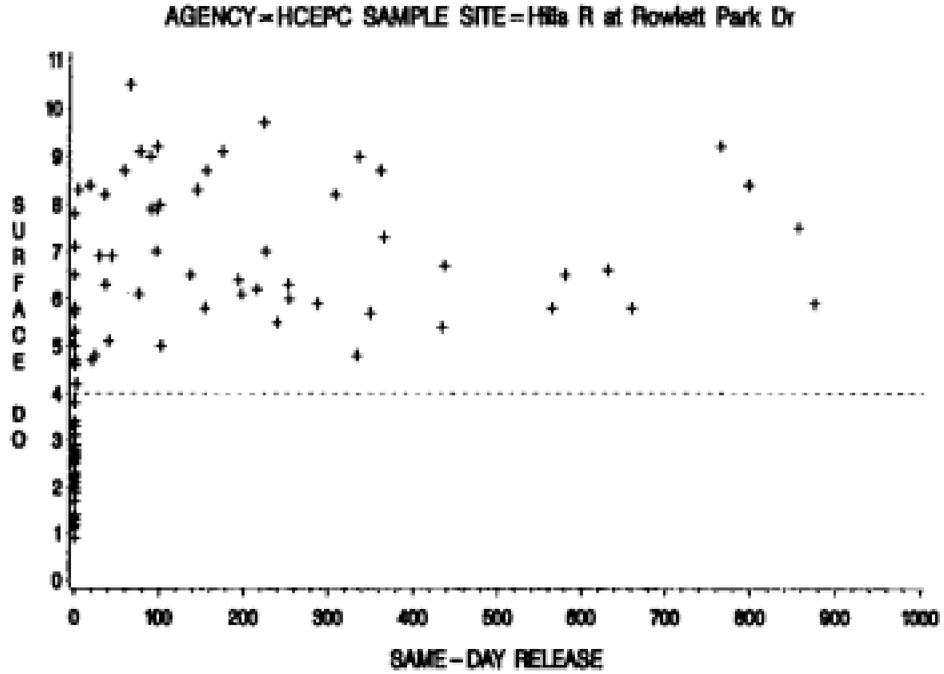


APPENDIX H

Plots of surface, mid-depth and bottom dissolved oxygen concentrations at the HCEPC stations vs. discharge from the Hillsborough River Reservoir. (Units are mg/l for dissolved oxygen and cfs for discharge).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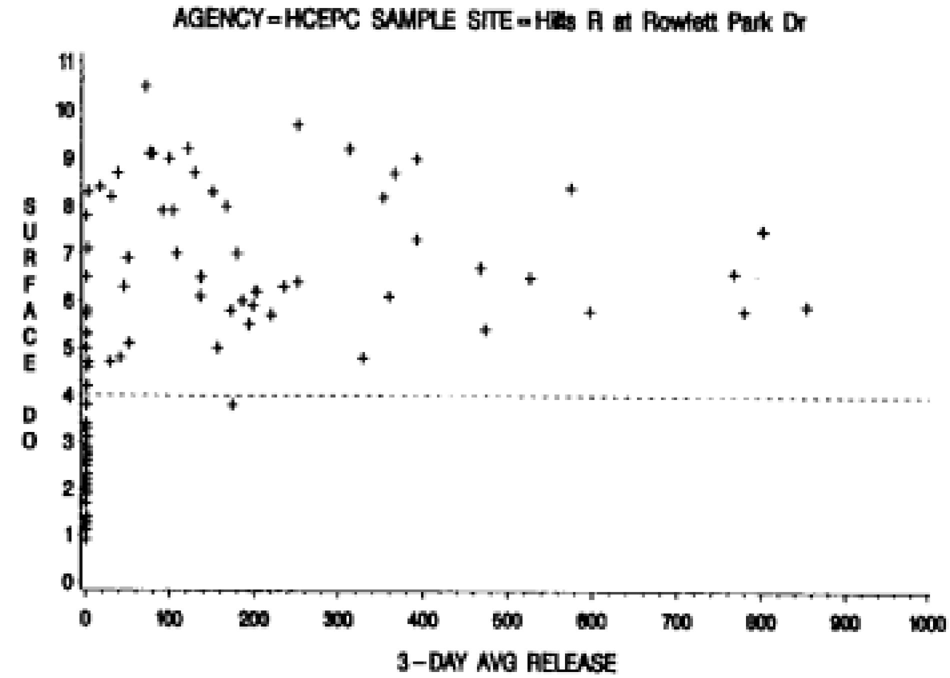
SURFACE DO
SAME-DAY RELEASE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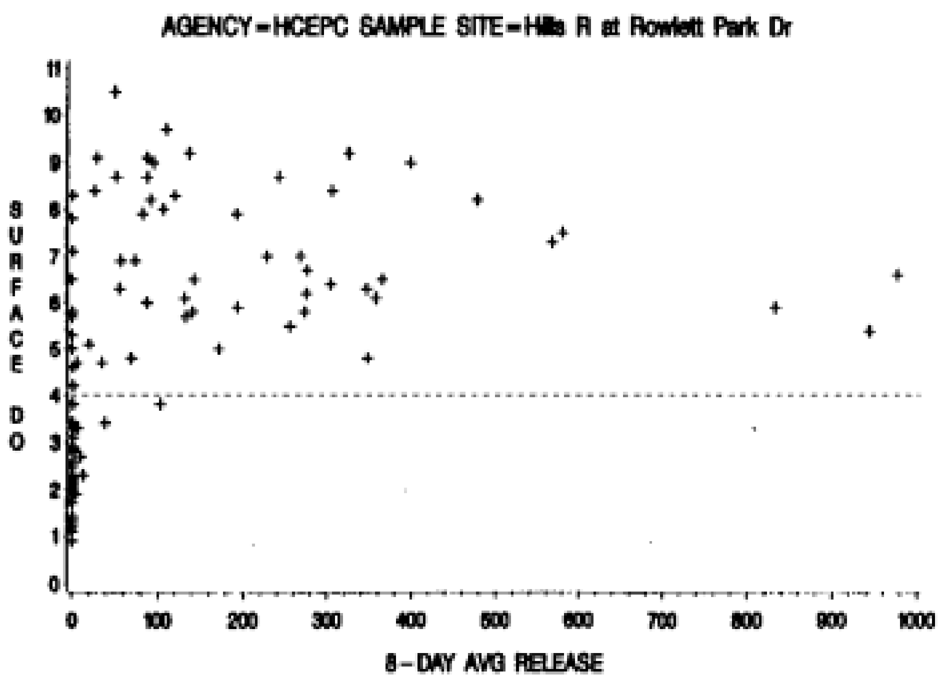
SURFACE DO
3-DAY AVG RELEASE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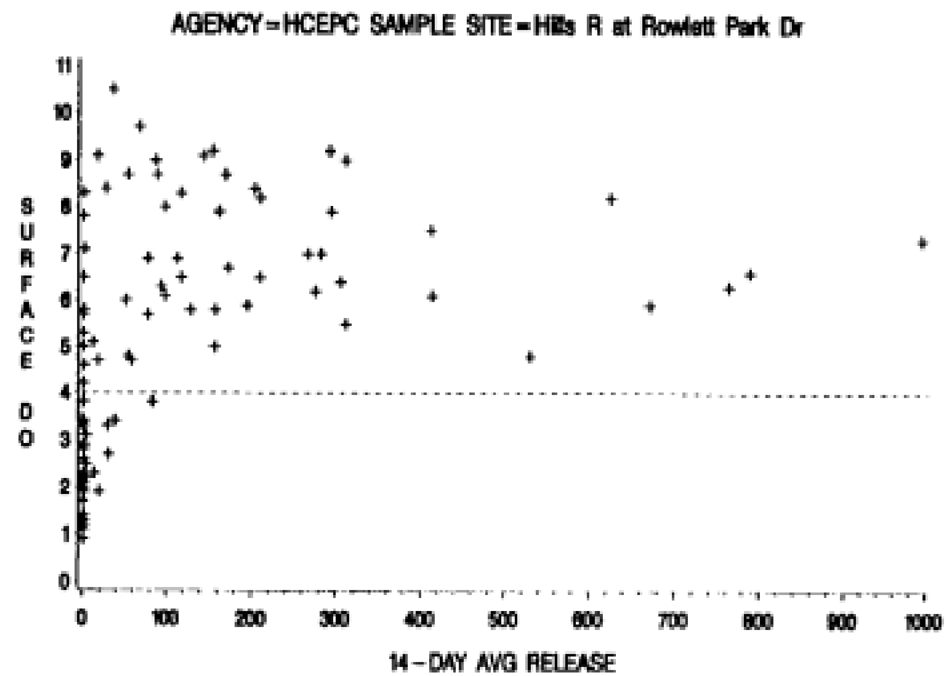
SURFACE DO
8-DAY AVG RELEASE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SURFACE DO
14-DAY AVG RELEASE

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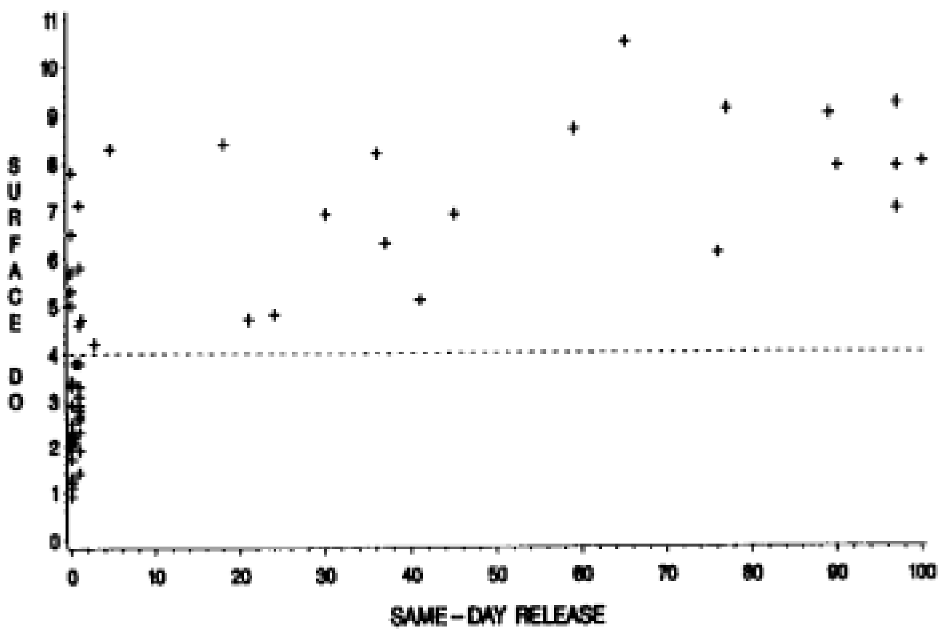

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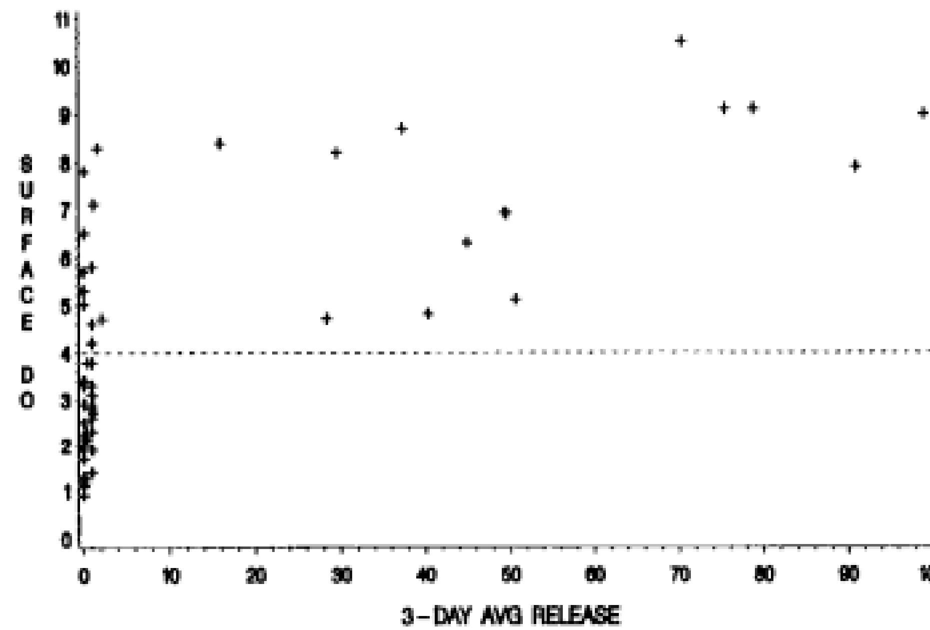

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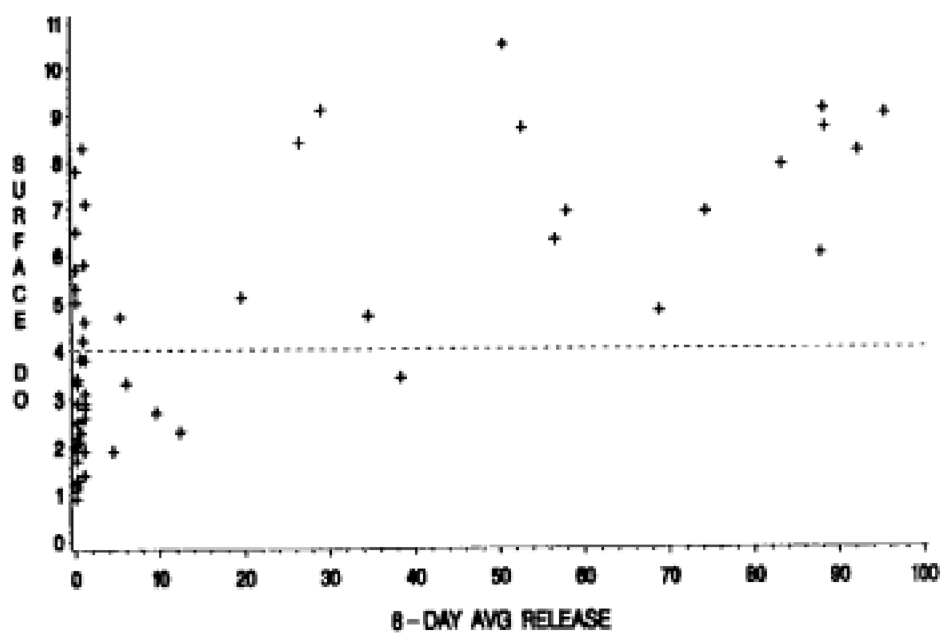

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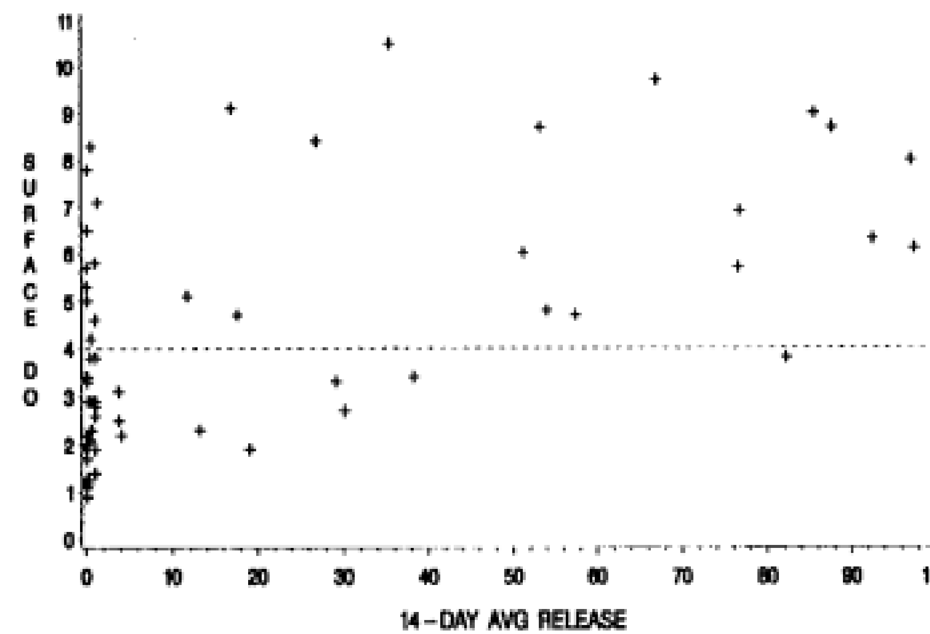
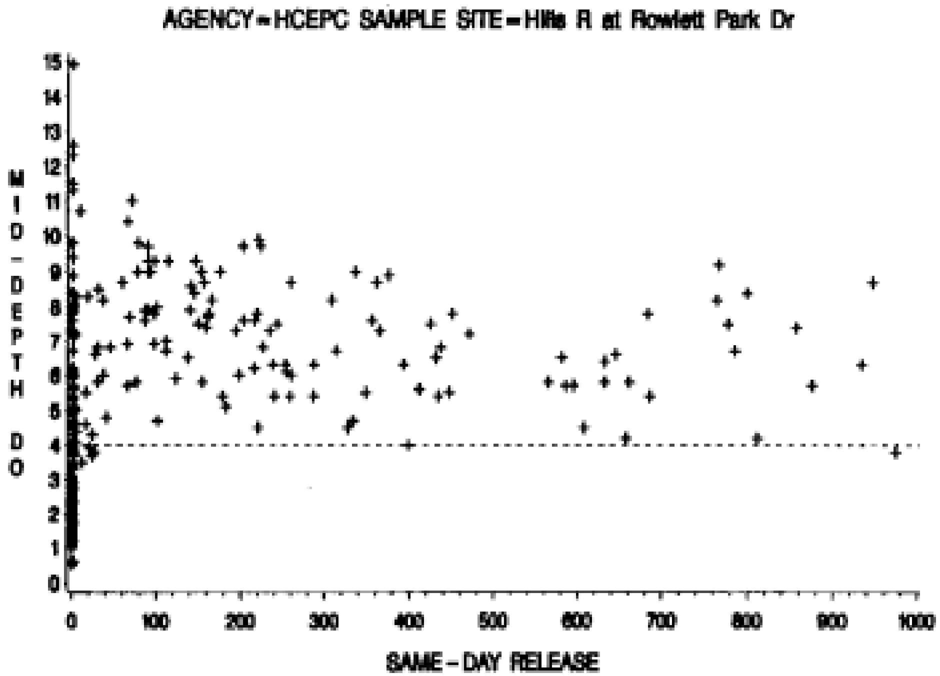


H-2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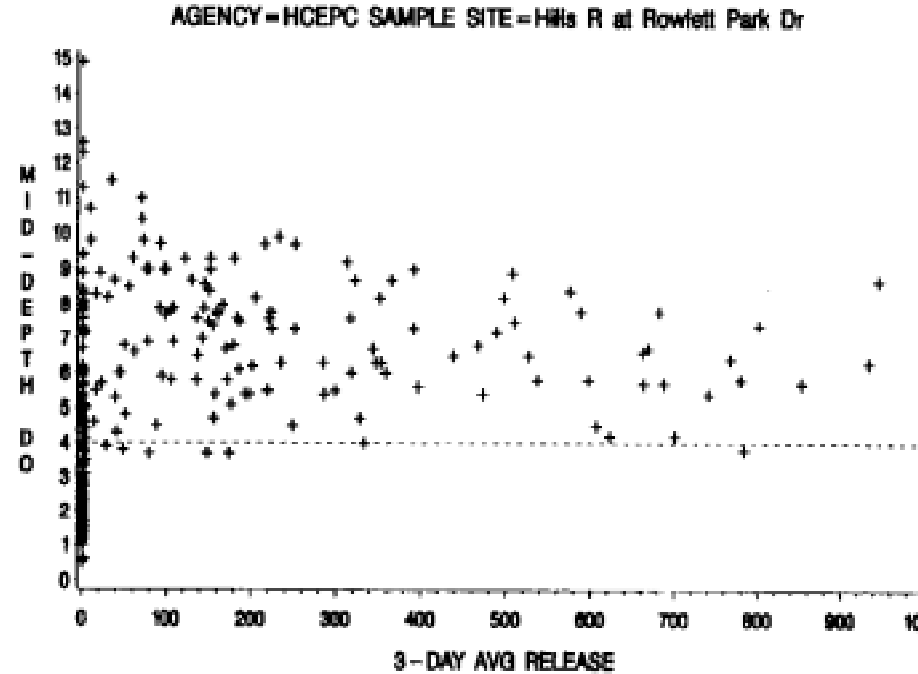
MID-DEPTH DO
SAME-DAY RELEASE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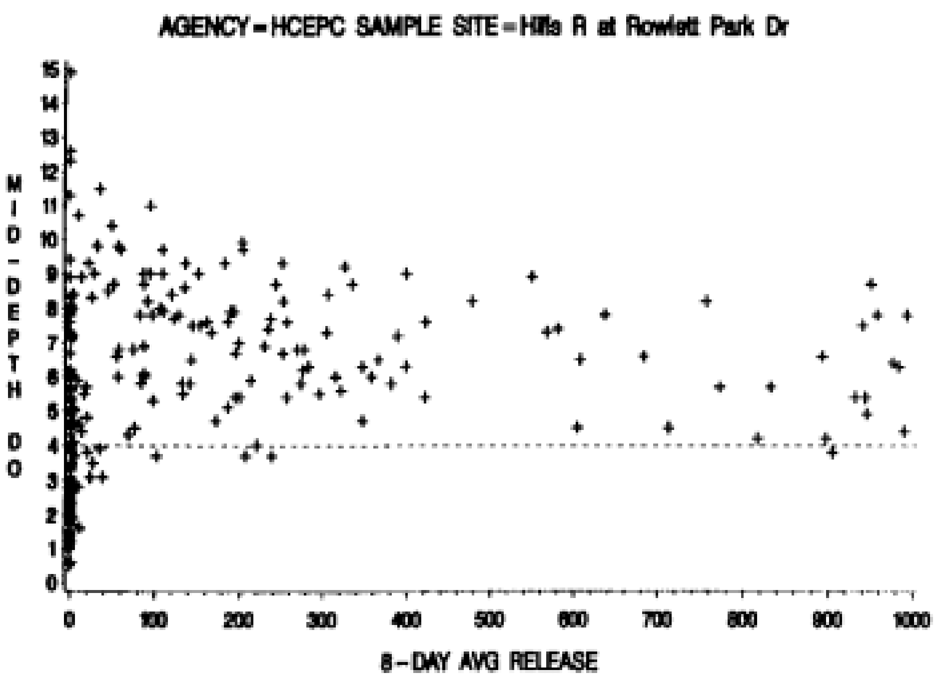
3-DAY AVG RELEASE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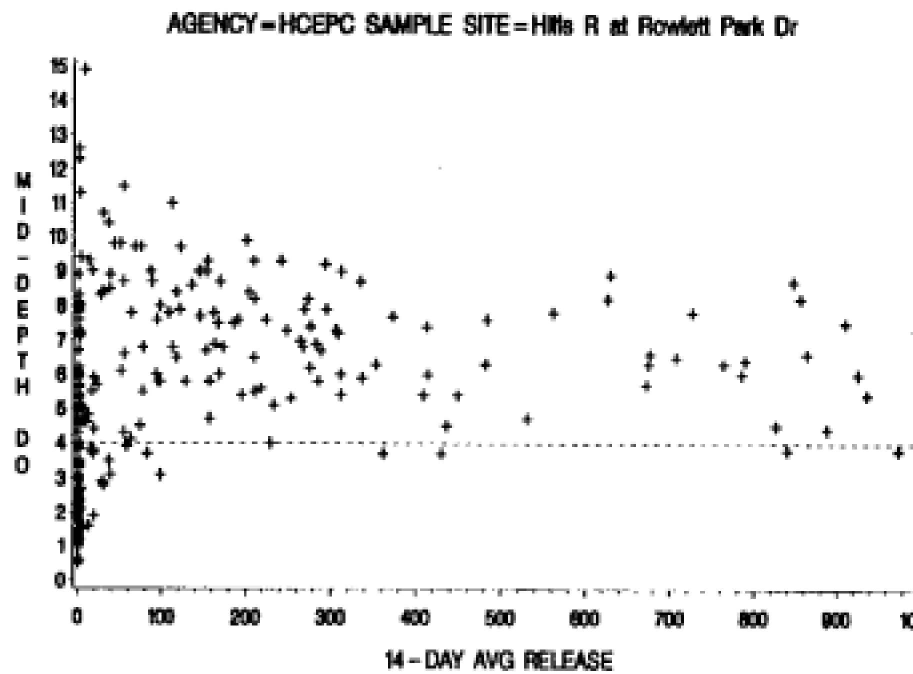
MID-DEPTH DO
8-DAY AVG RELEASE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MID-DEPTH DO
14-DAY AVG RELEASE

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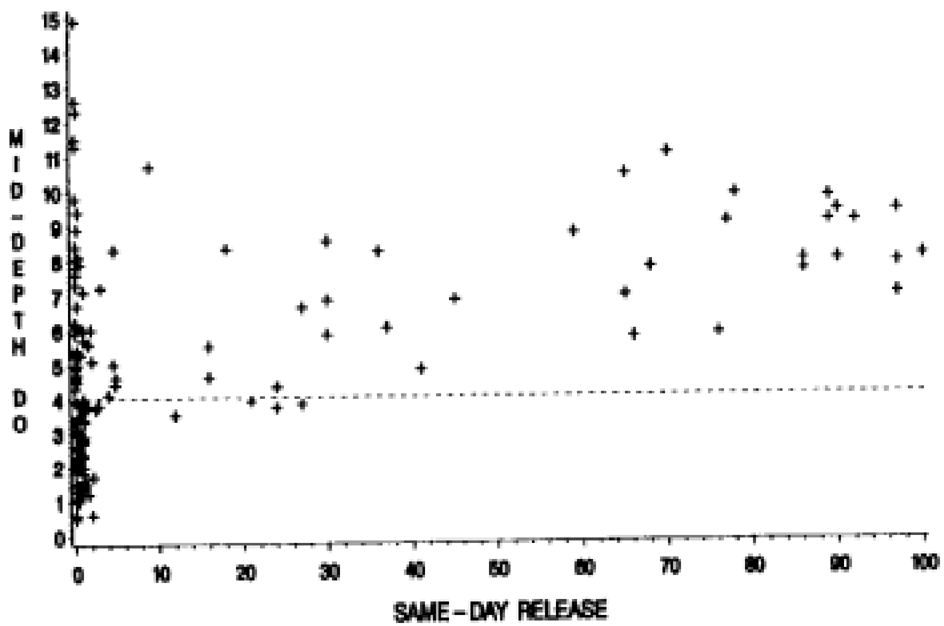

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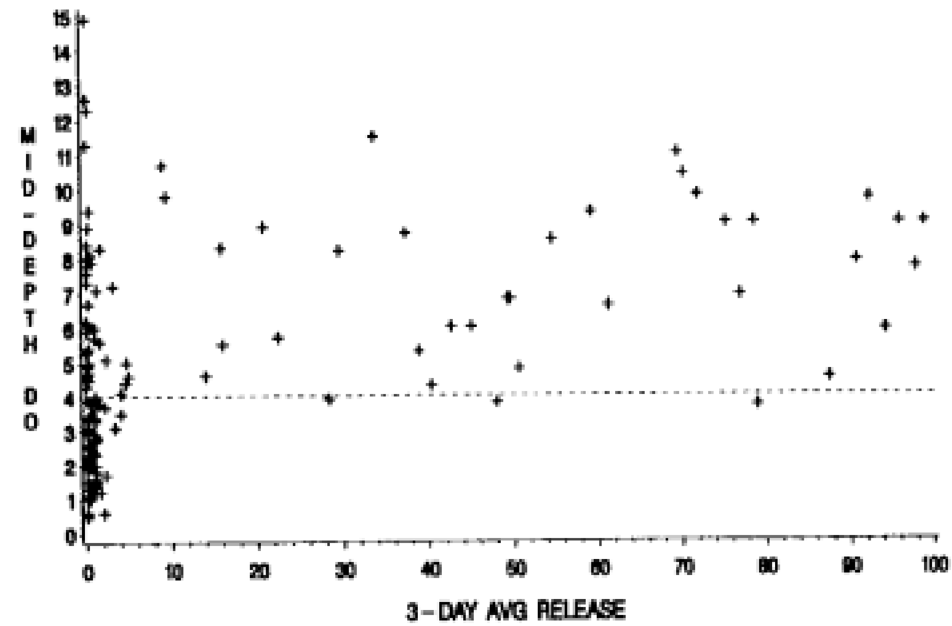

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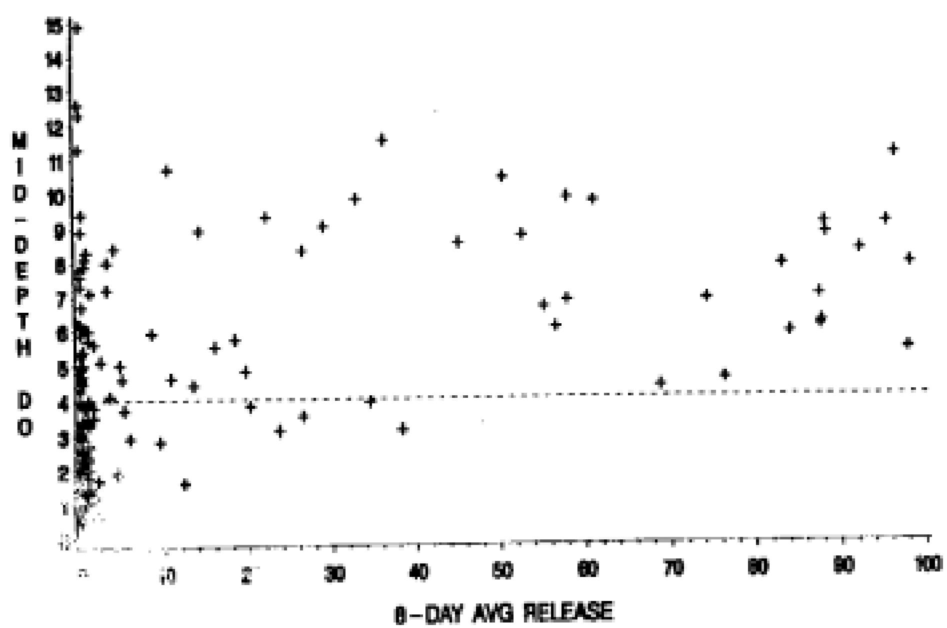

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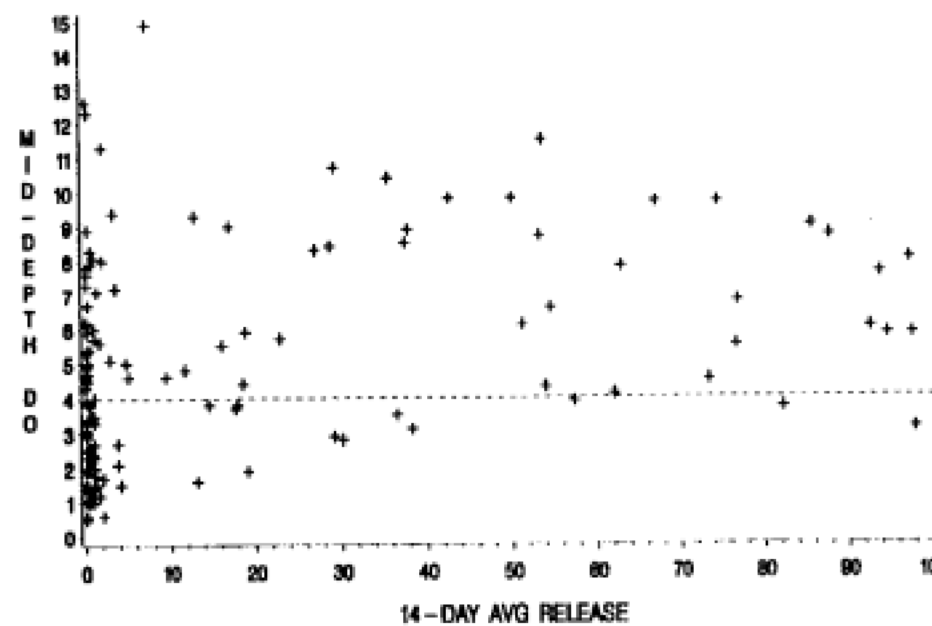

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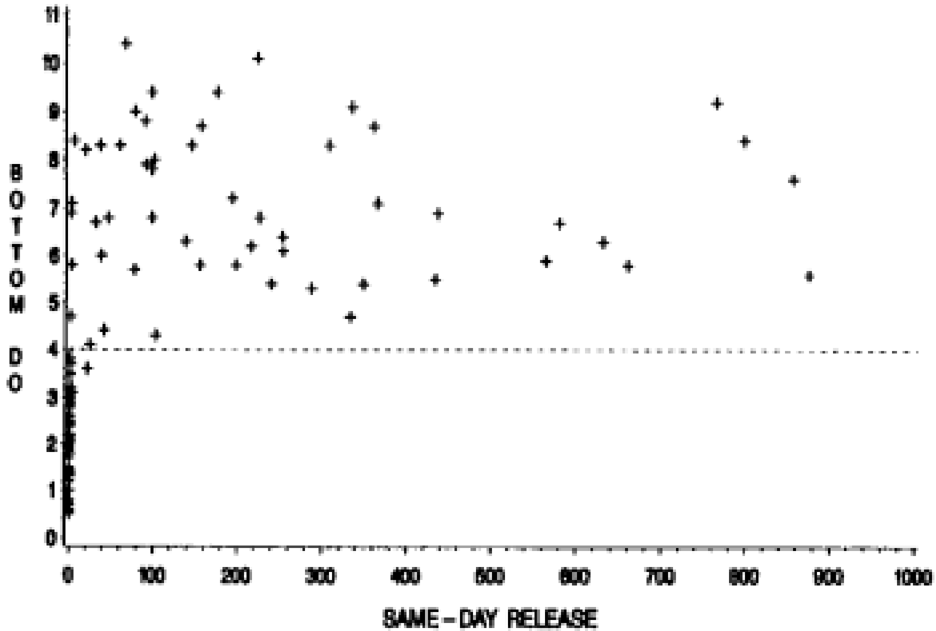

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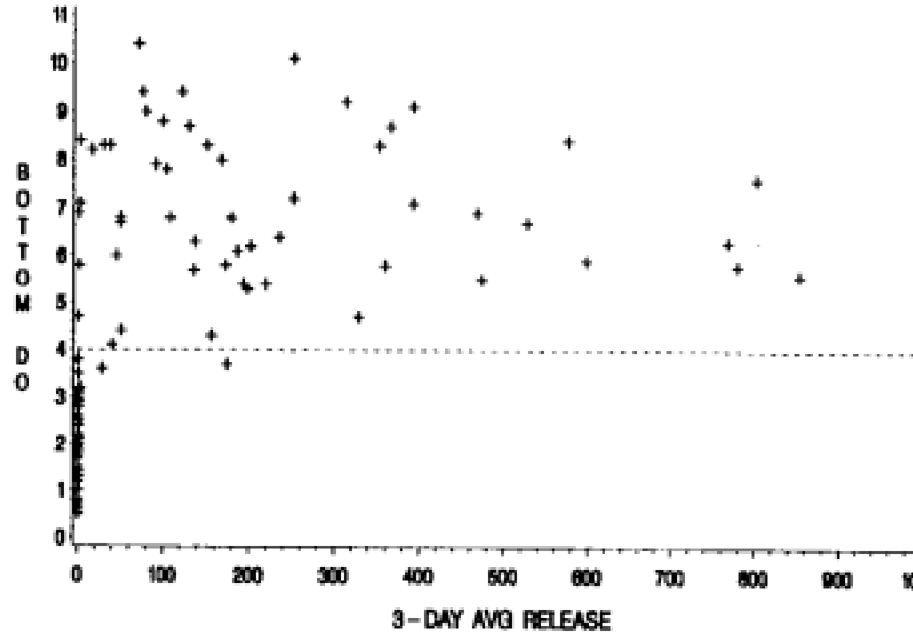

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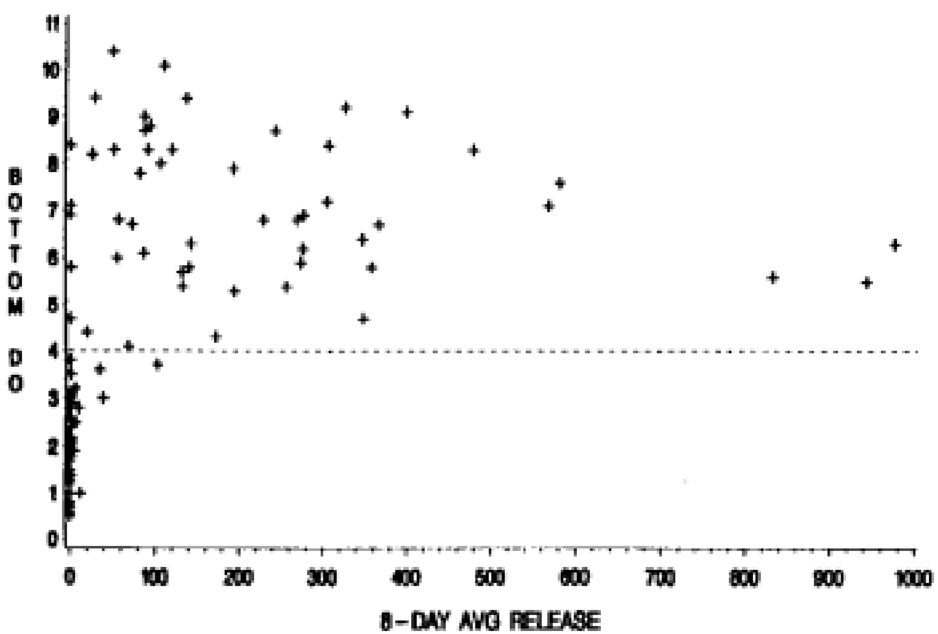

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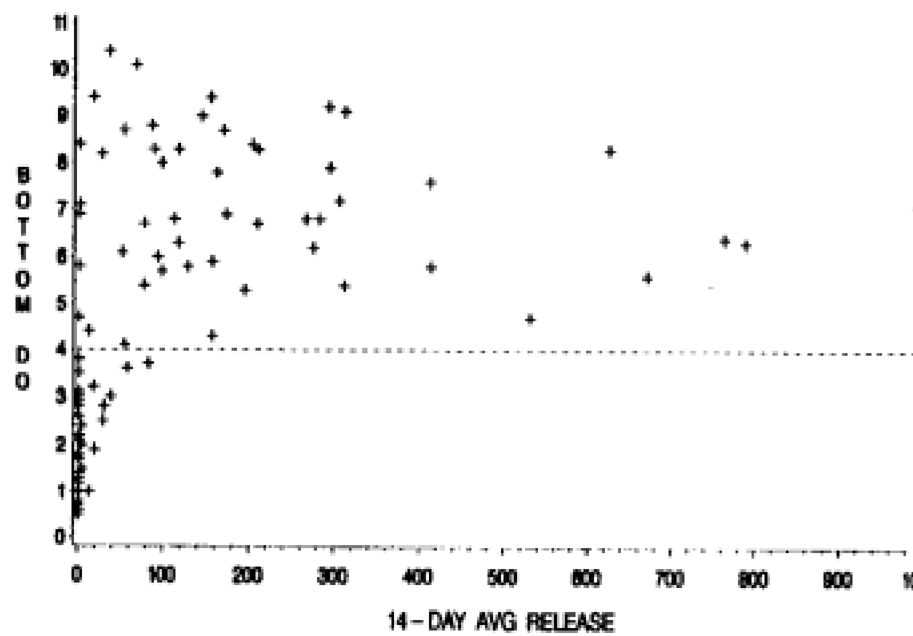

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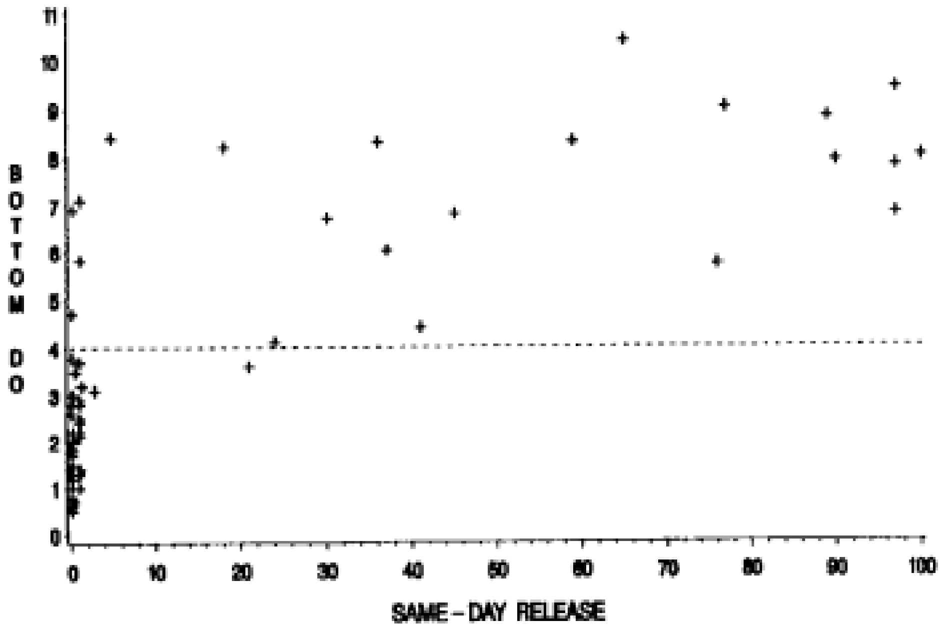

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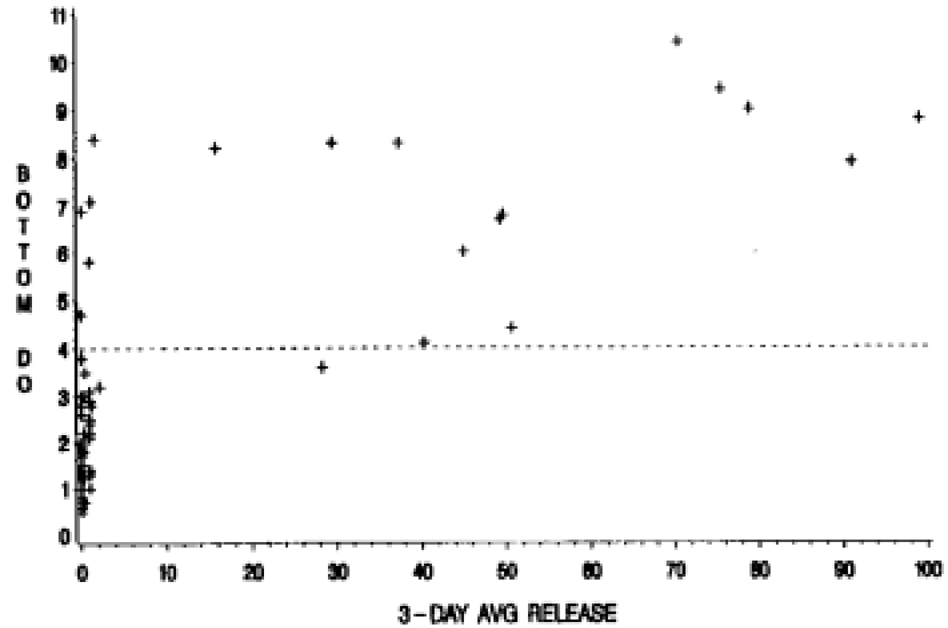

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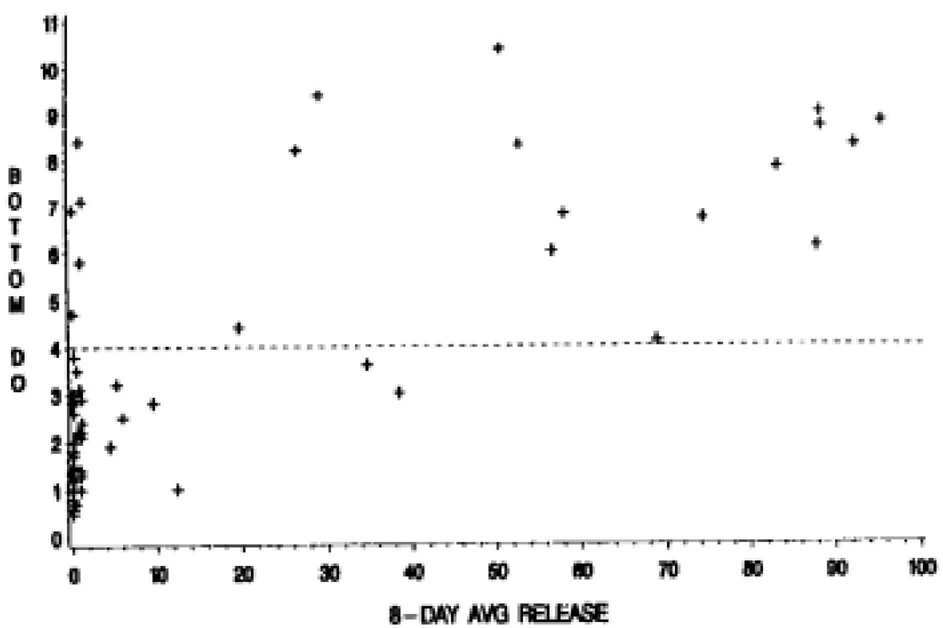

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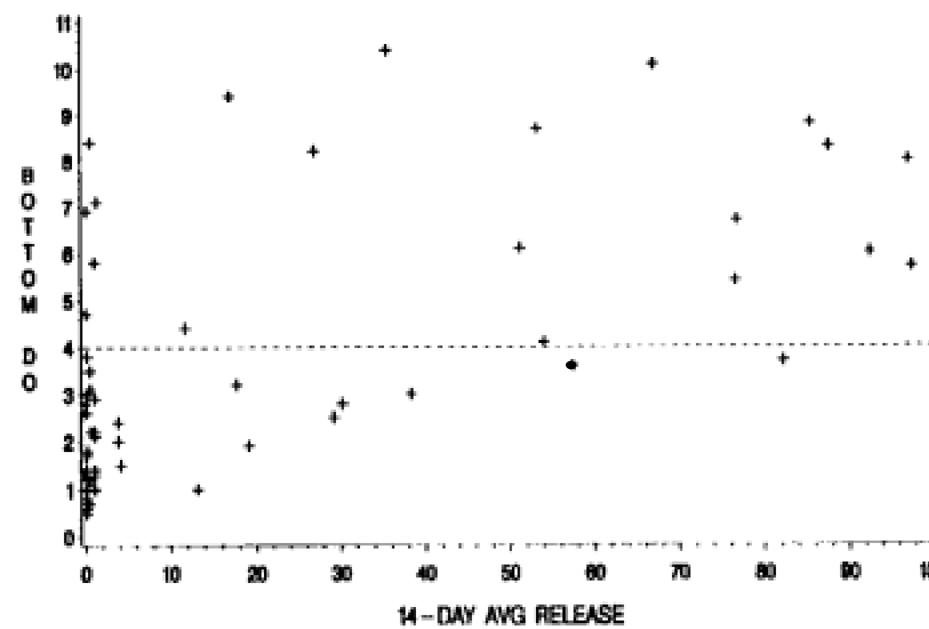

H-7

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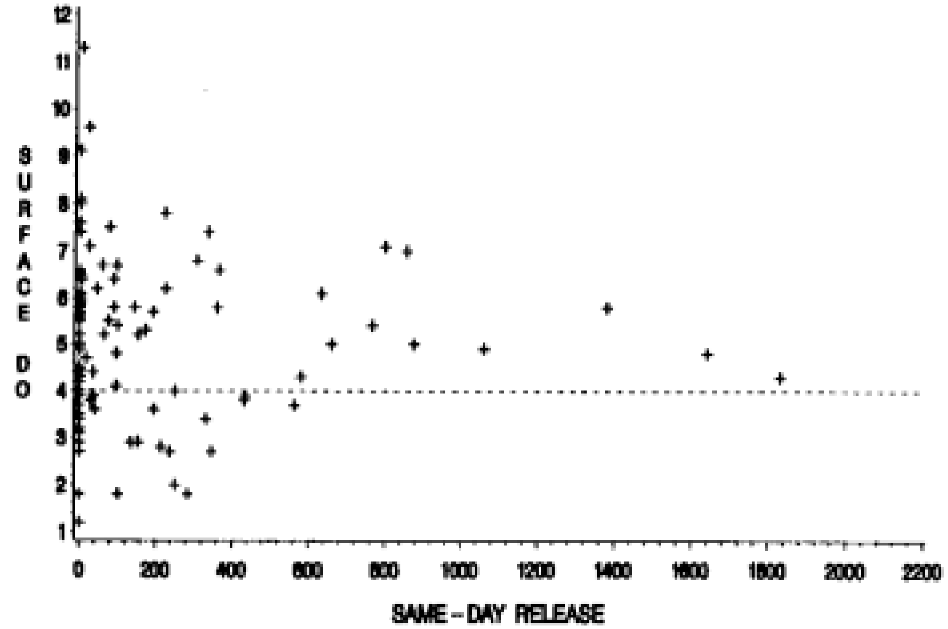

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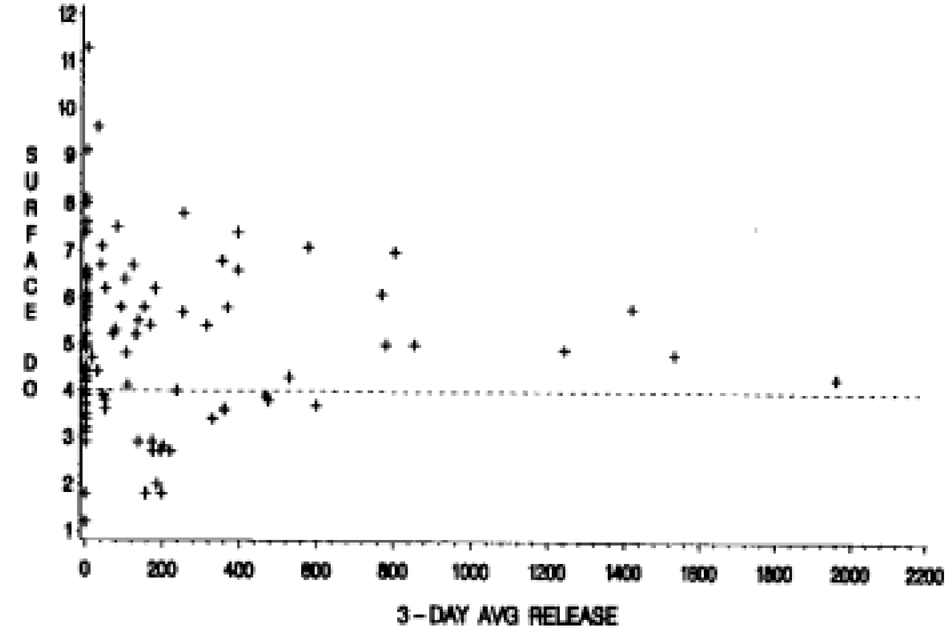

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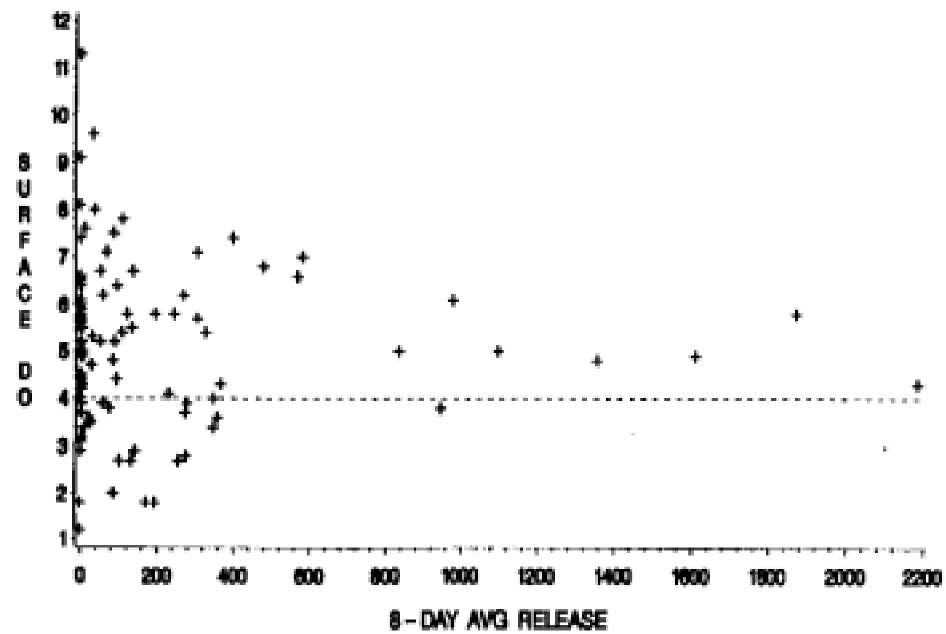

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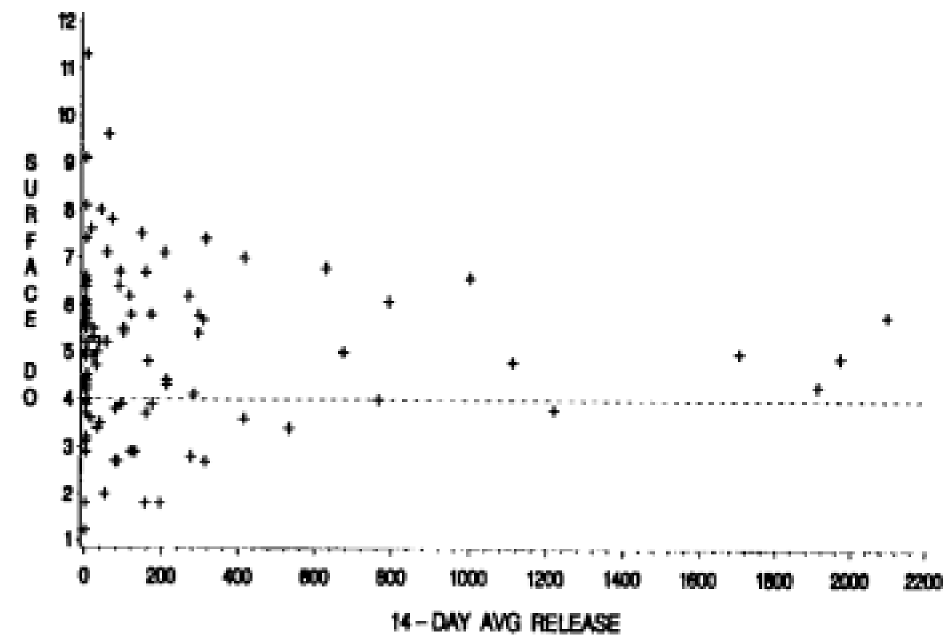

8-H

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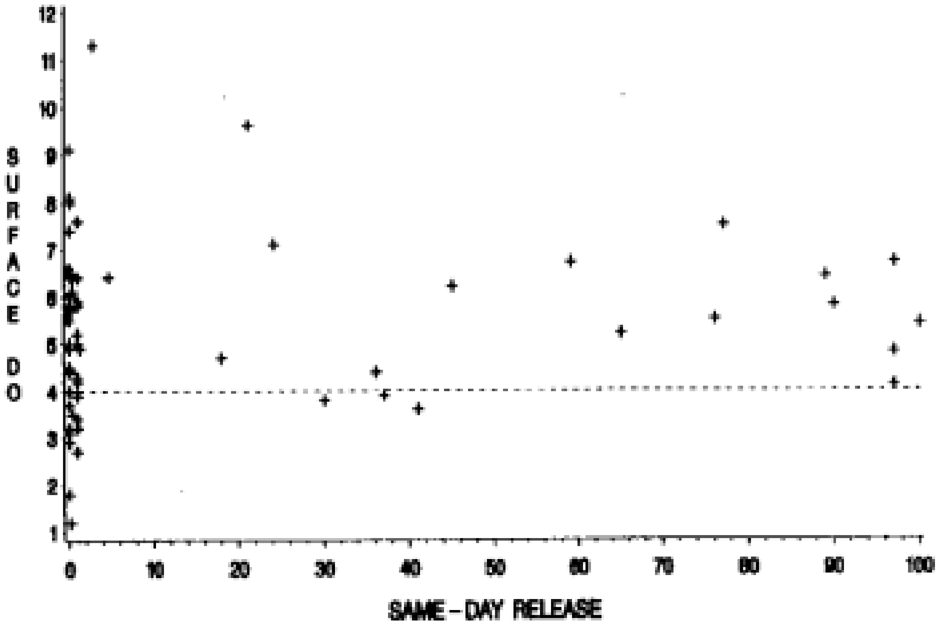

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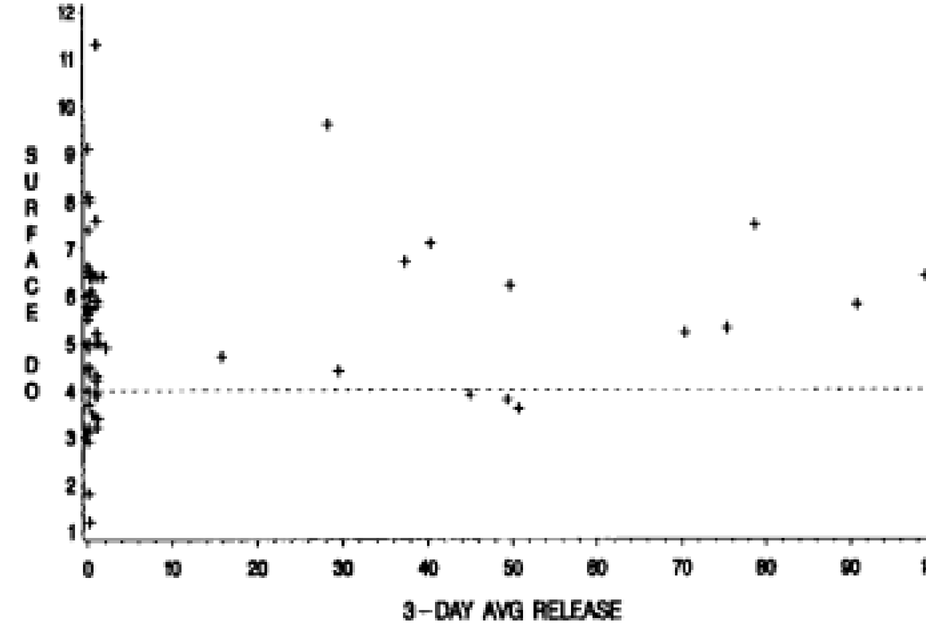

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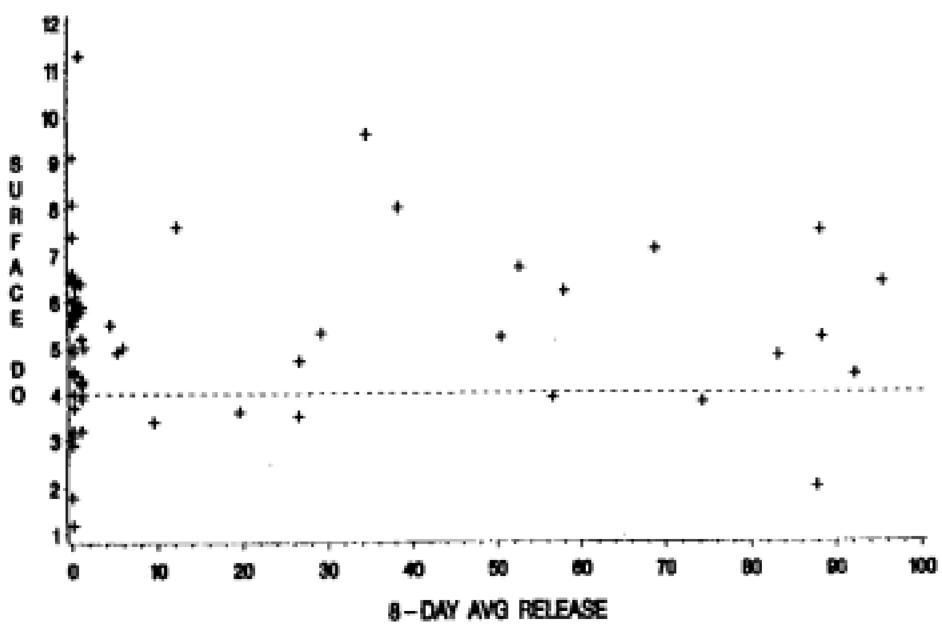

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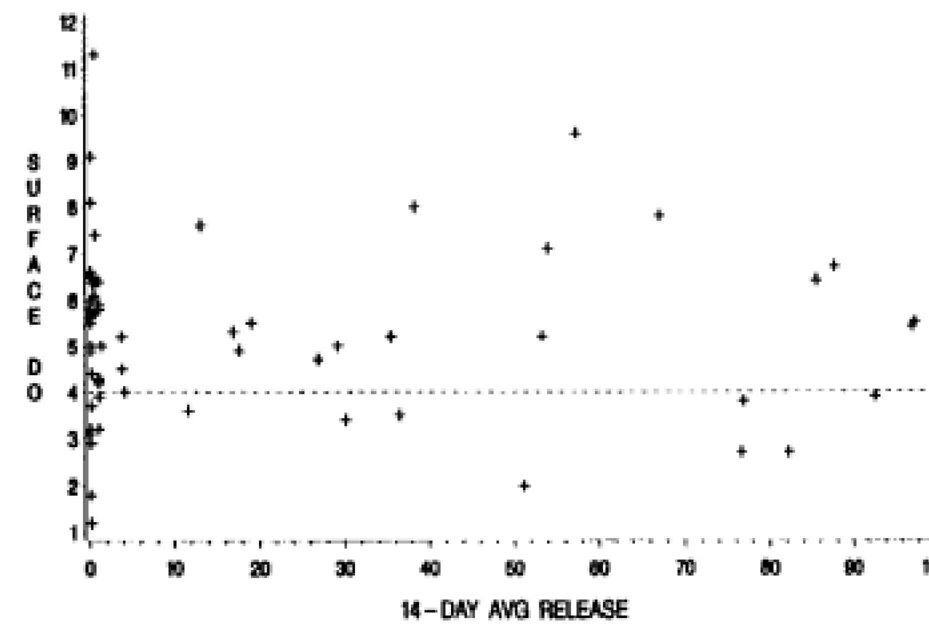

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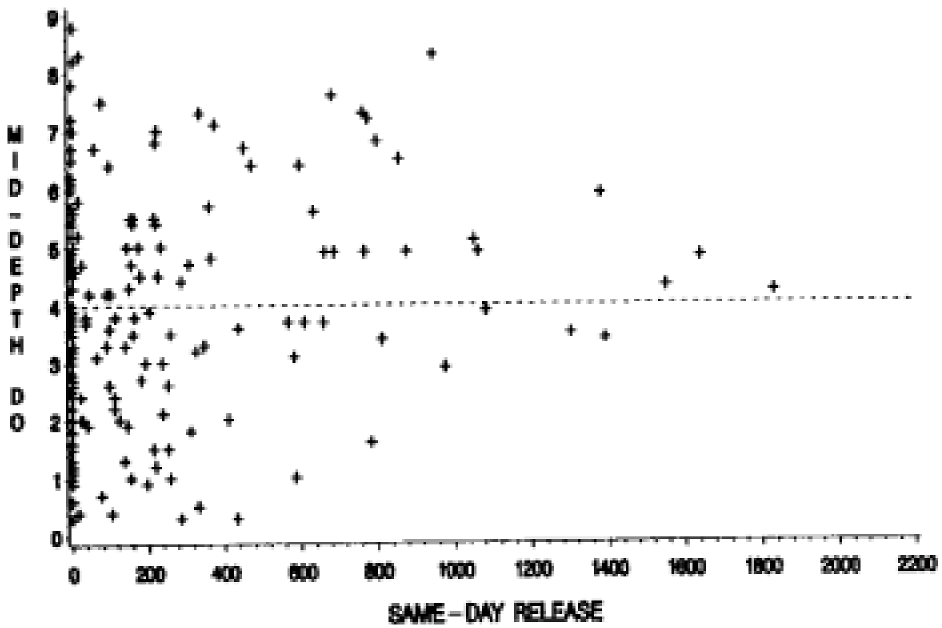

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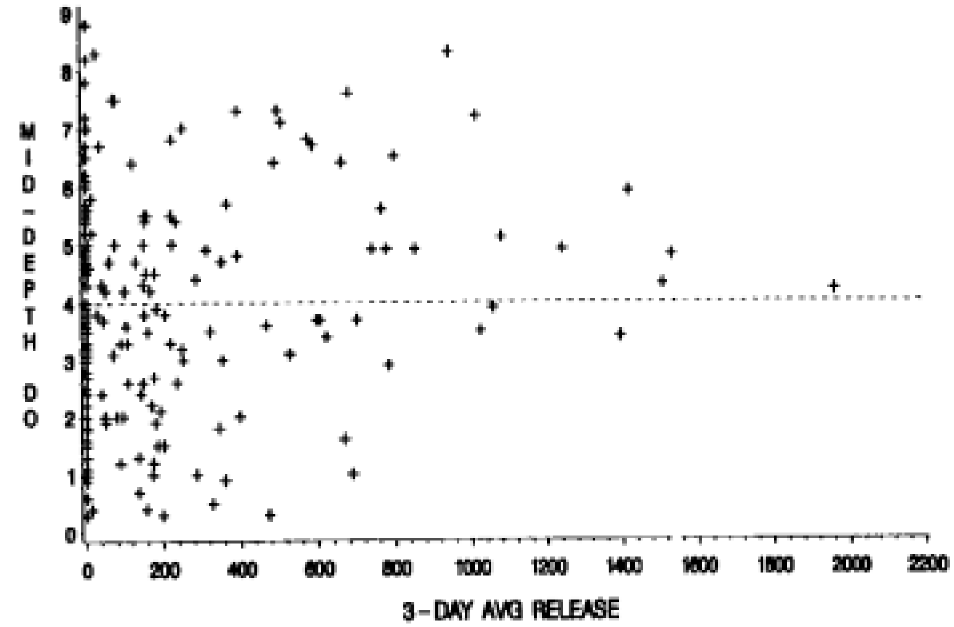

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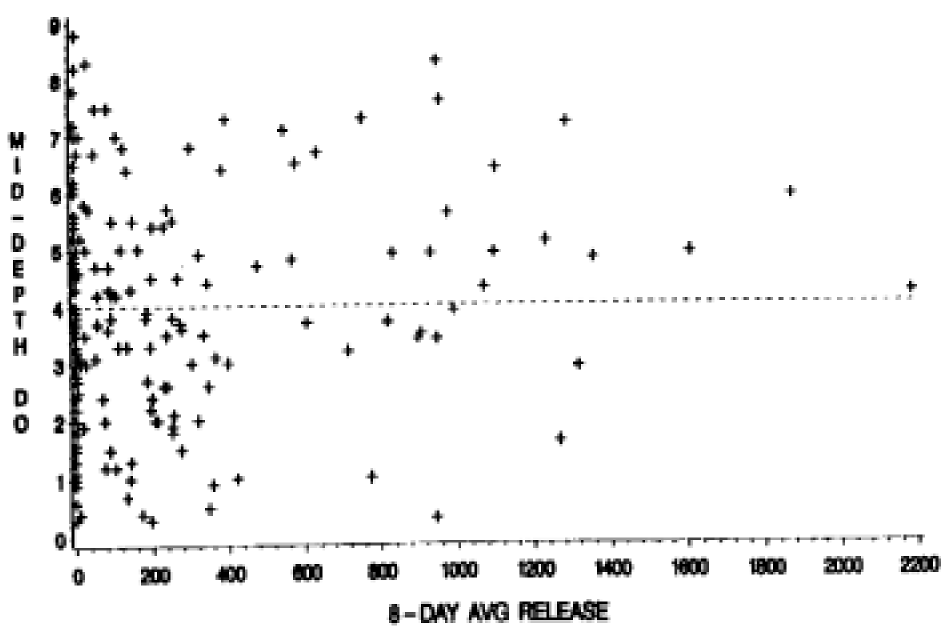

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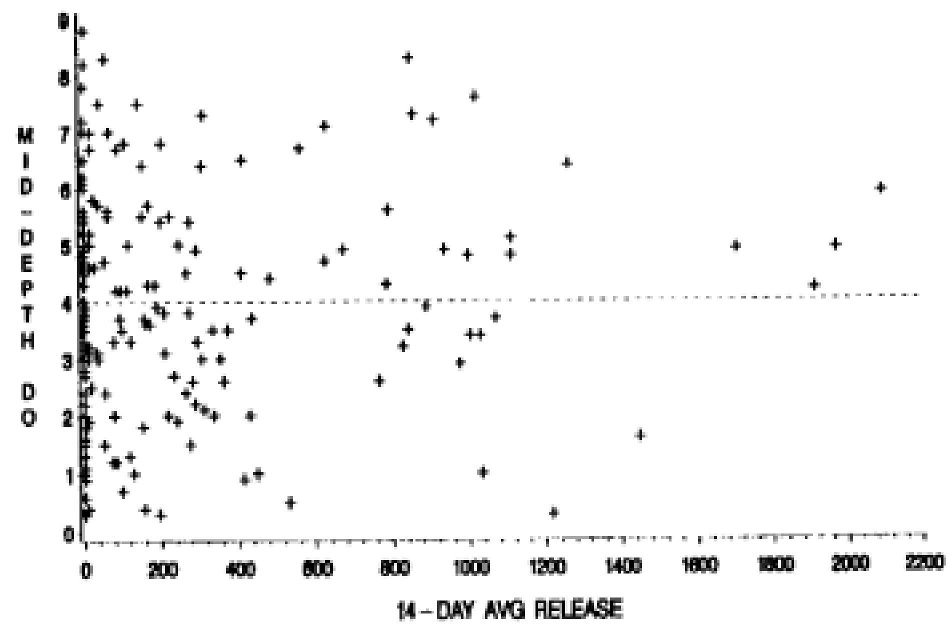

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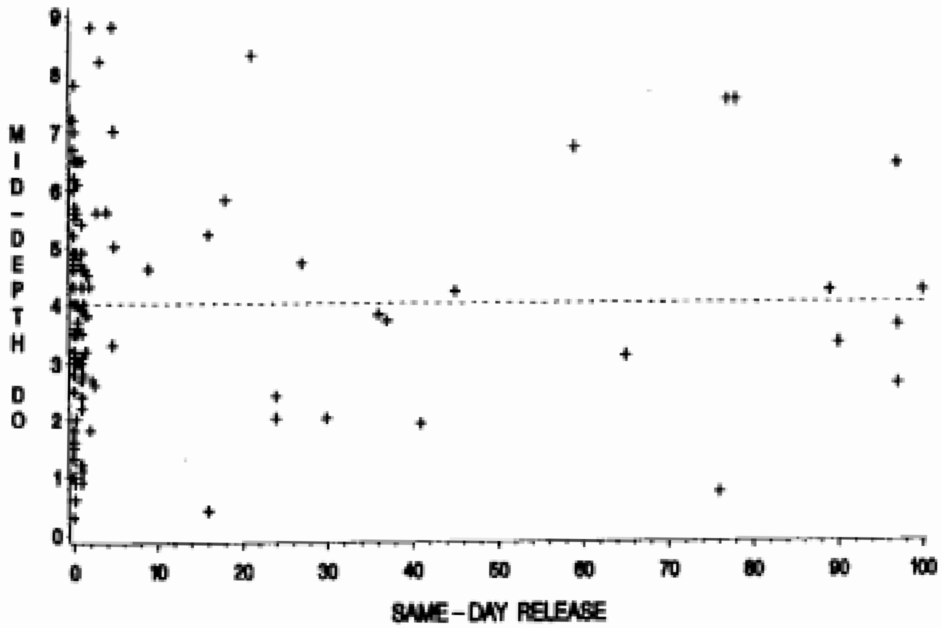

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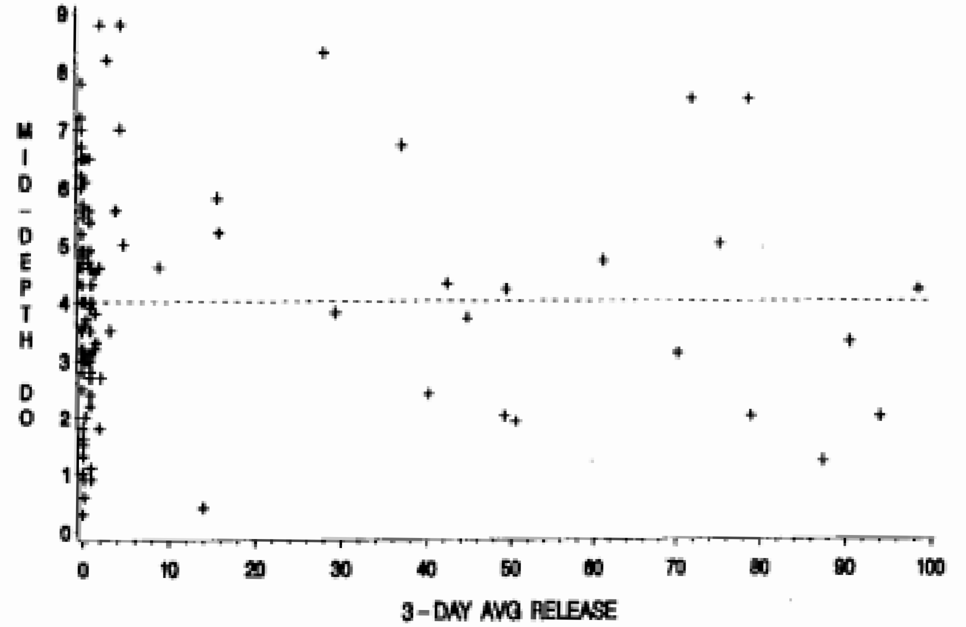

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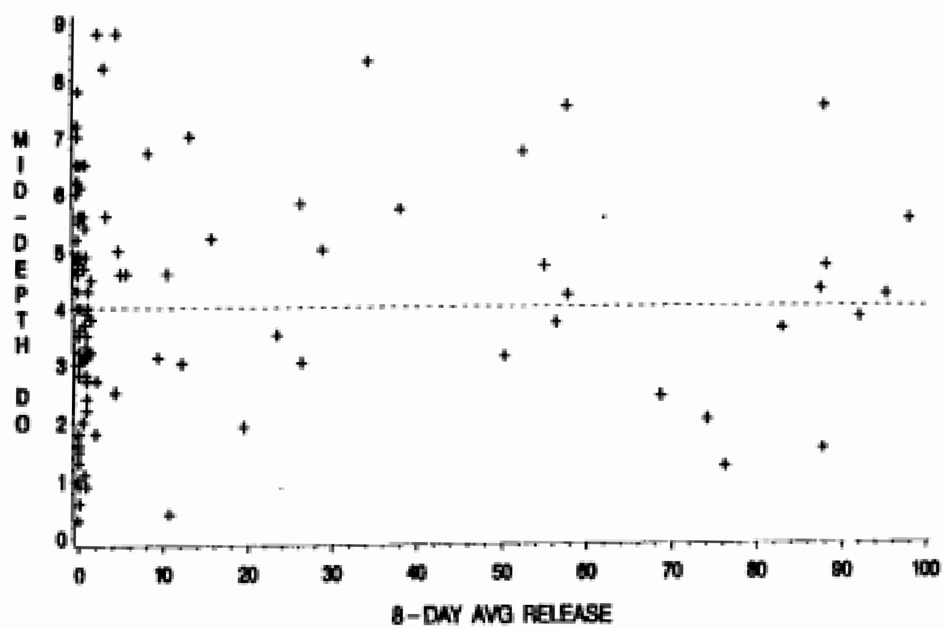

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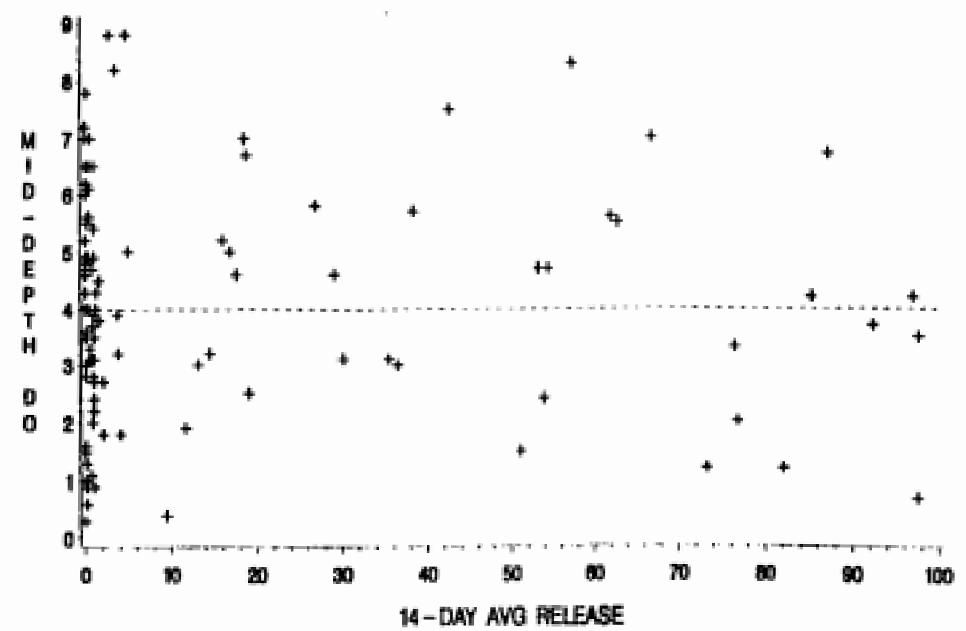

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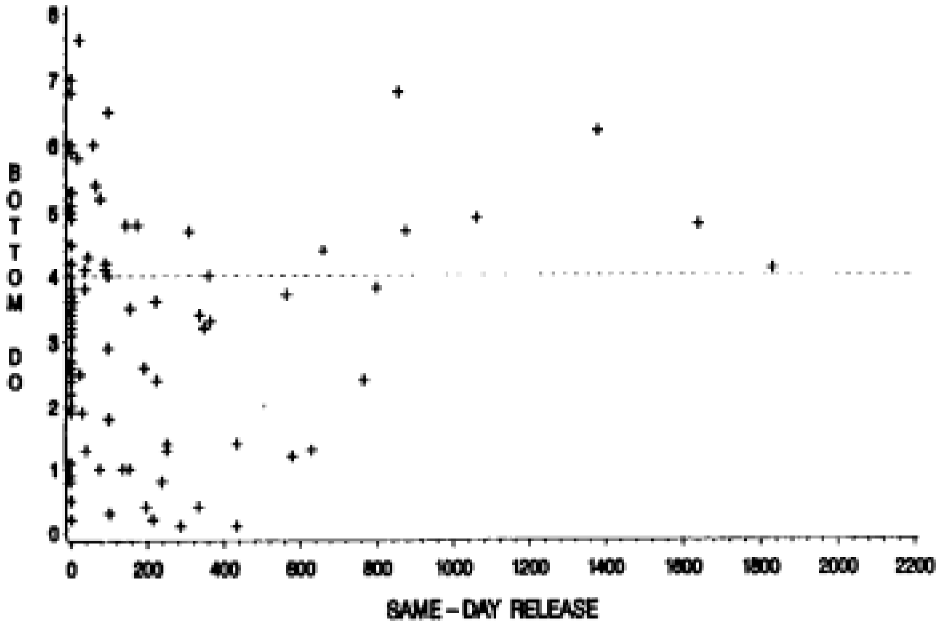

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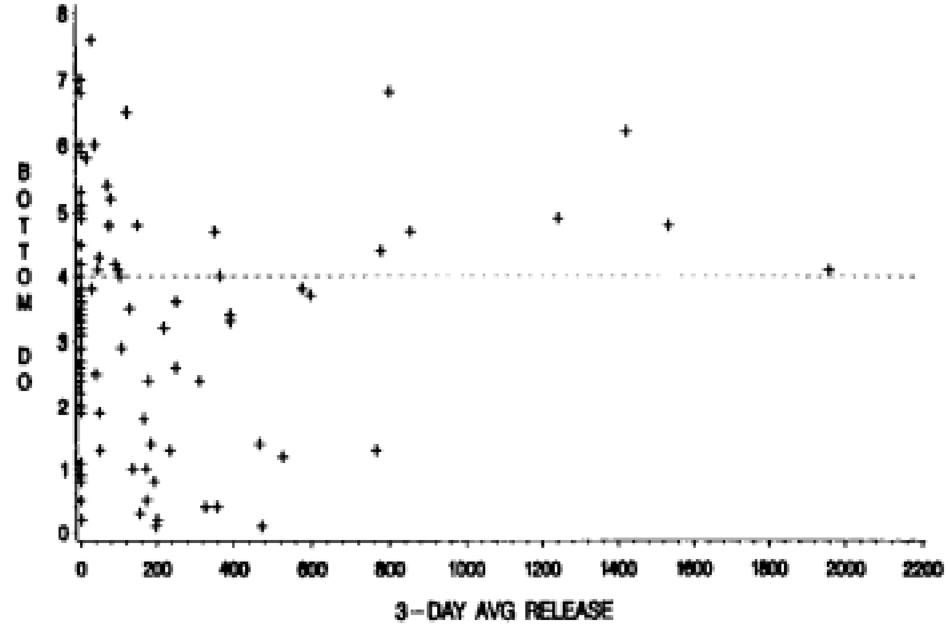

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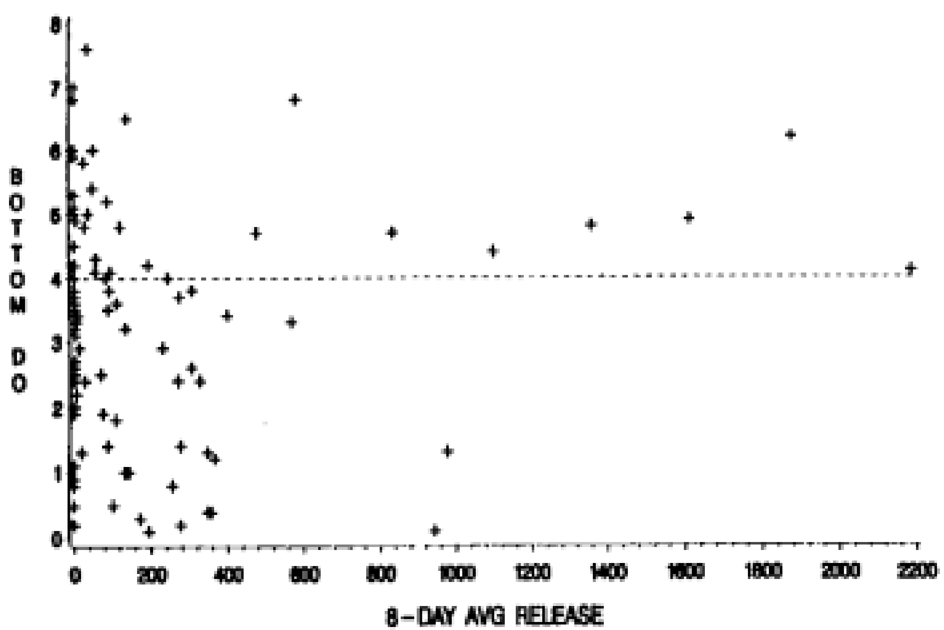

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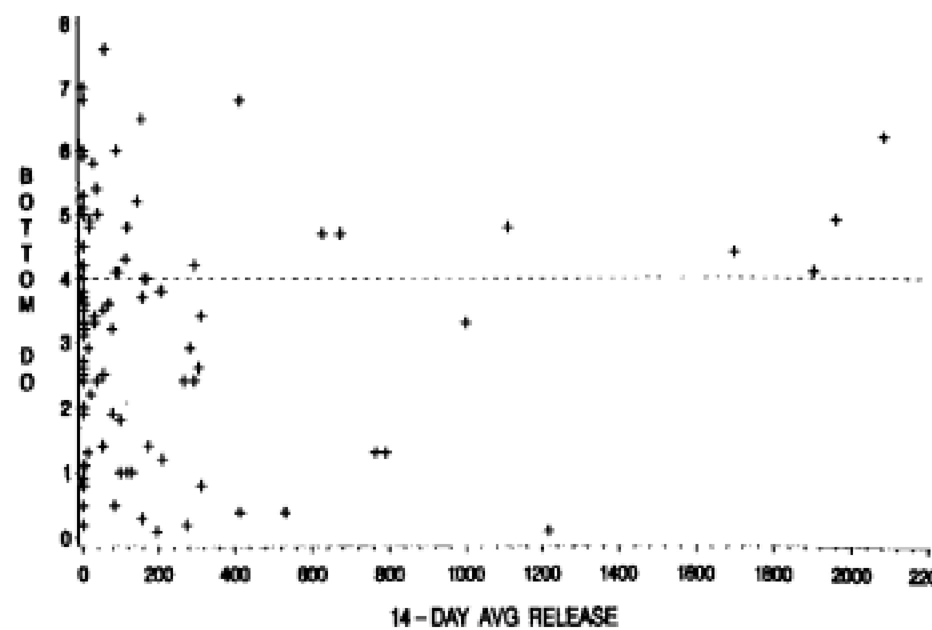

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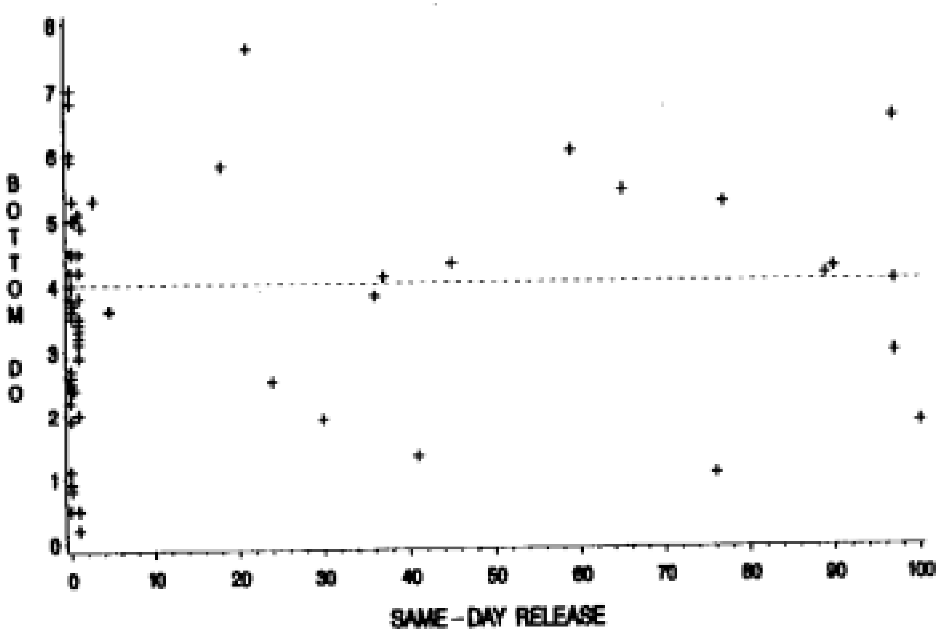

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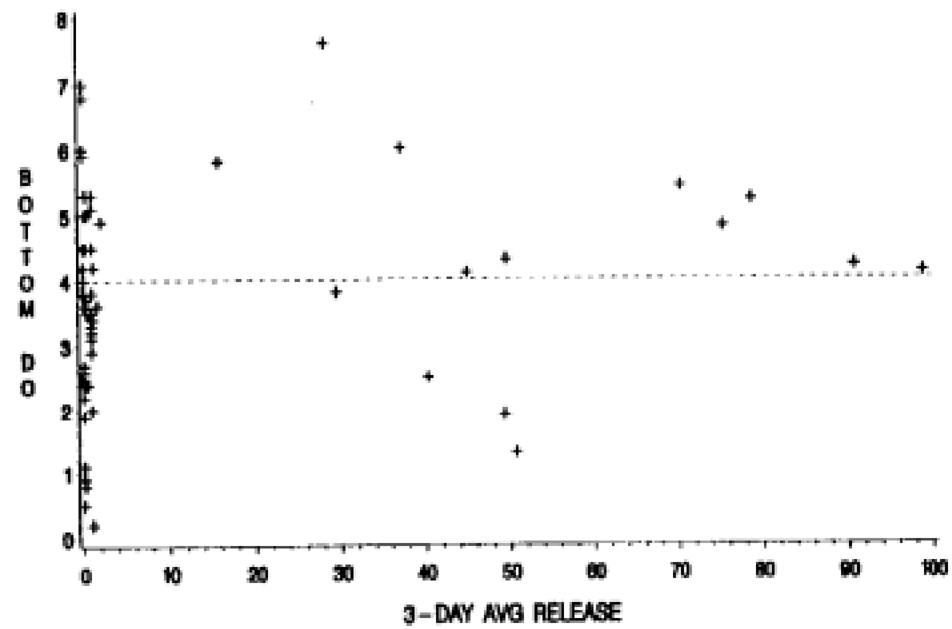

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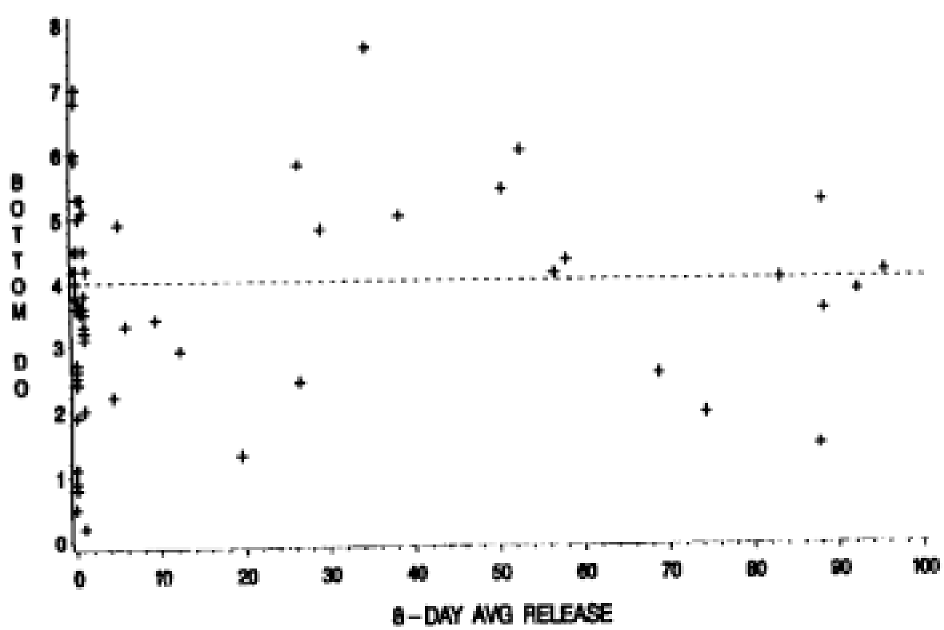

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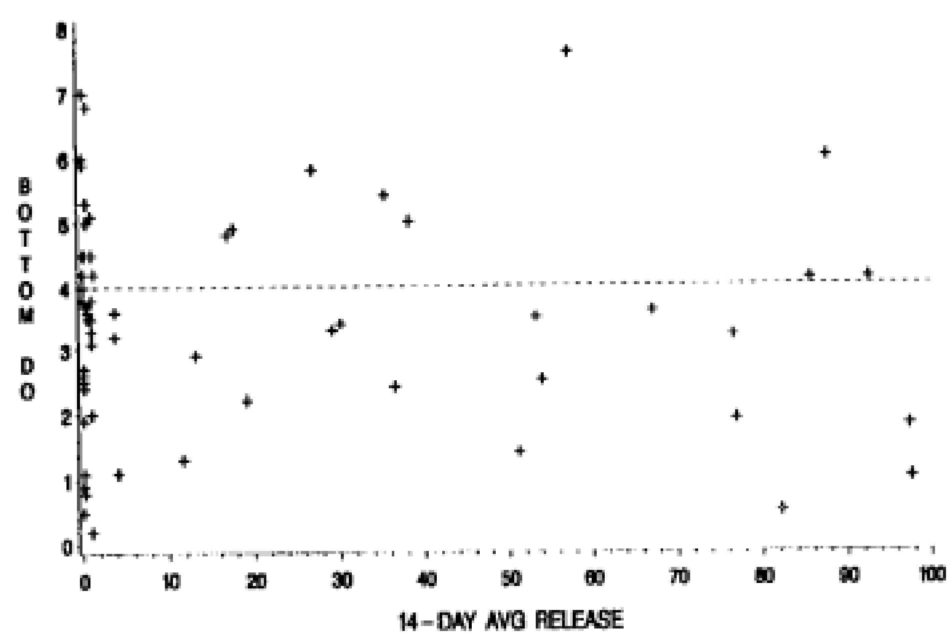

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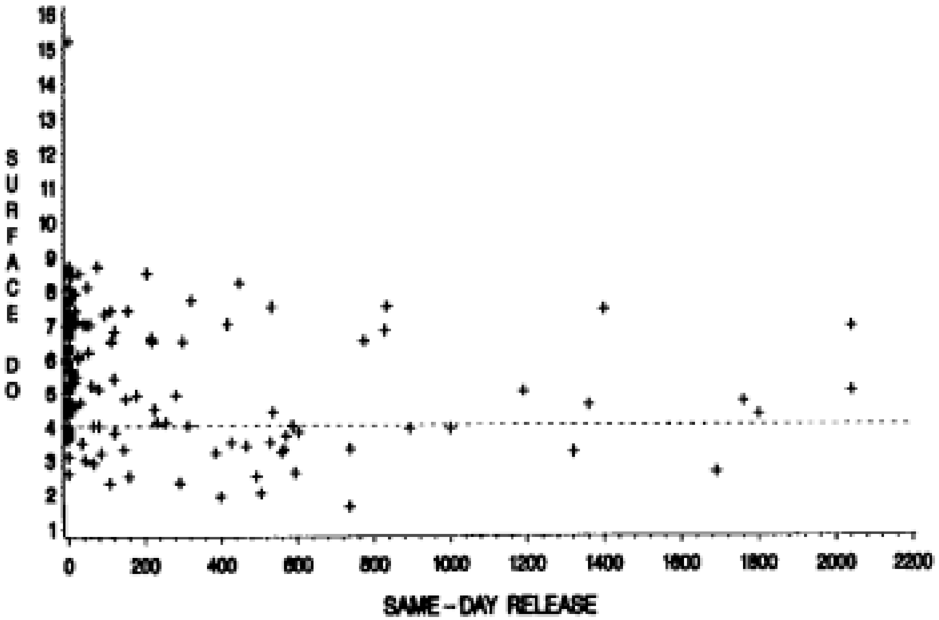

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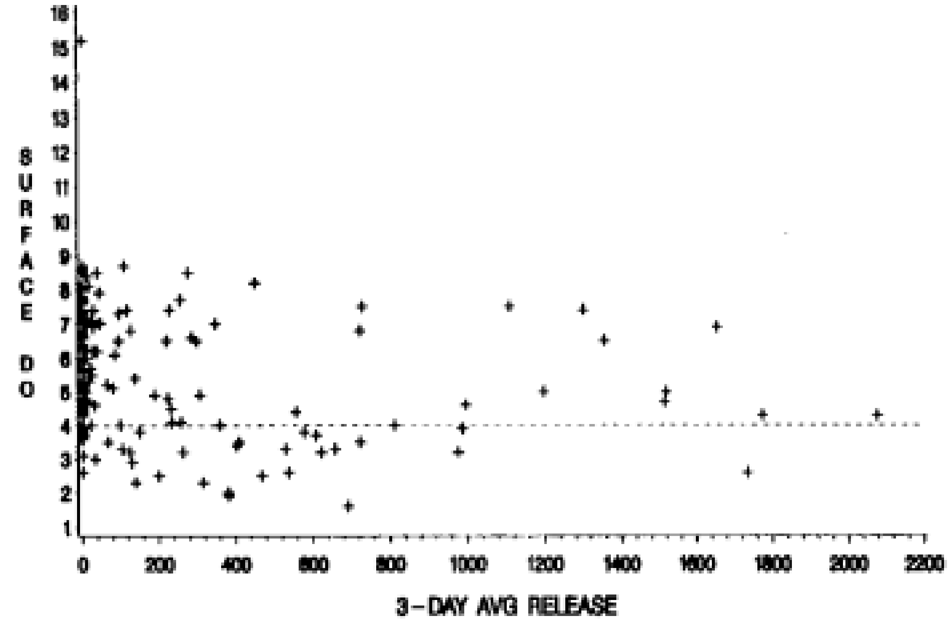

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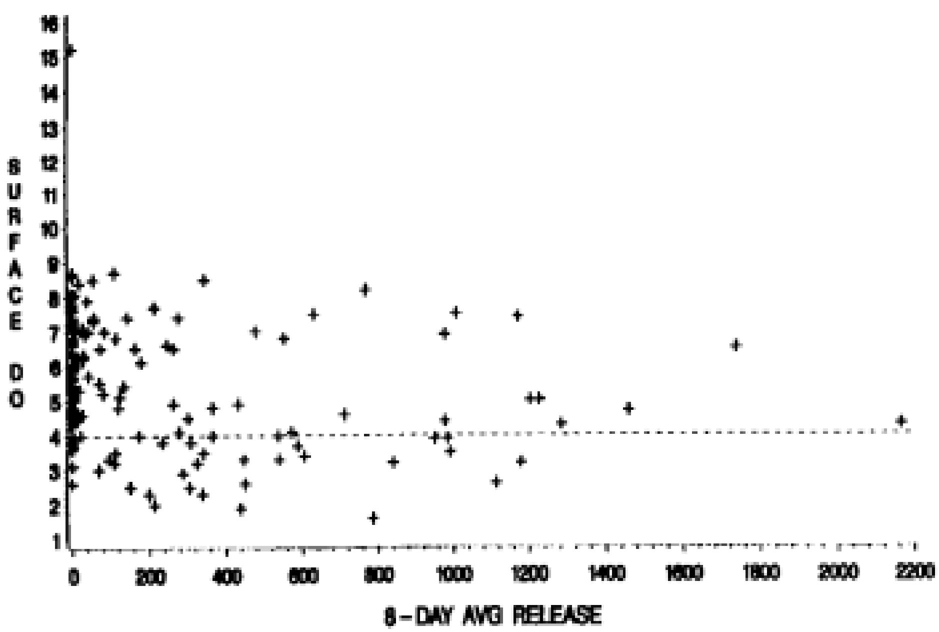

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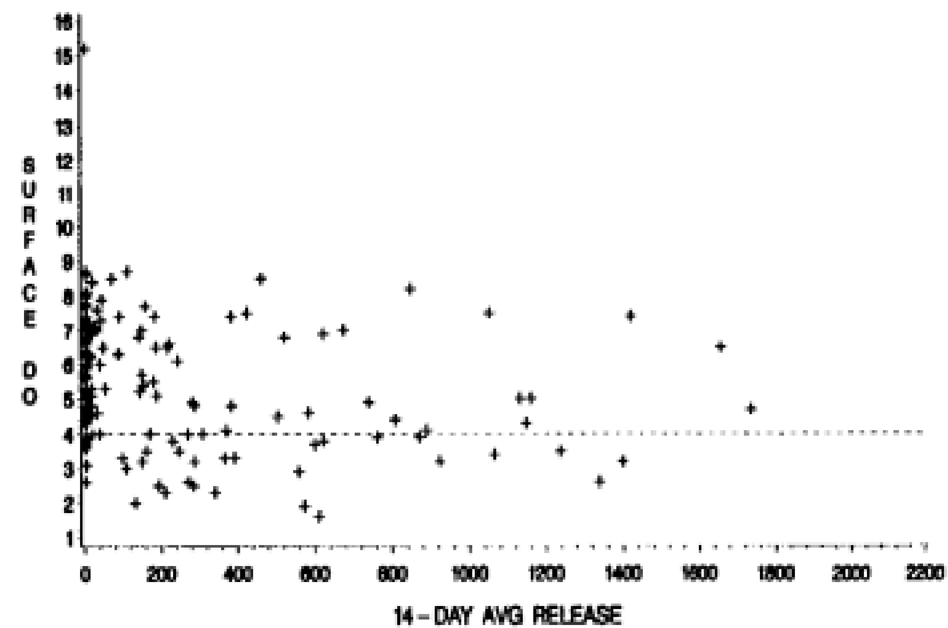

H-13

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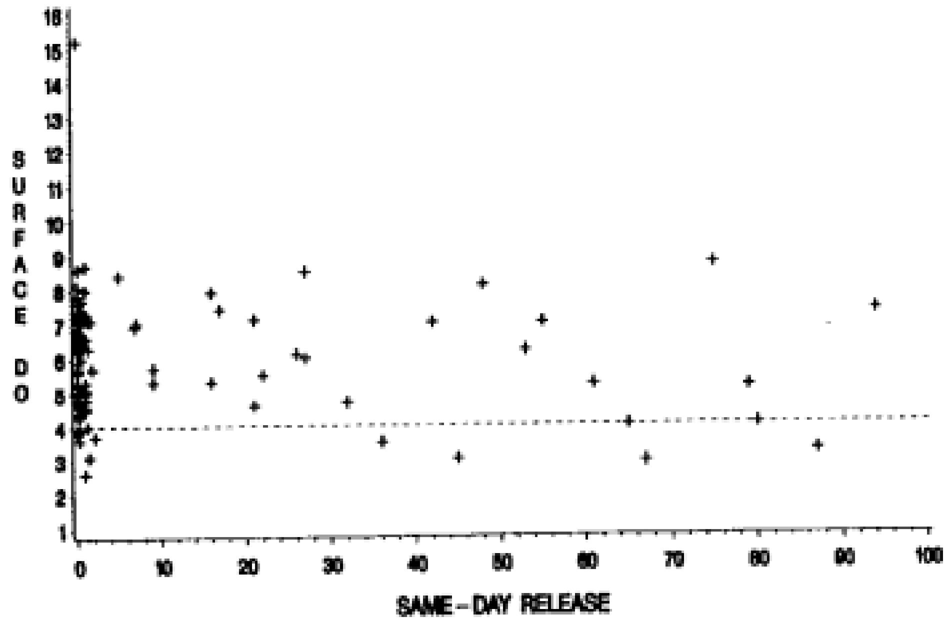

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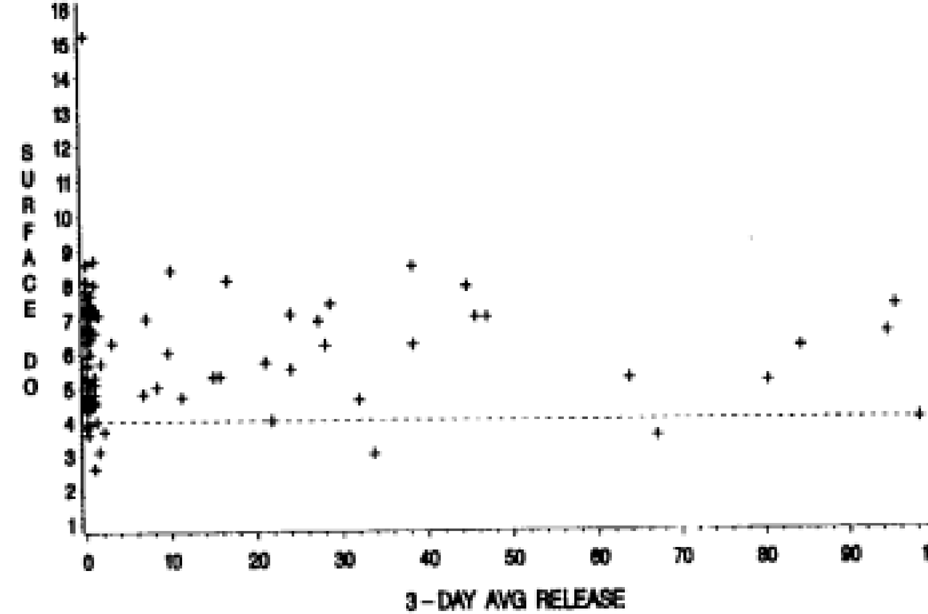

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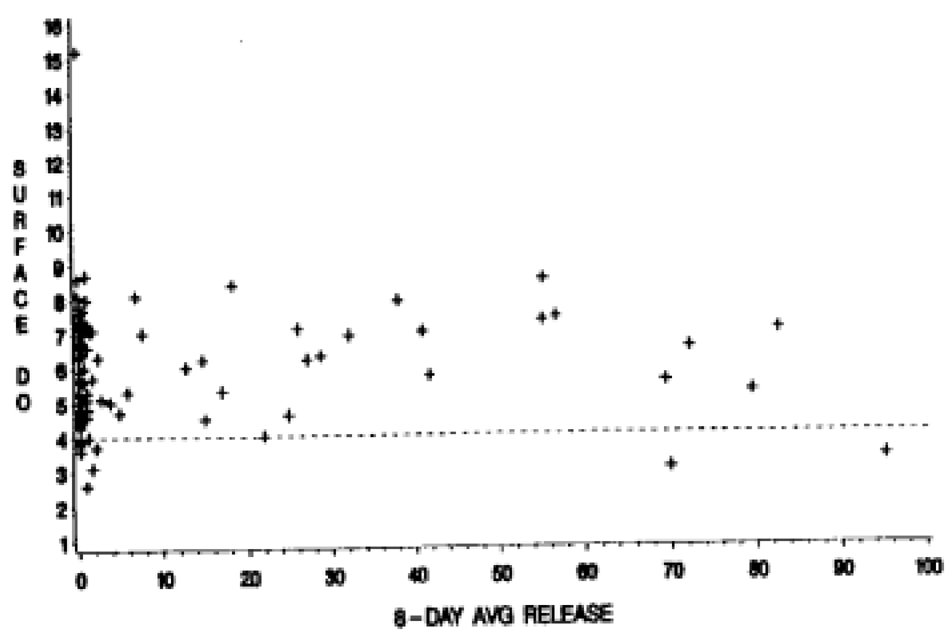

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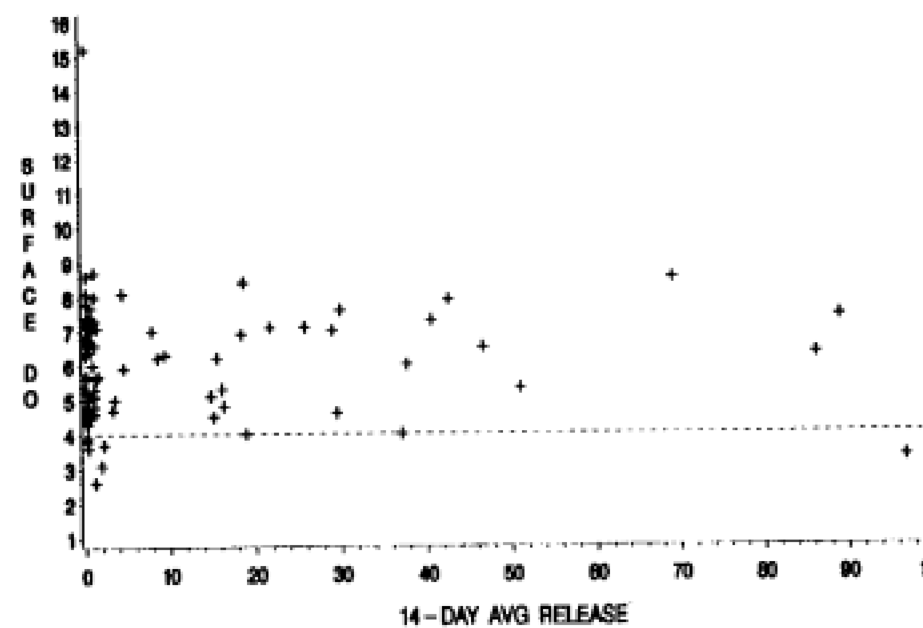

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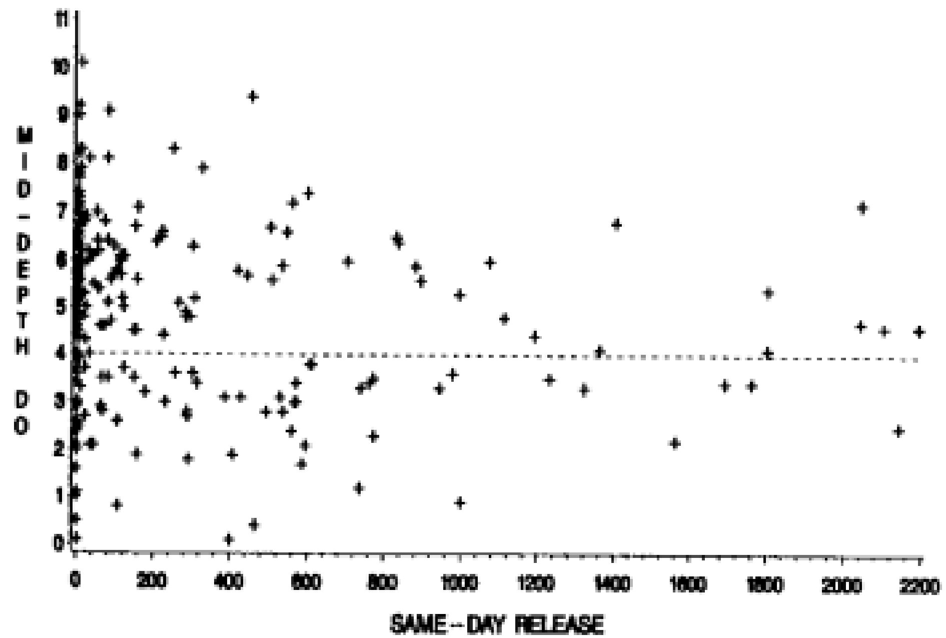

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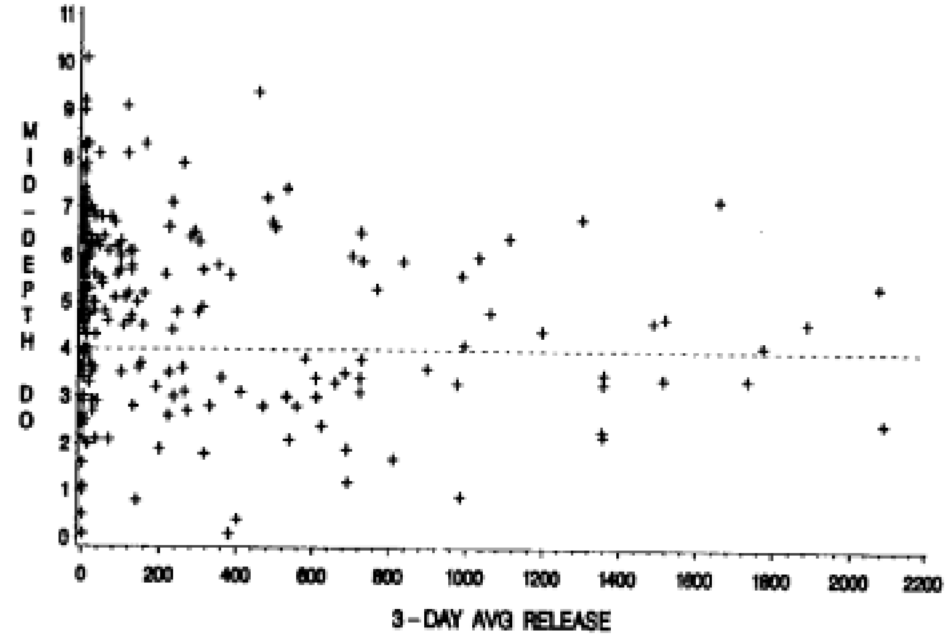

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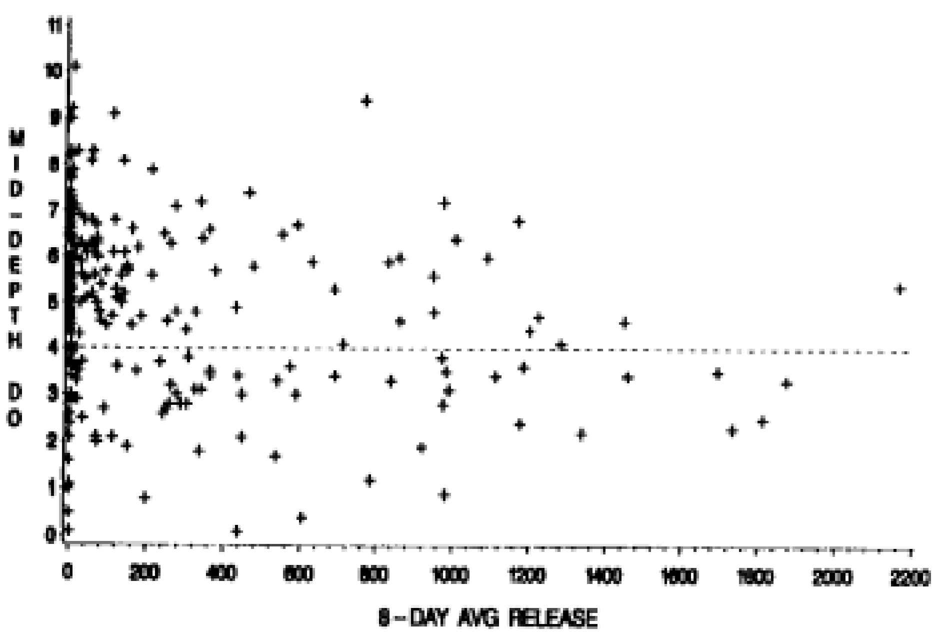

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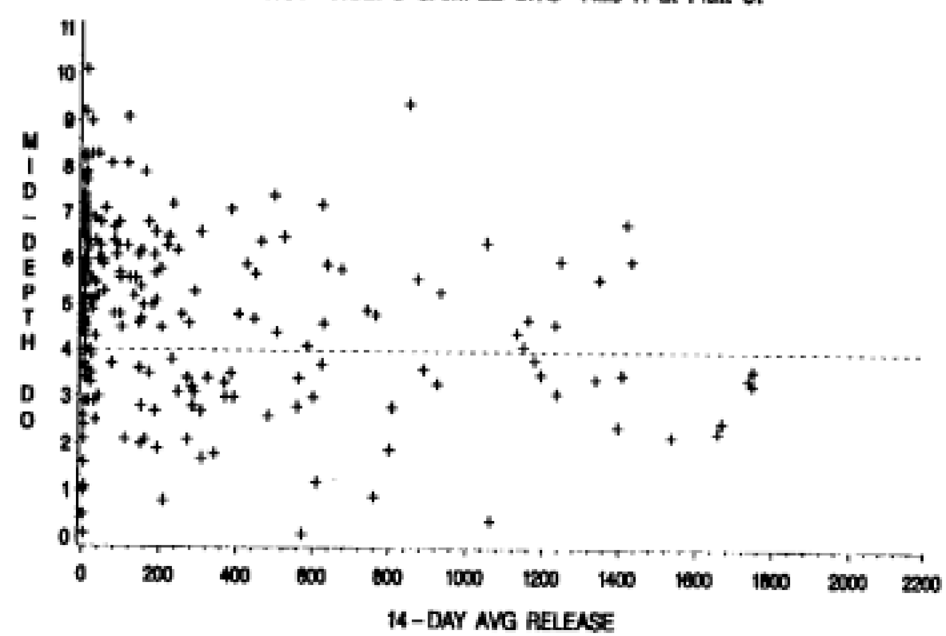

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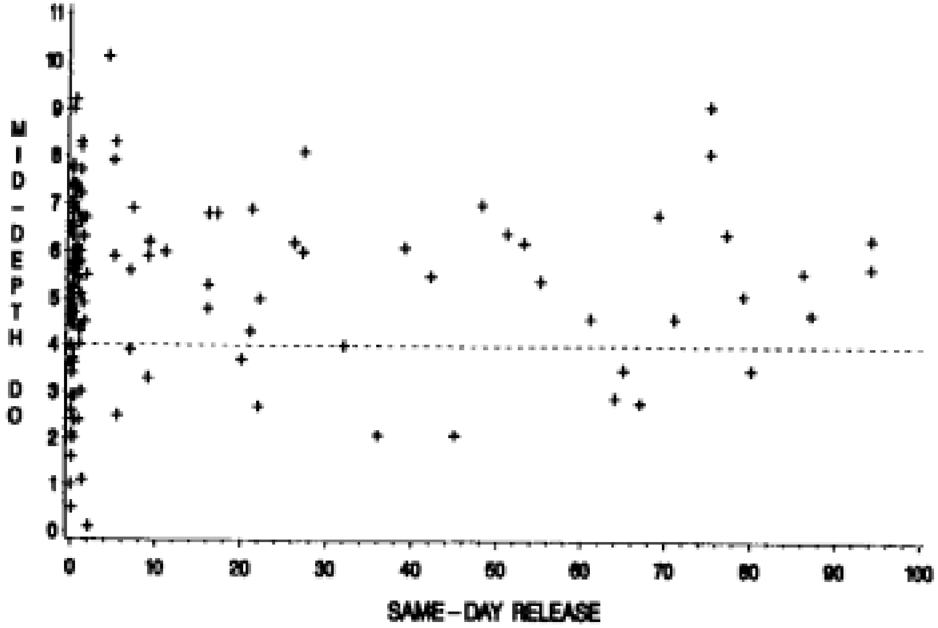

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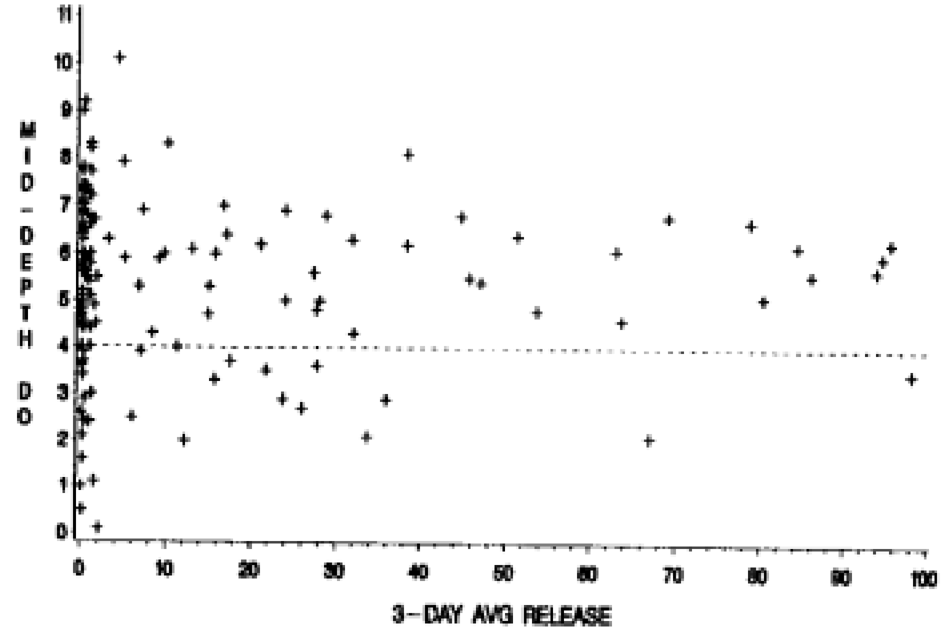

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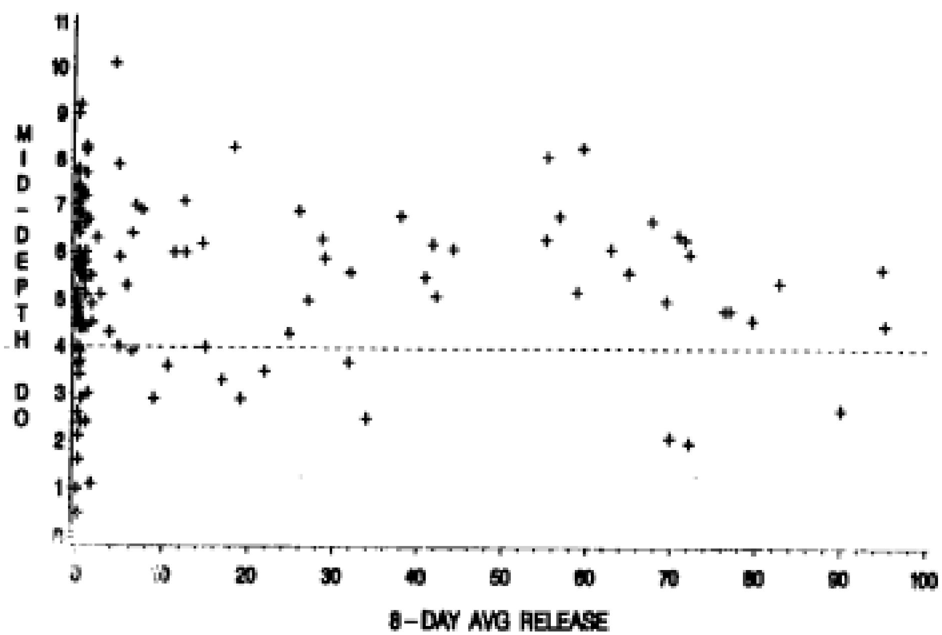

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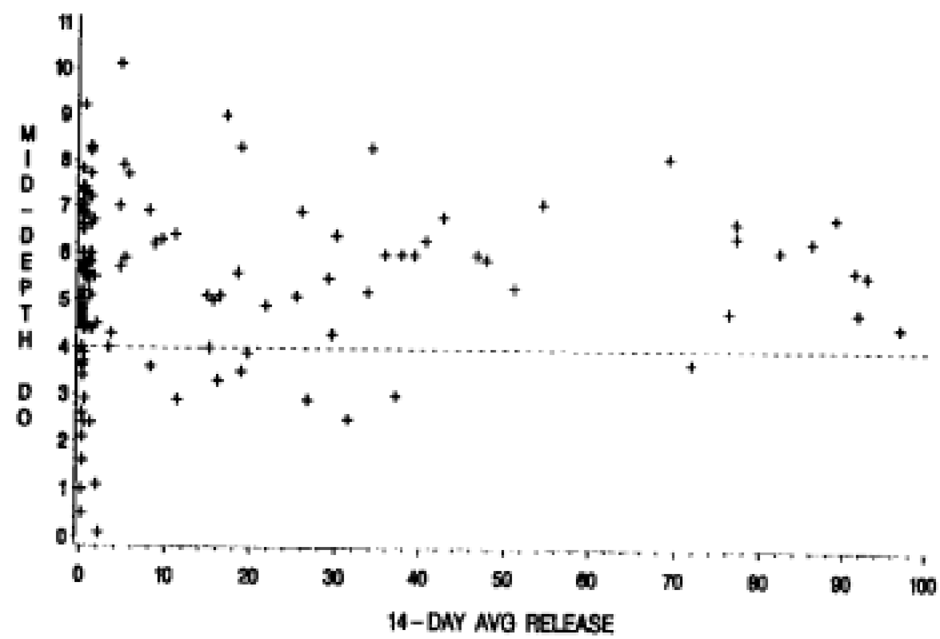

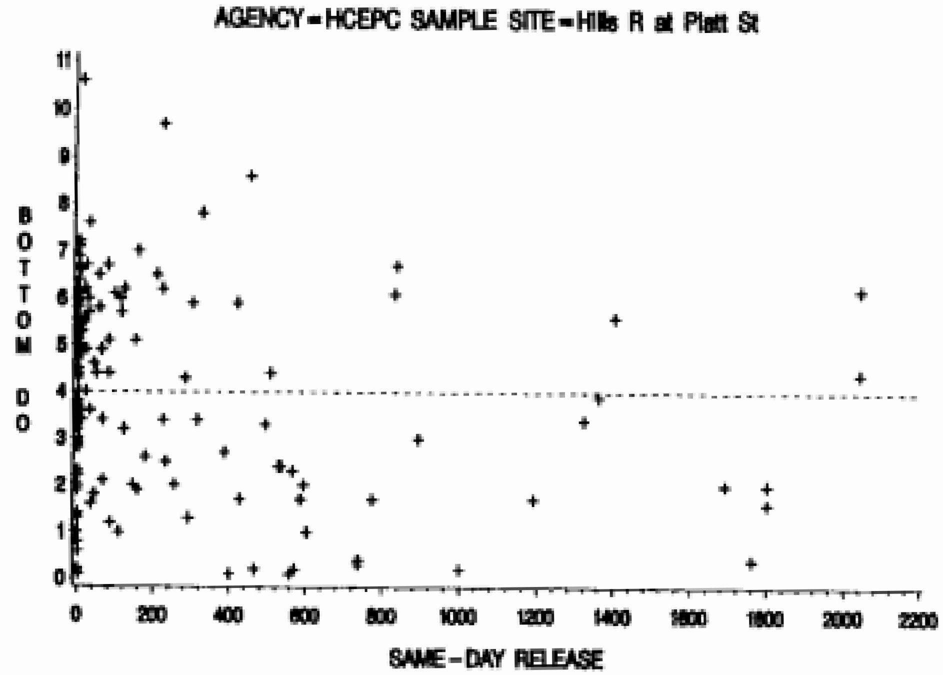
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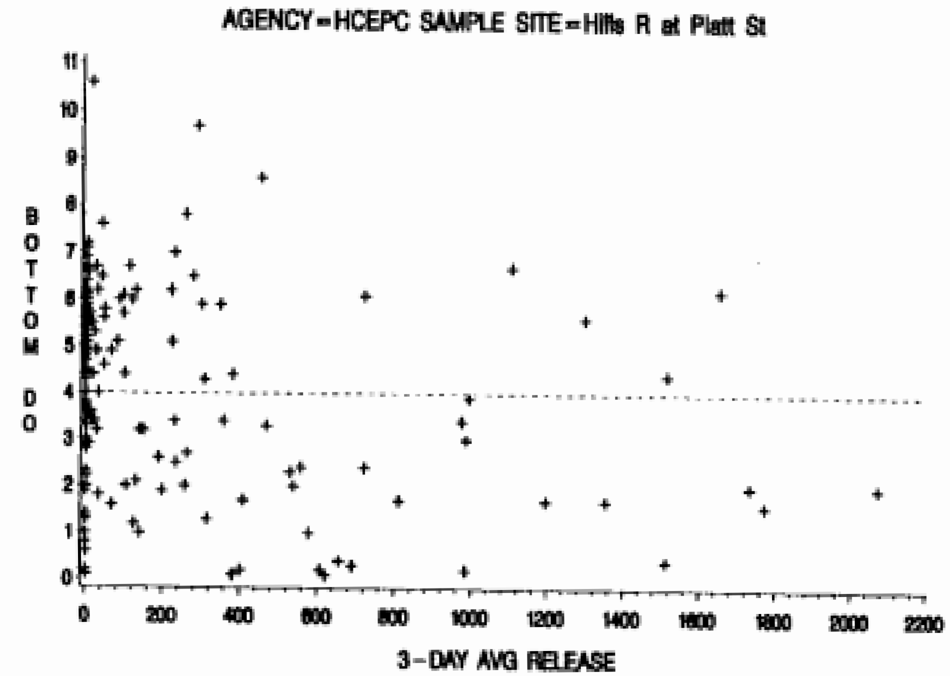
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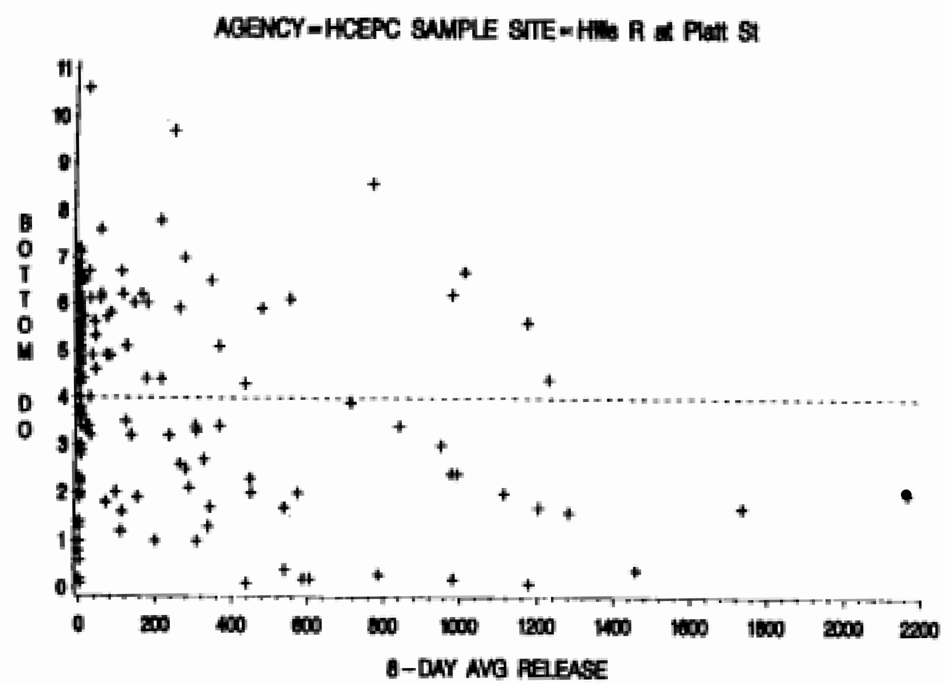
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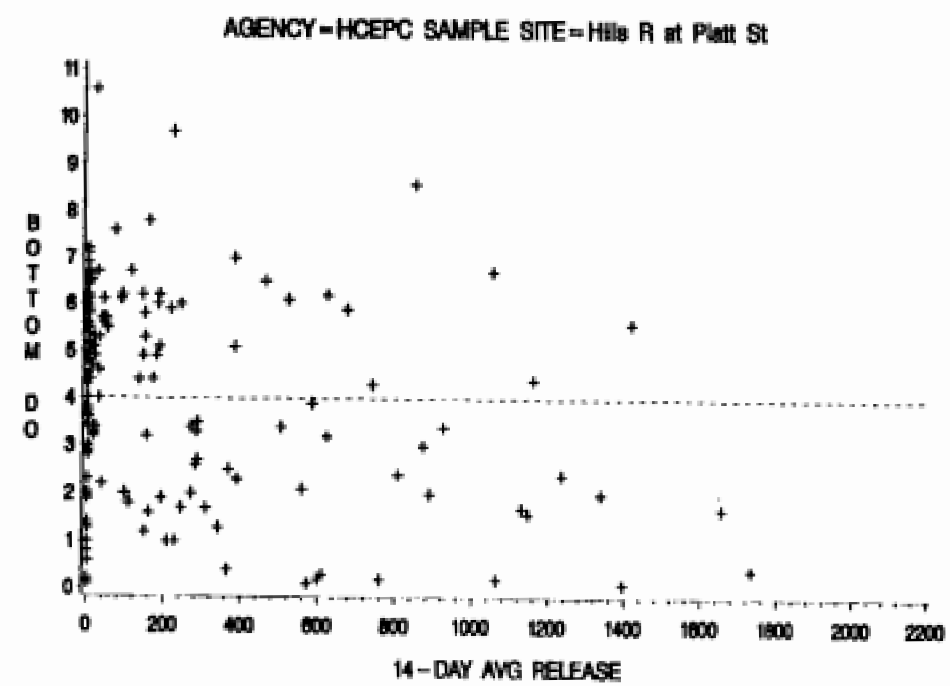
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14-DAY AVG RELEASE

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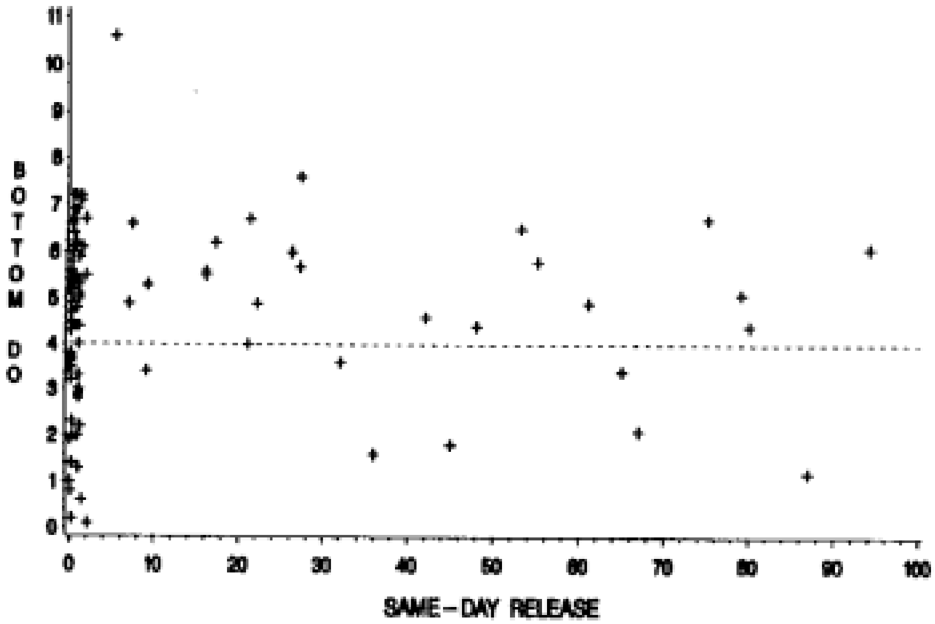

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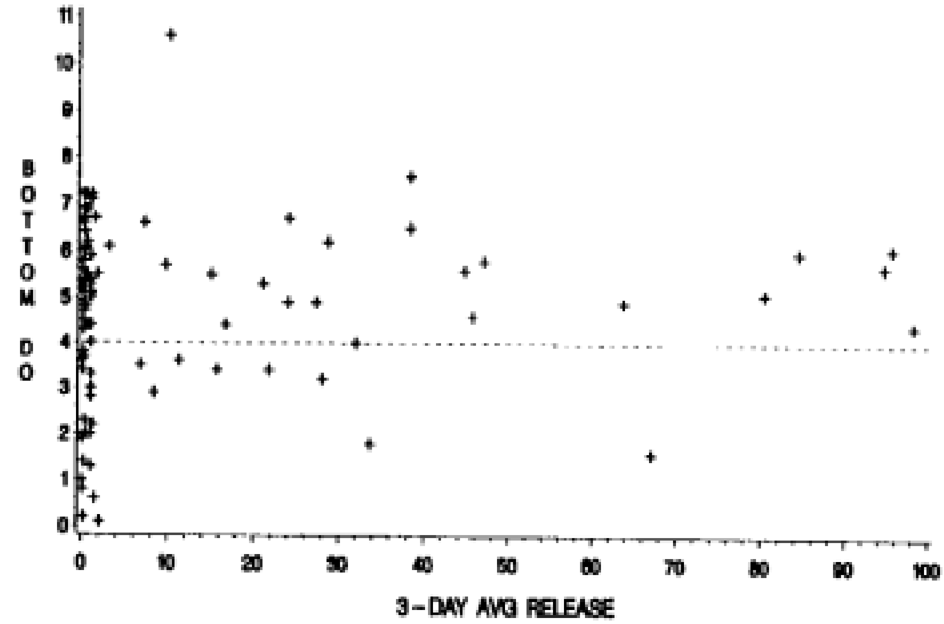

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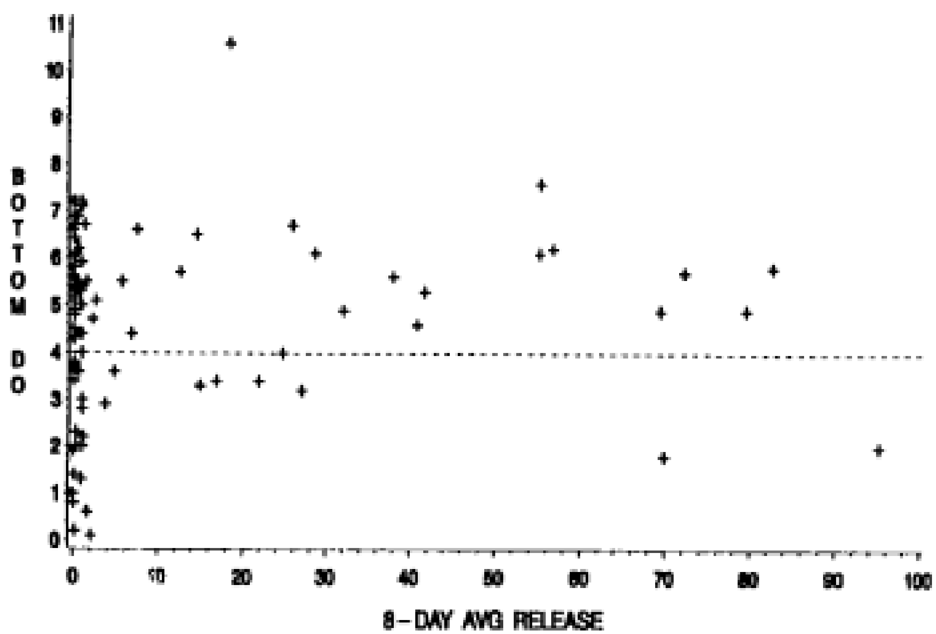

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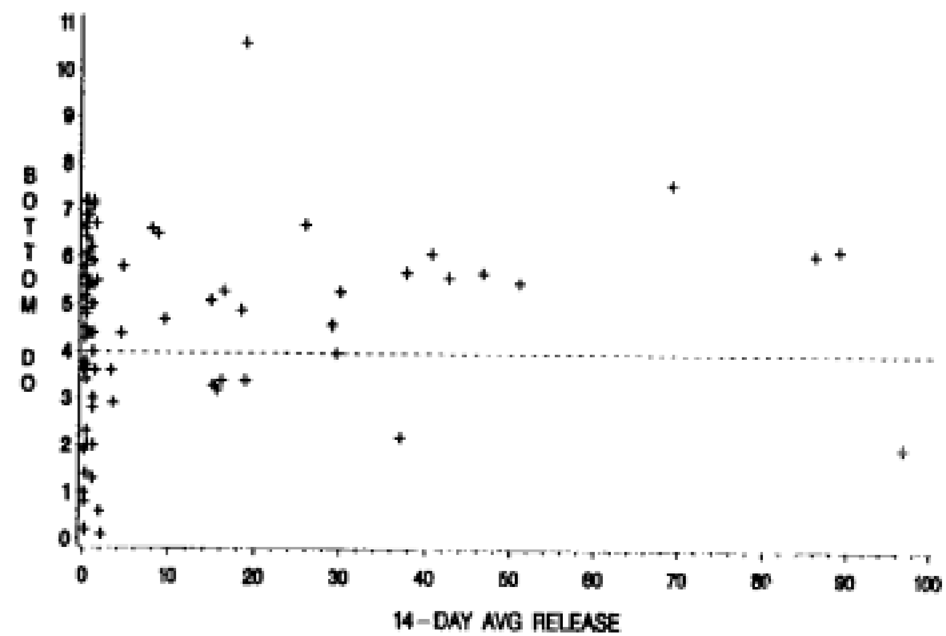

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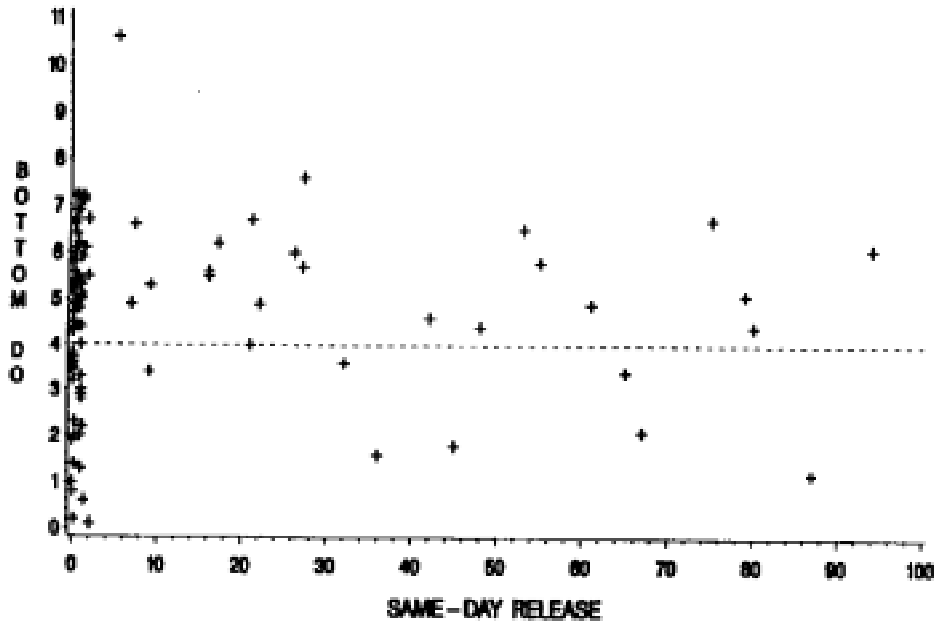

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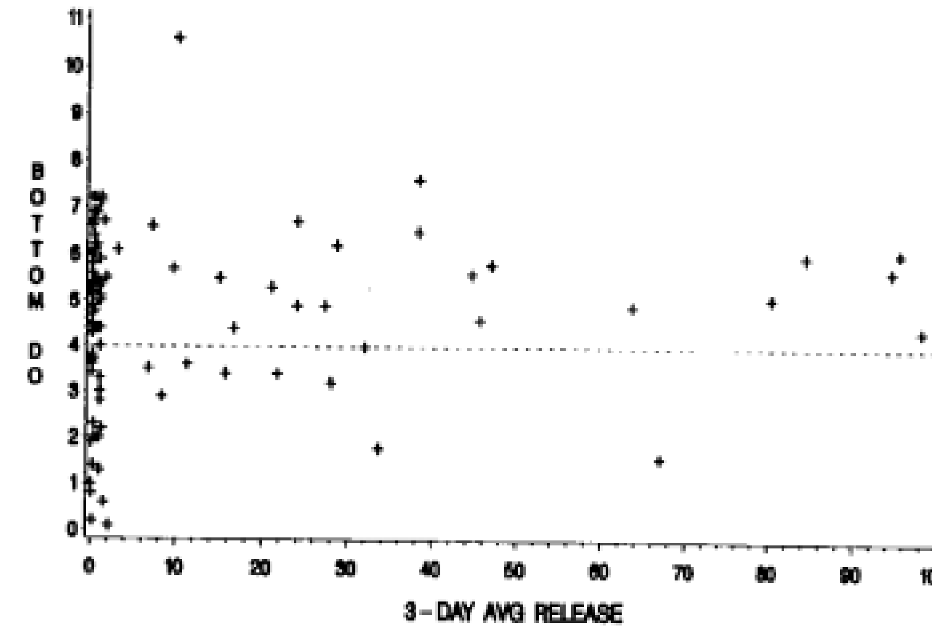

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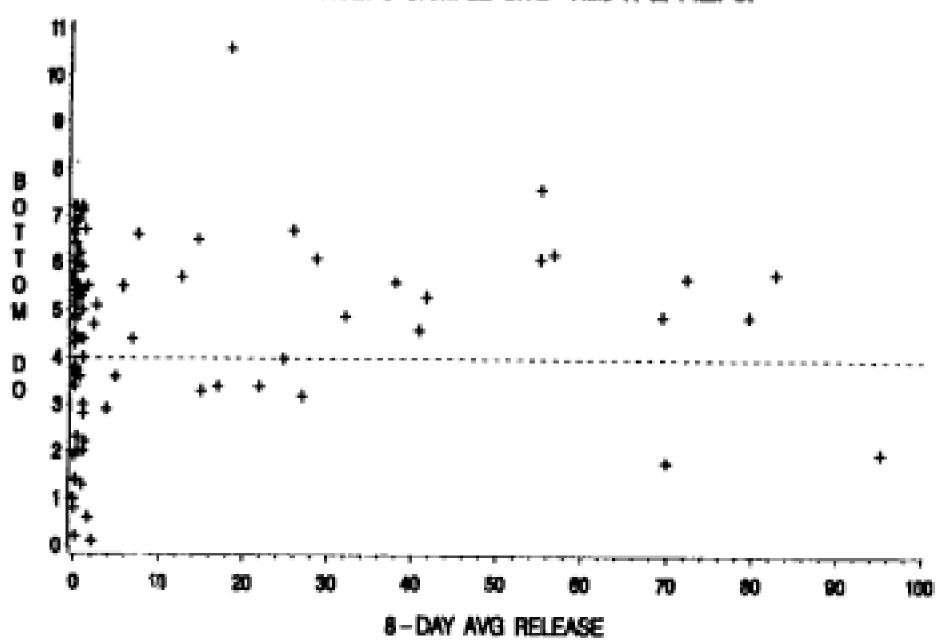

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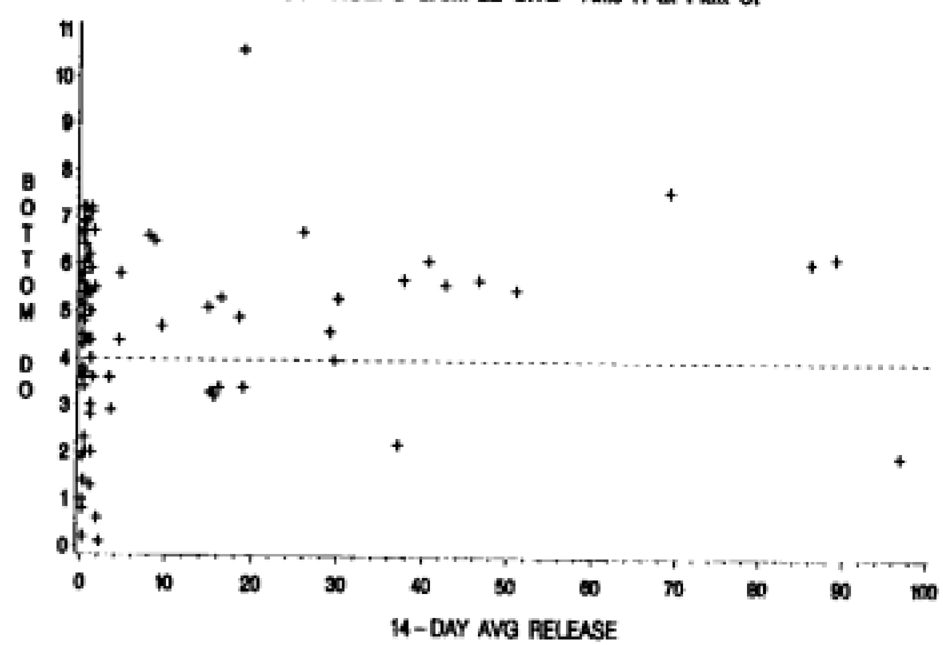


Appendix I

Reductions of USGS mid-depth salinity data at
Rowlett Park Drive to produce event-based salinity data.

Data reductions to create data base with event-based 8-day flows for the USGS recorder at Rowlett Park. Reductions were perfored on those dates with 8-day flows between 1 and 50 cfs. Dates highlighted in bold were removed from the data base. Dates not in bold were retained.

Date	8-day Flow	Same-day Flow	Salinity
14OCT81	**23.59**	**0.4**	**0.2**
15OCT81	23.59	0.4	0.3
16OCT81	14.14	0.4	0.5
17OCT81	8.19	0.4	0.8
18OCT81	**1.49**	**0.4**	**1.4**
19OCT81	1.49	0.4	1.0
20OCT81	**1.49**	**0.4**	**0.8**
01JAN82	10.90	81.0	1.0
02JAN82	31.94	169.0	0.4
08FEB82	49.88	28.0	0.1
09FEB82	38.71	4.7	0.1
10FEB82	31.84	20.0	0.1
11FEB82	**29.09**	**15.0**	**0.1**
12FEB82	24.04	6.6	0.1
13FEB82	**20.04**	**9.0**	**0.1**
14FEB82	17.16	16.0	0.1
15FEB82	**18.66**	**50.0**	**0.1**
16FEB82	34.66	156.0	0.1
02MAY82	42.88	1.6	0.2
03MAY82	34.83	1.6	0.7
04MAY82	**21.15**	**1.6**	**1.4**
05MAY82	**21.18**	**1.6**	**1.6**
06MAY82	**21.20**	**1.6**	**2.1**
07MAY82	**10.40**	**1.6**	**3.3**

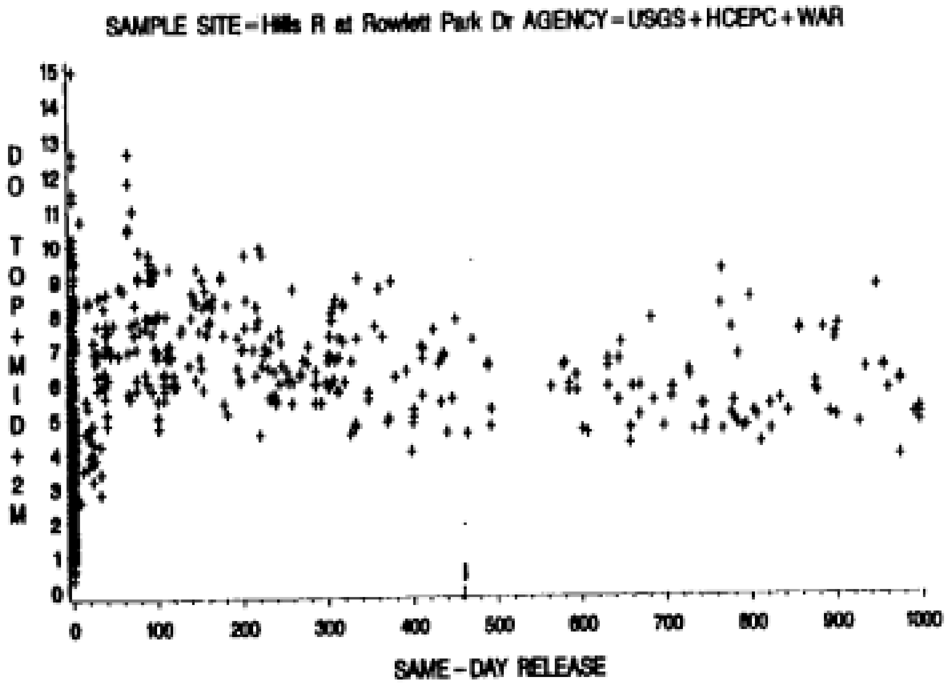
08MAY82	1.60	1.6	3.8
09MAY82	1.60	1.6	3.4
10MAY82	1.60	1.6	3.1
11MAY82	1.60	1.6	3.0
12MAY82	1.60	1.6	3.4
13MAY82	1.60	1.6	3.7
14MAY82	1.60	1.6	4.2
15MAY82	1.60	1.6	4.7
16MAY82	1.60	1.6	4.6
17MAY82	1.60	1.6	3.7
18MAY82	1.60	1.6	3.6
19MAY82	1.60	1.6	3.8
20MAY82	1.60	1.6	4.0
21MAY82	1.60	1.6	4.3
22MAY82	1.60	1.6	4.4
23MAY82	1.59	1.5	3.9
24MAY82	1.58	1.5	3.3
25MAY82	1.56	1.5	3.0
26MAY82	1.55	1.5	2.3
27MAY82	1.54	1.5	2.3
28MAY82	1.53	1.5	2.5
29MAY82	1.51	1.5	3.0
30MAY82	1.50	1.5	3.0
31MAY82	1.50	1.5	0.5
01JUN82	17.56	130.0	0.2
02JUN82	17.56	1.5	0.2
03JUN82	34.13	134.0	0.0
04JUN82	34.13	1.5	0.1
05JUN82	34.13	1.5	0.2
06JUN82	35.16	9.8	0.4
07JUN82	40.23	42.0	0.2
08JUN82	40.23	1.5	0.2
09JUN82	24.16	1.5	0.2
10JUN82	24.16	1.5	0.4
11JUN82	7.60	1.5	0.6
12JUN82	7.60	1.5	0.8
13JUN82	7.60	1.5	1.0
14JUN82	6.56	1.5	1.2

15JUN82	1.50	1.5	1.0
16JUN82	1.49	1.4	0.7
17JUN82	1.46	1.3	0.7
18JUN82	1.43	1.2	0.0
19JUN82	1.38	1.1	0.1
20JUN82	1.30	0.9	0.1
21JUN82	1.21	0.8	0.1
22JUN82	1.11	0.7	0.2
24JUN82	24.33	188.0	0.1

APPENDIX I-1

Plots of dissolved oxygen concentrations at four locations from the combined data set vs. discharge from the Hillsborough River Reservoir. (Values from surface, 1 meter and 2 meters depths are shown. Units are mg/l for dissolved oxygen and cfs for discharge).

T1-1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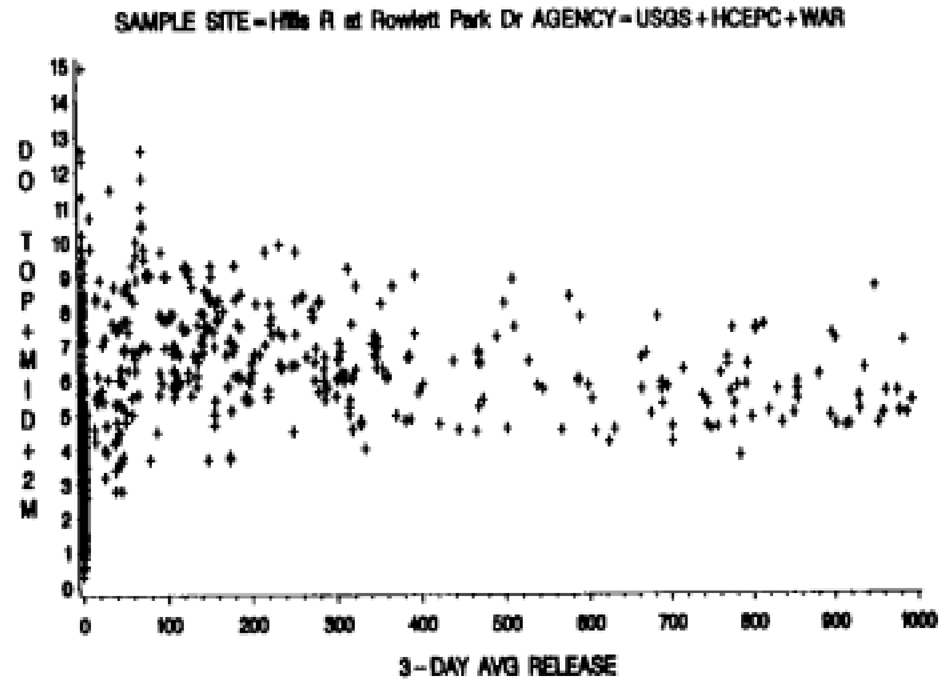
SAME-DAY RELEASE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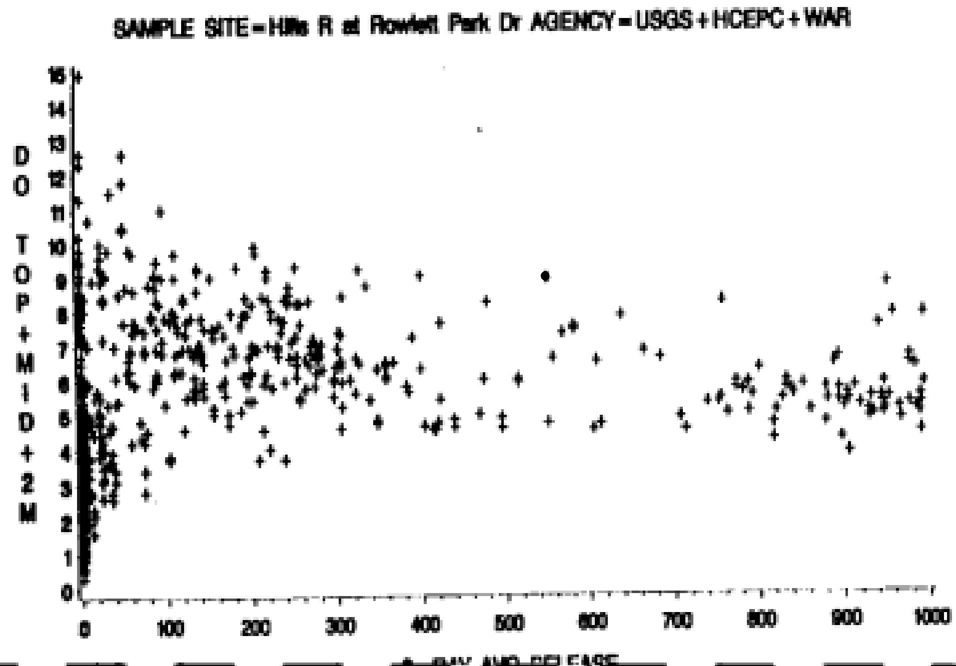
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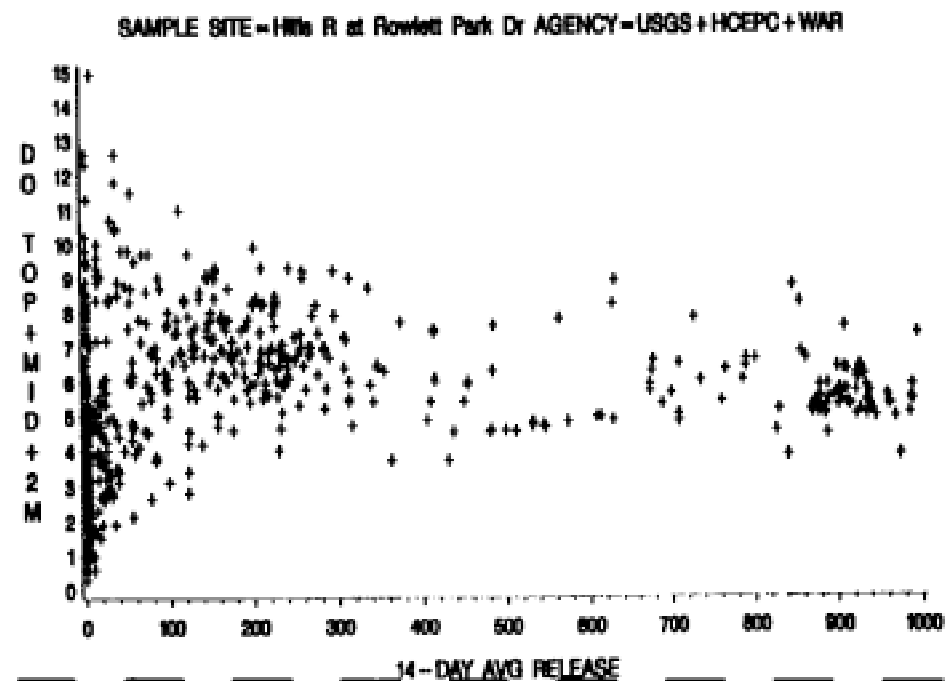
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14-DAY AVG RELEASE

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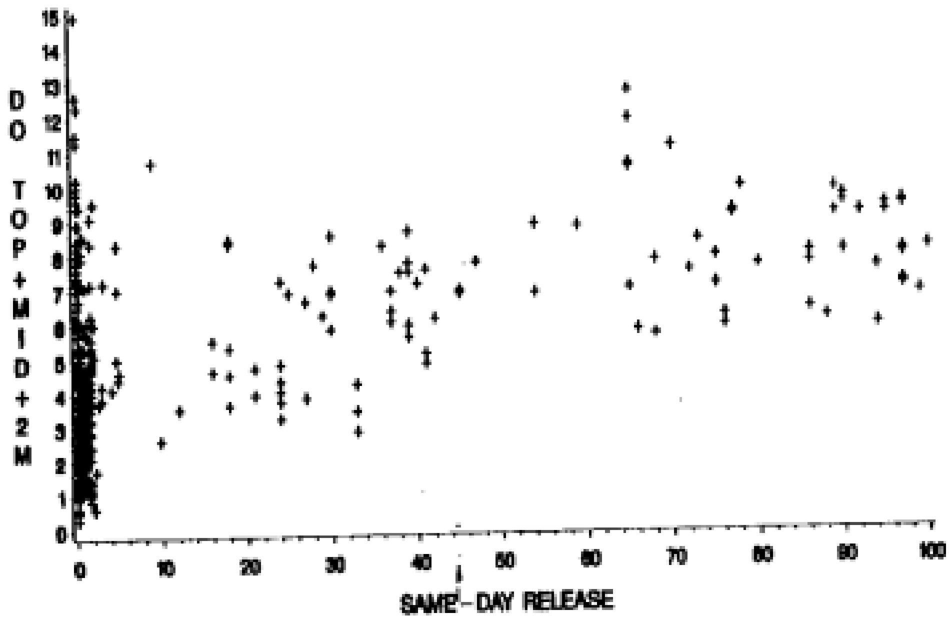

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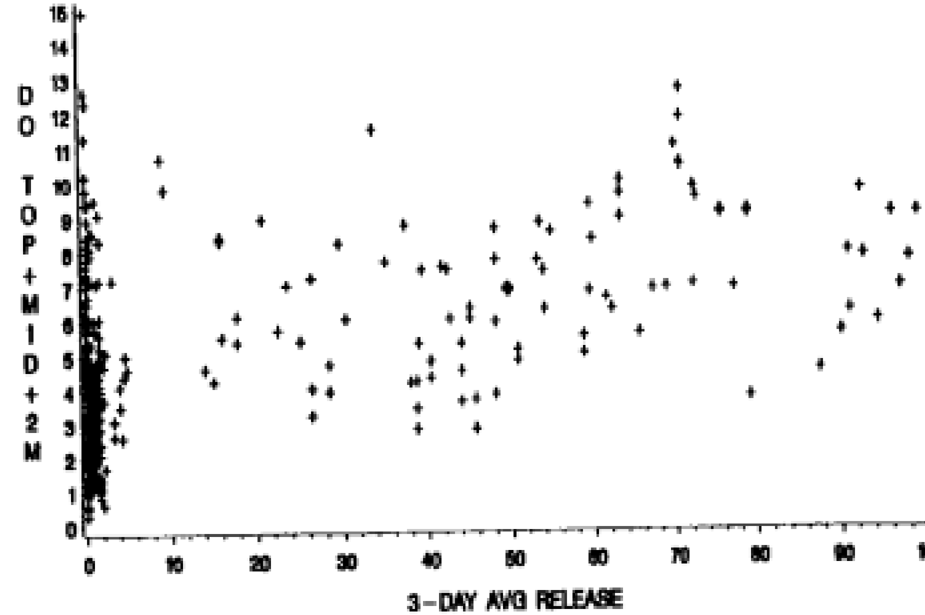

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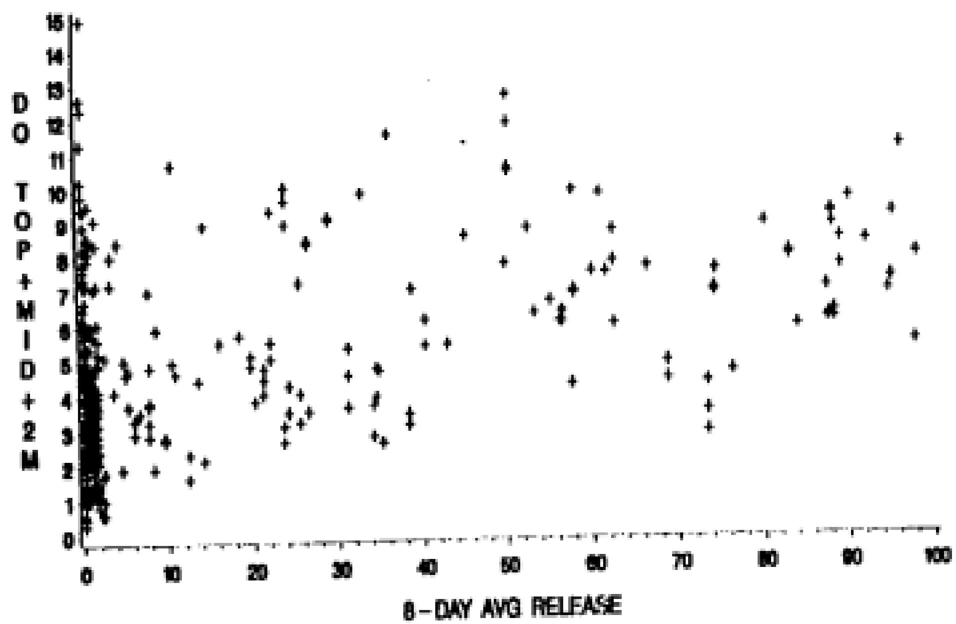

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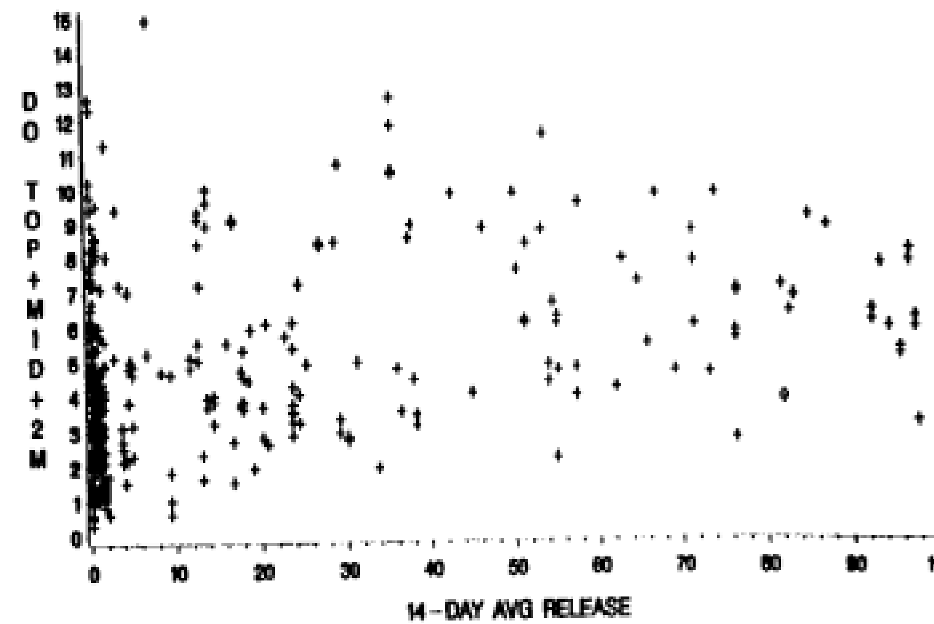
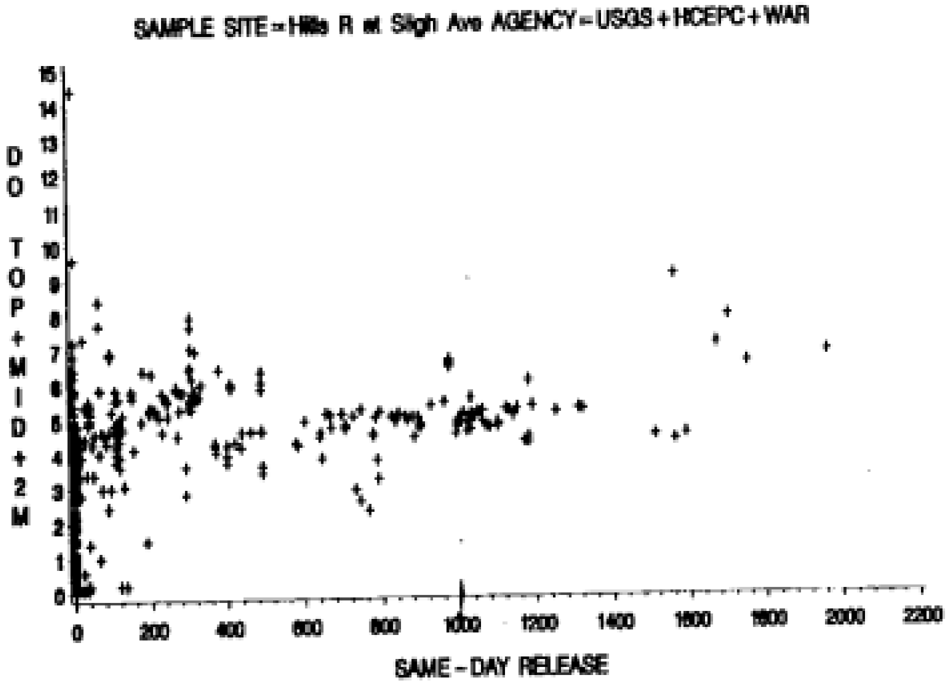


T1-2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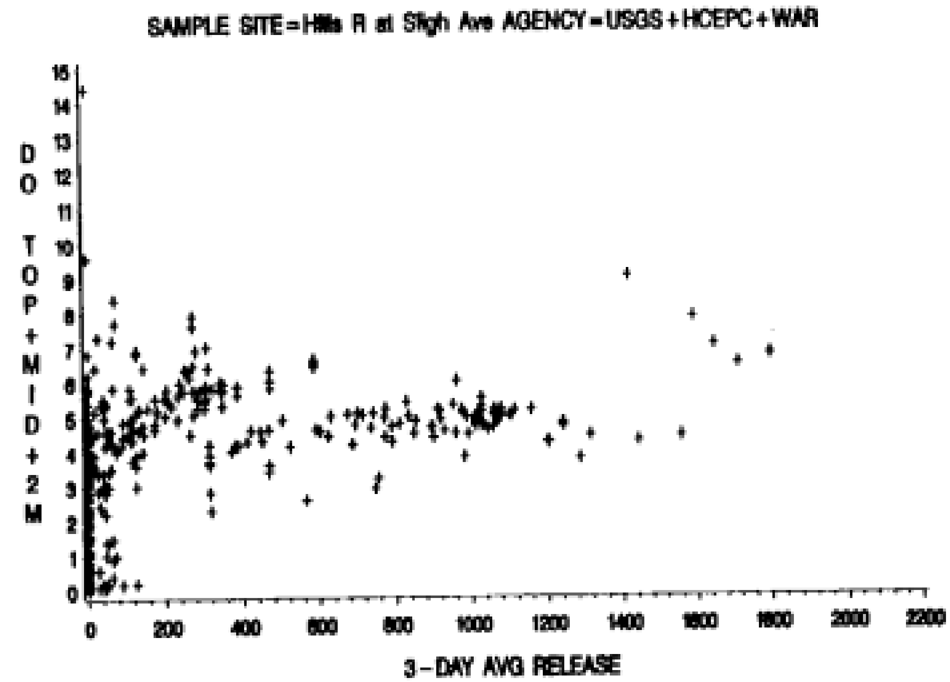
SAME-DAY RELEASE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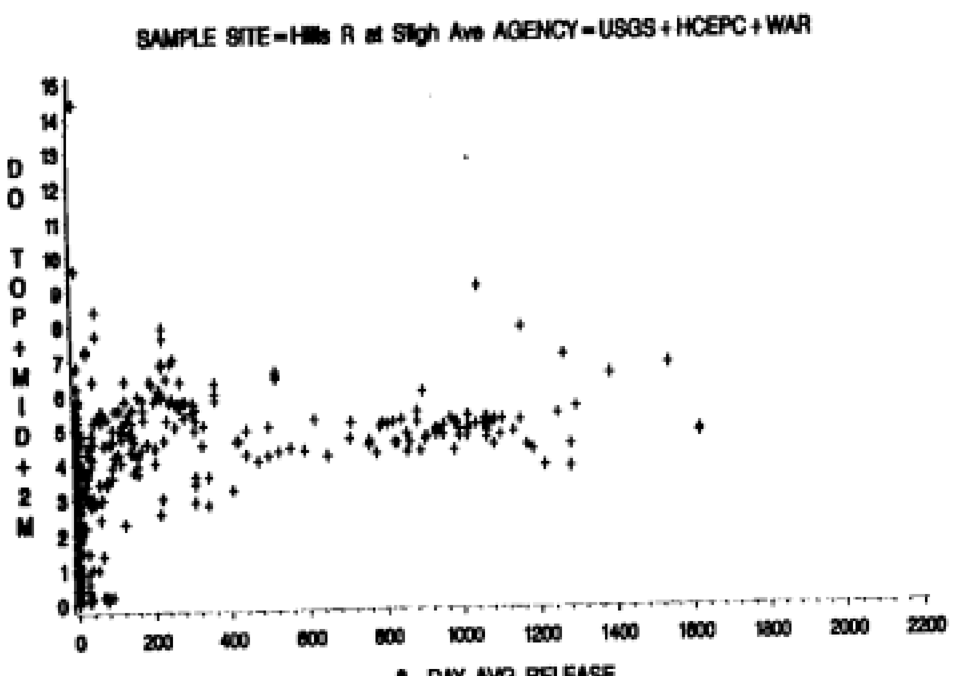
3-DAY AVG RELEASE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DO TOP+MID+2M
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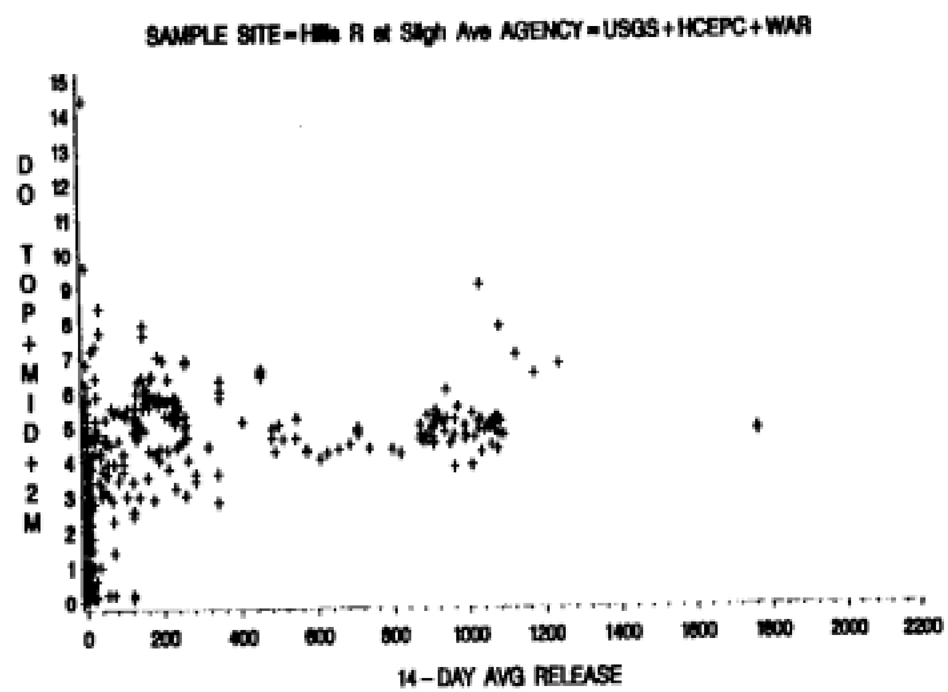
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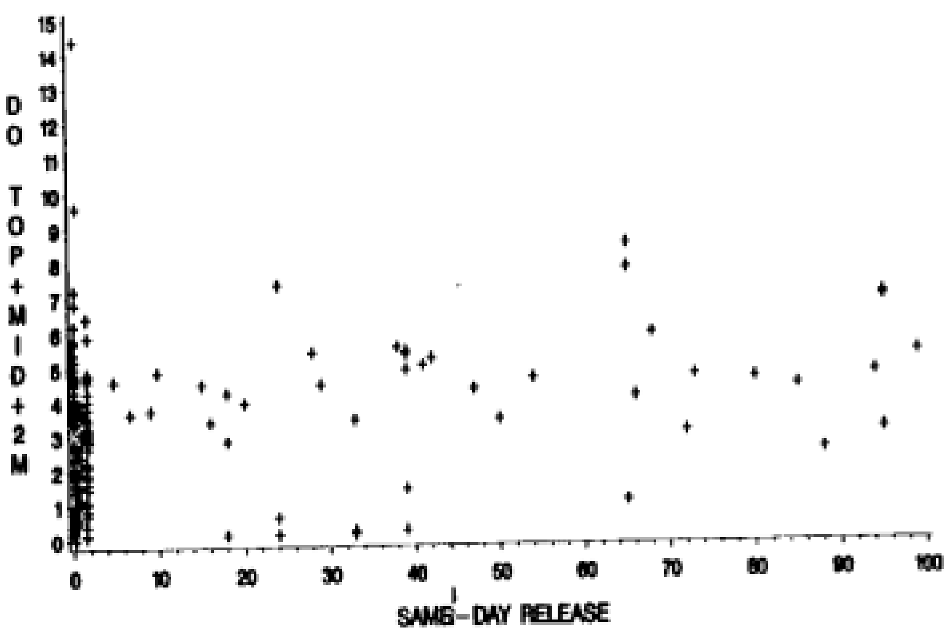
14-DAY AVG RELEASE

T/-3

SAMPLE SITE=Hills R at Sligh Ave AGENCY=USGS+HCEPC+WAR



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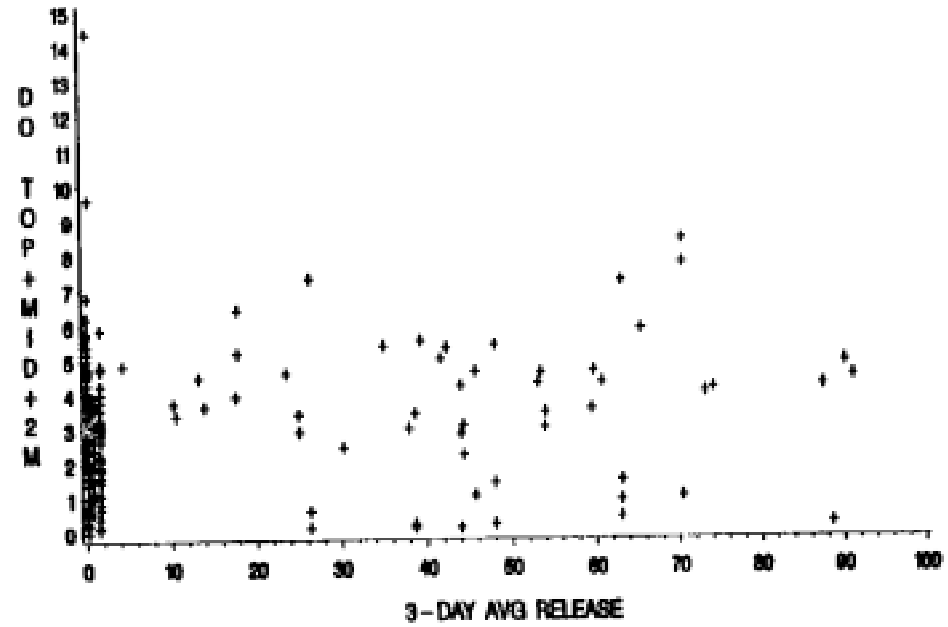

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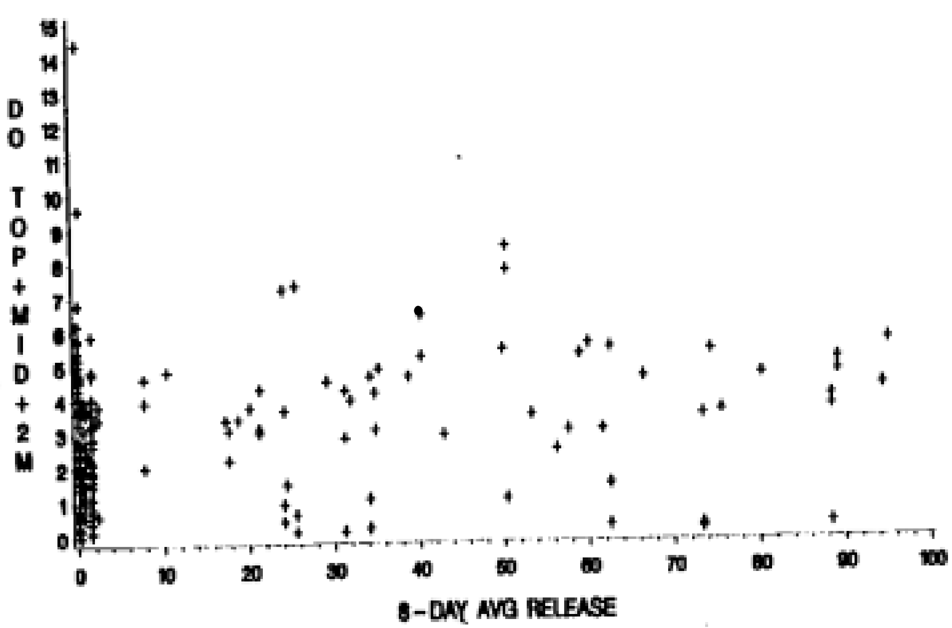

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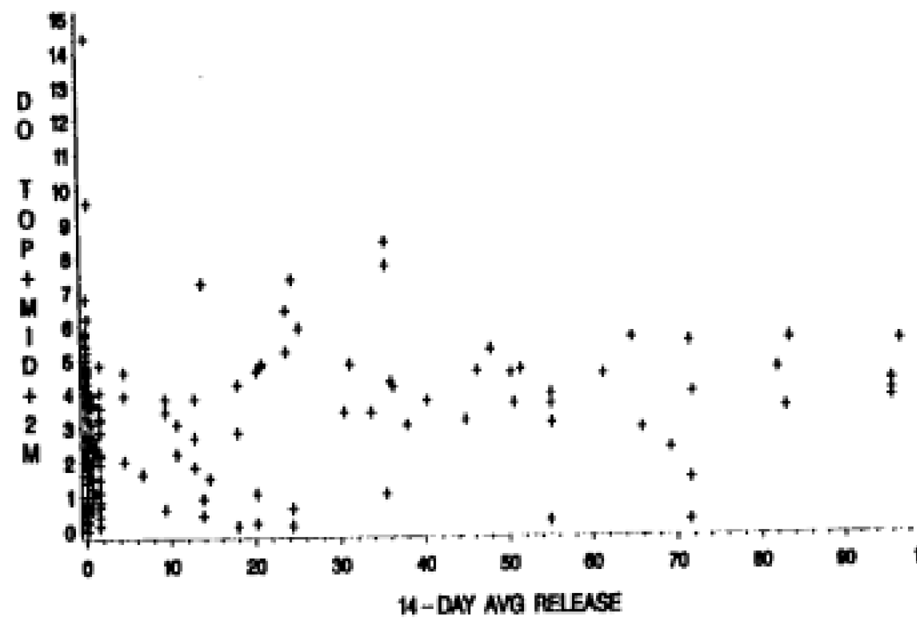

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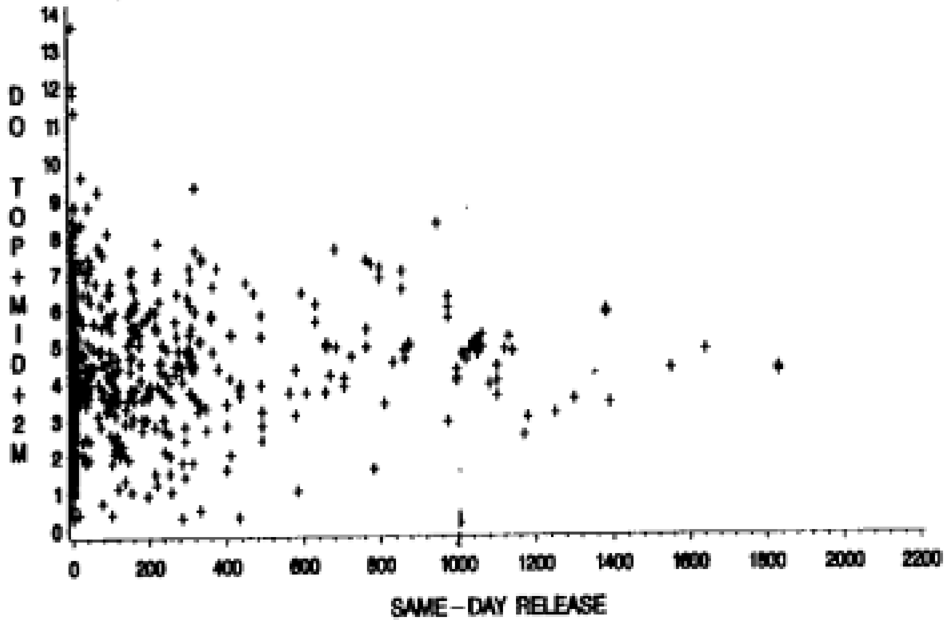

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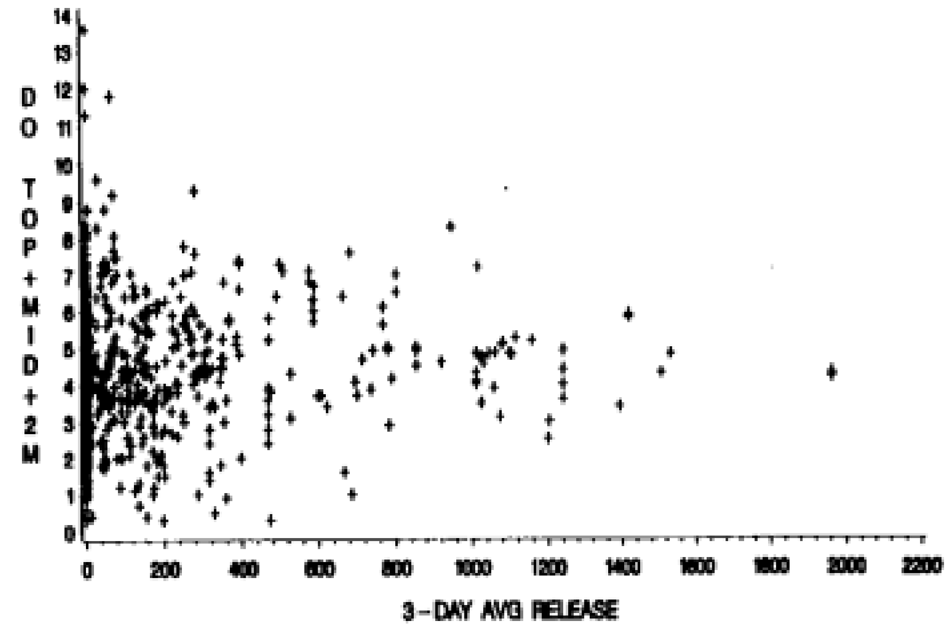

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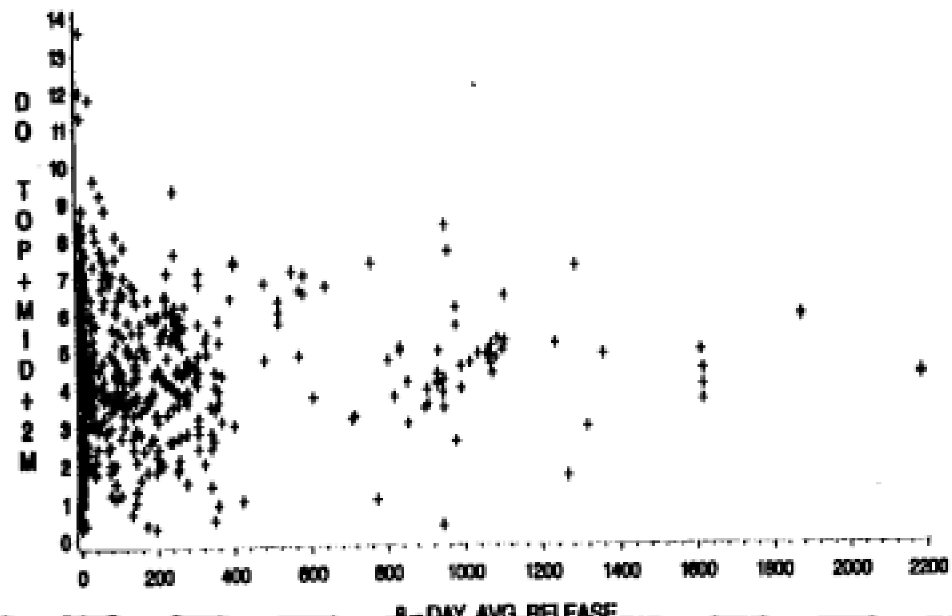

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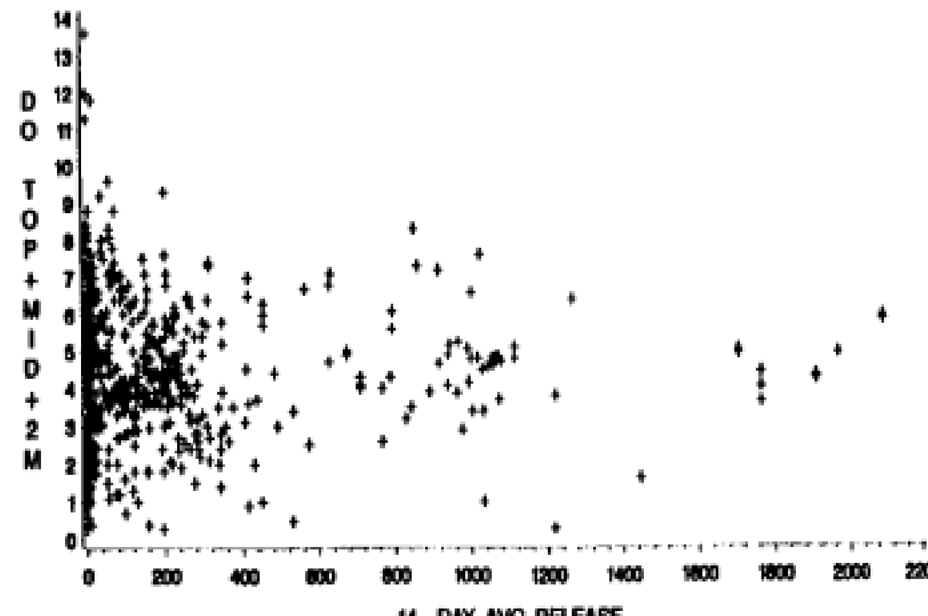

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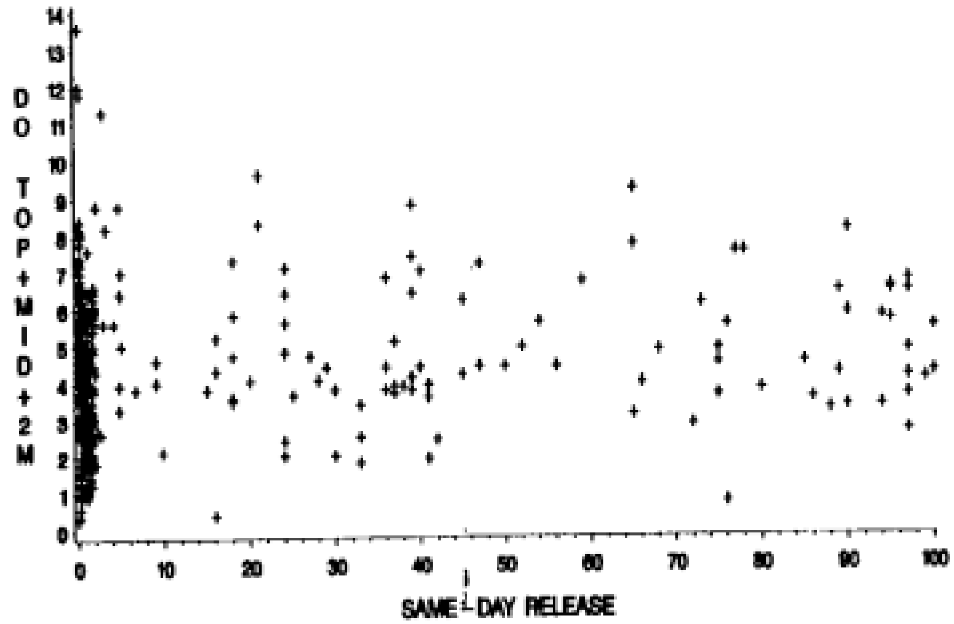

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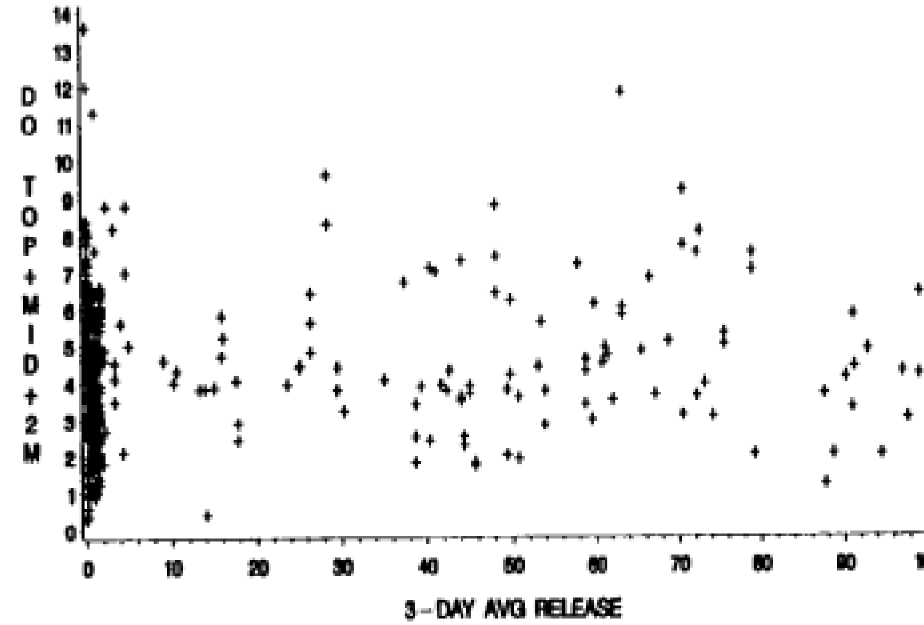

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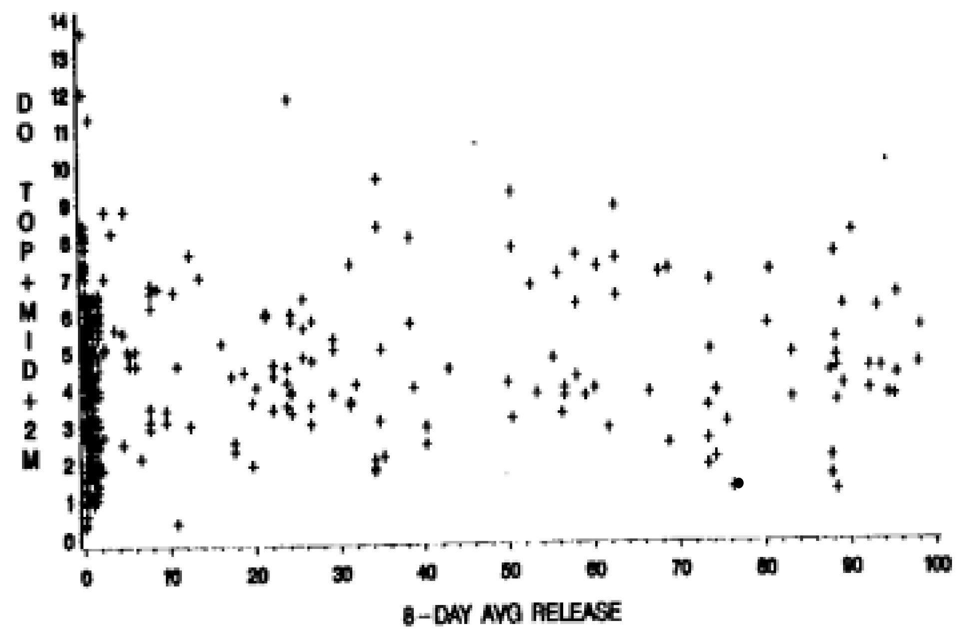

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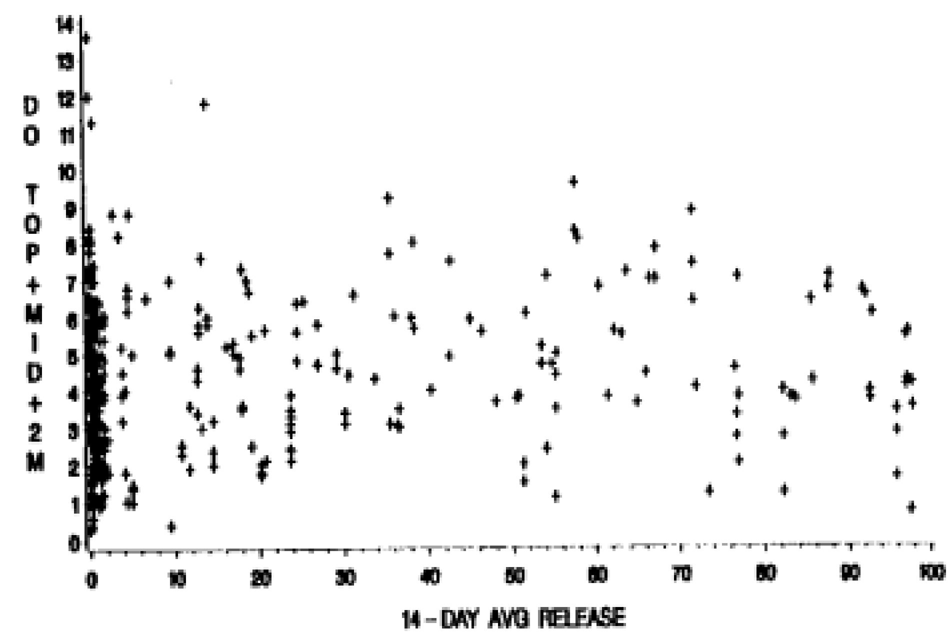

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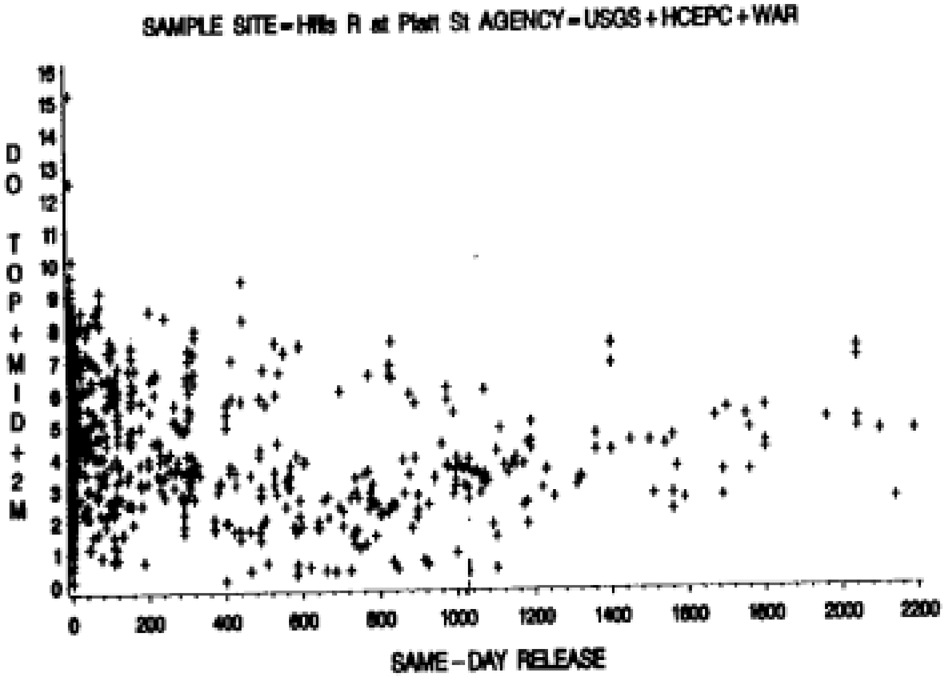
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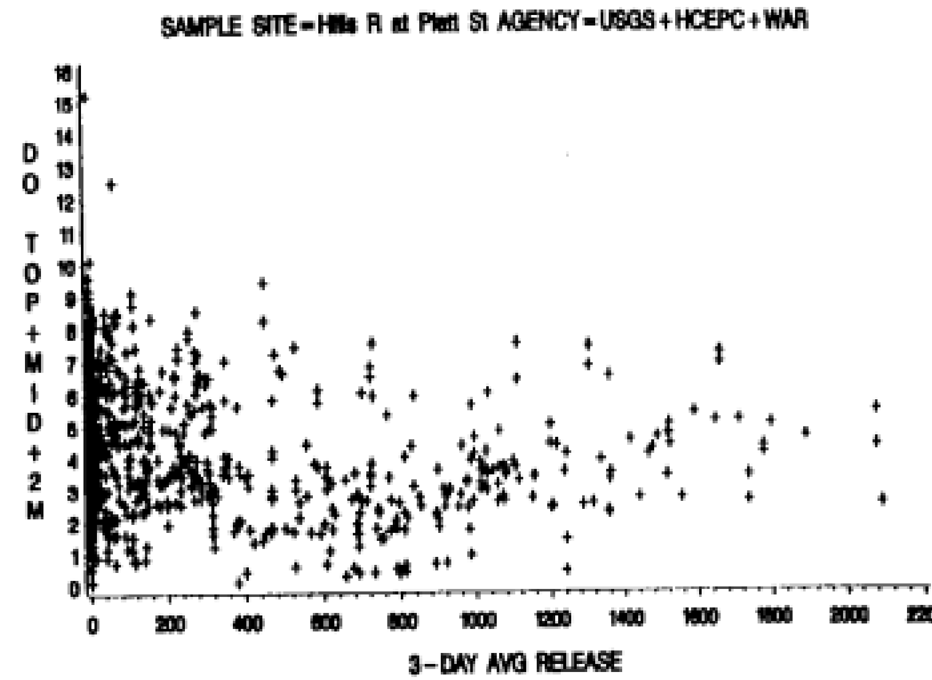
DO TOP+MID+2M
SAME-DAY RELEASE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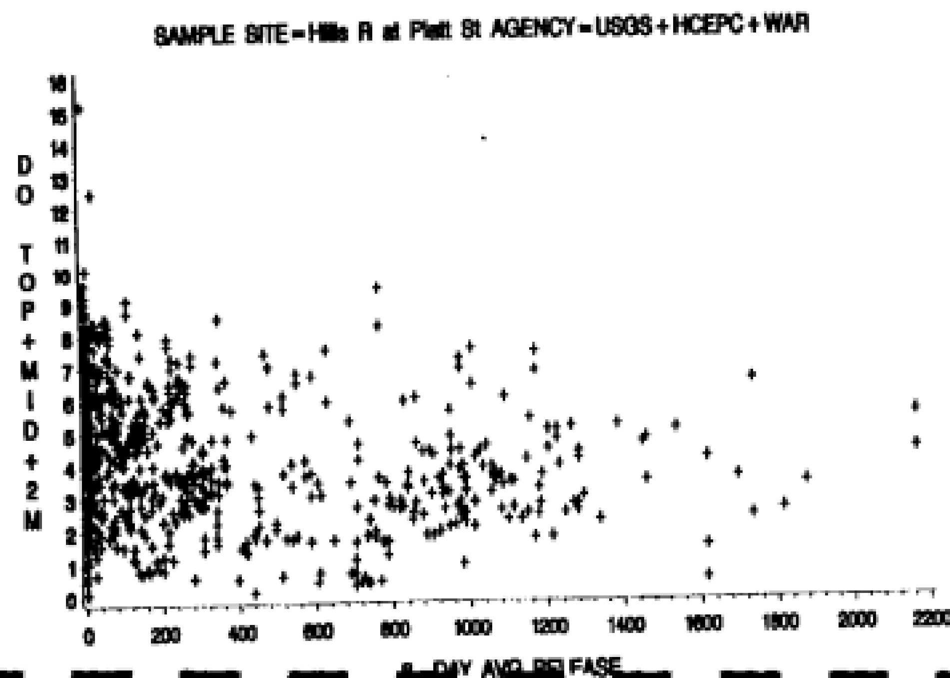
DO TOP+MID+2M
3-DAY AVG RELEASE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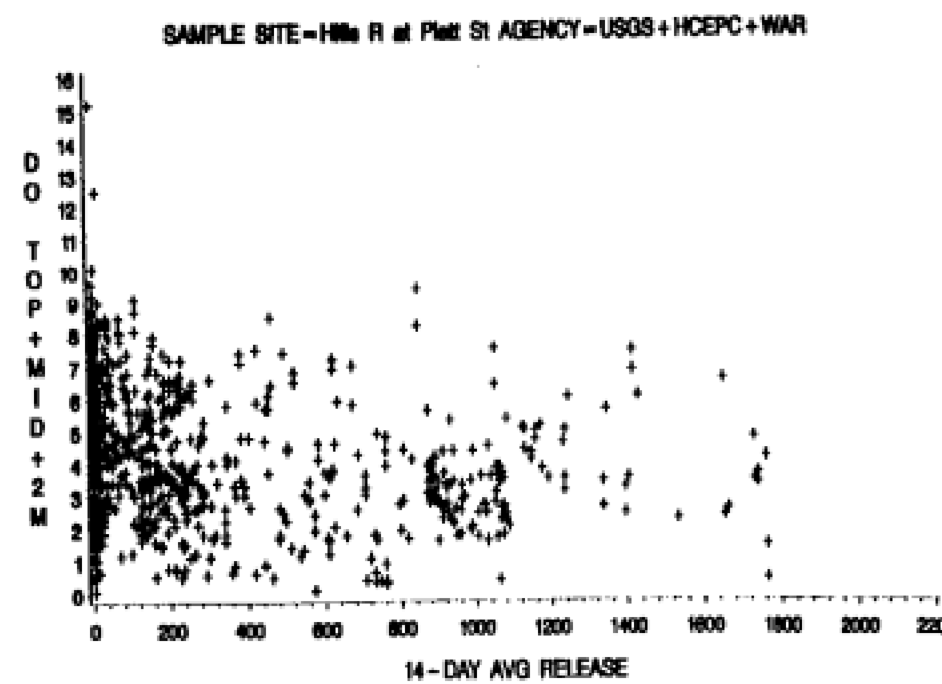
DO TOP+MID+2M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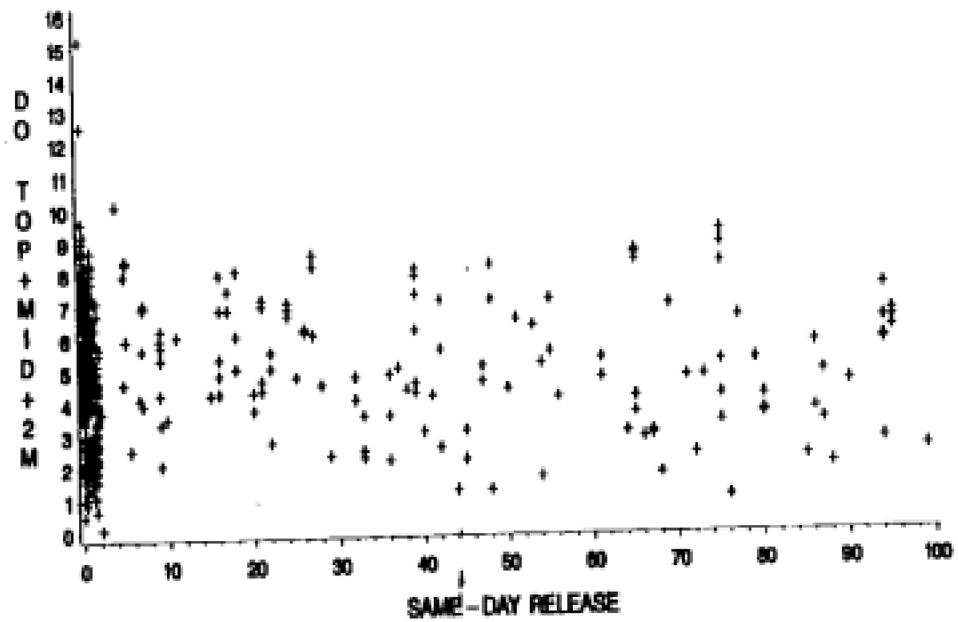
DO TOP+MID+2M
14-DAY AVG RELEASE

SAMPLE SITE=Hills R at Platt St AGENCY=USGS+HCEPC+WAR



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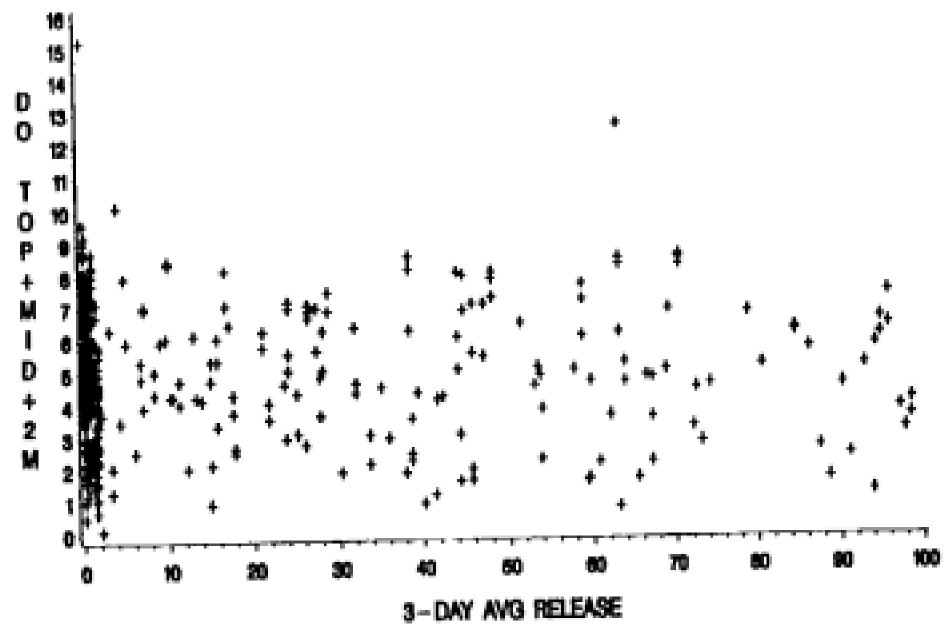

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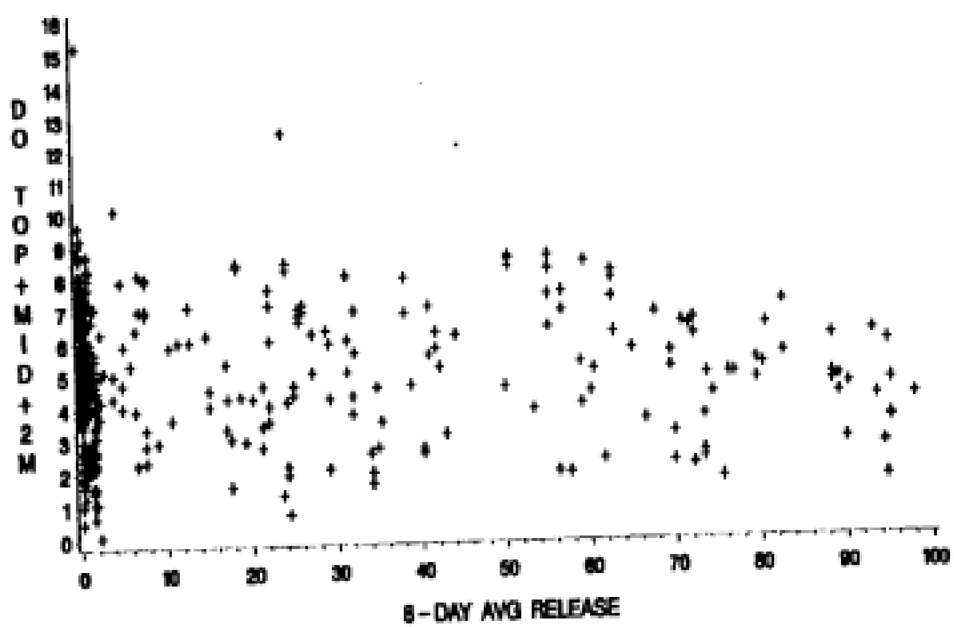
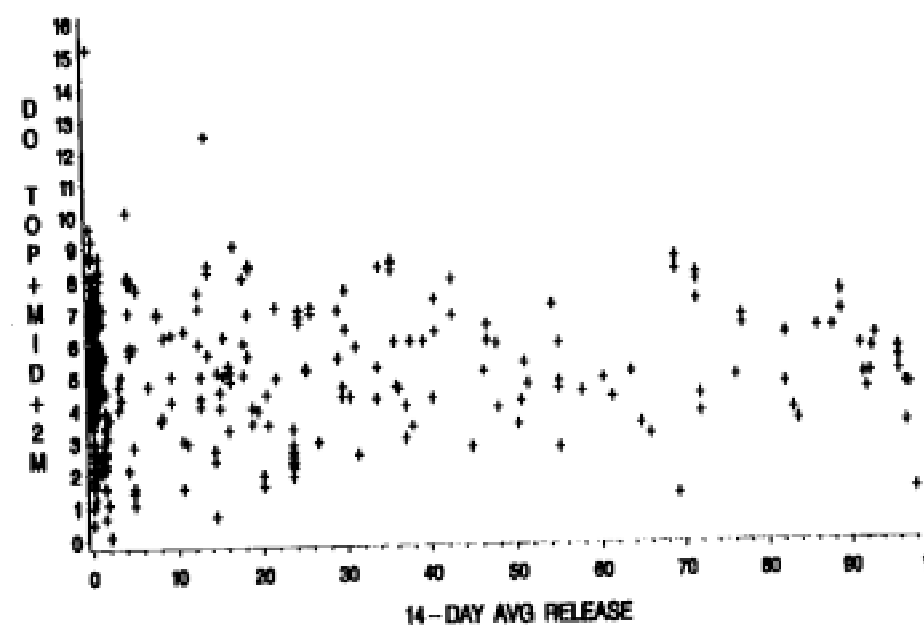


SAMPLE SITE=Hills R at Platt St AGENCY=USGS+HCEPC+WAR



APPENDIX I-2

Results of District breakpoint analysis of dissolved oxygen/discharge relationships in the Lower Hillsborough River.

DO vs FLOW BREAK POINTS (flow ranges 0-5, 5-95 by 10)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
ROWLETT	ROWLETT	U+H+W	S+M+2	3	5|5	5|5
ROWLETT	STA3	W	ALL	3	45|45	45|45
ROWLETT	ROWLETT	U	(MIN)	3	5|15	5|15
ROWLETT	ROWLETT	U	(MEAN)	3	5|15	5|15
ROWLETT	ROWLETT	U	(INST)	3	5|15	5|15&55|55
ROWLETT	STA2	W	ALL	3	5|25	45|45
ROWLETT	STA2&3	W	S+1M	3	5|25	45|45
ROWLETT	STA3	W	S+1M	3	5|25	45|45
ROWLETT	STA2	W	S+1M	3	5|25	5|25
ROWLETT	ROWLETT	H	S+M	3	5|5	5|5
ROWLETT	ROWLETT	H	ALL	3	5|5	5|5

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
SLIGH	STA5	W	S+1M	3	45|45	U
SLIGH	SLIGH	U	(MEAN)	3	5|15	65|65
SLIGH	SLIGH	U	(INST)	3	5|5&95|95+	15|15
SLIGH	SLIGH	U+W	S+M+2	3	65|65	65|65
SLIGH	STA6	W	S+1M	3	65|65	U
SLIGH	STA5	W	ALL	3	75|95+	U
SLIGH	STA6	W	ALL	3	75|95+	65|65
SLIGH	STA7	W	ALL	3	75|95+	75|95+
SLIGH	STA7	W	S+1M	3	U	U
SLIGH	SLIGH	U	(MIN)	3	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COLUMBUS	COLUMBUS	U	(INST)	3	55|55	95|95+
COLUMBUS	COLUMBUS	U	(MEAN)	3	5|5	55|55
COLUMBUS	COLUMBUS	U+H+W	S+M+2	3	5|5	U
COLUMBUS	STA8	W	S+1M	3	U	U
COLUMBUS	COLUMBUS	H	S+M	3	U	U
COLUMBUS	COLUMBUS	H	ALL	3	U	U
COLUMBUS	STA9	W	ALL	3	U	U
COLUMBUS	STA8	W	ALL	3	U	U
COLUMBUS	COLUMBUS	U	(MIN)	3	U	U
COLUMBUS	STA9	W	S+1M	3	U	U

DO vs FLOW BREAK POINTS (flow ranges 0-5, 5-95 by 10)

<table>
<tr><th>GENERAL</th><th></th><th></th><th></th><th></th><th colspan="2">DISSOLVED OXYGEN</th></tr>
<tr><th>LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th><2</th><th>>4</th></tr>
<tr><td>PLATT</td><td>PLATT</td><td>U+H+W</td><td>S+M+2</td><td>3</td><td>35|35*</td><td>85|85*</td></tr>
<tr><td>PLATT</td><td>STA10</td><td>W</td><td>S+1M</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>PLATT</td><td>STA10</td><td>W</td><td>ALL</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>PLATT</td><td>PLATT</td><td>U</td><td>(MIN)</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>PLATT</td><td>PLATT</td><td>H</td><td>S+M</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>PLATT</td><td>PLATT</td><td>H</td><td>ALL</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>PLATT</td><td>PLATT</td><td>U</td><td>(MEAN)</td><td>3</td><td>U</td><td>U</td></tr>
</table>

* NOTE: negative relationship of dissolved oxygen and flow (ie., higher flows are associated with lower DOs)

<table>
<tr><th>GENERAL</th><th></th><th></th><th></th><th></th><th colspan="2">DISSOLVED OXYGEN</th></tr>
<tr><th>LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th><2</th><th>>4</th></tr>
<tr><td>COMBINED</td><td>ROWLETT+SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>3</td><td>5|5</td><td>15|15</td></tr>
<tr><td>COMBINED</td><td>COLUMBUS+PLATT</td><td>U</td><td>(MIN)</td><td>3</td><td>5|5</td><td>5|5&95|95+</td></tr>
<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(INST)</td><td>3</td><td>5|5&95|95+</td><td>35|35&95|95+</td></tr>
<tr><td>COMBINED</td><td>SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>3</td><td>5|5&95|95+</td><td>95|95+</td></tr>
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<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(MIN)</td><td>3</td><td>95|95+</td><td>15|15</td></tr>
<tr><td>COMBINED</td><td>COLUMBUS+PLATT</td><td>U</td><td>(MEAN)</td><td>3</td><td>U</td><td>5|5</td></tr>
<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(MEAN)</td><td>3</td><td>U</td><td>55|55</td></tr>
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<table>
<tr><th>GENERAL</th><th></th><th></th><th></th><th></th><th colspan="2">DISSOLVED OXYGEN</th></tr>
<tr><th>LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th><2</th><th>>4</th></tr>
<tr><td>ROWLETT</td><td>STA3</td><td>W</td><td>S+1M</td><td>14</td><td>15|15</td><td>5|5&25|35</td></tr>
<tr><td>ROWLETT</td><td>STA2&3</td><td>W</td><td>S+1M</td><td>14</td><td>15|15</td><td>15|15</td></tr>
<tr><td>ROWLETT</td><td>STA2</td><td>W</td><td>S+1M</td><td>14</td><td>15|15</td><td>15|15</td></tr>
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<tr><td>ROWLETT</td><td>ROWLETT</td><td>H</td><td>S+M</td><td>14</td><td>25|25</td><td>5|5&85|85</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>H</td><td>ALL</td><td>14</td><td>25|25</td><td>5|5&85|85</td></tr>
<tr><td>ROWLETT</td><td>STA3</td><td>W</td><td>ALL</td><td>14</td><td>25|35</td><td>25|35</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U+H+W</td><td>S+M+2</td><td>14</td><td>35|35</td><td>5|5&35|35</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(MIN)</td><td>14</td><td>55|55</td><td>45|45</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(INST)</td><td>14</td><td>55|55</td><td>5|5&85|95+</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(MEAN)</td><td>14</td><td>5|5</td><td>35|35</td></tr>
</table>

I2-3

DO vs FLOW BREAK POINTS (flow ranges 0-5, 5-95 by 10)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
SLIGH	SLIGH	U	(MEAN)	14	25|25	15|15
SLIGH	SLIGH	U+H+W	S+M+2	14	25|25	15|15
SLIGH	STA5	W	S+1M	14	25|35	U
SLIGH	STA7	W	S+1M	14	25|35	U
SLIGH	SLIGH	U	(INST)	14	45|45	15|15
SLIGH	SLIGH	U	(MIN)	14	75|75	75|75
SLIGH	STA5	W	ALL	14	75|95+	55|65
SLIGH	STA7	W	ALL	14	75|95+	55|65
SLIGH	STA6	W	ALL	14	75|95+	75|95+
SLIGH	STA6	W	S+1M	14	75|95+	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COLUMBUS	COLUMBUS	U	(MIN)	14	25|25	25|25
COLUMBUS	COLUMBUS	U	(INST)	14	25|25	25|25
COLUMBUS	COLUMBUS	U	(MEAN)	14	25|25	5|5
COLUMBUS	COLUMBUS	U+H+W	S+M+2	14	5|5	U
COLUMBUS	STA9	W	ALL	14	75|95+*	U
COLUMBUS	STA9	W	S+1M	14	U	U
COLUMBUS	STA8	W	ALL	14	U	U
COLUMBUS	COLUMBUS	H	ALL	14	U	U
COLUMBUS	STA8	W	S+1M	14	U	U
COLUMBUS	COLUMBUS	H	S+M	14	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
PLATT	STA10	W	S+1M	14	75|95+*	75|95+*
PLATT	STA10	W	ALL	14	75|95+*	75|95+*
PLATT	PLATT	U+H+W	S+M+2	14	95|95+*	75|75*
PLATT	PLATT	U	(MEAN)	14	95|95+*	95|95+*
PLATT	PLATT	H	S+M	14	U	95|95+*
PLATT	PLATT	H	ALL	14	U	U
PLATT	PLATT	U	(MIN)	14	U	U

* NOTE: negative relationship of dissolved oxygen and flow (ie., higher flows
are associated with lower DO)

DO vs FLOW BREAK POINTS (flow ranges 0-5, 5-95 by 10)

<table>
<tr><th>GENERAL LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th colspan="2">DISSOLVED OXYGEN</th></tr>
<tr><th></th><th></th><th></th><th></th><th></th><th><2</th><th>>4</th></tr>
<tr><td>COMBINED</td><td>COLUMBUS+PLATT</td><td>U</td><td>(MEAN)</td><td>14</td><td>25|25</td><td>25|25</td></tr>
<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(MIN)</td><td>14</td><td>25|25</td><td>45|45</td></tr>
<tr><td>COMBINED</td><td>SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>14</td><td>25|25</td><td>5|5</td></tr>
<tr><td>COMBINED</td><td>ROWLETT+SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>14</td><td>25|25</td><td>5|5&85|85</td></tr>
<tr><td>COMBINED</td><td>COLUMBUS+PLATT</td><td>U</td><td>(MIN)</td><td>14</td><td>25|25</td><td>15|15&85|85</td></tr>
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<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(INST)</td><td>14</td><td>25|25&75|75</td><td>5|5&85|95+</td></tr>
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<tr><td>COMBINED</td><td>ROWLETT+SLIGH</td><td>U</td><td>(MEAN)</td><td>14</td><td>35|35</td><td>25|25</td></tr>
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<tr><td>COLUMBUS</td><td>COLUMBUS</td><td>U</td><td>(INST)</td><td>SAME DAY</td><td>15|15</td><td>15|15</td></tr>
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<tr><td>COMBINED</td><td>ROWLETT+SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>SAME DAY</td><td>15|15</td><td>25|25</td></tr>
<tr><td>COMBINED</td><td>SLIGH+COLUMBUS</td><td>U</td><td>(INST)</td><td>SAME DAY</td><td>5|5</td><td>5|5&95|95+</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(INST)</td><td>SAME DAY</td><td>15|25</td><td>15|25</td></tr>
<tr><td>SLIGH</td><td>SLIGH</td><td>U</td><td>(INST)</td><td>SAME DAY</td><td>5|5</td><td>25|25</td></tr>
</table>

DO vs FLOW BREAK POINTS (flow ranges 0 to 100 by 10)

<table>
<tr><th>GENERAL LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th>DISSOLVED OXYGEN <2</th><th>DISSOLVED OXYGEN >4</th></tr>
<tr><td>ROWLETT</td><td>STA2</td><td>W</td><td>ALL</td><td>3</td><td>10|20</td><td>40|40</td></tr>
<tr><td>ROWLETT</td><td>STA3</td><td>W</td><td>S+1M</td><td>3</td><td>10|20</td><td>40|40</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U+H+W</td><td>S+M+2</td><td>3</td><td>10|10</td><td>10|10</td></tr>
<tr><td>ROWLETT</td><td>STA2</td><td>W</td><td>S+1M</td><td>3</td><td>10|20</td><td>10|20</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(INST)</td><td>3</td><td>10|10</td><td>10|10&50|50</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(MIN)</td><td>3</td><td>10|10</td><td>20|20</td></tr>
<tr><td>ROWLETT</td><td>STA2&3</td><td>W</td><td>S+1M</td><td>3</td><td>10|20</td><td>40|40</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>U</td><td>(MEAN)</td><td>3</td><td>10|10</td><td>10|10</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>H</td><td>ALL</td><td>3</td><td>20|20</td><td>10|10</td></tr>
<tr><td>ROWLETT</td><td>STA3</td><td>W</td><td>ALL</td><td>3</td><td>40|40</td><td>50|50</td></tr>
<tr><td>ROWLETT</td><td>ROWLETT</td><td>H</td><td>S+M</td><td>3</td><td>10|10&20|20</td><td>20|20</td></tr>
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<tr><th>GENERAL LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th>DISSOLVED OXYGEN <2</th><th>DISSOLVED OXYGEN >4</th></tr>
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<tr><td>SLIGH</td><td>SLIGH</td><td>U</td><td>(MEAN)</td><td>3</td><td>10|10</td><td>10|10</td></tr>
<tr><td>SLIGH</td><td>STA5</td><td>W</td><td>S+1M</td><td>3</td><td>30|30</td><td>80|100+</td></tr>
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<tr><td>SLIGH</td><td>STA6</td><td>W</td><td>S+1M</td><td>3</td><td>70|70</td><td>U</td></tr>
<tr><td>SLIGH</td><td>STA7</td><td>W</td><td>ALL</td><td>3</td><td>80|100+</td><td>80|100+</td></tr>
<tr><td>SLIGH</td><td>STA6</td><td>W</td><td>ALL</td><td>3</td><td>80|100+</td><td>80|100+</td></tr>
<tr><td>SLIGH</td><td>STA7</td><td>W</td><td>S+1M</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>SLIGH</td><td>SLIGH</td><td>U</td><td>(MIN)</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>SLIGH</td><td>SLIGH</td><td>U+H+W</td><td>S+M+2</td><td>3</td><td>U</td><td>50|50</td></tr>
</table>

<table>
<tr><th>GENERAL LOCATION</th><th>STATION</th><th>AGENCY</th><th>DEPTH</th><th>FLOW</th><th>DISSOLVED OXYGEN <2</th><th>DISSOLVED OXYGEN >4</th></tr>
<tr><td>COLUMBUS</td><td>COLUMBUS</td><td>U</td><td>(INST)</td><td>3</td><td>10|10</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>COLUMBUS</td><td>U+H+W</td><td>S+M+2</td><td>3</td><td>10|10&50|50</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>COLUMBUS</td><td>U</td><td>(MEAN)</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>STA9</td><td>W</td><td>ALL</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>STA8</td><td>W</td><td>S+1M</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>STA8</td><td>W</td><td>ALL</td><td>3</td><td>U</td><td>U</td></tr>
<tr><td>COLUMBUS</td><td>COLUMBUS</td><td>H</td><td>S+M</td><td>3</td><td>U</td><td>U</td></tr>
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</table>

DO vs FLOW BREAK POINTS (flow ranges 0 to 100 by 10)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
PLATT	PLATT	U+H+W	S+M+2	3	30|30*	U
PLATT	STA10	W	ALL	3	U	U
PLATT	PLATT	U	(MEAN)	3	U	U
PLATT	PLATT	U	(MIN)	3	U	U
PLATT	PLATT	H	ALL	3	U	U
PLATT	PLATT	H	S+M	3	U	U
PLATT	STA10	W	S+1M	3	U	U

• NOTE: negative relationship of dissolved oxygen and flow (ie., higher flows are associated with lower DOs)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COMBINED	ROWLETT+SLIGH	U	(MEAN)	3	10|10	10|10
COMBINED	ROWLETT+SLIGH	U	(INST)	3	10|10	30|30
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(INST)	3	10|10	20|20
COMBINED	SLIGH+COLUMBUS	U	(INST)	3	10|10	20|20
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(MEAN)	3	10|10&50|50	U
COMBINED	COLUMBUS+PLATT	U	(MEAN)	3	U	U
COMBINED	COLUMBUS+PLATT	U	(MIN)	3	U	60|60
COMBINED	ROWLETT+SLIGH	U	(MIN)	3	U	20|20
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(MIN)	3	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
ROWLETT	STA2&3	W	S+1M	14	10|10	10|10
ROWLETT	STA3	W	S+1M	14	10|10	10|10
ROWLETT	STA2	W	S+1M	14	10|10	10|10
ROWLETT	STA2	W	ALL	14	10|10	10|10
ROWLETT	ROWLETT	U	(MEAN)	14	20|20	30|30
ROWLETT	ROWLETT	U+H+W	S+M+2	14	20|20	U
ROWLETT	ROWLETT	H	ALL	14	20|20	U
ROWLETT	ROWLETT	H	S+M	14	20|20	U
ROWLETT	STA3	W	ALL	14	30|30	30/10
ROWLETT	ROWLETT	U	(MIN)	14	60|60	U
ROWLETT	ROWLETT	U	(INST)	14	60|60	U

DO vs FLOW BREAK POINTS (flow ranges 0 to 100 by 10)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
SLIGH	STA5	W	S+1M	14	10|10	U
SLIGH	STA7	W	S+1M	14	20|20	U
SLIGH	SLIGH	U+H+W	S+M+2	14	30|30	U
SLIGH	SLIGH	U	(MEAN)	14	30|30	20|20
SLIGH	SLIGH	U	(INST)	14	30|30	20|20
SLIGH	STA7	W	ALL	14	10|10	100|100+
SLIGH	STA6	W	ALL	14	U	U
SLIGH	SLIGH	U	(MIN)	14	U	100|100+
SLIGH	STA5	W	ALL	14	U	U
SLIGH	STA6	W	S+1M	14	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COLUMBUS	COLUMBUS	U+H+W	S+M+2	14	10|10	U
COLUMBUS	COLUMBUS	U	(INST)	14	30|30	30|30
COLUMBUS	COLUMBUS	U	(MEAN)	14	30|30	30|30
COLUMBUS	COLUMBUS	U	(MIN)	14	40|40	20|20
COLUMBUS	COLUMBUS	H	S+M	14	U	U
COLUMBUS	COLUMBUS	H	ALL	14	U	U
COLUMBUS	STA8	W	S+1M	14	U	U
COLUMBUS	STA8	W	ALL	14	U	U
COLUMBUS	STA9	W	S+1M	14	U	U
COLUMBUS	STA9	W	ALL	14	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
PLATT	PLATT	U+H+W	S+M+2	14	U	U
PLATT	PLATT	H	ALL	14	U	U
PLATT	PLATT	H	S+M	14	U	U
PLATT	STA10	W	S+1M	14	U	U
PLATT	STA10	W	ALL	14	U	U
PLATT	PLATT	U	(MIN)	14	U	U
PLATT	PLATT	U	(MEAN)	14	U	U

DO vs FLOW BREAK POINTS (flow ranges 0 to 100 by 10)

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COMBINED	ROWLETT+SLIGH	U	(INST)	14	30|30	U
COMBINED	COLUMBUS+PLATT	U	(MIN)	14	30|30	U
COMBINED	SLIGH+COLUMBUS	U	(INST)	14	30|30	30|30
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(INST)	14	30|30	30|30
COMBINED	ROWLETT+SLIGH	U	(MIN)	14	30|30	60|60
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(MEAN)	14	30|30	30|30
COMBINED	ROWLETT+SLIGH	U	(MEAN)	14	20|20&40|40	20|20
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(MIN)	14	30|30&70|70	50|50
COMBINED	COLUMBUS+PLATT	U	(MEAN)	14	U	U

GENERAL LOCATION	STATION	AGENCY	DEPTH	FLOW	DISSOLVED OXYGEN <2	DISSOLVED OXYGEN >4
COLUMBUS	COLUMBUS	U	(INST)	SAME DAY	10|10	U
COMBINED	SLIGH+COLUMBUS	U	(INST)	SAME DAY	10|10	10|10
COMBINED	ROWLETT+SLIGH	U	(INST)	SAME DAY	10|10	20|20
COMBINED	ROWLETT+SLIGH+COLUMBUS	U	(INST)	SAME DAY	10|10	20|20
ROWLETT	ROWLETT	U	(INST)	SAME DAY	10|20	10|20
SLIGH	SLIGH	U	(INST)	SAME DAY	10|10	20|20

APPENDIX J-1

Summary statistics for water quality parameters at Hillsborough County Environmental Protection Commission stations in the lower Hillsborough River

Means, standard deviations, medians and number of observations (n) for water quality parameters at HCEPC Station 105 (Rowlett Park Drive) for discharge and no-discharge conditions. No-discharge conditions have an 8-day flow less than 2 cfs.

		Discharge					No Discharge		
	Mean	Std	Median	(N)		Mean	Std	Median	(N)
8-day discharge (cfs)	387	561	154	195		.4	.4	.2	92
pH	7.3	.4	7.3	82		7.2	.2	7.2	36
Color (pcu)	77.7	39	73	194		27.6	17.5	23.5	92
Chloro-phyll a (ug/l)	7.2	10.5	4.4	188		21.7	27.4	10.1	92
B.O.D. (Mg/l)	1.6	1	1.3	194		2.7	1.7	2.2	91
T.S.S. (mg/l)	7.9	7.7	5	54		60.3	160.2	12	27
Turbidity (ntu)	3.2	2.5	3	194		49.4	231.6	4	92
Total-N (mg/l)	1.10	.36	1.07	138		1.29	.43	1.26	65
NO3-N (mg/l)	.18	.26	.13	73		.25	.33	.17	36
P-Total (mg/l)	.35	.23	.31	194		.72	2.82	.23	92
P-Ortho (mg/l)	.38	.43	.31	36		.35	.63	.2	35
Total Coliforms (col./100ml)	2557	5072	1000	194		5098	11062	1100	91
Fecal Coliforms (col./100ml)	983	2992	200	190		907	2352	270	90
Fecal Streptococci (col./100ml)	1622	2752	600	9		866	611	1000	3

Means, standard deviations, medians and number of observations (n) for water quality parameters at HCEPC Station 137 (Columbus Ave.) for discharge and no-discharge conditions. No-discharge conditions have an 8-day flow less than 2 cfs.

		Discharge				No Discharge		
	Mean	Std	Median	(N)	Mean	Std	Median	(N)
8-day discharge (cfs)	367	550	144	154	.5	.5	.3	65
pH	7.2	.4	7.2	83	8.0	4.3	7.4	40
Color (pcu)	56.5	36.3	51	153	17.5	19.4	14	65
Chlorophyll a (ug/l)	15.1	29.1	4.9	148	24.7	23.5	18.1	65
B.O.D. (mg/l)	2.0	1.7	1.6	154	3.0	1.6	2.6	65
T.S.S. (Mg/l)	11.3	10.9	8	22	26.7	13.7	27	6
Turbidity (ntu)	4.1	4.9	3	154	4.9	2.9	4	65
Total-N (mg/l)	1.28	.65	1.21	138	1.16	.63	1	65
NO3-N (mg/l)	.17	.12	.18	32	.15	.15	.05	9
P-Total (mg/l)	.37	.16	.35	154	.37	.19	.32	65
P-Ortho (mg/l)	.31	.16	.28	51	.20	.06	.21	36
Total Coliforms (col./100ml)	8990	43838	1300	154	1790	3381	700	65
Fecal Coliforms (col./100ml)	3159	15460	360	154	676	1697	200	65
Fecal Streptococci (col./100ml)	4324	17073	470	154	1314	2555	200	65

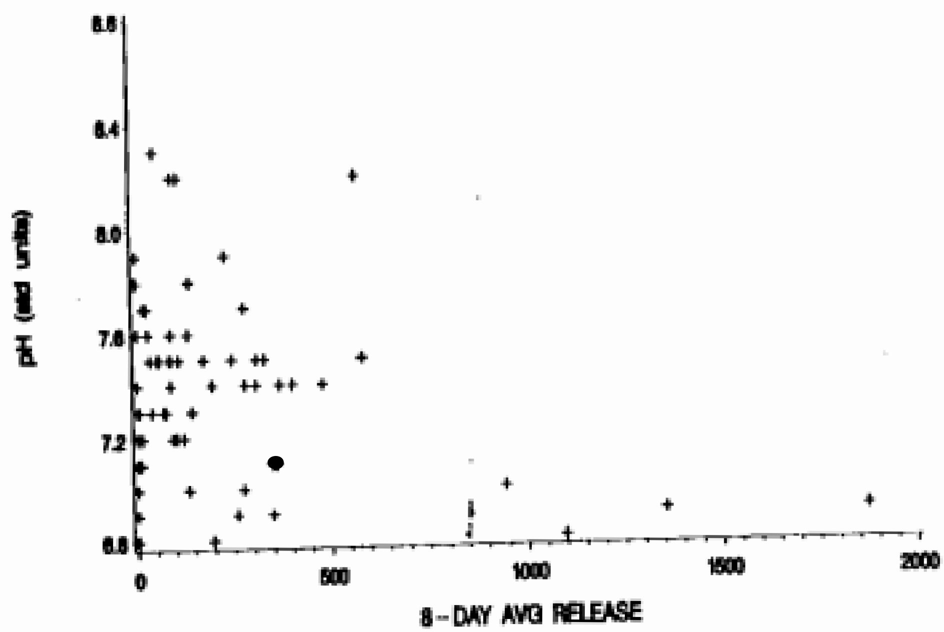
Means , standard deviations , median and number of observations (n) for water quality parameters at HCEPC Station 2 (Platt St.) For discharge and no-discharge conditions. No-discharge conditions have an 8-day flow less than 2 cfs.

		Discharge				**No Discharge**		
	Mean	**Std**	**Median**	**(N)**	**Mean**	**Std**	**Median**	**(N)**
8-day discharge (cfs)	357.1	481.8	139.1	186	.4	.4	.2	89
pH	7.5	.3	7.5	107	7.8	.3	7.8	61
Color (pcu)	31.1	29.6	18	181	10.4	4.6	10	86
Chloro-phyll a (ug/l)	14.5	11.1	11	186	15.1	9.2	12.3	89
B.O.D. (mg/l)	2.0	1.4	1.8	186	2.4	1.5	2	89
T.S.S. (mg/l)	25	16.6	20	34	45.5	19.2	47	22
Turbidity (ntu)	4.9	4.2	4	185	4.6	2.2	4	89
Total-N (mg/l)	103	.38	.97	128	.83	.24	.8	63
NO3-N (mg/l)	.09	.07	.07	74	.06	.05	.04	33
P-Total (mg/l)	.61	.34	.51	182	.65	.42	.49	85
P-Ortho (mg/l)	.65	.4	.54	90	.63	.49	.35	57
Total Coliforms (col./100ml)	12950	75220	700	185	974	2938	240	89
Fecal Coliforms (col./100ml)	8697	61611	180	184	303	1103	100	86
Fecal Streptococci (col./100ml)	783	2128	260	121	418	788	120	55

APPENDIX J-2

Plots of water chemistry parameters measured at HCEPC stations in the lower Hillsborough River vs. discharge from the Hillsborough River Reservoir

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



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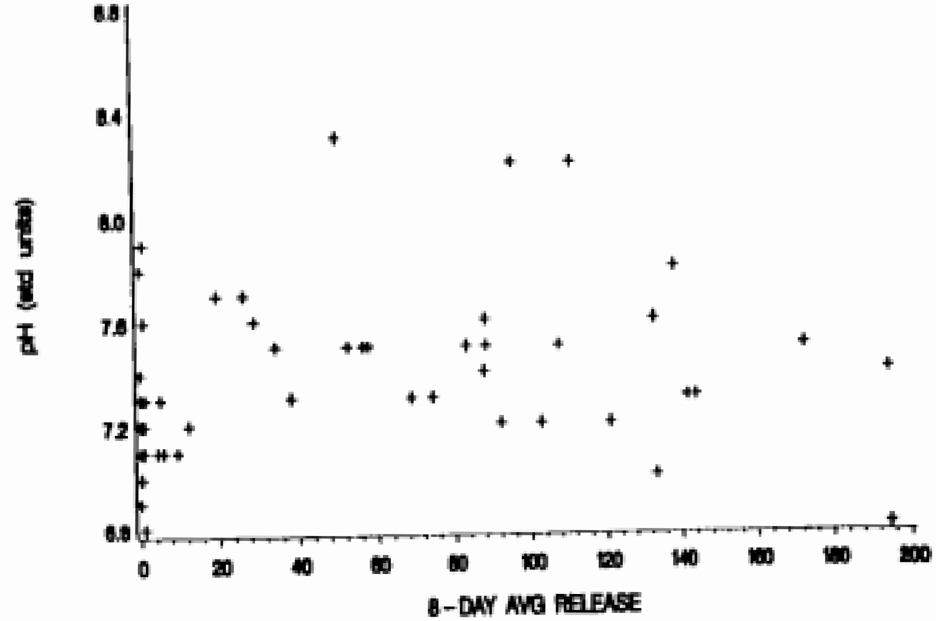
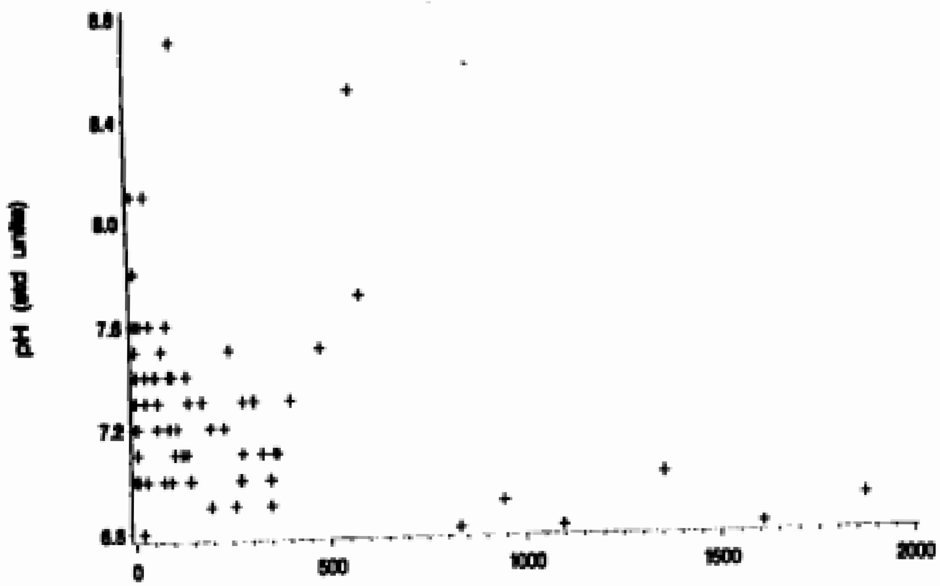


J2-1

AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



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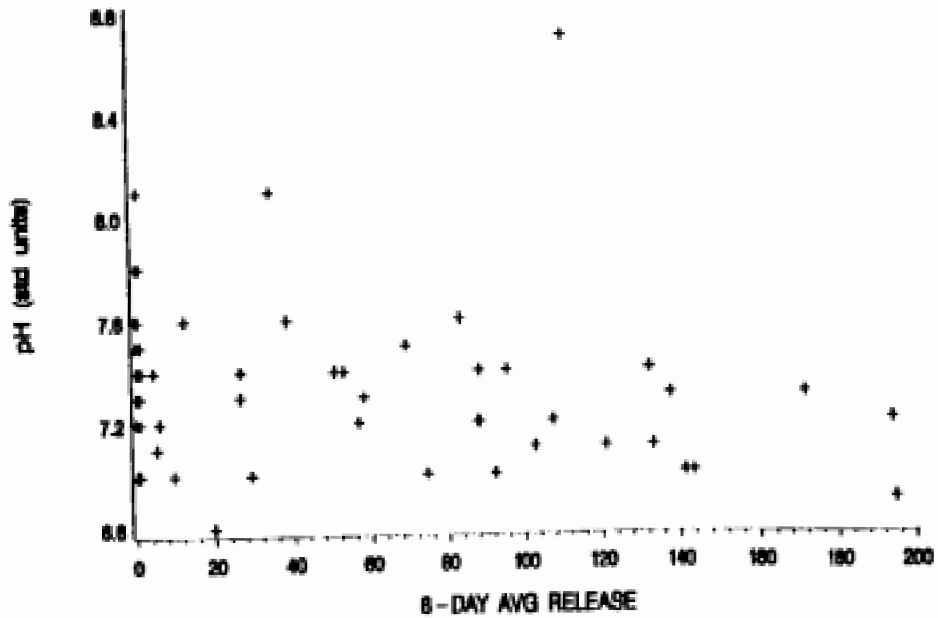

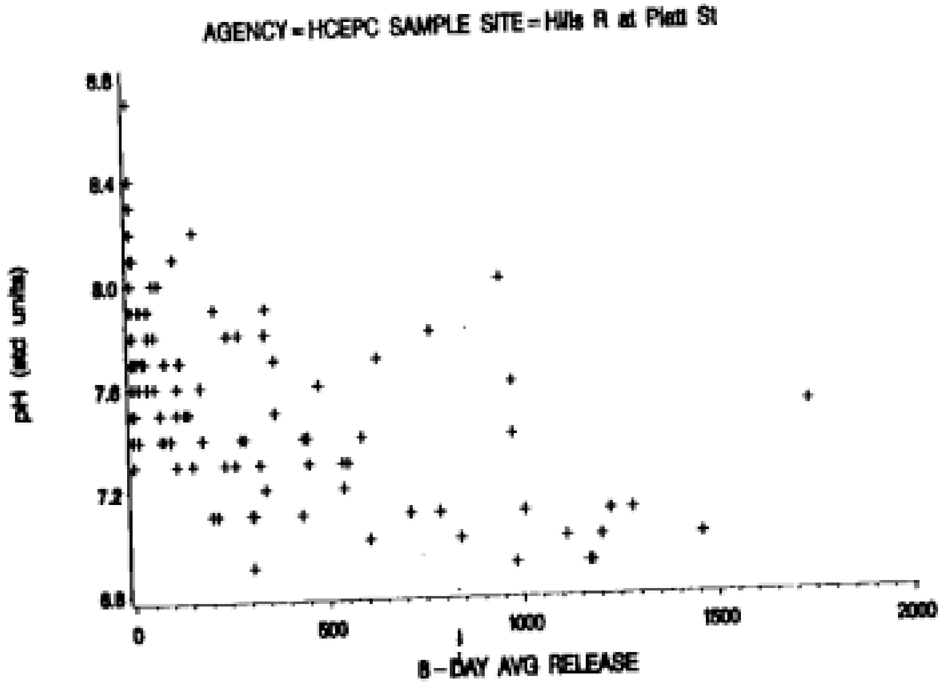
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
pH (std units)
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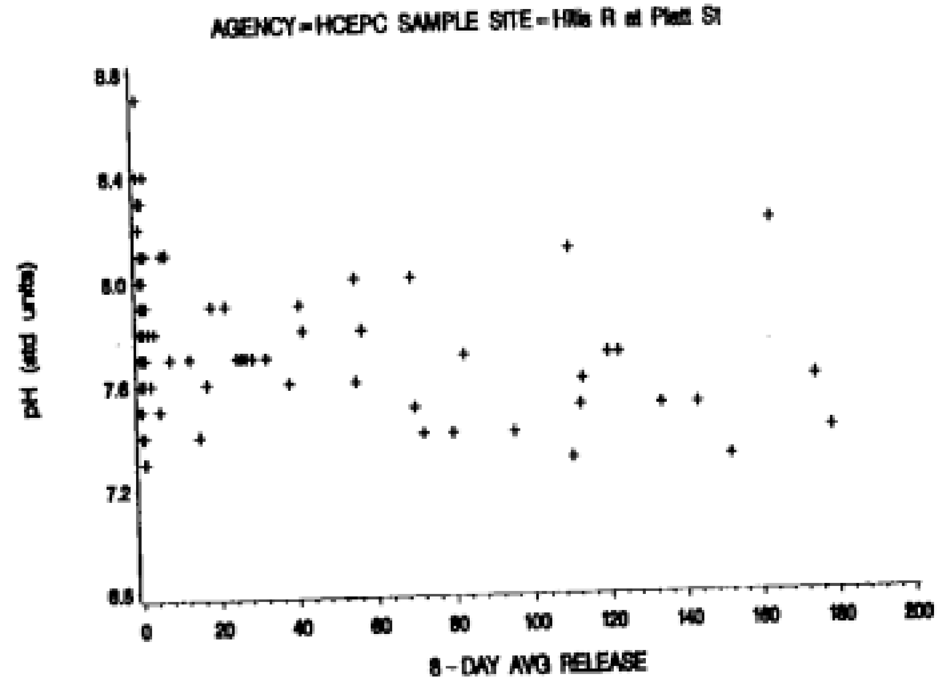
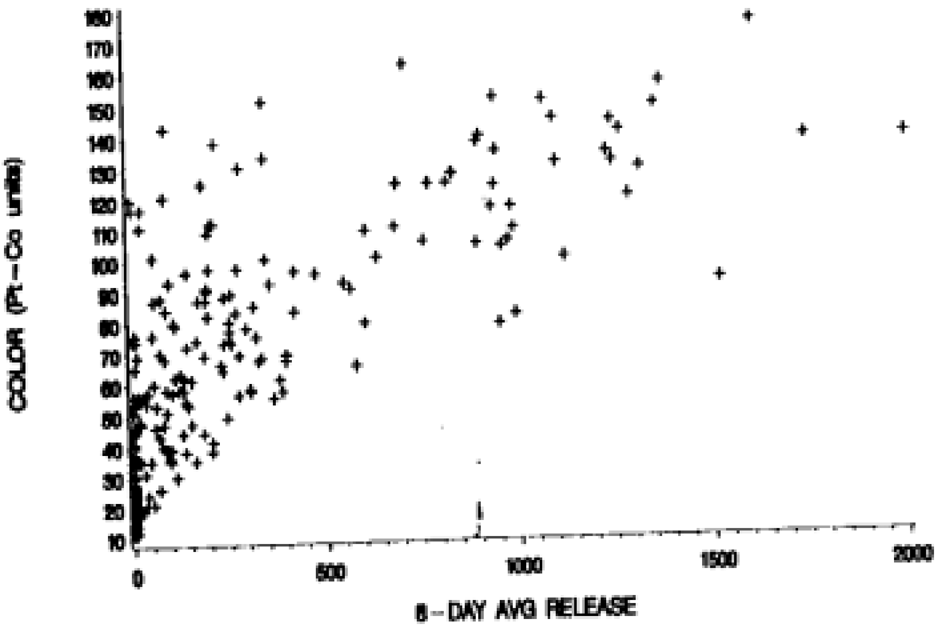
8.4
8.0
7.6
7.2
6.8
0
500
1000
1500
2000
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
pH (std units)
8.8
8.4
8.0
7.6
7.2
6.8
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE

J2-2

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



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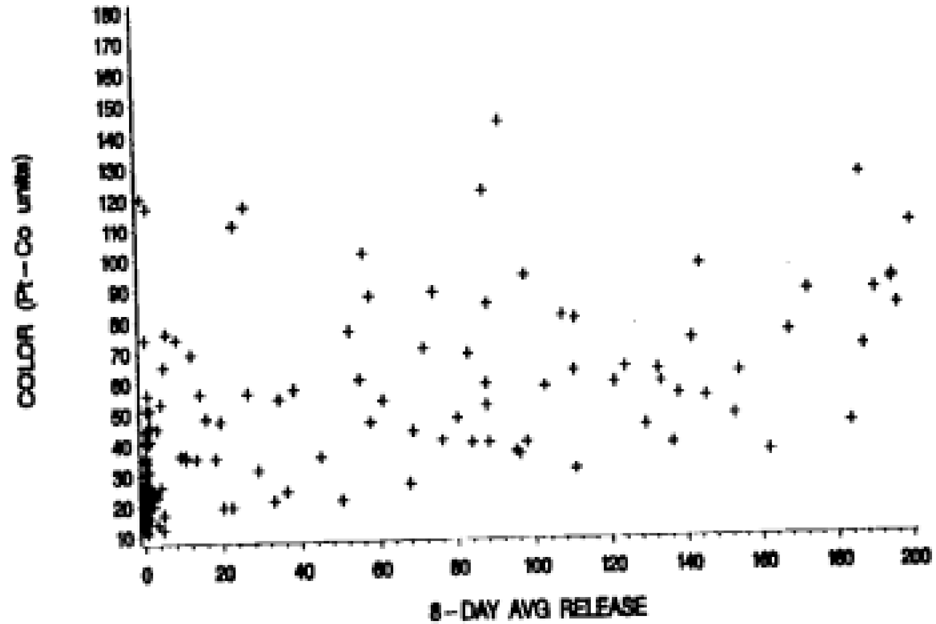

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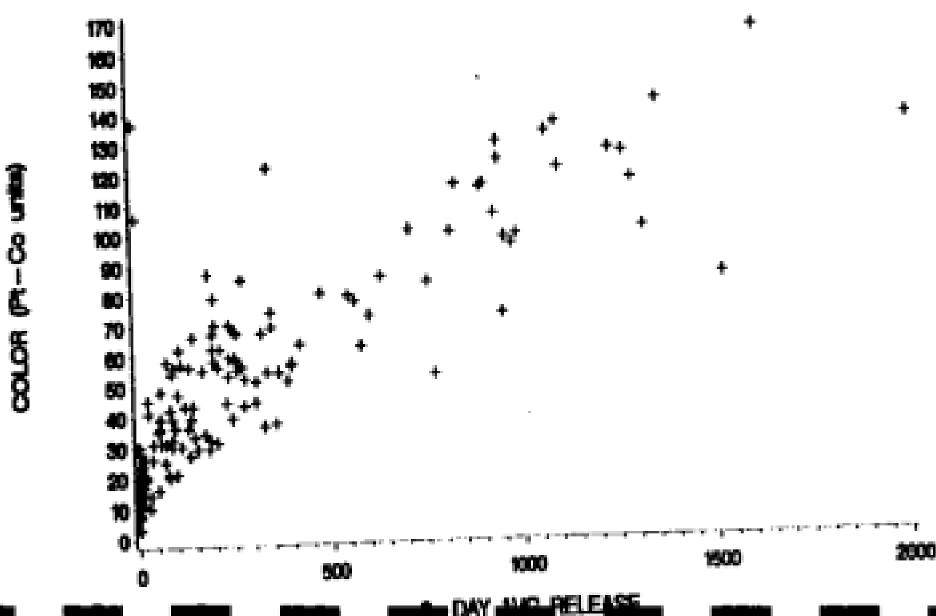

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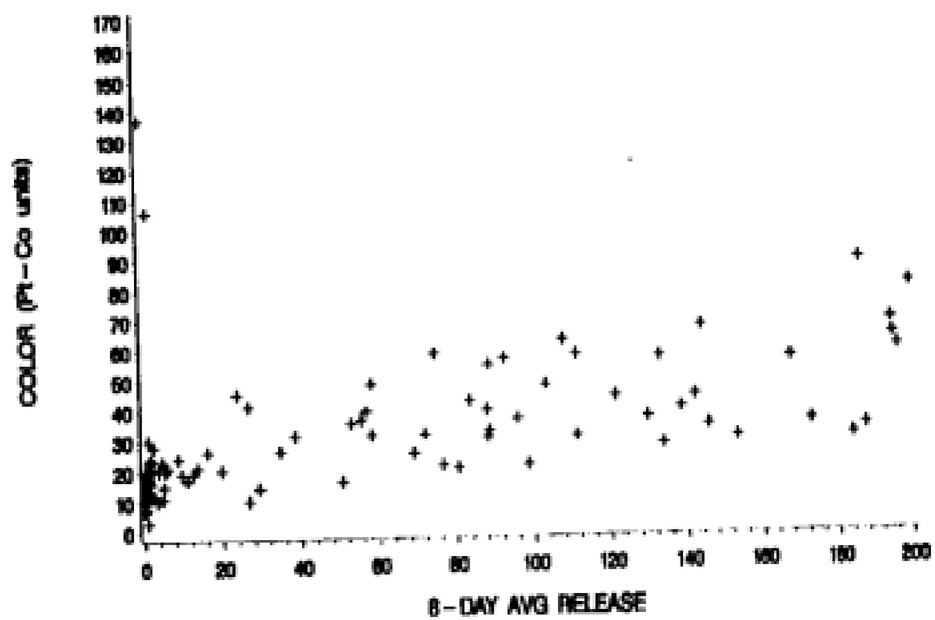

J2-3

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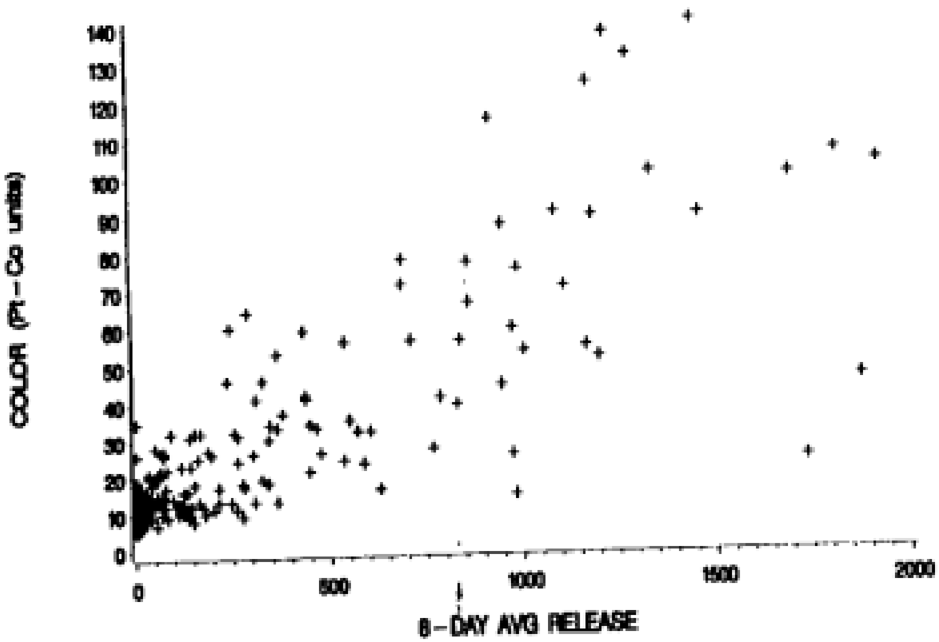

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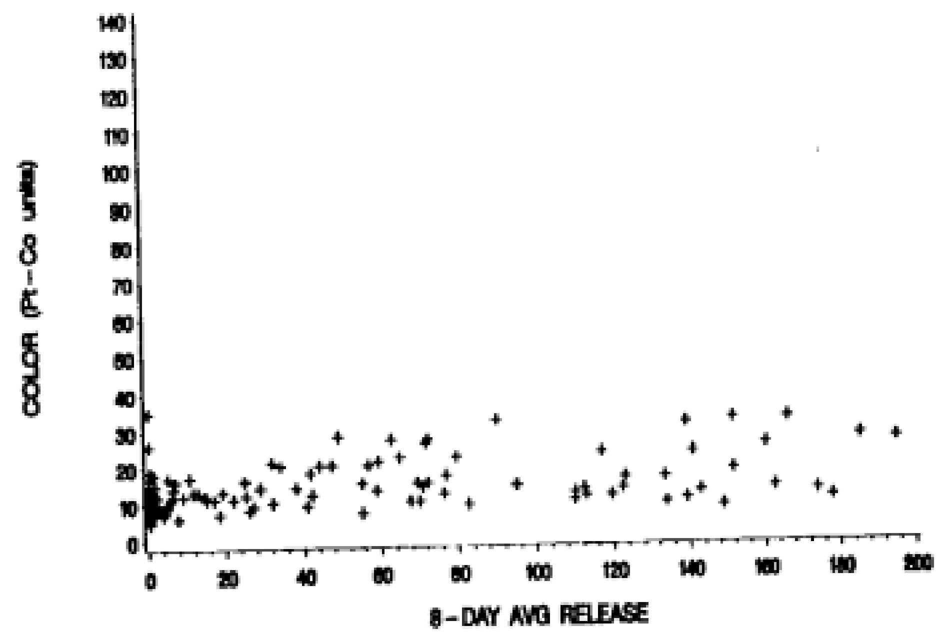
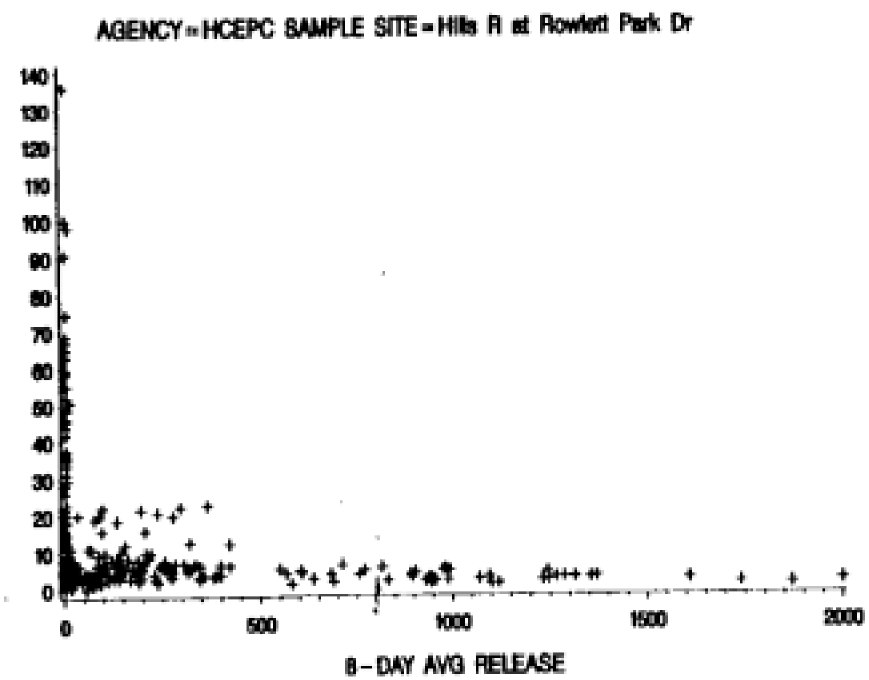


J2-4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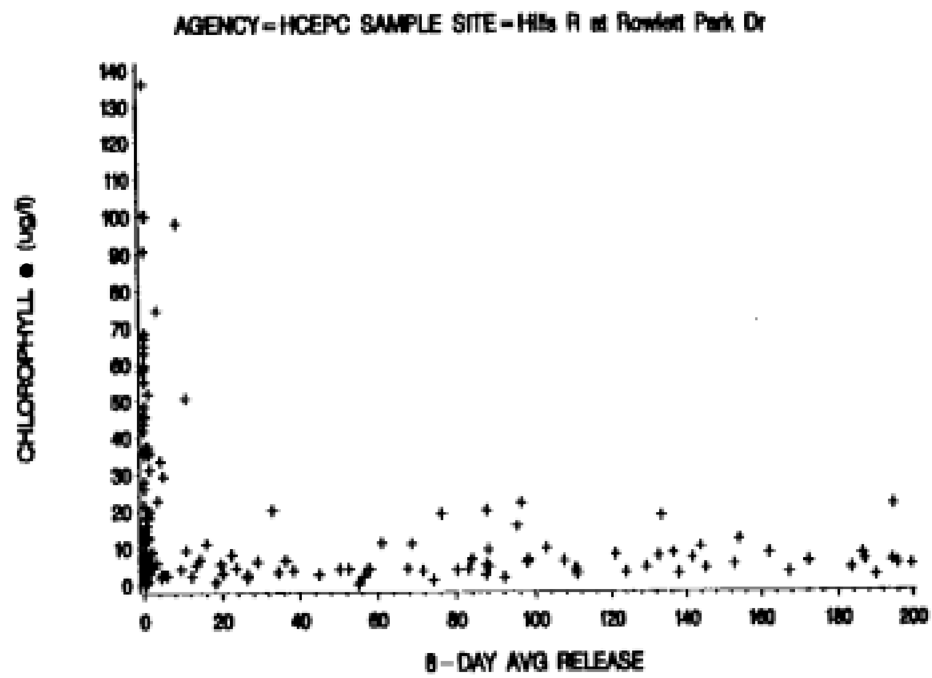
CHLOROPHYLL ● (ug/l)
8-DAY AVG RELEASE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CHLOROPHYLL ● (ug/l)
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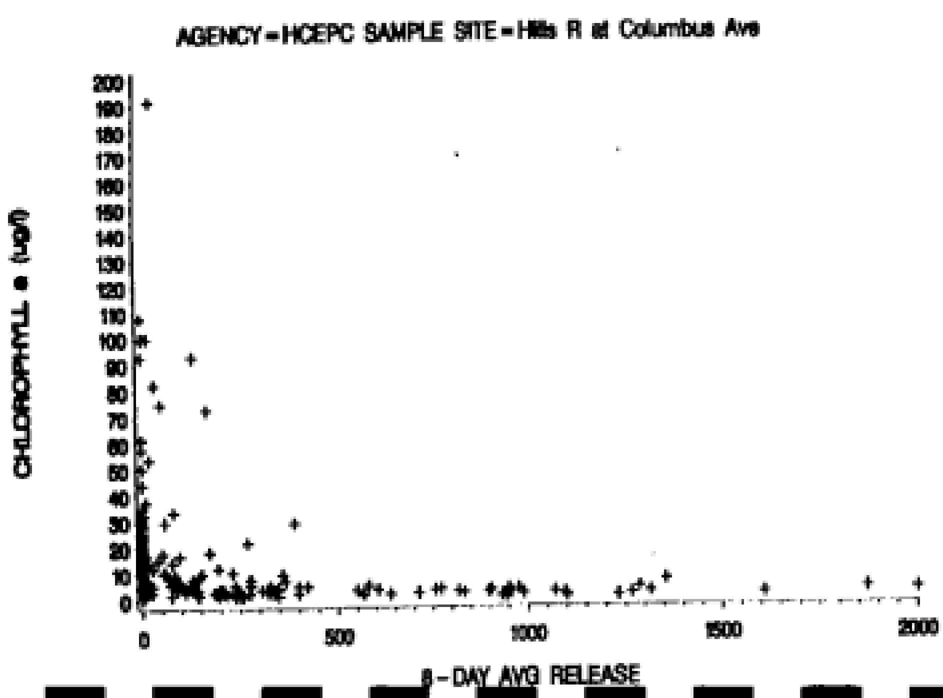
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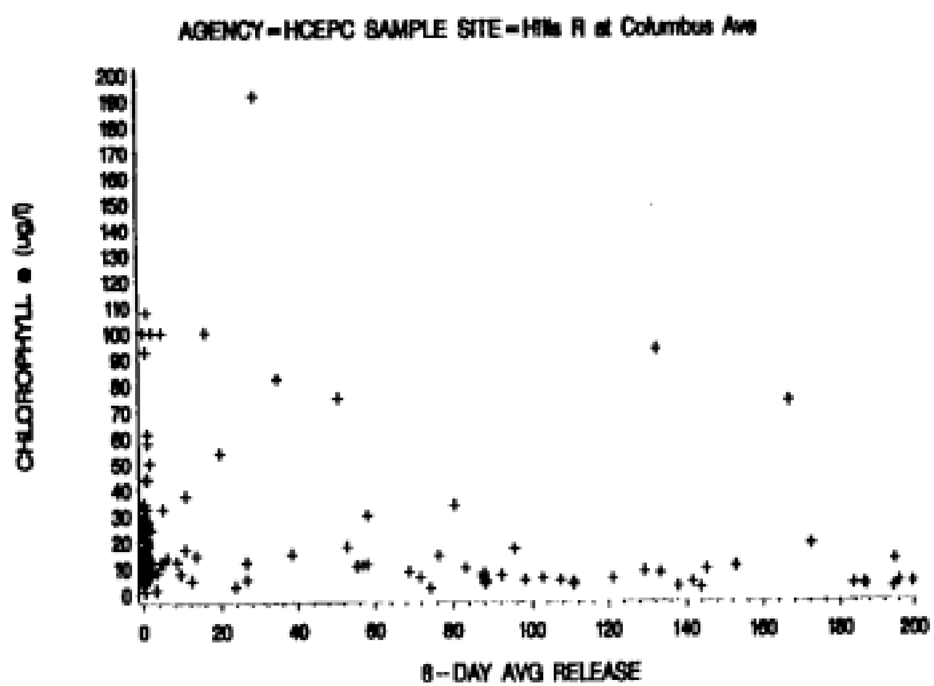
8-DAY AVG RELEASE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CHLOROPHYLL ● (ug/l)
8-DAY AVG RELEASE

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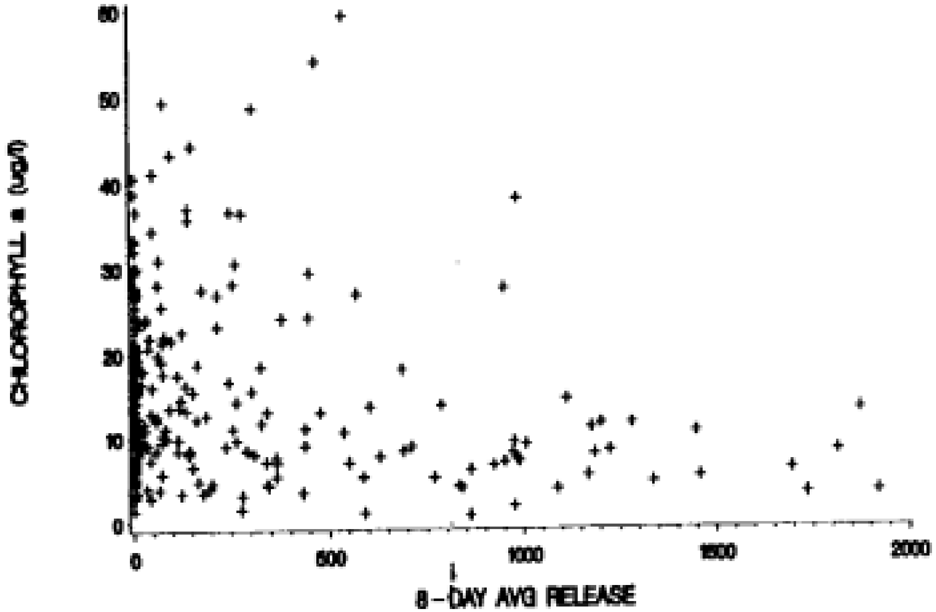
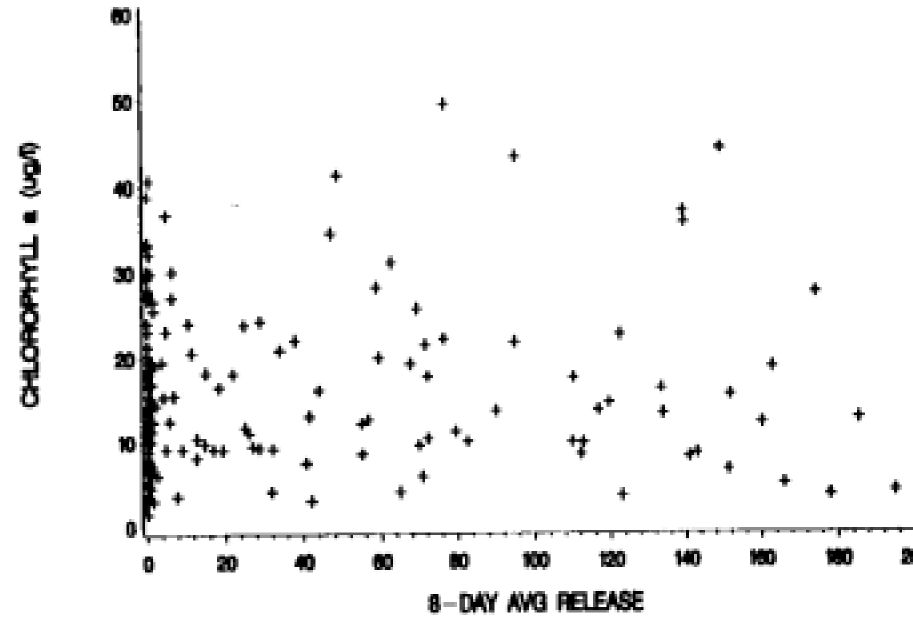
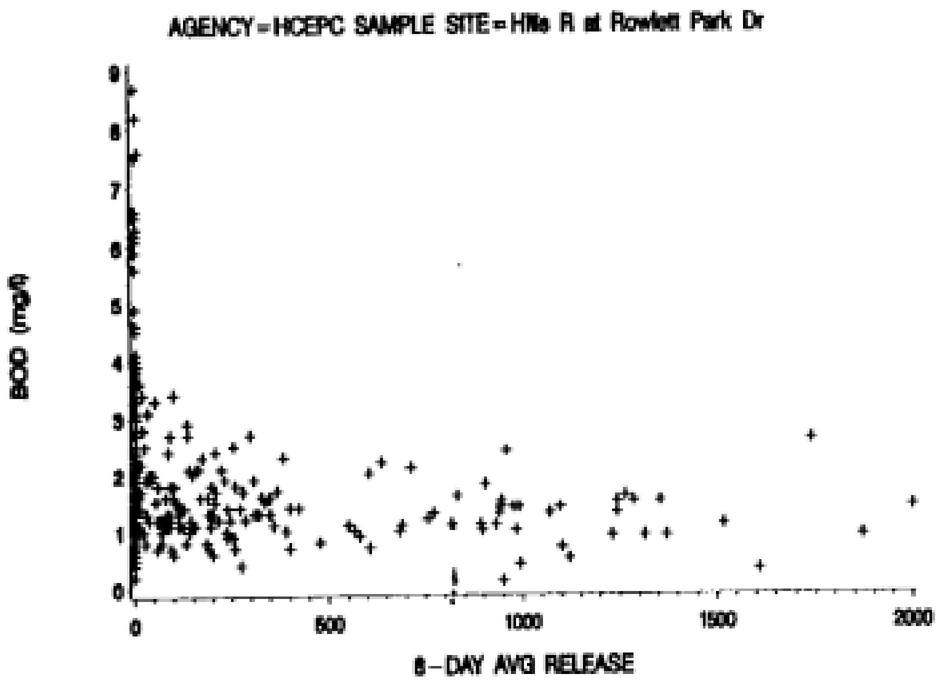


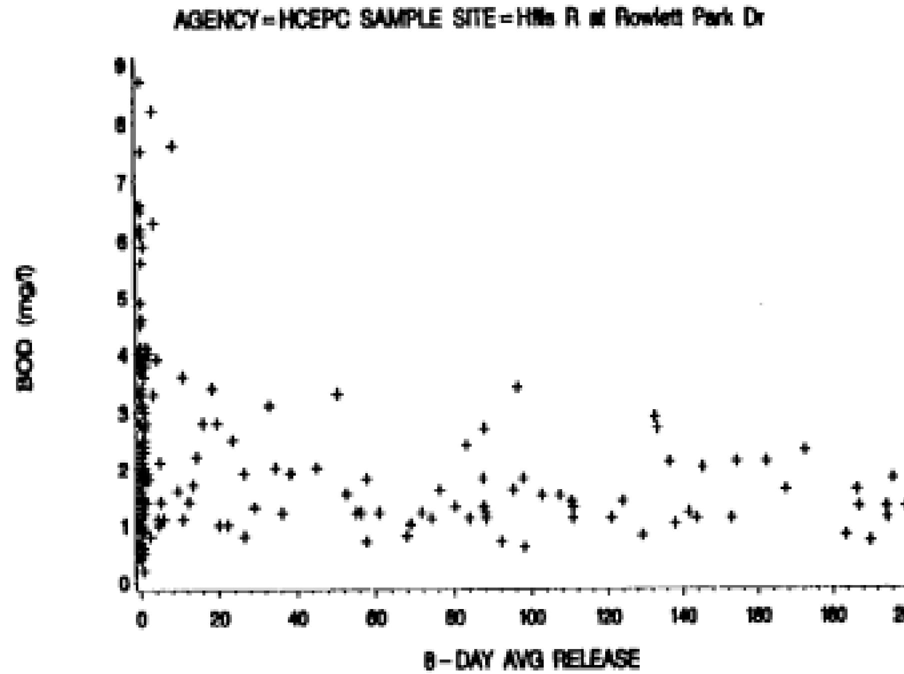
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

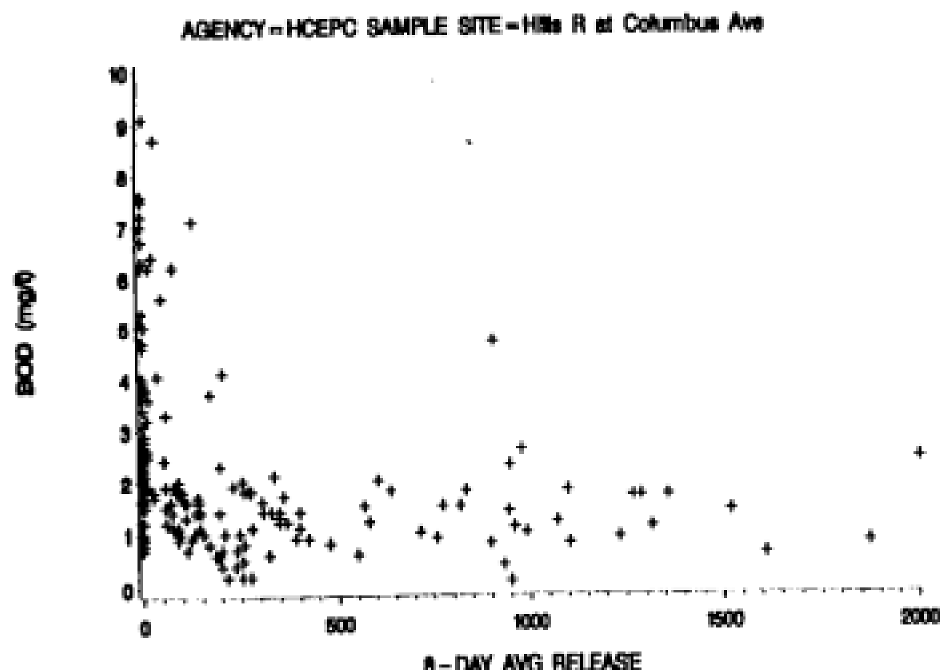


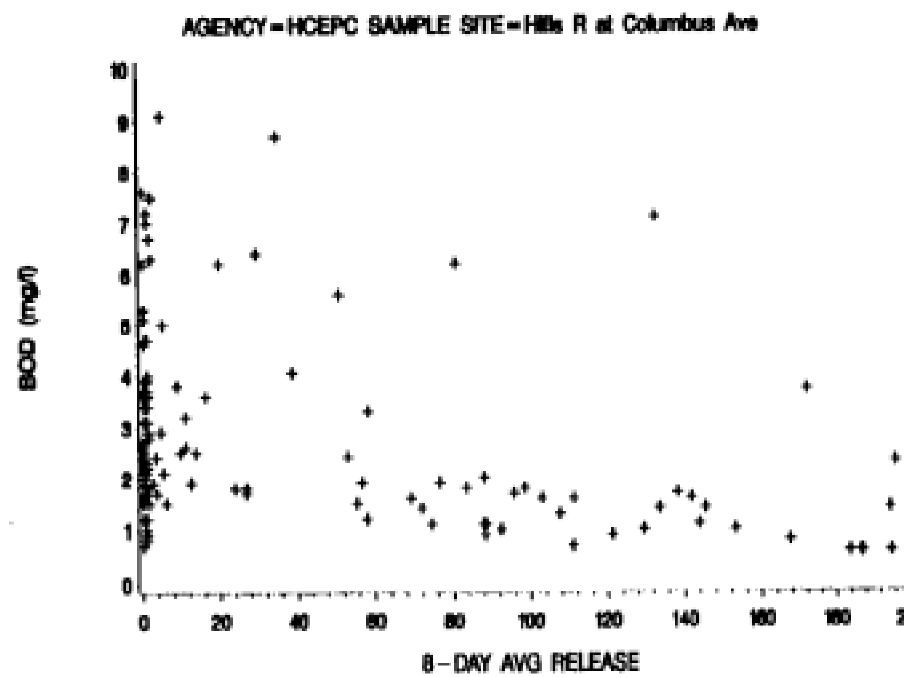
J2-6

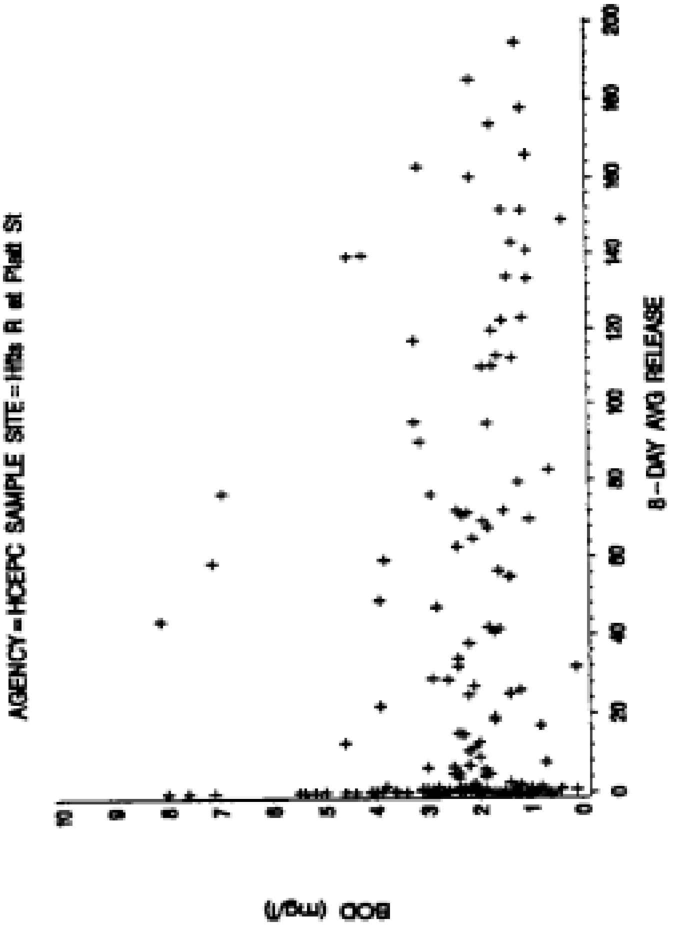
T2-7

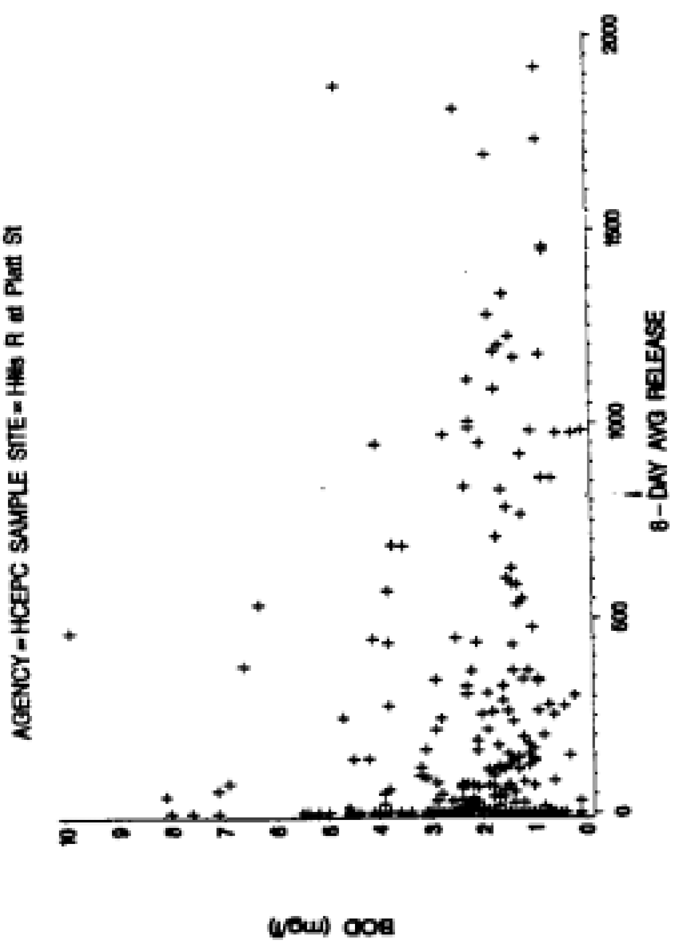

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
BOD (mg/l)
0
1
2
3
4
5
6
7
8
9
0
500
1000
1500
2000
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
BOD (mg/l)
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
BOD (mg/l)
0
1
2
3
4
5
6
7
8
9
10
0
500
1000
1500
2000
8-DAY AVG RELEASE

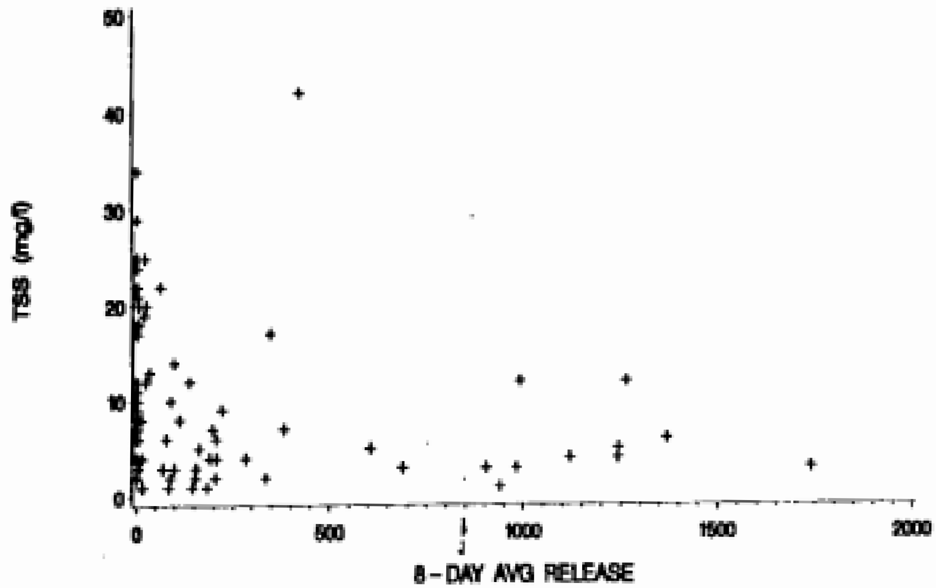

AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
BOD (mg/l)
0
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
BOD (mg/l)
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
BOD (mg/l)
8-DAY AVG RELEASE

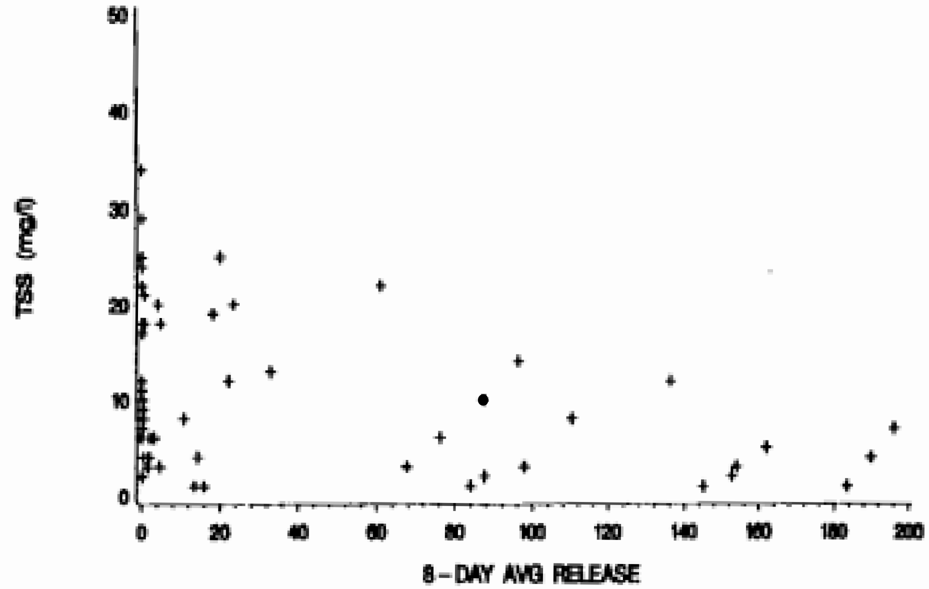
J2-8

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



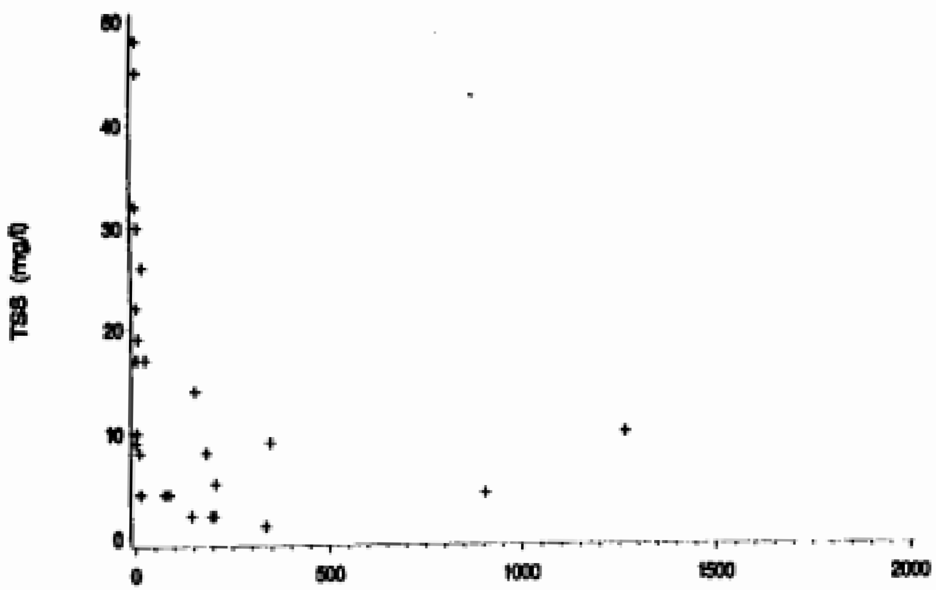
NOTE: 3 observations not shown had TSS values of [illegible], [illegible], and 794 for 8-day release <=2.0 cfs

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr

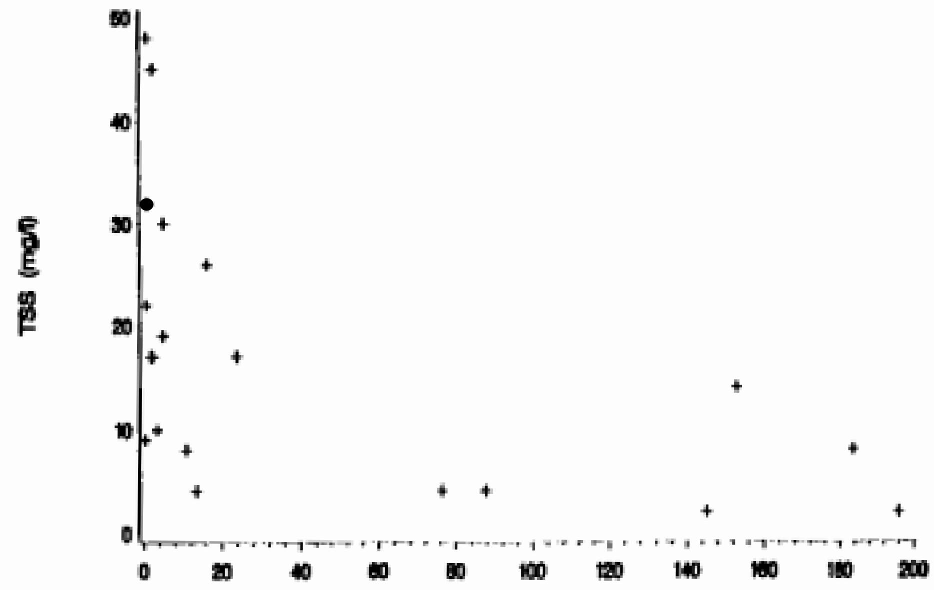


NOTE: 3 observations not shown had TSS values of [illegible], [illegible], and 794 for 8-day release <=2.0 cfs

AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave

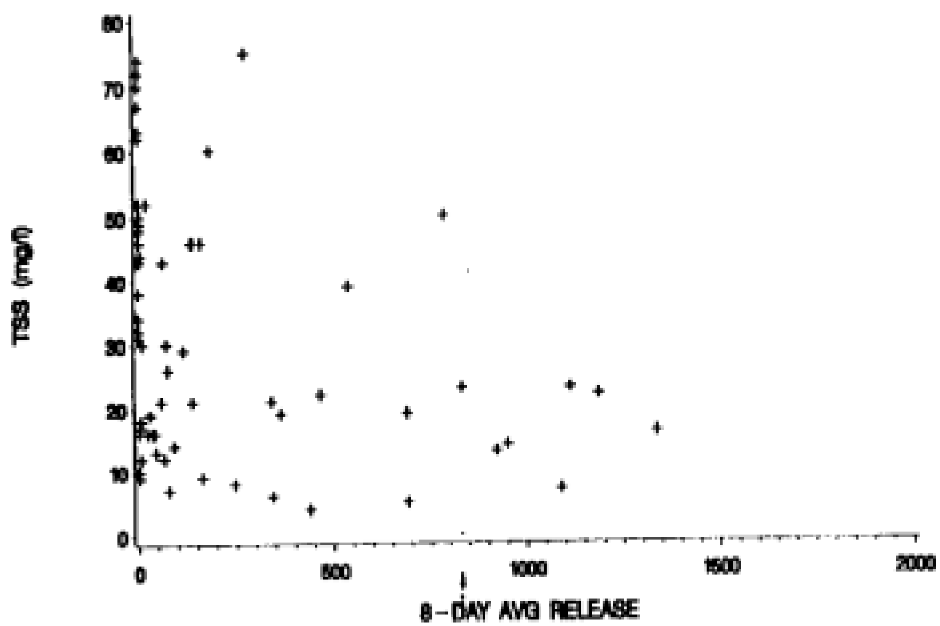


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave

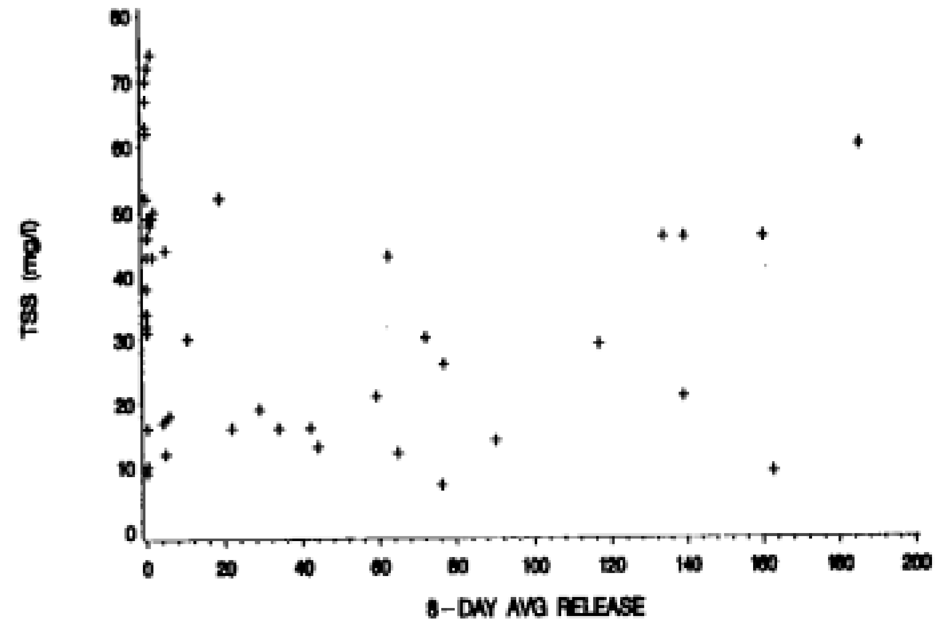


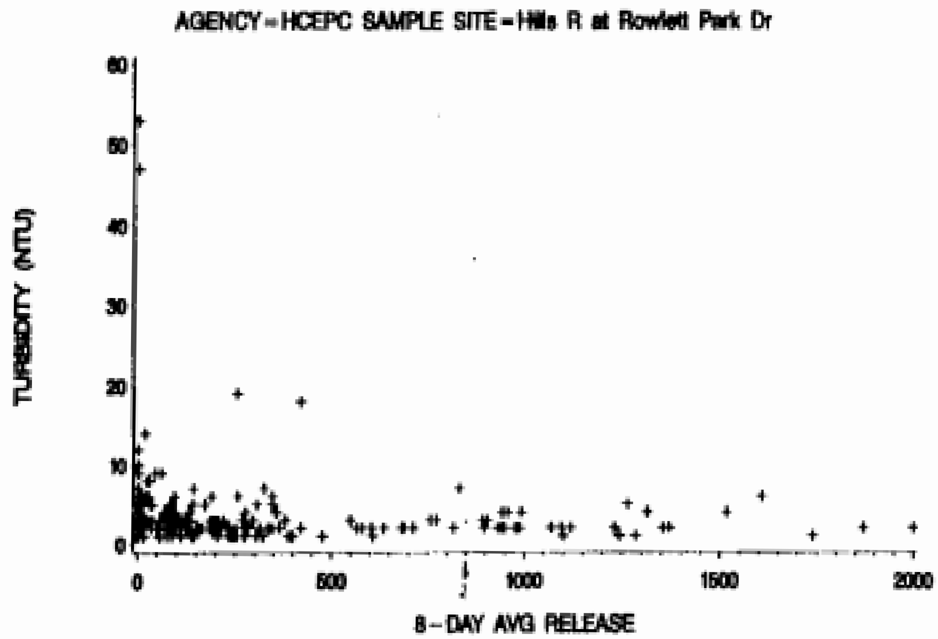
J2-9

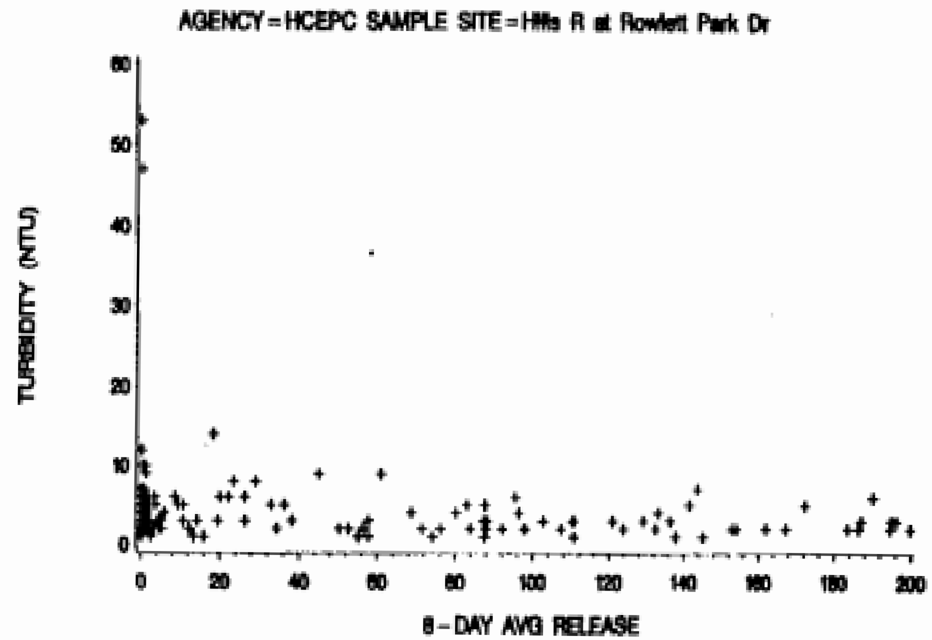
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

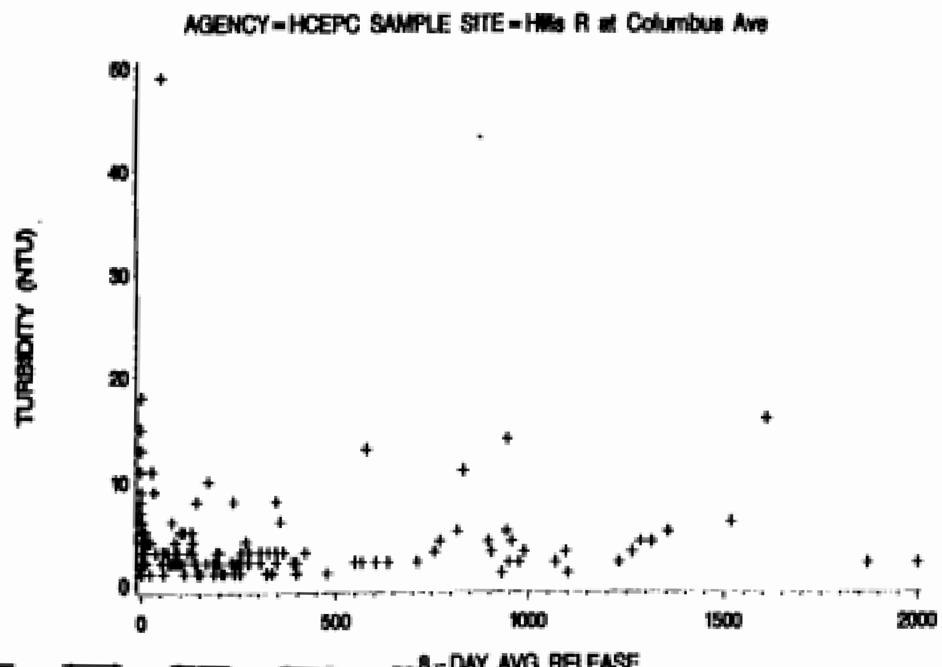


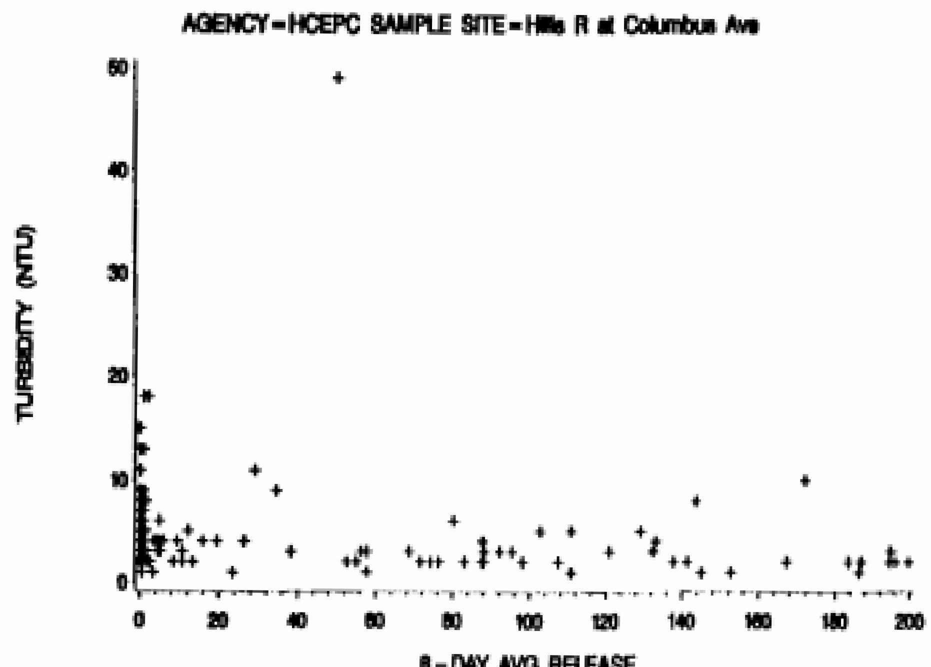
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

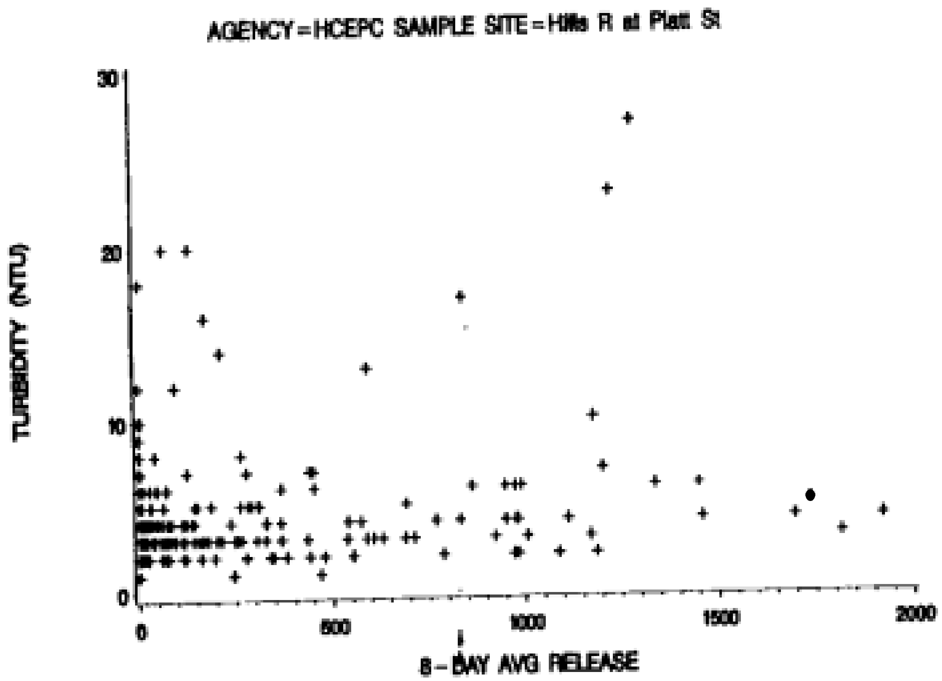



AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
TURBIDITY (NTU)
8-DAY AVG RELEASE

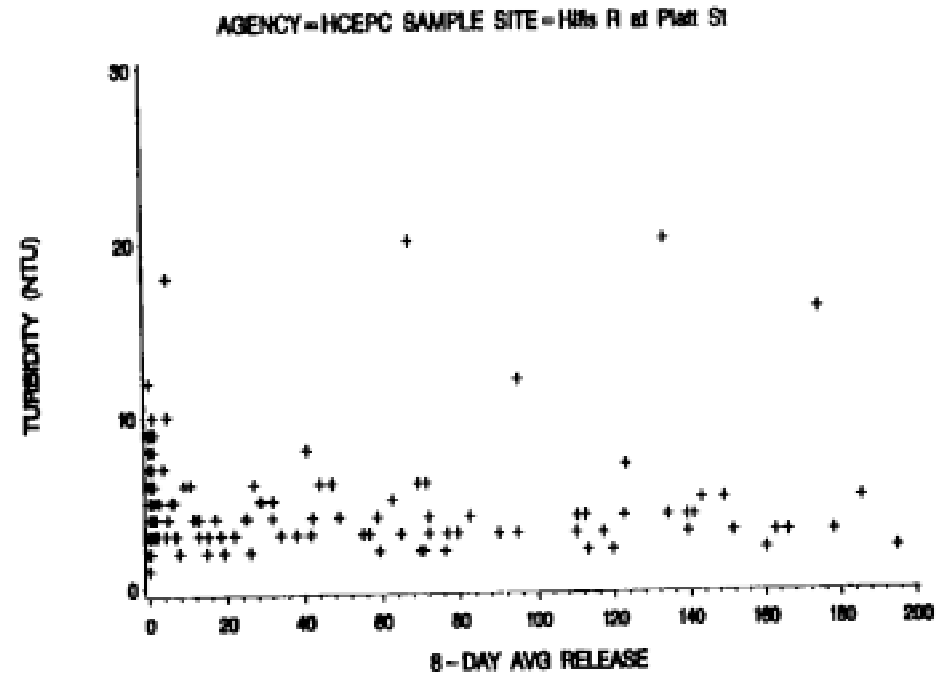

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
TURBIDITY (NTU)
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
TURBIDITY (NTU)
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
TURBIDITY (NTU)
8-DAY AVG RELEASE



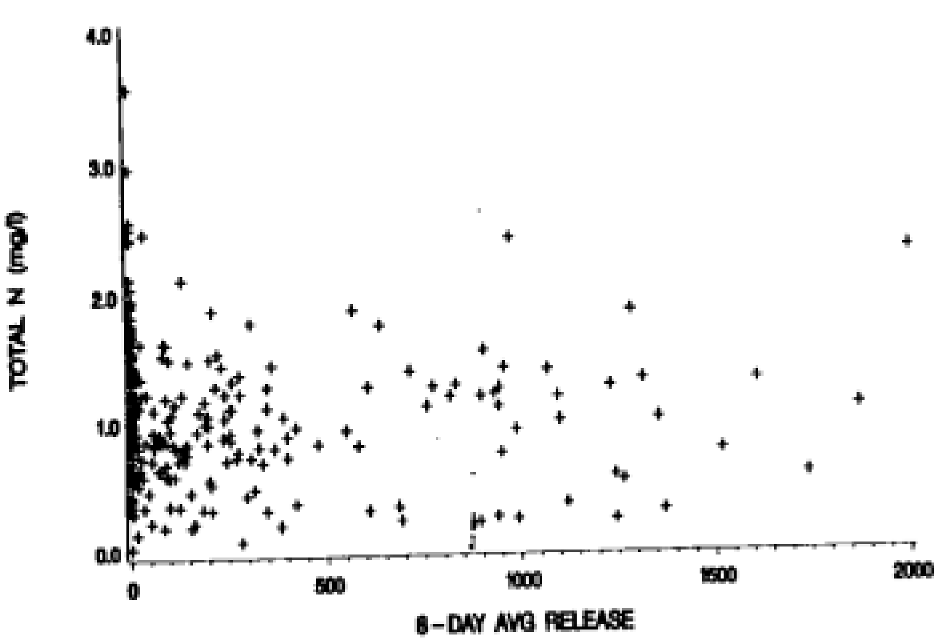
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TURBIDITY (NTU)
0
10
20
30
0
500
1000
1500
2000
8-DAY AVG RELEASE



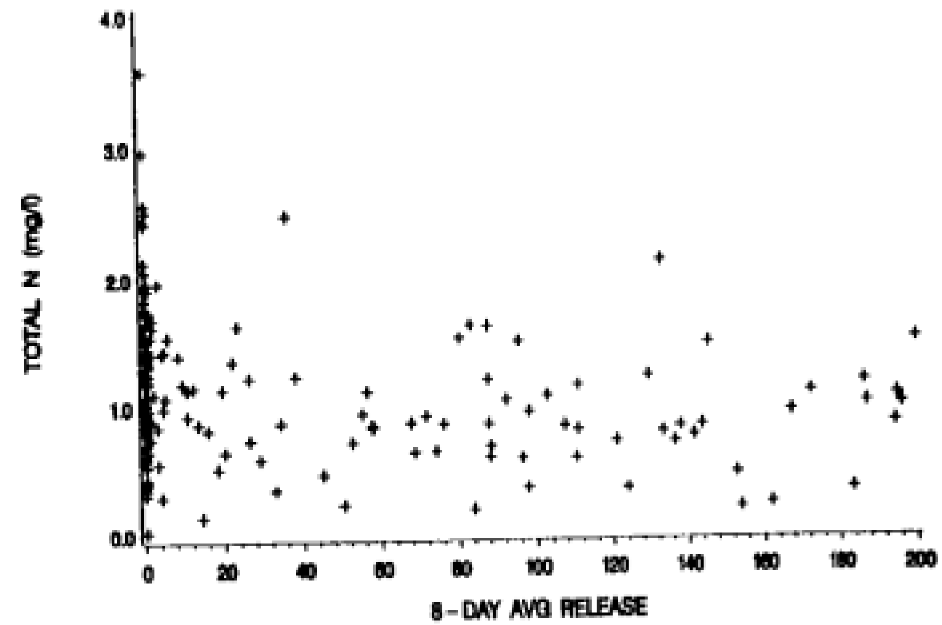
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TURBIDITY (NTU)
0
10
20
30
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE

J2-12

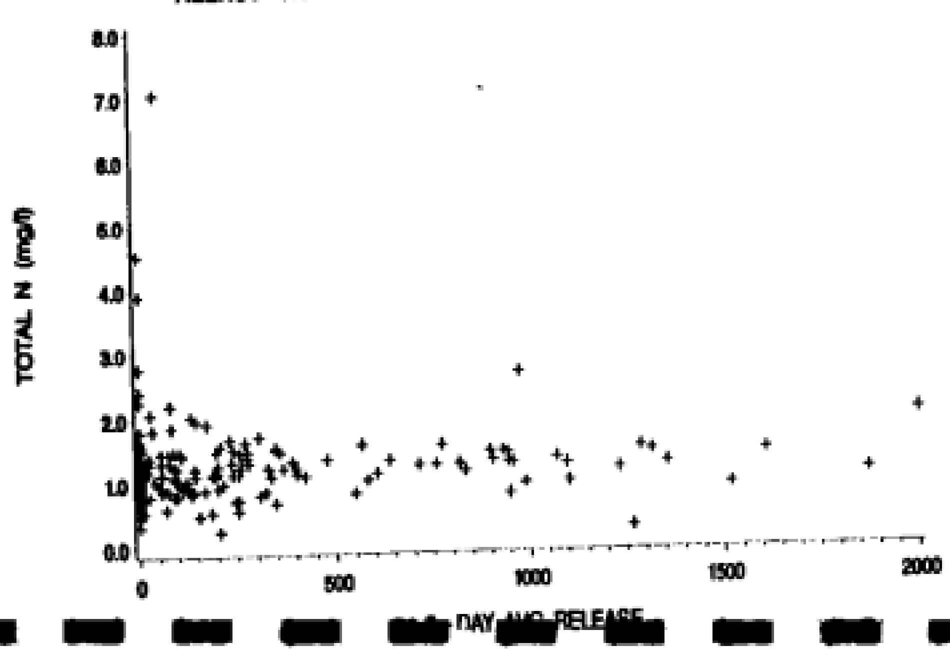
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



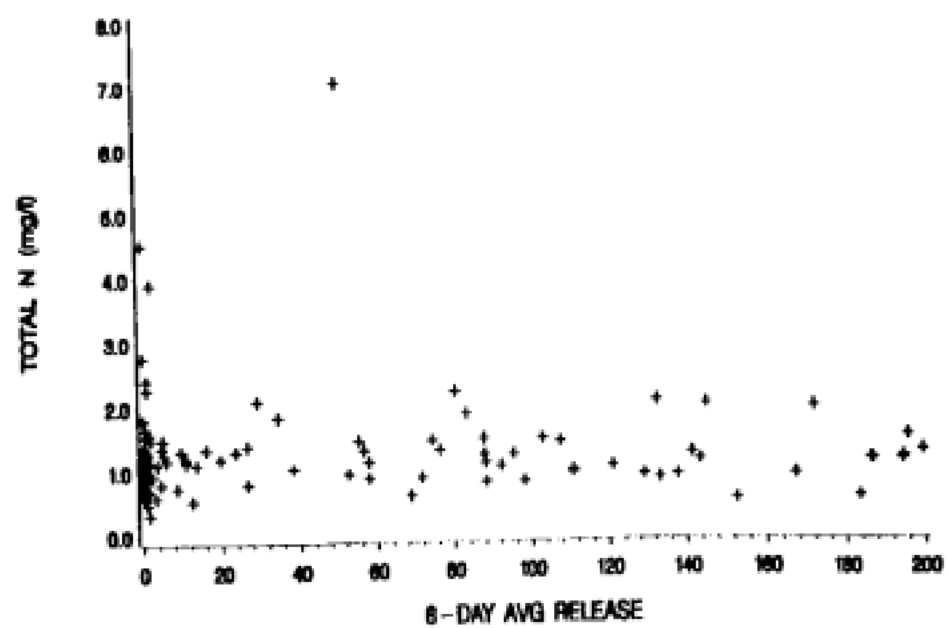
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave

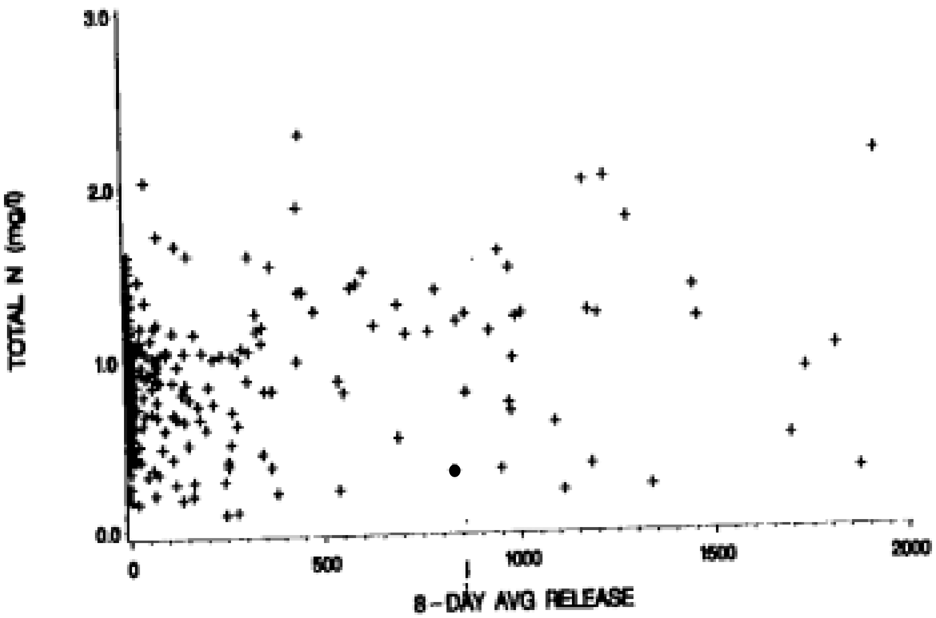


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave

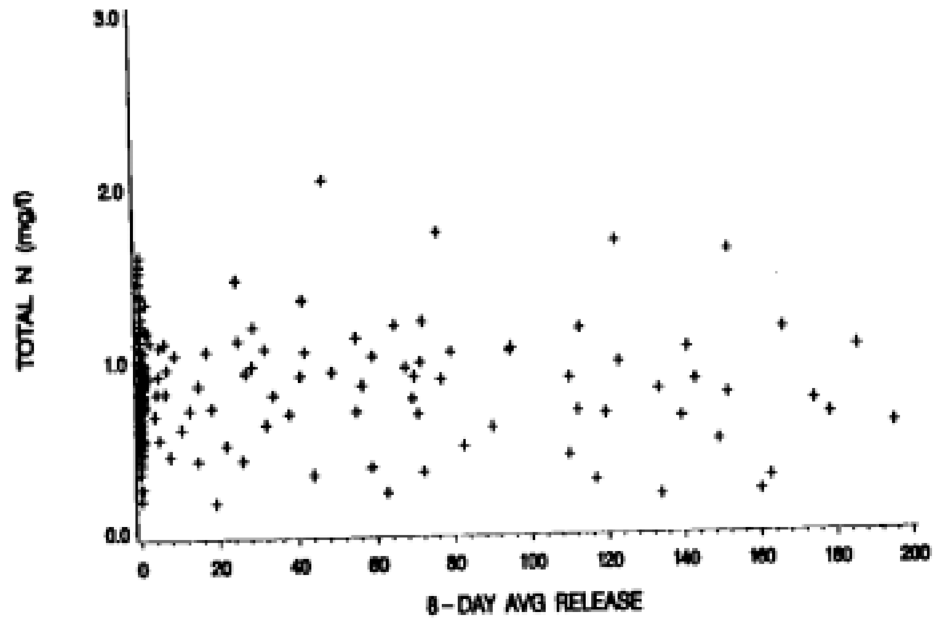


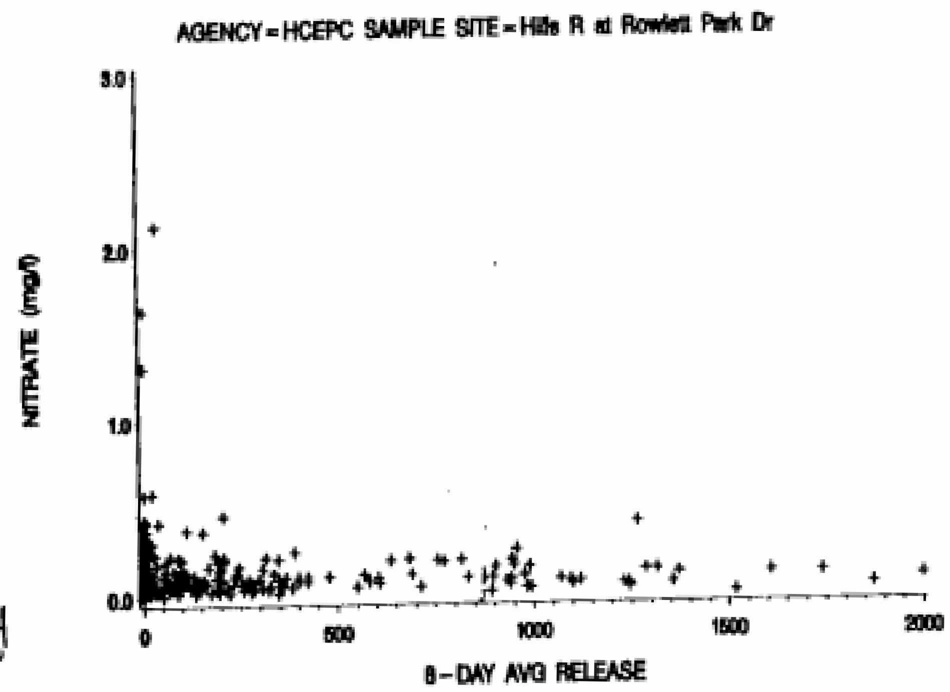
J2-14

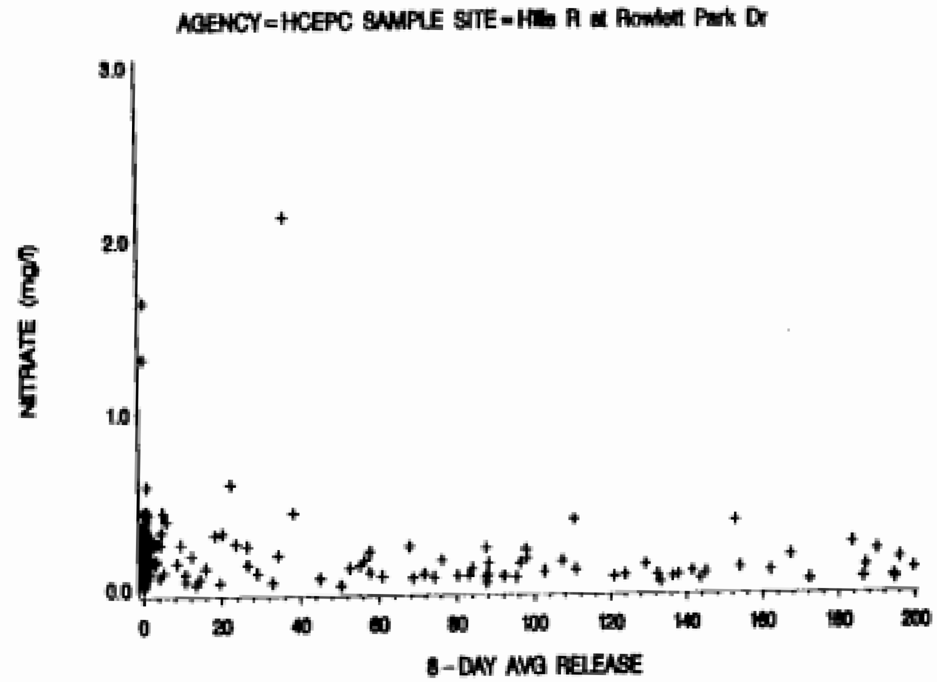
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

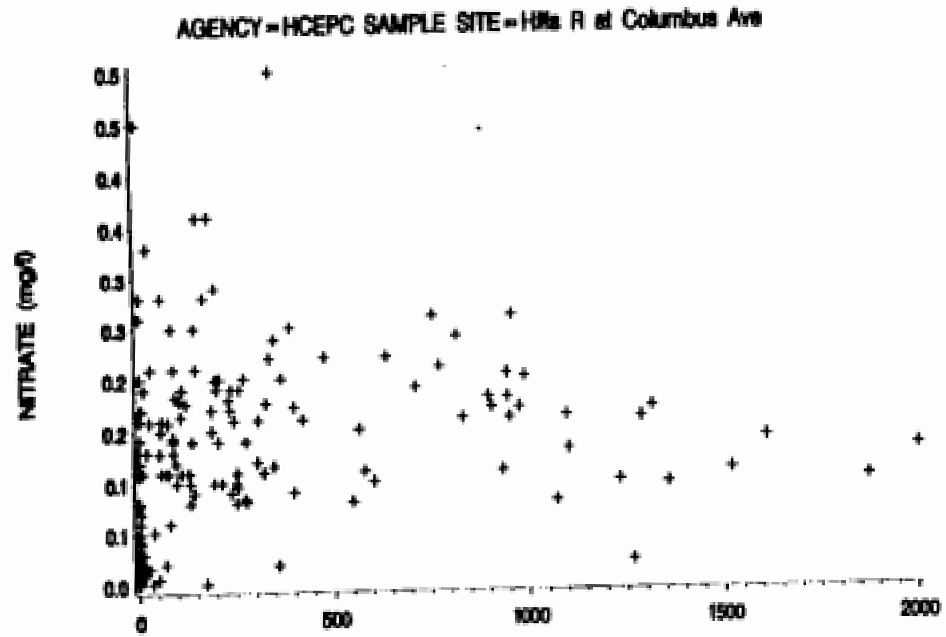


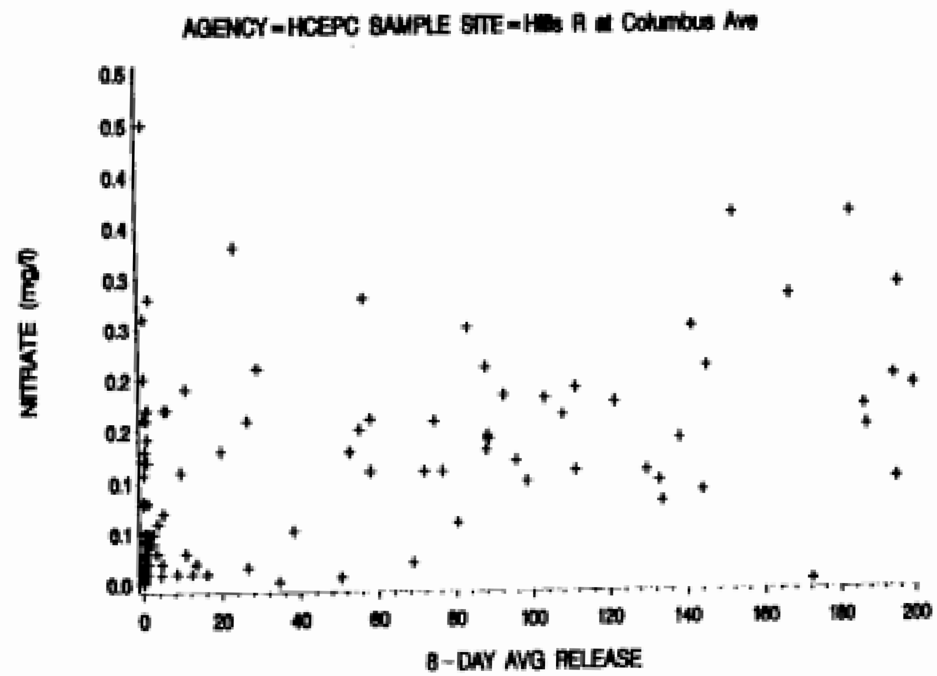
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St




AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
NITRATE (mg/l)
3.0
2.0
1.0
0.0
0
500
1000
1500
2000
8-DAY AVG RELEASE

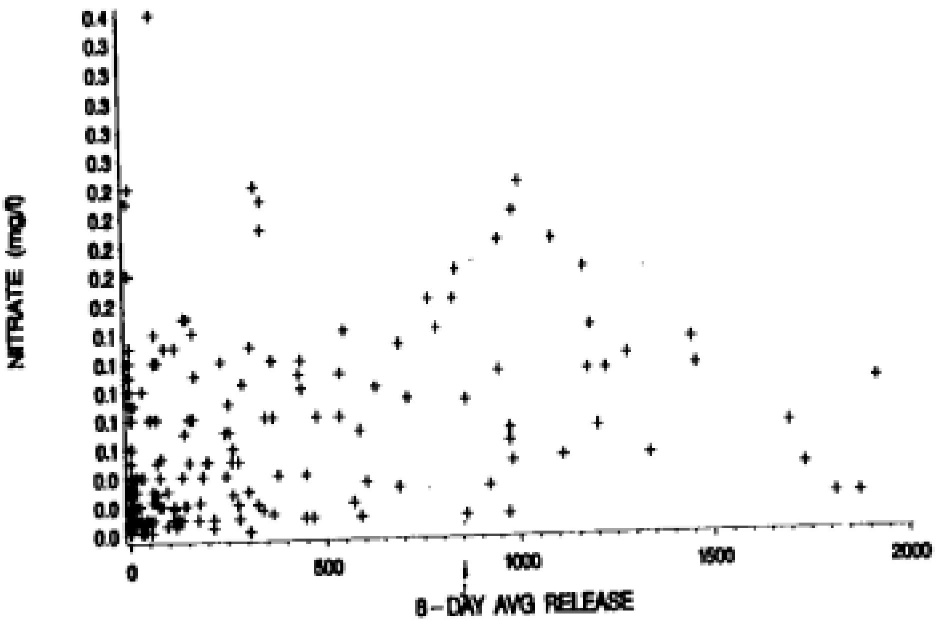

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
NITRATE (mg/l)
3.0
2.0
1.0
0.0
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
NITRATE (mg/l)
0.5
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
0
500
1000
1500
2000
8-DAY AVG RELEASE

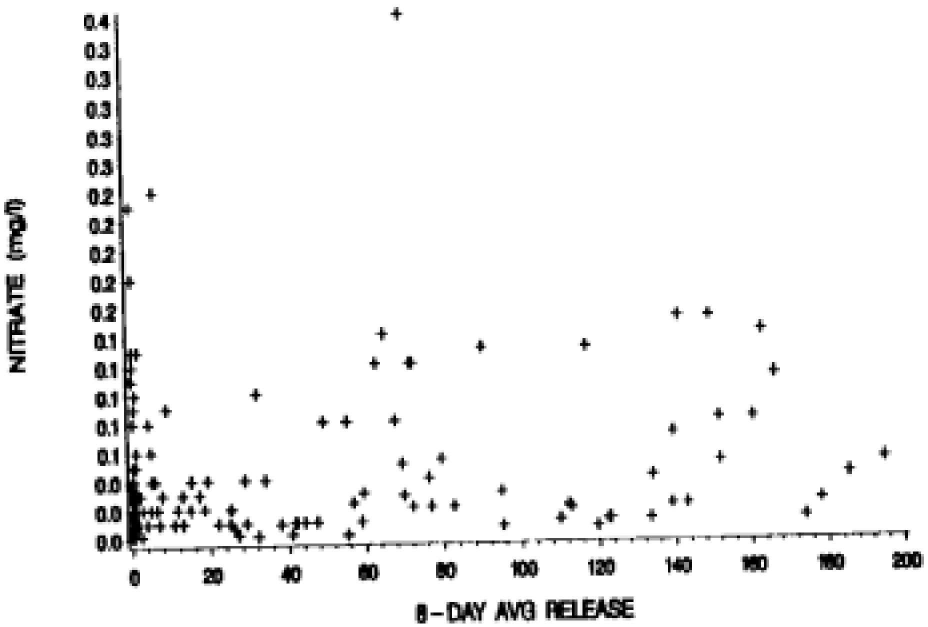

AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
NITRATE (mg/l)
0.5
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE

J2-15

AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

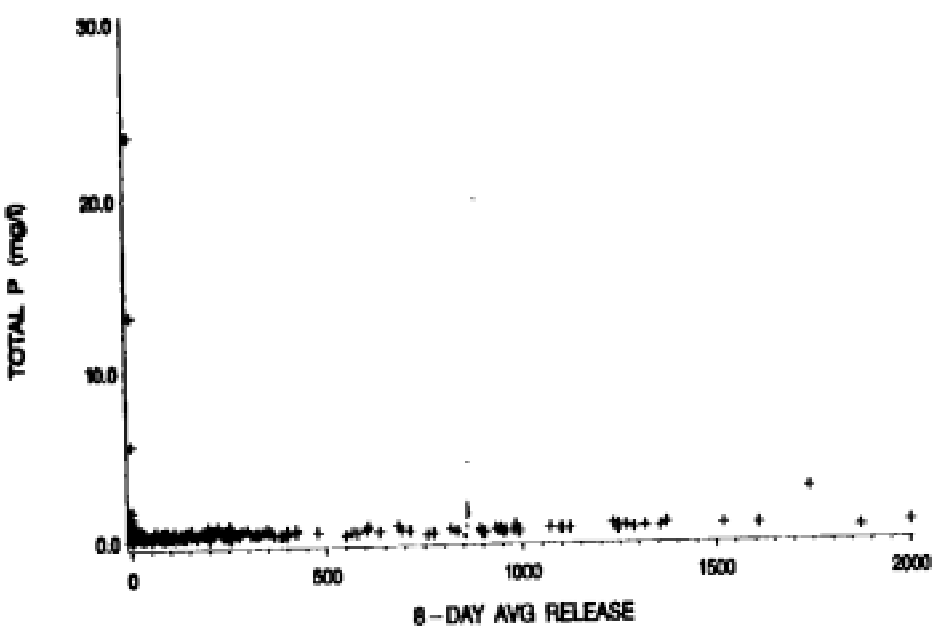


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

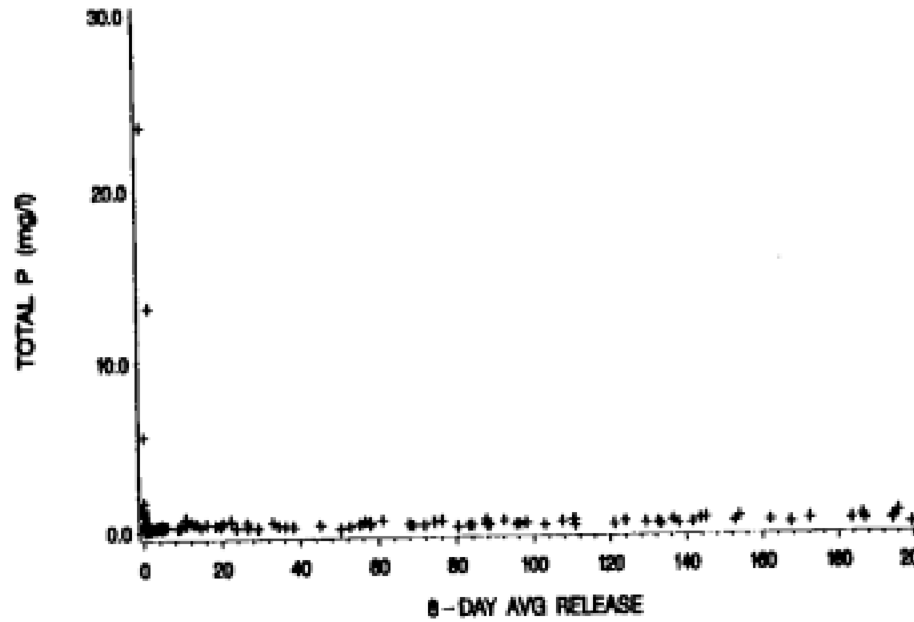


J2-16

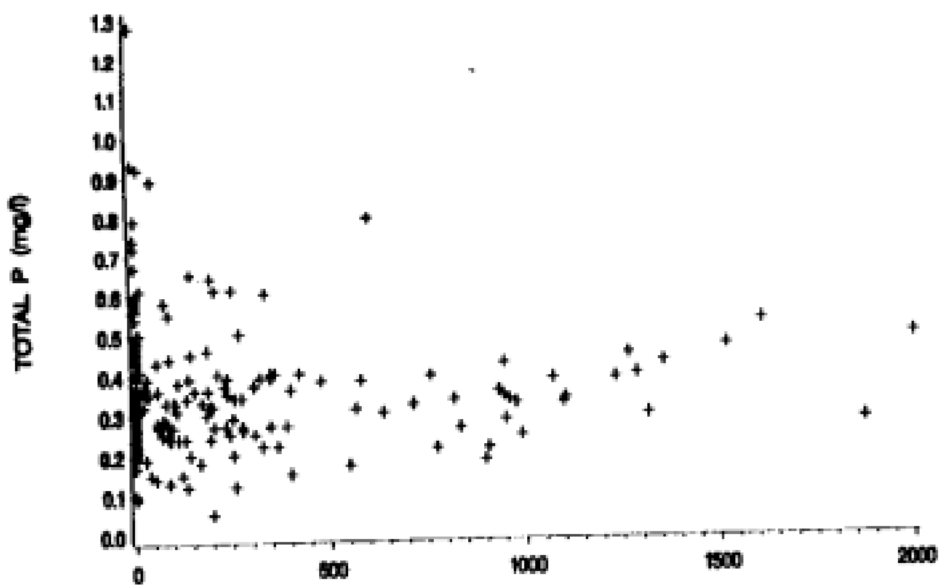
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



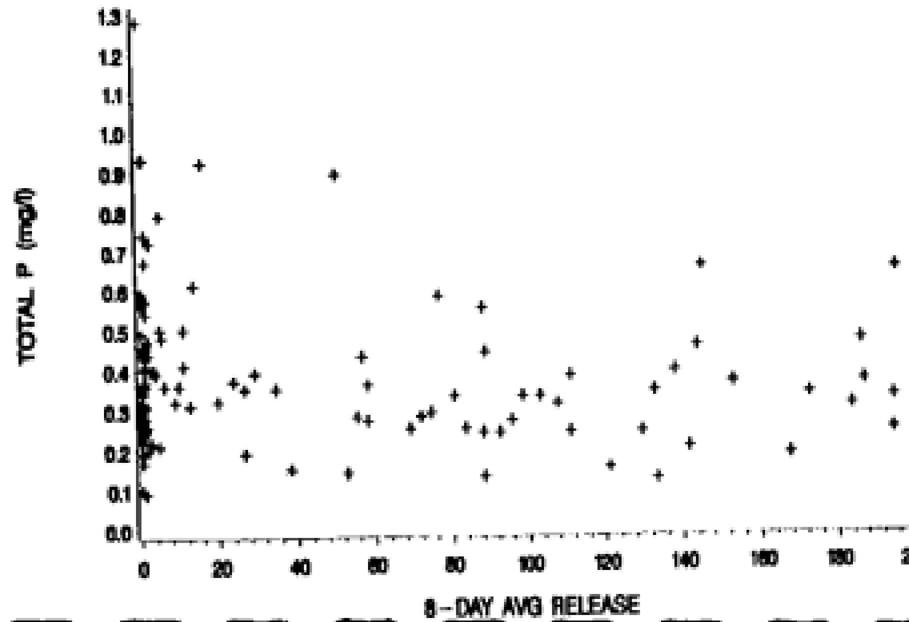
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



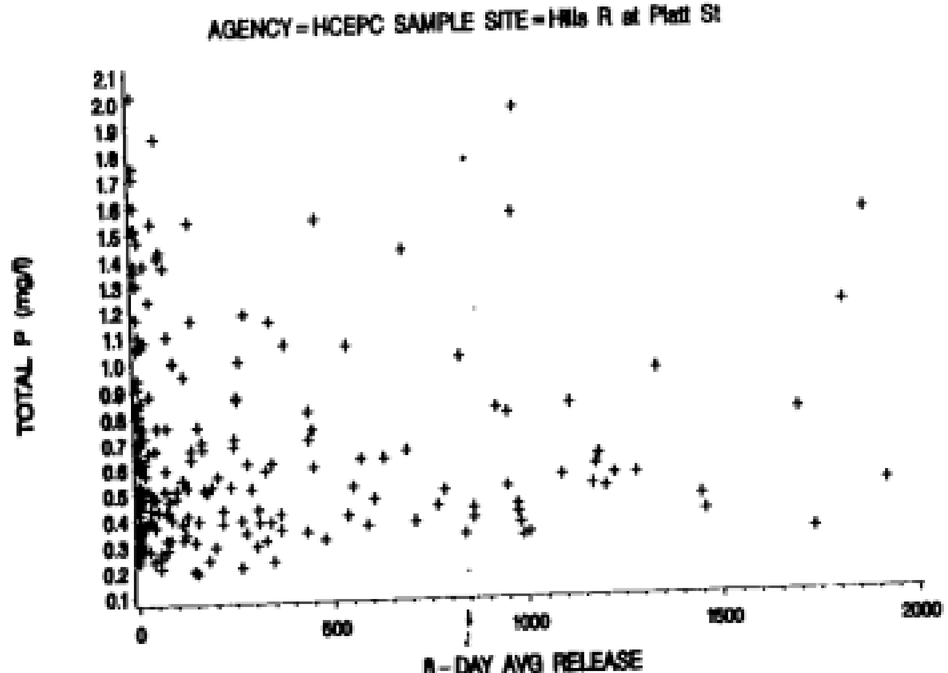
AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave

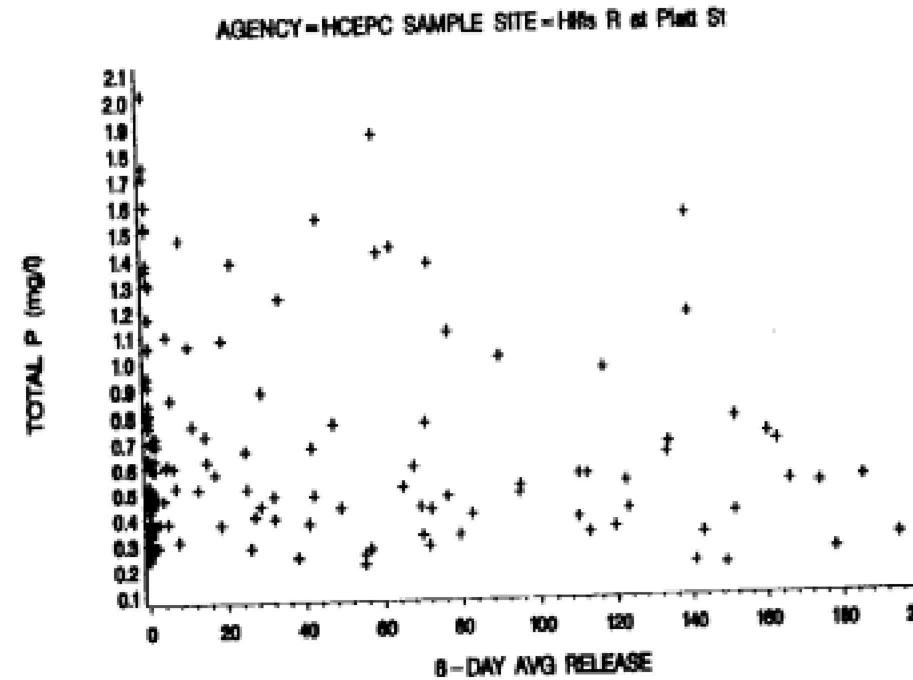


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



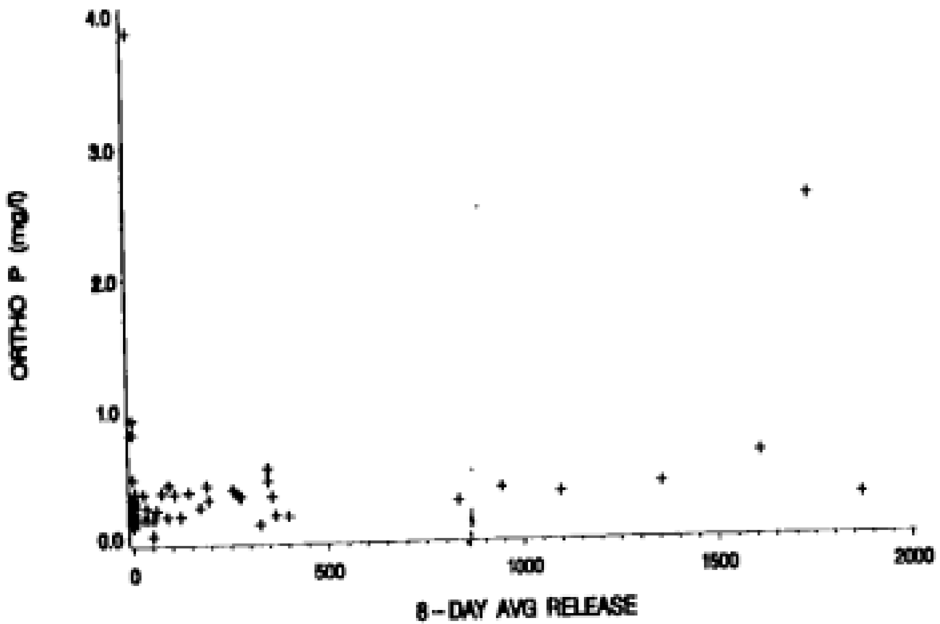
J2-17


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOTAL P (mg/l)
8-DAY AVG RELEASE

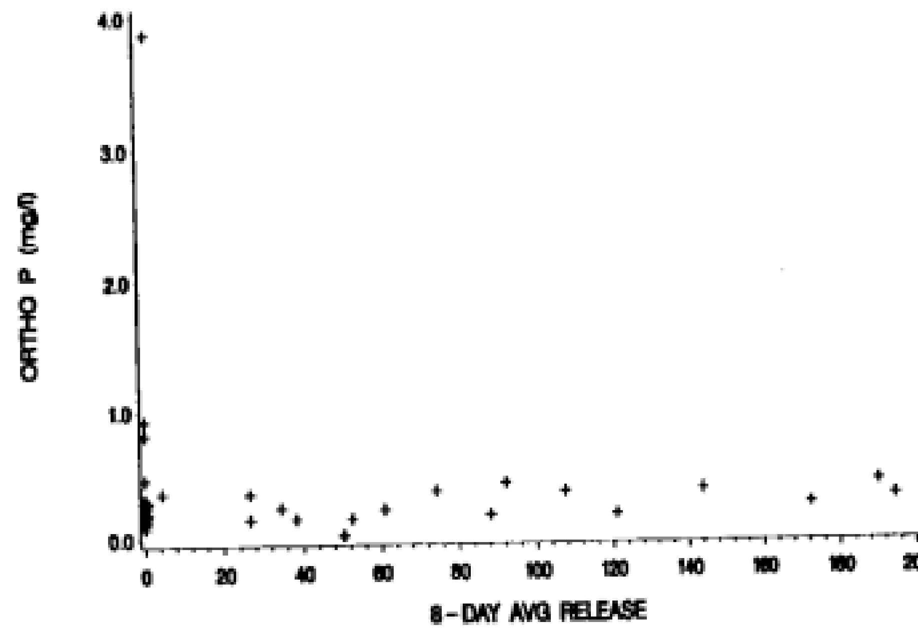

AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOTAL P (mg/l)
8-DAY AVG RELEASE

J2-18

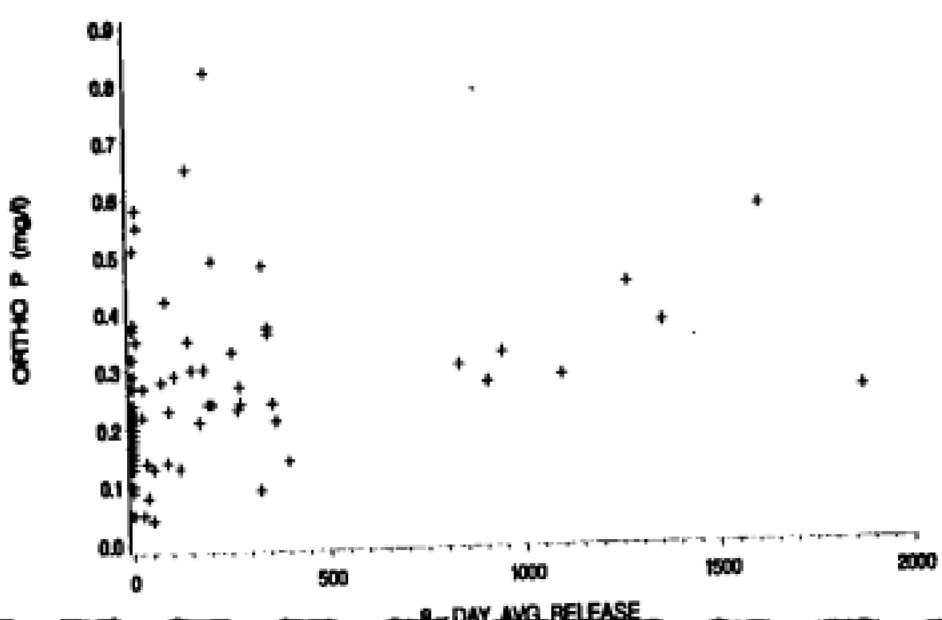
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



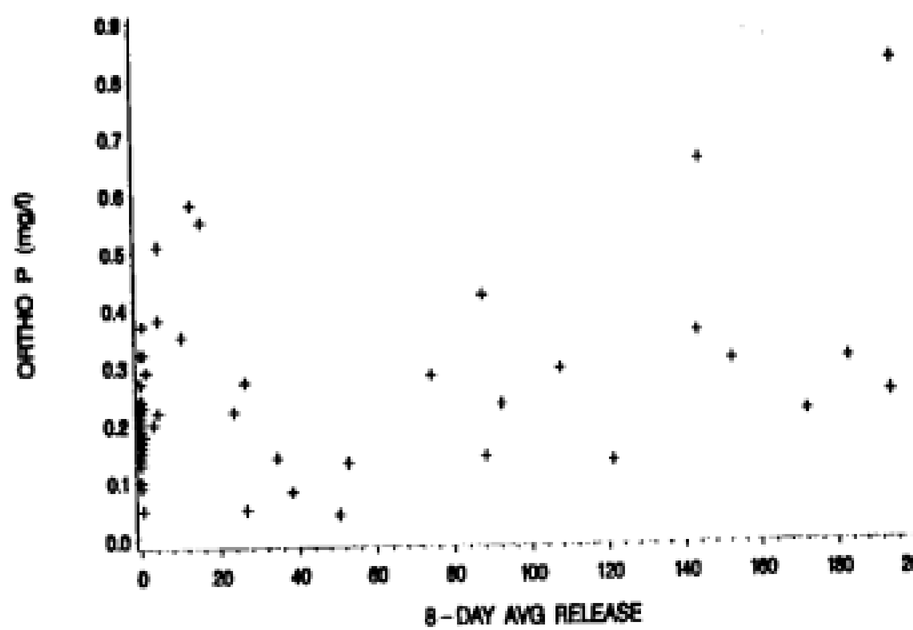
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



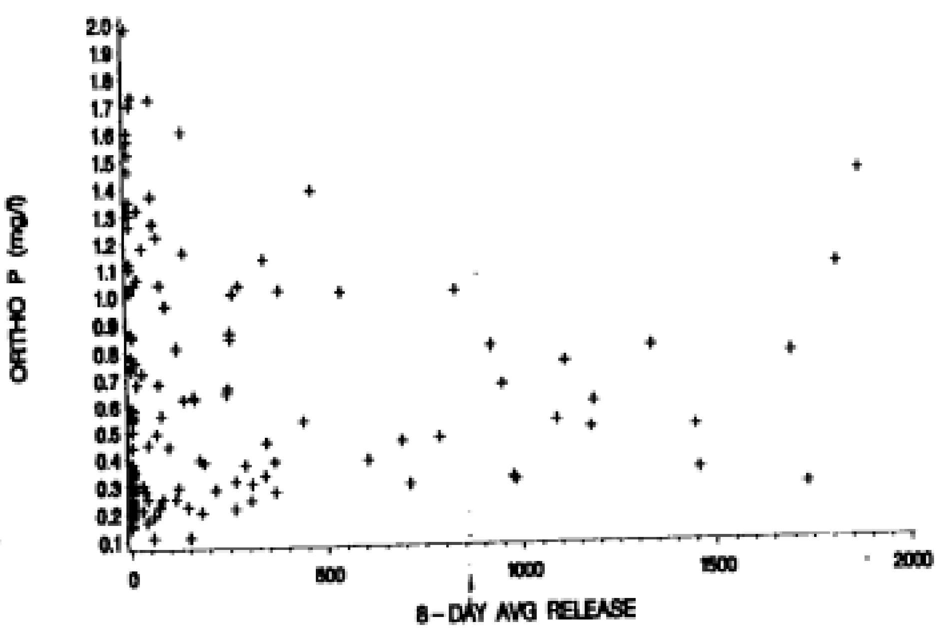
AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



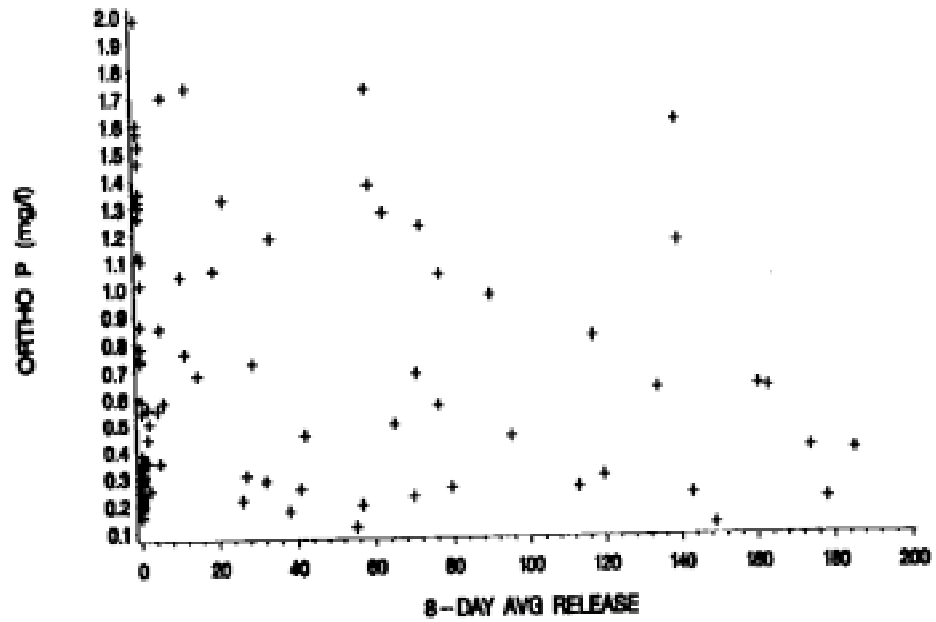
AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



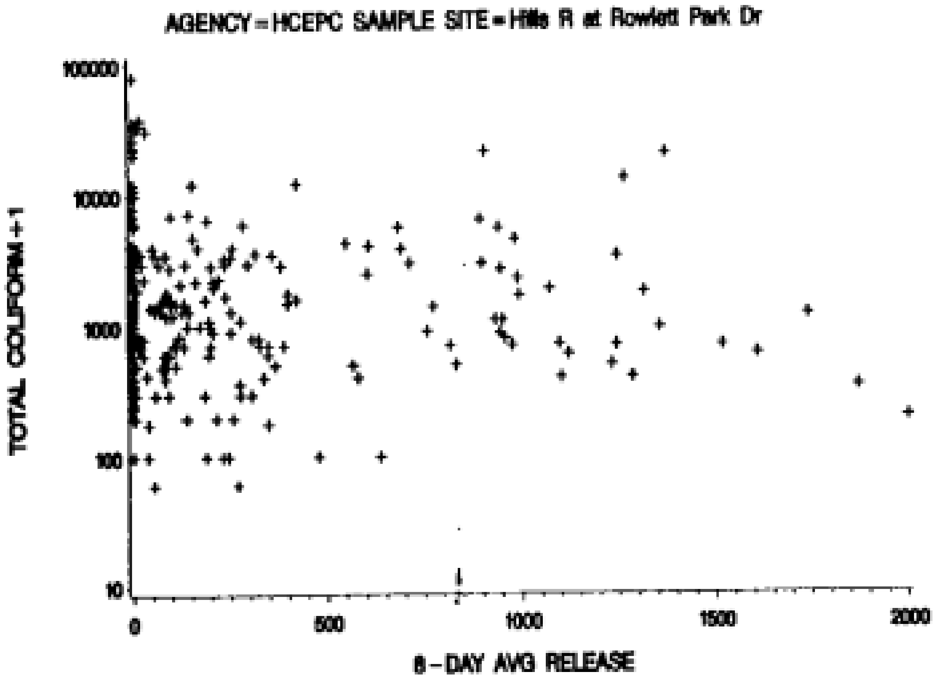
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

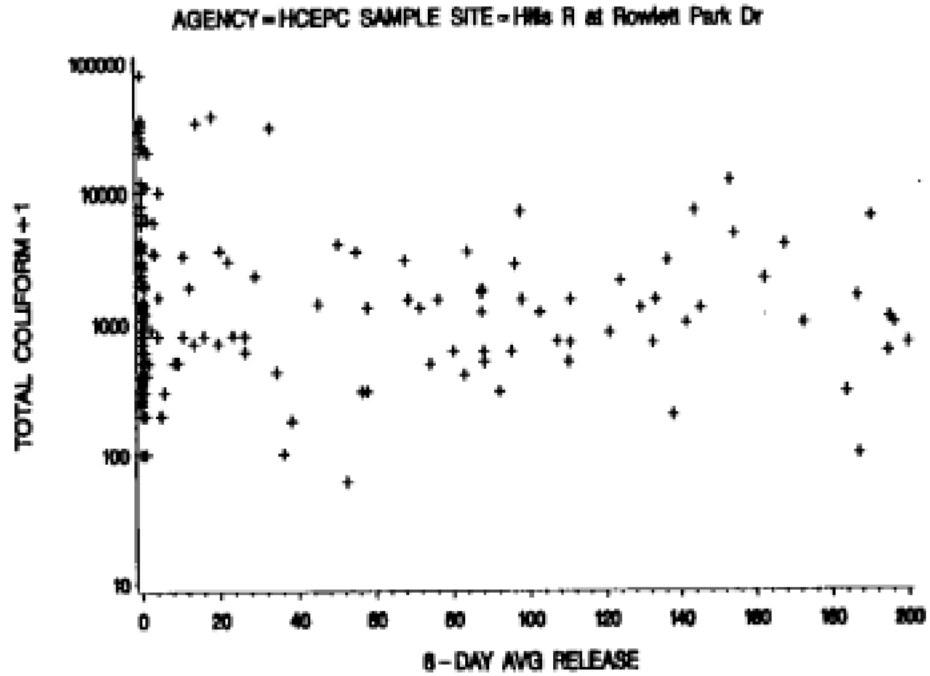


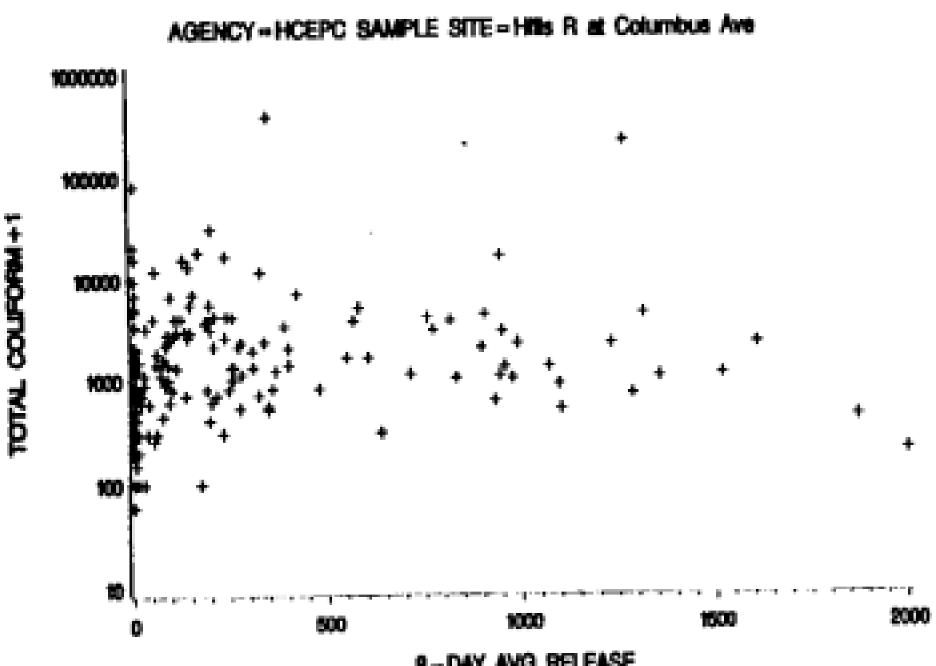
AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St

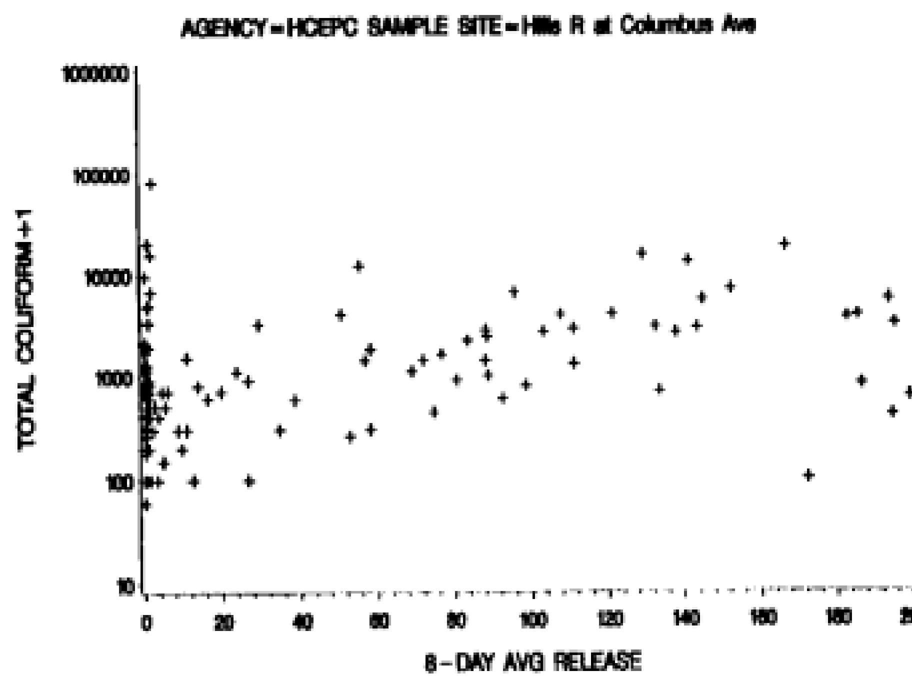


J2-20

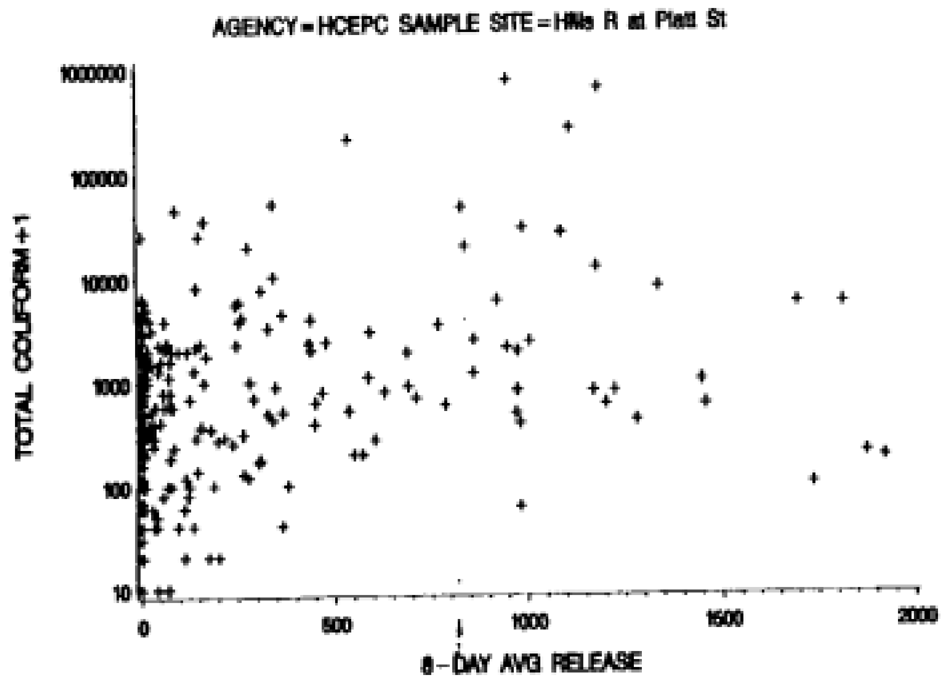

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
TOTAL COLIFORM+1
100000
10000
1000
100
10
0
500
1000
1500
2000
8-DAY AVG RELEASE

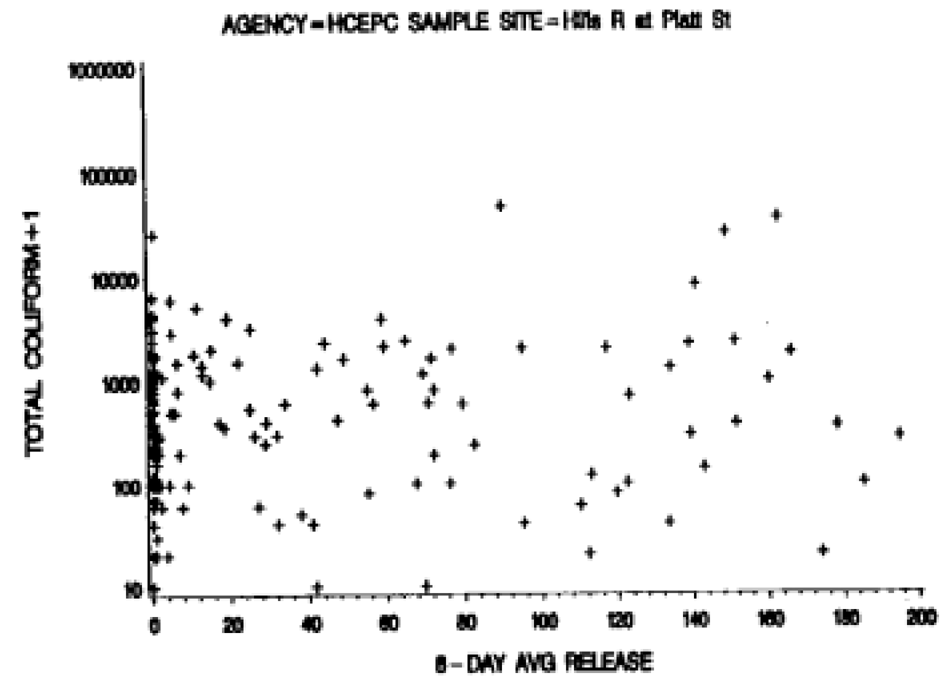

AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr
TOTAL COLIFORM+1
100000
10000
1000
100
10
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
TOTAL COLIFORM+1
1000000
100000
10000
1000
100
10
0
500
1000
1500
2000
8-DAY AVG RELEASE


AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave
TOTAL COLIFORM+1
1000000
100000
10000
1000
100
10
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE

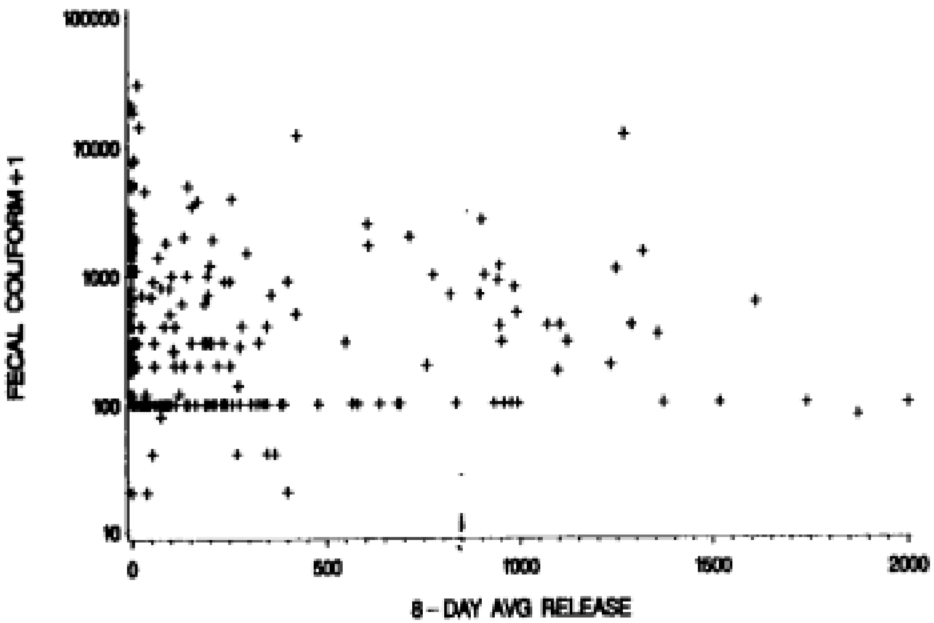
J2-21


AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOTAL COLIFORM+1
10
100
1000
10000
100000
1000000
0
500
1000
1500
2000
8-DAY AVG RELEASE

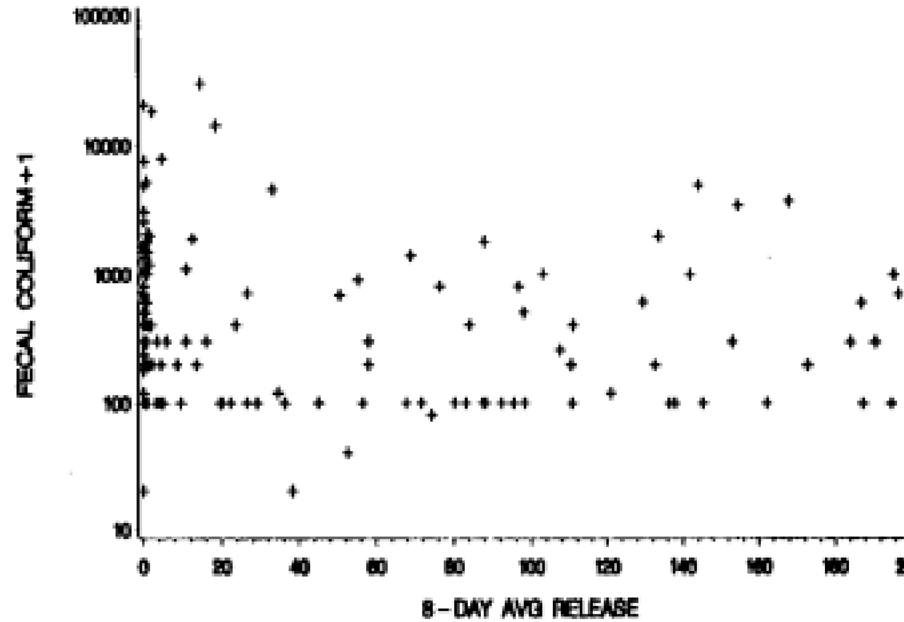

AGENCY=HCEPC SAMPLE SITE=Hills R at Platt St
TOTAL COLIFORM+1
10
100
1000
10000
100000
1000000
0
20
40
60
80
100
120
140
160
180
200
8-DAY AVG RELEASE

J2-22

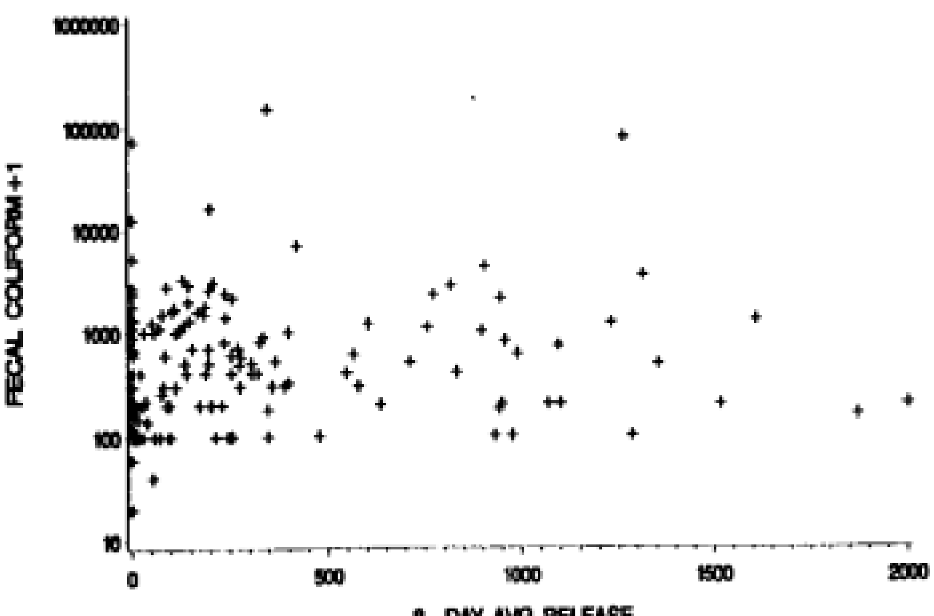
AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



AGENCY=HCEPC SAMPLE SITE=Hills R at Rowlett Park Dr



AGENCY=HCEPC SAMPLE SITE=Hills R at Columbus Ave



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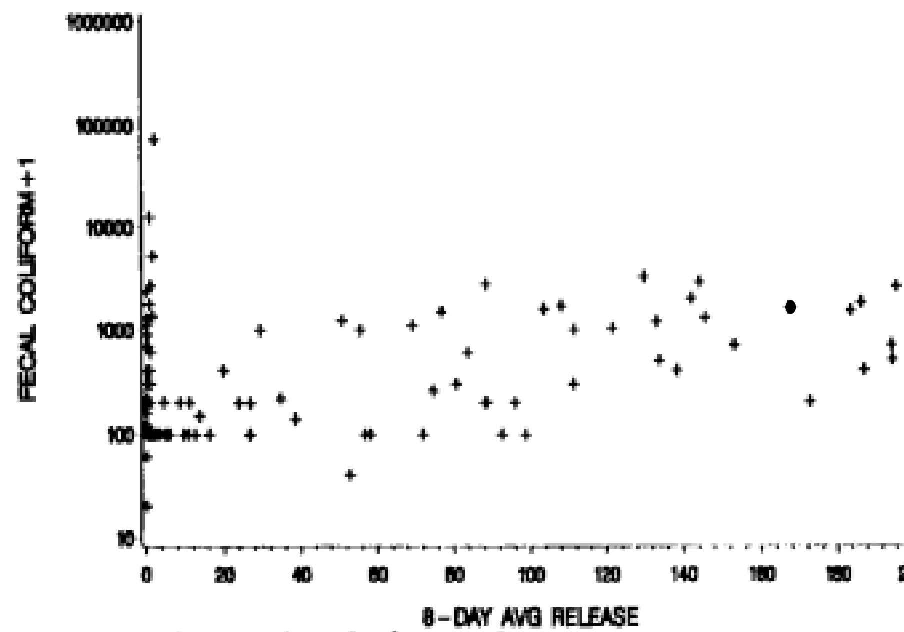

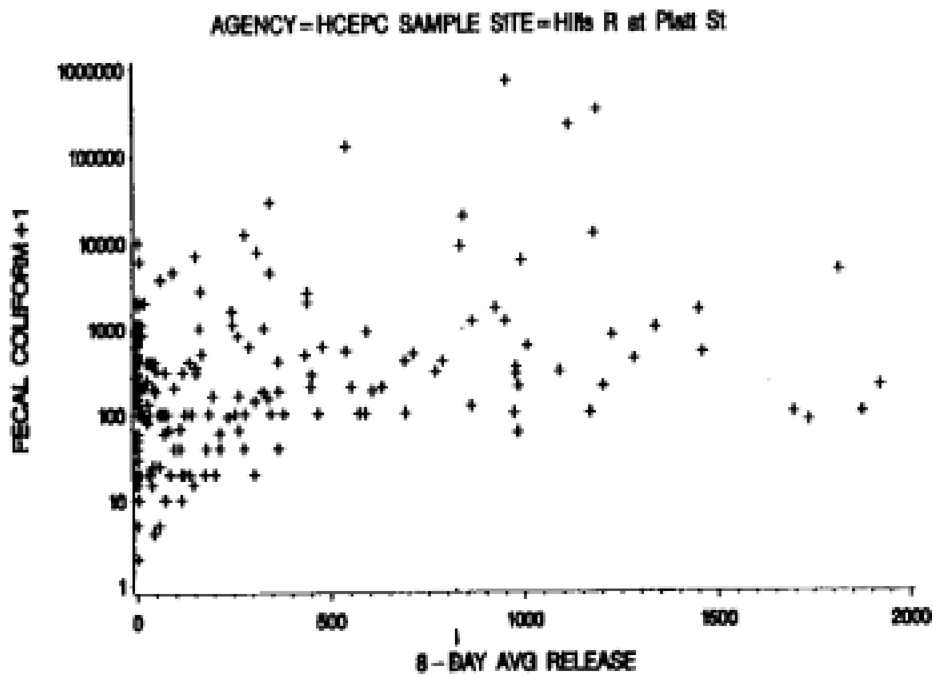
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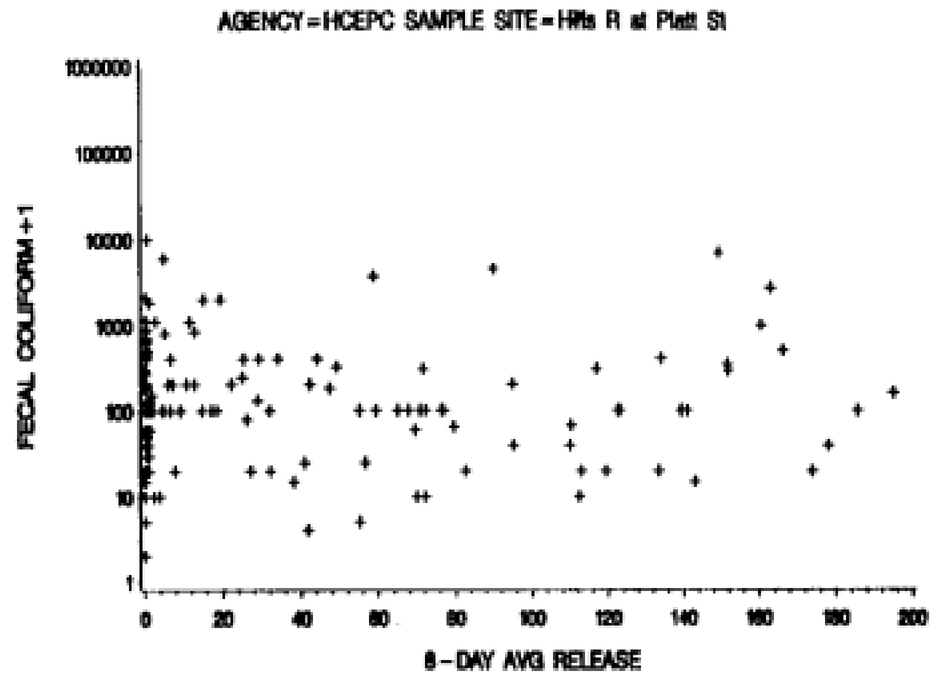
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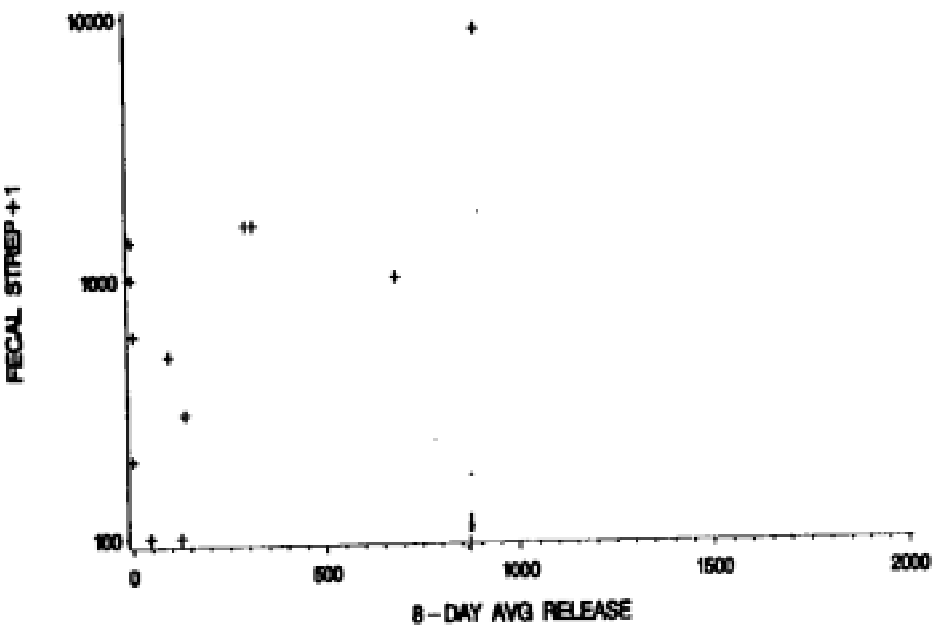

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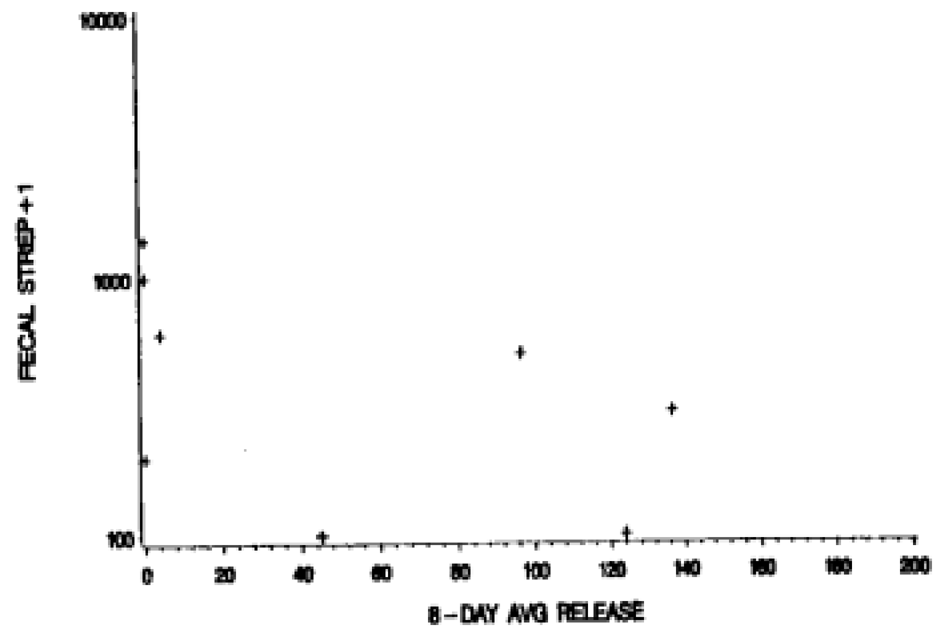

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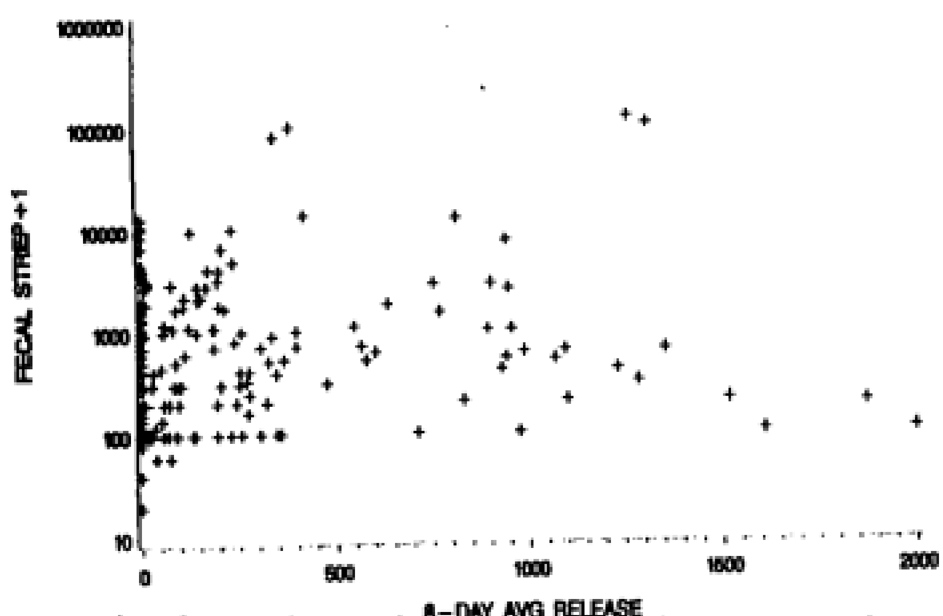

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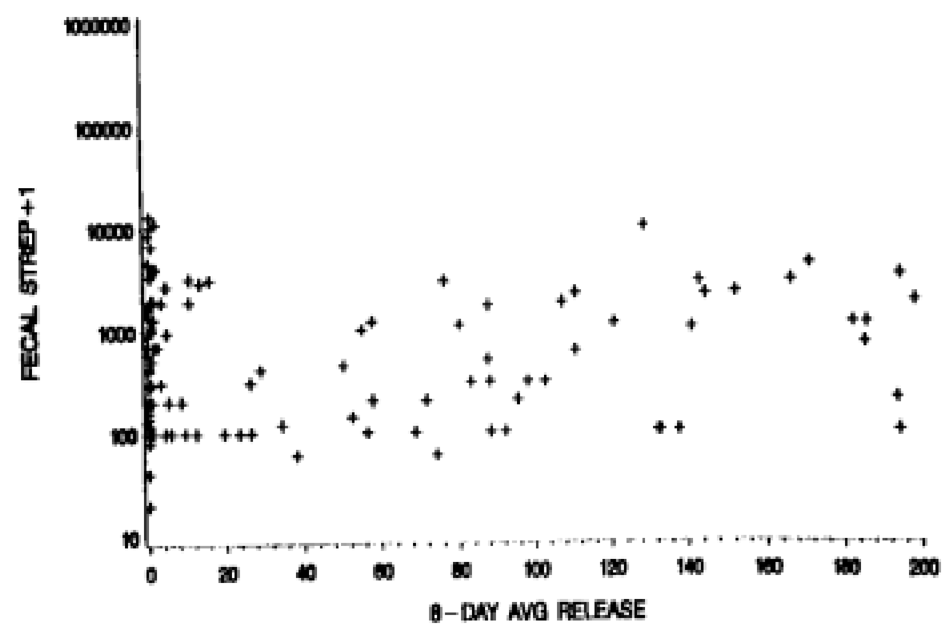

J2-25

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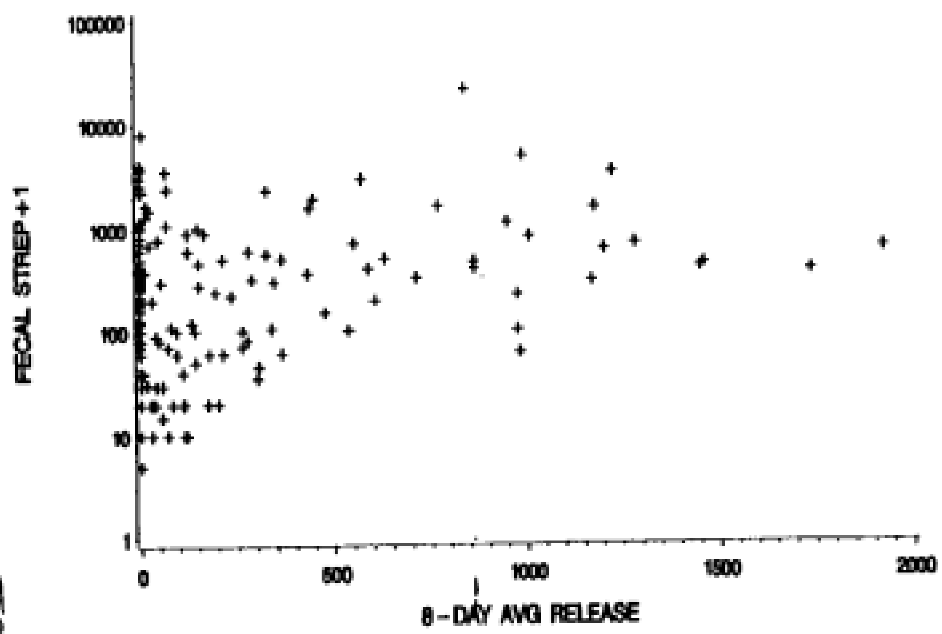

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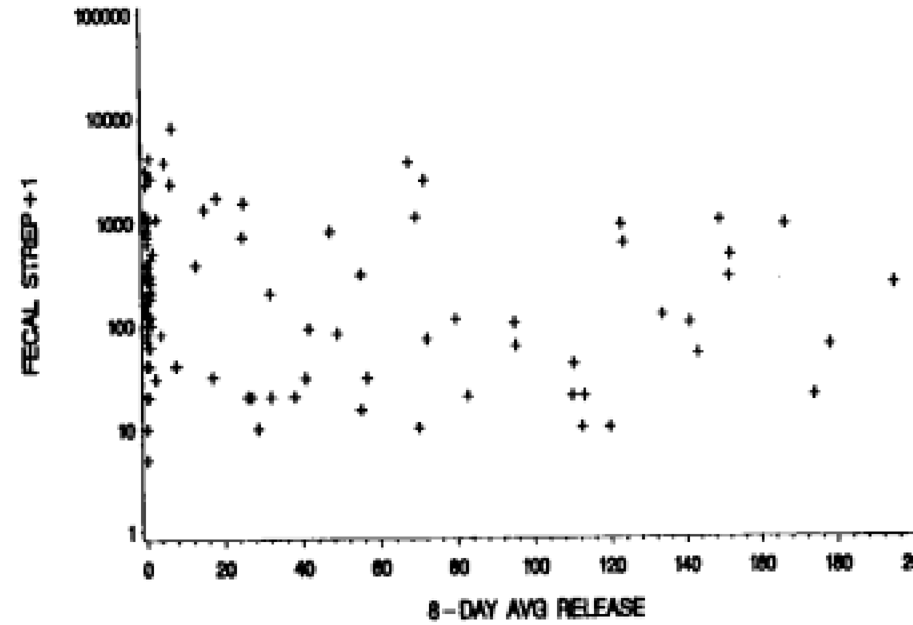

J2-26

APPENDIX J -3

Results of correlation analysis of water quality parameters in the lower Hillsborough River measured by the HCEPC with discharge from the Hillsborough River Reservoir

Hills R at Rowlett Park Dr

	ALL OBSERVATIONS		REL8 < =100 CFS	
	REL8	log10(REL8)	REL8	log10(REL8)
pH	**-0.27**	-0.01	**0.39**	**0.37**
	0.004	0.941	0.001	0.001
	118	118	75	75
Turbidity	-0.05	-0.10	-0.07	-0.08
	0.413	0.079	0.381	0.295
	286	286	168	168
Color	**0.73**	**0.79**	**0.44**	**0.53**
	<0.001	<0.001	<0.001	<0.001
	286	286	169	169
Chlorophyll a	**-0.23**	**-0.39**	**-0.23**	**-0.28**
	<0.001	<0.001	0.004	<0.001
	280	280	162	162
BOD	**-0.25**	**-0.44**	**-0.28**	**-0.31**
	<0.001	<0.001	<0.001	<0.001
	285	285	168	168
TSS	-0.10	-0.20	-0.13	-0.15
	0.370	0.072	0.359	0.314
	81	81	50	50
Nitrate	**-0.12**	**-0.19**	-0.09	-0.05
	0.041	0.001	0.268	0.535
	287	287	169	169
Total N	-0.04	**-0.21**	**-0.21**	**-0.25**
	0.478	<0.001	0.007	0.002
	278	278	163	163
Ortho P	**0.28**	0.14	-0.07	-0.03
	0.020	0.245	0.637	0.839
	71	71	46	46
Total P	0.01	-0.07	-0.07	-0.09
	0.917	0.225	0.366	0.237
	286	286	169	169
log10(total coliform)	0.02	-0.02	-0.06	-0.13
	0.752	0.697	0.476	0.100
	285	285	167	167
log10 (fecal coliform)	-0.02	-0.04	**-0.17**	**-0.16**
	0.786	0.485	0.028	0.037
	280	280	165	165
log10 (fecal strep)	**0.66**	0.26	-0.29	-0.47
	0.020	0.414	0.579	0.349
	12	12	6	6

Hills R at Columbus Ave

	ALL OBSERVATIONS		REL8 <= 100 CFS	
	REL8	log10(REL8)	REL8	log10(REL8)
pH	-0.06	-0.14	-0.08	-0.13
	0.529	0.120	0.468	0.244
	123	123	80	80
Turbidity	-0.05	-0.12	-0.03	0.02
	0.433	0.065	0.747	0.804
	219	219	127	127
Color	**0.81**	**0.77**	**0.33**	**0.40**
	<0.001	**<0.001**	**<0.001**	**<0.001**
	218	**218**	**127**	**127**
Chlorophyll a	**-0.27**	**-0.32**	-0.07	0.05
	<0.001	**<0.001**	0.414	0.585
	213	**213**	121	121
BOD	**-0.30**	**-0.43**	**-0.17**	-0.08
	<0.001	**<0.001**	**0.049**	0.367
	219	**219**	**127**	127
TSS	-0.25	**-0.66**	**-0.51**	**-0.55**
	0.201	**<0.001**	**0.038**	**0.024**
	28	**28**	**17**	**17**
Nitrate	**0.17**	**0.46**	**0.31**	**0.36**
	0.012	**<0.001**	**<0.001**	**<0.001**
	219	**219**	**127**	**127**
Total N	0.02	0.04	0.10	0.11
	0.745	0.579	0.258	0.227
	219	219	127	127
Ortho P	**0.35**	**0.40**	0.01	0.13
	0.001	**<0.001**	0.960	0.334
	87	**87**	54	54
Total P	0.07	-0.05	-0.07	0.04
	0.298	0.431	0.414	0.690
	219	219	127	127
log10(total coliform)	**0.22**	**0.37**	**0.19**	0.15
	0.001	**<0.001**	**0.035**	0.099
	219	**219**	**127**	127
log10 (fecal coliform)	**0.26**	**0.33**	0.00	-0.02
	<0.001	**<0.001**	0.957	0.832
	219	**219**	127	127
log10 (fecal strep)	**0.20**	**0.23**	-0.08	-0.05
	0.003	**0.001**	0.344	0.598
	219	**219**	127	127

Hills R at Platt St

	ALL OBSERVATIONS		REL8 < =100 CFS	
	REL8	log10(REL8)	REL8	log10(REL8)
pH	**-0.55**	**-0.57**	**-0.22**	**-0.29**
	<0.001	<0.001	0.026	0.003
	168	168	105	105
Turbidity	**0.15**	0.08	0.00	-0.01
	0.011	0.179	0.982	0.849
	274	274	170	170
Color	**0.80**	**0.61**	**0.27**	**0.37**
	<0.001	<0.001	0.001	<0.001
	267	267	166	166
Chlorophyll a	**-0.19**	-0.08	0.13	0.05
	0.002	0.197	0.092	0.494
	275	275	170	170
BOD	-0.12	**-0.13**	0.02	-0.05
	0.056	0.030	0.785	0.524
	275	275	170	170
TSS	**-0.33**	**-0.45**	**-0.47**	**-0.52**
	0.006	<0.001	0.002	0.001
	66	66	41	41
Nitrate	**0.33**	**0.36**	**0.21**	**0.17**
	<0.001	<0.001	0.007	0.030
	273	273	169	169
Total N	**0.27**	**0.21**	0.09	0.10
	<0.001	0.001	0.273	0.198
	262	262	162	162
Ortho P	-0.01	-0.01	0.05	0.09
	0.949	0.878	0.620	0.396
	147	147	92	92
Total P	0.04	-0.02	0.01	-0.02
	0.529	0.745	0.887	0.772
	267	267	164	164
log10(total coliform)	**0.31**	**0.35**	**0.18**	**0.22**
	<0.001	<0.001	0.017	0.004
	274	274	169	169
log10 (fecal coliform)	**0.37**	**0.35**	0.03	0.10
	<0.001	<0.001	0.728	0.196
	270	270	166	166
log10 (fecal strep)	**0.27**	**0.21**	-0.00	0.08
	<0.001	0.006	0.997	0.409
	176	176	110	110

TAMPA BAY
National Estuary Program

MEMORANDUM

TO: Dave Moore
Southwest Florida Water Management District

FROM: Richard Eckenrod RE
Director

Holly Greening HSG
Senior Scientist

DATE: July 10, 1997

CC: Minimum Flow Advisory Group

SUBJECT: Final Minimum Flows Advisory Group Recommendations

On behalf of the Advisory Group, attached are final recommendations of the Hillsborough River and Palm River/Tampa Bypass Canal Minimum Flows Advisory Group, for the District's consideration in preparing minimum flow rules for these systems. The final recommendations include revisions to the draft final recommendations suggested by several Group members.

The Tampa Bay National Estuary Program staff is pleased to have assisted with facilitation of this very competent Advisory Group, and believe that the final recommendations reflect the Group's strong technical review and consensus. If you have questions about the recommendations, please contact us at 893-2765.

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TAMPA BAY NATIONAL ESTUARY PROGRAM
111 7th Avenue South • St. Petersburg, FL 33701 • (813) 893-2765 • FAX (813) 893-2767 • SUNCOM 594-2765
POLICY COMMITTEE: US ENVIRONMENTAL PROTECTION AGENCY, FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

HILLSBOROUGH RIVER AND PALM RIVER/TBC MINIMUM FLOW ADVISORY GROUP

July 10, 1997
Summary recommendations to the Southwest Florida Water Management District

Advisory Group Objectives and Issues
The Southwest Florida Water Management District requested the Tampa Bay National Estuary Program (TBNEP) to convene a technical advisory group to provide recommendations for ecological criteria for setting minimum flows of the Hillsborough and Palm/TBC systems. The Advisory Group was initially convened in October 1996 and met approximately monthly through May 1997. The Group's objective as defined at the initial meeting was subsequently clarified as follows:

> Provide technically sound recommendations to SWFWMD staff for identifying and evaluating the water resources and ecological criteria necessary to establish minimum flows on the Hillsborough River downstream of the dam and on the Palm River/Tampa Bypass Canal downstream of Structure 160.

The Advisory Group was not asked by the District to recommend what would constitute "significantly harmful" withdrawals, as that term is used in Sec. 373.042, Florida Statutes.

The primary issues defined at the initial meeting were:

1. Low-salinity habitats in each of the river systems
2. Low levels of dissolved oxygen (hypoxia)
3. "Truncated" salinity regime on the Palm River/TBC

A Habitat Subcommittee and a Dissolved Oxygen Subcommittee were formed to address these issues. The Advisory Group or its Subcommittees met eleven times between October 16, 1996 and May 27, 1997. A summary of findings and recommendations of the Advisory Group follows. Comments by participants and opposing views (where voiced) are also noted.

Advisory Group Participating Entities
The following entities participated on the Advisory Group and subcommittees.

West Coast Regional Water Supply Authority
Southwest Florida Water Management District
USF Marine Science Department
City of Tampa Water Department
City of Tampa Stormwater Department
City of Tampa Sanitary Sewers

Tampa BayWatch
Palm River Management Committee
EPC of Hillsborough County
U.S. Fish and Wildlife Service
FDEP Florida Marine Research Institute
FDEP Water Standards
U.S. Geological Survey
Florida Game and Freshwater Fish Commission
National Audubon Society Florida Coastal Islands Sanctuary
Manatee County Planning Department
Manatee County Water Department
Concerned citizen
Canoe Escape
NOAA National Marine Fisheries Service
The Planning Commission
Hillsborough River Greenways Task Force
FDEP Hillsborough River Ecosystem Management
Mote Marine Laboratory
ASHORE Civic Group
Hillsborough River Interlocal Planning Board
Technical Advisory Committee to Hillsborough River Board

Summary of Findings

1. In order to offer maximum benefit to the most species of fish, the salinity gradient in a river should be complete (i.e., freshwater to greater than 18 parts per thousand (ppt) of salinity). Many estuarine fish species have abundance peaks at salinities less than 18 ppt, often much less.

2. Numbers of fish species and abundances of fishes in the estuarine reaches of the tributaries in this region tend to be reduced at dissolved oxygen levels less than 4.0 milligrams per liter (mg/l).

3. The Hillsborough River below the dam offers limited opportunity for shoreline vegetative habitat restoration. A visual shoreline survey estimated approximately 4,070 linear feet (3.3 acres) of potentially restorable habitat. The majority of the shoreline is hardened or has very steep banks unsuitable for vegetative habitat creation/restoration.

4. The Palm River/TBC below Structure 160 also offers minimum opportunity for vegetative habitat under its present condition. Maintaining a complete salinity gradient and meeting dissolved oxygen criteria/goals may not be feasible using flow management on the Palm River/TBC. However, the potential for considerable habitat creation exists on publicly-owned lands, but would require major physical alterations of the canal and shoreline.

Several options have been suggested, and the Hillsborough River Basin Board has agreed to act as the local sponsor of a study by the Corps of Engineers examining the feasibility of filling the deep area of the river.

5. The Advisory Group utilized several analytical tools and methods for evaluation of potential effects of various flows on salinity and dissolved oxygen in the Hillsborough River. These tools include the regression-based empirical models (developed by Coastal Environmental), the 2-dimensional, deterministic model (developed by SWFWMD staff), and examination and analysis of salinity and dissolved oxygen data.

   However, the Group found that each analytical tool has its limitations that should be recognized when evaluating their results relative to the salinity and dissolved oxygen criteria. Primary limitations of the tools are: 1) very little data on salinity and dissolved oxygen are available for low-flow conditions (between 1 cfs and 30 cfs) at any point along the Hillsborough River downstream of the dam; and 2) although statistically significant regressions were derived for dissolved oxygen and flow at various locations in the river, these regressions generally had low coefficients of determination (r^2 values). The use of these regressions for predictive purposes is not recommended.

   > *Comments from NEP staff and consultant (Coastal Environmental):* Due to the deficiency of low-flow data, the NEP staff finds that the empirical model cannot be used to reliably predict salinity levels in the river nor changes in salinity-based habitat due to dam releases when flows are greater than 0 cfs and less than 30 cfs. Similarly, the empirical models cannot be used to reliably predict dissolved oxygen concentrations at fixed stations within the river or to predict the frequency with which specified dissolved oxygen concentrations will be achieved throughout the river.
   >
   > NEP staff also feels that the advisory group had insufficient opportunity to fully evaluate the reliability of the 2-D model in predicting salinity changes as a function of dam release and Sulfur Spring discharge. NEP staff cautions the District not to rely heavily on the model results until after its performance has been adequately verified, especially for low flow conditions at locations between the dam and Sulfur Spring.
   >
   > NEP staff recommends that the limitations of these tools and methods should be made clear to policy makers when presenting results and making recommendations. Collection of additional salinity and dissolved oxygen data downstream of the dam at low flow conditions could be valuable for improving the predictive capabilities of the models.

Hillsborough River Recommendations

1. Define ecological criteria or goals for dissolved oxygen concentrations in the Hillsborough River as a minimum of 4.0 mg/l and average of 5.0 mg/l for optimizing fish utilization. If these criteria cannot be feasibly met at all times and in all locations, minimize time and areas in the river where dissolved oxygen is less than 4.0 mg/l.

    Comment: Several members of the Advisory Group expressed concern that "optimizing fish utilization" misrepresented the intent of the statement, and that "enhancing" may be a more appropriate term. Others did not share the same concern.

2. Maintain a salinity gradient from the estuary to the dam ranging from polyhaline (>18 ppt) to fresh (<0.5 ppt), to optimize estuarine-dependent fish species utilization.

3. Maintain a freshwater segment below the dam to provide a refuge for freshwater biota.

    Comment: Some members of the Group questioned the ecological value of maintaining freshwater biota below the dam. Although many members agreed that maintaining freshwater biota below the dam could be of value to the ecological integrity of the system, the Group did not reach full consensus on this issue.

4. Evaluate other ecological issues and analytical tools related to freshwater flow management, including impacts on manatees and changes in water quality related to diverting a portion of the Sulfur Springs discharge.

5. Test the reliability of the management tools through a series of controlled releases of freshwater from the reservoir. Commencement of this work should be contingent upon a determination by SWFWMD and the City of Tampa of the need for a controlled release experiment.

    Additional information from the District: The District has initiated new data collection on the river, including three continuous salinity recorders operated by the USGS and periodic boat measurements above Sligh Avenue. These data are being used for additional verification runs of the District's deterministic model.

Palm River/TBC Recommendations

1. Minimum flows on the Palm River/TBC should be set based on existing physical conditions of the water course. However, the minimum flows should be reevaluated once feasibility of filling deep areas of the river downstream of Structure 160, or other habitat creation options, has been established.

APPENDIX N-2

Chronological meeting summary of the Tampa Bay National Estuary Program Minimum Flows Advisory Group for the Lower Hillsborough River and the Tampa Bypass Canal.

Hillsborough River System Minimum Flow Advisory Group
Meeting Summaries
through May, 1997

In October, 1996, The Southwest Florida Water Management District requested that the Tampa :Bay National Estuary Program (TBNEP) convene a technical advisory group to provide recommendations for criteria for setting minimum flows of the Hillsborough and Palm/Tampa Bypass Canal systems. The following is a chronological summary of meetings held by the Advisory Group to develop recommendations to the District.

October 16, 1997
The first meeting was held on October 16, 1996, at which the Advisory Group adopted the following objective:

> Provide technically sound recommendations for determining ecological criteria necessary to set minimum flows to protect and restore riverine/estuarine habitats downstream of the Hillsborough River dam and Structure 160 on the Palm River/Tampa Bypass Canal.

Following a background presentation of ecological information available from recently completed studies on the two systems, the Advisory Group defined the following primary issues:

1. Low salinity habitats in each of the river systems
2. Low levels of dissolved oxygen (hypoxia)
3. "Truncated" salinity regime on the Palm River/TBC

December 13, 1996
The second meeting of the Minimum Flow Advisory Group was held on December 13, 1996. The objective of the second meeting was to define the process to be used for each of the issues defined above. TBNEP staff facilitated discussion and agreement by the Advisory Group of the following steps for defining ecological criteria for low-salinity habitat and for dissolved oxygen as follows.

Low-salinity Habitat

1. Assess opportunities for restoring/creating low-salinity habitat (<20 ppt) in the Hillsborough/Palm systems and throughout Hillsborough Bay. Identify the most feasible opportunities. Compare opportunities in the two river systems with overall TBNEP Hillsborough Bay restoration/creation target (68 acres of low-salinity habitat). Consider linear feet of habitat restored in addition to areal extent. Habitat restoration/creation opportunities may include the following:

Information sources: **WAR data**

4. If existing discharge does not meet criteria, define options for reaching D.O. requirements. Include flow management from existing structures, other potential sources of freshwater inflow, and other management options for increasing D.O. concentrations. Include combinations of options for reaching criteria.

   Responsible parties: NEP and Advisory Group
   When: Initiate in March
   Information sources: existing knowledge and information

A D.O. Subcommittee was formed to assist with the process and review results.

D.O. Subcommittee of the
Minimum Flows Advisory Group

Tom Cardinale	HCEPC
Sid Flannery	SWFWMD
Marjorie Guillory	City of Tampa
Ernst Peebles	USF
Yvonne Stoker	USGS
Mike Coates	WCRWSA
Bob Musser	Tampa Baywatch
Charles Kovach	FDEP
Gerold Morrison	SWFWMD-SWIM

Tom Cardinale of EPCHC presented recommendations of the Palm River Committee for consideration by this Advisory Group. The Palm River Committee, which has been meeting for almost 10 years, recommends that an option for strong consideration is to fill in the deeper dredged areas immediately downstream of Structure 160, for both anticipated water quality and habitat improvements.

February 3, 1997 Subcommittee meeting summary

Both Subcommittees reviewed data and GIS maps compiled and presented by Coastal Environmental for TBNEP, which consisted of the following:

EPC long-term Water Quality Monitoring

- 3 Stations in Hillsborough River
  Monthly 1974- Present
  Physical and chemical parameters

Jim Beever	FGFWFC
Sid Flannery	SWFWMD
Bob Musser	Tampa Baywatch
Dave Bracciano	WCRWSA
Roger Johansson	City of Tampa
Brandt Henningsen	SWFWMD-SWIM
Bob McMichael	FMRI
Tim McDonald	FMRI
Manny Lopez	SWFWMD
Steve Grabe	EPCHC

Dissolved oxygen

TBNEP staff presented a summary of existing data addressing fish species found in low-salinity habitats and dissolved oxygen preferences (see attached sheet). After discussion of fish species and D.O. requirements or preferences with fisheries scientists on the Advisory Group, the Group adopted the following:

> Provisionally define ecological criteria for dissolved oxygen concentrations as a minimum of 4.0 mg/l and average of 5.0 mg/l, for optimizing fish utilization.

The Advisory Group further agreed to the following process for defining minimum flows associated with reaching adopted dissolved oxygen criteria:

1. Review D.O./flow relationships. Consider location in the river systems (horizontal and vertical), other factors contributing to D.O. concentrations and the relative importance of flows to D.O. concentrations. Quantify D.O./flow relationships for various release options.

   Responsible parties: NEP and Advisory Group
   When: Mid-February
   Information sources: WAR data

2. Determine when, where and under what conditions existing patterns and volumes of discharge meet D.O. criteria.

   Responsible parties: NEP and Advisory Group
   When: Mid-February
   Information sources: WAR data

3. Consider adverse effects of increased freshwater release, including water quality impacts.

   Responsible parties: NEP and Advisory Group
   When: Following results from Steps 1 and 2

•   <u>Develop analytical tools to examine relationships between flow, salinity in the rivers, and amount of habitat exposed to specific salinity ranges at various flows.</u>

Specifically:

- Develop an empirical, regression based approach to relate the location of salinity ranges in the rivers to flow, for flows throughout the period of record
- Using existing land use/habitat maps, photos and a shoreline survey, estimate the amount of existing habitat and potentially restorable habitat exposed to specific salinity ranges and locations of those salinities in the rivers under various flows.

These tools will allow managers to estimate the amount of existing and restorable habitat which would be exposed to a specific salinity under various flow conditions.

The Subcommittee recommended that the analytical tools be capable of providing estimates for the following parameters:

surface area
bottom area
a measure of linear habitat
acreage
volume
shoreline type

Several potential confounding factors were identified, including the following:

sediment type
vertical stratification and anoxic conditions
navigation restrictions
stormwater functions
tidal fluctuations

•   <u>Identify resources of concern and salinity preferences for those resources</u>

Several Subcommittee members recommended that the definition of low salinity as 20 ppt be revisited, specifically for fishes. The Subcommittee agreed to examine a set of "representative" species to assist with defining ecologically important salinity ranges in these rivers. FMRI fisheries researchers will be working with TBNEP staff to assist with this element of the process, for review by the Habitat Subcommittee.

After development of the analytical tools in the first step, specific salinities associated with identified resources of concern can be "plugged in" to estimate amount of existing and restorable habitat associated with these salinities under various flow rates.

Dissolved Oxygen Subcommittee

After reviewing existing data, the Subcommittee discussed analytical techniques which the data would support to relate dissolved oxygen to flow, and recommend the following:

- 3 Stations in Palm River/TBC (one of those above Structure 160)
  - Monthly 1974-Present
  - Physical and chemical parameters

Water and Air Research Special Study

- 10 stations in Hillsborough River
  - Monthly October 1992- September 1994
  - Physical and chemical parameters

- 5 stations in Palm River/TBC (one of those above Structure 160)
  - One station sampled October 1992-September 1994
  - Four stations sampled October 1992-September 1993
  - Physical and chemical parameters

EPC Benthic Studies

- 2 Stations in Hillsborough River (Platt Street and Columbus Drive)
  - Diel dissolved oxygen and other Hydrolab parameters
    - September 1995 and October 1996

- 1 Station in Palm River/TBC
  - Diel dissolved oxygen and other Hydrolab parameters
    - September 1995 and October 1996

GIS Map elements

- SWFWMD 1990 land use/land cover maps
- Public lands from Planning Commission

USGS water quality data

USGS is currently compiling existing data for delivery to TBNEP for inclusion in the analyses. These data will include continuous D.O., temperature and conductivity collected at several locations in the Hillsborough River during the early 1980s, and conductivity and temperature collected at two downstream locations for two years in the early 1990s. Additional continuous data (conductivity and temperature) are currently being collected at one site on the Hillsborough River.

Habitat Subcommittee recommendations

Following review of available data, the Habitat Subcommittee discussed potential analytical and technical methods which would assist with assessing opportunities for restoring/creating low salinity habitat in each of the river systems. The Habitat Subcommittee recommends the following specific steps, and agree that available data can support these steps:

have abundance peaks at salinities less than 20 ppt (often much less).

6.) In the case of truncated salinity gradient, some species that generally occupy lower salinity areas during their early life history will follow the gradient until they encounter the obstacle that is truncating the gradient.

7). In order to offer maximum benefit to the most species of fish, the salinity gradient needs to be complete (i.e., freshwater to polyhaline).

A summary of potential habitat restoration or creation areas along the shoreline as estimated by a visual survey from a boat indicated the following:

- Along the Hillsborough River, the shoreline survey estimated approximately 4,070 linear feet (3.3 acres) of potentially restorable vegetation habitat The majority of the shoreline is hardened or has very steep banks unsuitable for vegetative habitat creation/restoration.

- Along the Palm River/TBC, the shoreline survey identified small areas of existing *Juncus* marsh (less than one acre) on the north side of the river behind an existing berm. The potential for considerable habitat creation exists on publicly-owned lands, but will require major physical alternations.

A summary of potential habitat creation sites identified during this shoreline survey is attached.

The Subcommittees also reviewed preliminary analyses from existing salinity and D.O. data sets collected in the Hillsborough River, and received updates of progress on the development of analytical tools to relate salinity, river mile, D.O. and flow from Tony Janicki (Coastal Environmental, Inc.) and Sid Flannery (SWFWMD).

March 4, 1997
The full Advisory Committee met to revise summaries of the Results, Findings and Recommendations for submittal to SWFWMD staff as follows:

WORKING GROUP RESULTS AND FINDINGS
Hillsborough River

- A visual shoreline survey estimated approximately 4,070 linear feet (3.3 acres) of potentially restorable vegetation habitat. The majority of the shoreline is hardened or has very steep banks unsuitable for vegetative habitat creation/restoration.

- In order to offer maximum benefit to the most species of fish, the salinity gradient in a river needs to be complete (i.e., freshwater to polyhaline). Many estuarine species have

- Develop an empirical regression-based approach to relate river flow (as measured at or near the structure) with midday dissolved oxygen measurements within the river.

  Note: much of the available dissolved oxygen data, including the long-term monthly measurements collected by EPC, are collected between mid-morning and mid-afternoon.

- Develop an empirical regression-based approach to relate midday D.O.with minimum D.O. for those data sets which have both measurements. The Subcommittee recognized some risk in applying the regression to time frames outside of the period in which the data were actually collected.

- Using the regression developed in the first step, relate minimum D.O. to flow.

- Determine when, where and under what conditions existing patterns and volumes of discharge meet the minimum target of 4.0 mg/l.

Both Subcommittees recognized that recommendations for the Palm River/TBC regarding both low-salinity habitat and dissolved oxygen may be very different than those for the Hillsborough River.

February 20, 1997

The Habitat and D.O. Subcommittees met jointly to hear and discuss a presentation from FDEP/FMRI concerning available fish habitat and D.O. preference data. Ed Matheson from FMRI presented information collected during extensive fisheries studies on the Little Manatee River (attached table) which indicated salinity preferences for almost 50 species. He summarized his major points as follows:

1). Most of the fish occurring in the estuarine portion of Tampa Bay's tributaries are euryhaline; over their life cycle they may normally travel from full-strength seawater habitats to very low salinity (perhaps even freshwater) habitats.

2) Although the salinity tolerances of these species are broad, they may "prefer" or be attracted to different salinity zones at different times during their life cycle (i.e., peak abundance may occur at different salinities for different life-history stages).

3.) Salinity "preference" is species-specific.

4.) Fish species richness may be highest at salinities greater than 20 ppt, but fish productivity may be highest at much lower salinities (generally lower mesohaline to freshwater).

5). In a Tampa Bay tributary with no water control structures, the Little Manatee River, many estuarine species (including both numerically dominant and economically valuable species)

WORKING GROUP RECOMMENDATIONS
Palm River/TBC

The Palm River/TBC has the potential to provide considerable low-salinity and estuarine habitat to the Hillsborough Bay system. Several options have been suggested, and a process to examine the feasibility of filling deep areas of the river has been initiated.

- Minimum flows on the Palm River/TBC should be set based on existing physical conditions of the water course by October 1, 1997. However, the minimum flows will be reevaluated as part of the feasibility of filling deep areas of the river downwatershed of Structure 160, or other habitat creation options.
- Evaluate optimizing existing conditions to address habitat and D.O. criteria/goals.

Ongoing Activities

1. Complete the characterization of existing salinity and dissolved oxygen conditions in the Hillsborough River and Palm River/TBC.
2. Continue development of an empirically-based management tool to predict salinity and dissolved oxygen distributions in the Hillsborough River and Palm River/TBC as a function of flow using recently observed water quality and flow data.
3. Test the reliability of the management tools through a series of controlled releases of freshwater from the Hillsborough River and Palm River/TBC structures. This work will be contingent upon a determination by SWFWMD and the City of Tampa of the need for the controlled release experiment following analyses of prior tasks.
4. Develop a method to estimate environmental benefits of maintaining/restoring various salinity and dissolved oxygen distributions in the Hillsborough River and Palm River/TBC.
5. If existing discharge does not meet criteria, define options for reaching D.O. and salinity gradient goals. Include flow management from existing structures, other potential sources of freshwater flow, and other management options. Include combinations of options for reaching goals.

abundance peaks at salinities less than 20 ppt, often much less.

- Development of analytical tools and methods to relate flow to dissolved oxygen and salinity in the river is ongoing.

WORKING GROUP RECOMMENDATIONS
Hillsborough River

- Provisionally define ecological criteria for dissolved oxygen concentrations as a minimum of 4.0 mg/l and average of 5.0 mg/l, for optimizing fish utilization. If a minimum D.O. concentration of 4.0 cannot be maintain at all times in all locations, minimize the length of time with D.O. less than 4.0 mg/l.

- Maintain a salinity gradient from river mouth to the dam ranging from polyhaline (>20 ppt) to fresh (0 ppt), to optimize estuarine-dependent fish species utilization. Maintain some portion of the river at salinities less than 10 ppt.

- Maintain a freshwater segment in the upper portion of the river.

Further recommendations:

- Continue development of analytical tools to estimate flow management options to meet dissolved oxygen and salinity criteria as defined for the Hillsborough River.

- Refine DO and salinity gradient criteria (i.e., seasonal or daily fluctuations, depth of measurement, length or volume of optimal salinity ranges, etc.).

- Consider other factors including adequate freshwater flows for manatees.

WORKING GROUP RESULTS AND FINDINGS
Palm River/TBC

- Salinity and DO criteria may not be met using flow management under current conditions.

- A visual shoreline survey identified small areas of existing *Juncus* marsh (less than one acre) on the north side of the river behind an existing berm. The potential for considerable habitat creation exists on publicly-owned lands, but will require major physical alternations.

- Several options for physical alteration, including "shallowing" of the dredged areas of the river and creation of small tributaries along the shoreline, are being considered.

April 24, 1997
April 30, 1997
May 6, 1997

The next three meetings of the Advisory Group were devoted mainly to examining the results of the statistical model for the Hillsborough and Palm River/TBC developed by Coastal Environmental. Fisheries researchers from FMRI also presented more detailed data analyses of salinity range associations with various species of fish found in Tampa Bay tributaries. and results of a deterministic model (with graphics representing salinity in Hillsborough River under various flow release scenarios) developed by the District were shown. The following attachments received from Coastal Environmental and FDEP FMRI are provided as a summary of the presentations received by the Advisory Group (results of the deterministic model presented by the District are not yet available).

Attachment 1. Map of sampling stations (from Water and Air Research, 1995)

Attachment 2: Hillsborough River results (statistical model developed by Coastal Environmental for TBNEP)

2-1 Cumulative frequency (%) of measured Hillsborough River flow (cfs) from the dam recorded during the WAR sampling period (1991-1993) and during 1985-1993, for flows up to 1000 cfs

2-2 Cumulative frequency (%) of Hillsborough River flow (cfs) from the dam recorded during the WAR sampling period and during 1985-1993, for flows up to 200 cfs.

2-3 Percentile breakdown of release from dam (cfs) and inflow to the Hillsborough Reservoir from upstream (cfs). Information provided by SWFWMD (Sid Flannery).

2-4 Summary of r^2 for regressions of salinity and flow, by station and depth. Regressions used recorded data (flow) from Sulfur Springs and the dam.

2-5 Map of Hillsborough River showing river mile and WAR station locations

2-6 Estimated isohaline locations (surface) for 0 cfs flow from the dam. (NOTE: A flow of 31 cfs (the average flow recorded from the Springs for the WAR study period) is assumed from Sulfur Springs for those areas below the Springs discharge. However, flow on this and the following graphics indicates flow from the dam only.)

4-6 Density-weighted mean salinities for species collected in ten or more samples.

4-7 Mean and standard deviation of density-weighted salinities for 13 species of estuarine-dependent fishes collected in this study.

Centropomis undecimalis	snook
Diapterus plumerii	striped mojarra
Pogonias cromis	black drum
Elops saurus	ladyfish
Mugil cephalus	black mullet
Archosargus probatocephalus	sheepshead
Lagodon rhomboides	pinfish
Eucinostomus harengulus	tidewater mojarra
Cynoscion nebulosus	spotted seatrout
Sciaenops ocellatus	red drum
Eucinostomus gula	silver jenny
Cynoscion arenarius	sand seatrout

An overall summary of fisheries information provided by FMRI noted that, at all times of the year, some estuarine species are found in the freshwater and oligohaline sections of these Tampa Bay rivers.

f:\holly\comp\min_flow.sm5

2-21 Mid-day D.O. and flow regression; percent of observations with D.O. less than 5 mg/l. 3-day average flow from the dam. Combined observations from 0m, 1m, 2m, 3m, and bottom depths.

Attachment 3 Palm River/Tampa Bypass Canal (statistical model developed by Coastal Environmental for TBNEP)

3-1 Cumulative frequency (%) of measured Palm River/Tampa Bypass Canal flow (cfs) from Structure 160 recorded during the WAR sampling period (1991-1993) and during 1985-1993, for flows up to 1000 cfs

3-2 Cumulative frequency (%) of measured Palm River/Tampa Bypass Canal flow (cfs) from Structure 160 recorded during the WAR sampling period and during 1985-1993, for flows up to 200 cfs.

3-3 Summary of r^2 for regressions of salinity and flow, by station and depth. All regressions used recorded data (flow) from Structure 160.

3-4 Cumulative shoreline (miles) by river mile (0 miles is at Structure 160).

3-5 Cumulative surface area (acres) by river mile.

3-6 Table: Changes in habitat (shoreline length and surface area) associated with increased flow from Structure 160.

Attachment 4. Summary of fisheries data provided by FDEP Marine Research Institute (Tim McDonald).

4-1 Map of sampling site locations on the Alafia, Little Manatee and Manatee Rivers, 1994-1996, including boat seine samples and otter trawl samples.

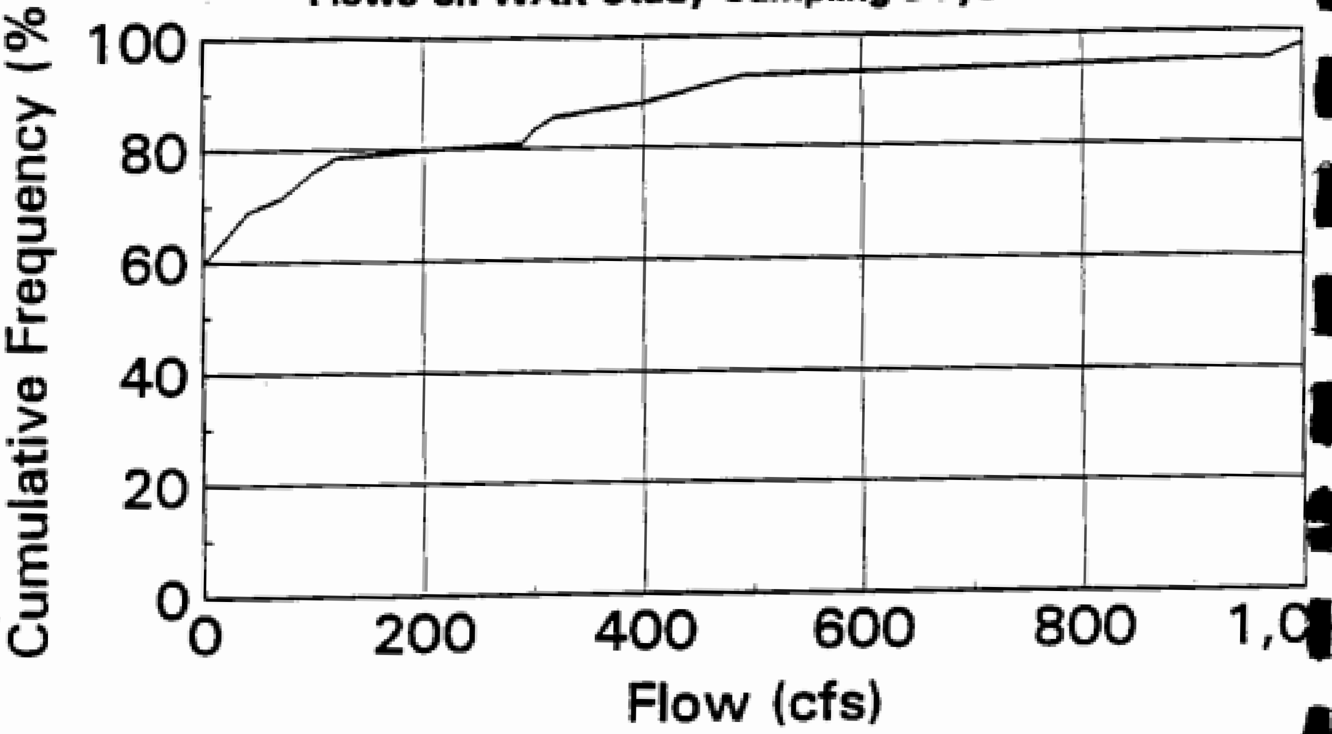
4-2 Distribution of surface and bottom salinities on the Alafia, Little Manatee and Manatee Rivers during sample collections.

4-3 Distribution of surface and bottom dissolved oxygen measurements on the Alafia, Little Manatee and Manatee Rivers during sample collections.

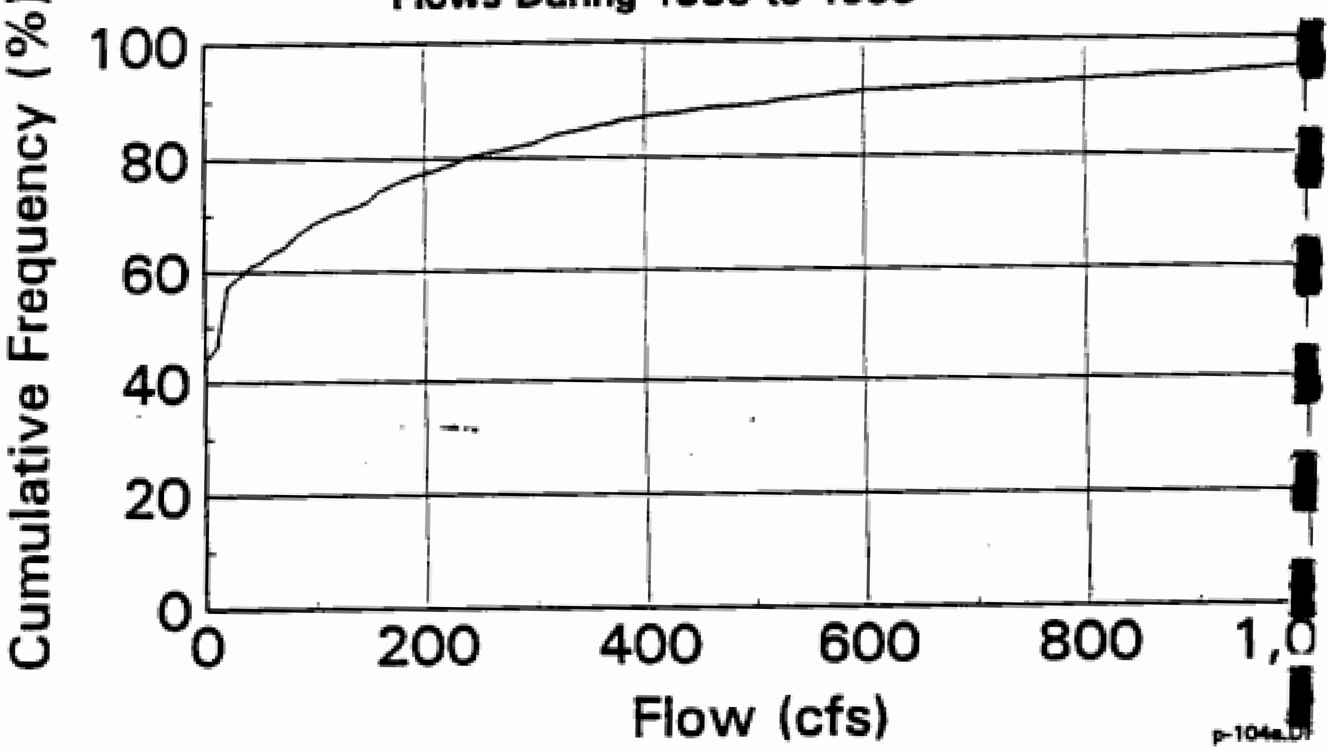
4-4 Salinity classification system used for the FDEP FMRI study.

4-5 Number of samples collected by salinity classification and gear for each river system.

Hillsborough River
Flows on WAR Study Sampling Days



Hillsborough River
Flows During 1985 to 1993



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(1)

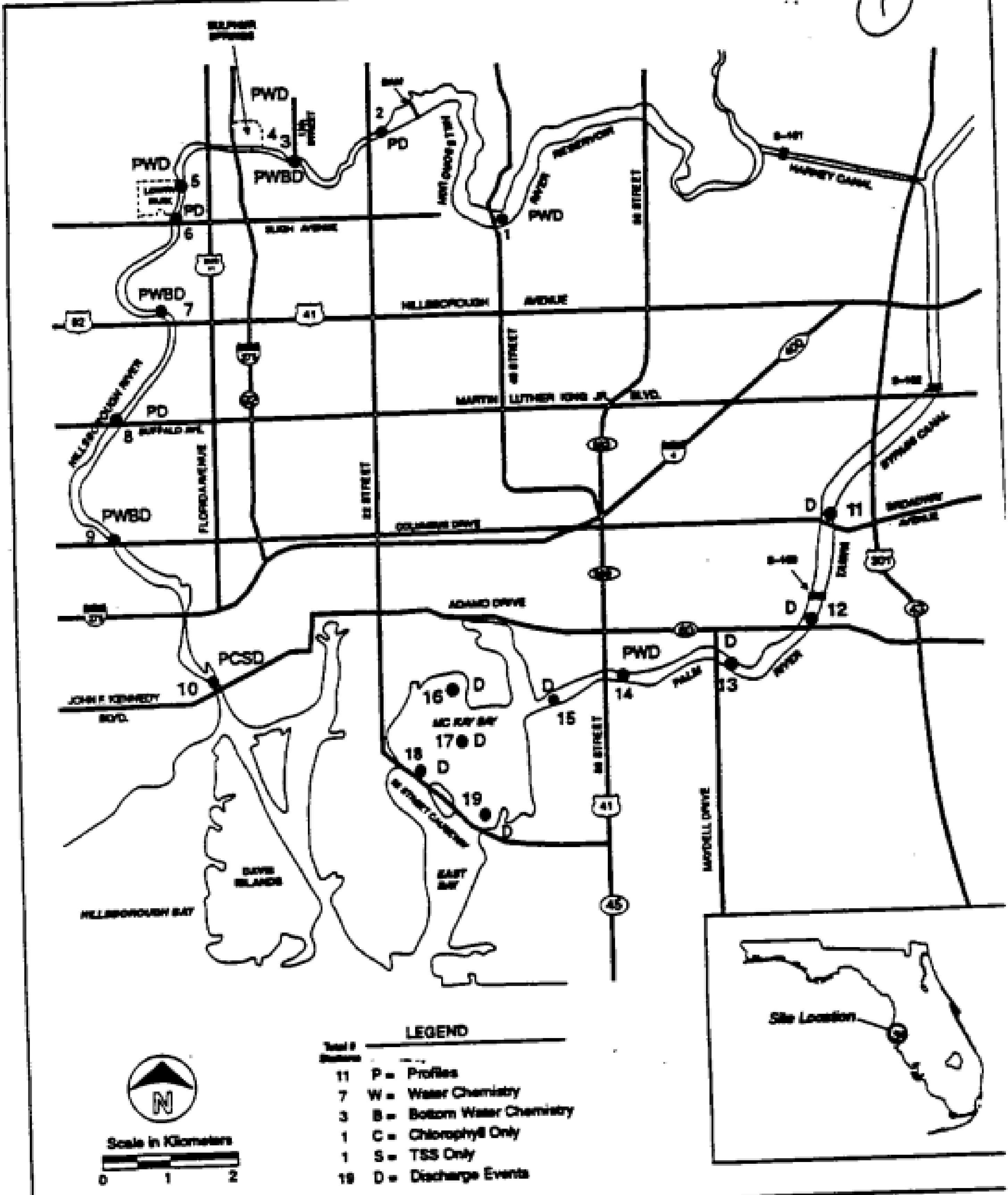
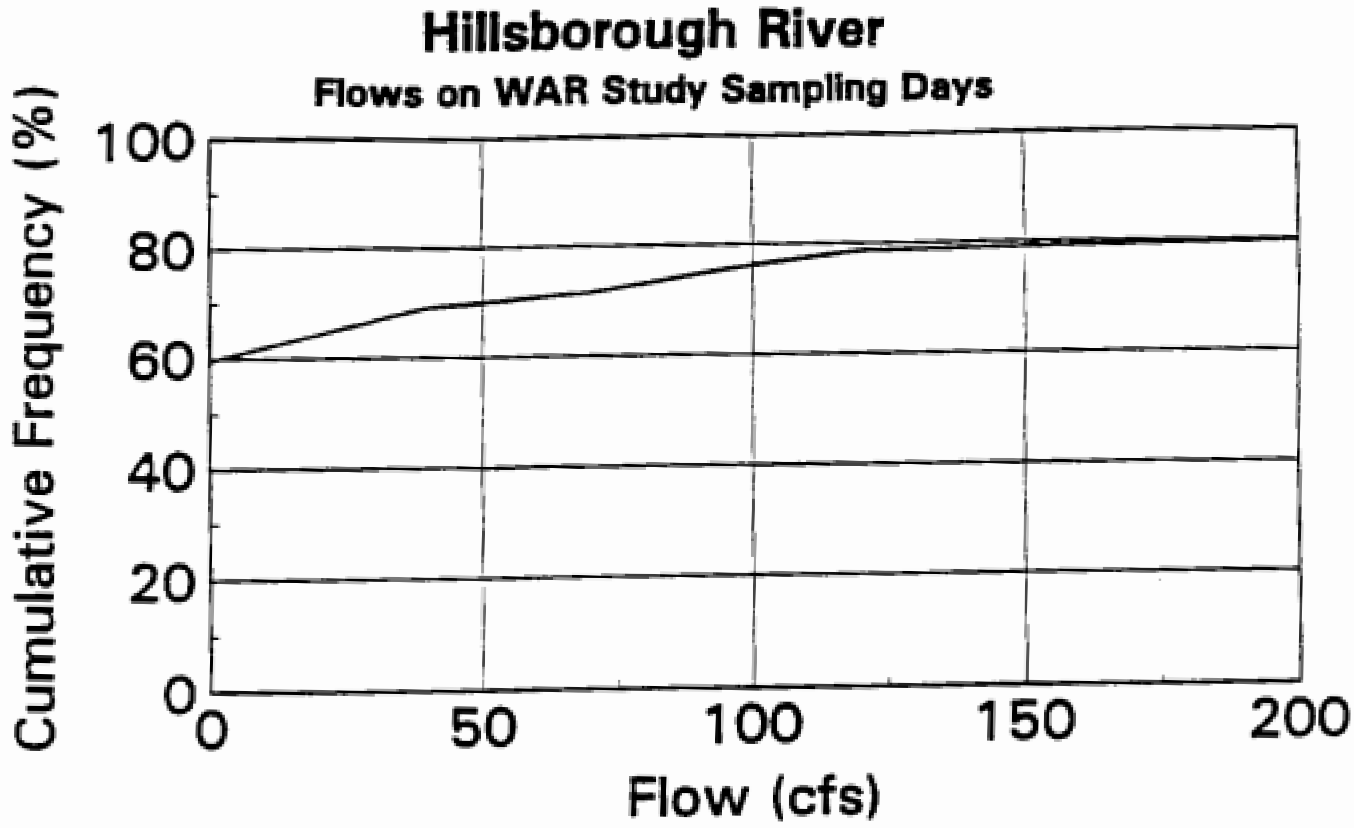


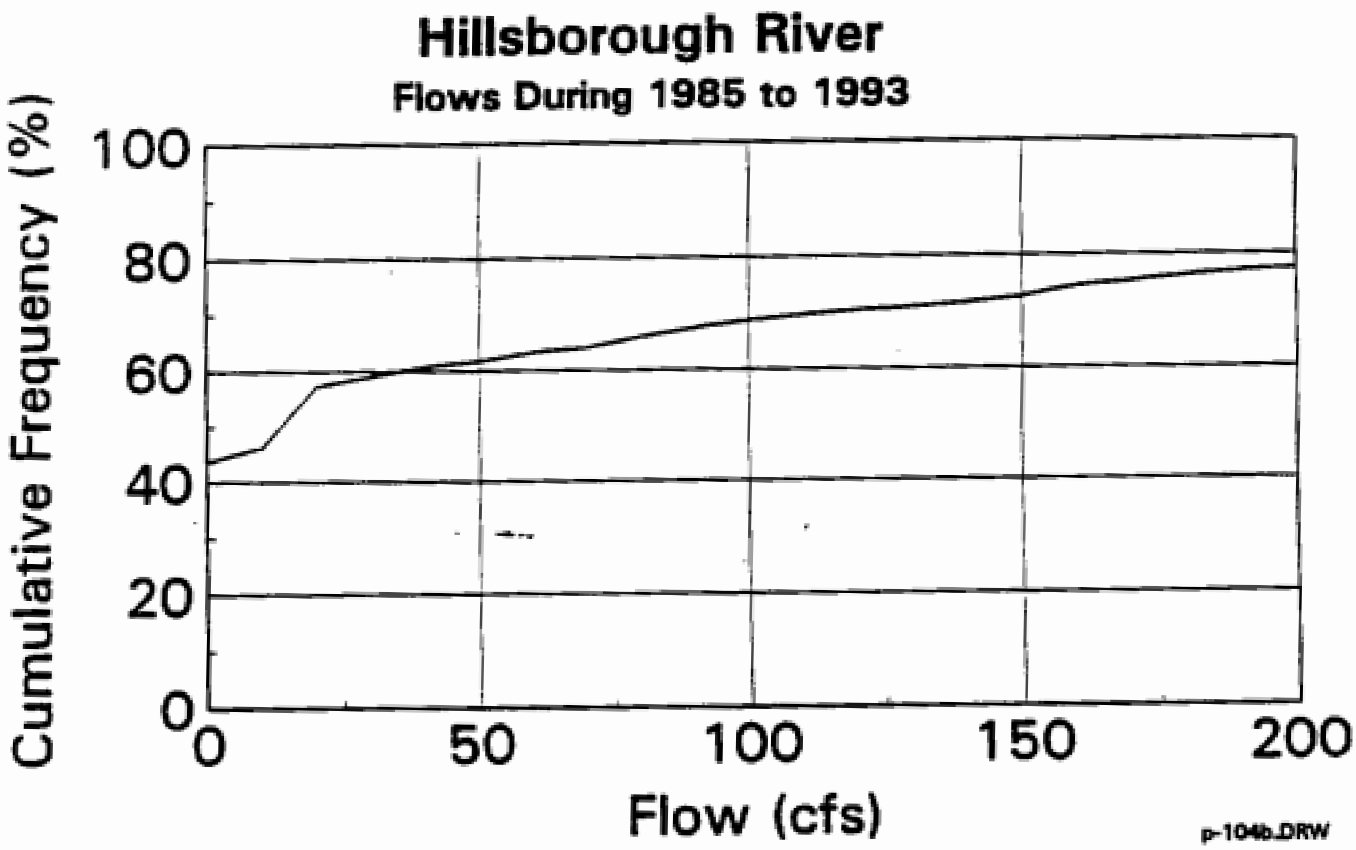
FIGURE 2-3.
Year 3 Sampling Locations

LOWER HILSBOROUGH RIVER FLOW FREQUENCIES
SIX YEARS (1988 - 1994)

percentile	release	inflow
min	0.1	35
10	0.1	58
20	0.1	69
30	0.2	81
40	0.6	98
50	1	116
60	22	145
70	32	191
80	151	291
90	359	515
100	3830	3119

May 21, 1997





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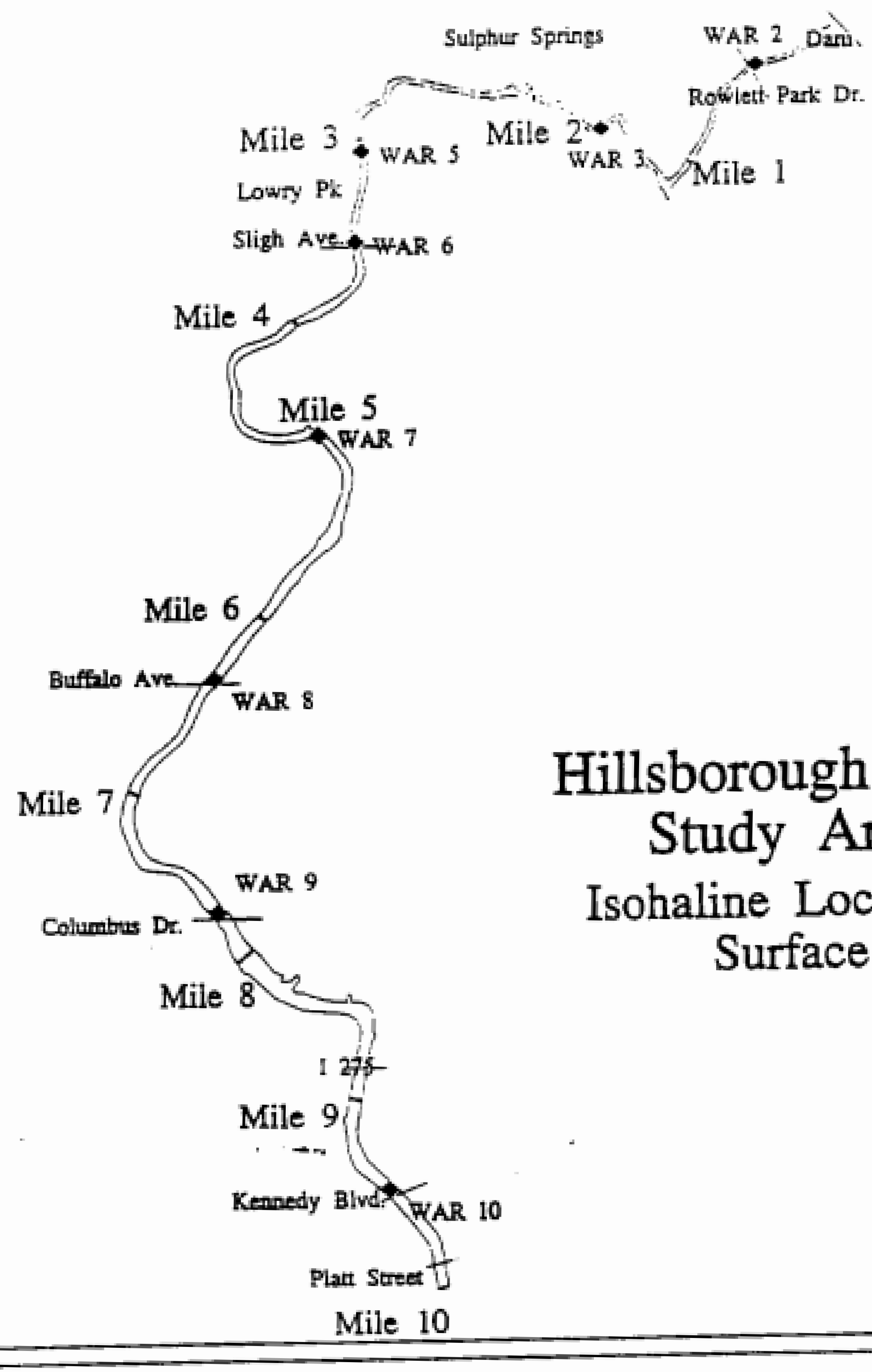


Hillsborough River Study Area

Isohaline Locations Surface

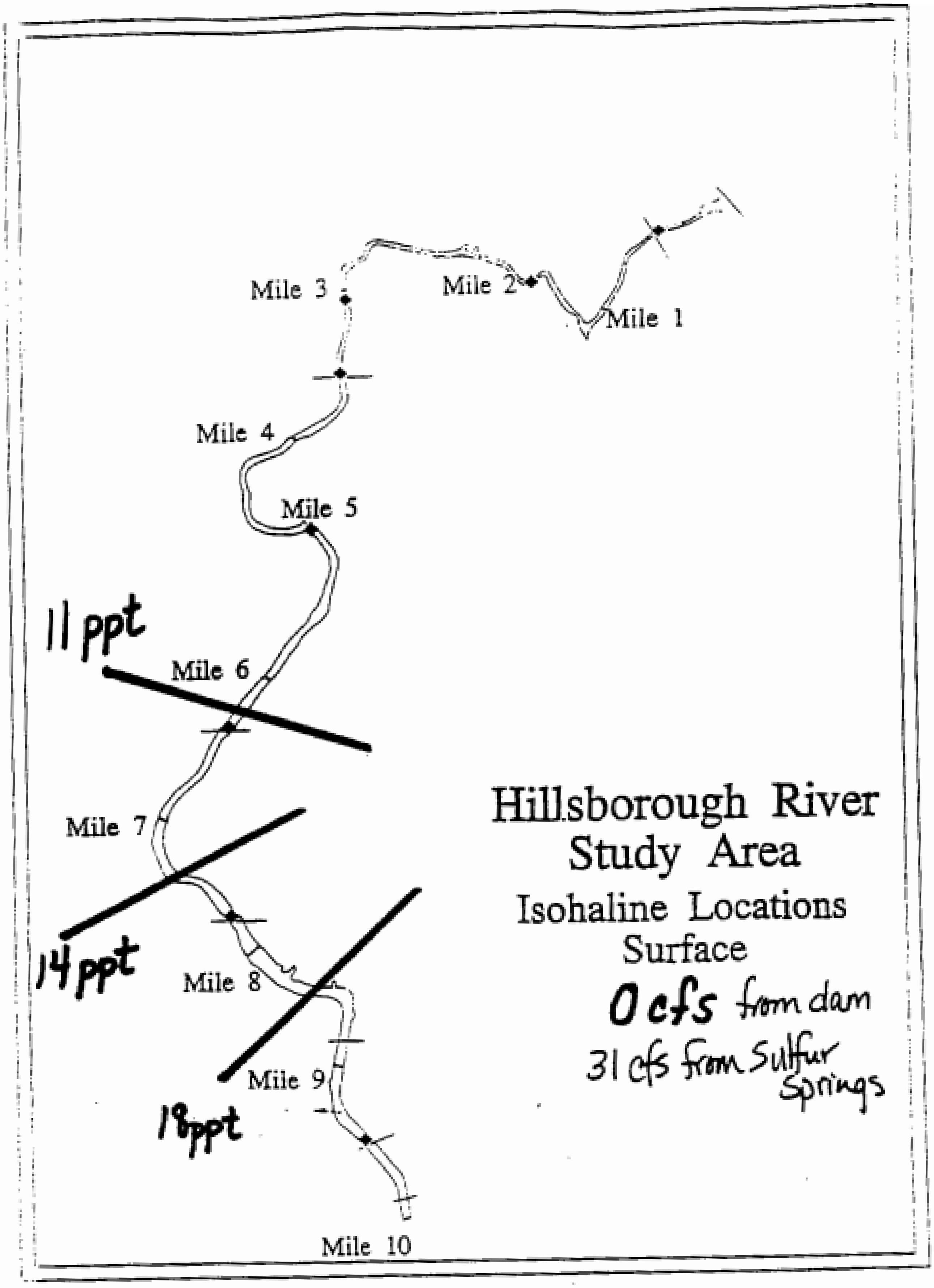
May 21, 1997

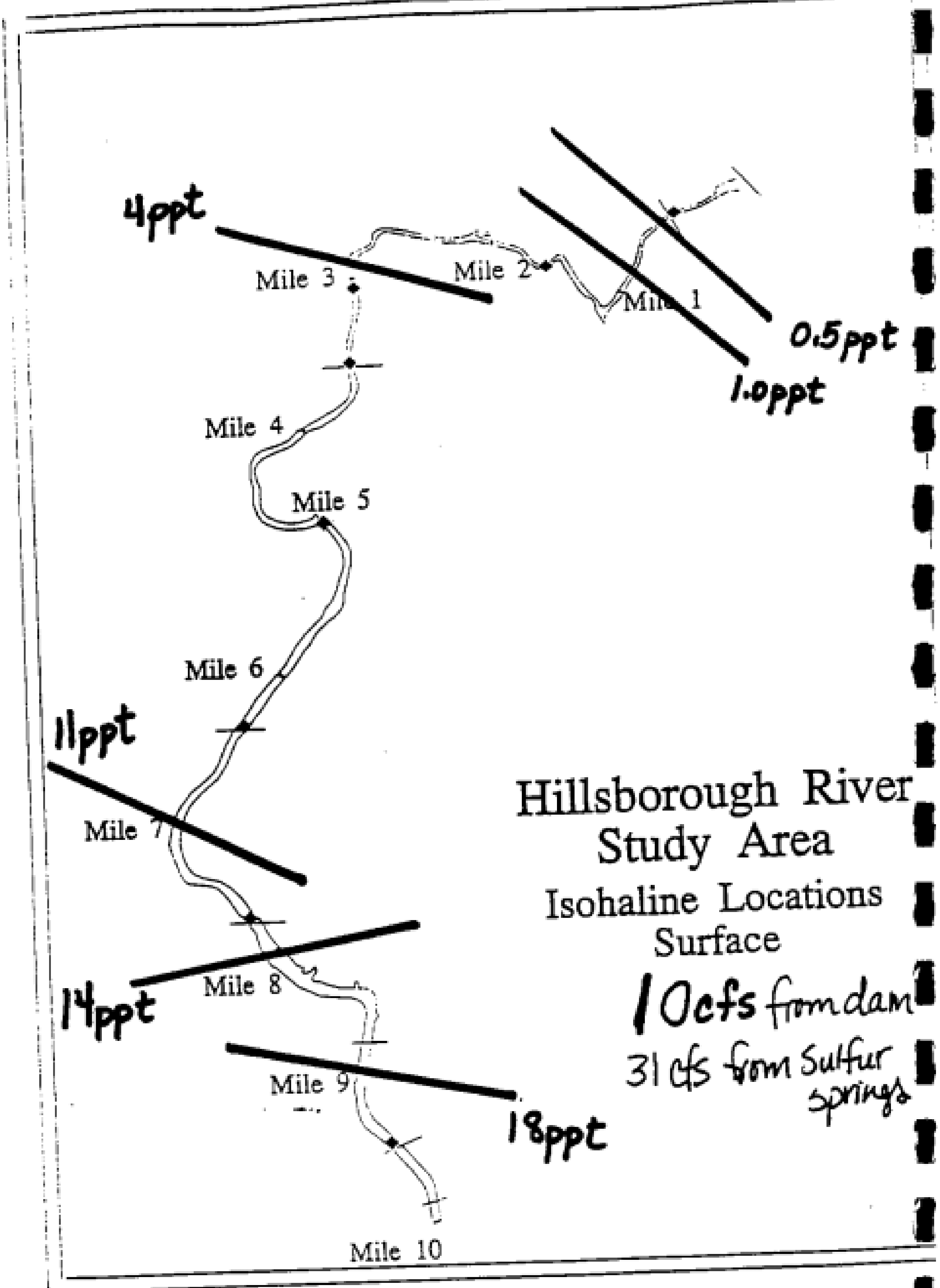
r^2 by Station and Depth

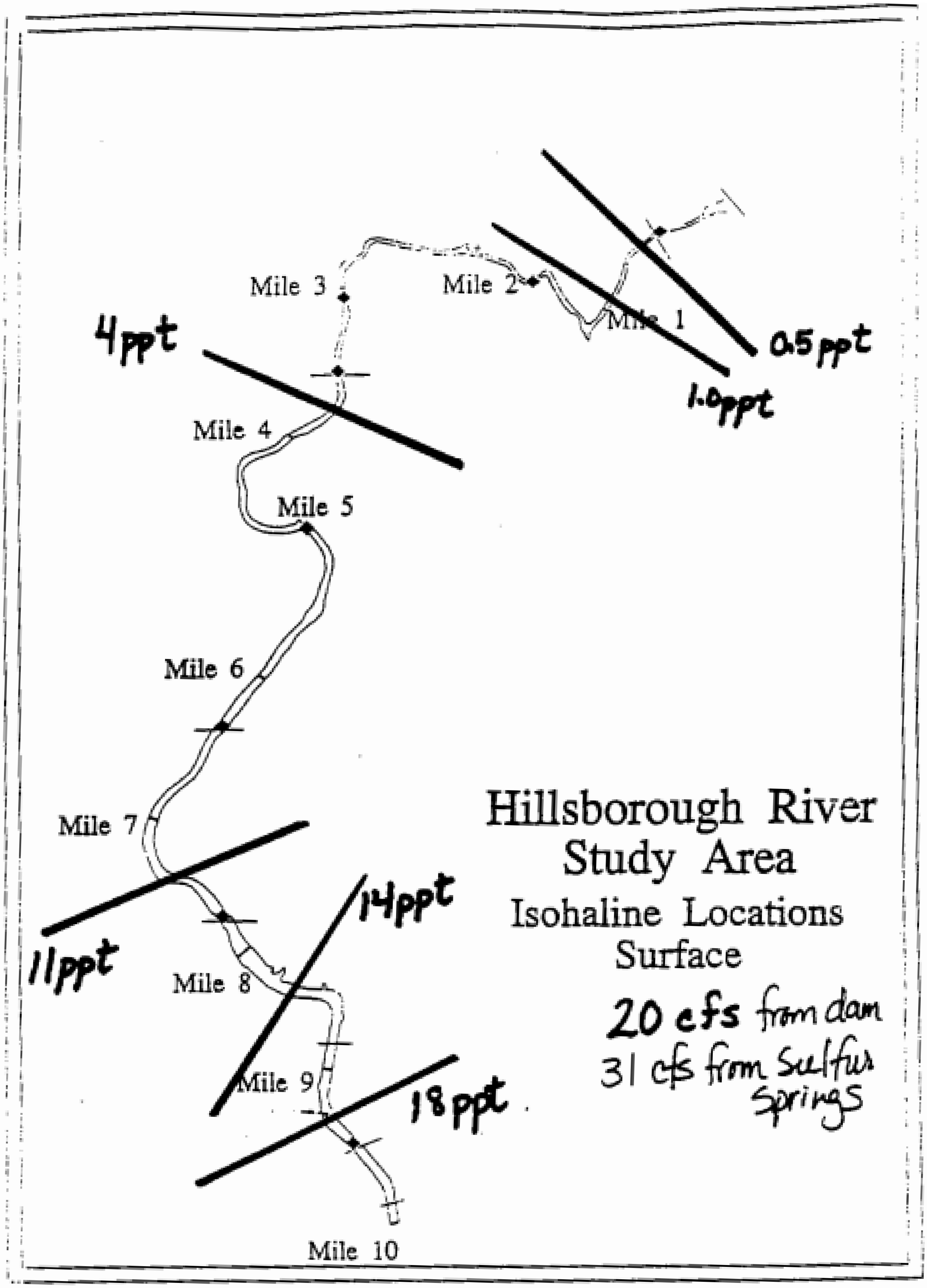
Hillsborough River
Salinity vs. Flow

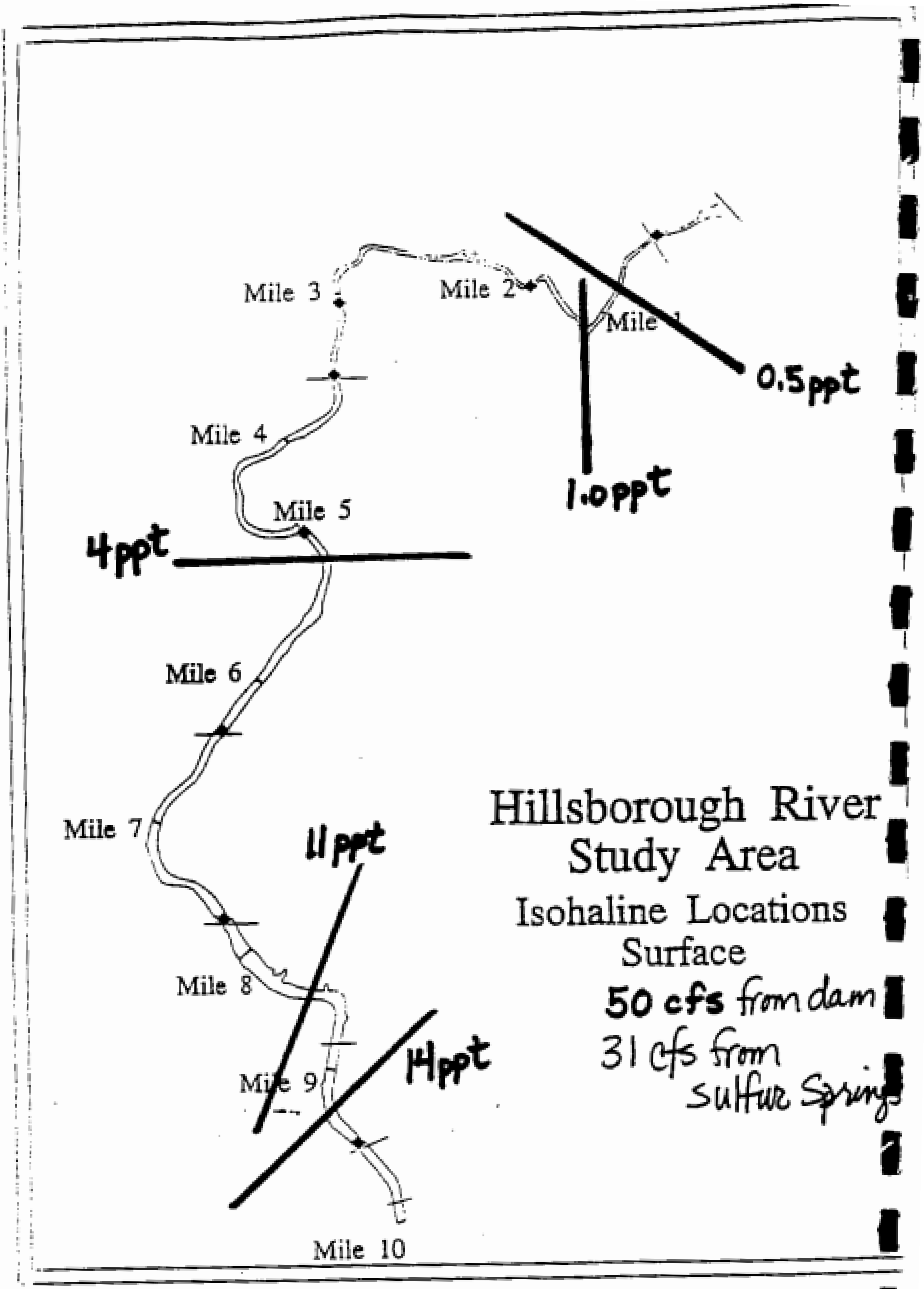
Station	Depth (m)				
	0	**1**	**2**	**3**	**Bottom**
2	-	-	-	-	-
3	**0.72**	**0.68**	**0.60**	**0.57**	**0.63**
5-10	**0.87**	**0.78**	**0.73**	**0.83**	**0.76**
	Overall r^2 = 0.82				

hb_r2.wpd

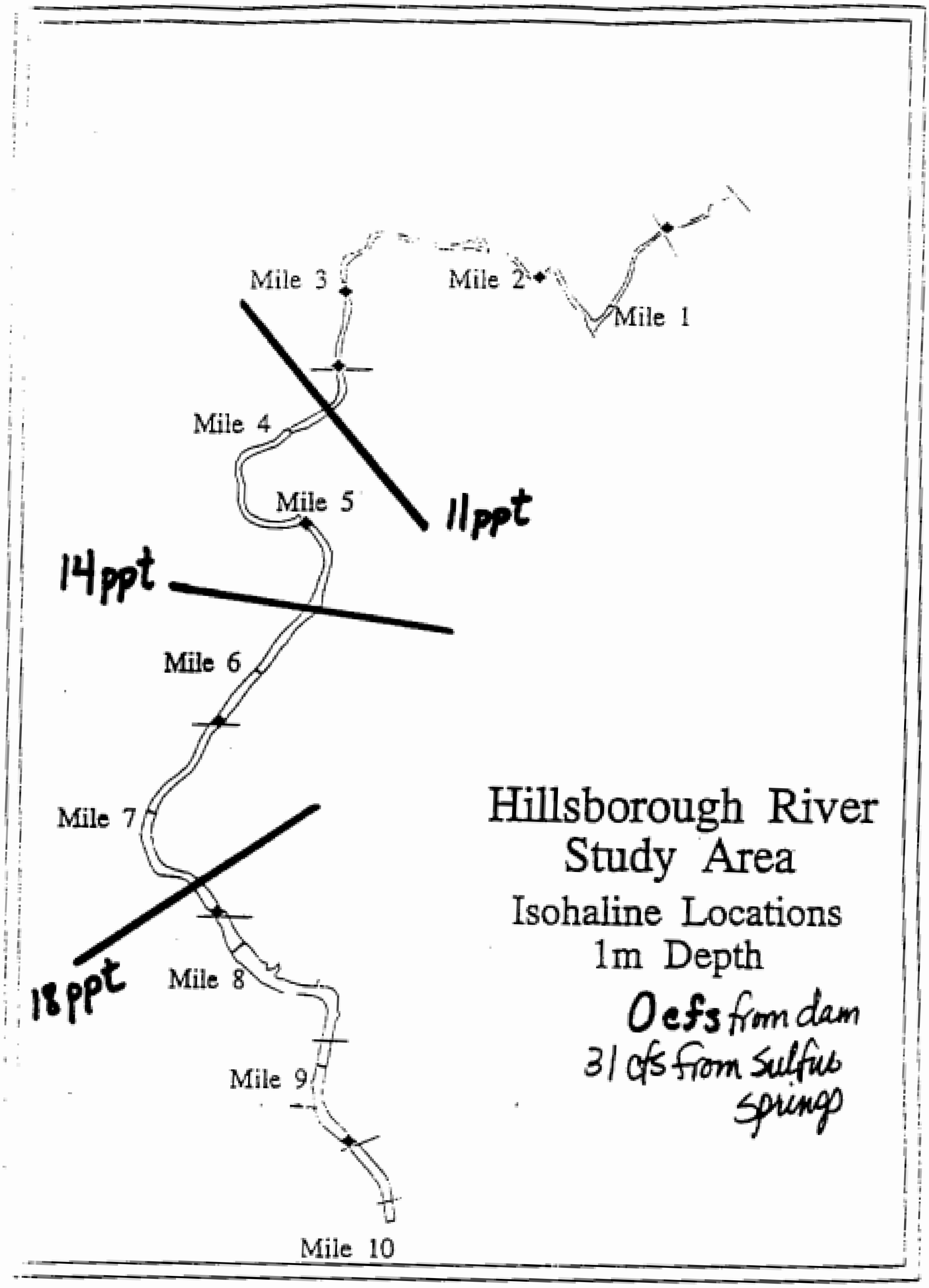

Mile 1
Mile 2
Mile 3
Mile 4
Mile 5
11 ppt
Mile 6
Mile 7
14 ppt
Mile 8
Mile 9
18ppt
Mile 10
Hillsborough River
Study Area
Isohaline Locations
Surface
0 cfs from dam
31 cfs from Sulfur Springs


4ppt
Mile 3
Mile 2
Mile 1
0.5ppt
1.0ppt
Mile 4
Mile 5
Mile 6
11ppt
Mile 7
14ppt
Mile 8
Mile 9
18ppt
Mile 10
Hillsborough River
Study Area
Isohaline Locations
Surface
10cfs from dam
31 cfs from Sulfur springs


Mile 1
Mile 2
Mile 3
Mile 4
Mile 5
Mile 6
Mile 7
Mile 8
Mile 9
Mile 10
0.5ppt
1.0ppt
4ppt
11ppt
14ppt
18ppt
Hillsborough River
Study Area
Isohaline Locations
Surface
20 cfs from dam
31 cfs from Sulfur Springs

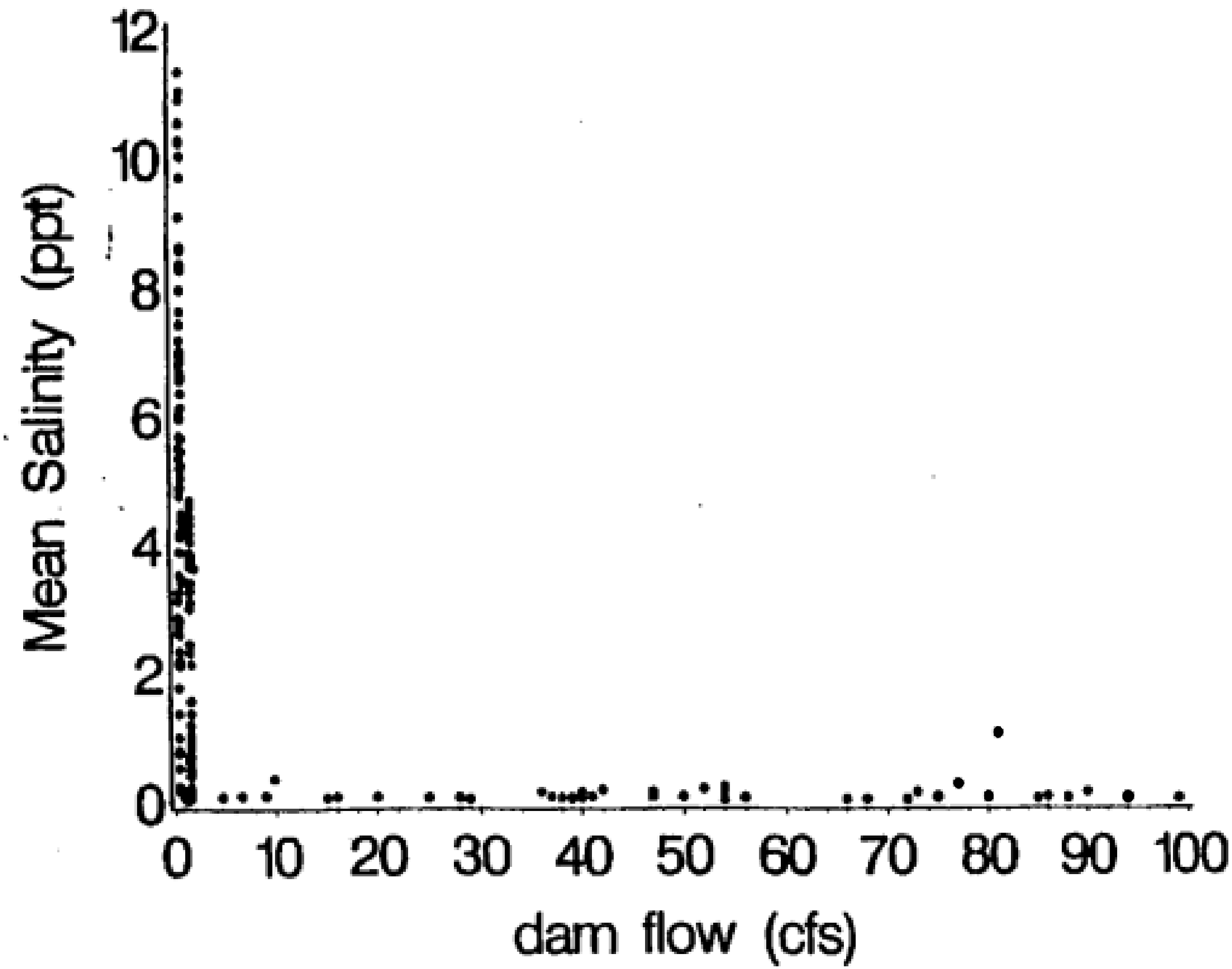


Mile 3
Mile 2
Mile 1
0.5ppt
1.0ppt
Mile 4
Mile 5
4ppt
Mile 6
Mile 7
11ppt
Mile 8
Mile 9
14ppt
Mile 10
Hillsborough River
Study Area
Isohaline Locations
Surface
50 cfs from dam
31 cfs from
sulfur Springs

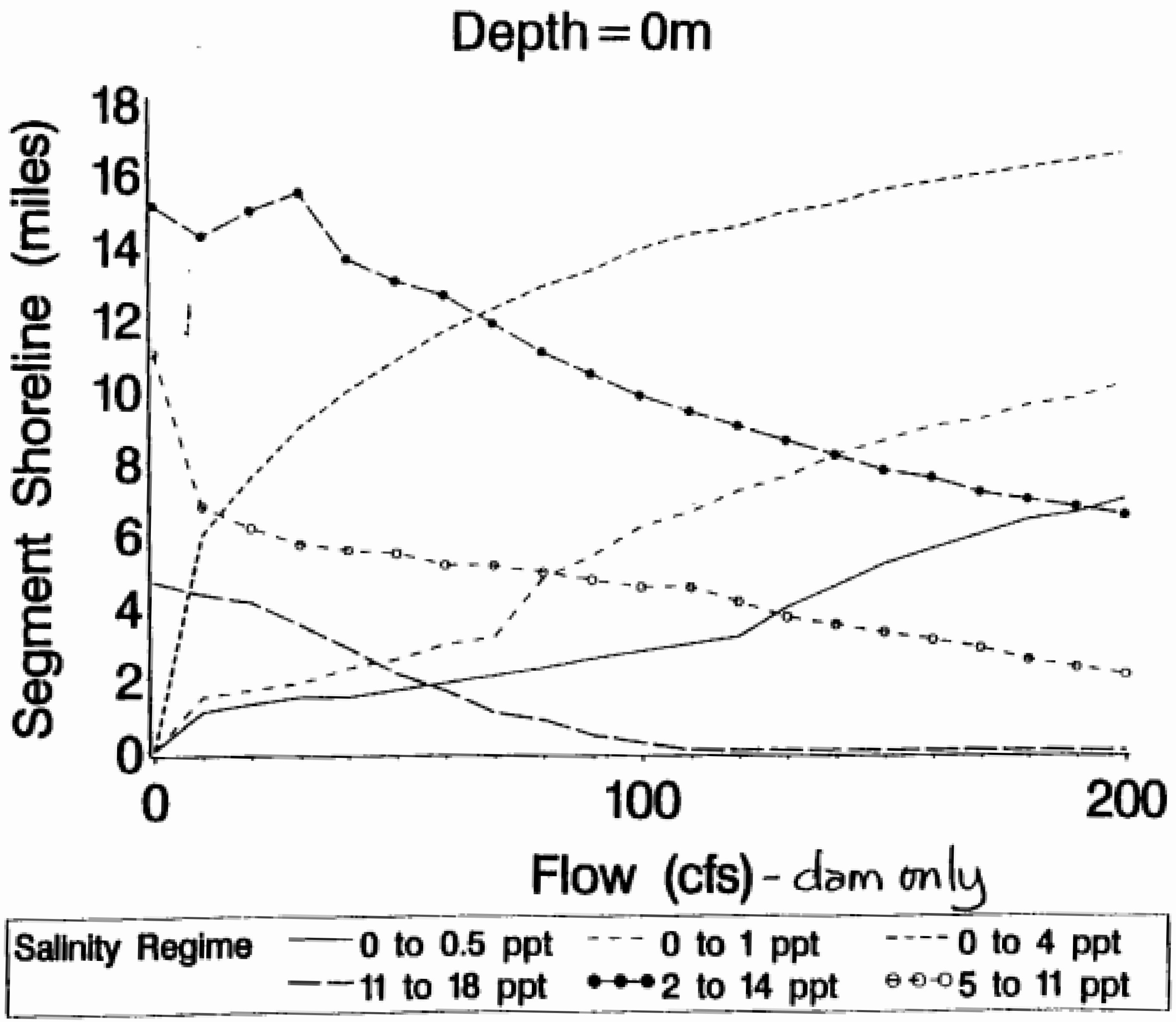

Mile 1
Mile 2
Mile 3
Mile 4
Mile 5
Mile 6
Mile 7
Mile 8
Mile 9
Mile 10
11ppt
14ppt
18ppt
Hillsborough River
Study Area
Isohaline Locations
1m Depth
0 cfs from dam
31 cfs from Sulfur
Springs

P 5/5 USGS

Subset of data for Damflow <= 100 cfs
STREET=Rowlett Pk. Dr.

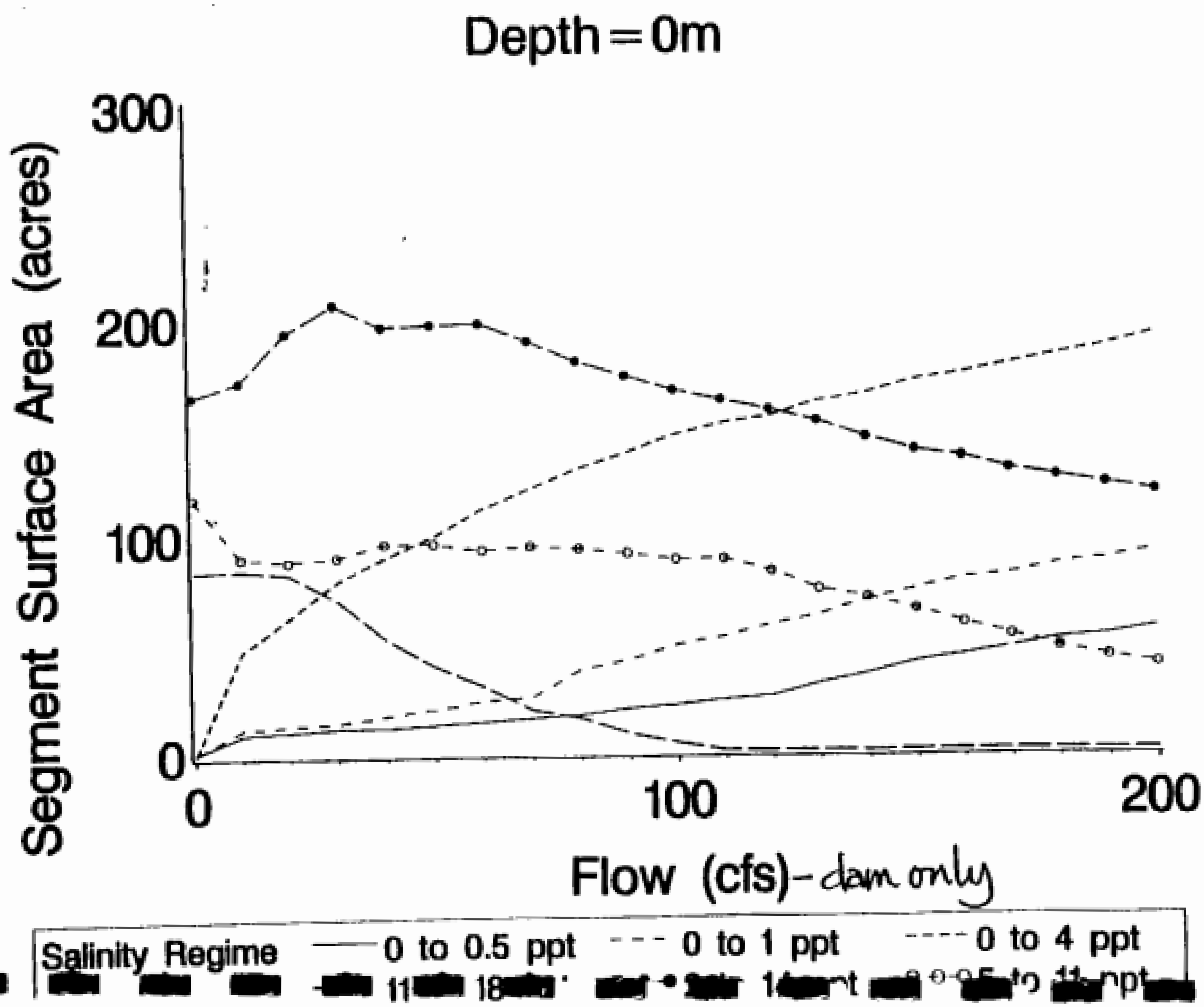


May 21 1997

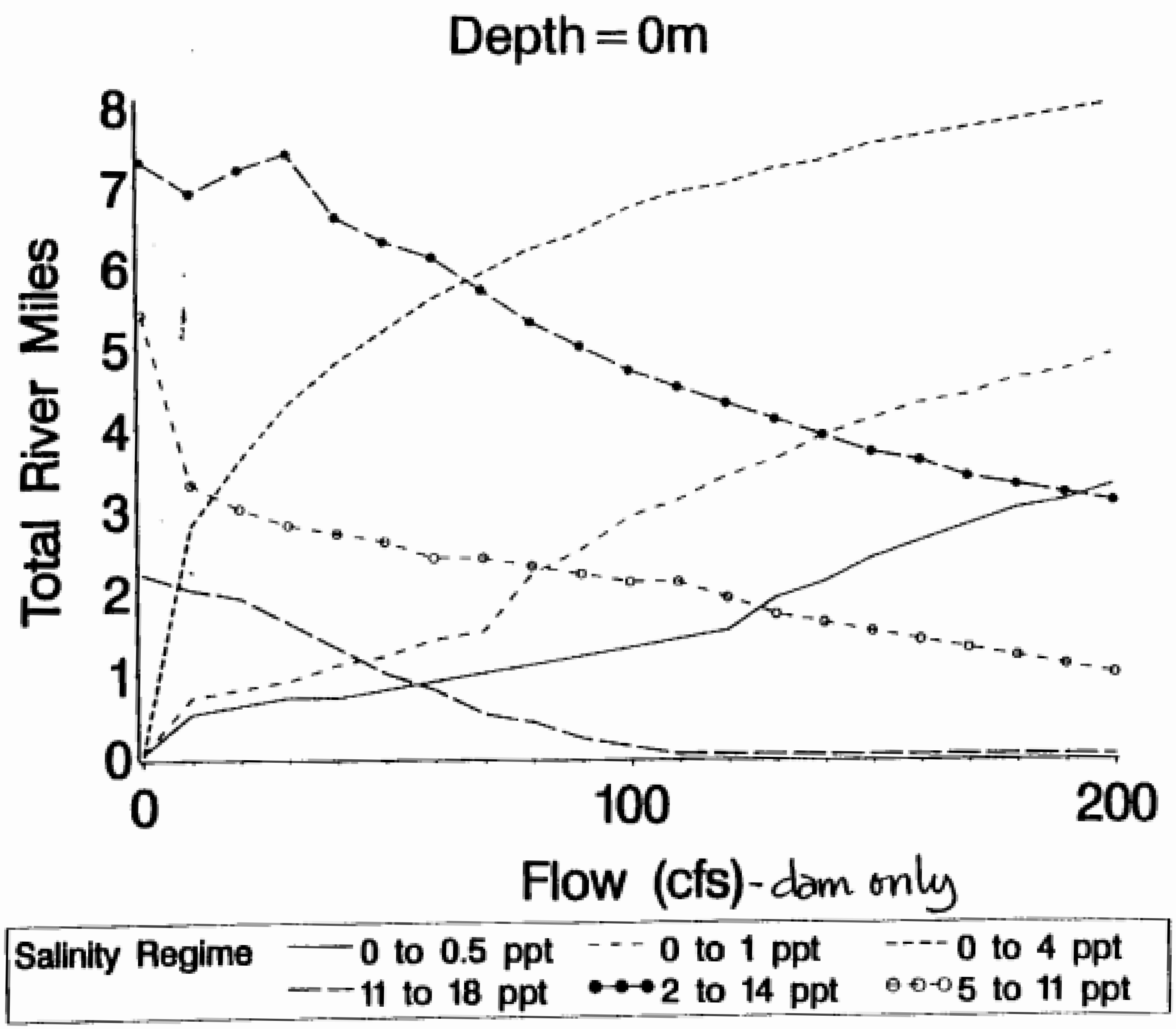


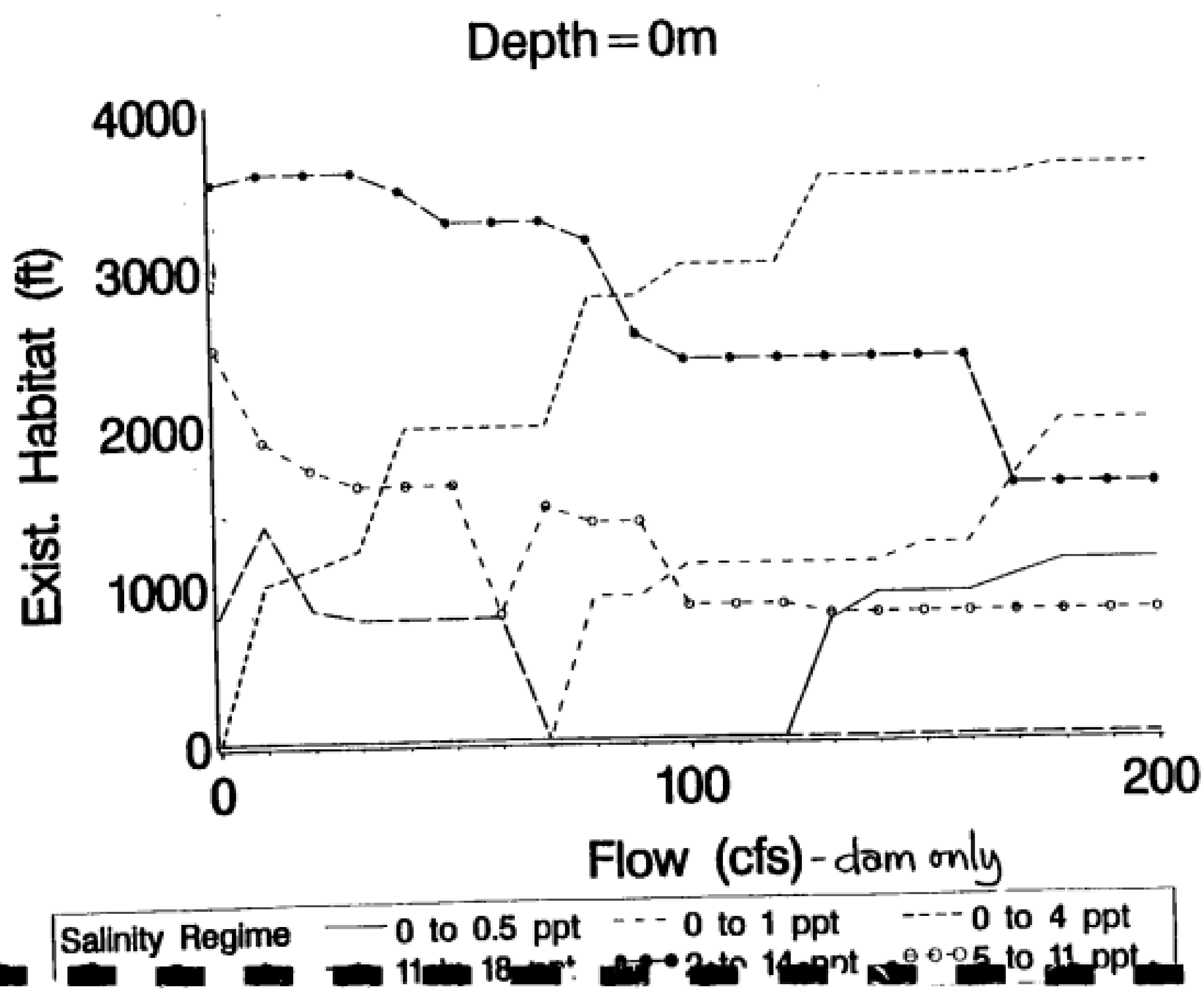
Depth = 0m
Segment Shoreline (miles)
18
16
14
12
10
8
6
4
2
0
0
100
200
Flow (cfs) - dam only
Salinity Regime
0 to 0.5 ppt
0 to 1 ppt
0 to 4 ppt
11 to 18 ppt
2 to 14 ppt
5 to 11 ppt

May 21 1997


Depth = 0m
300
200
100
0
Segment Surface Area (acres)
0
100
200
Flow (cfs)-dam only
Salinity Regime
0 to 0.5 ppt
0 to 1 ppt
0 to 4 ppt

May 21 1997

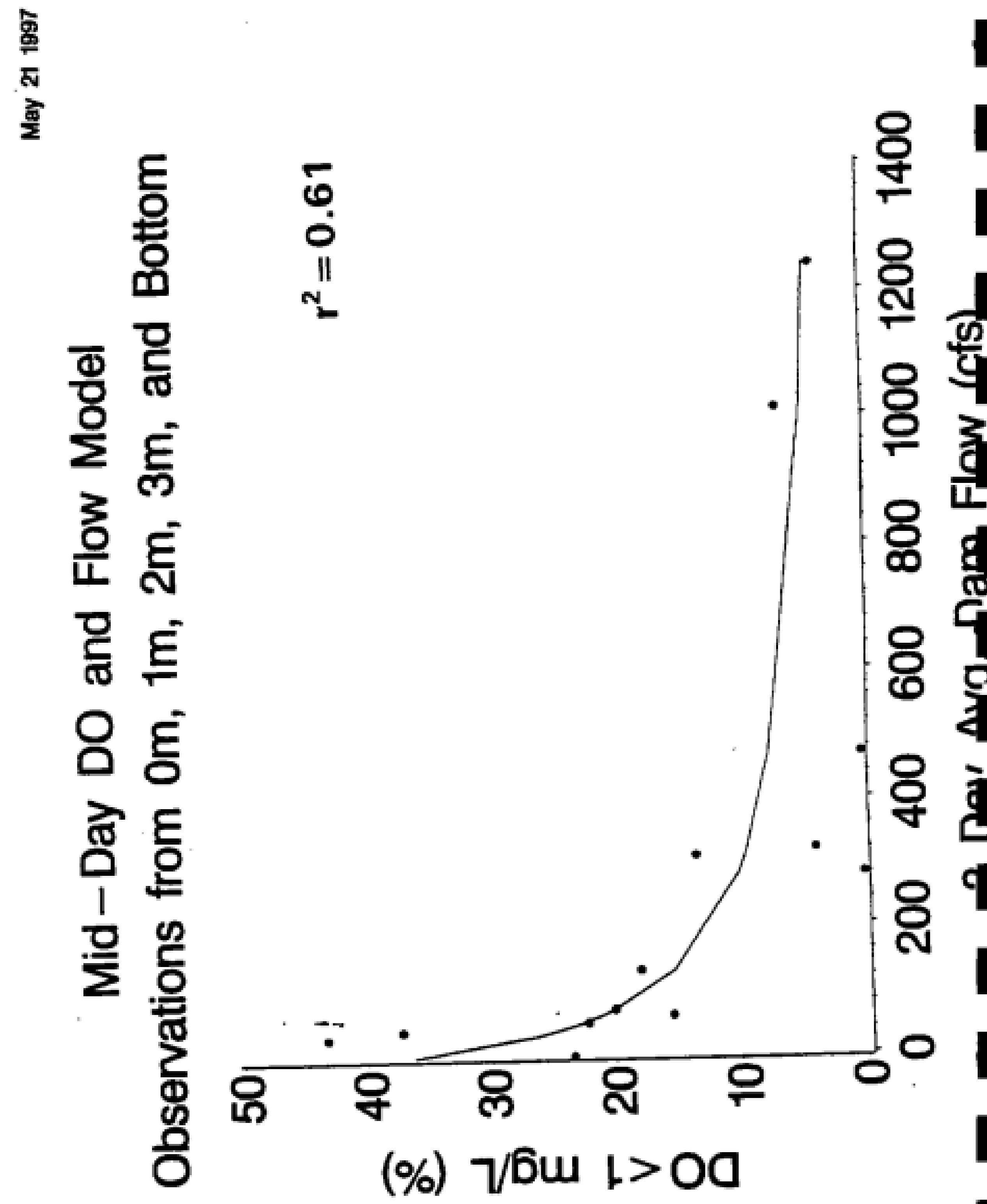

Depth = 0m
Total River Miles
Flow (cfs) - dam only
Salinity Regime
0 to 0.5 ppt
0 to 1 ppt
0 to 4 ppt
11 to 18 ppt
2 to 14 ppt
5 to 11 ppt
0
1
2
3
4
5
6
7
8
0
100
200


Depth = 0m
Exist. Habitat (ft)
4000
3000
2000
1000
0
0
100
200
Flow (cfs) - dam only
Salinity Regime
0 to 0.5 ppt
0 to 1 ppt
0 to 4 ppt
11
18
14
to 11 ppt

Hillsborough River
Changes in Habitat Associated With Increased Flow

Salinity Range / Habitat Type	Baseline Condition (0 Release)	Change from Baselinefor 10 cfs Flow Releases									
		10	20	30	40	50	60	70	80	90	100
0-0.5 ppt											
Shoreline Length (ft)	0	5,513	6,600	7,657	7,657	8,719	9,778	10,846	11,899	13,296	14,385
Surface Area (ac)	0	8	10	11	11	12	14	15	17	19	21
Volume (ac-ft)	0	16	19	21	26	33	36	42	58	66	75
0-1 ppt											
Shoreline Length (ft)	0	7,657	8,719	9,778	11,899	13,296	15,435	16,487	25,012	28,270	32,551
Surface Area (ac)	0	11	12	14	17	19	23	25	37	42	49
Volume (ac-ft)	0	21	28	36	51	61	77	88	123	135	157
0-4 ppt											
Shoreline Length (ft)	0	31,450	39,954	47,351	52,684	57,148	61,430	64,670	67,899	70,158	73,338
Surface Area (ac)	0	47	62	79	89	99	112	121	130	137	145
Volume (ac-ft)	0	114	157	205	287	350	411	469	516	583	625
2-14 ppt											
Shoreline Length (ft)	79,781	-4,386	-668	1,911	-7,741	-10,946	-13,029	-17,237	-21,473	-24,675	-27,874
Surface Area (ac)	164	4	18	26	20	20	21	16	10	5	1
Volume (ac-ft)	649	154	318	421	466	517	566	574	550	538	526
5-11 ppt											
Shoreline Length (ft)	58,227	-22,651	-25,780	-28,077	-28,947	-29,430	-31,134	-31,265	-32,309	-33,426	-34,489
Surface Area (ac)	118	-24	-25	-24	-19	-18	-21	-20	-21	-23	-25
Volume (ac-ft)	376	60	146	171	227	233	230	221	208	214	194
11-18 ppt											
Shoreline Length (ft)	24,529	-1,848	-2,943	-6,179	-9,561	-13,406	-15,970	-19,193	-20,266	-22,374	-23,457
Surface Area (ac)	83	0	-2	-14	-31	-44	-54	-64	-68	-75	-80
Volume (ac-ft)	630	23	27	-14	-91	-117	-172	-221	-265	-313	-339

Note: Salinity response to dam flow between station 2 and dam is consistent (i.e., flow>0 = 0 salinity at station 2)

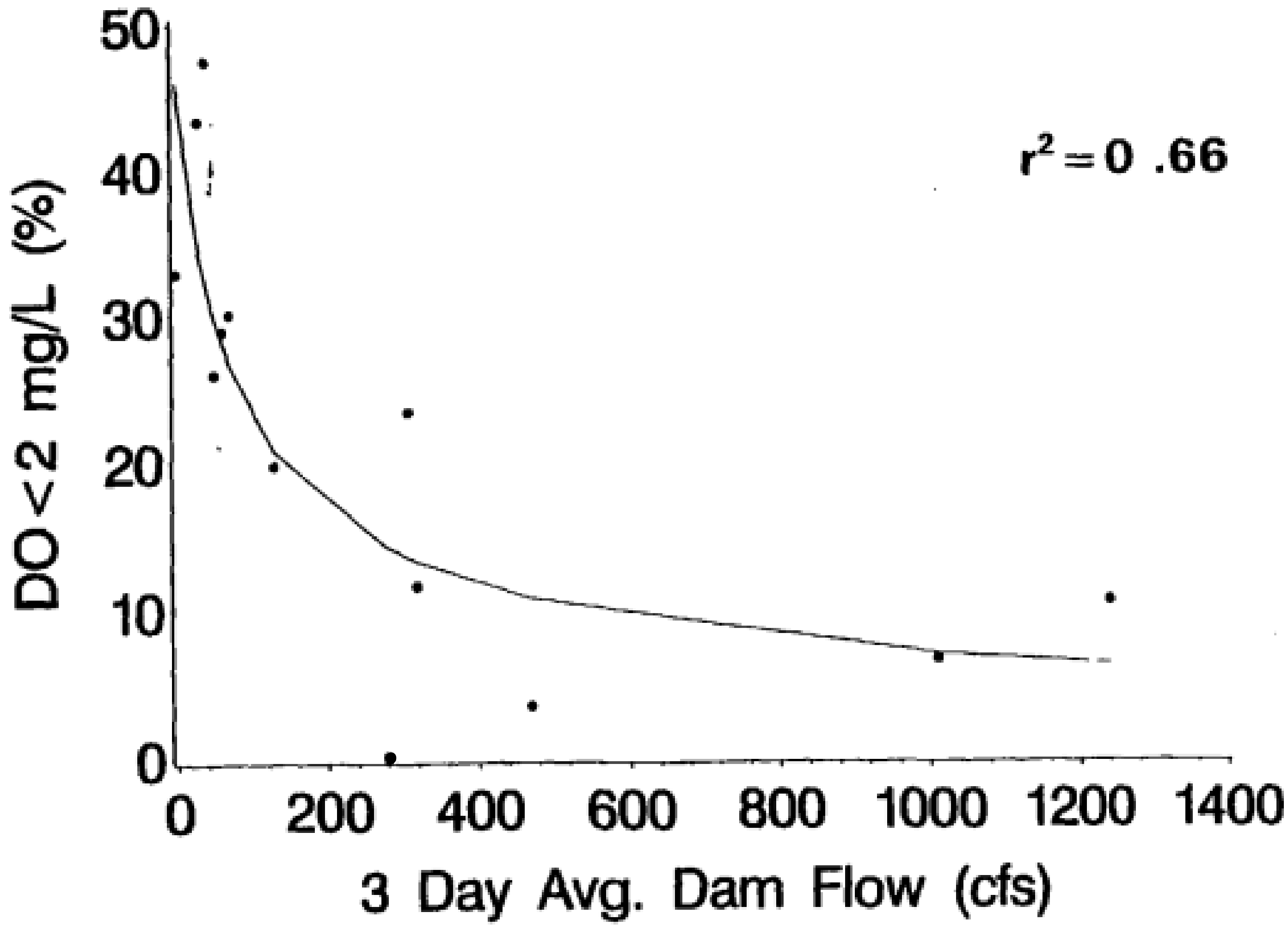

May 21 1997
Mid – Day DO and Flow Model
Observations from 0m, 1m, 2m, 3m, and Bottom
r² = 0.61
DO<1 mg/L (%)
0
10
20
30
40
50
0
200
400
600
800
1000
1200
1400
3 Day Avg Dam Flow (cfs)

N-2 32

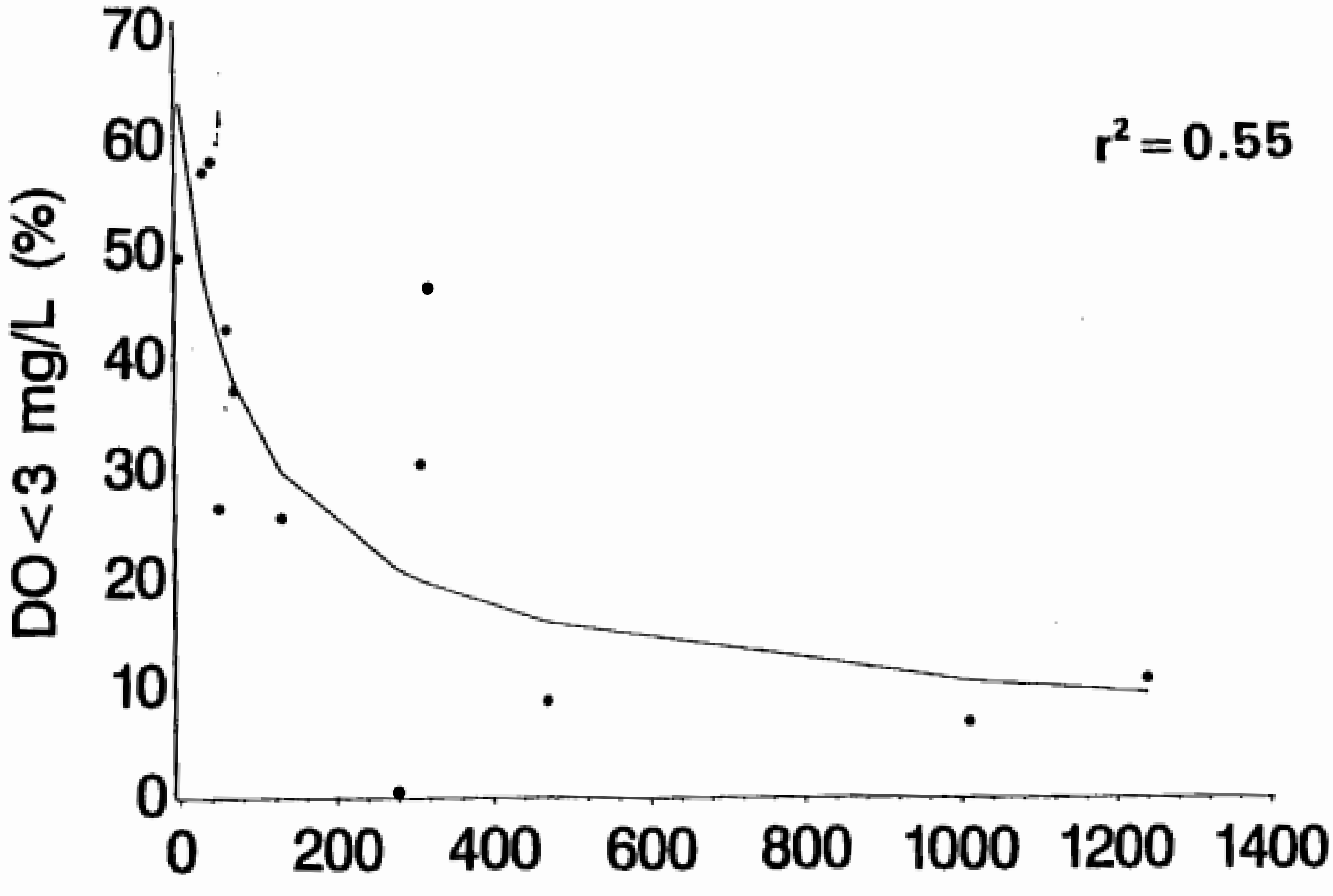
May 21 1997

Mid – Day DO and Flow Model

Observations from 0m, 1m, 2m, 3m, and Bottom

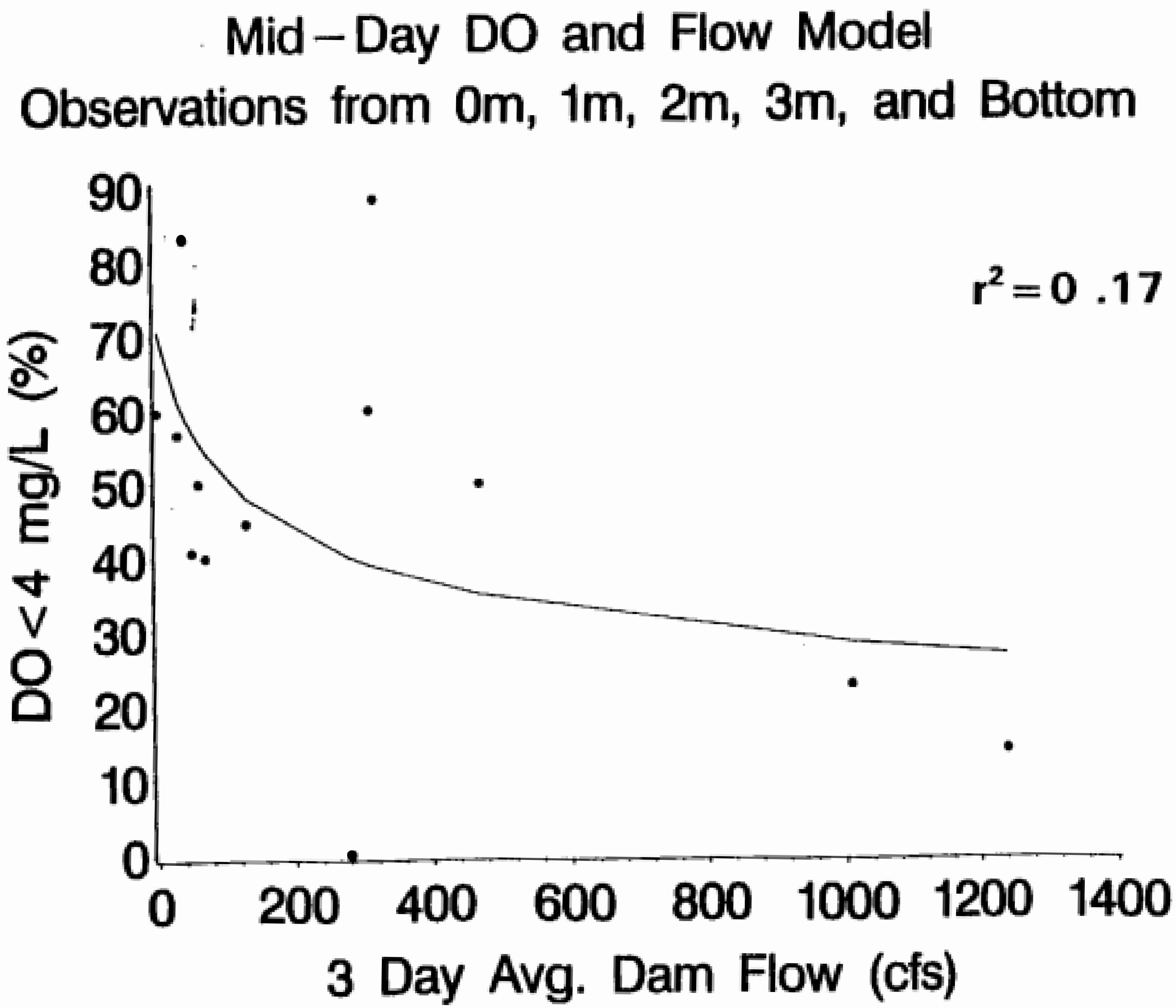


Mid-Day DO and Flow Model
Observations from 0m, 1m, 2m, 3m, and Bottom



N-2 34

May 21 1997

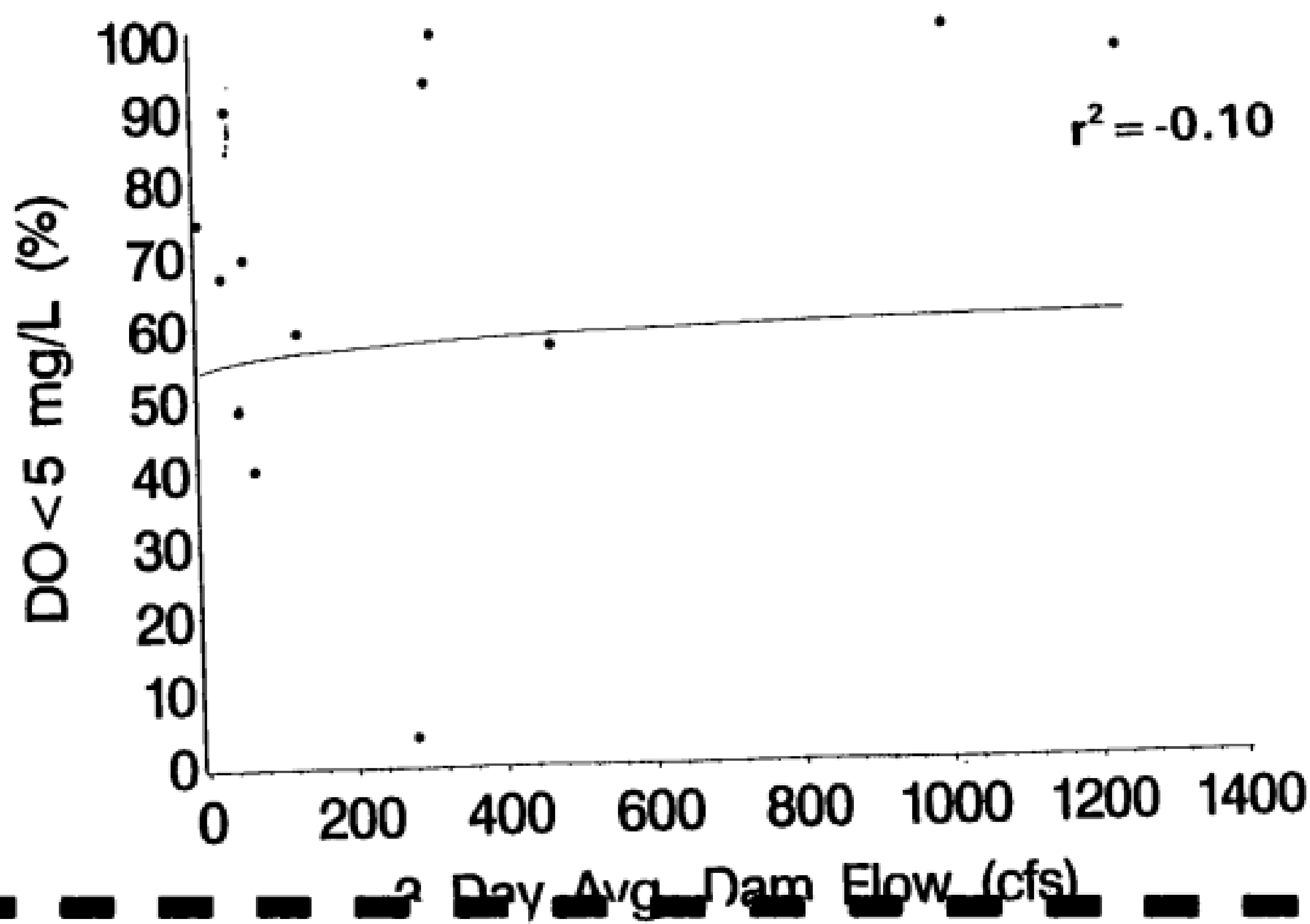


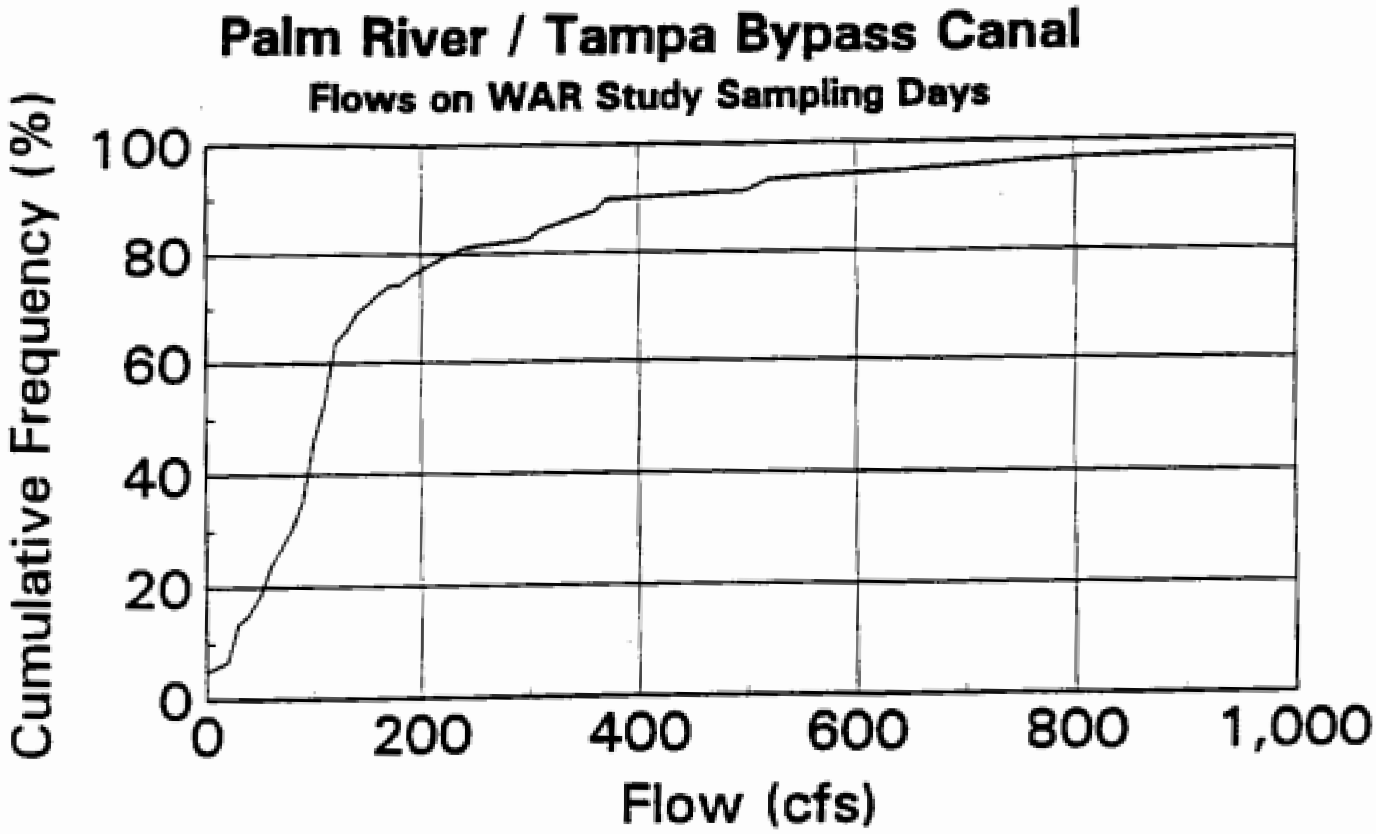
Mid – Day DO and Flow Model
Observations from 0m, 1m, 2m, 3m, and Bottom
$r^2 = 0.17$
DO<4 mg/L (%)
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
3 Day Avg. Dam Flow (cfs)

May 21 1997

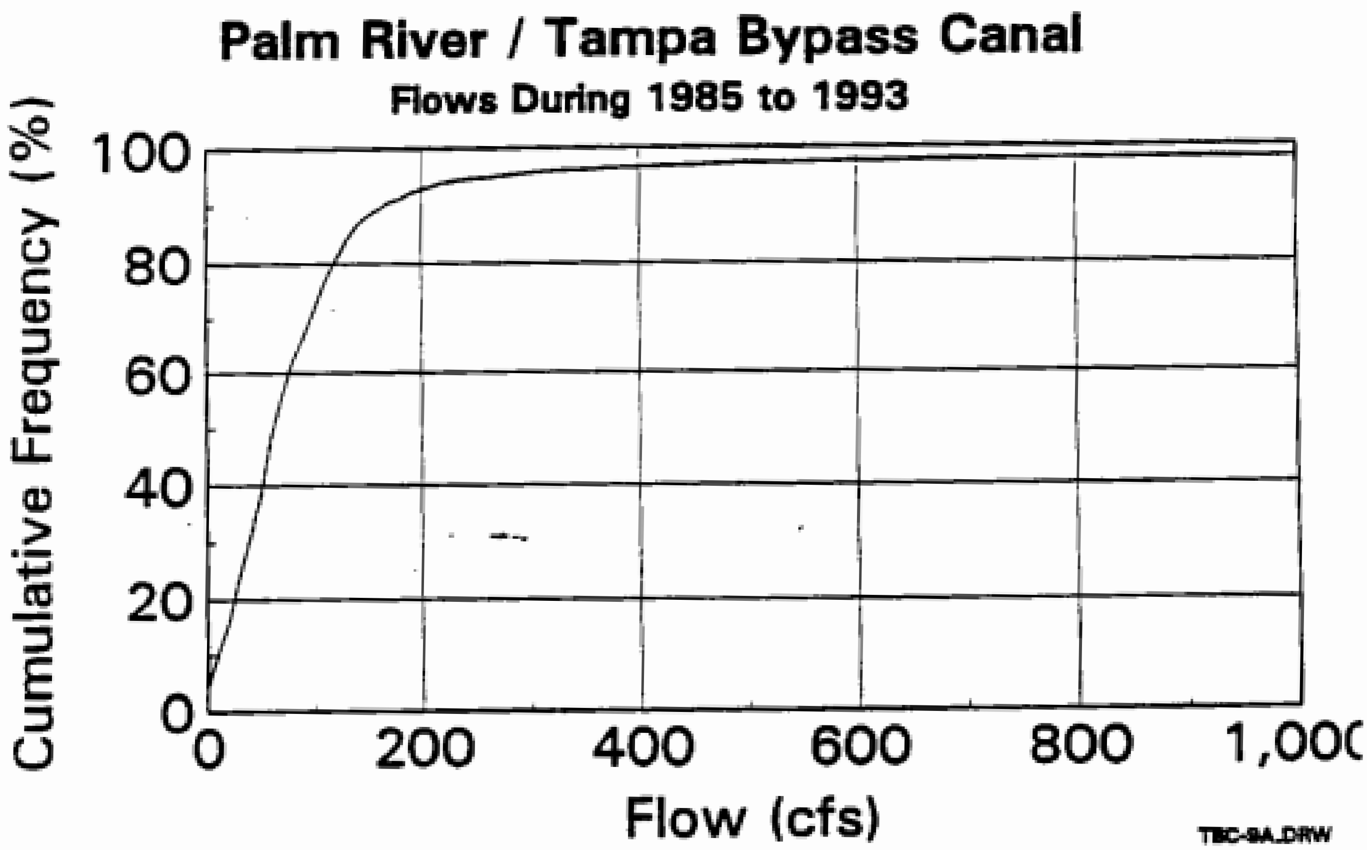
Mid-Day DO and Flow Model

Observations from 0m, 1m, 2m, 3m, and Bottom



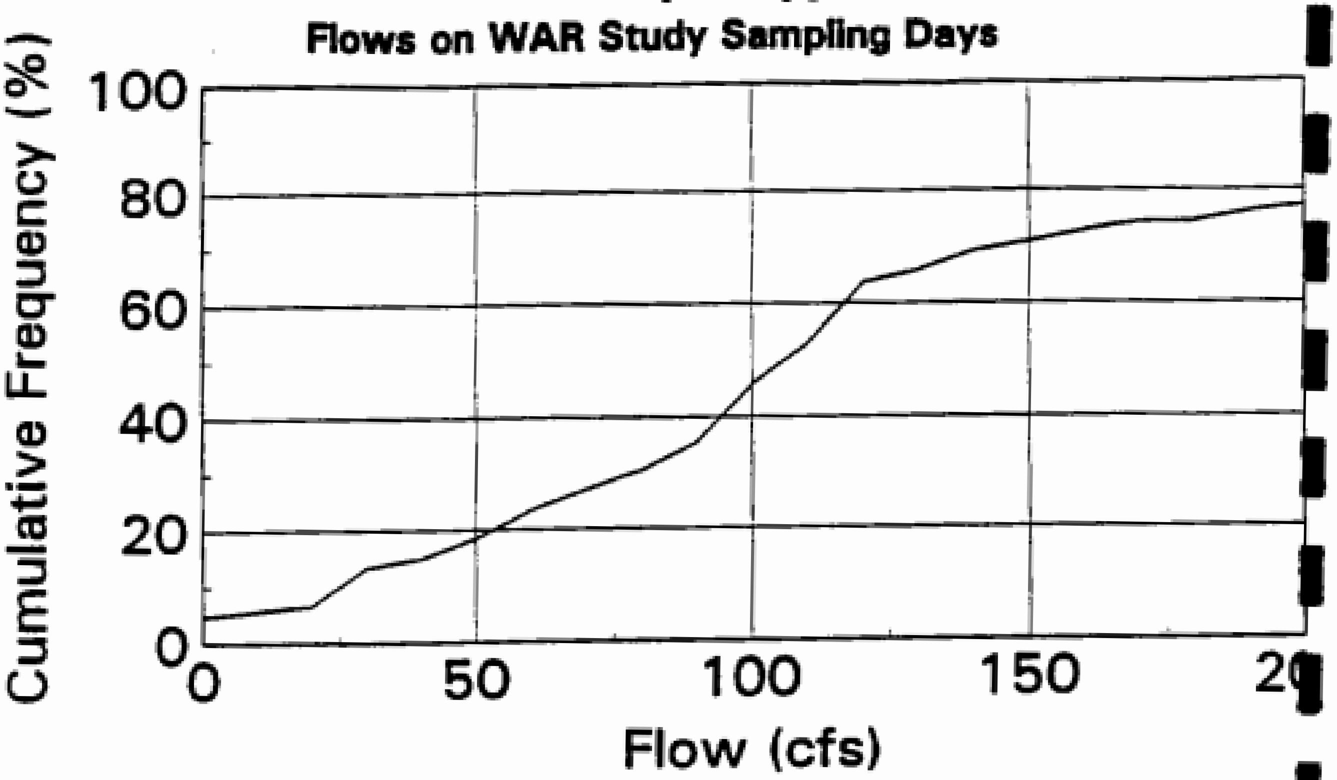


Palm River / Tampa Bypass Canal
Flows on WAR Study Sampling Days
Cumulative Frequency (%)
100
80
60
40
20
0
0
200
400
600
800
1,000
Flow (cfs)

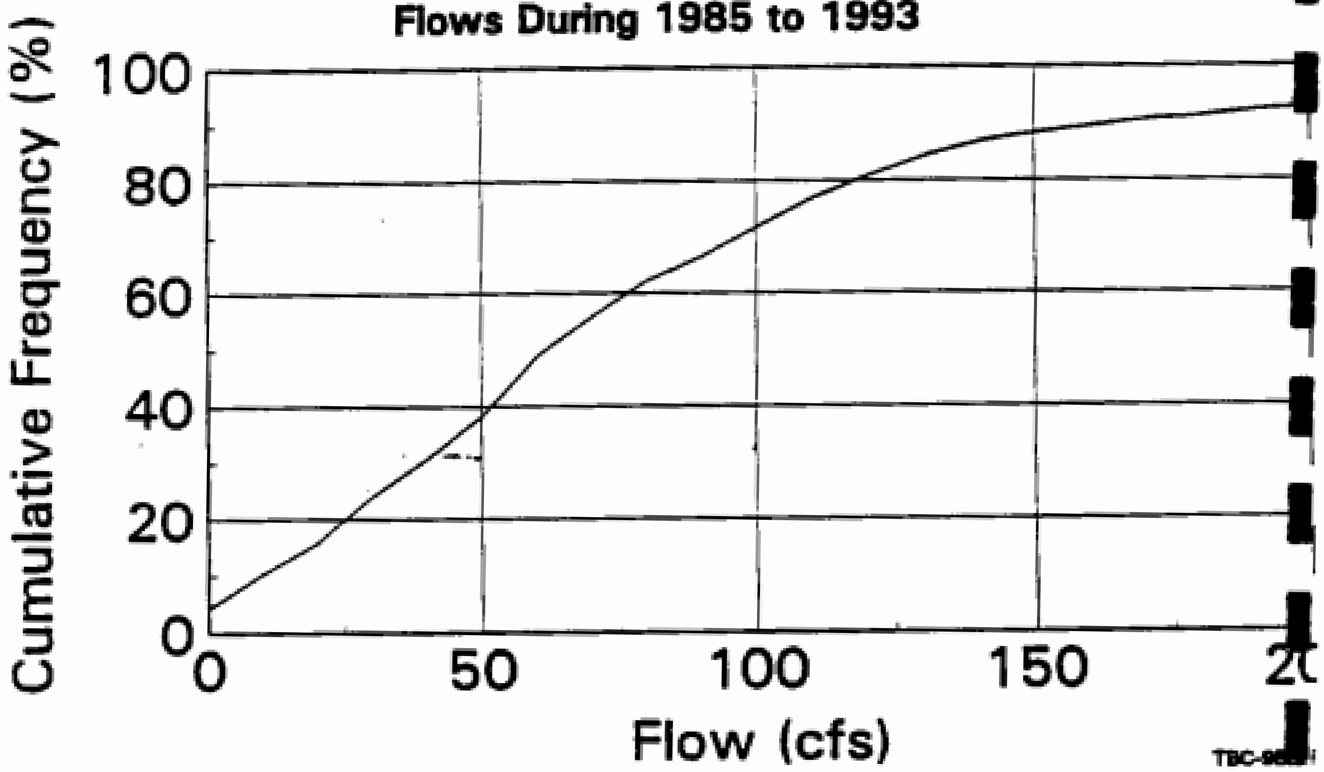


Palm River / Tampa Bypass Canal
Flows During 1985 to 1993
Cumulative Frequency (%)
100
80
60
40
20
0
0
200
400
600
800
1,000
Flow (cfs)
TBC-9A.DRW

Palm River / Tampa Bypass Canal
Flows on WAR Study Sampling Days



Palm River / Tampa Bypass Canal
Flows During 1985 to 1993



TBC-9

r^2 by Station and Depth

Palm River/Tampa Bypass Canal
Salinity vs. flow

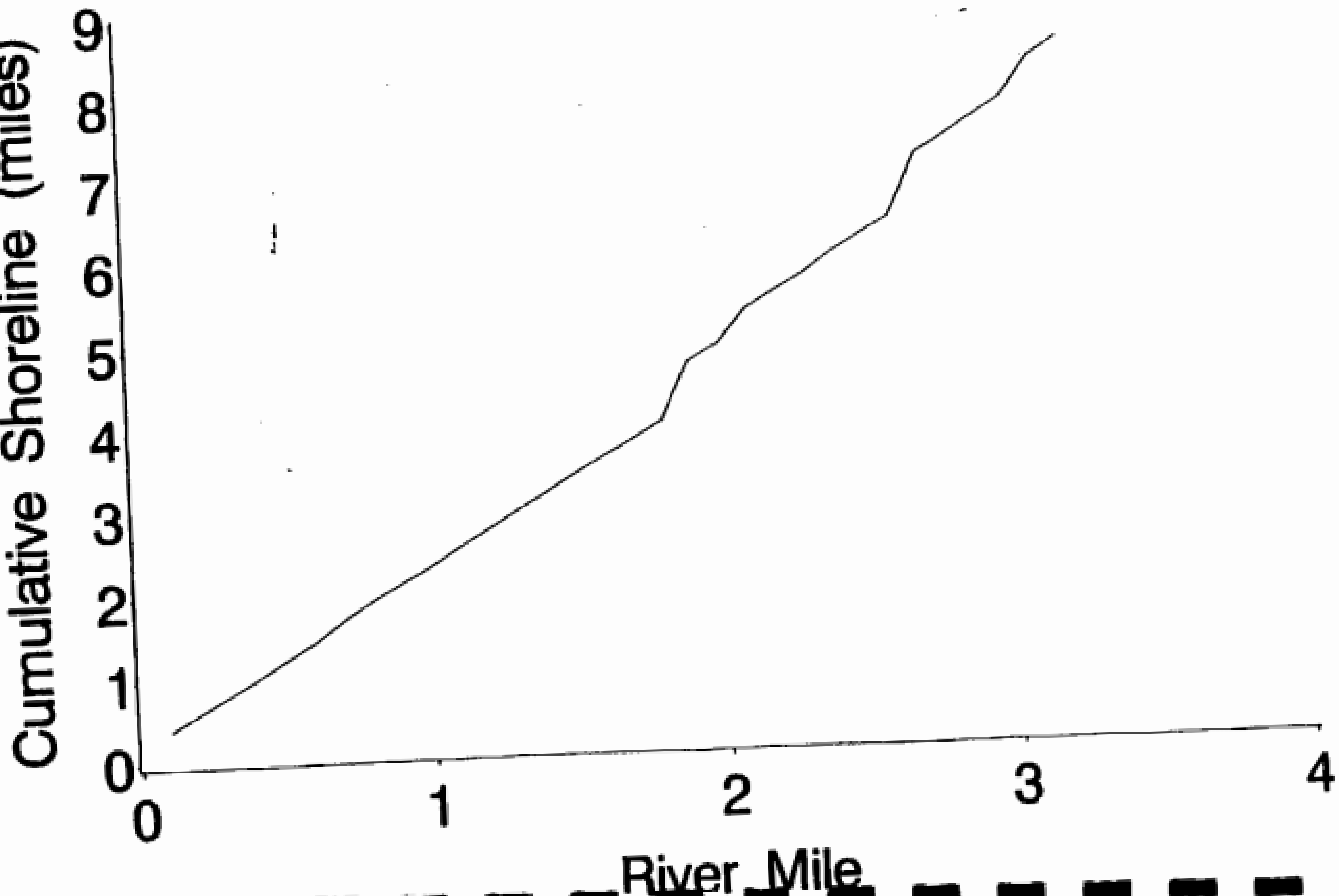
May 21, 1997

Station	Depth (m)							
	0	**1**	**2**	3	4	5	6	Bottom
12	**0.46**	**0.59**	**0.62**	0.49	0.35	0.12	-	0.12
13	**0.61**	**0.70**	**0.67**	0.51	0.38	0.06	-	0.12
14	**0.74**	**0.72**	**0.60**	0.39	0.31	0.14	0.21	0.20
15	**0.71**	**0.74**	**0.42**	0.29	0.13	0.14	-	0.13

Overall $r^2 = 0.69$

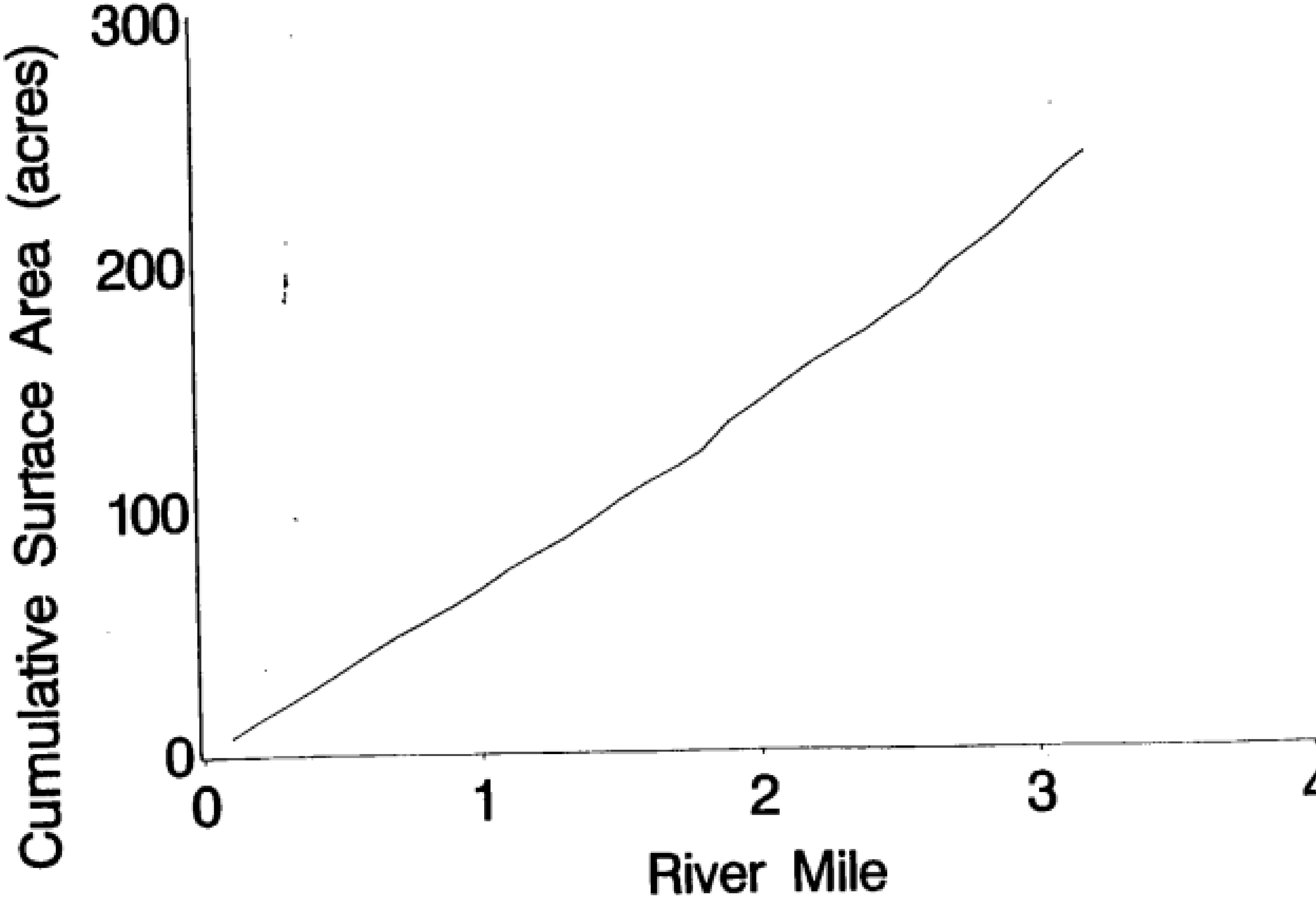
r2.wpd

May 21 1997



N-2 40
3-4

May 21 1997



3-5

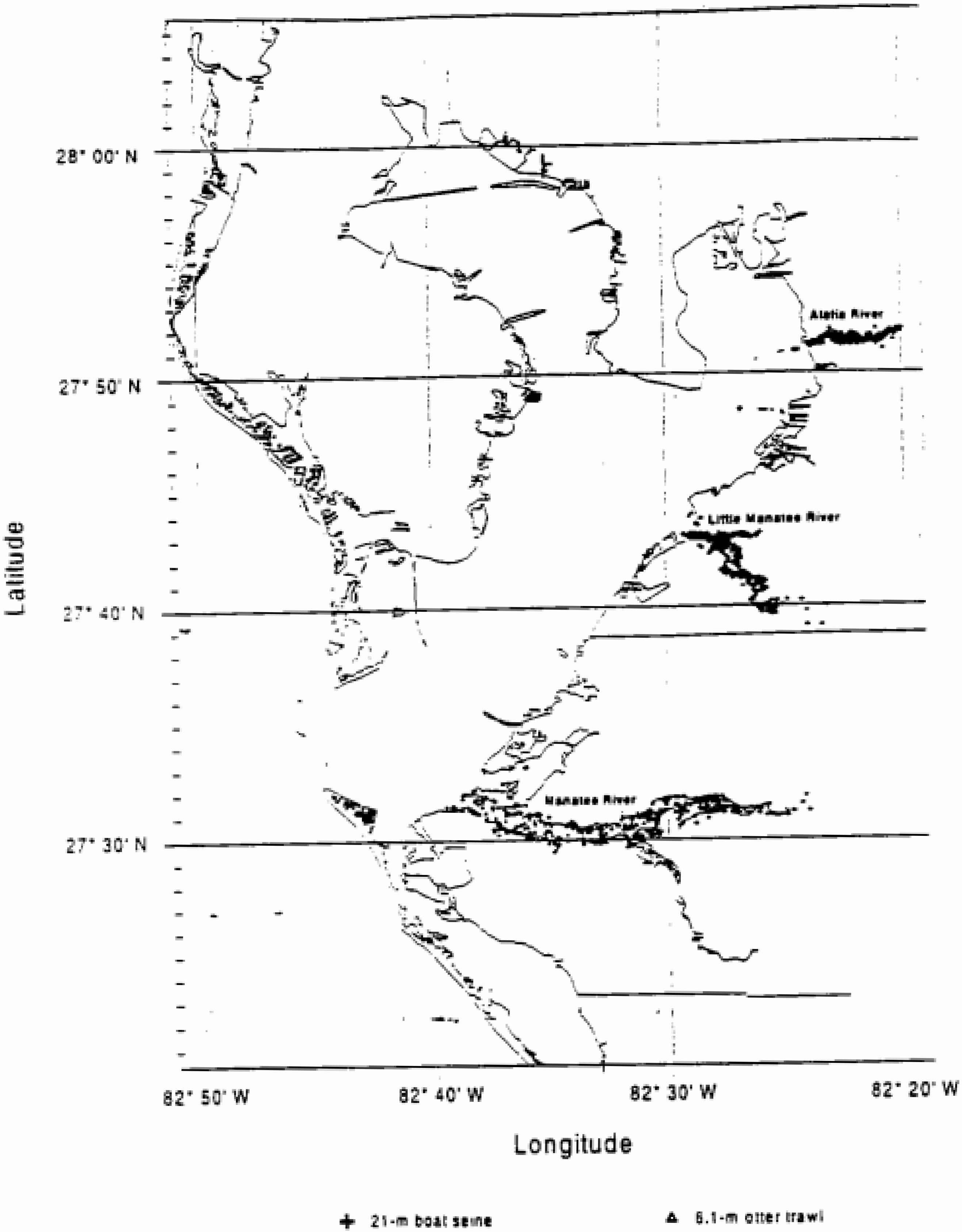
Palm River / Tampa Bypass Canal
Changes in Habitat Associated With Increased Flow

May 21, 1997

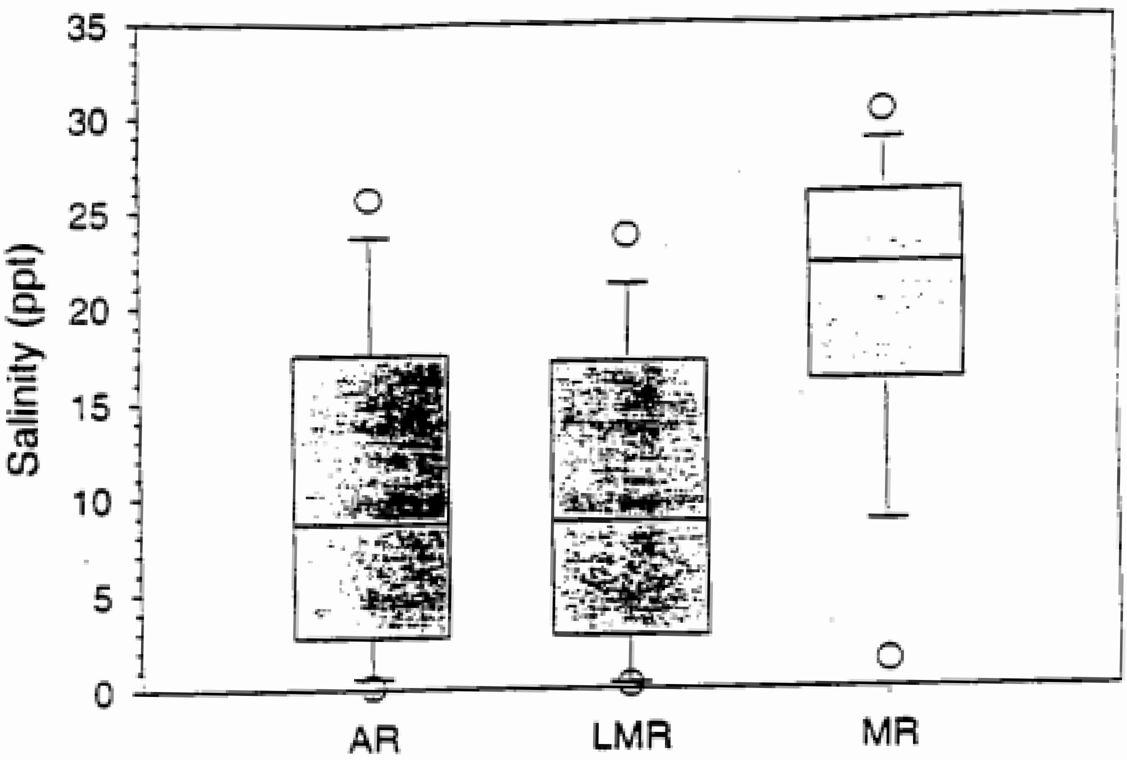
Salinity Range Habitat Type	Baseline Condition (0 Release)	Change from Baseline for 10 cfs Flow Releases						
		10	20	30	40	50	100	200
0-1 ppt (Freshwater)								
Shoreline Length (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
1-10 ppt								
Shoreline Length (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
10-20 ppt								
Shoreline Length (ft)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	9,919 (—)	43,508 (—)
Surface Area (ac)	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	52 (—)	233 (—)
> 20 ppt								
Shoreline Length (ft)	43,508	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	-9,919 (-22%)	-43,508 (-100%)
Surface Area (ac)	233	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	-52 (-23%)	-233 (-100%)

tbcsal2.wpd

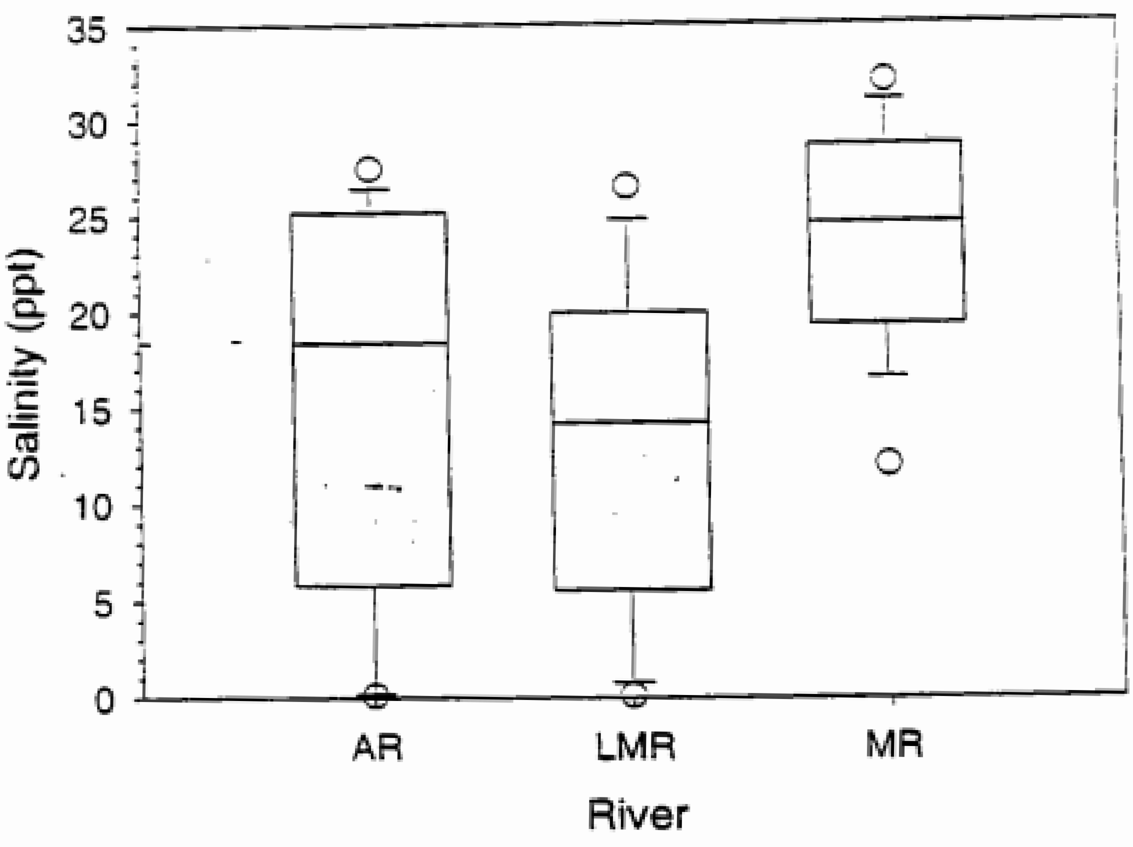
Alafia, Little Manatee and Manatee Rivers, 1994-1996
21-m boat seines and 6.1-m otter trawls only

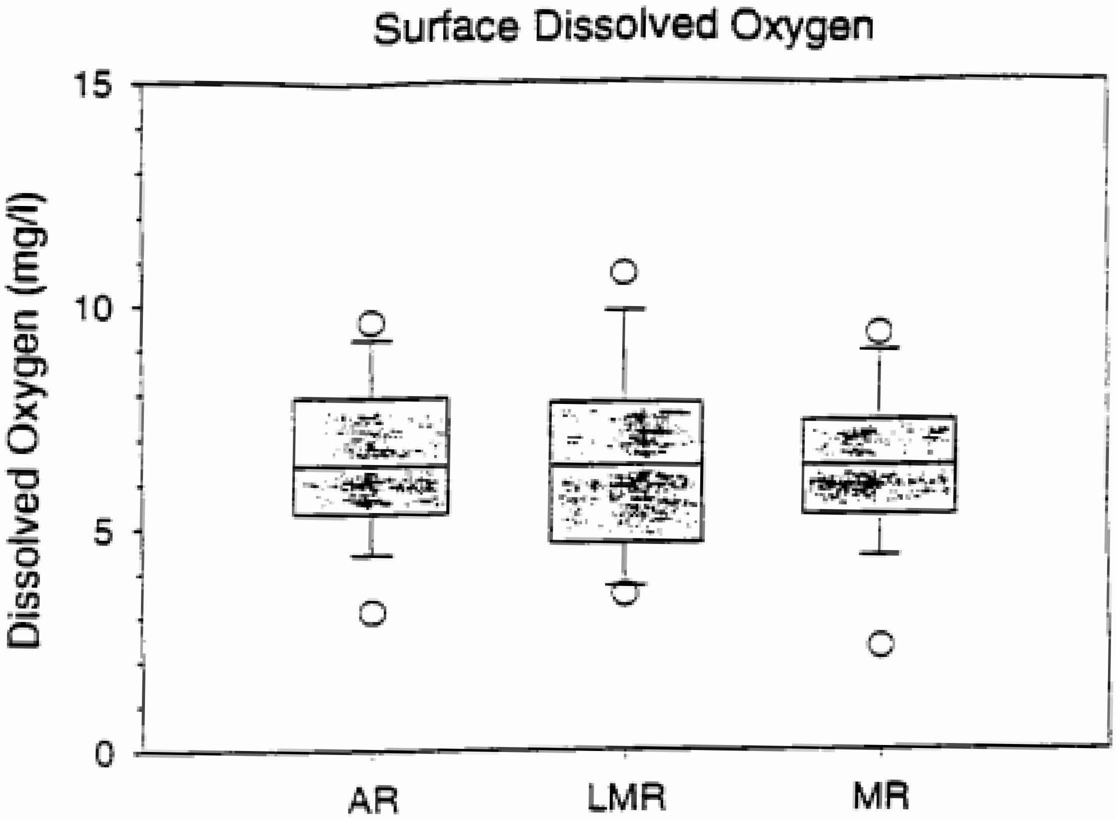


Surface Salinity

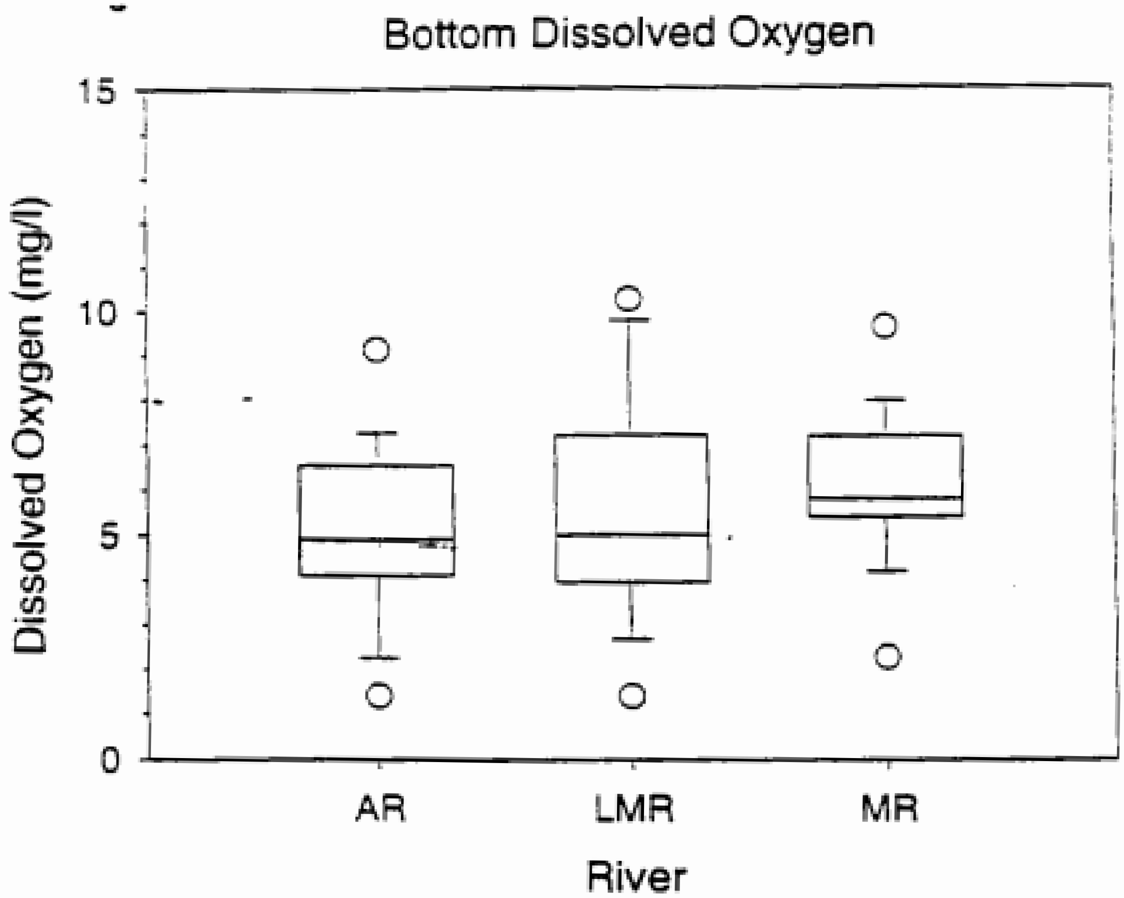


Bottom Salinity





Surface Dissolved Oxygen
Dissolved Oxygen (mg/l)
15
10
5
0
AR
LMR
MR



Bottom Dissolved Oxygen
Dissolved Oxygen (mg/l)
15
10
5
0
AR
LMR
MR
River

Salinity Classifications

Salinity Range (ppt)	Classification
0.0 - 0.5	Freshwater
0.5 - 5.0	Oligohaline
5.0 - 11.0	Lower Mesohaline
11.0 - 18.0	Upper Mesohaline
>=18.0	Polyhaline

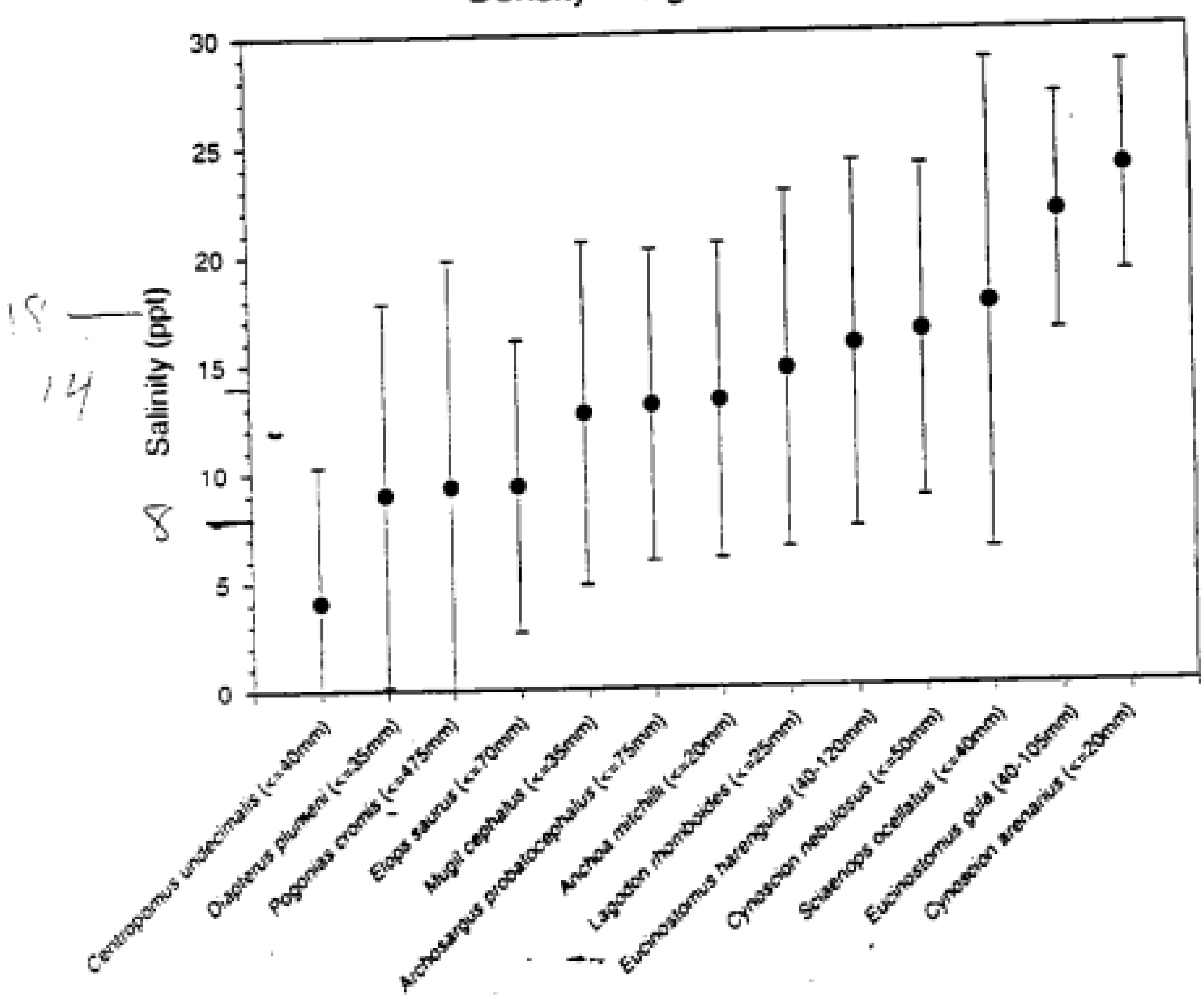
Number of samples collected by salinity classification and gear

	21-m Seines				6.1-m Otter Trawls			
	AR	LMR	MR	Total	AR	LMR	MR	Total
Freshwater	11	29	11	51	10	8	0	18
Oligohaline	46	43	5	94	5	14	2	21
Lower Mesohaline	35	25	17	77	6	15	2	23
Upper Mesohaline	29	34	28	91	12	25	19	56
Polyhaline	31	29	115	175	29	31	86	146
Total	**152**	**160**	**176**	**488**	**62**	**93**	**109**	**264**

Density-Weighted Mean Salinities for species collected in ten or more samples. Species are sor[illegible] in order from lowest mean salinity to highest mean salinity.

Species	Lengths Analyzed (mm)	Density-Weighted Salinity Mean	Density-Weighted Salinity Std
Labidesthes sicculus	<= 65	0.11	0.12
Notropis petersoni	<= 55	0.22	0.15
Lepomis macrochirus	<= 165	0.68	1.07
Micropterus salmoides	<= 205	0.99	1.43
Fundulus seminolis	<= 105	1.36	1.92
Opisthonema oglinum	<= 160	1.66	5.95
Gambusia holbrooki	<= 45	1.69	3.29
Heterandria formosa	<= 30	2.80	5.83
Trinectes maculatus	<= 25	3.30	6.27
Centropomus undecimalis	<= 40	4.05	6.24
Diapterus plumieri	<= 35	8.97	8.84
Pogonias cromis	<= 475	9.32	10.45
Elops saurus	<= 70	9.34	6.70
Membras martinica	<= 55	9.73	8.55
Gobiosoma spp.	<= 50	9.77	8.90
Tilapia spp.	<= 295	10.04	6.88
Lepisosteus osseus	<= 1155	10.43	6.39
Lucania parva	<= 50	11.05	12.34
Poecilia latipinna	<= 75	11.95	12.74
Fundulus grandis	<= 105	12.03	7.12
Archosargus probatocephalus	<= 75	12.65	7.86
Brevoortia spp.	<= 35	12.97	5.44
Mugil cephalus	<= 35	12.98	7.14
Anchoa mitchilli	<= 20	13.14	7.21
Microgobius gulosus	<= 75	13.26	8.43
Menidia spp.	<= 110	13.66	9.37
Eucinostomus spp.	<= 75	13.67	7.99
Lagodon rhomboides	<= 25	14.53	8.14
Cyprinodon variegatus	<= 55	14.77	6.12
Callinectes sapidus	<= 30	14.92	8.13
Floridichthys carpio	<= 65	15.47	7.63
Eucinostomus harengulus	40-120	15.64	8.37
Cynoscion nebulosus	<= 50	16.22	7.61
Mugil gyrans	<= 170	16.67	4.19
Syngnathus scovelli	<= 115	16.77	9.62
Arius felis	<= 365	17.10	7.71
Sciaenops ocellatus	<= 40	17.43	[illegible]
Bathygobius soporator	<= 75	17.89	[illegible]
Oligoplites saurus	<= 100	18.19	[illegible]
Penaeus duorarum	<= 45	18.52	[illegible]
Symphurus plagiusa	<= 70	18.60	[illegible]
Bairdiella chrysoura	<= 30	19.08	[illegible]
Bagre marinus	<= 515	19.26	[illegible]
Harengula jaguana	<= 115	19.53	[illegible]
Strongylura timucu	<= 425	19.65	[illegible]
Fundulus majalis	<= 100	19.72	[illegible]
Gobiesox strumosus	<= 40	19.74	[illegible]
Chasmodes saburrae	<= 60	19.97	[illegible]
Lutjanus griseus	<= 215	20.12	[illegible]
Strongylura marina	<= 420	20.16	[illegible]
Achirus lineatus	<= 40	20.92	[illegible]
Gymnura micrura	<= 480	21.20	[illegible]
Microgobius thalassinus	<= 65	21.53	[illegible]
Eucinostomus gula	40-105	21.56	[illegible]
Strongylura notata	<= 380	21.95	[illegible]
Leiostomus xanthurus	<= 30	22.11	[illegible]
Dasyatis sabina	<= 365	22.33	[illegible]
Opsanus beta	<= 245	22.45	[illegible]
Orthopristis chrysoptera	<= 35	22.67	[illegible]
Syngnathus louisianae	<= 265	23.14	[illegible]
Prionotus tribulus	<= 95	23.21	[illegible]
Chaetodipterus faber	<= 50	23.23	[illegible]
Anchoa hepsetus	<= 30	23.50	[illegible]
Menticirrhus saxatilis	<= 190	23.56	[illegible]
Cynoscion arenarius	<= 20	23.59	[illegible]
Synodus foetens	<= 75	23.86	[illegible]
Sphoeroides nephelus	<= 30	24.12	[illegible]
Prionotus scitulus	<= 55	24.31	[illegible]
Menticirrhus americanus	<= 25	24.44	[illegible]
Paralichthys albigutta	<= 310	25.71	[illegible]
Chilomycterus schoepfi	<= 225	27.86	[illegible]

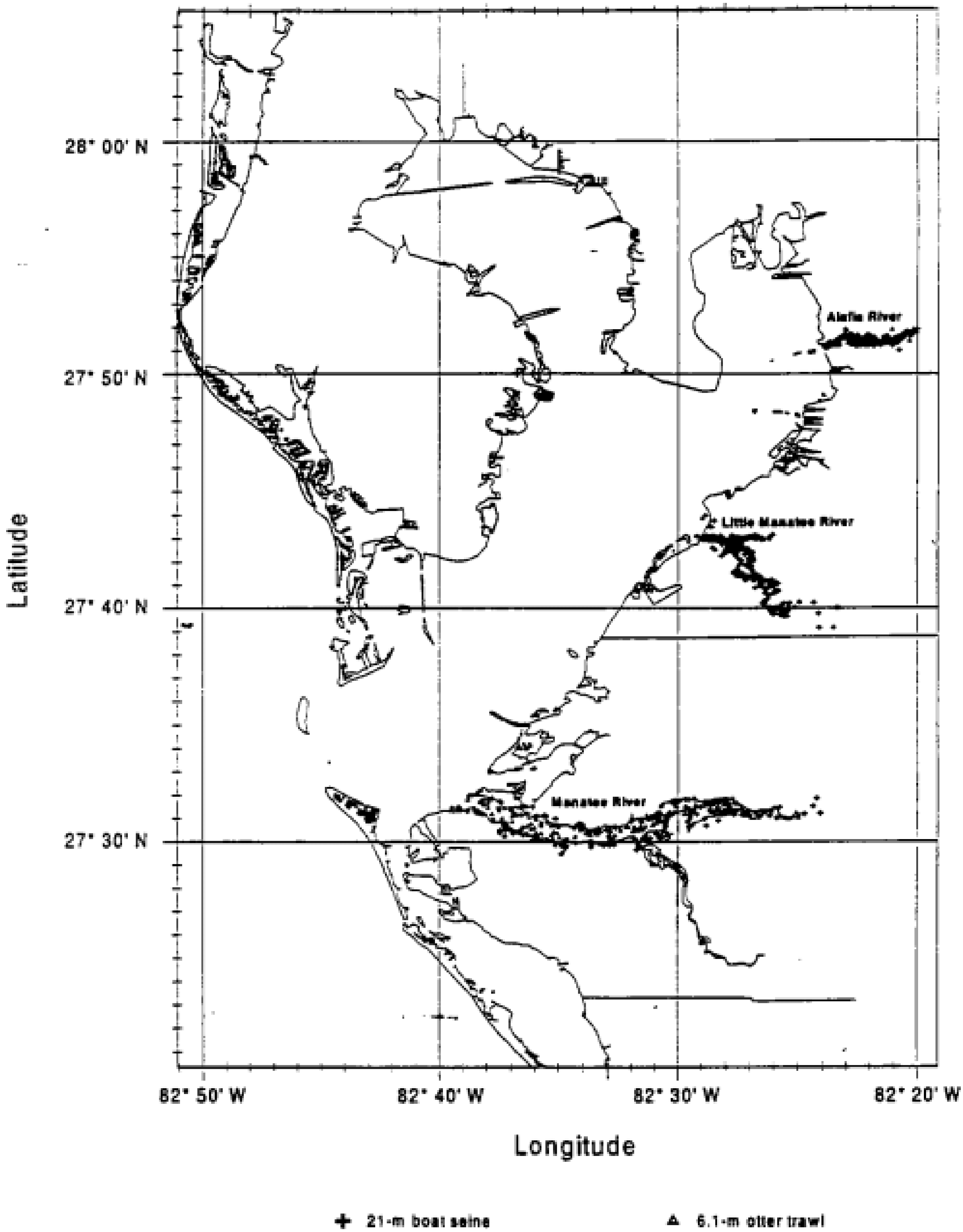
Density-Weighted Salinities

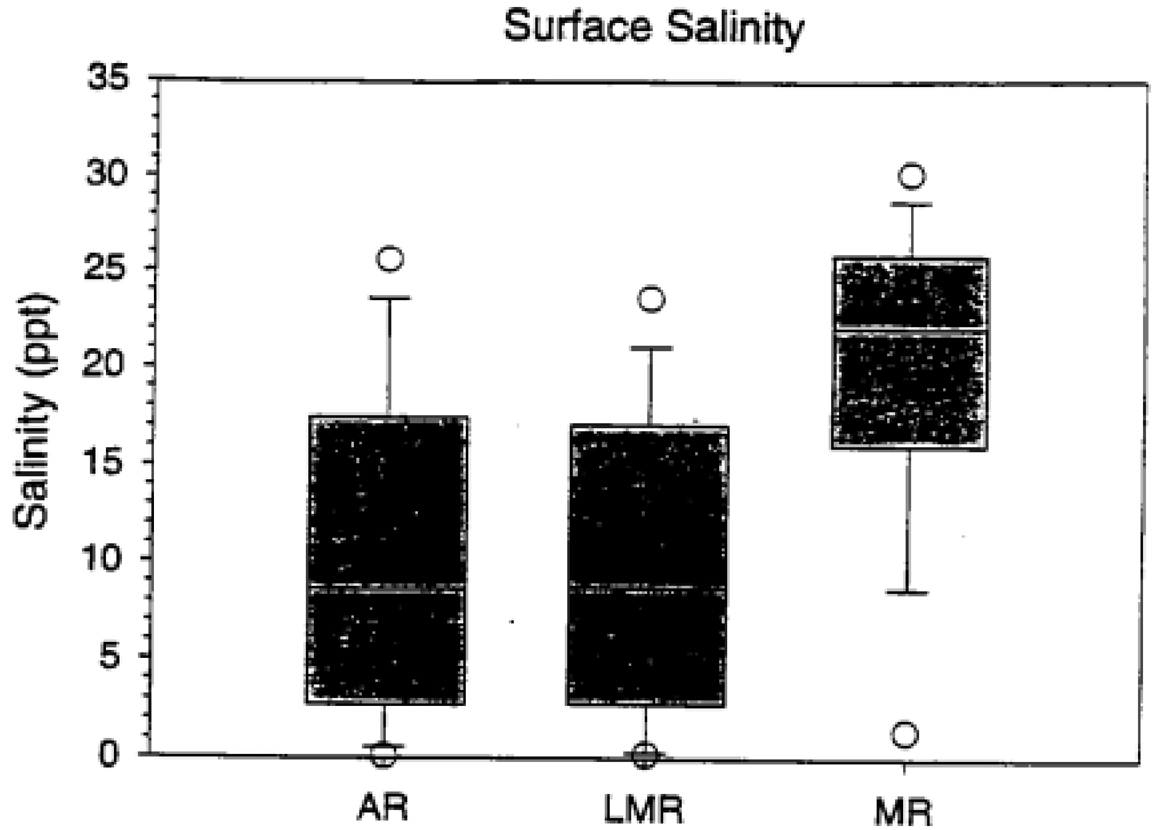


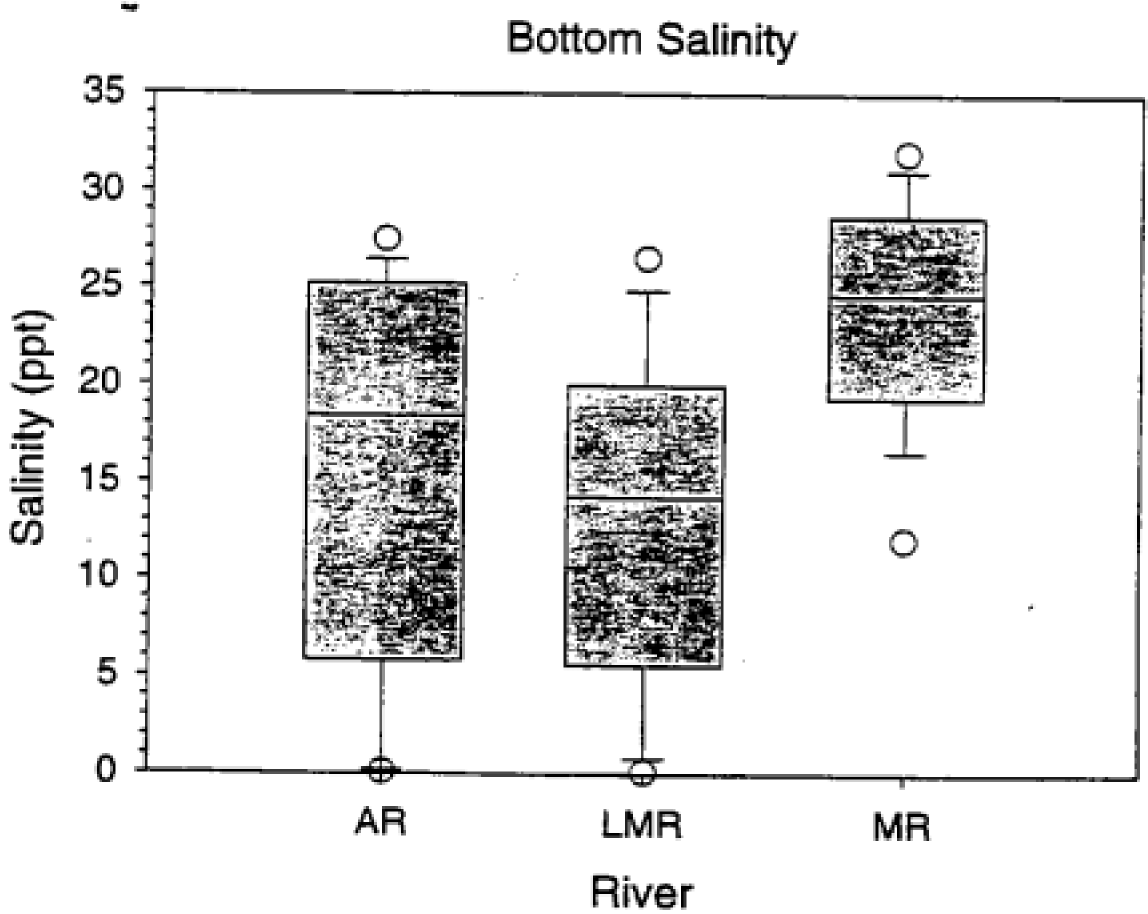
APPENDIX N-4

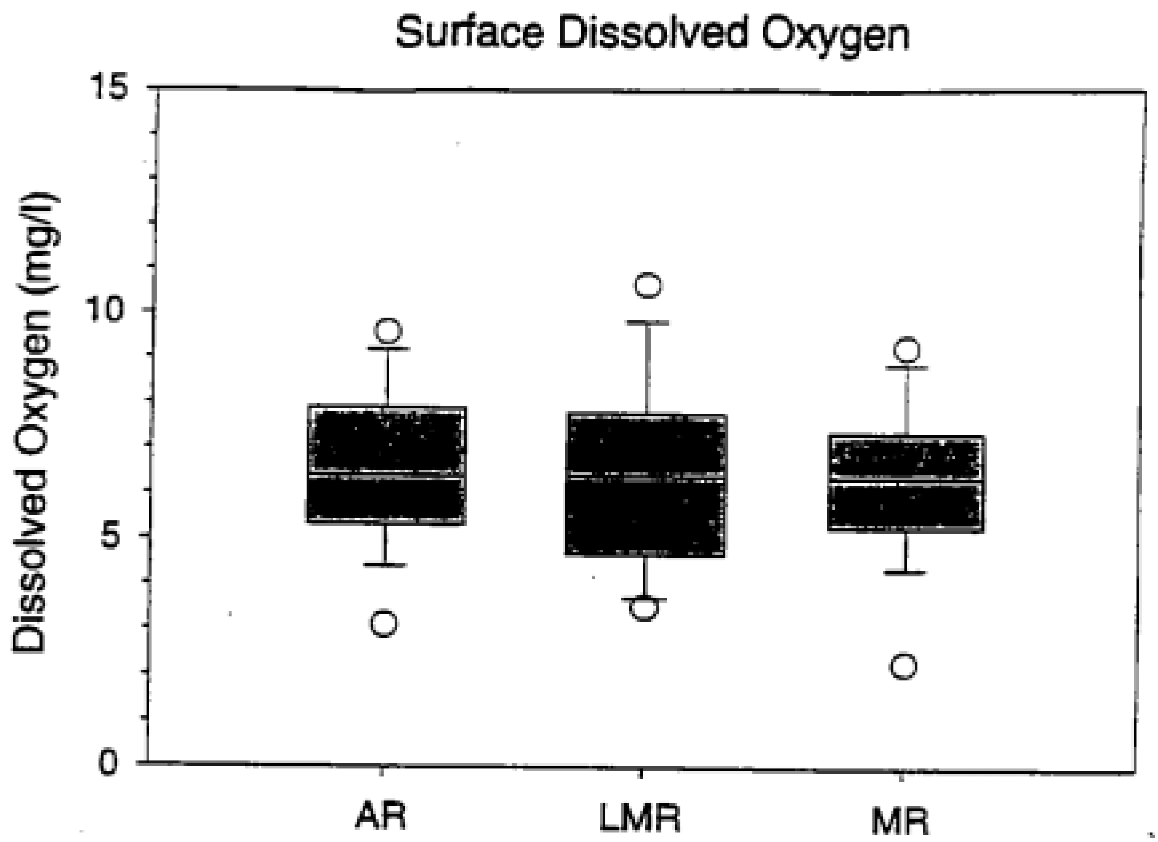
Results of analyses of fish catch data conducted by the Florida Department of Environmental Protection Florida Marine Research Institute.

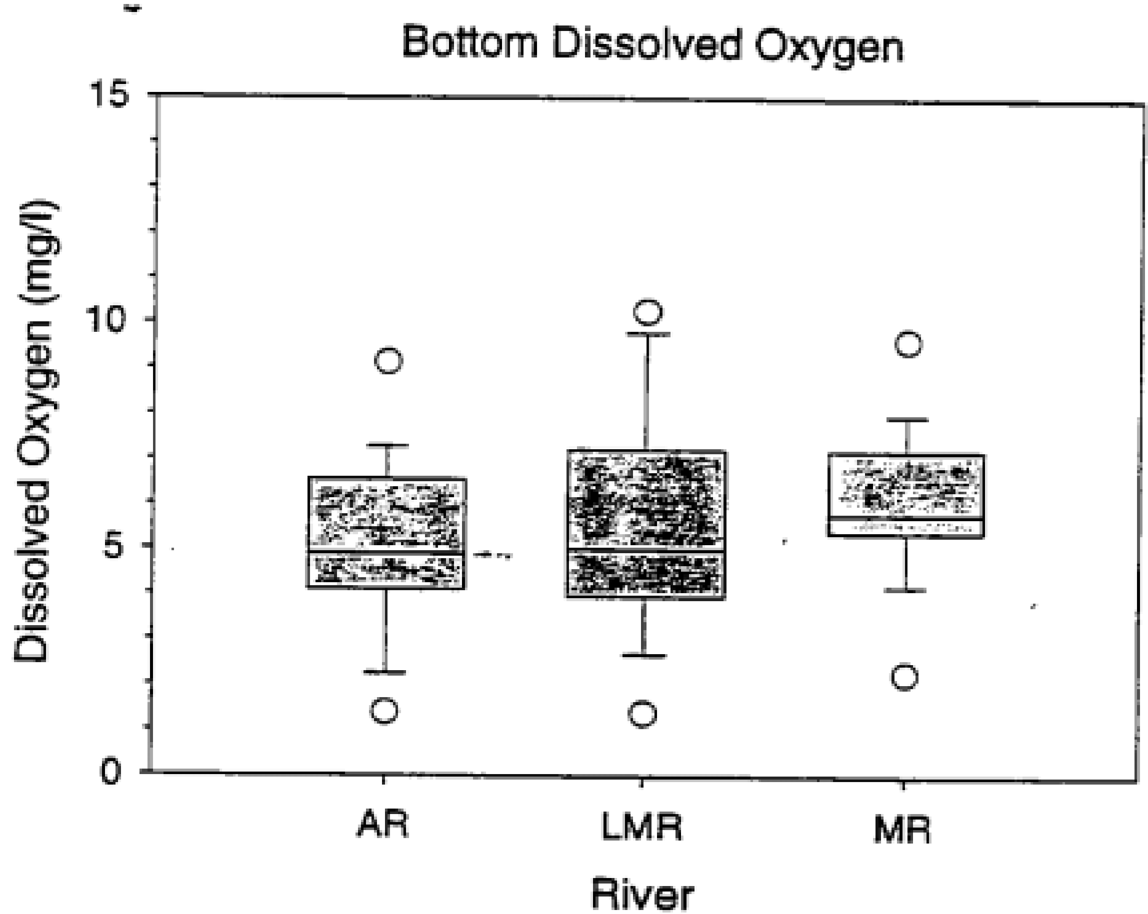
Alafia, Little Manatee and Manatee Rivers, 1994-1996
21-m boat seines and 6.1-m otter trawls only

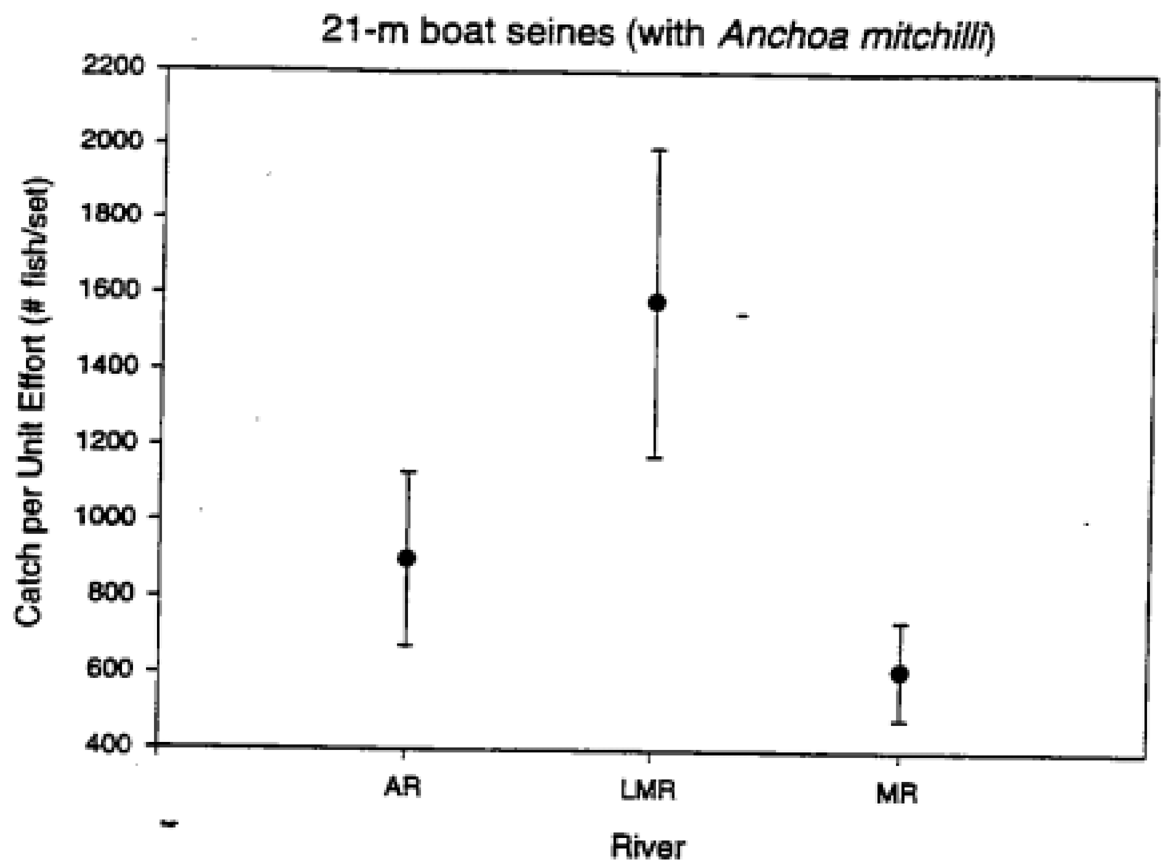


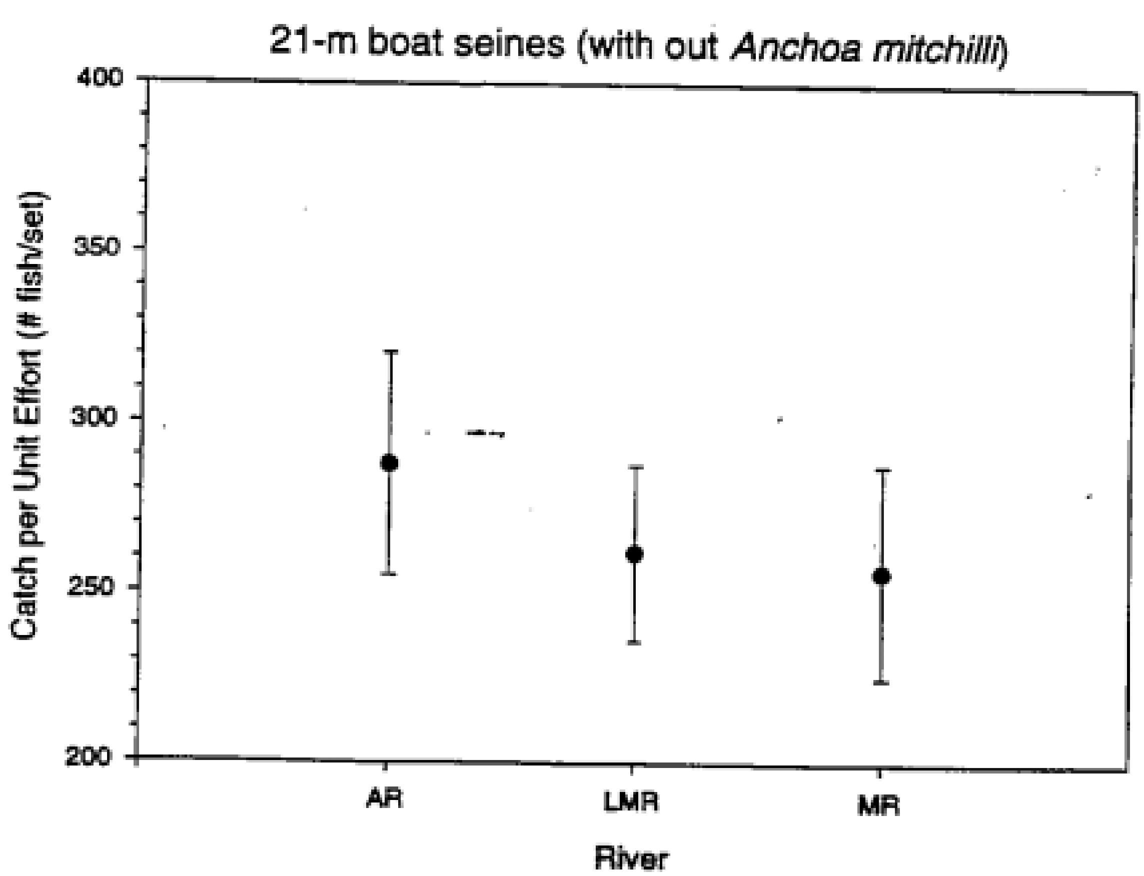

Surface Salinity
Salinity (ppt)
35
30
25
20
15
10
5
0
AR
LMR
MR

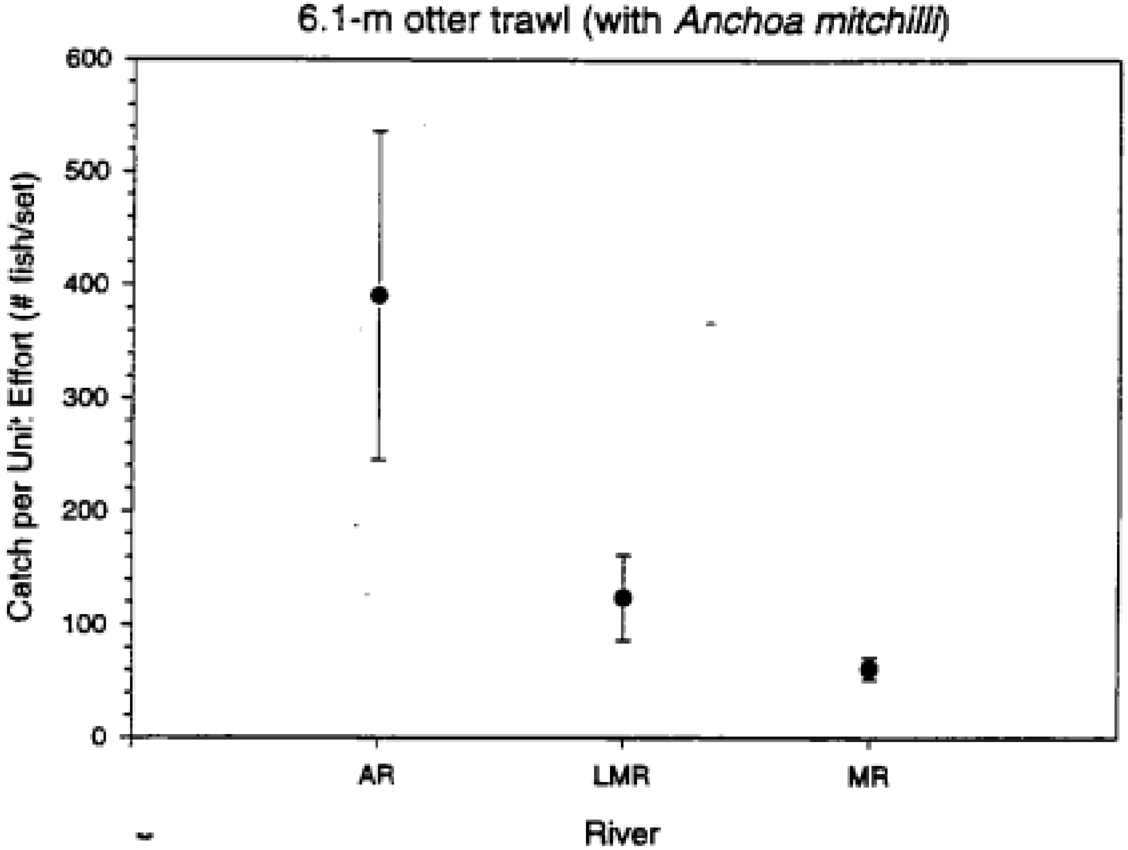

Bottom Salinity
Salinity (ppt)
35
30
25
20
15
10
5
0
AR
LMR
MR
River

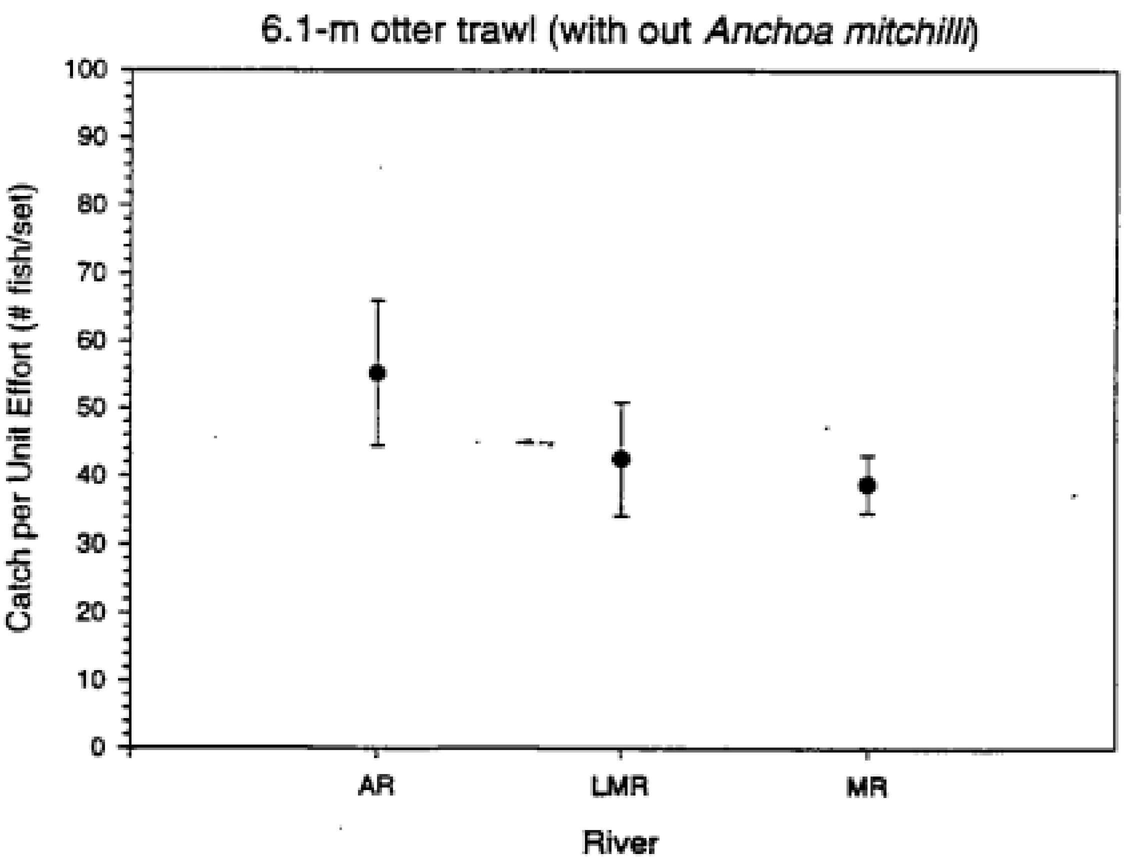

Surface Dissolved Oxygen
Dissolved Oxygen (mg/l)
15
10
5
0
AR
LMR
MR


Bottom Dissolved Oxygen
Dissolved Oxygen (mg/l)
15
10
5
0
AR
LMR
MR
River


21-m boat seines (with Anchoa mitchilli)
Catch per Unit Effort (# fish/set)
2200
2000
1800
1600
1400
1200
1000
800
600
400
AR
LMR
MR
River


21-m boat seines (with out Anchoa mitchilli)
Catch per Unit Effort (# fish/set)
400
350
300
250
200
AR
LMR
MR
River


6.1-m otter trawl (with *Anchoa mitchilli*)
600
500
400
300
200
100
0
Catch per Unit Effort (# fish/set)
AR
LMR
MR
River


6.1-m otter trawl (with out *Anchoa mitchilli*)
100
90
80
70
60
50
40
30
20
10
0
Catch per Unit Effort (# fish/set)
AR
LMR
MR
River

Percent Similiarity among the three river systems. AR=Alafia River, LMR=Little Manatee River, MR=Manatee River

	AR	LMR	MR
AR	.	.	.
LMR	83.45	.	.
MR	82.60	71.65	.

Salinity Classifications

Salinity Range (ppt)	Classification
0.0 - 0.5	Freshwater
0.5 - 5.0	Oligohaline
5.0 - 11.0	Lower Mesohaline
11.0 - 18.0	Upper Mesohaline
>=18.0	Polyhaline

Number of samples collected by salinity classification and gear

	21-m Seines				6.1-m Otter Trawls			
	AR	LMR	MR	Total	AR	LMR	MR	Total
Freshwater	11	29	11	51	10	8	0	18
Oligohaline	46	43	5	94	5	14	2	21
Lower Mesohaline	35	25	17	77	6	15	2	23
Upper Mesohaline	29	34	28	91	12	25	19	56
Polyhaline	31	29	115	175	29	31	86	146
Total	**152**	**160**	**176**	**488**	**62**	**93**	**109**	**264**

Table 1. Table listing the mean catch per unit effort (# animals/set) and standard error, by salinity classification for each species collected by 21-m boat set seines during stratified-random sampling in the Alafia, Little Manatee and Manatee Rivers between 1994 and 1996. Salinity classifications are defined as freshwater (0-0.5 ppt), oligohaline (0.5-5 ppt), lower mesohaline (5-11 ppt), upper mesohaline (11-18ppt), polyhaline (>18ppt). The number in parentheses after the salinity classification indicates the number of samples taken within that classification. Shaded species represent species that are of direct commercial and/or recreational importance.

		Freshwater (51)		Oligohaline (94)		Lower Mesohaline (77)		Upper Mesohaline (91)		Polyhaline (175)	
Species	Number	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Anchoa mitchilli	371,293	38.25	19.96	116.94	36.57	840.52	305.77	1989.13	716.87	643.54	202.50
Menidia spp.	66,321	113.02	23.94	134.19	30.12	147.77	25.40	102.23	19.09	155.78	27.73
Eucinostomus spp.	8,605	3.94	1.10	17.14	4.93	22.84	8.92	22.20	5.86	17.22	3.70
Lucania parva	6,211	11.84	2.77	30.51	11.19	11.84	4.82	2.03	0.51	9.38	8.16
Gambusia holbrooki	5,723	72.90	24.97	16.11	5.49	4.70	1.85	0.29	0.15	0.59	0.40
Lagodon rhomboides	4,809	0.49	0.18	5.15	1.78	9.78	4.20	11.69	2.16	14.19	2.66
Fundulus majalis	4,387	0.73	0.39	1.69	1.37	4.45	2.03	11.74	6.22	15.89	5.50
Eucinostomus harengulus	4,338	3.08	1.00	6.77	2.24	8.35	3.27	9.63	1.67	11.58	1.80
Trinectes maculatus	2,584	21.78	5.21	8.26	2.07	1.70	0.37	0.86	0.25	2.79	1.13
Sciaenops ocellatus	2,501	1.14	0.74	5.05	1.13	8.39	3.66	4.13	0.99	5.41	3.21
Poecilia latipinna	2,442	17.10	8.52	3.15	1.09	4.08	2.78	1.66	1.07	4.62	3.35
Leiostomus xanthurus	2,137		.	7.01	5.81	1.29	0.57	4.13	1.28	5.73	1.81
Bairdiella chrysoura	2,060	0.04	0.03	1.01	0.58	9.55	5.33	7.77	3.40	2.98	1.10
Harengula jaguana	1,635	0.06	0.06	0.10	0.07	4.22	2.98	1.27	0.69	6.75	3.00
Mugil cephalus	1,473	1.18	0.82	1.01	0.98	3.81	2.67	6.53	4.82	2.46	0.82
Eucinostomus gula	1,372	0.04	0.04	0.15	0.12	1.12	0.73	3.37	1.16	5.50	1.09
Fundulus seminolis	1,331	11.80	4.34	7.27	2.53	0.55	0.55	0.01	0.01	0.02	0.01
Cyprinodon variegatus	1,193	0.20	0.13	0.07	0.04	4.42	3.39	6.01	4.93	1.65	1.02
Microgobius gulosus	1,143	2.10	0.60	1.67	0.35	3.13	1.26	2.30	0.75	2.45	0.88
Fundulus grandis	961	1.04	0.81	1.17	0.44	3.32	1.22	3.80	1.50	1.12	0.29
Gobiosoma spp.	911	5.25	1.32	1.18	0.31	2.47	0.78	1.26	0.26	1.30	0.33
Diapterus plumieri	834	3.02	1.42	1.79	0.35	2.61	0.65	1.41	0.52	1.05	0.36
Floridichthys carpio	825	.	.	0.01	0.01	6.13	4.10	0.64	0.39	1.68	0.71
Menticirrhus americanus	751	.	.	0.02	0.02	0.03	0.02	0.21	0.09	4.16	2.35
Penaeus duorarum	671	.	.	0.66	0.26	1.44	0.47	0.95	0.21	2.35	0.51
Notropis petersoni	451	8.69	6.23	0.09	0.09	.	.	.	.	.	.
Labidesthes sicculus	413	8.00	3.70	0.05	0.05	.	.	.	.	.	.
Brevoortia spp.	395	.	.	1.91	1.87	0.04	0.03	1.77	1.54	0.29	0.10

(Continued)

Species	Number	Freshwater (51) Mean	Freshwater (51) Stderr	Oligohaline (94) Mean	Oligohaline (94) Stderr	Lower Mesohaline (77) Mean	Lower Mesohaline (77) Stderr	Upper Mesohaline (91) Mean	Upper Mesohaline (91) Stderr	Polyhaline (175) Mean	Polyhaline (175) Stderr
Cynoscion nebulosus	377	0.02	0.02	0.47	0.16	1.13	0.33	0.90	0.26	0.93	0.25
Oligoplites saurus	347	0.02	0.02	0.20	0.09	0.56	0.20	0.70	0.20	1.26	0.41
Membras martinica	304	1.35	1.33	0.01	0.01	1.96	1.36	0.16	0.11	0.39	0.28
Opisthonema oglinum	272	4.90	3.59	0.06	0.06	0.01	0.01	.	.	0.09	0.06
Callinectes sapidus	255	0.43	0.16	0.30	0.06	0.16	0.05	0.43	0.12	0.88	0.23
Cynoscion arenarius	255	0.04	0.03	0.93	0.40	0.06	0.04	0.23	0.14	0.79	0.44
Tilapia spp.	222	0.18	0.11	0.51	0.39	1.01	0.91	0.01	0.01	0.49	0.30
Strongylura timucu	153	.	.	0.18	0.13	0.03	0.02	0.14	0.07	0.69	0.37
Orthopristis chrysoptera	149	.	.	.	.	.	.	0.24	0.16	0.73	0.28
Centropomus undecimalis	128	0.27	0.11	0.36	0.11	0.35	0.12	0.25	0.08	0.17	0.08
Strongylura notata	124	.	.	0.01	0.01	0.06	0.03	0.20	0.09	0.57	0.18
Archosargus probatocephalus	121	0.16	0.07	0.39	0.09	0.30	0.15	0.35	0.15	0.12	0.05
Achirus lineatus	110	0.02	0.02	.	.	0.21	0.17	0.12	0.05	0.47	0.14
Mugil gyrans	99	.	.	0.03	0.02	0.14	0.13	0.82	0.75	0.06	0.03
Synodus foetens	90	.	.	.	.	.	.	0.04	0.02	0.49	0.10
Notropis maculatus	87	1.71	1.71	.	.	.	.	.	.	.	.
Lepomis macrochirus	80	0.96	0.46	0.33	0.19	.	.	.	.	.	.
Fundulus confluentus	74	1.22	0.83	0.13	0.12	.	.	.	.	.	.
Strongylura spp.	73	0.02	0.02	0.17	0.10	0.08	0.04	0.04	0.02	0.26	0.10
Arius felis	71	.	.	0.06	0.03	0.49	0.38	0.14	0.07	0.08	0.08
Syngnathus scovelli	71	.	.	0.16	0.08	0.13	0.05	0.08	0.03	0.22	0.06
Sphoeroides nephelus	63	.	.	0.01	0.01	.	.	.	.	0.35	0.07
Symphurus plagiusa	56	.	.	0.08	0.05	0.03	0.03	0.05	0.03	0.25	0.10
Prionotus scitulus	52	.	.	.	.	0.01	0.01	0.03	0.03	0.27	0.09
Micropterus salmoides	51	0.24	0.12	0.38	0.21	0.04	0.03	.	.	.	.
Trachinotus falcatus	51	.	.	.	.	.	.	.	.	0.29	0.29
Strongylura marina	49	0.02	0.02	0.01	0.01	0.01	0.01	0.05	0.04	0.23	0.08
Anchoa hepsetus	48	.	.	0.07	0.05	0.09	0.04	0.09	0.06	0.15	0.10
Pogonias cromis	48	.	.	0.01	0.01	.	.	0.02	0.02	0.26	0.18
Heterandria formosa	42	0.57	0.23	0.09	0.05	.	.	.	.	0.03	0.02
Notropis spp.	40	0.78	0.45	.	.	.	.	.	.	.	.
Bathygobius soporator	37	0.02	0.02	.	.	0.06	0.03	0.10	0.04	0.13	0.04
Lucania goodei	36	0.51	0.38	0.10	0.07	.	.	.	.	0.01	0.01

(Continued)

Species	Number	Freshwater (51) Mean	Freshwater (51) Stderr	Oligohaline (94) Mean	Oligohaline (94) Stderr	Lower Mesohaline (77) Mean	Lower Mesohaline (77) Stderr	Upper Mesohaline (91) Mean	Upper Mesohaline (91) Stderr	Polyhaline (175) Mean	Polyhaline (175) Stderr
Paralichthys albigutta	32	.	.	.	.	.	.	.	.	0.18	0.07
Gobiesox strumosus	28	.	.	.	.	0.01	0.01	0.07	0.03	0.12	0.05
Menticirrhus saxatilis	28	.	.	.	.	0.06	0.06	0.02	0.02	0.12	0.04
Adinia xenica	27	0.02	0.02	0.17	0.10	0.01	0.01	0.10	0.10	.	.
Lepomis spp.	27	0.51	0.37	0.01	0.01	.	.	.	.	.	.
Syngnathus louisianae	27	.	.	0.03	0.02	0.01	0.01	0.03	0.02	0.11	0.03
Fundulus spp.	19	0.06	0.06	0.09	0.06	0.04	0.04	0.05	0.05	.	.
Elops saurus	15	.	.	0.06	0.04	0.01	0.01	0.02	0.02	0.03	0.02
Etropus spp.	10	.	.	.	.	.	.	0.11	0.11	.	.
Lepomis microlophus	10	0.18	0.11	0.01	0.01	.	.	.	.	.	.
Belonesox belizanus	9	.	.	0.04	0.04	0.06	0.06	.	.	.	.
Prionotus tribulus	8	.	.	.	.	.	.	.	.	0.05	0.02
Chasmodes saburrae	7	.	.	.	.	.	.	0.02	0.02	0.03	0.01
Dasyatis sabina	7	.	.	.	.	.	.	0.01	0.01	0.03	0.02
Gymnura micrura	6	.	.	.	.	.	.	.	.	0.03	0.03
Lutjanus griseus	6	.	.	.	.	.	.	0.01	0.01	0.03	0.02
Microgobius thalassinus	6	.	.	.	.	.	.	.	.	0.03	0.03
Caranx hippos	5	.	.	.	.	0.01	0.01	0.02	0.02	0.01	0.01
Chaetodipterus faber	4	.	.	.	.	.	.	0.01	0.01	0.02	0.01
Lepisosteus osseus	4	0.02	0.02	0.02	0.01	.	.	0.01	0.01	.	.
Opsanus beta	4	.	.	.	.	0.01	0.01	0.02	0.02	0.01	0.01
Lepisosteus platyrhincus	3	0.04	0.03	0.01	0.01	.	.	.	.	.	.
Lepomis gulosus	3	0.02	0.02	0.02	0.02	.	.	.	.	.	.
Mugil curema	3	.	.	.	.	0.03	0.02	.	.	0.01	0.01
Rhinoptera bonasus	3	.	.	.	.	0.01	0.01	0.01	0.01	0.01	0.01
Syngnathus floridae	3	.	.	.	.	.	.	.	.	0.02	0.01
Ameiurus catus	2	0.04	0.03	.	.	.	.	.	.	.	.
Hippocampus zosterae	2	.	.	.	.	.	.	.	.	0.01	0.01
Hypostomus spp.	2	.	.	0.02	0.01	.	.	.	.	.	.
Hypsoblennius hentzi	2	.	.	.	.	.	.	.	.	0.01	0.01
Micropterus punctulatus	2	0.02	0.02	.	.	0.01	0.01	.	.	.	.
Sphyraena picudilla	2	.	.	.	.	.	.	.	.	0.01	0.01
Chilomycterus schoepfi	1	.	.	.	.	.	.	.	.	0.01	0.01

(Continued)

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Species	Number	Freshwater (51) Mean	Freshwater (51) Stderr	Oligohaline (94) Mean	Oligohaline (94) Stderr	Lower Mesohaline (77) Mean	Lower Mesohaline (77) Stderr	Upper Mesohaline (91) Mean	Upper Mesohaline (91) Stderr	Polyhaline (175) Mean	Polyhaline (175) Stderr
Cichlidae spp.	1	.	.	0.01	0.01	.	.	.	.	.	.
Elopidae spp.	1	.	.	0.01	0.01	.	.	.	.	.	.
Gambusia spp.	1	.	.	.	.	.	.	.	.	.	.
Hyporhamphus unifasciatus	1	.	.	.	.	.	.	.	.	0.01	0.01
Hypostomus plecostomus	1	0.02	0.02	.	.	.	.	.	.	0.01	0.01
Jordanella floridae	1	0.02	0.02	.	.	.	.	.	.	.	.
Lepomis punctatus	1	0.02	0.02	.	.	.	.	.	.	.	.
Micropogonias undulatus	1	.	.	.	.	.	.	.	.	0.01	0.01
Selene vomer	1	.	.	.	.	.	.	.	.	0.01	0.01
Totals	502,131	340.08	48.51	375.67	57.07	1115.78	305.89	2202.77	719.27	932.04	206.07

Table 2. Table listing the mean catch per unit effort (# animals/set) and standard error, by salinity classification for each species collected by 6.1-m otter trawls during stratified-random sampling in the Alafia, Little Manatee and Manatee Rivers between 1994 and 1996. Salinity classifications are defined as freshwater (0-0.5 ppt), oligohaline (0.5-5 ppt), lower mesohaline (5-11 ppt), upper mesohaline (11-18ppt), polyhaline (>18ppt). The number in parentheses after the salinity classification indicates the number of samples taken within that classification. Shaded species represent species that are of direct commercial and/or recreational importance.

		Freshwater (18)		Oligohaline (21)		Lower Mesohaline (23)		Upper Mesohaline (56)		Polyhaline (146)	
Species	Number	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Anchoa mitchilli	15,119	2.28	1.47	130.19	73.39	79.13	54.16	38.25	13.89	57.41	18.69
Cynoscion arenarius	1,643	0.39	0.23	2.43	1.56	4.17	2.65	2.66	0.80	9.18	4.25
Trinectes maculatus	1,531	52.00	18.82	5.81	2.21	3.78	1.27	5.20	1.50	0.65	0.17
Menticirrhus americanus	1,408	.	.	3.95	3.71	0.78	0.66	3.34	0.85	7.67	2.84
Penaeus duorarum	1,296	.	.	1.52	0.88	1.52	0.69	8.07	3.31	5.32	1.19
Callinectes sapidus	731	0.72	0.21	1.48	0.85	1.52	0.51	3.25	0.61	3.22	0.44
Arius felis	714	0.72	0.35	2.57	1.38	3.57	2.02	5.21	2.18	1.87	0.73
Eucinostomus gula	593	.	.	.	.	0.04	0.04	0.52	0.23	3.86	0.83
Bairdiella chrysoura	569	.	.	1.71	1.57	0.04	0.04	3.61	2.26	2.26	0.71
Eucinostomus spp.	418	0.11	0.08	1.10	0.77	4.39	3.41	1.09	0.48	1.58	0.73
Prionotus scitulus	247	.	.	0.05	0.05	.	.	0.38	0.36	1.54	0.27
Orthopristis chrysoptera	217	.	.	.	.	.	.	0.75	0.70	1.20	0.34
Symphurus plagiusa	208	.	.	0.76	0.71	.	.	1.34	0.53	0.80	0.22
Leiostomus xanthurus	174	0.06	0.06	1.00	0.86	1.36	1.26	0.02	0.02	0.82	0.25
Eucinostomus harengulus	170	0.83	0.45	0.48	0.30	0.26	0.22	1.05	0.36	0.55	0.15
Chaetodipterus faber	154	.	.	0.10	0.10	.	.	0.46	0.20	0.86	0.38
Lagodon rhomboides	148	.	.	0.43	0.22	1.87	1.28	0.39	0.21	0.51	0.11
Dasyatis sabina	147	.	.	0.62	0.37	0.17	0.08	0.21	0.06	0.81	0.14
Microgobius gulosus	136	0.28	0.19	0.95	0.59	0.48	0.24	0.41	0.12	0.53	0.12
Sciaenops ocellatus	117	1.39	1.27	1.95	1.07	1.39	1.06	0.11	0.05	0.09	0.05
Gobiosoma spp.	93	0.17	0.12	0.81	0.36	0.43	0.22	0.23	0.08	0.34	0.10
Microgobius thalassinus	91	.	.	0.05	0.05	.	.	0.71	0.42	0.34	0.09
Pogonias cromis	84	.	.	3.62	3.32	0.13	0.10	0.09	0.09	.	.
Achirus lineatus	61	.	.	0.29	0.21	.	.	0.13	0.05	0.33	0.10
Archosargus probatocephalus	58	0.22	0.10	0.38	0.18	0.43	0.25	0.16	0.08	0.16	0.05
Synodus foetens	55	.	.	.	.	0.04	0.04	0.07	0.04	0.34	0.07
Anchoa hepsetus	49	.	.	.	.	.	.	.	.	0.34	0.19
Paralichthys albigutta	46	.	.	.	.	.	.	0.05	0.04	0.29	0.06

(Continued)

Species	Number	Freshwater (18)		Oligohaline (21)		Lower Mesohaline (23)		Upper Mesohaline (56)		Polyhaline (148)	
		Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Diapterus plumieri	40	0.39	0.23	1.00	0.54	0.17	0.14	0.13	0.11	0.01	0.01
Chilomycterus schoepfi	39	.	.	.	.	.	.	0.02	0.02	0.26	0.07
Cynoscion nebulosus	39	.	.	0.19	0.15	0.09	0.06	0.13	0.06	0.18	0.07
Chloroscombrus chrysurus	36	.	.	0.38	0.38	.	.	0.34	0.34	0.06	0.03
Syngnathus louisianae	31	.	.	.	.	0.04	0.04	0.07	0.03	0.18	0.05
Menticirrhus spp.	27	.	.	.	.	.	.	0.07	0.04	0.16	0.13
Opsanus beta	26	.	.	.	.	.	.	0.04	0.03	0.16	0.05
Prionotus tribulus	26	.	.	0.05	0.05	0.04	0.04	0.07	0.03	0.14	0.05
Sphoeroides nephelus	26	.	.	.	.	.	.	0.04	0.03	0.16	0.06
Bagre marinus	25	0.06	0.06	0.05	0.05	0.09	0.06	0.18	0.16	0.08	0.04
Gobiesox strumosus	25	.	.	.	.	0.22	0.18	0.07	0.04	0.11	0.05
Ictalurus punctatus	24	1.28	0.98	0.05	0.05	.	.	.	.	.	.
Menticirrhus saxatilis	23	.	.	.	.	.	.	.	.	0.16	0.11
Syngnathus scovelli	19	.	.	0.10	0.10	0.13	0.10	0.09	0.04	0.06	0.03
Gymnura micrura	16	.	.	0.19	0.19	.	.	0.02	0.02	0.08	0.02
Etropus crossotus	12	.	.	.	.	.	.	.	.	0.08	0.03
Dasyatis say	10	.	.	.	.	.	.	.	.	0.07	0.03
Menippe mercenaria	9	.	.	.	.	.	.	.	.	0.06	0.04
Lepisosteus osseus	8	0.06	0.06	.	.	0.09	0.09	0.05	0.03	0.01	0.01
Menidia spp.	7	.	.	0.05	0.05	0.13	0.13	0.02	0.02	0.01	0.01
Ameiurus catus	6	0.22	0.17	0.10	0.07	.	.	.	.	.	.
Lactophrys quadricornis	6	.	.	.	.	.	.	.	.	0.04	0.02
Lutjanus griseus	6	.	.	.	.	.	.	0.05	0.04	0.02	0.01
Opisthonema oglinum	6	.	.	0.05	0.05	0.17	0.17	.	.	0.01	0.01
Harengula jaguana	4	.	.	.	.	.	.	.	.	0.03	0.02
Monacanthus hispidus	4	.	.	.	.	.	.	.	.	0.03	0.02
Urophycis floridana	4	.	.	.	.	.	.	.	.	0.03	0.02
Centropomus undecimalis	3	.	.	0.14	0.10	.	.	.	.	.	.
Micropogonias undulatus	3	.	.	.	.	.	.	.	.	0.02	0.02
Rhinoptera bonasus	3	.	.	.	.	.	.	.	.	0.02	0.01
Selene vomer	3	.	.	.	.	.	.	.	.	0.02	0.02
Chasmodes saburrae	2	.	.	.	.	.	.	0.02	0.02	0.01	0.01
Gunterichthys longipenis	2	.	.	.	.	.	.	0.04	0.03	.	.

(Continued)

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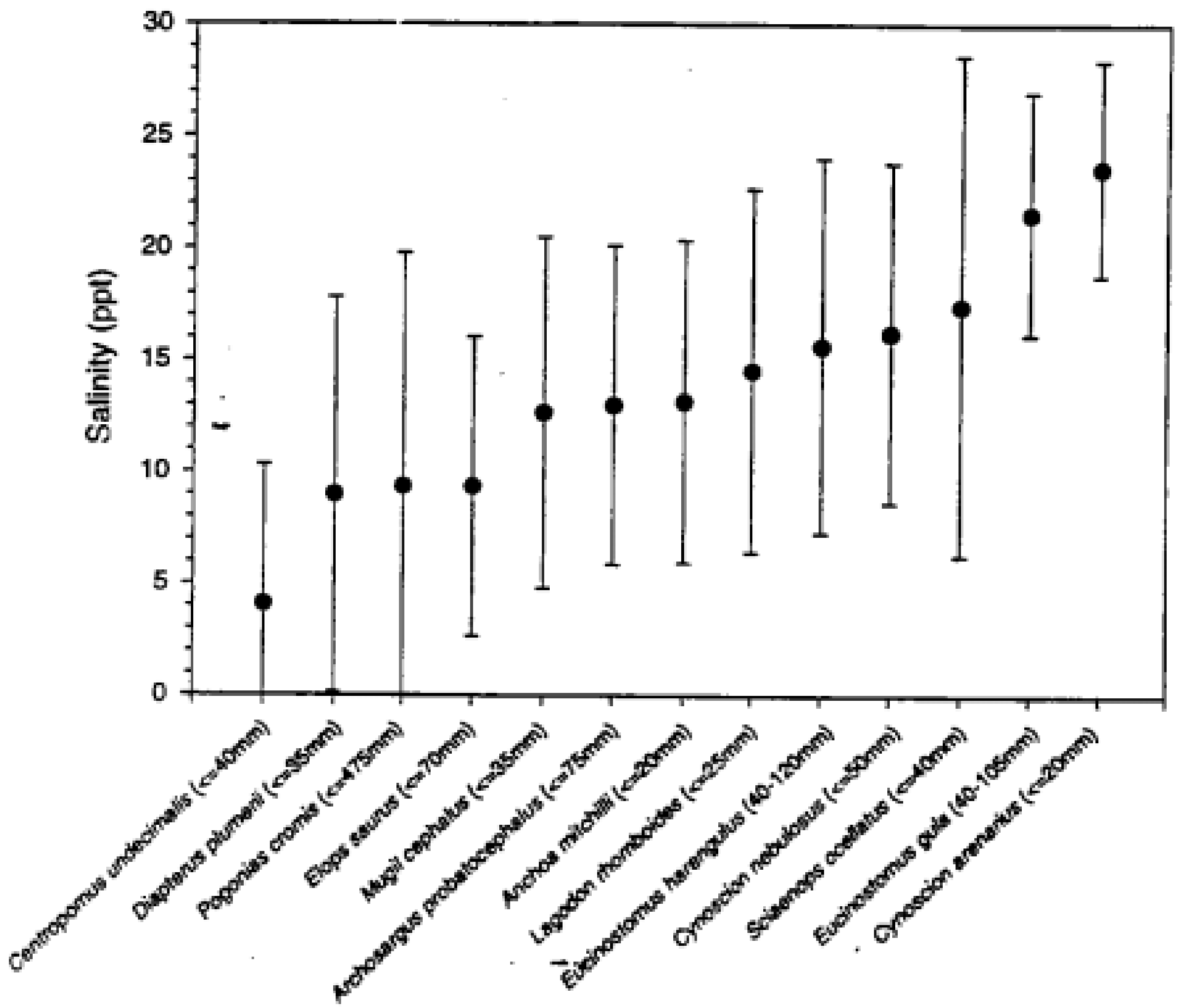
Species	Number	Freshwater (18)		Oligohaline (21)		Lower Mesohaline (23)		Upper Mesohaline (56)		Polyhaline (146)	
		Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Ictalurus spp.	2	.	.	0.10	0.07	.	.	.	.	.	.
Lucania parva	2	0.06	0.06	0.05	0.05	.	.	.	.	.	.
Lutjanus synagris	2	.	.	.	.	.	.	.	.	0.01	0.01
Menippe spp.	2	.	.	.	.	.	.	.	.	0.01	0.01
Notropis spp.	2	.	.	.	.	.	.	.	.	0.01	0.01
Aluterus schoepfi	1	.	.	.	.	.	.	.	.	0.01	0.01
Ameiurus nebulosus	1	0.06	0.06	.	.	.	.	.	.	.	.
Ancylopsetta quadrocellata	1	.	.	.	.	.	.	.	.	0.01	0.01
Bathygobius soporator	1	.	.	.	.	.	.	.	.	0.01	0.01
Blenniidae spp.	1	.	.	.	.	.	.	0.02	0.02	.	.
Brevoortia spp.	1	.	.	.	.	.	.	.	.	0.01	0.01
Carangidae spp.	1	.	.	.	.	.	.	.	.	0.01	0.01
Clupeidae spp.	1	.	.	.	.	.	.	.	.	0.01	0.01
Hippocampus zosterae	1	.	.	.	.	.	.	.	.	0.01	0.01
Lepisosteus platyrhincus	1	.	.	.	.	.	.	.	.	0.01	0.01
Microgobius spp.	1	.	.	.	.	.	.	0.02	0.02	.	.
Mugil cephalus	1	.	.	.	.	.	.	.	.	0.01	0.01
Rachycentron canadum	1	.	.	.	.	.	.	.	.	0.01	0.01
Sphoeroides spengleri	1	.	.	.	.	.	.	.	.	0.01	0.01
Strongylura timucu	1	.	.	.	.	.	.	.	.	0.01	0.01
Totals	**26,820**	**61.28**	**18.68**	**164.71**	**73.30**	**106.74**	**55.07**	**79.27**	**14.45**	**105.24**	**21.96**

Density-Weighted Mean Salinities for species collected in ten or more samples. Species are s[illegible] in order from lowest mean salinity to highest mean salinity.

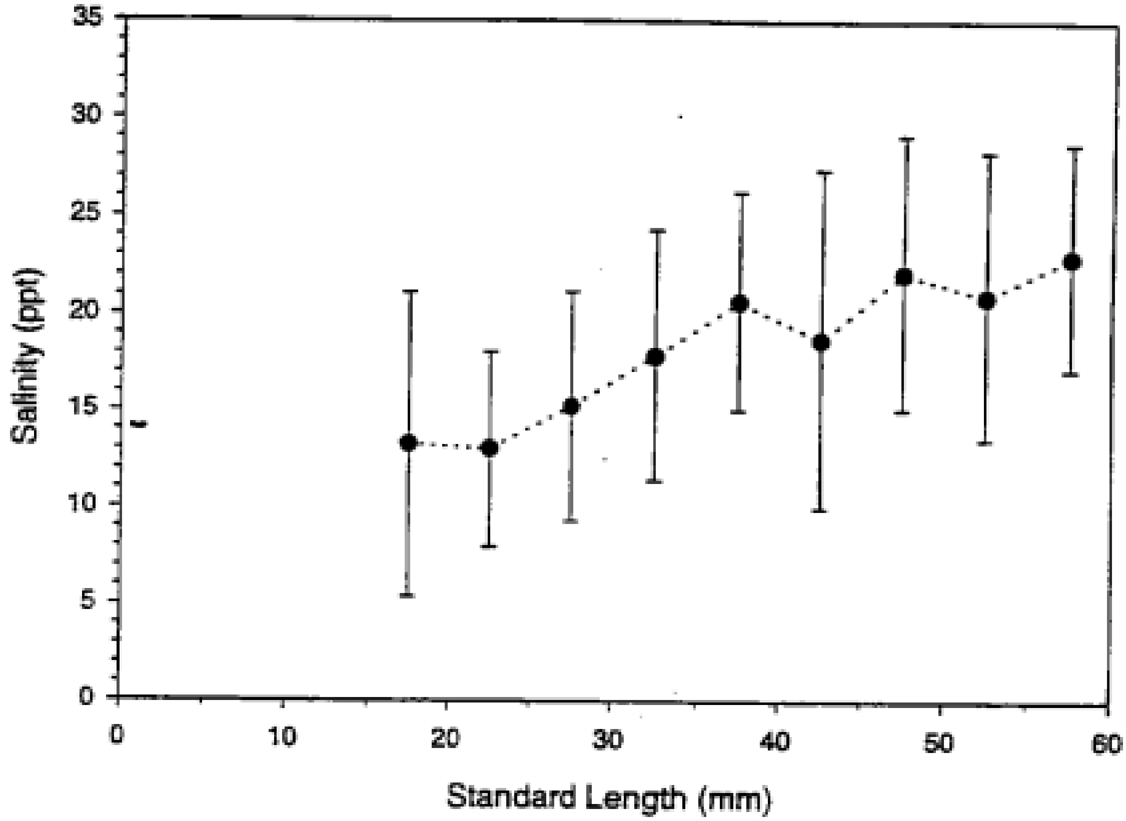
Species	Lengths Analyzed (mm)	Density-Weighted Salinity Mean	Std
Labidesthes sicculus	<= 65	0.11	0.12
Notropis petersoni	<= 55	0.22	0.15
Lepomis macrochirus	<= 165	0.68	1.07
Micropterus salmoides	<= 205	0.99	1.43
Fundulus seminolis	<= 105	1.36	1.92
Opisthonema oglinum	<= 160	1.66	5.95
Gambusia holbrooki	<= 45	1.89	3.29
Heterandria formosa	<= 30	2.80	5.83
Trinectes maculatus	<= 25	3.30	6.27
Centropomus undecimalis	<= 40	4.05	6.24
Diapterus plumieri	<= 35	8.97	8.84
Pogonias cromis	<= 475	9.32	10.45
Elops saurus	<= 70	9.34	6.70
Membras martinica	<= 55	9.73	8.55
Gobiosoma spp.	<= 50	9.77	8.90
Tilapia spp.	<= 295	10.04	6.88
Lepisosteus osseus	<= 1155	10.43	8.39
Lucania parva	<= 50	11.05	12.34
Poecilia latipinna	<= 75	11.95	12.74
Fundulus grandis	<= 105	12.03	7.12
Archosargus probatocephalus	<= 75	12.65	7.86
Brevoortia spp.	<= 35	12.97	5.44
Mugil cephalus	<= 35	12.98	7.14
Anchoa mitchilli	<= 20	13.14	7.21
Microgobius gulosus	<= 75	13.26	8.43
Menidia spp.	<= 110	13.66	9.37
Eucinostomus spp.	<= 75	13.87	7.99
Lagodon rhomboides	<= 25	14.53	8.14
Cyprinodon variegatus	<= 55	14.77	6.12
Callinectes sapidus	<= 30	14.92	8.13
Floridichthys carpio	<= 65	15.47	7.63
Eucinostomus harengulus	40-120	15.64	8.37
Cynoscion nebulosus	<= 50	16.22	7.61
Mugil gyrans	<= 170	16.67	4.19
Syngnathus scovelli	<= 115	16.77	9.62
Arius felis	<= 365	17.10	7.71

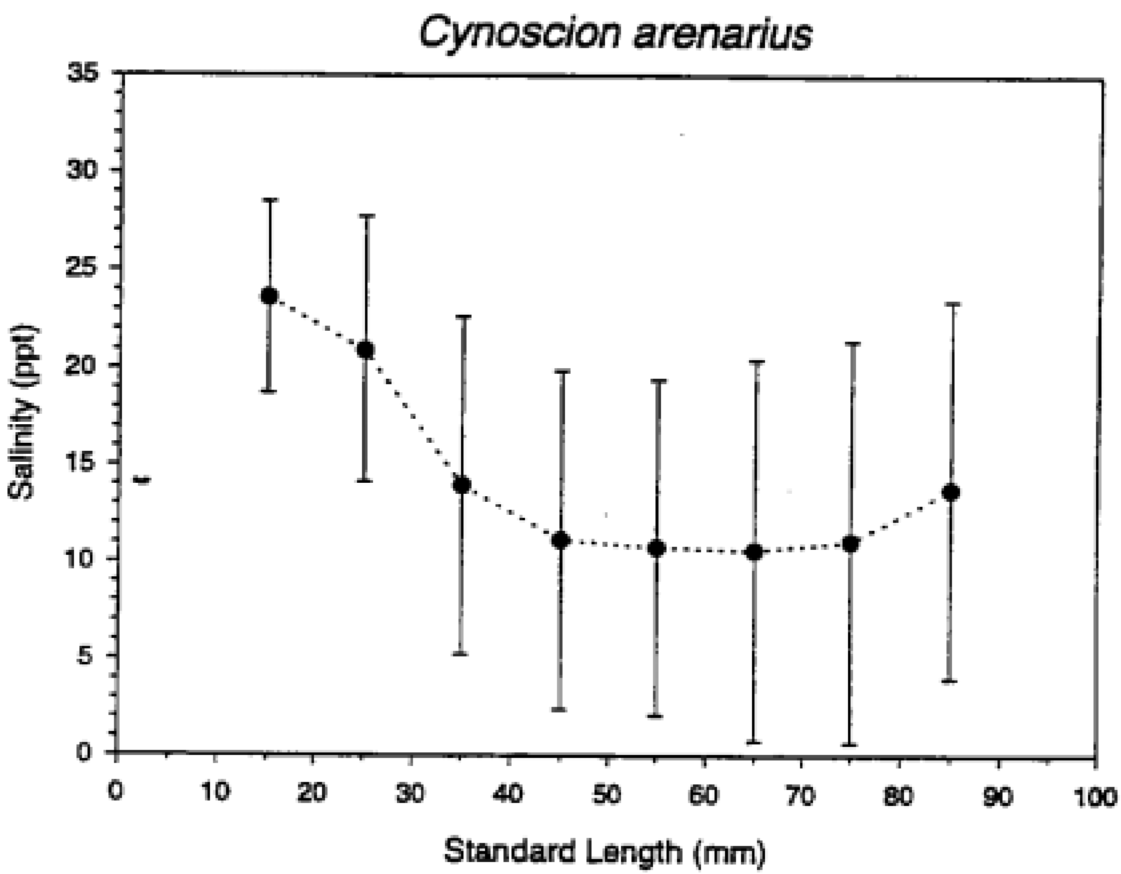
Species	Lengths Analyzed (mm)	Density-Weighted Salinity Mean	Std
Sciaenops ocellatus	<= 40	17.43	[illegible]
Bathygobius soporator	<= 75	17.89	[illegible]
Oligoplites saurus	<= 100	18.19	[illegible]
Penaeus duorarum	<= 45	18.52	[illegible]
Symphurus plagiusa	<= 70	18.60	[illegible]
Bairdiella chrysoura	<= 30	19.08	[illegible]
Bagre marinus	<= 515	19.26	[illegible]
Harengula jaguana	<= 115	19.53	[illegible]
Strongylura timucu	<= 425	19.65	[illegible]
Fundulus majalis	<= 100	19.72	[illegible]
Gobiesox strumosus	<= 40	19.74	[illegible]
Chasmodes saburrae	<= 60	19.97	[illegible]
Lutjanus griseus	<= 215	20.12	[illegible]
Strongylura marina	<= 420	20.16	[illegible]
Achirus lineatus	<= 40	20.92	[illegible]
Gymnura micrura	<= 480	21.20	[illegible]
Microgobius thalassinus	<= 65	21.53	[illegible]
Eucinostomus gula	40-105	21.56	[illegible]
Strongylura notata	<= 390	21.95	[illegible]
Leiostomus xanthurus	<= 30	22.11	[illegible]
Dasyatis sabina	<= 365	22.33	[illegible]
Opsanus beta	<= 245	22.45	[illegible]
Orthopristis chrysoptera	<= 35	22.67	[illegible]
Syngnathus louisianae	<= 265	23.14	[illegible]
Prionotus tribulus	<= 95	23.21	[illegible]
Chaetodipterus faber	<= 50	23.23	[illegible]
Anchoa hepsetus	<= 30	23.50	[illegible]
Menticirrhus saxatilis	<= 190	23.56	[illegible]
Cynoscion arenarius	<= 20	23.59	[illegible]
Synodus foetens	<= 75	23.86	3.39
Sphoeroides nephelus	<= 30	24.12	[illegible]
Prionotus scitulus	<= 55	24.31	[illegible]
Menticirrhus americanus	<= 25	24.44	[illegible]
Paralichthys albigutta	<= 310	25.71	[illegible]
Chilomycterus schoepfi	<= 225	27.86	[illegible]

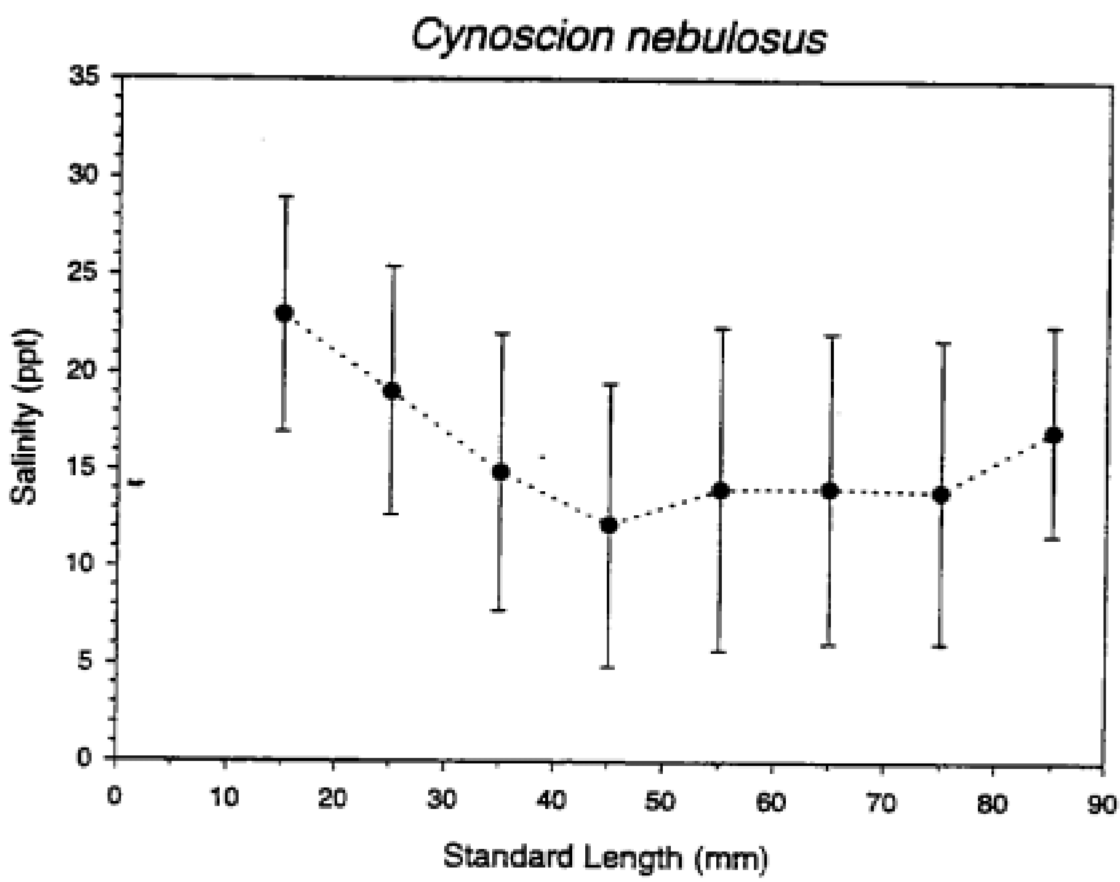
Density-Weighted Salinities



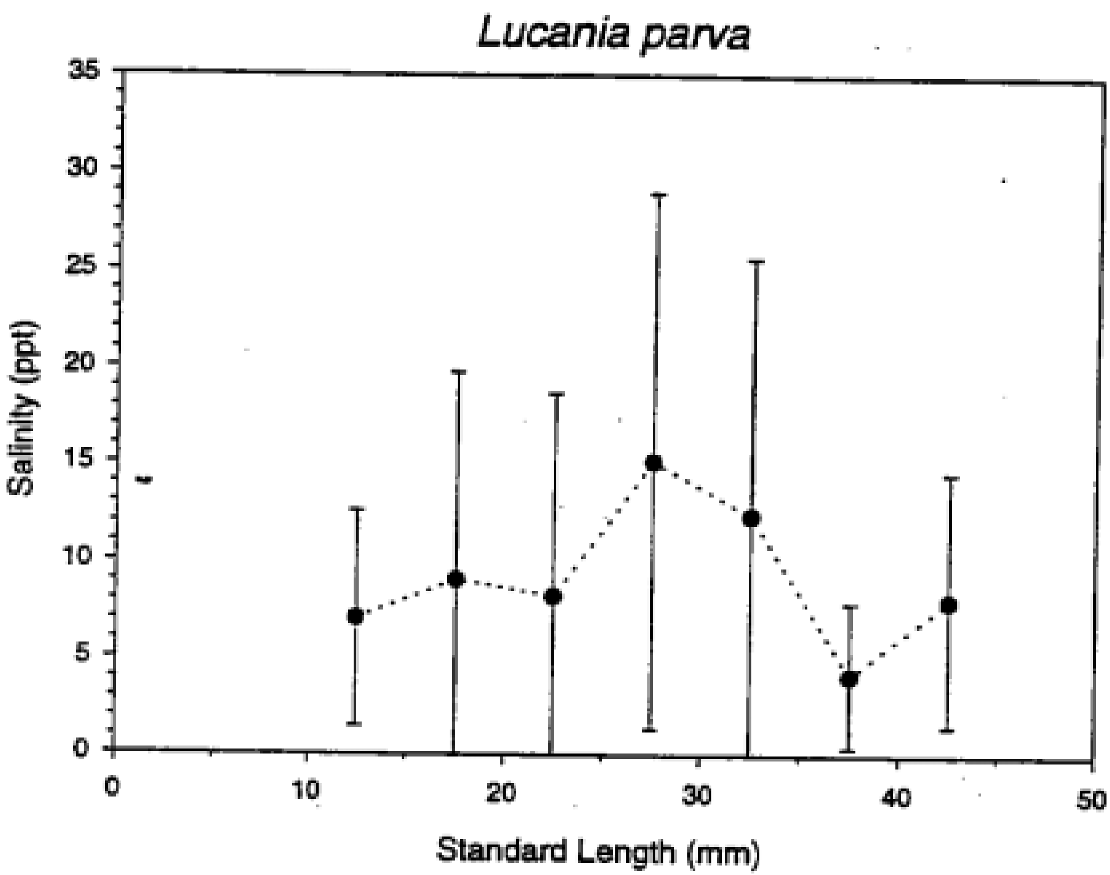
Anchoa mitchilli



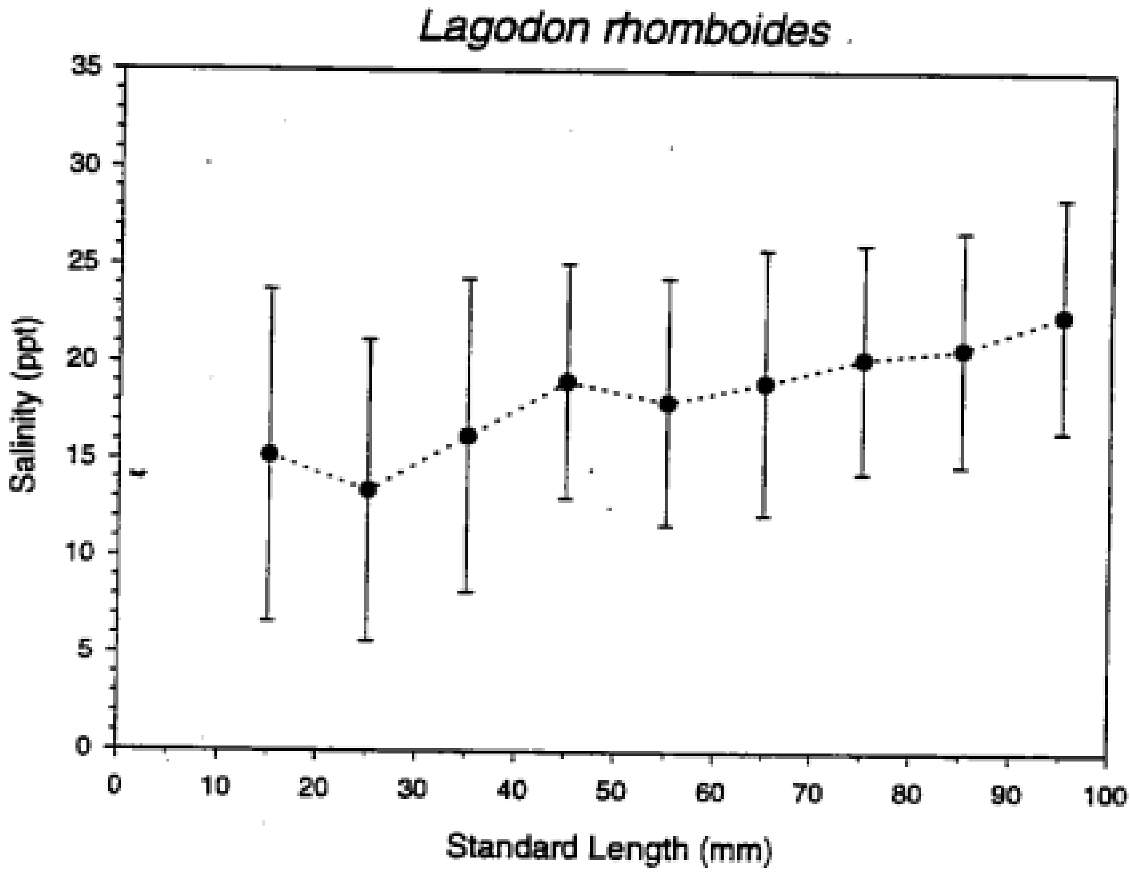

Cynoscion arenarius
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Standard Length (mm)

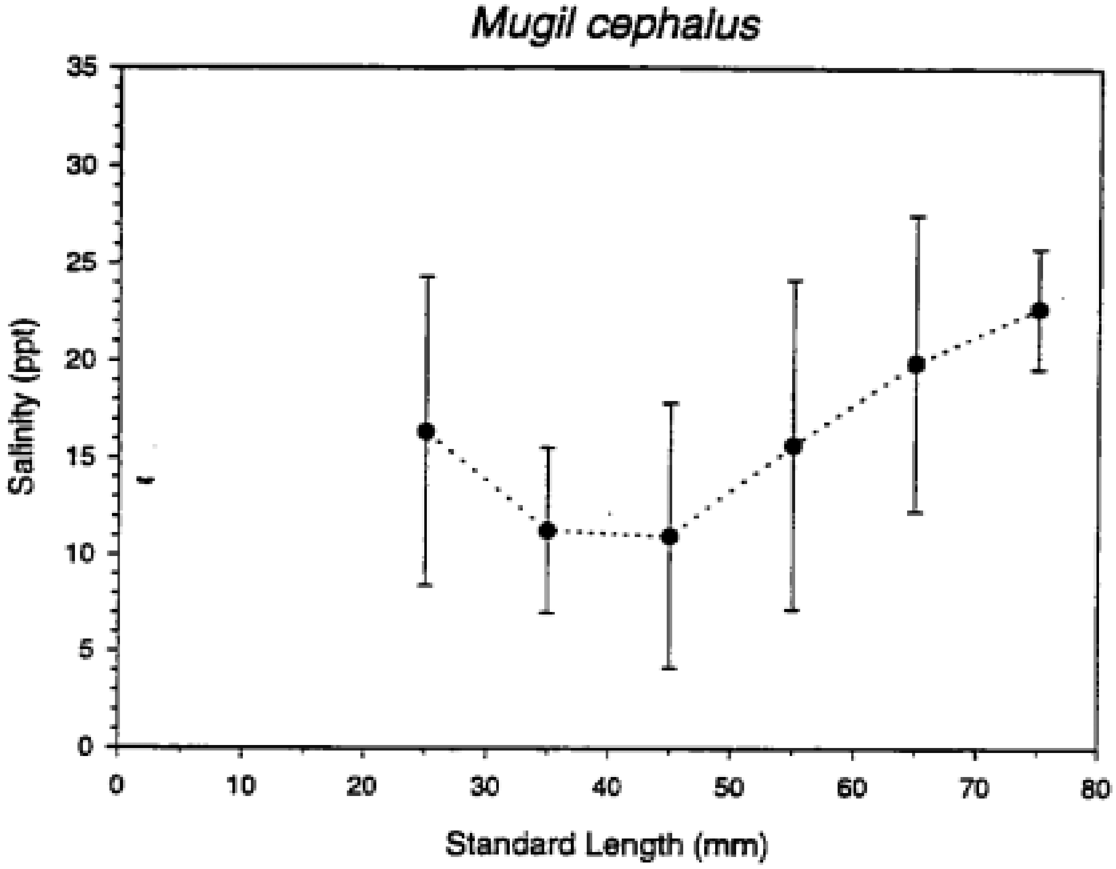


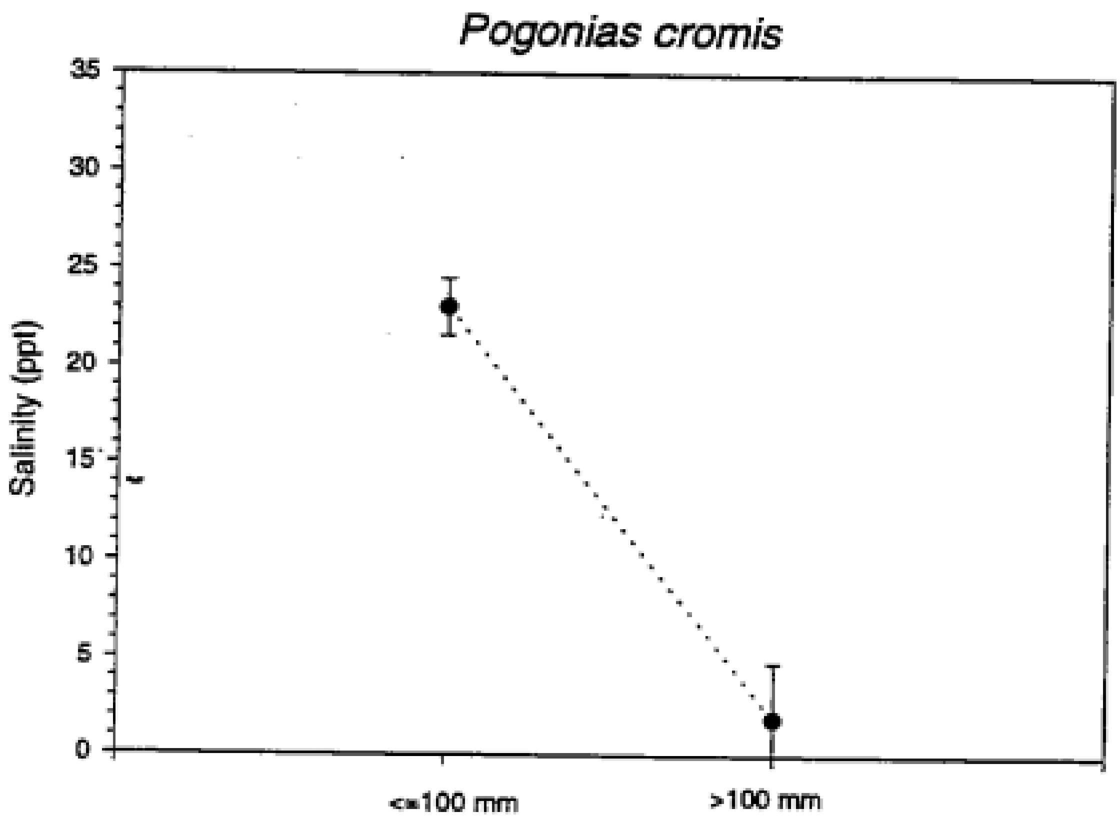
Cynoscion nebulosus
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
Standard Length (mm)

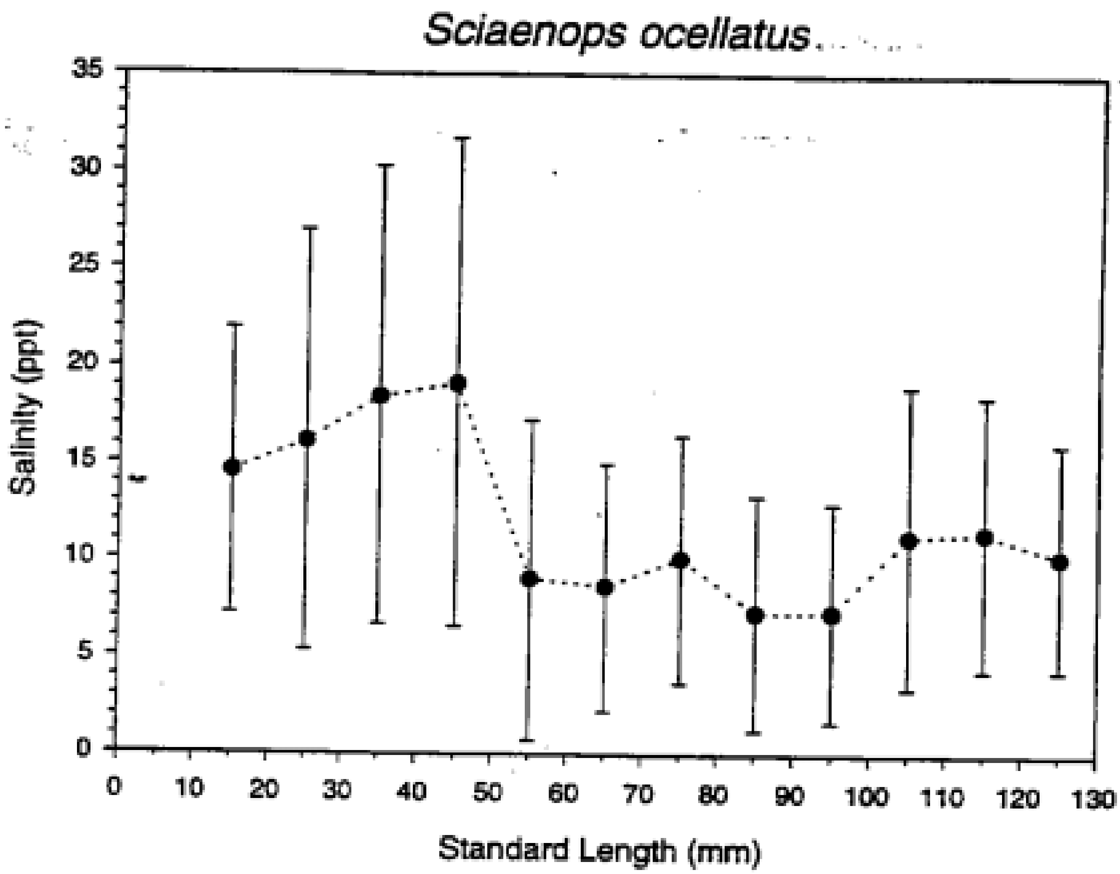


Lucania parva
Salinity (ppt)
Standard Length (mm)
0
5
10
15
20
25
30
35
0
10
20
30
40
50


Lagodon rhomboides
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Standard Length (mm)


Mugil cephalus
Salinity (ppt)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
Standard Length (mm)


Pogonias cromis
35
30
25
20
15
10
5
0
Salinity (ppt)
<=100 mm
>100 mm


Sciaenops ocellatus
Salinity (ppt)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Standard Length (mm)

Number of samples collected by shoreline classification

	AR	LMR	MR	Total
Unveg	6	8	11	25
Emmergent	67	86	90	243
Overhanging	59	56	39	154
Hardened	20	14	36	70
Total	**152**	**164**	**176**	**492**

Table 3. Table listing the mean catch per unit effort (# animals/set) and standard error, by shore vegetation classification for each species collected by 21-m boat set seines during stratified-random sampling in the Alafia, Little Manatee and Manatee Rivers between 1994 and 1996. The number in parentheses after the shore vegetation classification indicates the number of samples taken within that classification. Shaded species represent species that are of direct commercial and/or recreational importance.

Species	Number	Unvegetate (25) Mean	Unvegetate (25) Stderr	Emmergent (243) Mean	Emmergent (243) Stderr	Overhanging (154) Mean	Overhanging (154) Stderr	Hardened (70) Mean	Hardened (70) Stderr
Anchoa mitchilli	373,266	219.92	145.07	1050.40	291.44	345.38	142.23	847.60	377.19
Menidia spp.	66,423	165.04	51.13	133.88	20.08	141.71	22.28	113.46	24.03
Eucinostomus spp.	8,762	3.12	1.27	21.67	4.15	10.61	2.18	25.43	7.27
Lucania parva	8,248	15.24	5.40	11.12	6.01	19.91	7.03	1.43	0.44
Gambusia holbrooki	5,971	55.36	36.59	8.90	2.95	15.17	5.94	1.27	1.06
Lagodon rhomboides	4,820	2.76	1.82	10.76	1.95	9.67	1.69	9.47	4.56
Eucinostomus harengulus	4,417	11.40	8.89	9.14	1.42	8.34	1.14	8.97	2.92
Fundulus majalis	4,390	12.16	4.43	13.96	4.57	4.31	1.36	0.43	0.25
Trinectes maculatus	2,595	6.64	3.15	2.45	0.69	11.57	2.27	0.73	0.29
Sciaenops ocellatus	2,546	3.92	2.24	6.03	2.35	2.67	0.56	6.19	3.90
Poecilia latipinna	2,506	5.16	2.47	4.93	2.57	7.18	2.98	1.07	0.55
Leiostomus xanthurus	2,137	8.84	7.24	3.82	0.96	5.80	3.59	1.34	0.63
Bairdiella chrysoura	2,061	1.88	1.76	4.53	1.81	3.85	1.78	4.57	2.79
Harengula jaguana	1,673	0.72	0.72	4.83	2.18	0.67	0.37	5.41	3.19
Eucinostomus gula	1,514	0.52	0.35	3.59	0.70	1.31	0.66	6.10	2.02
Mugil cephalus	1,474	15.88	8.43	1.34	0.56	4.61	2.75	0.81	0.74
Fundulus seminolis	1,331	16.88	8.82	1.82	0.74	2.58	1.09	0.97	0.57
Cyprinodon variegatus	1,197	2.04	1.18	4.16	2.24	0.84	0.39	0.10	0.05
Microgobius gulosus	1,144	1.44	0.59	1.56	0.30	2.76	0.73	4.36	2.11
Fundulus grandis	1,010	6.24	3.86	1.95	0.54	2.08	0.59	0.87	0.39
Gobiosoma spp.	911	1.84	0.92	1.55	0.30	2.03	0.44	2.50	0.81
Diapterus plumieri	838	2.48	1.05	1.07	0.28	2.70	0.58	1.44	0.59
Floridichthys carpio	825	1.64	1.39	2.58	1.37	0.59	0.34	0.96	0.62
Menticirrhus americanus	751	0.12	0.09	2.73	1.69	0.44	0.26	0.24	0.13
Penaeus duorarum	671	0.16	0.12	1.06	0.22	1.41	0.40	2.79	0.88
Notropis petersoni	451	.	.	1.25	1.24	0.91	0.72	0.11	0.11
Labidesthes sicculus	413	5.92	5.92	0.13	0.11	1.52	0.80		
Brevoortia spp.	395	.	.	0.76	0.58	1.32	1.14	0.10	0.08
Cynoscion nebulosus	380	0.52	0.48	0.77	0.16	0.60	0.12	1.27	0.57

(Continued)

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Species	Number	Unvegetate (25) Mean	Unvegetate (25) Stderr	Emmergent (243) Mean	Emmergent (243) Stderr	Overhanging (154) Mean	Overhanging (154) Stderr	Hardened (70) Mean	Hardened (70) Stderr
Oligoplites saurus	348	0.56	0.35	0.79	0.27	0.36	0.09	1.23	0.52
Membras martinica	304	2.72	2.72	0.08	0.04	0.91	0.57	1.09	1.09
Opisthonema oglinum	272	.	.	0.22	0.17	1.38	1.17	0.09	0.09
Callinectes sapidus	256	0.60	0.34	0.34	0.05	0.61	0.09	1.14	0.53
Cynoscion arenarius	255	.	.	0.37	0.16	1.01	0.50	0.14	0.06
Tilapia spp.	222	0.12	0.12	0.14	0.08	0.73	0.39	1.03	1.00
Strongylura timucu	156	.	.	0.27	0.12	0.55	0.39	0.07	0.04
Orthopristis chrysoptera	149	.	.	0.52	0.21	0.10	0.06	0.10	0.09
Centropomus undecimalis	134	0.32	0.21	0.24	0.06	0.32	0.08	0.26	0.13
Strongylura notata	125	0.08	0.08	0.32	0.12	0.05	0.02	0.53	0.18
Archosargus probatocephalus	123	0.20	0.16	0.09	0.02	0.42	0.08	0.46	0.23
Achirus lineatus	112	0.04	0.04	0.36	0.11	0.03	0.01	0.29	0.14
Mugil gyrans	99	.	.	0.08	0.05	0.48	0.44	0.07	0.04
Synodus foetens	90	0.04	0.04	0.27	0.06	0.10	0.04	0.13	0.05
Notropis maculatus	87	.	.	.	.	0.56	0.56	.	.
Lepomis macrochirus	80	.	.	0.03	0.03	0.47	0.19	.	.
Fundulus confluentus	74	1.00	0.70	0.00	0.00	0.31	0.26	.	.
Strongylura spp.	73	0.36	0.32	0.19	0.07	0.10	0.04	0.04	0.02
Arius felis	71	0.04	0.04	0.15	0.12	0.20	0.10	0.04	0.04
Syngnathus scovelli	71	0.20	0.08	0.15	0.04	0.13	0.05	0.13	0.05
Sphoeroides nephelus	65	0.08	0.06	0.19	0.05	0.02	0.01	0.19	0.08
Symphurus plagiusa	56	.	.	0.16	0.07	0.08	0.04	0.06	0.03
Prionotus scitulus	52	.	.	0.15	0.05	0.10	0.06	0.01	0.01
Micropterus salmoides	51	0.08	0.08	0.05	0.03	0.24	0.12	.	.
Trachinotus falcatus	51	.	.	0.21	0.21	.	.	.	.
Anchoa hepsetus	49	0.20	0.20	0.07	0.03	0.01	0.01	0.36	0.24
Strongylura marina	49	0.20	0.20	0.07	0.04	0.15	0.07	0.07	0.05
Pogonias cromis	48	.	.	0.18	0.13	0.03	0.01	.	.
Heterandria formosa	42	0.32	0.32	0.08	0.04	0.10	0.04	.	.
Notropis spp.	40	0.32	0.32	0.03	0.03	0.16	0.13	.	.
Bathygobius soporator	39	.	.	0.12	0.03	0.03	0.01	0.09	0.03
Lucania goodei	36	.	.	0.10	0.08	0.08	0.05	.	.
Paralichthys albigutta	32	0.04	0.04	0.12	0.06	.	.	0.03	0.02

(Continued)

Species	Number	Unvegetate (25)		Emmergent (243)		Overhanging (154)		Hardened (70)	
		Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Gobiesox strumosus	28	.	.	0.06	0.03	0.06	0.02	0.07	0.05
Menticirrhus saxatilis	28	.	.	0.10	0.04	.	.	0.04	0.02
Adinia xenica	27	.	.	0.05	0.04	0.09	0.06	0.03	0.02
Lepomis spp.	27	.	.	0.00	0.00	0.17	0.12	.	.
Syngnathus louisianae	27	.	.	0.07	0.02	0.04	0.02	0.06	0.03
Fundulus spp.	19	.	.	0.05	0.03	0.05	0.03	.	.
Elops saurus	15	.	.	0.02	0.01	0.06	0.03	0.01	0.01
Etropus spp.	10	.	.	0.04	0.04	.	.	.	.
Lepomis microlophus	10	.	.	.	.	0.06	0.04	.	.
Belonesox belizanus	9	.	.	.	.	0.03	0.03	0.07	0.07
Prionotus tribulus	8	.	.	0.01	0.01	0.02	0.01	0.04	0.03
Chasmodes saburrae	7	.	.	0.01	0.01	.	.	0.07	0.03
Dasyatis sabina	7	.	.	0.01	0.01	0.03	0.02	0.01	0.01
Gymnura micrura	6	.	.	.	.	.	.	0.09	0.09
Lutjanus griseus	6	.	.	0.02	0.01	0.01	0.01	.	.
Microgobius thalassinus	6	.	.	.	.	.	.	0.09	0.07
Caranx hippos	5	.	.	0.02	0.01	.	.	.	.
Mugil curema	5	0.04	0.04	0.01	0.01	0.01	0.01	.	.
Chaetodipterus faber	4	0.04	0.04	0.00	0.00	.	.	0.03	0.03
Lepisosteus osseus	4	.	.	0.01	0.01	0.01	0.01	.	.
Opsanus beta	4	.	.	0.00	0.00	0.01	0.01	0.03	0.02
Lepisosteus platyrhincus	3	.	.	0.00	0.00	0.01	0.01	.	.
Lepomis gulosus	3	.	.	0.01	0.01	.	.	.	.
Rhinoptera bonasus	3	.	.	0.01	0.01	0.01	0.01	.	.
Syngnathus floridae	3	.	.	0.01	0.01	0.01	0.01	.	.
Ameiurus catus	2	.	.	0.00	0.00	0.01	0.01	.	.
Hippocampus zosterae	2	.	.	0.01	0.01	.	.	.	.
Hypostomus spp.	2	0.04	0.04	.	.	0.01	0.01	.	.
Hypsoblennius hentzi	2	.	.	0.00	0.00	.	.	0.01	0.01
Micropterus punctulatus	2	.	.	0.01	0.01	.	.	.	.
Sphyraena picudilla	2	.	.	0.01	0.01	.	.	.	.
Chilomycterus schoepfi	1	.	.	0.00	0.00	.	.	.	.
Cichlasoma octofasciatum	1	.	.	0.00	0.00	.	.	.	.

(Continued)

Species	Number	Unvegetate (25)		Emmergent (243)		Overhanging (154)		Hardened (70)	
		Mean	Stderr	Mean	Stderr	Mean	Stderr	Mean	Stderr
Cichlidae spp.	1	.	.	.	.	0.01	0.01	.	.
Elopidae spp.	1	.	.	.	.	0.01	0.01	.	.
Gambusia spp.	1	.	.	.	.	0.01	0.01	.	.
Hyporhamphus unifasciatus	1	.	.	0.00	0.00	.	.	.	.
Hypostomus plecostomus	1	.	.	.	.	0.01	0.01	.	.
Jordanella floridae	1	.	.	.	.	0.01	0.01	.	.
Lepomis punctatus	1	.	.	.	.	0.01	0.01	.	.
Micropogonias undulatus	1	.	.	0.00	0.00	.	.	.	.
Selene vomer	1	.	.	0.00	0.00	.	.	.	.
Totals	505,132	575.48	208.20	1319.42	293.07	622.77	146.10	1060.29	374.09

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