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EFFECT OF A STEAM ELECTRIC GENERATING STATION ON THE EMERGENCE TIMING OF MAYFLY, *HEXAGENIA BILINEATA* (Say)[1]

MASTER

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INTRODUCTION

Several investigators have hypothesized that thermal effluents from power plants could cause changes in patterns of insect emergence (Coutant, 1962; Bregman, 1969; Hawkes, 1969; Langford and Daffern 1975). They suggested that the changes could result in a detrimental impact on mayfly populations, because early emergence of adults into abnormally cold air would cause reduced survivorship and reproductive success (Langford 1975). Laboratory studies of temperature and emergence formed this basis of the hypothesis of change in emergence pattern and have continued to support it (Rothwell 1971; Nebeker 1971 a & b; Fremling 1973); however, few field studies have generated supportive data. Coutant (1968) found that caddis flies in the Columbia River emerged earlier in areas downstream from the Hanford nuclear reactors. The effect was probably thermally induced, since emergence above and below the plants occurred at similar temperatures. Rothwell (1971) found evidence to indicate a relatively early emergence of Trichoptera in a heated lake, but there was no control group for comparison. Alternatively, Rothwell (1971) could find no evidence for early emergence of several species of Chironomidae in this heated lake, and an extensive study by Langford and Daffern (1975) and Langford (1975) failed to demonstrate effects of heated water on emergence of Ephemeroptera, Megaloptera or Trichoptera on the River Severn in England. There has been no equivalent study of sites located on lakes or reservoirs. Because of the potential for power plant siting on mainstream reservoirs, there is a need for generation of data applicable for determining the potential for impact via changes in emergence pattern.

This paper presents results of a study of emergence of Hexagenia bilineata, a large burrowing mayfly with a wide distribution over areas of the southeast U. S. It is part of an ongoing analysis of mayfly population dynamics in relation to thermal effects. Evidence from our benthic collections of nymphs indicated that the maximum mean size was reached one month earlier in a thermally affected area than in two other areas (Auerbach et al., 1977). Preliminary laboratory studies indicated acceleration of growth and earlier emergence at higher temperatures (Dye and Mattice, unpublished data) and suggested the advisability of a field investigation of temperature effects on Hexagenia bilineata emergence patterns.

SITE DESCRIPTION

The study of emergence timing centered on the Kingston Steam Plant (Figure 1), a coal-fired electricity generating station near Kingston, Tennessee, U.S.A. (84 31'W, 35 54'N). The plant is made up of nine units generating 1600 megawatts of electrical energy. Plant intake water (3671 m^3 per minute when all units are operating) is drawn directly from a 1372 m intake canal which is separated from the Emory River by a skimmer wall. This wall has a 5 m opening 8 m below the water surface. The discharge-to-intake water temperature differential is 7.5 to 8.0 C. Operational specifications also call for intermittent chlorination of the condenser cooling water with addition of chlorine ranging from 499 to 2722 kg (1100 to 6000 lbs.) per day depending on time of year. Most of the plant discharge water is released directly to the Clinch River, but there is some circulation into the discharge cove.

Identification of the source of intake water is complicated. The plant is sited on a peninsula at the confluence of the Clinch and Emory Rivers. Both are part of the Watts Bar reservoir, a multiple use impoundment with a regular winter drawdown of approximately 2 meters. Watts Bar stratifies during the summer so that the intake water is hypolimnetic and is generally derived from the cooler flows of the Clinch River. During the winter, the intake water source is generally the Emory River, although occasionally Clinch River water is forced up the Emory and enters the intake.

The three specific areas of study were the intake canal and the reference and discharge coves (Figure 1). The intake and reference areas are unstratified throughout the year. In the discharge cove, a thermocline develops rapidly in late April at 4 to 5 meters and remains at about 5 m until its rapid disappearance in early October. About 30% of the cove bottom is below 5 m. Further differences found between the coves include some sewage input to the reference cove and coal pile runoff into the upper end of the discharge cove.

MATERIALS AND METHODS

The emergence of the mayfly Hexagenia bilineata was measured using two types of traps and daily observation. The first trap type, which was modified from Sublette and Dendy (1959), was placed on the bottom and collected mayflies as they emerged.

These submerged traps were made of weighted polyethylene cones covering an area of 0.8 m^2. The apex was attached to a 1 ℓ glass jar half filled with air to (1) hold the trap upright in the water and (2) form an air-water interface in which the emerging mayflies became trapped. Seven submerged traps were placed in each cove on June 24, 1976. Distribution of the traps was limited to the most favorable substrate (qualitatively identified as adhesive mud) at three depth intervals: 2-4, 4-6 and > 6 m according to the relative percent of each depth in each cove. No traps were placed in the 0-2 m depth because this area is exposed during the winter months. Traps were sampled each week (more often during the two peak emergence periods), and the number of traps redistributed according to the relative depth distribution in the cove. As each trap was removed from the water it was examined to make sure that it had been operational during the sampling interval. Absence of air in the bottle or presence of mud on the inside of the trap were used as criteria to exclude the trap data.

The second type of trap ("sticky trap") was a 12 oz. soda can covered with a 12 x 20 cm strip of polyethylene sprayed with Tree Tanglefoot (Tanglefoot Co., Grand Rapids, MI) and suspended from a tree limb. Mayflies which had emerged and were either in the sub-imago or imago stages stuck to the traps on contact and could be identified and counted when the polyethylene strips were replaced. Sampling was at least weekly; frequency being aimed at avoiding trap saturation. The sticky traps were hung on trees about equidistant along the shoreline and about 1-2 m above the water surface. Twelve traps each were hung around the intake and discharge coves and ten around the reference cove beginning on June 9.

RESULTS

Water temperatures in the three areas followed the typical seasonal trend found in most temperate areas (Fig. 2). The discharge cove temperature above the thermocline averaged 5.0 ± 0.56 °C higher than the intake canal and 3.1 ± 0.87 °C higher than the reference cove. The temperature of the water below the thermocline in the discharge (about 30% of the area) was similar to the intake water temperature.

The pattern of emergence derived from the two types of trapping was generally similar although there were some differences (Fig. 3abc). Exact timing of emergences (Fig. 3c) was based on daily field observations as well as the stages of mayflies found on the sticky traps. Emergence was intermittent from early June through August. Emergences generally occurred simultaneously in the three coves, although occasionally initiation of emergence in one of the coves was out of synchrony by a day (June 10, July 12, August 18). In two cases emergences were skipped in the reference cove. In all coves the major peaks of emergence occurred in early and late July and each was continuous over several days. Actual numbers and relative size of each emergence varied among the coves. Within each cove mean numbers per trap per week over the season for the two collection methods were positively correlated ($p \leq 0.01$) with R^2 values of 0.49, 0.60 and 0.68 for the intake, reference and discharge areas, respectively.

Further statistical comparisons between coves were carried out only on the basis of sticky trap data. Variation in the numbers of mayflies collected by traps in each cove was high even for a single emergence. Numbers of mayflies collected by sticky traps on a per trap basis were about an order of magnitude higher than submerged traps. Statistical analysis using submerged trap data was not carried out because it was complicated by the variation in weekly trapping effort due to non-functional or missing traps and by low numbers.

Analysis of emergence timing was carried out by comparing distributions of cumulative % emergence over the season (Fig. 4) and the time of median emergence in each of the three coves (Table 1). Comparison of the cumulative % distributions using the Kolmogorov-Smirnov two-sample nonparametric test indicated that: $D > I$ ($p < .001$); $R > I$ ($p < .001$); and $D > R$ ($.05 < p > .10$). In this case, greater than ($>$) is equivalent to earlier than. Using data from individual traps in each cove, the date on which 50% of the mayflies had emerged was calculated (June 1 was taken as day 1). The intake and reference sites were not significantly different, but the discharge site was significantly earlier (Duncan's Multiple Range Test; $\alpha = 0.05$) than either of them (Table 1). Median emergence occurred about 2 and 3 weeks earlier in the discharge cove than in the reference cove or intake canal, respectively.

DISCUSSION

It is likely that the differences observed in emergence timing in the three coves are primarily a function of temperature. Increased growth at temperatures higher than those normally found in the field have been reported for *Hexagenia bilineata*

(Fremling 1967) and Hexagenia limbata (Hunt 1953). Preliminary data collected in our laboratory indicate that growth and emergence of local H. bilineata occur faster at 25 than 15°C. Finally, the changes in timing of emergence correlate well with expectations based on a hypothesis of temperature causation: the order of time to median emergence is discharge, reference and intake--the same order as for mean temperature. Oxygen content of water in the discharge was lower than in the intake and reference areas, the latter two of which are not significantly different from each other (students t, $\alpha = 0.05$). However, the lower discharge levels (minimum June, July and August concentration was greater than 5.0 mg/l on the bottom in the unstratified area where most mayflies were found) should not be sufficiently low to affect emergence (Nebeker 1972; Eriksen 1964). Other water quality factors are not expected to be related such that a D - R - I order of effect in ascending or descending order would be expected. A thermal cause for the observed differences, thus seems reasonable.

The magnitude of the shift to earlier emergence in the discharge is probably underestimated by these data. A "fairly large" emergence was reported by fishermen to have occurred in the discharge on May 27 before our traps were operative. Residents of homes on the reference cove did not note an emergence at that time. No information is available for the intake canal. Inclusion of this probable early emergence in the discharge would increase the difference in time to median emergence which we calculated. In addition, mayflies distributed on the bottom below the thermocline in the discharge area would be expected to emerge later in the summer and, thus, tend to obscure the effect of the increased temperature.

How early emergence affects the mayfly population is presently speculative. If there is no change in mortality or reproductive success, the shift in emergence timing could result in an increase in annual mayfly production if emergence occurred early enough to allow development and reproduction of a summer generation. Alternatively, early emergence might merely be a minor change in seasonal timing with no real life cycle or production changes. As a third possibility, early emergence could result in changes in survivorship or reproductive success. Then, population numbers might increase or decline depending on population regulatory factors and their timing. The known variability in life cycles at other locations (Hunt 1953) indicates the probability that the effects will be highly site specific. An ongoing benthic sampling program in the three study areas may help in evaluating the alternative hypotheses regarding impact.

The accelerated emergence in the discharge cove of the Kingston Steam Plant is probably not significant for mayfly populations of the whole reservoir. All three study areas combined equal less than 0.01% of the area of Watts Bar Reservoir. Any effect of operation of the Kingston Steam Plant on emergence patterns is thus localized and would not translate to ecosystem changes in, for example, predator populations. A change of this sort might be significant under other conditions. In smaller systems or in systems with a high concentration of thermal input, a potential exists for change of greater magnitude.

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Table 1. Summary of analysis of days to 50% emergence using Duncan's Multiple-Range test. Any two means not underscored by the same line are significantly different $\alpha = 0.05$.

	Intake	Reference	Discharge
Days to 50% Emergence*	53.2	44.4	29.6

(A single line underscores 53.2 and 44.4.)

*Day 1 was June 1.

FIGURE LEGENDS

Figure 1. A diagrammatic view of the relation of the three study areas to the Kingston Power Plant showing depth isolines (2 meter intervals) for each of the areas. Water flows are generally from right to left.

Figure 2. Seasonal temperature regimes for each of the study areas. Temperatures plotted are averages of surface and deepest bottom temperatures for the Intake and Reference areas. The average of surface and upper thermocline temperatures (A) and lower thermocline and deepest bottom temperatures (B) were plotted separately in the Discharge area for the period of stratification. Discharge temperatures above the thermocline average 5°C and 3°C above the intake and reference temperatures, respectively.

Figure 3. Seasonal time-course of emergences (a) and mean numbers of mayflies collected per trap using submerged traps (b) and sticky traps (c). Sticky traps were placed on June 9. Submerged traps were not placed until June 24. Both trap types indicated intermittent emergence with peaks in early and late July. Emergences usually occurred simultaneously in all three coves.

Figure 4. Cumulative percent emergence in each of the coves as a function of time from initial emergence (June 8 was taken as day 0). The tendency toward early emergence paralleled the relationship of mean temperature in the three coves (Discharge > Reference > Intake).

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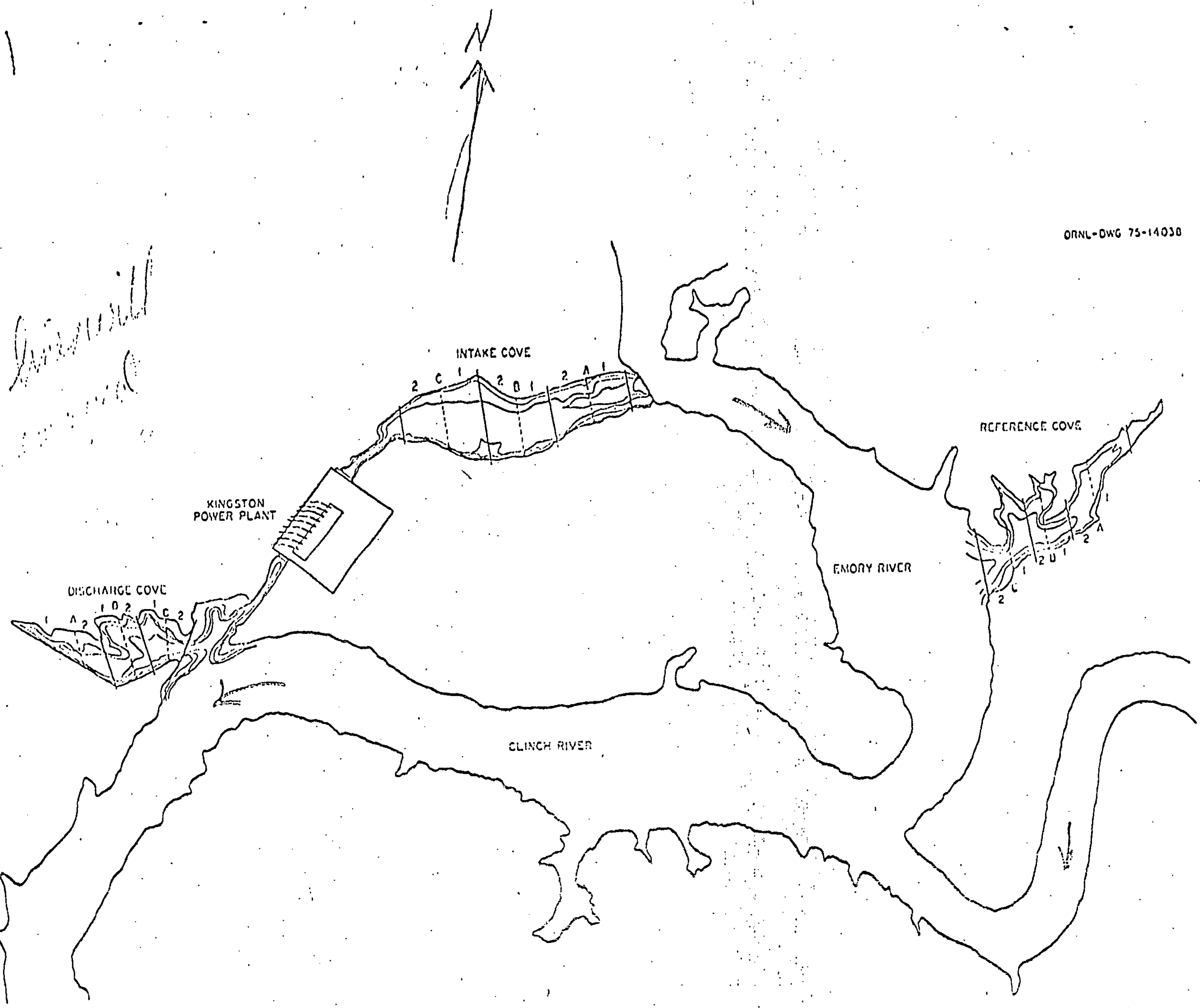

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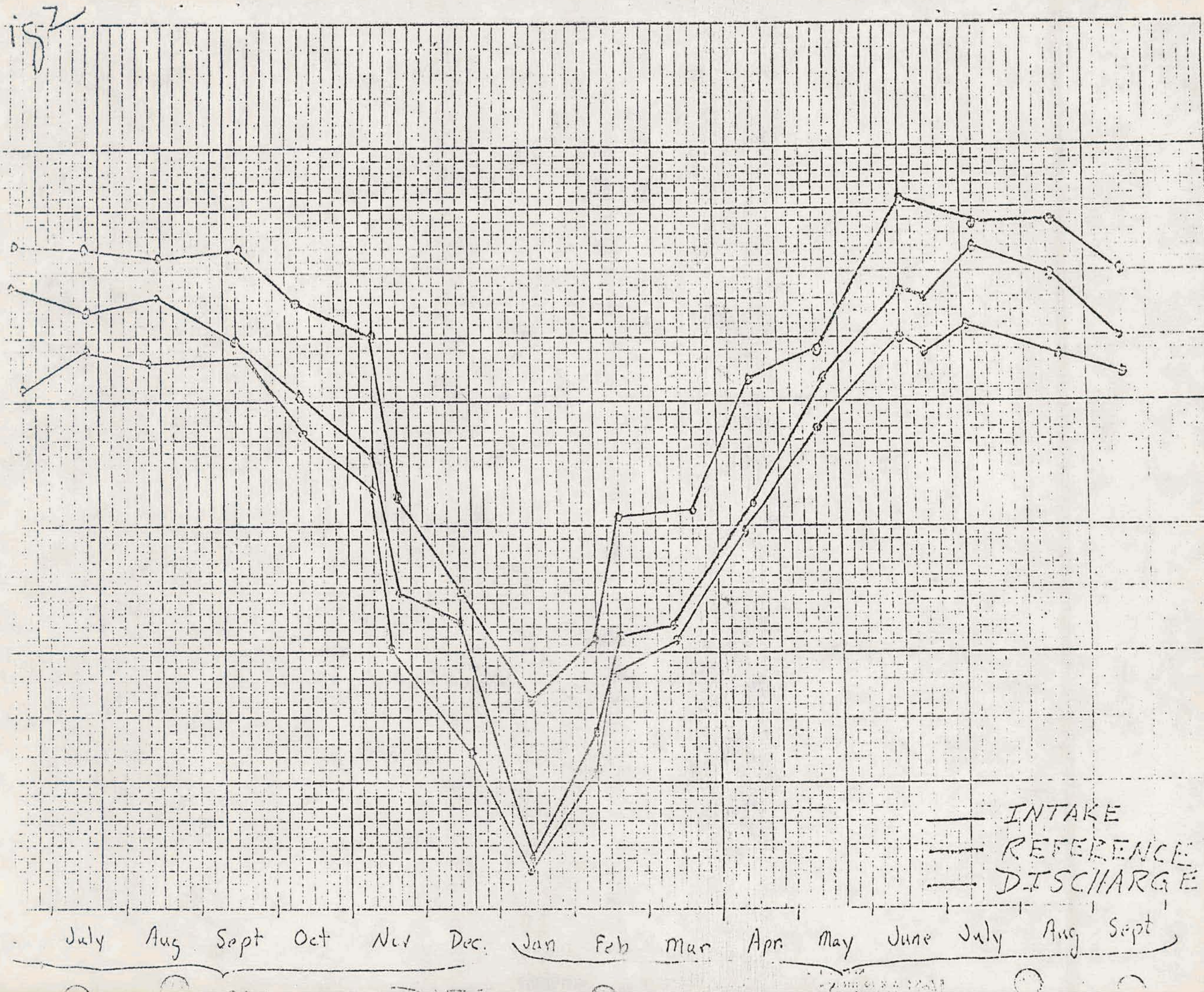
INTAKE
REFERENCE
DISCHARGE
July
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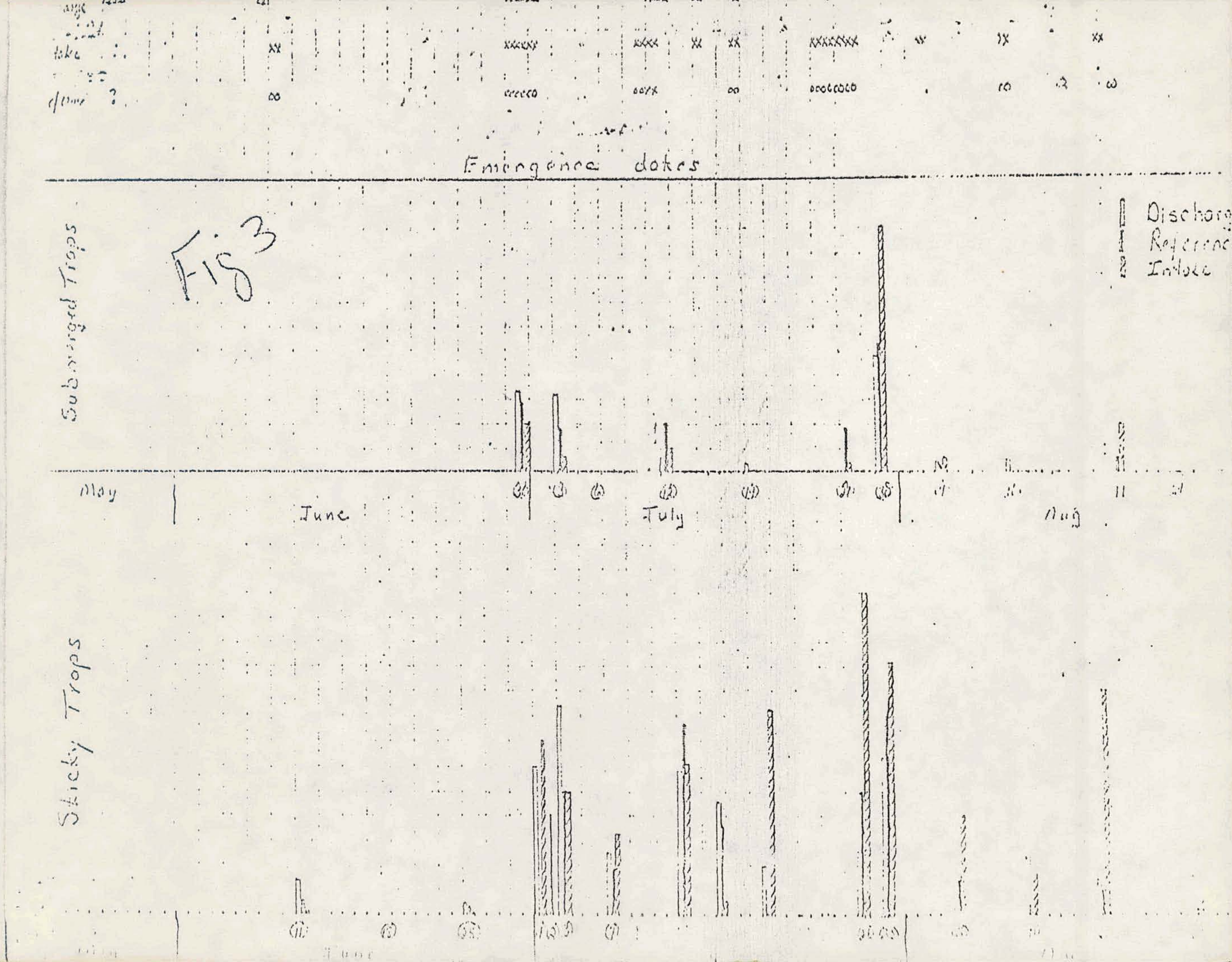
Fig 3
Emergence dates
Submerged Traps
Sticky Traps
Discharg
Referenc
Intake
May
June
July
Aug

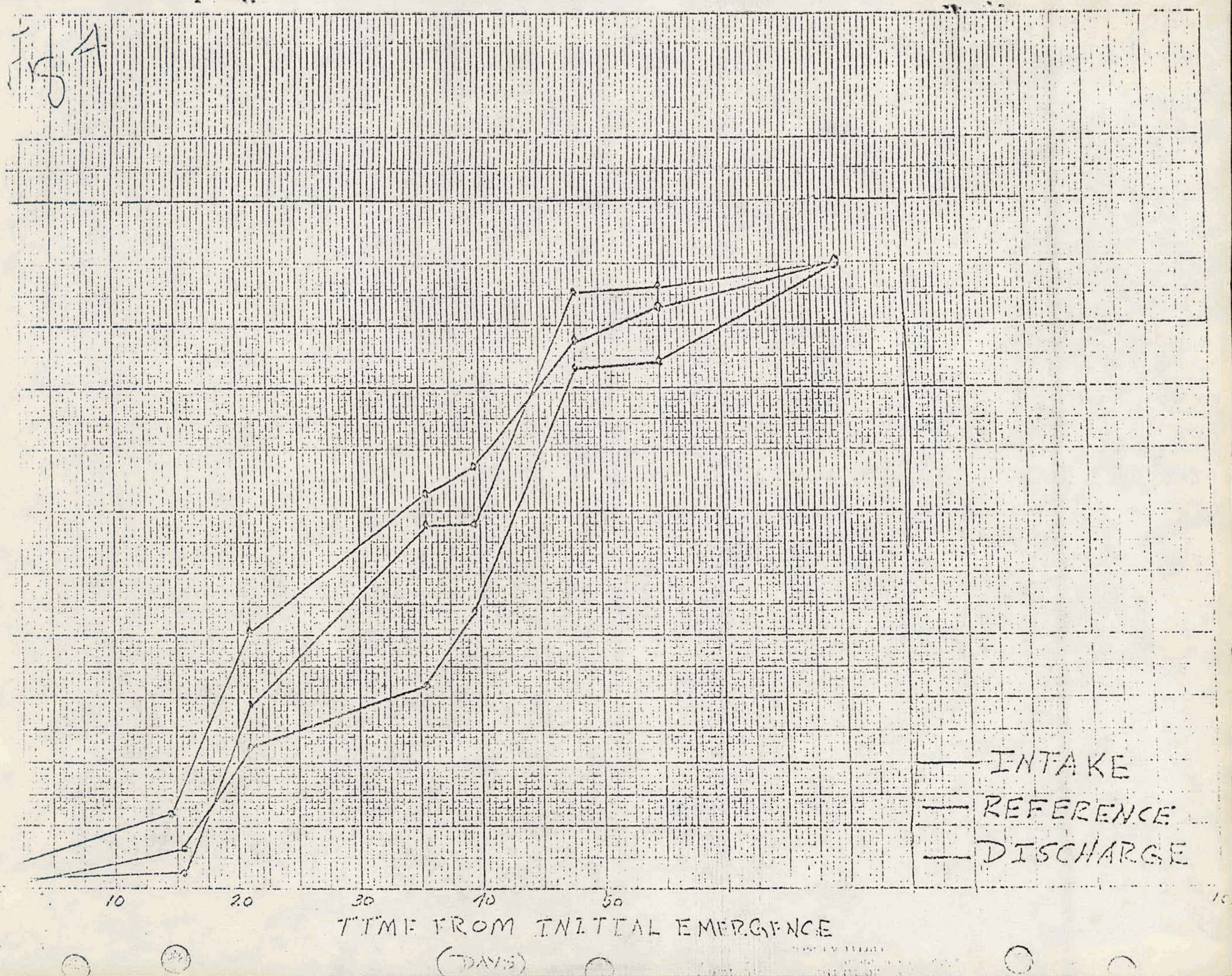
Fig 4
INTAKE
REFERENCE
DISCHARGE
10
20
30
40
50
TIME FROM INITIAL EMERGENCE
(DAYS)