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Biological Treatment and Toxicity Studies

T. W. Beak Consultants Limited

ENVIRONMENTAL PROTECTION SERVICE,
WATER POLLUTION CONTROL DIRECTORATE.

ECONOMIC AND TECHNICAL REVIEW REPORT EPS3—WP—73—6

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Biological Treatment Study

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ABSTRACT

The results of a comprehensive survey of three aerated lagoons treating kraft mill effluents in Western Canada are presented. Each lagoon is provided with surface mechanical aeration and has a residence time of five days.

Long term operating data for each system is reported including summer and winter BOD removal efficiencies, aerator loadings, and oxygen transfer efficiencies. Consideration was given to start-up procedures, temperature losses through the lagoon, optimum nutrient additions, pH effects, quiescent zones, and sludge accumulations. A detailed investigation of the overall mixing conditions in an aerated lagoon was made using Fluorescent tracer techniques. Lagoon geometry was more important than aeration horsepower in determining the mixing characteristics. Mathematical mixing models were developed for each system and are useful both for aerated lagoon performance prediction and for aerated lagoon design.

DATE: SEPTEMBER 1972

SUMMARY

The results of a comprehensive survey of three 5-day aerated lagoons treating unbleached, partially bleached, and bleached kraft mill effluents in Western Canada are presented. The mills are located at Hinton, Alberta; Port Alberni, British Columbia; and Kitimat, British Columbia. Aeration at each installation is provided by floating surface mechanical aerators.

Tracer residence time distribution studies show that geometry has a significant effect on the overall mixing behaviour in aerated lagoons and some data is presented to support a theoretically predicted effect of geometry on BOD removal. A partially mixed system, as found in larger length:width ratio lagoons, shows operational advantages over a totally mixed system, as characterized by lower length:width ratios.

A BOD_5 loading rate of between 2 and 2.5 lbs per nameplate horsepower-hour is shown to be optimum. Lower loading rates produce a smaller removal of BOD_5 per nameplate horsepower-hour, while maintaining a high BOD_5 removal efficiency. However, at higher loadings, the BOD_5 removal rate is larger but the percent BOD_5 removal efficiency decreases. When dissolved oxygen is not a limiting factor, 75 percent of the BOD_5 is removed in a 5-day aerated lagoon on a year-round average.

On the basis of a BOD_{20}:BOD_5 ratio of 1.7:1, the oxygen transfer efficiency of high speed mechanical surface aerators was estimated to be 2.8 lbs oxygen per nameplate horsepower-hour.

It is recommended that "tapered" aeration be used in larger L:W systems when spacing aerators. A correlation is developed relating the axial dispersion model parameters to lagoon geometrical parameters for this purpose.

Provision of a quiescent settling zone at the end of the aerated lagoon is of benefit in reducing the suspended solids level in the effluent. Approximately 0.3 days residence time is adequate to remove settleable solids. Quiescent residence times as large as 1.5 days are not as efficient because anaerobic conditions will result in re-suspension of settled material in such a large zone.

Supplemental nutrients to raise the BOD_5:N:P ratio to 100:3.0:0.5 are required to promote efficient biological treatment of kraft mill effluents.

Seeding is not required either for start-up or for recovery after a serious spill in aerated lagoons treating kraft mill wastes which include barking wastes.

The heat losses in an aerated lagoon occur mainly through the surface. With influent temperatures of 36°C to 30°C, an ambient temperature range of +20°C to -20°C caused only a 16.5°C drop in the mean lagoon temperature between summer and winter conditions. This corresponded to a 10 percent decrease in BOD_5 removal efficiency.

Influent pH variations between 7 and 11 have no detrimental effect on lagoon operation due to the mixing and neutralization capacity in a completely mixed lagoon. The partially mixed lagoons appear to tolerate shock pH variations between 5.8 and 10.0.

Aerated lagoon operating data throughout the duration of this study is reported and significant sludge accumulations were noted in a lagoon that had been in operation over four years.

DATE: SEPTEMBER 1972

1. INTRODUCTION

This report, a comprehensive study of aerated lagoon performance, was prepared by T.W. BEAK Consultants Limited, Vancouver, British Columbia. The project was financed jointly by the Department of Energy, Mines and Resources (now the Department of the Environment) of the Canadian Federal Government and by three pulp and paper mills whose treatment facilities were the object of the investigation.

The three mills were :

1. North Western Pulp & Power Ltd.,
   Hinton, Alberta.
   (NWP&P)

2. MacMillan Bloedel Ltd.,
   Alberni Pulp & Paper Division,
   Port Alberni, British Columbia.
   (ALPULP)

3. Eurocan Pulp & Paper Company Ltd.,
   Kitimat, British Columbia
   (EUROCAN)

The Federal Government provided direct financial support while the mills together contributed an equivalent amount in terms of manpower and the use of laboratory equipment and supplies to perform the field-work.

The data reported herein were collected from Spring 1970 to Fall 1971.

SCOPE

The general objective of this work was to investigate the performance of full scale aerated lagoons in the treatment of pulp and paper mill effluents. Specifically, the following topics were considered :

1. Determination of treatment efficiency as a function of operating variables such as
   - BOD loading and aeration horsepower
   - temperature
   - nutrients
   - pH.

2. Development of a mathematical model for each system that adequately describes the mixing conditions and permits reliable prediction of treatment efficiency.

3. A comparative evaluation of the three systems with respect to
   - pond geometry
   - aerator spacing
   - provision of quiescent zones.

4. Evaluation of mechanical surface aerator performance with respect to
   - oxygen transfer
   - mixing.

5. Determination of heat losses from aerated lagoons operating in cold climates.

6. Determination of the importance of the operating variables during the start-up phase of the treatment system.

7. Operating data for each system over an extended period of time.

3. CONCLUSIONS AND IMPLICATIONS FOR AERATED LAGOON DESIGN AND PERFORMANCE

The following points summarize the findings of this study of aerated lagoon treatment of fully bleached (NWP&P), partially bleached (ALPULP), and unbleached (EUROCAN) kraft mill effluents in Western Canada.

3.1 BOD Loading and Horsepower Requirements:

For a particular system, the BOD_5 removal efficiency generally decreases as the BOD_5 loading per nameplate horsepower-hour increases. Neglecting mixing and temperature effects, when the loading rate was greater than about 4.0 lbs BOD_5/NPHP-hr, the removal efficiency was less than 50 percent, but with a loading rate of less than about 4.0, the efficiency was between 50 and 80 percent (see Figure 7).

The BOD_5 removal per NPHP-hr was essentially independent of the BOD_5 loading rate above 2.2 lbs BOD_5 load/NPHP-hr. Below this point, the BOD_5 removal rate decreased linearly with decreasing BOD_5 loading rate (see Figure 8). However, the percentage BOD5 removal decreased with increasing BOD_5 loading rate (see Figure 7). This results in an optimum BOD_5 loading rate of between 2 and 2.5 lbs/NPHP-hr. At ALPULP where dissolved oxygen was not limiting, the resulting average BOD_5 removal efficiency was approximately 75 percent (year-round) whereas at NWP&P an average removal efficiency of about 60 percent was observed possibly due to a shortage of dissolved oxygen. The scatter in the data in Figures 7 and 8 may well be due to variations in lagoon temperatures, residence time, and mixing conditions.

3.2 Temperature Effects:

Typically, mean ambient temperature varied approximately from +20°C to -20°C resulting in temperature drops across the lagoon from about

6^oC in summer and about 13.5^oC in winter respectively. Temperatures of the lagoon influent were about 36^oC in summer and 30^oC in winter. When dissolved oxygen was not limiting, a 10 percent difference in BOD_5 removal efficiency was observed between summer and winter conditions corresponding to a lagoon temperature of 30^oC and 16.5^oC respectively (see Figure 9). For a dissolved oxygen limited situation, this difference was observed to be about 20 percent.

3.3 Nutrient Additions:

Without supplemental nutrient additions, the BOD_5 removal efficiency in a 5-day aerated lagoon treating kraft mill effluent can be expected to be less than 50 percent. A nutrient ratio of 100:3.0:0.5 BOD_5:N:P (including nutrients already in the effluent) appears to be adequate for efficient biological treatment in a 5-day aerated lagoon. These values were confirmed in batch studies carried out to determine optimum nutrient ratios for start-up.

3.4 pH Effects:

Bleach plant acid wastes were used to neutralize the aerated lagoon influent at NWP&P and ALPULP. This practice was successful in maintaining the influent pH below 8.0 at NWP&P and 7.3 at ALPULP ninety-five percent of the time. At NWP&P, influent pH values reached 10.0 only one percent of the time. The experience at EUROCAN has shown that pH control before biological treatment is not required for an unbleached kraft mill effluent. Successful operation of this well-mixed aerated lagoon within a pH range of approximately 7.5 to 9.0 was possible with influent pH variations from 7 to 11 (five and ninety-five percentile limits).

3.5 Mathematical Modelling:

This study has demonstrated the usefulness of mathematical mixing models for investigating oxygen transfer, BOD removal, BOD profiles, lagoon geometry, overall mixing characteristics, effect of aeration horsepower input, and optimization of aerator placement. Six hypothetical mathematical mixing models were fitted to the tracer data from each lagoon. These results show that for hand calculation of a predicted BOD_5 removal for each system, the unequal mixed tanks-in-series model is very useful and relatively simple. However, the more complicated dispersion model may be used to predict the BOD_5 profile along the lagoon. In both cases, first order BOD_5 removal rates obtained from batch studies inoculated with adequate nutrients and seeded with sludge from the prototype system were used for the reaction rate constants in making the predictions. Actual field measurements on the prototype systems confirmed the value of combining batch rate data with mixing models derived from tracer residence time distributions.

3.6 Optimum Lagoon Shape:

Residence time distribution studies using fluorescent tracer techniques have indicated that geometry plays a very important part in determining the overall mixing behaviour in an aerated lagoon. The relatively square EUROCAN lagoon approached completely mixed behaviour. However, the other lagoons had a larger length:width ratio and, while not being true plug flow systems, did exhibit partially mixed behaviour.

Assuming a first order BOD_5 removal mechanism and if all other variables such as residence time, BOD_5 loading, temperature, aeration horsepower, etc. are held constant, then theoretical mixing considerations dictate that a partially mixed system will yield approximately a 7 percentage point better BOD_5 removal than a completely mixed system (see Table 10).

In fact, because of the large number of variables associated with waste treatment in this study, it was difficult to detect the difference. However, oxygen uptake rates in the ALPULP lagoon (L:W = 12.5:1) ranged from about 4.0 ppm/hr at the influent end to approximately zero at the effluent end of the lagoon, indicating that the immediate oxygen demand of the waste was satisfied. At EUROCAN (L:W = 1.2:1), oxygen uptake rates were more uniform throughout the lagoon (1.5 to 2.5 ppm/hr) indicating that all the short-term oxygen demand was not satisfied in the effluent.

Furthermore, the residence time distribution studies show that about 13.4 percent of the total waste flow at EUROCAN received biological treatment for a period of 24 hours or less. The corresponding value at ALPULP is 5.3 percent of the total flow. This becomes increasingly important when high BOD and/or toxicity removals are required. Therefore, a lagoon with a large length:width ratio should give better performance than one whose length:width ratio approaches unity, all else being the same.

However, it should be noted that a balance must be struck between plug flow behaviour and the more practical consideration of the buffer capacity for shock loads and self-seeding of lagoons. At the partially mixed ALPULP lagoon, shock loads had no significant long-term detrimental effect on treatment efficiency.

3.7 Aerator Spacing:

When locating aerators, it is of advantage to provide "tapered" aeration by spacing them closer at the head end of the lagoon than at the lower end. The designer can do this rationally by calculating the dimensionless dispersion number $\frac{D}{uL}$ from equation 4 and using this to predict the BOD profile along the lagoon with equation 5-2 in Appendix 5. The aerator spacing may then be weighted according to the BOD profile.

3.8 Provision of Quiescent Zones:

At ALPULP and EUROCAN, provision of a settling zone at the end of the aerated lagoon of approximately 0.3 days residence time removed nearly all of the settleable solids and about 5 to 10 percent of the suspended solids. AT NWP&P, the large 1.5 day quiescent zone only reduced the settleable solids concentration from about 60 ppm to about 40 ppm and the suspended solids by about 20 to 30 percent. The anaerobic activity in this large quiescent zone caused some re-suspension of the settled sludge, thereby affecting the quality of the treated effluent.

3.9 Aerator Performance:

A year-round average of 1.87 lbs of BOD_5 were removed per nameplate horsepower-hour in the ALPULP lagoon while 1.45 lbs BOD_5/NPHP-hr was removed at NWP&P (see Table 2 and Figure 8). Based on one pound of oxygen supplied per pound of BOD_{20} removed, the oxygen transfer efficiency of the ALPULP surface aerators was estimated to be 3.18 lbs 0_2/NPHP-hr. At NWP&P, it was 2.47 lbs 0_2/NPHP-hr. It is estimated that 2.8 lbs 0_2/NPHP-hr would be the average transfer efficiency for these aerators. The EUROCAN data were not used in this analysis because below a BOD_5 loading of 2.2 lbs/NPHP-hr, a lower BOD_5 removal rate is observed.

Residence time distribution studies have shown that the overall mixing behaviour in an aerated lagoon is significantly more dependent upon the system geometry than upon the aeration horsepower input for the energy input range of 2.4 to 11.6 HP/10^6 US gallons.

Radial velocity profiles about an aerator showed an outward flow at the surface beneath which was a null point and then an inward flow. The depth of the null point increased with distance from the aerator. These results support the NCASI (1971) studies which were published after this work was undertaken. At NWP&P it was found that the 50 HP high speed aerators can draw water from depths of 22 ft as evidenced by the lack of sludge accumulation immediately beneath the aerators. In this study there was no evidence to indicate what maximum depth can be employed for aerated lagoon design.

3.10 Heat Losses:

Temperature drops across the aerated lagoons ranged from 6^{o}C in summer to 13.5^{o}C in winter. When the system is well mixed (e.g. EUROCAN) the entire lagoon is essentially at the outflow temperature whereas in a partially mixed system there is a linear temperature profile along the lagoon. The major heat-loss was through the lagoon surface and was correlated to the difference between ambient and mean lagoon temperature. The heat transfer coefficient, f, [Eckenfelder (1961)] was calculated to be 8.66×10^{-6} USMGD/ft^2 for Western Canadian climatic conditions. No relationship between the heat transfer coefficient and the aeration horsepower input was evident in this study possibly because higher aeration horsepower inputs produced a greater foam cover that acted as a better insulator against heat losses.

3.11 Start-up:

Aerated lagoons treating kraft mill effluents require no seed inoculum when starting up or for recovery after a toxic spill. In the mills tested, which included the waste from debarking operations, the very high bacterial content thereby rendered the aerated lagoon system self-seeding. This study did not investigate mills without debarking operations. Oxygen uptake rates, a rapid method of determining the degree of biological activity, increased from 0.5 to 4.0 ppm O_2/hr following the addition of nutrients during start-up of the ALPULP system. Correspondingly, the BOD_5 removal efficiency also showed a marked increase following nutrient additions during the start-up phase of operation. Successful start-up at ALPULP was achieved by filling the aerated lagoon with undiluted waste and then adding nutrients. At EUROCAN, where the mill operation started concurrently with the aerated lagoon, the importance of installing a toxic spill basin and settling ponds ahead of the aerated lagoon, and the provision of adequate and separate supervision of the waste treatment facilities were evident.

3.12 Shock Loading:

During the monitoring period, no shock loads were experienced of sufficient magnitude to significantly affect the long-term operation of any of the lagoons.

3.13 Operating Data:

Aerated lagoon operating data recorded during the course of this investigation are presented. Sludge accumulations are likely to occur in the vicinity of the influent line and in relatively unmixed regions between aerators and in corners. Approximately 0.2 lbs of solids were produced per pound of BOD_5 removed in the NWP&P aerated lagoon.

4. LITERATURE REVIEW

4.1 General Comments:

The development of aerated lagoon design has logically evolved from waste stabilization pond design. Natural surface reaeration and photosynthetic oxygen are inadequate to meet the oxygen demanded by a highly loaded stabilization basin. Consequently, supplemental oxygen must be introduced by either diffused air or mechanical surface agitatio in order to maintain desirable aerobic conditions. The first aerated lagoons were fairly shallow with depths similar to those of waste stabilization ponds (4 to 6 ft) [McKinney & Edde (1961)]. Later designs have taken more advantage of the mixing capabilities of the aeration devices and depths of up to 22 feet have been used.

Eckenfelder (1961) has stated that the mechanism of removal of organic waste matter in aerated lagoons of relatively low turbulence levels is by both aerobic action in the liquid and anaerobic decomposition of settled solids on the lagoon bottom. In lagoons with high turbulence levels, no significant sludge deposits can occur; all the solids will be in suspension, and the system is analagous to a dilute activated slud system.

4.2 Aerated Lagoon Biokinetics:

Commonly it has been assumed that the biological oxidation of organic matter in aerated lagoons can be represented mathematically by a first order rate expression [Bartsch and Randall (1971)]. However, Eckenfelder (1961) has suggested use of a retardant mechanism, and O'Connor and Eckenfelder (1960) state that some effluents can best be fitted by a ze order mechanism. Marais and Capri (1970) extended concepts previously developed for waste stabilization lagoons [Marais (1970)] to include the benthal demand of settled solids in a first order removal kinetic mechanism.

The temperature dependence of the first order reaction rate constant (k), at temperature T, has been found to follow the relationship:

$$k_T = k_{20}\ \theta^{(T-20)}$$

where θ is reported to range from 1.035 to 1.09 and k_{20} ranges from about 0.2 to 1.0 $days^{-1}$ for various waste [O'Connor & Eckenfelder (1960), Eckenfelder (1966), NCASI (1966), Carpenter et al. (1968), Marais & Capri (1970)].

In a survey of several aerated lagoons [NCASI (1971)] overall design parameters for optimum BOD removal were found to be 2.0 lb BOD_5 applied/HP/hr, which resulted in an average of 1.75 lb BOD_5 removed/HP/hr. In addition, Eckenfelder and Ford (1970) state that from 0.9 to 1.4 pounds oxygen are required for every pound of BOD_5 removed.

4.3 <u>Aerated Lagoon Mixing:</u>

For design purposes, it has been assumed that all aerated lagoons behave like completely mixed reactors [Eckenfelder (1967), Mancini & Barnhart (1968)]. The standard design textbooks reiterate this assumption [Eckenfelder (1966), Eckenfelder & Ford (1970)]. A study by the National Council of the Pulp and Paper Industry for Air and Stream Improvement [NCASI (1971)] reported concentrations of BOD_5 and suspended solids throughout several lagoons and concluded that only those basins of relatively square geometry were, in fact, completely mixed. It was found that for horsepower mixing inputs greater than 8 HP/10^6 US gallons and a length:width ratio of less than 4:1, the lagoon would be relatively homogeneous in BOD_5 and suspended solids content.

Very little work has been done on determining aerated lagoon mixing characteristics by means of the more fundamental residence time distribution approach. O'Connor and Eckenfelder (1960) injected a tracer into an aerated lagoon of 2:1 length:width ratio. Sparjers provided mixing and diffused aeration. Following a qualitative examination of the system's tracer response, COD and oxygen uptake rate profiles, they concluded that the system could be considered completely mixed. In a report prepared for Metropolitan Winnipeg [Burns et al.(1970)] on aerated lagoons treating municipal waste, a tracer test was attempted using fluorescein and Rhodamine B tracers. Unreliable quantitative results were obtained due to photochemical decay and adsorption of tracer; however, a qualitative analysis of the data indicated a "significant level of mixing ". Thirumurthi (1969) performed tracer tests in a lab scale vessel simulating an unmixed waste stabilization basin. The vessel exhibited neither ideal mixing nor ideal plug flow and the dispersion model was used to describe the mixing behavior of the system.

4.4 Mechanical Aerator Performance:

The mechanical aerator performs two basic functions - first, it must supply adequate oxygen to meet the requirements of the aerobic biochemical oxidation mechanism, and second, it must provide sufficient mixing to promote contact between the untreated waste and the suspended biomass in the lagoon.

The NCASI study (1971) reported velocity profiles and zones of influence in the vicinity of mechanical aerators. It was found that significant radial velocities could be detected up to 100 feet from a 50 HP aerator and 175 feet from a 100 HP unit. Furthermore, random background velocities beyond these radii were adequate to maintain a dissolved oxygen level for an additional 50 to 100 feet. For aerators of relatively small size, it was found that a large number of small horsepower units (i.e., 5 units x 10 HP each) provided a larger zone of influence than a small number of large horsepower units (i.e., 2 units x 25 HP each). However, the inverse was true for aerators greater than 25 HP each. The velocity measurements for one installation indicated that 100 HP aerators could circulate liquid from the bottom of an 18 foot deep lagoon. It was recommended that the aerators be placed to meet the oxygen demand of the system. For example, a uniform aerator spacing would be suitable for a completely mixed lagoon, whereas in a partially mixed system, more aeration capacity should be located nearer the incoming waste than near the lagoon outlet.

Amberg et al. (1971) also reported that two 75 HP units were "more efficient mixing and aeration devices" than six 25 HP units.

To maintain a uniform dissolved oxygen concentration, but still allow settleable solids deposition, suggested overall design parameters vary from 15 to 20 HP/10^6 US gallons [Eckenfelder (1966), Beychok (1971)] down to 4 to 8 HP/10^6 US gallons [Eckenfelder (1967), Gillespie (1970), NCASI (1971)] . The NCASI survey (1971) concluded that if the lagoon loading were less than 600 lbs BOD_5/USMGD, only about 0.1 to 0.2 lbs suspended solids per pound of BOD_5 removed would be produced and much of this would be in a non-settleable dispersed growth form. However, if the lagoon loading were increased above 600 lbs BOD_5/USMGD, considerably more settleable solids production would occur per pound of BOD_5 removed. To prevent the deposition of these solids, they recommended using at least

14 $HP/10^6$ US gallons; otherwise, only enough horsepower sufficient to induce adequate oxygen transfer is necessary.

Even so, Haynes (1968) still observed sludge deposits with power inputs of about 14 and 16 $HP/10^6$ US gallons. Eckenfelder (1967) has stated that bottom scour velocities of 0.4 to 0.5 ft/sec are necessary to keep all solids in suspension and that this would be roughly equivalent to 30 to 60 $HP/10^6$ US gallons.

4.5 Solids Production and Deposition:

Sludge deposits in an aerated lagoon are the result of carry-over and subsequent sedimentation of settleable solids from the primary treatment system and deposition of a portion of the biological solids produced during stabilization of the organic waste.

Laing (1968) in observing a lagoon of 2.13 x 10^6 US gallons volume with a power input of approximately 8.5 $HP/10^6$ US gallons noted that solids deposition was greatest at the mid-points between the aerators. The NCASI report (1971) stated that considerable sludge will accumulate around the influent pipe and after that, settleable solids will be found in regions of limited mixing influence such as corners and the mid-points between aerators.

In general, microbial solids production in aerated lagoons is in the order of 0.1 to 0.2 lb suspended solids per pound of BOD_5 removed [O'Connor & Eckenfelder (1960), Amberg et al. (1971)] . However, the Metropolitan Winnipeg study [Burns et al. (1970)] reported unexpectedly high sludge yields typical of values common to an activated sludge process (approximately 0.4 to 0.5 lb SS/lb BOD_5 removed). The system's performance deteriorated in the summer and this was attributed to the build-up of sludge.

As mentioned previously, Marais and Capri (1970) have formulated an aerated lagoon model based on a completely mixed system but accounting for the benthic demand of the settled sludge. Inadequate available experimental information necessitated that they guess appropriate values for their model parameters. A computer simulation study using this model clearly showed the effects of sludge deposits. In the cold seasons, the very temperature-sensitive anaerobic processes in the sludge deposits are slow and the continual deposition of solids increases the total volume of the settled sludge. During the warmer seasons the anaerobic decomposition rates greatly increase and the accumulated volume of settled sludge declines. A portion of the anaerobic byproducts enters solution thereby contributing an additional organic loading on the aerobic processes in the lagoon.

For design purposes, Eckenfelder and Ford (1970) suggest using a safety factor to account for this feedback of anaerobic products when calculating the load on the aerators. They recommended a factor of 1.2 for summer conditions and 1.05 for winter conditions.

4.6 Nutrient Additions:

Supplemental nutrient additions (nitrogen and phosphorus) are required if if the waste is deficient in these two substances particularly when lagoon residence times are less than 10 days [Gillespie (1970), NCASI (1971)]. Suggested dosage rates in the literature are usually close to that found to be optimum for the activated sludge process, that is 100:5:1 BOD_5:N:P [Gillespie (1970), NCASI (1966)]. However, some workers report their figures in terms of BOD_5 removed:N:P. These ratios are slightly different: for example, 100:4:1 by Eckenfelder (1966) and 100:4.6:0.87 by Haynes (1968).

4.7 Thermal Losses

With such long residence times and large surface areas, significant heat losses readily occur from aerated lagoons when the liquid temperature differs from the ambient temperature. Eckenfelder (1961), (1966) has stated that the heat loss through the lagoon is proportional to the lagoon surface area and the mean liquid-air temperature differential as follows:

$$(T_i - T_e)Q = f\ A\ (T_m - T_a)$$

where T_i = influent temperature

T_e = effluent temperature

T_m = mean lagoon temperature

T_a = ambient air temperature

A = lagoon surface area (square feet)

Q = waste flowrate (USMGD)

and f = proportionality constant accounting for heat transfer coefficients, wind effects, humidity effects, surface area increases as a result of aeration, and other factors.

Assuming a completely mixed system, the proportionality constant, f, has been found to be 12×10^{-6} for the Central United States [Eckenfelder (1961)]. Presumably this value is an overall mean and no account of variations in foam cover is taken.

5. MILL AND TREATMENT SYSTEM DESCRIPTIONS

A brief description of the mill processes and waste treatment systems follows. A more comprehensive outline of the waste treatment facilities at each mill appears in Appendix 1.

5.1 NWP&P:

The NWP&P mill, situated in Hinton, Alberta, on the Athabasca River, produces approximately 600 TPD of fully bleached kraft pulp utilizing a CEHDED six stage bleaching sequence. The wood furnish at NWP&P is approximately 60 percent spruce and 40 percent pine. It is hauled to the mill by land.

The waste treatment system, completed in 1967, was designed to treat the total pulp mill and woodroom effluents except the bleach plant acid waste. It consists of primary clarification, nutrient additions, pH adjustment, and biological treatment in a 5-day aerated lagoon. An aerial photograph and a waste treatment system schematic are shown in Figures 1 and 4 respectively.

5.2 ALPULP:

The ALPULP mill, situated in Port Alberni, B.C., at the head of Alberni Inlet, is an integrated mill complex producing approximately 900 tons per day (TPD) of kraft pulp and 1000 TPD of groundwood. About 300 TPD of the kraft pulp is bleached utilizing a CEH sequence. The wood furnish at ALPULP is about 80 percent hemlock and balsam, 10 percent fir, and 10 percent cedar. It is transported to the mill by water.

The waste treatment facilities comprise collector sewers, primary clarification and a 5-day retention aerated lagoon. Approximately

50 percent of the total mill waste flow receives treatment. This accounts for about 85 percent of the total volatile suspended solids and about 60 percent of the total BOD_5 from the mill. Nutrients are added to the waste stream to promote efficient biological treatment. An aerial photograph and a waste treatment schematic are shown in Figures 2 and 5 respectively.

5.3 EUROCAN:

The EUROCAN mill, situated in Kitimat, B.C., on the Kitimat River, consists of an unbleached kraft mill producing linerboard, sack paper and pulp, and a sawmill. The mill, with a design production rate of 915 TPD of kraft pulp and 130,000 Mfbm/A of sawn lumber, was brought on-stream in early October, 1970. The wood furnish at EUROCAN is about 30 percent hemlock, 22 percent balsam, 30 percent lodgepole pine, 11 percent spruce and 7 percent miscellaneous. It is transported to the mill both by water and over land.

The waste treatment facilities were designed to treat the total effluent from both the pulp mill and the wood mill. A clarifier, a spill basin, two solids settling ponds and a 5-day retention aerated lagoon are the principal components of the treatment process. Nutrients are also added to the waste stream. An aerial photograph and a waste treatment system schematic are shown in Figures 3 and 6 respectively.

5.4 Required Effluent Standards:

The effluent quality standards presently specified by the provincial regulatory agencies for each of the mills are summarized in Table 1.

These figures represent the requirements for the total wastewater discharge from the mills, and differ due to the variations in the mills, the mill locations, and the watercourses into which the wastes are discharged.

6. DESCRIPTION AND EVALUATION OF TESTING PROCEDURES

Most of the analyses for the study were performed in the laboratory facilities of each participating mill. With the exception of some minor modifications, all analyses were conducted in accordance with the procedures given in the 12th Edition of Standard Methods for the Examination of Water and Wastewater (1965). A description of any modification used is given in Appendix 2. Several test evaluations were performed to assess the validity and reproducibility of the testing procedures as used at each mill, and to ensure that the test results from each of the mills were comparable. These results are also reported in Appendix 2.

The BOD_5 determinations followed the Standard Methods (12th ed.) procedure with the exception of minor variations in seeding of the dilution water at each mill.

Suspended solids were determined using the asbestos mat/Gooch crucible method at NWP&P. Quantitative filter paper (recommended by the Technical Section CPPA) was normally used for routine suspended solids analysis at ALPULP and EUROCAN. Glass fibre filters were also tried at NWP&P, ALPULP and EUROCAN.

Dissolved oxygen was measured in BOD bottles with a YSI dissolved oxygen meter with a self-stirring probe. In situ measurements at the lagoon were made with an EIL Model 5420 meter with a submersible probe. Periodic calibration checks were performed using the Standard Winkler procedure.

Oxygen uptake rate measurements (the rate at which dissolved oxygen is depleted in a waste sample) are described in Appendix 2.

Determination of alpha values (the ratio of the overall mass transfer coefficient of the waste ($k_L a$) to the overall mass transfer coefficient of tap water) is also described in Appendix 2.

Total and soluble organic carbon analyses were performed by the Department of the Environment in Calgary, Alberta.

7. STUDY EXECUTION

To fulfill the objectives of this study, an extensive sampling and testing program was performed to determine the operating parameters and treatment characteristics at each of the lagoons. Six detailed system characterization studies were conducted at NWP&P, four at ALPULP and two at EUROCAN. Following a sufficient time to allow for the establishment of equilibrium conditions, each study took about 2 weeks to complete. The only variable changed during the studies was the aeration horsepower.

The aerator configuration was set and operated for at least one week before testing was started. On day 1, the tracer study was begun by installing and calibrating the fluorometer, and injecting the tracer at the lagoon inlet. On day 2, cross-sectional profiles of the lagoon were taken at two locations and analyzed for temperature, dissolved oxygen (D.O.), pH, and suspended solids. The next day, longitudinal profiles of temperature, D.O., pH, suspended and total solids, BOD_5, COD, TOC, SOC, and oxygen uptake rate were measured. Batch treatment studies were set up in the laboratory during each study.

During the second week the system monitoring program included aerator velocity profiles, nutrient analyses, evaluation of the testing methods and some further lagoon sampling. Twenty-four hour composite samples of lagoon influent and effluent were analyzed daily throughout the entire testing period at each mill.

Details of the techniques used to sample the lagoon are outlined in Appendix 3.

8. TREATMENT EFFICIENCY AS A FUNCTION OF OPERATING VARIABLES

8.1 Effect of BOD_5 Loading and Aeration Horsepower:

The monthly aerator performance, as measured by the amount of BOD_5 removed per unit horsepower input is summarized for the three systems in Table 2.

For a particular system, the percent BOD_5 removal efficiency generally decreased as the BOD_5 loading per horsepower-hour on the lagoon increased, as shown in Figure 7. Neglecting mixing and temperature effects for the moment, it is seen that when the loading rate was greater than about 4.0 lbs BOD_5/NPHP-hr, the removal efficiency was less than 50 percent, but with a loading rate of less than about 4.0 the removal was between 50 to 80 percent.

The BOD_5 removal per nameplate horsepower-hour as a function of the BOD_5 loading per NPHP-hr is illustrated in Figure 8 for the three systems. It is seen that the BOD_5 removal rate was relatively independent of the loading rate above 2.2 lbs BOD_5 load/NPHP-hr. Below this point, the BOD_5 removal rate varied approximately linearly with the BOD_5 loading rate.

From an examination of Figures 7 and 8, it is evident that there is an optimum BOD loading rate of between 2 and 2.5 lbs BOD_5/NPHP-hr.

Comparing the results from NWP&P and ALPULP in Table 2, it is noted that the BOD_5 loading rate was about the same but at NWP&P the removal efficiency was about 22.5 percent less per HP-hr input. This could be the result of several factors which could not be evaluated easily. The NWP&P lagoon had been used for about four years and contained a layer of sludge deposits through most of the lagoon. Because the dissolved oxygen concentration was zero throughout the lagoon, soluble end products from the anaerobic decomposition of the bottom sludges could exert an oxygen demand which was not measured by the reduction from influent to effluent BOD_5 concentration This is further supported by Figure 8. In this system, the BOD5 removal rate was somewhat lower at NWP&P than at ALPULP indicating an unmeasured source of BOD_5 into the system. Other less probable explanations could be that the aerators at NWP&P were smaller, 50 vs 75 HP, and were an earlier design Welles aerator. The waste characteristics were different, although laboratory testing indicated that the "alpha value" of the wastes were approximately the same (0.75 to 0.80).

8.2 Effect of Temperature:

During the study period, the normal seasonal temperature variations of the waste entering the aerated lagoons was from about 36°C to 30°C for summer and winter conditions respectively. Seasonal ambient temperature variations were from about +20°C to -20°C. These conditions resulted in mean lagoon temperatures of about 30°C in summer and about 16.5°C in winter.

The effects of temperature on the BOD_5 removal have been documented for many biological waste treament processes in laboratory studies. The maximum removal rate generally occurs around 37°C, which is the optimum temperature for mesophylic bacteria, and decreases both above and below this temperature. In most systems operating in cold climates, temperature becomes a limiting parameter affecting the system's treamcnt efficiency, yet little has been published dealing with the effects of temperature in full scale aerated lagoons. Generally for purposes of design, laboratory data have simply been extrapolated to the expected lagoon conditions. The typical winter operating performance for the three mills is summarized in Table 3.

The temperature effects on the BOD_5 removal for the five-day lagoons studied have been summarized in Figure 9. The data points shown are the average of five consecutive daily composite samples.

The effects of the mean lagoon temperature were more pronounced in the NWP&P lagoon. In the range of 20 to 30^{o}C, the BOD_5 removal efficiency was increased about 16 percentage points at NWP&P, while the increase was only about 10 percentage points at ALPULP and EUROCAN. The increased temperature sensitivity and lower BOD_5 removal efficiency at NWP&P could be the result of oxygen deficiency. The NWP&P lagoon was "overloaded" in terms of oxygen transfer capacity and the treatment was limited by the lack of any residual dissolved oxygen concentration in parts of the lagoon. The other two systems operated with a residual D.O. of from about 2 ppm at ALPULP to as great as 6 ppm at EUROCAN. Also shown in Figure 9 are the results of laboratory batch treatment studies.

It should be noted that the trends seen in Figure 9 are general indicators of temperature dependence only. At this stage of the data analysis, no consideration was given to variations in BOD_5 removal with respect to differences in the overall mixing characteristics of each lagoon or to fluctuations in the BOD_5 loading on the lagoons.

8.3 Effect of Nutrients:

The quantity of nitrogen and phosphorous nutrients contained in the three kraft mill wastes was inadequate to maintain efficient biological treatment. Therefore, nitrogen and phosphorus were added to promote the rapid microbial synthesis which must occur for successful waste treatment in an aerated lagoon.

Nutrient Additions at NWP&P

Measured nitrogen and phosphorous concentrations in the waste streams at NWP&P are given in Table 4. The phosphorous concentrations are presented as ppm total orthophosphate (PO_4). Chemical additions during the period June through October 1970 averaged 475 pounds/day of urea and 275 pounds/day of mono-ammonium phosphate (250 pounds of nitrogen/day and 58 pounds of phosphorus/day The average measured levels of 7.3 ppm nitrogen and 1.4 ppm phosphorus prior to October 1970 were equivalent to a total BOD5:N:P ratio of 100:4.3:0.8. The BOD_5 removal efficiency during the June through October period averaged about 60 percent.

On 10 October 1970 the addition of mono-ammonium phosphate was stopped. During the following period, November 1970 to July 1971 the measured nutrient concentrations averaged 4.6 ppm nitrogen ar 1.0 ppm total phosphorus (as PO_4) equivalent to a nutrient ratio of 100:3.2:0.7. The average BOD_5 removal efficiency remained constant at about 60 percent; the reduced nutrient levels had no noticeable effect on the treatment efficiency.

In mid-July 1971 the addition of both chemical nutrients was stopped and the treatment efficiency subsequently decreased about 15 percent. Thus it is apparent that additional nitrogen and phosphorus was required for efficient BOD_5 removal in the aerated lagoon.

The measured concentration entering the aerated lagoon averaged considerably greater than the amounts added because some nutrients were contained in the sanitary waste flows of both the mill and the Town of Hinton which are also treated in the NWP&P lagoon. Before October 1970 the mill waste contained approximately 50 percent of the required nitrogen and phosphorus, the town sewer 20 to 25 percent and the additions of urea and ammonium phosphate supplied about 30 percent. The main nutrient sources within the mill included the woodroom effluent and caustic wash liquor for nitrogen and phosphorus from the boiler water treatment and the lime kiln scrubber waste water.

The total Kjedahl nitrogen concentration exhibited a 20% increase while the total phosphorous concentration decreased slightly through the aerated lagoon. The nitrogen increase is likely due to denitrification processes occurring in the quiescent zone of the aerated lagoon.

Nutrient Additions at ALPULP:

Nutrient concentrations and additions for the ALPULP lagoon are shown in Table 5. The initial chemical addition rates averaged 100:3.2:0.8. The average BOD_5 removal efficiency during this period was about 75 percent.

The additions of urea and ammonium phosphate were reduced in June 1971 to nutrient addition ratio of 100:1.8:0.25. No detrimental effects on the biological treatment process were evident. In fact, the BOD_5 removal efficiency increased to an average 82 percent during August and September 1971. It is probable that the increased efficiency was due to the increased lagoon temperature which averaged 32°C, an increase of 8°C from that recorded during the initial period. The measured nitrogen and phosphorous concentrations averaged 7.4 ppm and 3.1 ppm as PO_4 respectively from June through September, equivalent to an overall BOD_5:N:P ratio of approximately 100:2.9:0.4. The BOD_5 removal was about 48,000 pounds/day or 1.95 pounds BOD_5/HP-hr.

The measured nutrient concentrations indicate that the mill wastes contain the equivalent of approximately 35 to 50 pounds/day of phosphorus and 300-400 pounds/day of nitrogen, about 20 percent of the total nutrients supplied to the aerated lagoon. Both the nitrogen and the phosphorous levels decreased through the lagoon.

Nutrient Additions at EUROCAN:

The addition of nitrogen and phosphorus was irregular at EUROCAN due to mechanical problems and sporadic operation of the mill during this start-up period. The addition ratio averaged 100:3.9:1.0 (Table 6) during the initial operating period, November 1970 through April 1971, and the average measured concentrations of nitrogen and phosphorus were 4.5 ppm N and 2.14 ppm (as PO_4) respectively. Thus the mill wastes contained approximately 100 pounds/day of nitrogen and about 40 pounds/day of phosphorus.

When mono-ammonium phosphate additions were stopped during May through September 1971, the BOD_5 removal efficiency decreased to approximately 72 percent. However, the BOD_5 loading to the lagoon was sporadic and below normal, averaging about 1.35 lbs BOD_5/HP-hr. The nitrogen and phosphorous concentrations decreased slightly through the lagoon.

General

The operation of both the ALPULP and NWP&P aerated lagoon indicates that during summer operation efficient biological treatment of kraft mill effluent can be achieved with a BOD_5:N:P nutrient ratio of approximately 100:3.0:0.5. The nutrients contained in the raw kraft mill waste averaged about 20 to 50 percent of the total nitrogen and phosphorous requirements. At NWP&P an additional 25 percent of the required nutrients was contained in the domestic sewer from the Town of Hinton.

8.4 Effect of pH

The importance of pH control of biological oxidation processes is well described in the literature, which recommends a pH of 6 to 8 for optimum BOD reduction when treating pulp and paper mill wastes. Influent and effluent pH probability ranges for each of the systems are shown in Table 7 for 5 and 95 percent probability, and Figure 10 for all probabilities.

The pH at NWP&P is controlled by two automatic controllers in series. The waste pH is adjusted to about 7.5 before the primary clarifier and is further trimmed to 7.0 before entering the lagoon. Bleach plant acid wastes are used for pH control and there is provision for using sulphuric acid during periods when the bleach plant is inoperative. In the aerated lagoon the pH was within the recommended range over 95 percent of the time. Only one percent of the time did the influent pH reach 10.0. This shock loading did not appear to affect the lagoon operation.

At ALPULP, the pH of the selected waste streams receiving biological treatment was consistent and did not require neutralization to maintain the desired pH in the aerated lagoon. The waste pH was generally lower than the other systems and changed only slightly during the biological oxidation process.

The mill effluent pH at EUROCAN was subject to wide variation during the mill start-up period. However, the biological processes in the aerated lagoon buffered the high influent pH. The influent pH exceeded 8.0 over 95 percent of the time but the lagoon pH exceeded 8.0, the recommended upper limit for normal aerated lagoon operation, about 50 percent of the time. The BOD_5 removal efficiency of the lagoon was not significantly affected by the high pH and consistently averaged about 75 percent. However, the BOD_5 loading rate was not as great as for the other lagoons, being approximately 1.3 lbs BOD_5/HP-hr, and a high level of dissolved oxygen (3 to 6 ppm) was maintained throughout the lagoon.

9. MATHEMATICAL MODELLING

9.1 Introduction :

An aerated lagoon system is basically a partially mixed reactor and as such, its performance is dependent upon two general subsystems - the hydraulic mixing conditions, and the kinetic behaviour of the reaction occurring in the lagoon. Mathematical models defining each subsystem can be combined in order to formulate an overall model for the system.

Independent information on the mixing behaviour of the reactor may be obtained from tracer studies. In this work, the determination of the system residence time distribution was selected as the most convenient means of obtaining mixing information. This is readily done by injecting an instantaneous impulse of tracer solution into the process input stream and continuously monitoring the tracer concentration in the output stream. The residence time distribution is indicative of how long each particle in the output stream has remained in the system. Levenspiel (1962) offers a more detailed discussion of this topic.

Specification of the reaction kinetic model and determination of the kinetic rate constant(s) provide the information necessary to combine with the mixing model and make overall reactor performance predictions.

9.2 Experimental Techniques :

Rhodamine-WT was selected as the inert tracer to use in the residence time distribution studies. A discussion of the tracer evaluation, tracer input injection and output monitoring points, the monitoring equipment, and fluorometer calibrations appears in Appendix 4.

9.3 Mathematical Mixing Models

Six hypothetical models, traditionally popular in the Chemical Engineering literature, were used to characterize the mixing behaviour of each aerated lagoon. The models are: the axial dispersion model, the equal tanks-in-series model, the unequal tanks-in-series model, and the backflow-cell model. Commonly, it has been assumed that aerated lagoons are either ideal plug flow or ideal completely mixed systems. Thus, for comparative purposes, these two simple models were fitted to each system as well.

An illustrative schematic of each model appears in Figure 11. The ideal plug flow tubular reactor (PFTR) is a completely non-mixed model wherein the fluid proceeds in piston-like flow down the length of the vessel. The ideal completely mixed model (CSTR) is a completely mixed model wherein the concentrations of all species at all points in the reactor are equal and are the same as the effluent concentrations. The axial dispersion model is a PFTR with a longitudinal diffusion mechanism superimposed upon the piston-like flow. The remaining three models represent series combinations of CSTR's useful for describing partially mixed behaviour. A complete mathematical description of each model appears in Appendix 5.

9.4 Data Analysis and Results:

Details of the mathematical and statistical techniques used to fit the mixing models may be found in Appendix 5. The best model parameter estimates are in Table 8. Plots showing typical experimental residence time distributions (black dots) and the fitted models (plotted lines) are shown in Figures 12 through 17, Figures 18 through 21, and

and Figures 22 and 23 for NWP&P, ALPULP and EUROCAN respectively. The legend appearing immediately ahead of these figures provides a guide to distinguish between the plotted mixing model residence time distributions.

9.5 Discussion of Model-Fitting Results:

Examination of the residual sum of squares values in Table 8 indicates that the dispersion model and the unequal CSTR's-in-series model were, in general, the better fits to the data. However, for runs A-2 and A-3, the backflow-cell model, although not as good as the unequal CSTR's-in-series model, was a somewhat better fit than the dispersion model. In all cases, the equal CSTR's-in-series model was the poorest fit.

To test the validity of the models, the predicted BOD_5 conversion was compared to the measured conversion calculated from BOD_5 data averaged over the course of a tracer run. A first order biokinetic rate mechanism was used in the models and the rate constant was determined from batch data following the procedure outlined in Appendix 2. These comparisons are reported only for those runs in which the aerator horsepower input was sufficient to maintain a measurable dissolved oxygen concentration in the lagoon. Table 9 presents the measured as well as the predicted dimensionless BOD_5 removal ratios for each of the four partially-mixed models used. For comparative purposes, those conversions predicted for a single CSTR and a single PFTR of similar residence times are also tabulated. It is seen that in general, the "best" model for each run is a good predictor of the aerated lagoon's performance. As expected the ideal CSTR, the ideal PFTR and the equal CSTR's-in-series model are the poorest predictors.

Table 9 implies that either the axial dispersion model, the unequal CSTR's-in-series model, or the backflow-cell model is likely to be useful in making accurate performance predictions. For rapid calculation, it is recommended that the unequal CSTR's-in-series model be used. The dimensionless output concentration for this model is given in Appendix 5.

However, the axial dispersion model is useful for obtaining a BOD_5 concentration profile along the lagoon. Wehner and Wilhelm (1956) have derived an expression for the profile and it is also given in Appendix 5. It is recommended that this expression be used whenever a BOD_5 profile is required for proper placement of aerators in a tapered aeration configuration. As the dispersion model is particularly useful for this purpose, a further investigation of its behaviour seemed warranted.

9.6 Prediction of Aerated Lagoon Overall Mixing Characteristics

In an attempt to elucidate a relationship between the mixing levels and the operating and design variables in an aerated lagoon, various correlations were sought between D, $\frac{D}{uL}$, flowrate, horsepower, volume, lagoon dimensions, and residence time. In using the axial dispersion model to describe overall mixing effects in activated sludge aeration tanks, Murphy (1971) has proposed a correlation between the dispersion coefficient, D, the cross-sectional area of the vessel A_x, and the unit mixing energy input. This correlation is plotted in Figure 24 along with the corresponding results from this study. It may be assumed that over the rather narrow spectrum of unit energy inputs employed in this study (0.02 to 0.10 HP/10^3 cu ft), no dependence of D/A_x on the unit energy input was found. Likewise, a plot of the dispersion coefficient versus the cross-sectional area as shown in Figure 25 also showed no reasonable correlation.

Consequently, it was assumed that the dispersion coefficient, D, was equal to a constant, K, for the system studied:

$$D = K \tag{1}$$

Noting that $u = L/\tau$, the dimensionless dispersion number may then be written for these systems as :

$$\frac{D}{uL} = K \frac{\tau}{L^2} \tag{2}$$

A plot of $\frac{D}{uL}$ versus τ/L^2 appears in Figure 26. The proportionality constant K is equal to 3.10×10^4 when τ is expressed in hours and L in feet. From Figure 26, it is evident that a significant trend exists between aerated lagoon geometry, as specified by τ/L^2, and the overall mixing behaviour, as characterized by the dimensionless dispersion number D/uL.

It is of interest to pursue the interpretation of the quotient τ/L^2. Noting that $\tau = \frac{(\text{Volume})}{(\text{Flowrate})}$, this quotient may be expanded for rectangular aerated lagoons to be :

$$\frac{\tau}{L^2} = \frac{(\text{Length})\ (\text{Width})\ (\text{Depth})}{(\text{Flowrate})\ (\text{Length})^2} = \frac{(\text{Width})\ (\text{Depth})}{(\text{Flowrate})\ (\text{Length})} \tag{3}$$

or $$\frac{D}{uL} = K \frac{\tau}{L^2} = K \frac{A_x}{QL}$$

where Q = flowrate through the lagoon (ft^3/hr)

and A_x = cross-sectional area (ft^2).

9.7 Prediction of BOD_5 Profiles :

In order to evaluate the use of the dispersion model to predict the BOD_5 profile along an aerated lagoon, actual field measurements of the BOD_5 profile taken during each tracer run were compared to that profile predicted by the dispersion model. Only those runs in which the aeration horsepower input was adequate to produce a measurable dissolved oxygen concentration throughout the lagoon were selected for this comparison. For the NWP&P runs, only the aeration section was considered.

Equation 5-2 in Appendix 5 was used to calculate the predicted BOD_5 profile. The first order BOD_5 removal rate constant was determined according to the procedure outlined in Appendix 2. The temperature dependence of this rate constant is illustrated in Figure 27. The residence time (τ) was estimated by dividing the aerated lagoon volume by the flowrate averaged over the duration of the run, and the dimensionless dispersion number (D/uL) was taken from Figure 26.

The various measured and predicted profiles appear in Figures 28 through 33. The experimentally measured data were averaged over the course of a run ($>$2 weeks). Although scatter is apparent in some of the runs, it is evident that the dispersion model in conjunction with batch reactor data can provide a reasonable estimate of the BOD_5 profile along an aerated lagoon. Much of the scatter can be attributed to the unavoidable fact that the flowrate and influent BOD_5 concentrations exhibited their normal daily fluctuations during the course of each run.

10. AERATED LAGOON GEOMETRY

10.1 Length:Width Ratios:

Having selected the aerated lagoon residence time, the design engineer generally bases the shape of the aerated lagoon on economic considerations of construction costs. These are usually determined by local topographic conditions. However, as illustrated in the following discussion, the aerated lagoon process performance is dependent not only upon the overall residence time but also on the lagoon geometry.

Assuming a first order BOD removal mechanism and if all other variables such as residence time, BOD loading, effluent characteristics, temperature, aeration horsepower etc. are held constant, then theoretical considerations [Levenspiel (1962)] dictate that a plug flow system will yield a more efficient percent BOD removal than a completely mixed system. The results of the tracer tests reported previously have shown that a relatively square lagoon approaches completely mixed behaviour whereas a system with a large L:W ratio, although not ideally plug flow, nevertheless is only partially mixed.

Consider the two geometrical extremes studied in this report : EUROCAN (L:W = 1.2:1) and ALPULP (L:W = 12.5:1). The unequal CSTR's-in-series mixing model was used to make a comparison between these two systems because the simplicity of its functional form makes it amenable to hand calculations.

The parameters for the mixing models were averaged over those listed in Table 8 for each tracer run of the respective system and these were normalized such that the total residence time for each model was 5.00 days. A reaction rate constant of 0.350 days^{-1} was assumed.

Table 10 shows the results of this comparison. From Table 10 it is evident that the different mixing conditions between the long narrow ALPULP lagoon and the relatively square EUROCAN lagoon result in a 7.0 percentage point difference in predicted treatment efficiency in favour of the long narrow system. The difference between the NWP&P and EUROCAN predicted efficiencies was 5.2 percentage points. Conversely it may be shown that the relatively square lagoon would require about 34.5 percent more residence time than the long narrow system to achieve the same treatment efficiency.

It should be emphasized that these predictions are hypothetical and do not account for the many other differences between the two systems; however, consideration of oxygen uptake rates in the two lagoons tends to support this theory. At ALPULP, the oxygen uptake rate in the lagoon varied from 4.0 ppm/hr at the head to zero near the end of the lagoon indicating that the oxygen demand of the waste was satisfied. However, at EUROCAN, oxygen uptake rates were more uniform throughout the lagoon varying from about 1.5 to 2.5 depending upon the BOD loading to the system. This suggests that the oxygen demand of the treated effluent at EUROCAN was not totally satisfied.

Furthermore, a fundamental consideration of the residence time distribution for each system also supports this theory. By definition, the area under a residence time distribution curve from time zero to time τ is equal to that fraction of the outflow stream that has spent time τ or less in the system. Taking tracer runs H-5, A-3, and E-1 as being typical for each system, approximately 7.7 percent, 5.3 percent and 13.4 percent of the outflow stream has received biological treatment in the aerated lagoon for a period of 24 hours or less. Therefore, one may expect a higher fraction of partially treated effluent from the EUROCAN lagoon than from the ALPULP system, all other factors being the same. This becomes increasingly important when high BOD and/or toxicity removals are required.

In practice, consideration must be given to self-seeding and shock-load buffer capacity. Very large L:W ratio systems, which approach plug flow behaviour, will be more sensitive to these effects than smaller L:W ratio systems, which approach completely mixed behaviour, and the optimum design must account for these factors. Therefore, the final shape of an aerated lagoon should reflect consideration given not only to economical construction costs, but also to mixing conditions and to anticipated shock loading.

10.2 Aerator Spacing:

From equation 4 it is evident that the dimensionless dispersion number is a function of the geometrical configuration of the aerated lagoon and the liquid throughput rate.

This is of considerable importance to the design engineer. Knowing geometry and anticipated flowrate for a proposed aerated lagoon, Figure 26 may be used to predict the dispersion number. With this information, the BOD concentration profile along the lagoon may be calculated using equation 5-2 in Appendix 5 and the aerators may be positioned accordingly to satisfy the local biochemical oxygen demand of the lagoon contents. This enables the designer to follow a rational procedure when spacing the aerators to provide for tapered aeration. In general, the result will be more closely spaced aerators near the inlet of the lagoon for relatively large length:width ratio systems and a more uniform spacing for relatively square aerated lagoons.

10.3 Quiescent Zones :

Each of the installations studied had a quiescent zone preceding the outlet of the lagoon where any remaining settleable material in the waste could settle prior to discharge from the lagoon.

At NWP&P, a portion of the U-shaped lagoon was not aerated, creating a quiescent zone of approximately 1.5 days residence time. The treated waste flowed from the aerated zone directly into the quiescent zone around the end of the centre berm separating the two regions. The decrease in suspended solids concentration through the quiescent settling zone averaged 20 to 30 percent at a mean final effluent concentration of 75 ppm. Sludge depths through the settling zone averaged one to two feet. The lagoon has been operating continuously since 1967. The BOD_5 of the waste also decreased noticeably in the quiescent zone; total BOD_5 concentrations decreased approximately 9 percent (equivalent to 12 ppm). The accumulated sludge layer in the settling zone was anaerobic as evidenced by the release of gas bubbles and occasionally by odours from the lagoon (although odour was not a major problem).

Settleable solids concentrations increased from about 20 ppm in the influent waste to about 60 ppm through the NWP&P aerated lagoon, but showed only a slight decrease through the quiescent zone to about 40 ppm. Anaerobic conditions in the 1.5 day quiescent zone caused re-suspension of settled matter thereby impairing the quality of the final effluent.

The aerators at ALPULP were more widely spaced in the latter half of the lagoon to provide quiescent areas for the removal of any remaining settleable material. Through the quiescent area, about 300 feet in length before the outlet of the lagoon, there was no noticeable change in suspended solids concentration, and the BOD_5 decrease was less than 5 percent. The residence time of this quiescent area was approximately 0.3 days.

At ALPULP, settleable solids concentrations increased from 15 ppm in the influent waste to about 20 ppm in the lagoon. At the end of the quiescent zone, settleable solids concentrations in the final effluent ranged from 0 to 5 ppm.

At EUROCAN, a wooden dyke about 450 feet in length, created a quiescent zone immediately before the outlet weir from the aerated lagoon. The residence time of this zone was also about 0.3 days. The concentration of suspended solids decreased about 10 percent (5 ppm) through this zone, and the total and soluble BOD_5 concentration decrease averaged 5 ppm. Normally, the level of suspended solids in the EUROCAN aerated lagoon was lower than in the other two systems as the waste was clarified and then settled in an 8-hour retention settling pond immediately before entering the lagoon.

Settleable solids concentrations in the EUROCAN lagoon averaged 30 ppm. However, during the testing period when the settleable solids were being investigated, the settling ponds before the lagoon became nearly full and significant settleable solids quantities overflowed into the aerated lagoon increasing the concentration to about 80 ppm in the lagoon. Following the quiescent zone, the settleable solids in the final effluent varied from about 0 to 5 ppm.

11. AERATOR PERFORMANCE

In an aerated lagoon the two main functions of an aerator are to transfer oxygen into the waste for the biological oxidation processes, and to provide turbulent mixing required for dispersion of the dissolved oxygen and for contacting the reactants.

11.1 Oxygen Transfer:

The amount and rate of oxygen transfer in an aerated lagoon is affected by many factors, among which are the BOD loading, the temperature, the dissolved oxygen concentration, the so-called "alpha value" of the waste, and the rate of biological activity in the lagoon.

The ultimate BOD reduction (defined as BOD_{20}) through the ALPULP lagoon averaged 1.7 times the BOD_5 reduction while the COD to BOD_5 ratio average 1.5. The oxygen transfer efficiency of the surface aerators, based on one pound of oxygen required to remove one pound of BOD_{20}, was 1.87 x 1.7 = 3.18 lbs 0_2 transferred/NPHP-hr. The average D.O. level maintained in the lagoon effluent was 3.5 ppm. This value compares favourably with the design 0_2 transfer efficiency of 3.2 lbs 0_2/NPHP-hr based on test data and using constants derived in bench scale tests.

It is possible that a significant fraction of the BOD entering a newly commissioned lagoon such as ALPULP is removed by sedimentation of incompletely oxidized material and accumulates as sludge on the bottom. In the case of an old lagoon, such as NWP&P, it is likely that a fraction of this sludge will exert an oxygen demand on the system due to anaerobic decomposition within the sludge. It can be anticipated, therefore, that the long-term removal will be intermediate between the ALPULP and NWP&P results shown in Figure 8.

Using a similar BOD_{20}:BOD_5 ratio as that used to predict the ALPULP oxygen transfer efficiency, the value for NWP&P will be 1.45 x 1.7 = 2.47 lbs oxygen/NPHP-hr. It is possible that the actual oxygen transfer efficiency is intermediate between these two values - that is, 2.8 lbs oxygen/NPHP-hr.

11.2 Aerator Mixing:

The mixing characteristics of an aerator in a lagoon can be evaluated by several parameters. The parameter of HP input per unit volume has been used to measure turbulence with suggested values of 8 to 25 HP/10^6 US gallons to maintain a uniform D.O. throughout the lagoon and values as large as 50 to 100 HP/10^6 US gallons to maintain a uniform suspended solids level. Data from this study and recent literature publications indicate that this parameter is not a valid measure of the degree of mixing when used to compare different systems. The aeration power inputs were 8 to 10 HP/10^6 US gallons in the three lagoons, yet the variations in D.O. and suspended solids levels were considerable. The mixing is a function of the geometry of the lagoon, the spacing and placement of the aerators and the pumping characteristics of the aerators.

The relatively square EUROCAN lagoon approximated a completely mixed system; the standard deviation of the D.O. concentration throughout the lagoon was approximately ± 4 percent. Suspended solids averaged 70 ppm with a standard deviation of ± 15 percent. The aerator HP input of 10 HP/10^6 US gallons, distributed evenly through the lagoon at a spacing of about 300 feet (3 feet/HP), provided a uniform level of turbulence throughout the lagoon.

The ALPULP and NWP&P lagoons were plug-flow type with length to width ratios of approximately 12.5:1 and 7:1 respectively. Non-conservative variables such as BOD_5 and temperature decreased through the length of the lagoon; the temperature decrease was linear while the BOD_5 showed a non-linear profile which was dependent on other system variables.

At NWP&P, with an aerator HP input of about 8 HP/10^6 US gallons, the variation in suspended solids concentration throughout the aerated section of the lagoon was $\pm$ 20 percent at an average level of 150 ppm. The aerators, spaced at about 125 feet (2.5 feet/HP) between centres maintained a relatively uniform concentration of suspended solids except in the immediate inlet area and in the corners of the rectangular lagoon. The cross-sectional profiles showed a suspended solids variation of about 6 percent across the width of the lagoon and about the same variation with depth to twenty feet.

The aerator spacing in the ALPULP lagoon was somewhat greater than at NWP&P. Near the inlet the centre spacing was about 175 feet and this increased to about 300 feet on the outlet side of the lagoon. The tapered aeration provided a mixing energy input of 12 HP/10^6 US gallons at the head end of the lagoon and approximately 6 HP/10^6 US gallons in the final section. The level of suspended solids was noticeably greater near the inlet and the variation through the lagoon was about $\pm$25 to $\pm$30 percent at a mean concentration of 90 ppm.

The dissolved oxygen concentration generally increased through the ALPULP lagoon. Near the inlet where the BOD_5 concentration was the highest, the oxygen uptake rates were also maximum and the D.O. was less than 0.1 ppm. Through the second half of the lagoon the oxygen uptake rates decreased and the D.O. concentration increased to an average concentration of 2 to 3 ppm or more in the treated effluent. The cross-sectional profiles showed a variation in suspended solids levels of approximately 20 percent and a D.O. variation of about 10 percent.

In general, the concentration of settleable and suspended solids in the waste entering the aerated lagoons varied widely depending on conditions in the mill, the operation of the primary clarifier, and at EUROCAN, the operation of the settling ponds before the lagoon. As a result, the suspended solids levels in the aerated lagoons were largely dependent both on the solids concentration in the influent waste and on the aeration horsepower level. The dependency of settleable solids on the aeration horsepower level is shown in Figure 34.

Settleable solids concentrations in both the lagoon influent and the lagoon contents are listed in Table 11. At the higher aerator power levels a differential exists between the settleable solids levels in the influent and the average concentration through the lagoons.

11.3 Velocity Profiles:

Velocity profiles were measured about various aerators to determine the local mixing patterns. The magnitude and direction of the fluid velocity were measured at various distances and depths using a Decca current meter. The details of the experimental procedure are given in Appendix 2 .

The results of the velocity studies are shown graphically in Figure 35 to 38.

The recorded magnitude and direction of the horizontal fluid flow were used to resolve the velocity vector into components along a radial line from the aerator centre. By this procedure, the effect of vortex flow was eliminated and only the resultant inward and outward flow considered. Generally, the flow was outward near the surface diminished to zero and then became inward at greater depths. Because the vertical flow component is not reported here, no attempt to estimate aerator pumpage rates was made. Although the use of radially resolved horizontal velocities does not completely describe the flow and mixing patterns of an aerator, it does, however, provide a good indication of the net fluid flow around the aerator.

The most obvious feature of the velocity profiles is the cross-over point from horizontal flow away from the aerator to flow toward the aerator. This is observed in all the profiles except the 75 HP high speed aerator at 100 feet, which was taken about 75 feet from the lagoon bank and hence, possibly influenced by side-wall effects. With this exception, the profiles can be considered to represent aerator influence only and hence would be approximately symmetrical around the aerator. The depth of the cross-over point increases with distance from the aerator, for both the high and low speed aerators. At 25 feet from the aerator centre the change-over occurred in the top 3 feet while at the 50 foot location, the change-over occurred at about 6 feet depth.

The maximum flow velocity occurred at, or close to, the surface in all cases. The high speed aerators appear to produce a higher surface velocity than the low speed aerators. It is evident that at 100 feet, the aerators still have a significant influence on the flow in the lagoon.

These results compare favourably with the findings of the National Council [NCASI (1971)] in their study of the mixing characteristics in aerated stabilization basins.

12. HEAT LOSSES

During the study period, the extreme temperatures of the waste entering the aerated lagoons ranged from 38°C to 15°C, whereas the effluent temperature extremes varied from 31°C to 10°C. The temperature decrease through the three five-day aerated lagoons (influent minus effluent temperature) is shown in Figure 39 plotted against the ambient air temperature. A greater decrease in waste temperature is associated with lower ambient air temperature. The maximum observed temperature loss through the five-day lagoons was about 16°C at an ambient temperature of minus 30°C (minus 22°F). The data are average values taken over a four-day period and are quite scattered due to the numerous factors affecting heat losses that are not accounted for, which include such variables as wind velocity, relative humidity, solar radiation, foam cover over the lagoon, and the surface area increase due to aerator turbulence.

Figure 40 indicates that the temperature decrease is more closely related to the difference between the mean lagoon temperature and ambient air temperature. The liquid temperature within an aerated lagoon will depend upon the rate at which heat is lost and the extent of mixing that exists. The mixing regime is dependent upon the lagoon geometry and on the aerator horsepower. At NWP&P and ALPULP, which have a large length:width ratio, there is a linear temperature decrease through the five-day lagoon, while at EUROCAN, where the length:width ratio is approximately 1.2:1, the aerated lagoon is well mixed with a uniform temperature profile throughout.

If the heat loss is mainly through the lagoon surface, the heat loss will be proportional to the air liquid temperature differential and the surface area:

$$(T_i - T_e)\ Q = fA\ (T_m - T_a) \tag{5}$$

where : T_i = influent temperature

T_e = effluent temperature

T_m = mean lagoon temperature

T_a = ambient air temperature

A = lagoon surface area in square feet

Q = waste flow rate in million gallons (US) per day and

f = proportionality factor or overall heat transfer coefficient.

This relationship was used by Eckenfelder (1966) to estimate the heat loss from aerated lagoons and is quite useful for design purposes.

Because the temperature decrease through the large length:width ratio lagoons is approximately linear, the mean lagoon temperature (T_m) can be calculated as the arithmetic mean between the waste temperature at the inlet of the lagoon (T_i) and the lagoon effluent temperature (T_e). In the well mixed lagoon, the mean lagoon temperature (T_m) is the same as the effluent temperature (T_e).

In Figure 41, the heat loss per unit surface area is plotted against the air-lagoon temperature difference. From equation (5), the slope of the least squares straight line is the proportionality factor "f". This slope was calculated to be 8.66×10^{-6}, with a correlation coefficient of 0.757. In comparison, Eckenfelder has recommended the value of 12×10^{-6} for the central United States.

This relationship assumes that the major heat loss is through the surface of the lagoon. The temperature near the surface of the lagoons was generally about 1.0 to 1.5°C less than the waste temperature at a depth of ten feet, supporting the postulate that most of the heat loss occurs at the surface by radiation and convection to the atmosphere. An approximate calculation indicated that the heat loss to the ground was small and would account for only 5 to 10 percent of the total loss from the lagoon.

It has been postulated that the intensity of agitation of the lagoon surface could have significant effects on the heat loss from an aerated lagoon. In Figure 42, the overall heat transfer coefficient "f" for the three lagoons is plotted against the total aerator horsepower input. The aeration horsepower levels range from 3 to 10 $HP/10^6$ US gallons. No definable correlation between the aeration horsepower and the overall heat transfer coefficient of the five-day lagoons is evident. One possible explanation is that the mixing action of the aerators tends to generate a stable foam which blankets the lagoon. As the number of aerators increases the foam cover is greater and the insulating effect of the foam reduces the heat losses from the surface and balances the additional heat lost as the waste is dispersed into the air by the aerators.

13. INITIAL START-UP OF THE TREATMENT SYSTEMS AT ALPULP AND EUROCAN

13.1 Establishing Biological Activity :

To determine if biological seeding would be required for the start-up of the aerated lagoon at ALPULP, a series of treatability studies was performed by ALPULP personnel during the design stage of the effluent treatment facilities. Representative composite samples of the mill waste to be treated were collected and divided into one-litre batches in the laboratory. Ten percent settled seed material was added to each batch reactor. The seed employed consisted of those liquids that possibly could be added to the lagoon should they prove beneficial; these included waste from a domestic sewage treatment lagoon, river water from a point below the existing mill outfall, surface water from a long pond, and river water trapped in the lagoon before the mill waste was added. Nutrients nitrogen and phosphorous were added to each composite sample in the ratio of approximately 100:2.5:0.8 for BOD_5:N:P. The batches were aerated at a room temperature for five days with daily sampling for biochemical oxygen demand (BOD_5). These results are shown in Figure 43.

The BOD_5 reduction curves are very similar for all of the seeded batch reactors. The unseeded batch required a longer period than the seeded batches to develop sufficient bacteria for rapid BOD_5 reduction, but after five days aeration the same degree of treatment was achieved. It was concluded that no additional bacterial seed was required to achieve a high degree of BOD_5 removal after five days of aeration in the batch systems.

To test if the results at ALPULP were also typical for an unbleached kraft waste, a similar laboratory study was performed using the total effluent from the EUROCAN unbleached kraft mill. The seed materials used included: effluent from a domestic sewage treatment lagoon, settled sludge from the EUROCAN aerated lagoon and treated effluent from the aerated lagoon. The results obtained, shown in Figure 44, indicate a similar phenomenon. There was somewhat less BOD_5 removed during the first three days of aeration but after five days aeration the reduction in BOD_5 was approximately the same for all of the seeded and unseeded batches.

As these tests seemed to indicate additional seed was not required, total bacterial plate counts were performed to establish some relative measure of the bacterial content in the mill effluents. Results for both ALPULP and EUROCAN indicated a total bacterial count of approximately 10^6 per 100 millilitres of sample for the waste from the mill; tests on the effluent leaving the treatment lagoons indicated much bacterial growth, approximately 10^9 bacteria per 100 millilitres present. For both of these mills, woodroom waste from hydraulic barkers was part of the total flow and therefore some of the bacteria may have originated from this waste.

For both ALPULP and EUROCAN a successful start-up of the biological treatment facilities occurred without an external source of microorganisms. There was sufficient lagoon capacity at each installation to provide at least five days detention. This appears important for "self start-up", by the batch studies. The presence of suitable bacteria or microorganisms in the mill effluent is of double significance: first, it would appear unnecessary to expend time and money to provide extra seed for a five day treatment system; second, the system will re-seed itself in the event of a pulp process spill that could temporarily destroy the microorganisms present.

13.2 Effect of Nutrients:

To determine the effects of additional nutrients and to establish the optimum addition ratios for treating a particular pulp and paper waste, laboratory scale batch studies were conducted by ALPULP personnel. For various nutrient ratios, typical levels of BOD_5 removal achieved through five days aeration are shown in Figure 45. With no additional nutrients the BOD_5 removal was slight even after five days. As the amounts of nitrogen and phosphorous added were increased, there was a corresponding increase in the treatment efficiency to approximately 84 percent with a nutrient ratio of 100:2.5:0.8 after five days aeration.

During the actual start-up of each full-scale system, nutrient additions were found to be essential in establishing rapid biological activity. At each mill, although treating different types of waste, the BOD_5 removal through the aerated lagoons increased rapidly after the commencement of nitrogen and phosphorous additions. The results of the daily BOD_5 tests during the start-up of the treatment systems at ALPULP and EUROCAN are shown in Figures 46 and 47 respectively.

At ALPULP the aerated lagoon was filled with the mill waste and the aerators were installed and tested during the ensuing three weeks. During this time, the treatment achieved throughout the lagoon was in the order of 30 percent with little or no dissolved oxygen present.

With 12 of the 14 aerators installed and commencement of nutrient addition, the BOD_5 removal through the lagoon increased very rapidly, reaching 80 percent removal about one week after the addition of nutrients began. Nutrients were in the form of mono-ammonium phosphate and urea with a ratio of 100:2.5:0.8 for BOD_5:N:P. It is noted that two of the groundwood washers were not yet connected at this time and therefore the waste load was only 80 percent of the designed loading.

At EUROCAN a similar monitoring program was performed during start-up with the aerated lagoon treating the total effluent from the unbleached kraft mill. With the new mill there was a wide variation in the mill effluent BOD, although the same trends were present. With no nutrients, BOD removal was approximately 30 percent while soon after the addition of nutrients the BOD removal steadily increased to an average reduction of 80 percent. Phosphorous was added continuously in the form of mono-ammonium phosphate and nitrogen was added continuously in the form of anhydrous ammonia.

At both installations nutrients were not a limiting parameter as measurable soluble concentrations in excess of one ppm were available in the waste after treatment.

13.3 Oxygen Requirements:

An additional requirement for effective aerobic biological treatment is dissolved oxygen. At ALPULP the lagoon was filled with effluent before the aerators were started; thus, there was a period of approximately 20 days with no mechanical aeration during which time mill waste flowed through the treatment lagoon. Measurements during this period showed there was no detectable dissolved oxygen in the waste. When the aerators were started, the level of dissolved oxygen in the lagoon effluent increased to about 20 percent of saturation. No significant adverse effect on establishing aerobic activity in the lagoon when the aerators were started was noted although the lagoons were without oxygen for a 20-day period. As soon as nutrients were added aerobic biological activity increased rapidly decreasing the dissolved oxygen concentration to zero throughout the lagoon. As treatment progressed the dissolved oxygen gradually increased.

The relative biological activity was determined by measuring the oxygen uptake rate. Relatively low uptake rates in the order of 0.5 ppm oxygen per hour were found until the nutrients were added, following which the rates increased to about 4 ppm oxygen per hour. Upon stabilization of treatment, a gradient was established through the system with uptake rates of approximately 4 ppm oxygen per hour near the inlet decreasing to practically zero at the outlet. This indicated that the system was meeting the biological demand of the waste.

At EUROCAN, the oxygen requirement during initial start-up was far less than the design level as the waste load from the mill was very low. For the first two months of start-up, the dissolved oxygen level in the treatment lagoon ranged from 50 to 90 percent of saturation. After the addition of nutrients, biological activity reduced the BOD_5 by approximately 80 percent as shown on Figure 47. Oxygen uptake rates prior to nutrient addition averaged approximately 0.5 ppm oxygen per hour and following nutrient addition, they averaged 1.5 ppm/hr. Rates as high as 2.0 ppm oxygen per hour were obtained during higher BOD load fluctuations.

The routine use of dissolved oxygen levels and oxygen uptake rates is considered very useful for the daily operation of a treatment system. Fluctuations in dissolved oxygen indicate the fluctuations in waste load on the system. When this is coupled with the oxygen uptake rate, the relative degree of waste stability and demand for oxygen upon the receiving water is known. An example of how the BOD, dissolved oxygen and oxygen uptake rate varied through the ALPULP lagoon is illustrated in Figure 48. The dissolved oxygen concentration decreases near the outlet as the aerators are spaced further apart. By monitoring particular locations, shifts in treatment conditions can be detected which would be used as a signal for more detailed investigation. The advantage of dissolved oxygen and oxygen uptake rate measurements over BOD measurement as a control technique is the relatively short elapsed time interval between the actual sampling and the calculation of the result.

14. OPERATING DATA

14.1 Overall system performance:

The aerated lagoon operating data recorded during the study period are summarized in Figures 49, 50 and 51, which show chronological plots of the untreated and treated effluent variables. The points plotted are five day averages of daily samples. Frequency distribution plots of the same variables are shown on arithmatic probability paper in Figures 6-1 to 6-15 in Appendix 6. The probability plotted is the percentage of all measurements equal to or less than the stated value of the measured variable. A summary of the untreated and treated mill waste characteristics is shown in Table 12 which presents the waste characteristics of the 50 and 90 percentile (equal to or less than) levels.

14.2 Waste Effluent Characteristics:

The average waste characteristics were similar for the ALPULP and NWP&P mill while the EUROCAN waste was considerably different due to the variable mill operation during its initial start-up period. Ninety percent of the time the BOD_5 and suspended solids of the NWP&P and ALPULP wastes were less than or equal to about 360 ppm and 120 to 150 ppm respectively. At the 50 percent probability level there was little difference between the lagoon influent and treated effluent suspended solids concentrations. A comparison of total and filtered waste analyses is shown in Table 13. The difference between the total and filtered was generally greater in the untreated waste which contained higher concentrations of suspended solids.

The BOD_5, COD and TOC data, expressed as ratios, are presented in Table 14. The ratios were considerably different at each mill and the raw data showed much variation even between samples gathered at the same mill. The BOD_5 results at EUROCAN were consistently lower than those at the other mills thereby causing the COD/BOD_5, TOC/BOD_5, and BOD_{20}/BOD_5 ratios to be consistently higher. As a check, some EUROCAN samples were analysed for BOD_5 at the NWP&P lab but the same results were noted. At NWP&P, both the COD and TOC concentrations were somewhat higher than at the other two mills. In general, it was noted that the various oxygen demand ratios increased somewhat through the lagoon.

14.3 Sludge Accumulations:

Depth soundings were taken at NWP&P to determine the levels and regions of sludge build-up through the lagoon. There was considerable sediment accumulation in the immediate vicinity of the influent line. Sludge depths in this area were as great as 8 to 10 feet. Some settled solids build-ups were also found where mixing was limited: between the aerators, in corners and along the sloped sides of the lagoon. These localized sludge deposits varied in depth, but were usually less than three feet. There was also a sludge layer less than one foot deep covering most of the bottom of the lagoon, except in the immediate proximity of the aerators. The lagoon at NWP&P had been in operation for about four years and the bottom deposits had not been removed during this time.

In the ALPULP and EUROCAN lagoons, bottom deposits were negligible because the systems had been in operation for less than one year at the time of this study. There was, however, some build-up of solids in the vicinity of the lagoon influent line at ALPULP. There was no solids build-up in the EUROCAN lagoon, because essentially no settleable solids entered the lagoon except for the infrequent occasions when the settling pond ahead of the lagoon was full.

Generally it was not possible to determine the bacterial solids build-up as a function of BOD reduction in the lagoons. However, at NWP&P, there was a net increase of suspended solids concentration through the aerated lagoon (aeration section only) of about 25 ppm. If it is assumed that this increase is due to the production of biological solids, then about 0.2 pound of bacterial solids are produced per pound of BOD_5 removed.

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16. NOMENCLATURE

A	Lagoon Surface Area	$(L)^2$
BOD	Biochemical Oyxgen Demand	
CEH	Chlorination, Alkaline Extraction, Hypochlorination Bleaching Sequence	
CEHDED	Same as Above plus Chlorine Dioxide, Alkaline Extraction, Chlorine Dioxide Sequence	
COD	Chemical Oxygen Demand	
CSTR	Continuous Stirred Tank Reactor	
D	Dispersion Coefficient	$(L)^2/(T)$
D.O.	Dissolved Oxygen	
f	Proportionality Constant for Heat Transfer through Surface of Lagoons	$(L)/(T)$
HP	Horsepower	
K	Constant in Mixing Correlations	
k	First Order BOD_5 Removal Rate Constant (base e)	$(T)^{-1}$
L	Length of Lagoon	(L)
L:W	Length:Width Ratio	
NPHP	Nameplate Horsepower	
PFTR	Plug Flow Tubular Reactor	
Q	Flowrate	$(L)^3/(T)$
SS	Suspended Solids	
SOC	Soluble Organic Carbon	
T_a	Ambient Temperature	
T_e	Lagoon Effluent Temperature	
T_i	Lagoon Influent Temperature	
T_m	Mean Lagoon Temperature	
TOC	Total Organic Carbon	
TPD	Tons per Day	
u	Axial Velocity	$(L)/(T)$
x	Length Variable	(L)
θ	Temperature Dependence Coefficient for First Order Rate Constant	
τ	Residence Time	(T)

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Tables

TABLES

TABLE 1

EFFLUENT QUALITY STANDARDS

Parameter	ALPULP	EUROCAN	NWP&P
BOD_5	125 ppm average	80 ppm average	240 ppm summer 145 ppm winter
pH range	4.0 to 11.0	6.5 to 8.5	
Temperature	$<125^{\circ}$F	$<125^{\circ}$F	
Suspended Solids	165 ppm average	85 ppm average	
Total Solids	-	1100 ppm average	
Settleable Solids	-	$<$ 2.5 ml/1	
Zinc	$<$ 25 ppm		

(K4015)

TABLE 2

AERATION LAGOON PERFORMANCE

Date	BOD_5 Load lbs/NPHP-hr	BOD_5 Removal lbs/NPHP-hr	Mean Lagoon Temperature °C	Mean Aeration Nameplate Horsepower NPHP	Percent BOD_5 Removal
NWP&P					
1970					
May	2.63	1.80	30	650	68.6
June	3.02	1.78	32	650	59.0
July	2.46	1.54	32	750	62.4
Aug.	3.55	1.63	32	510	45.9
Sept.	2.86	1.59	27.5	685	55.6
Oct.	2.32	1.54	25	700	66.2
Nov.	3.08	1.35	21	620	43.8
Dec.	2.34	1.15	20	720	49.0
1971					
Jan.	3.02	1.56	20	500	51.7
Feb.	2.65	1.48	22.5	600	55.9
March	3.18	1.76	22	575	55.2
April	2.27	1.46	25	750	64.2
May	1.34	1.03	27.5	835	77.0
July	2.68	1.67	30	690	62.3
- *	7.50	2.70	32	250	35.9
Aug.**	2.36	1.31	32	630	55.3
Sept.**	2.43	1.50	27.5	800	61.9
Average	2.46	1.45			58.4%
ALPULP					
1971					
Jan.	2.68	1.90	22	850	70.9
Feb.	2.65	1.85	23	930	70.0
March	2.24	1.61	24	1010	72.0
April	2.87	1.82	24	1000	63.6
May *	3.79	2.16	29	690	56.9
June	2.22	1.66	29	1025	75.0
July	2.40	2.01	32	1025	83.6
Aug.	2.59	2.16	34	1025	84.1
Sept.	2.34	1.98	32	1025	84.6
Average	2.50	1.87			75.5%
EUROCAN					
1971					
Jan. *	2.28	1.31	17	350	57.5
Feb.	1.31	1.01	19	500	77.0
April	1.27	0.50	20	600	71.0
May	0.87	0.60	22.5	800	67.0
June	0.98	0.80	26	800	81.5
July	1.04	0.86	28	800	82.8
Aug.	1.82	1.35	27	800	74.4
Sept. **	1.11	0.76	25	700	68.4
Average	1.21	0.85			75.6%

* Unusually low aeration HP and therefore not included in averages.
** No nutrient additions and therefore not included in averages.

TABLE 3

TYPICAL WINTER OPERATING PERFORMANCE

Location	Temperature °C Influent	Effluent	Ambient	BOD_5 Removal Efficiency
NWP&P	27	13	- 10	45%
ALPULP	27	17	0	70%
EUROCAN	25	16	- 5	70%

(K4015)

TABLE 4

NUTRIENT CONCENTRATIONS - NWP&P

	LAGOON INFLUENT							LAGOON EFFLUENT							
	Nitrogen-ppmN			Phosphate-ppm PO_4				Nitrogen-ppmN			Phosphate-ppm PO_4				Percent BOD_5
Date	Soluble	Susp.	Total Kjeldahl	Soluble	Susp.	Poly	Total	Soluble	Susp.	Total Kjeldahl	Soluble	Susp.	Poly	Total	Removal
1970															
June	5.21	1.77	6.98	0.88	0.33	0.25	1.21	5.91	4.09	10.0	0.86	0.31	0.29	1.17	59.0
July	8.57	1.35	9.92	0.95	0.28	0.11	1.23	7.07	3.83	10.9	0.64	0.34	0.15	0.97	62.4
Aug.	2.54	1.98	4.52	1.20	0.31	0.10	1.51	3.18	3.74	6.92	0.95	0.48	0.30	1.42	45.9
Sept	5.74	-	-	1.28	0.27	0.19	1.55	5.66	7.37	13.0	0.46	0.91	0.15	1.37	55.6
Oct.	6.46	1.26	7.72	0.77	0.46	0.10	1.23	4.74	2.13	6.87	0.63	0.38	0.05	1.01	66.2
Avg.	5.70	1.59	7.29	1.02	0.33	0.15	1.35	5.31	4.23	9.54	0.71	0.48	0.19	1.10	58.0
Nov.	2.51	1.65	4.16	0.54	0.26	0.04	0.80	2.55	2.64	5.19	0.51	0.18	0.08	0.69	43.8
Dec.	1.42	2.97	4.39	0.40	0.23	0.12	0.63	1.81	2.46	4.27	0.54	0.13	0.04	0.67	49.0
1971															
Jan.	3.18	1.45	4.63	1.09	0.09	-	1.18	1.83	3.17	5.00	0.78	0.33	-	1.11	51.7
Feb.	3.08	1.62	4.70	0.63	0.31	-	0.98	1.91	3.51	5.42	0.73	0.27	-	1.10	55.9
March	3.55	1.55	5.10	0.82	0.26	-	1.08	2.09	2.85	4.94	0.90	0.28	-	1.18	55.2
April	3.69	1.63	5.32	0.64	0.46	-	1.10	2.58	3.42	6.00	0.80	0.24	-	1.04	64.2
May	3.54	1.66	5.20	0.83	0.39	-	1.21	2.36	2.33	4.69	0.85	0.27	-	1.12	77.0
June	3.22	1.04	4.26	0.71	0.47	0.00	1.18	2.56	1.67	4.23	0.84	0.22	0.20	1.06	-
July	2.73	0.84	3.57	0.72	0.30	0.12	1.02	2.21	3.18	5.39	0.65	0.21	0.26	0.86	62.3
Avg.	2.99	1.60	4.59	0.71	0.31	0.06	1.02	2.21	2.80	5.01	0.73	0.24	0.23	0.97	57.4
Aug.	1.80	2.01	3.81	-	-	-	-	2.80	2.84	5.64	-	-	-	-	35.9

Note: - Supplemental nutrient addition ratio (reported as BOD_5:N:P):
May 1970 to 10 October, 1970 - 100:1.0:0.3
10 October, 1970 to July 1971 - 100:1.1:0.0
17 July, 1971 to date - No additional nutrients added

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..... continued on next page

TABLE 4 (Contd.)

NUTRIENT CONCENTRATIONS - NWP&P

Note:	- Actual Nutrient addition ratio: (reported as BOD_5:N:P)	May 1970 to 10 October, 1970	- 100:4.3:0.8
		10 October, 1970 to July 1971	- 100:3.2:0.7

- BOD_5 removal efficiencies may not necessarily agree with those listed in Table 2. The efficiencies reported in this table correspond to periods when the nutrient concentrations listed here were measured.

TABLE 5

NUTRIENT ADDITIONS AND CONCENTRATIONS - ALPULP

Date	Nutrient Addition Ratio BOD_5:N:P	LAGOON INFLUENT Total Nitrogen ppm N	LAGOON INFLUENT Total Phosphate ppm PO_4	LAGOON EFFLUENT Total Nitrogen ppm N	LAGOON EFFLUENT Total Phosphate ppm PO_4	Percent BOD_5 Removal
Dec.	100:3.0:0.8	7.0	8.8	2.8	4.5	78
1971						
Jan.	100:2.8:0.8	4.9	5.6	1.9	2.9	71
Feb.	100:3.2:0.8	4.0	3.0	2.0	3.1	70
March	100:3.4:0.8	-	-	-	-	72
April	100:3.0:0.7	5.7	5.7	3.0	5.1	64
May	100:3.7:0.9	7.6	5.2	2.8	4.4	57
Avg.	100:3.2:0.8	4.8	5.7	2.5	4.0	69
June	100:3.0:0.3	7.5	5.9	1.3	3.0	76
July	100:1.9:0.3	4.6	2.5	0.8	3.1	83
Aug.	100:1.7:0.2	7.9	3.1	4.7	2.5	84
Sept.	100:1.5:0.2	9.8	3.7	3.1	1.9	85
Avg.	100:1.8:0.25	7.4	3.1	2.9	2.5	82

TABLE 6

NUTRIENT ADDITIONS AND CONCENTRATIONS - EUROCAN

Date	Nutrient Addition Ratio BOD_5N:P	LAGOON INFLUENT Nitrogen ppm N Total	LAGOON INFLUENT NO_3	LAGOON INFLUENT Total Phosphate ppm PO_4	LAGOON EFFLUENT Nitrogen ppm N Total	LAGOON EFFLUENT NO_3	LAGOON EFFLUENT Total Phosphate ppm PO_4	Percent BOD_5 Removal
1970								
Nov.	100:3.4:0.8	-	-	-	-	-	-	85
Dec.	100:3.5:0.9	-	-	-	-	-	-	78
1971								
Jan.	100:4.2:1.0	-	-	2.5	-	-	3.0	80
Feb.	100:0.5:1.0	3.2	-	1.7	2.8	-	1.0	77
Mar.	100:3.9:1.0	5.8	0.7	1.2	2.7	0.7	0.7	70
Apr.	100:5.0:1.1	-	0.7	2.5	-	0.5	0.6	72
Avg.	100:3.9:1.0	4.5	0.7	2.0	2.8	0.6	1.6	79
May	100:4.1:0.0	-	0.9	1.4	-	0.5	0.8	65
June	100:3.5:0.0	4.2	1.2	1.0	4.0	0.8	0.6	78
July	100:3.0:0.0	3.7	0.6	1.0	4.0	0.4	0.4	78
Sept.*	100:0.0:0.0	-	0.5	1.0	-	0.5	0.5	68
Avg.	100:2.9:0.0	4.0	0.9	1.1	4.0	0.5	0.6	74

* September not included in Average.

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TABLE 7

5 AND 95 PERCENT PROBABILITY LIMITS FOR pH

	NWP&P	ALPULP	EUROCAN
Influent	6.8 to 8.0	5.6 to 7.3	8.2 to 10.8
Effluent	7.3 to 8.1	6.1 to 6.8	7.3 to 9.1

TABLE 8

SUMMARY OF FITTED MODELS

Run #	H.P. Input	Flowrate (USmgd)	Calc'd from $\tau = \frac{\text{Volume}}{\text{Flowrate}}$ (hrs)	Calc'd from First Moment under RTD = τ (hrs)	Dispersion Model			Equal CSTR's-in-Series Model			Unequal CSTR's-in-Series Model				Backflow-Cell Model		
					τ (hrs)	$\frac{D}{uL}$	RSS	τ (hrs)	# of Tanks	RSS	τ_1 (hrs)	τ_2 (hrs)	τ_3 (hrs)	RSS	τ (hrs)	% (USmgd)	RSS
H-1	700	17.0	98.0	103.0	102.1	0.498	2.54×10^{-2}	28.1	3	1.69×10^{-1}	70.4	13.8	13.8	3.88×10^{-2}	33.8	9.52	6.44×10^{-2}
H-2	650	18.2	91.6	83.2	88.6	0.742	8.08×10^{-3}	24.4	3	2.94×10^{-1}	68.2	8.8	8.8	1.21×10^{-2}	30.6	17.7	2.27×10^{-2}
H-3	800	18.8	88.7	81.0	86.8	1.28	1.09×10^{-2}	23.5	3	5.81×10^{-1}	75.1	5.9	4.5	1.20×10^{-2}	31.6	30.4	2.64×10^{-2}
H-4	450	16.4	102.0	99.0	106.1	0.494	4.82×10^{-3}	29.8	3	1.06×10^{-1}	69.6	15.2	15.2	1.23×10^{-2}	34.2	7.55	2.49×10^{-2}
H-5	300	17.5	95.3	97.8	103.7	0.721	4.94×10^{-3}	28.2	3	2.31×10^{-1}	79.0	11.0	10.2	2.42×10^{-3}	35.7	16.7	8.92×10^{-3}
H-6	650	18.1	92.1	97.7	104.3	0.895	1.31×10^{-2}	28.1	3	3.18×10^{-1}	81.9	14.0	4.50	9.30×10^{-3}	36.8	22.1	1.58×10^{-2}
A-1	1025	19.4	160.0	177.0	187.0	0.395	3.90×10^{-3}	54.1	3	3.05×10^{-2}	111.4	32.3	32.3	6.20×10^{-3}	59.4	5.32	1.18×10^{-2}
A-2	650	19.4	160.0	180.0	200.4	0.623	8.43×10^{-3}	55.8	3	8.05×10^{-2}	131.0	45.8	9.44	2.29×10^{-3}	67.2	13.9	3.55×10^{-3}
A-3	825	23.2	134.0	173.0	188.4	0.447	1.22×10^{-2}	53.7	3	3.75×10^{-2}	117.0	29.9	30.0	4.25×10^{-3}	60.5	8.84	6.74×10^{-3}
A-4	350	28.1	110.0	116.0	102.4	0.331	4.99×10^{-2}	30.2	3	1.05×10^{-1}	59.4	19.2	19.2	7.87×10^{-2}	32.3	4.71	9.58×10^{-2}
E-1	800	16.6	146.0	142.0	147.2	4.17	5.72×10^{-3}	61.6	2	2.68×10^{-1}	141.0	5.49	-	7.14×10^{-3}	78.7	31.4	3.67×10^{-2}
E-2	500	19.2	126.0	131.0	116.7	3.17	6.63×10^{-2}	46.6	2	4.40×10^{-1}	111.0	5.31	-	7.16×10^{-2}	62.7	39.7	9.33×10^{-2}

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TABLE 9

COMPARISON OF PREDICTED AND MEASURED CONVERSIONS

Run No.	Temp. (°C)	Rate Constant $(hr.)^{-1}$	Measured Conversions	PREDICTED CONVERSIONS: Ideal CSTR	Ideal PFTR	Dispersion Model	Equal CSTR's	Unequal CSTR's	Backflow-Cell Model
H-1	32.0	0.0126	0.62	0.55	0.71	0.59	0.60	0.62	0.60
H-2	32.0	0.0126	0.57	0.54	0.69	0.58	0.55	0.56	0.55
H-3	33.0	0.0130	0.66	0.54	0.69	0.58	0.55	0.56	0.56
H-6	20.6	0.0092	0.53	0.46	0.57	0.49	0.50	0.52	0.51
A-1	20.0	0.0110	0.76	0.66	0.86	0.76	0.75	0.75	0.75
E-1	30.0	0.0146	0.75	0.69	0.88	0.70	0.84	0.70	0.80

(K4015)

TABLE 10

HYPOTHETICAL COMPARISON OF TREATMENT EFFICIENCIES

Aerated Lagoon	L:W Ratio	No. of Mixed Vessels in Series in the Mixing Model	Residence Time of Each Vessel (Days)	Dimensionless Output Concentration $\frac{C}{C_o} = \prod_{i=1}^{N} \left[\frac{1}{1 + k\tau_i}\right]$	Predicted BOD_5 Removal Efficiency $\left[1 - \frac{C}{C_o}\right] \times 100\%$
NWP&P	7.0:1	3	$\tau_1 = 3.90$ $\tau_2 = 0.55$ $\tau_3 = 0.55$	0.296	70.4%
ALPULP	12.5:1	3	$\tau_1 = 3.29$ $\tau_2 = 0.85$ $\tau_3 = 0.85$	0.278	72.2%
EUROCAN	1.2:1	2	$\tau_1 = 4.80$ $\tau_2 = 0.20$	0.348	65.2%

(K4015)

TABLE 11

SOME SETTLEABLE SOLIDS CONCENTRATIONS IN THE AERATED LAGOONS

	Power Level $HP/10^6$ US gallons	Influent Concentration ppm	Concentration in Lagoon ppm	Difference
NWP&P	8.5	23	58	35
EUROCAN	7.7	0	24	24
	7.7	40	68	28
	4.8	40	32	-
ALPULP	8.0	15	19	4
	2.7	20	6	-

(K4015)

TABLE 12

PROBABILITY OF RAW AND TREATED WASTE CHARACTERISTICS

Variable	NWP&P				ALPULP				EUROCAN			
	≤50%		≤90%		≤50%		≤90%		≤50%		≤90%	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
BOD_5 - ppm	280	115	370	165	285	65	350	105	115	40	190	55
S.S. - ppm	75	70	150	120	65	63	120	88	225*	20	>500*	65
Temp. - °C	32	23	37	29	26	18	34	24	28	18	33	24
pH	7.3	7.7	7.8	8.0	6.5	6.4	6.7	6.9	9.5	8.0	10.5	8.7
Flow - USMGD	18.0		20.0		23.0		27.4		16.0		18.0	

* These high values are due to the fact that the settling ponds ahead of the lagoon were filled and not operating effectively for a considerable percentage of the time.

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TABLE 13

TOTAL AND FILTERED WASTE CHARACTERISTICS

	RATIO OF TOTAL/FILTERED CONCENTRATIONS					
	BOD_5		COD		TOC	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
NWP&P	1.15	1.06	1.12	1.05	1.28	1.06
ALPULP	1.11	1.07	-	-	1.60	1.40
EUROCAN	1.20	1.13	1.25	1.10	1.21	1.15
Average	1.15	1.09	1.19	1.08	-	-

TABLE 14

OXYGEN DEMAND RATIOS

	COD/BOD_5		TOC/BOD_5		COD/TOC		BOD_{20}/BOD_5	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
NWP&P	4.00	6.67	1.67	2.00	2.86	3.33	-	-
ALPULP	1.67	2.86	0.77	1.43	1.67	1.82	1.7	1.9
EUROCAN	7.14	10.00	3.33	5.00	2.00	2.50	3.45	5.00

Figures

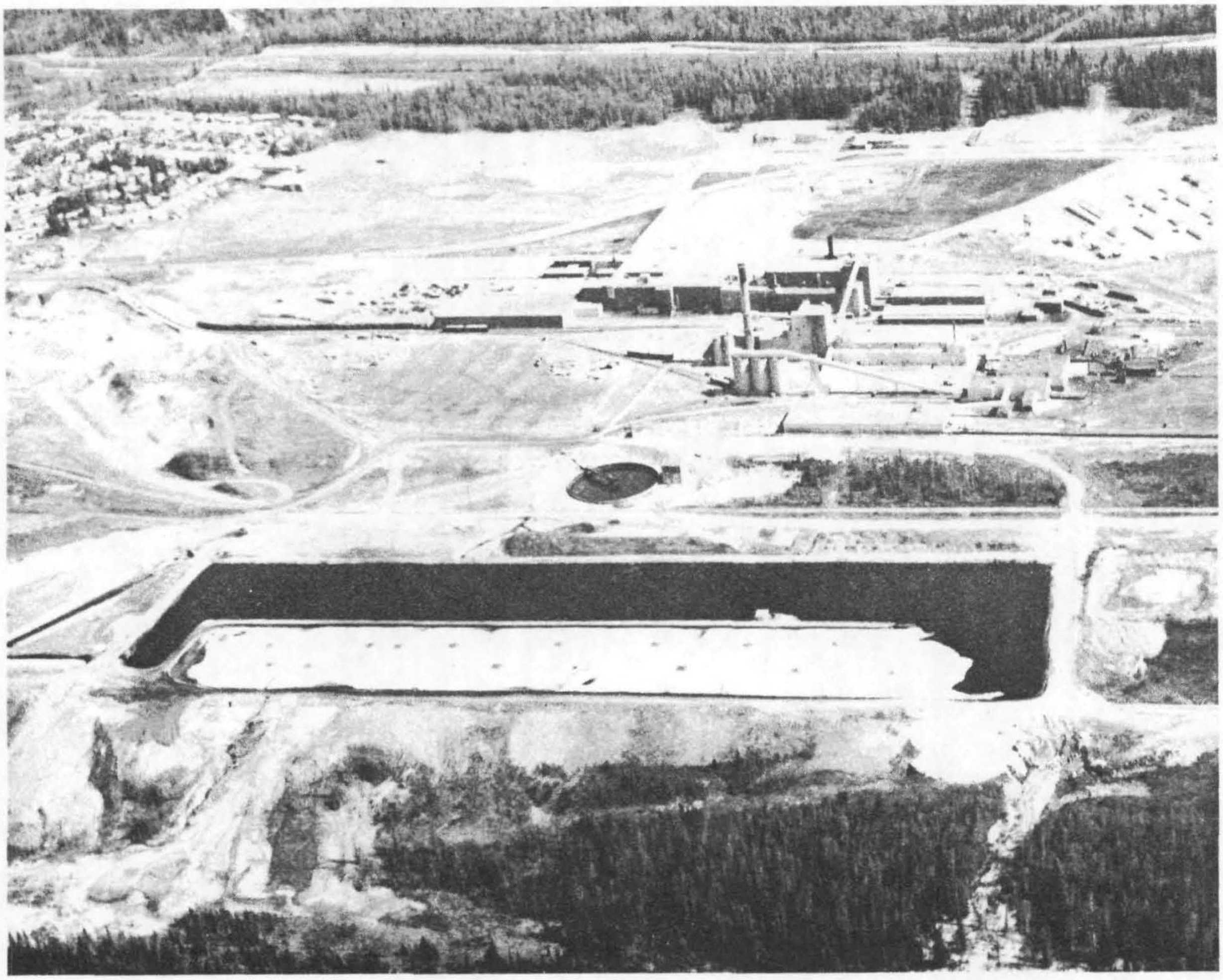


FIGURE 1

Aerial Photograph of NWP&P Aerated Lagoon

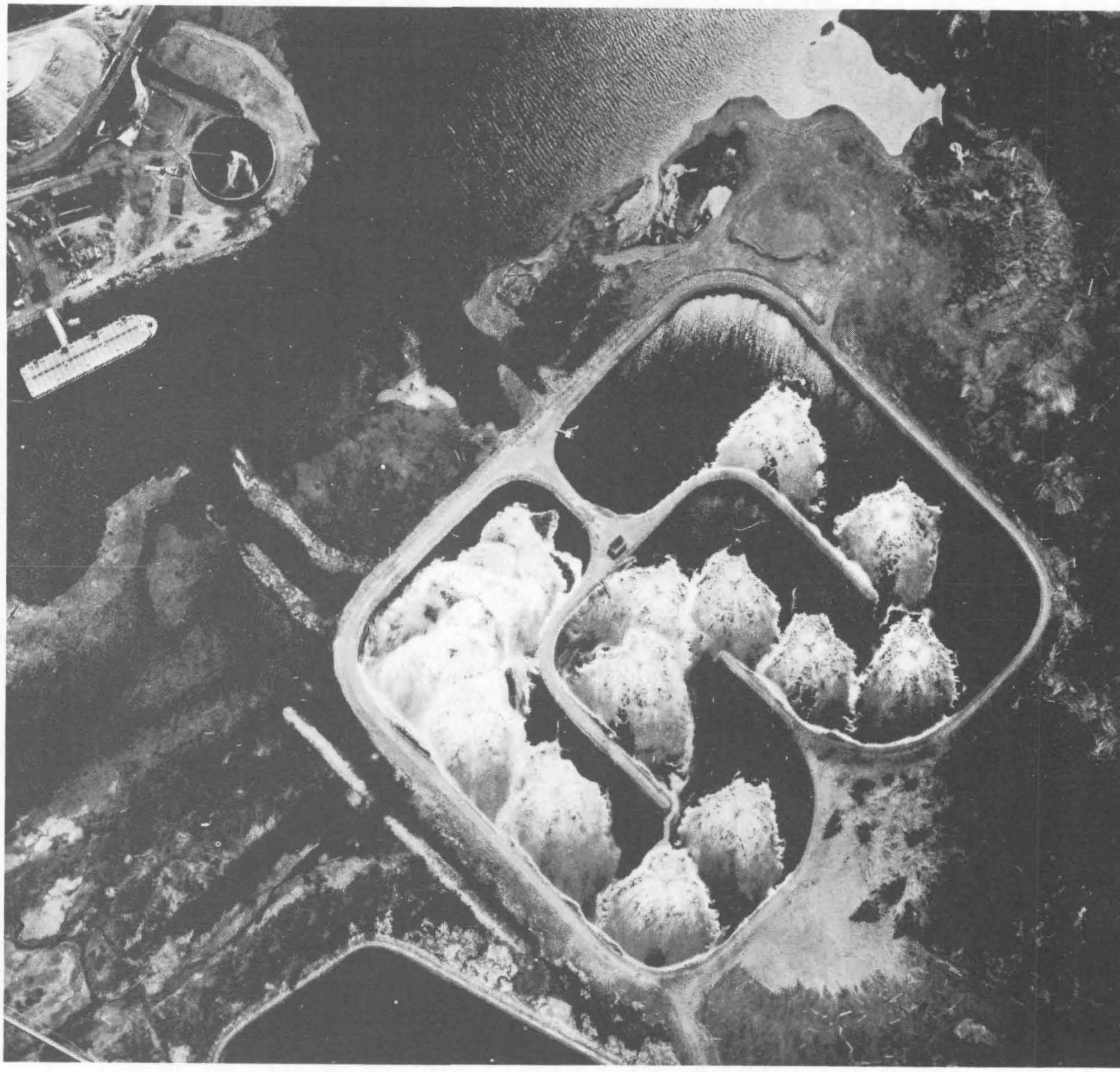


FIGURE 2

Aerial Photograph of ALPULP Aerated Lagoon

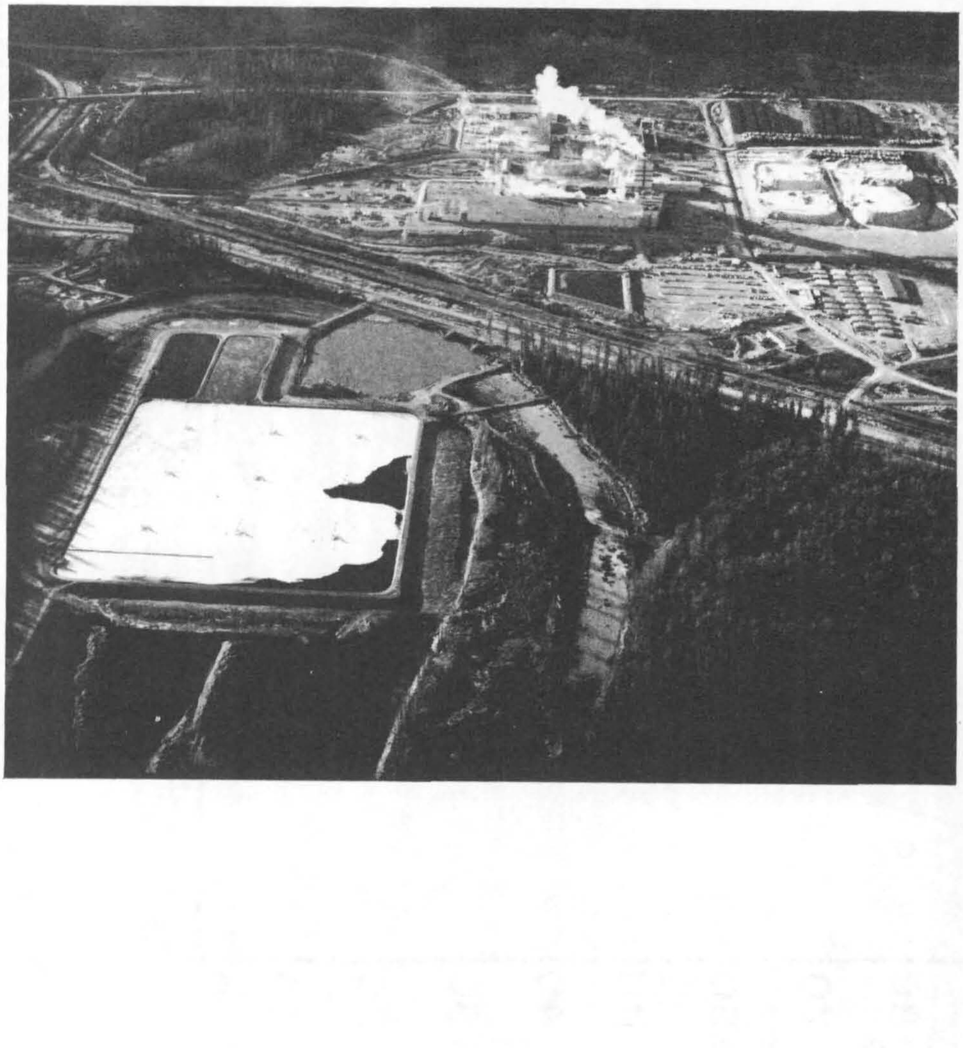
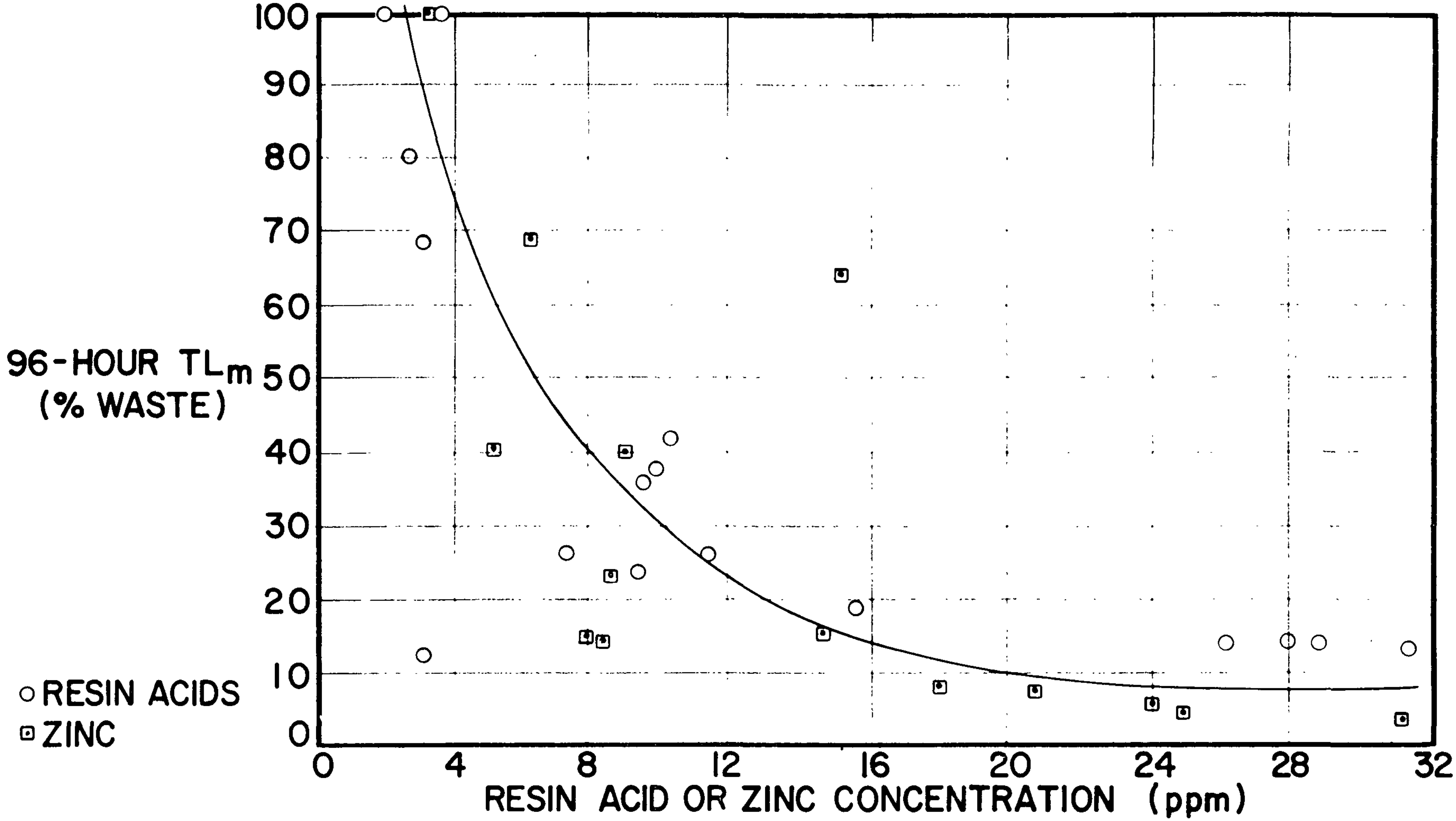


FIGURE 3

Aerial Photograph of EUROCAN Aerated Lagoon



RESIN ACID & ZINC CONCENTRATION Vs EFFLUENT TOXICITY

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS. RD DATE 17-3-72
DWG NO A4015-

LEGEND FOR DISTINGUISHING BETWEEN THE MIXING MODEL RESIDENCE TIME DISTRIBUTIONS

———————————— AXIAL DISPERSION MODEL

— — — — EQUAL TANKS-IN-SERIES MODEL

—— · —— · —— · —— UNEQUAL TANKS-IN-SERIES MODEL

- - - - - - - - - - - - - - BACKFLOW CELL MODEL

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DWG NO A4015-0	DATE 17-3-72

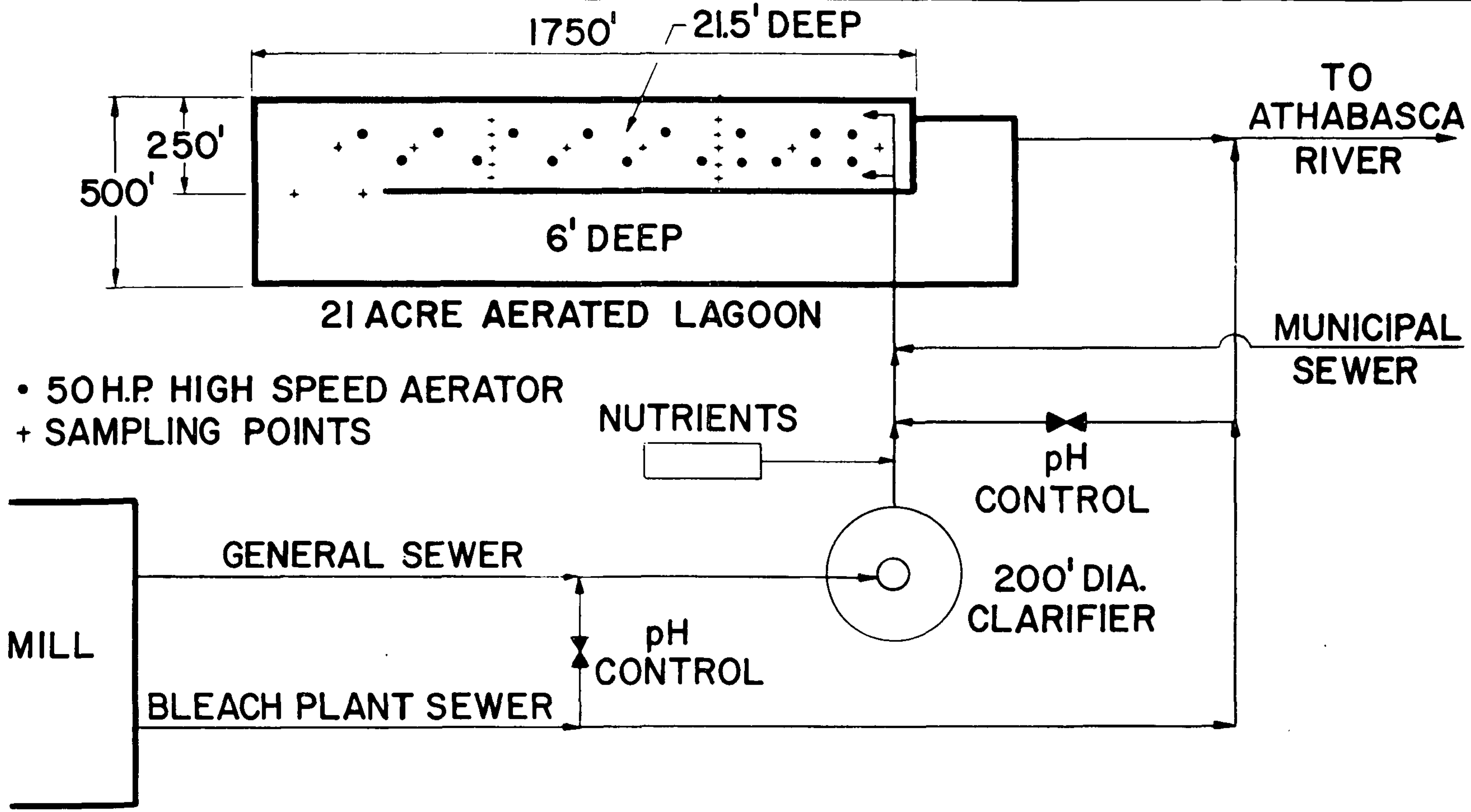


FIG. 4

SCHEMATIC OF NWP&P TREATMENT SYSTEM

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS. RD DATE 17-3-72 DWG NO A4015-4	

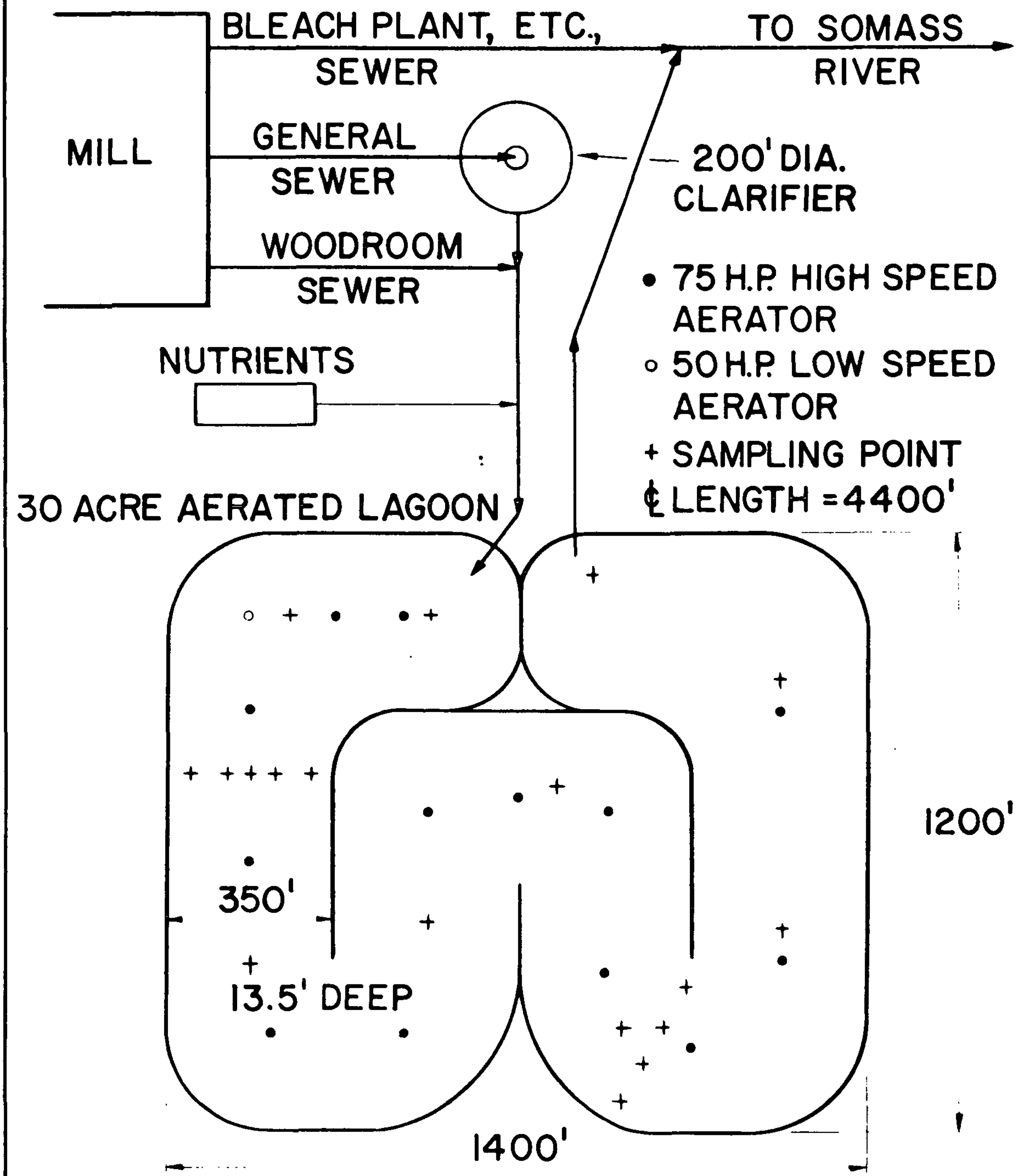


FIG. 5

SCHEMATIC OF ALPULP TREATMENT SYSTEM

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-5	

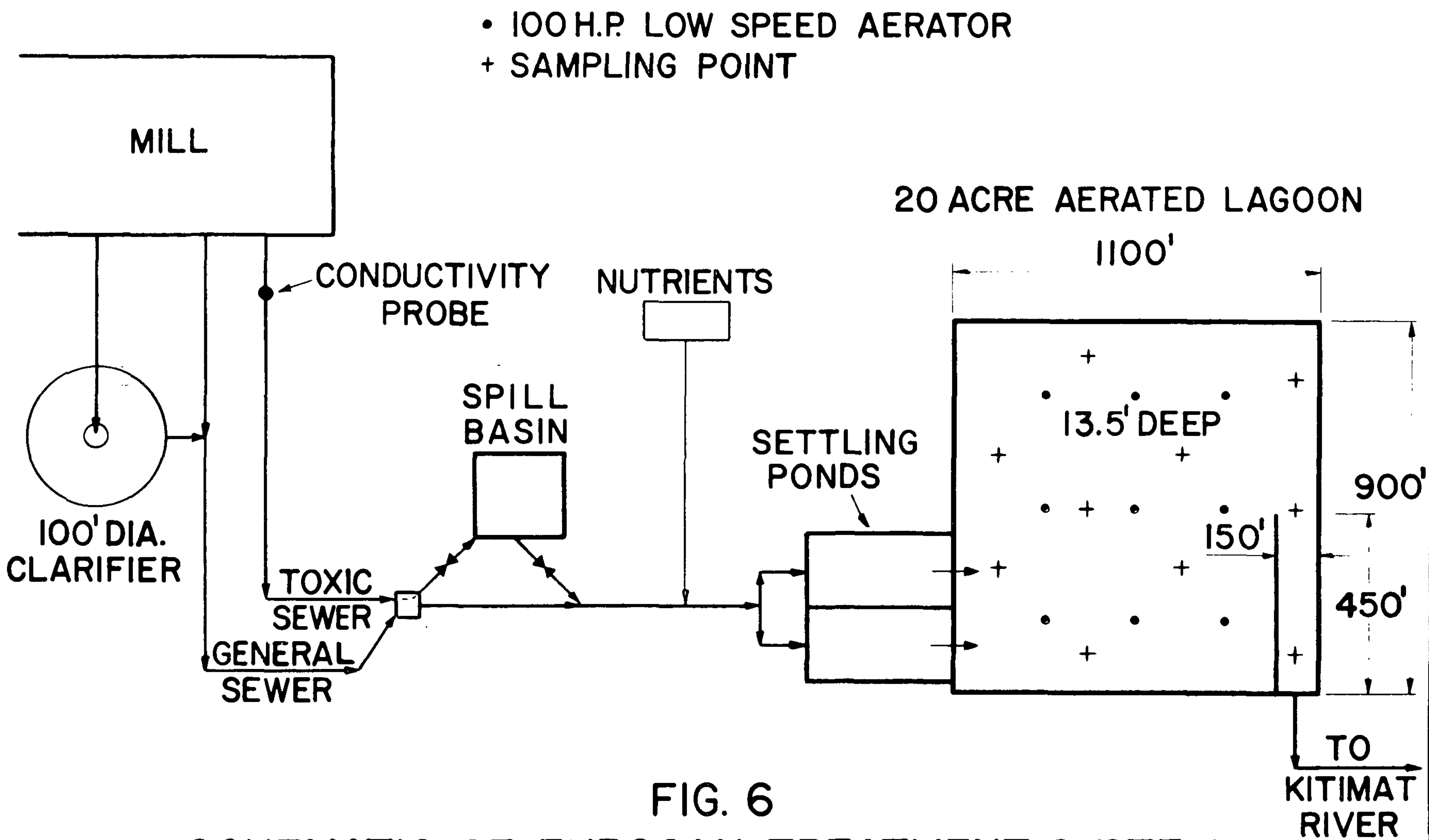


FIG. 6

SCHEMATIC OF EUROCAN TREATMENT SYSTEM

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DWG NO A4015-6	DATE 17-3-72

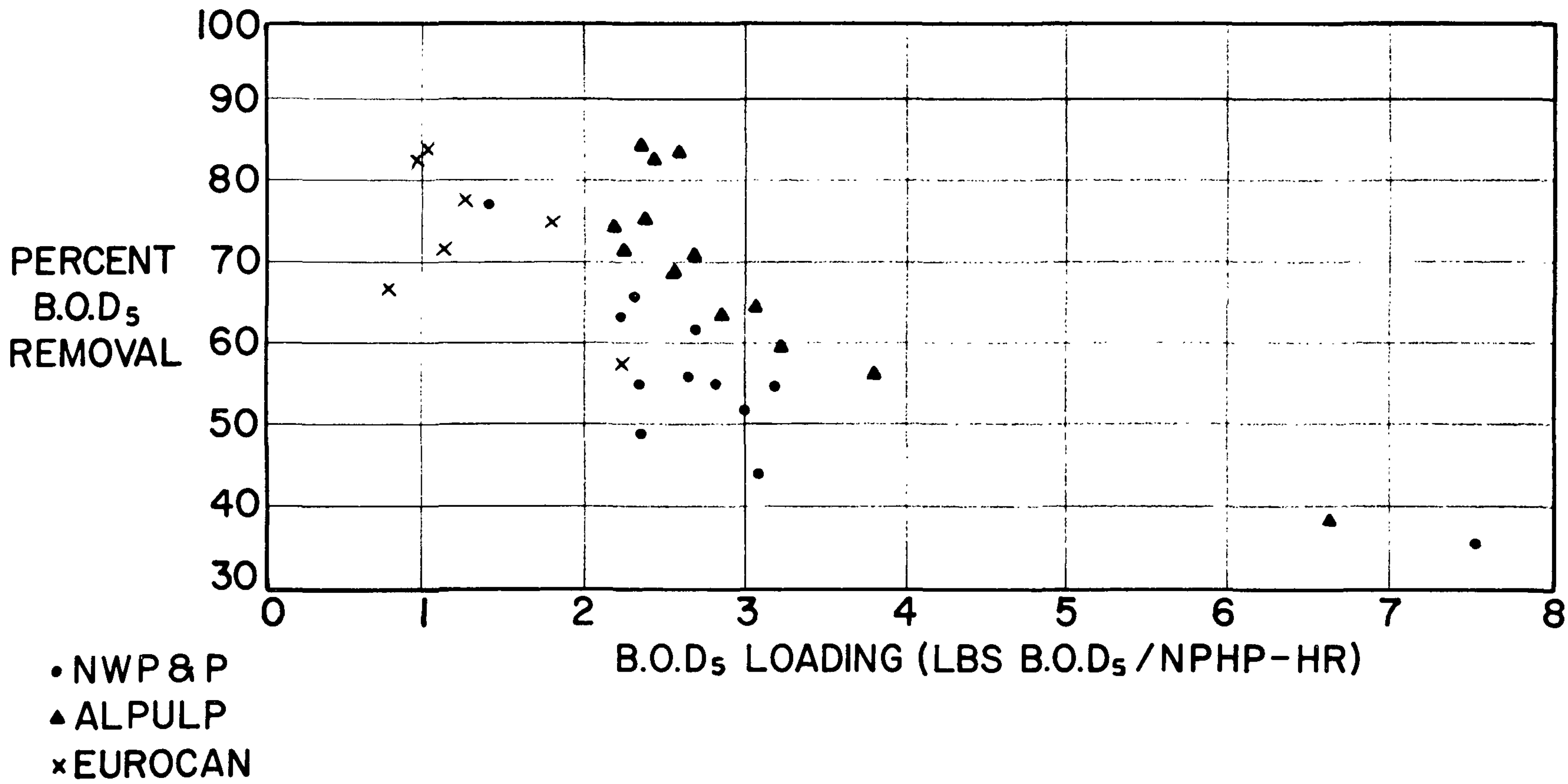


FIG. 7

B.O.D$_5$ REMOVAL EFFICIENCY V's B.O.D$_5$ LOADING

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD DATE 17-3-72 DWG NO A4015-7	

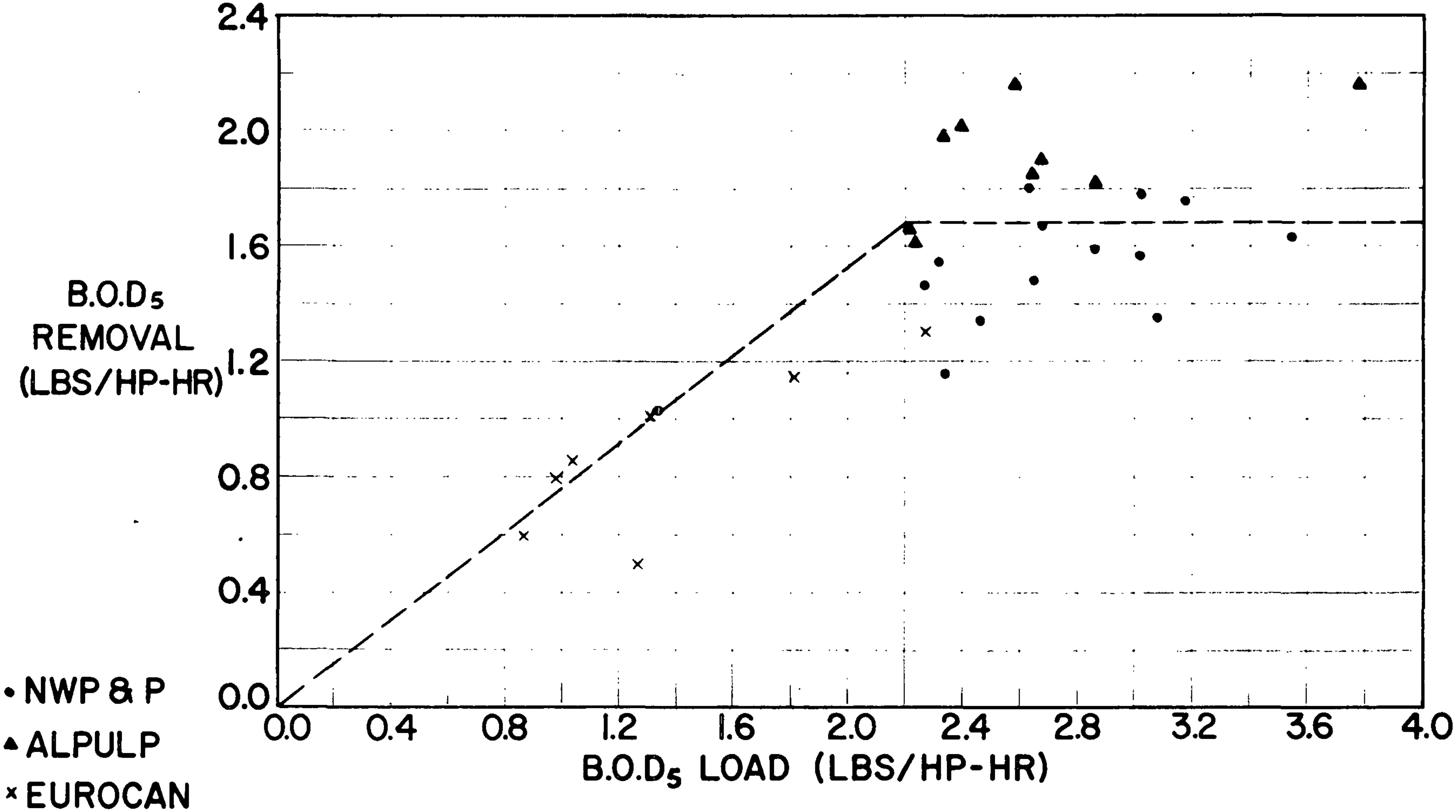


FIG. 8 – B.O.D_5 REMOVAL AS A FUNCTION OF B.O.D_5 LOADING

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD DATE 17-3-72 DWG NO A4015-8	

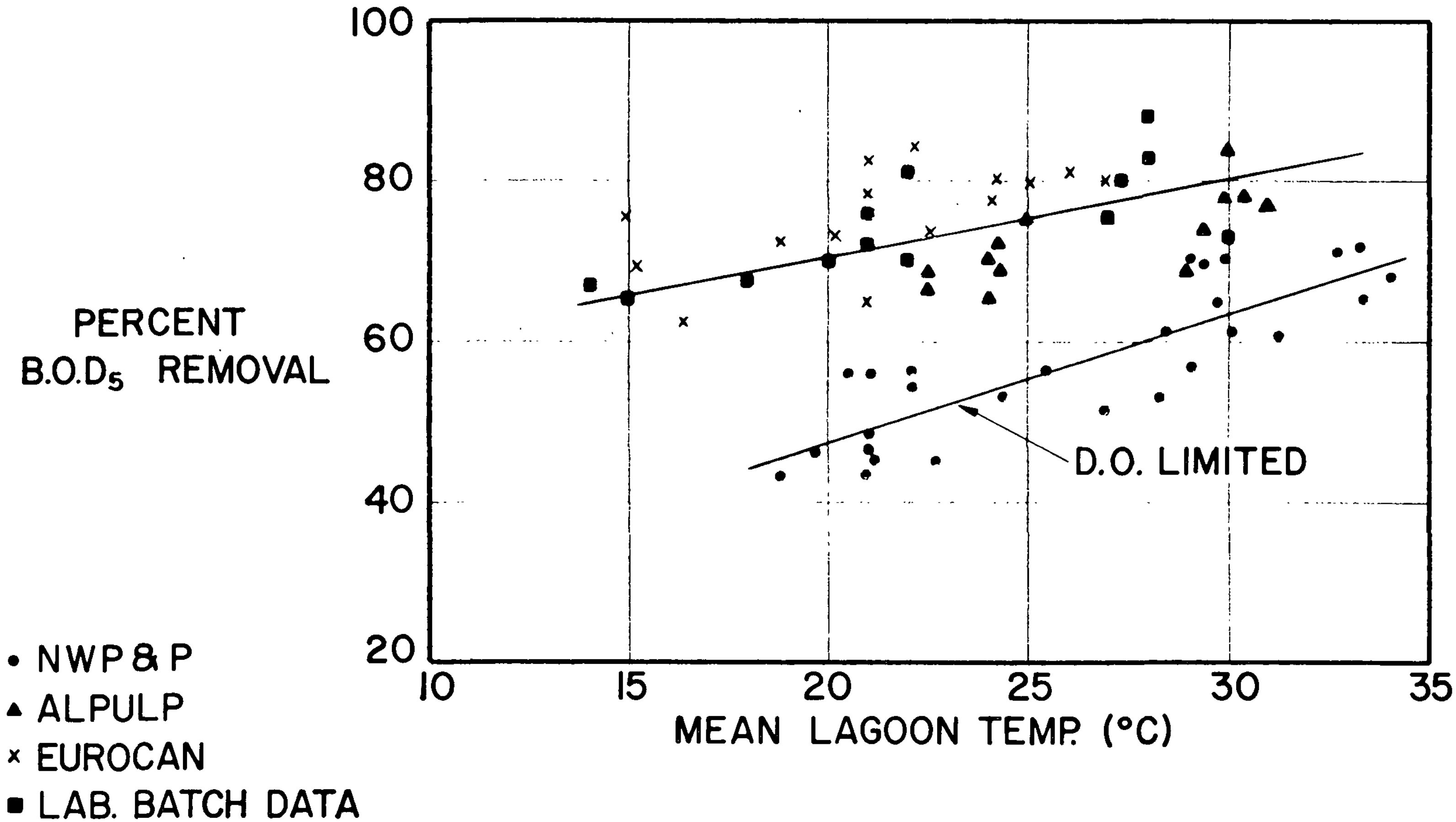


FIG. 9

EFFECT OF LAGOON TEMPERATURE ON B.O.D$_5$ REMOVAL

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		DWG NO A4015-9	

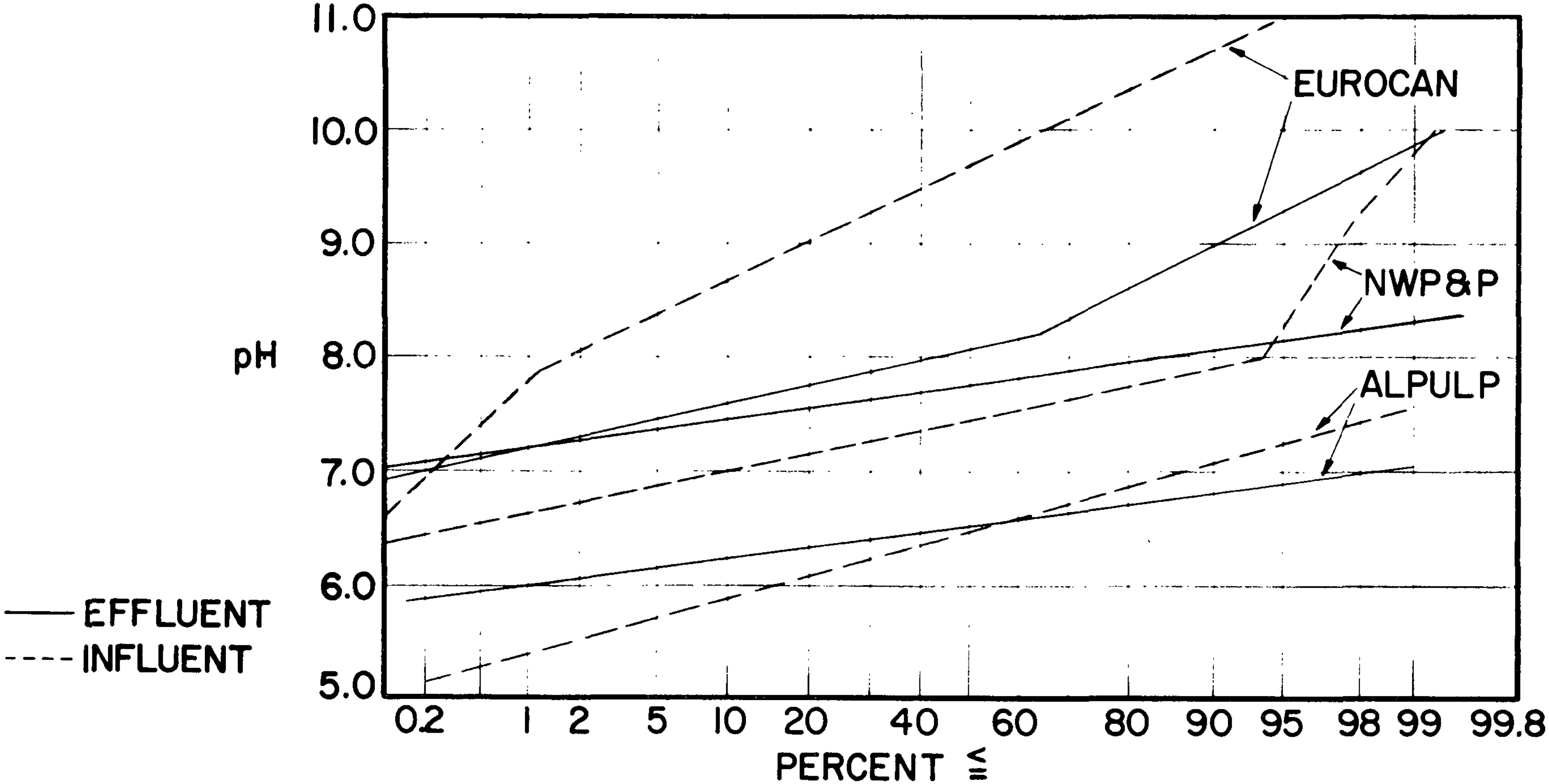


FIG. 10 — pH PROBABILITY PLOT

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS. RD DATE 17-3-72
DWG NO A 4015-10

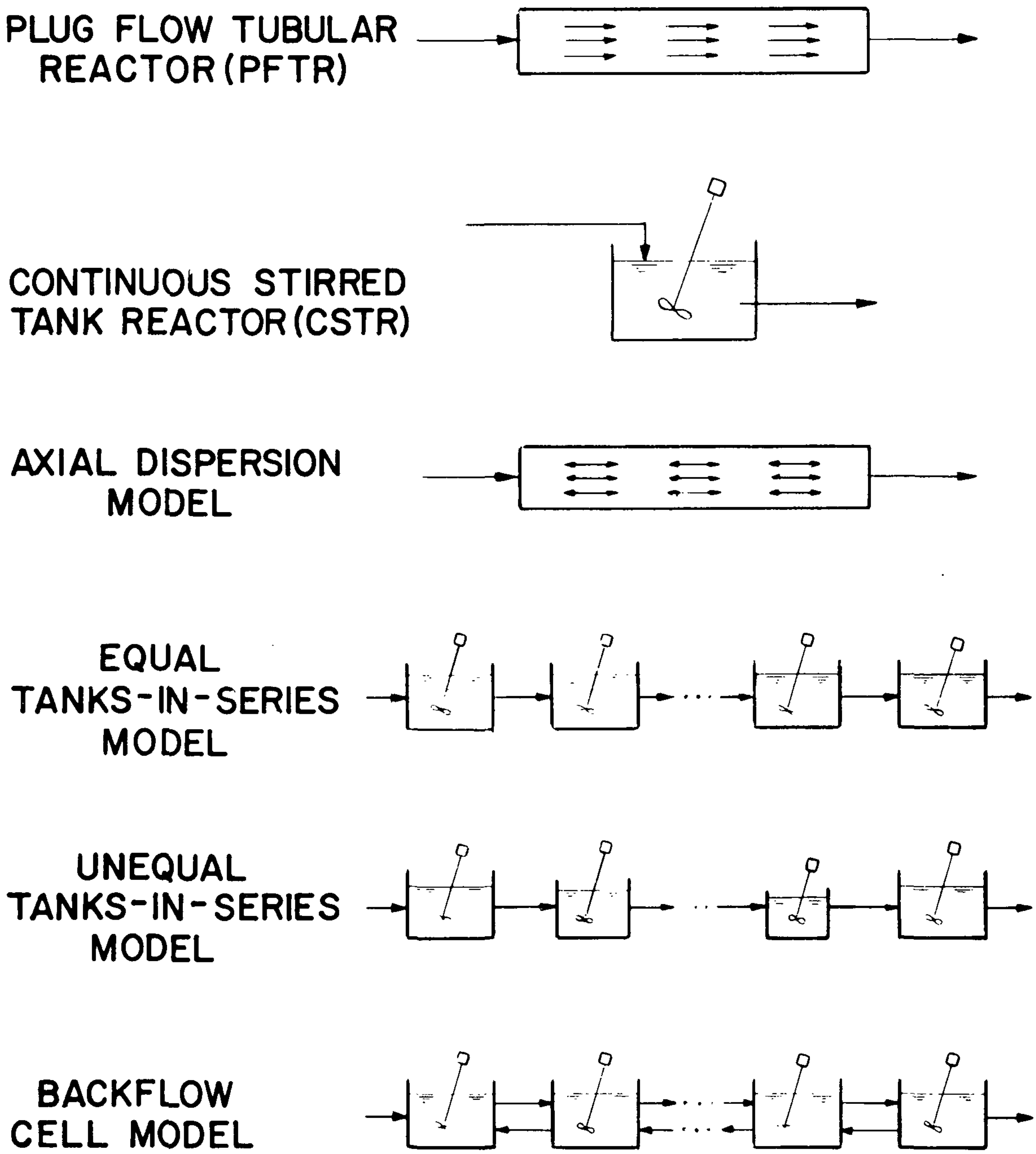


FIG. 11-ILLUSTRATIVE SCHEMATIC OF THE MIXING MODELS

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY SR. RD	DATE 17-3-72
		DWG NO A4015-11	

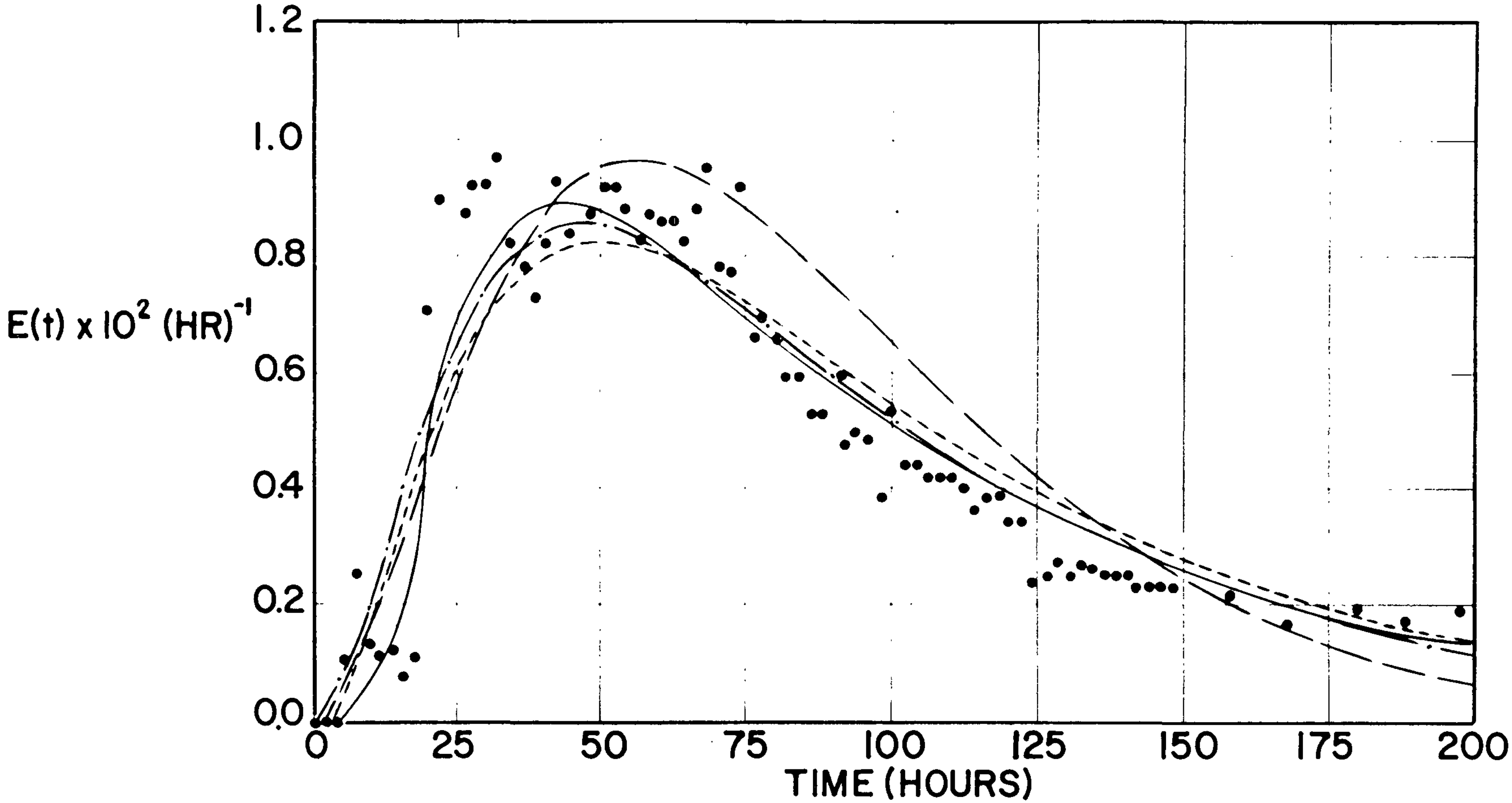


FIG. 12

RESIDENCE TIME DISTRIBUTION RUN H-1

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD DATE 17-3-72 DWG NO A4015-12	

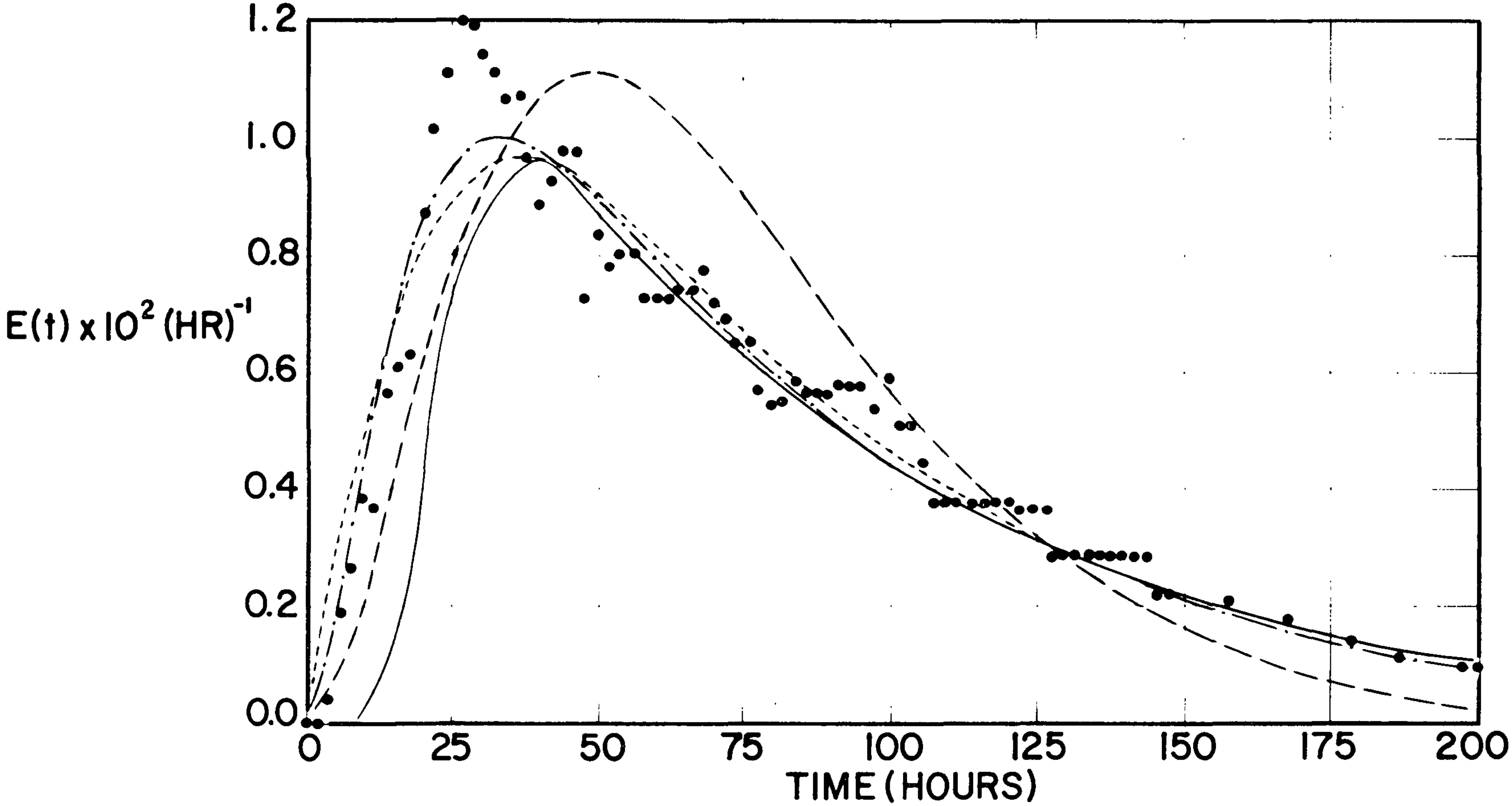


FIG. 13

RESIDENCE TIME DISTRIBUTION RUN H-2

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS. RD DATE 17-3-72
DWG NO A4015-13

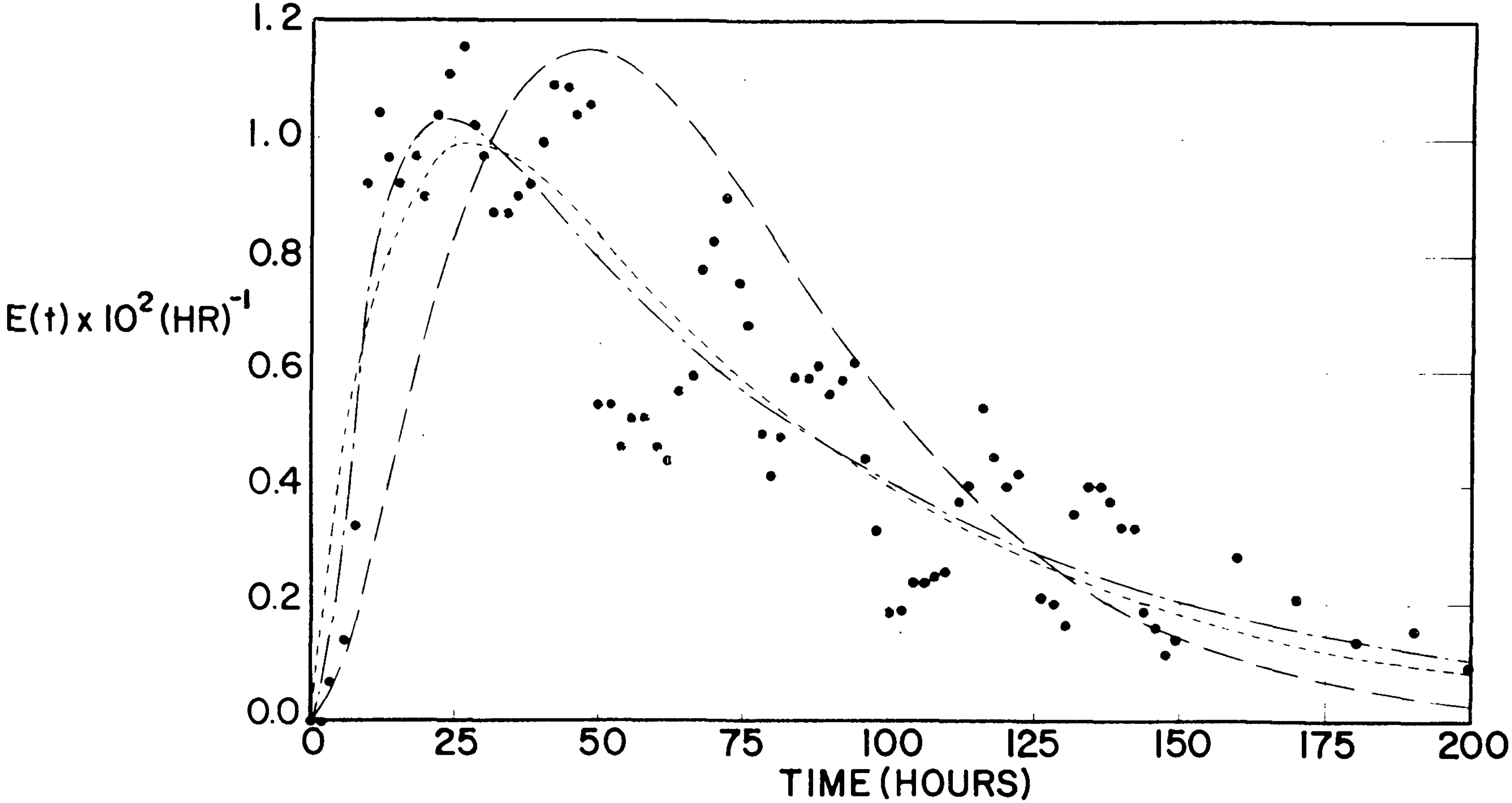


FIG. 14

RESIDENCE TIME DISTRIBUTION RUN H-3

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-14

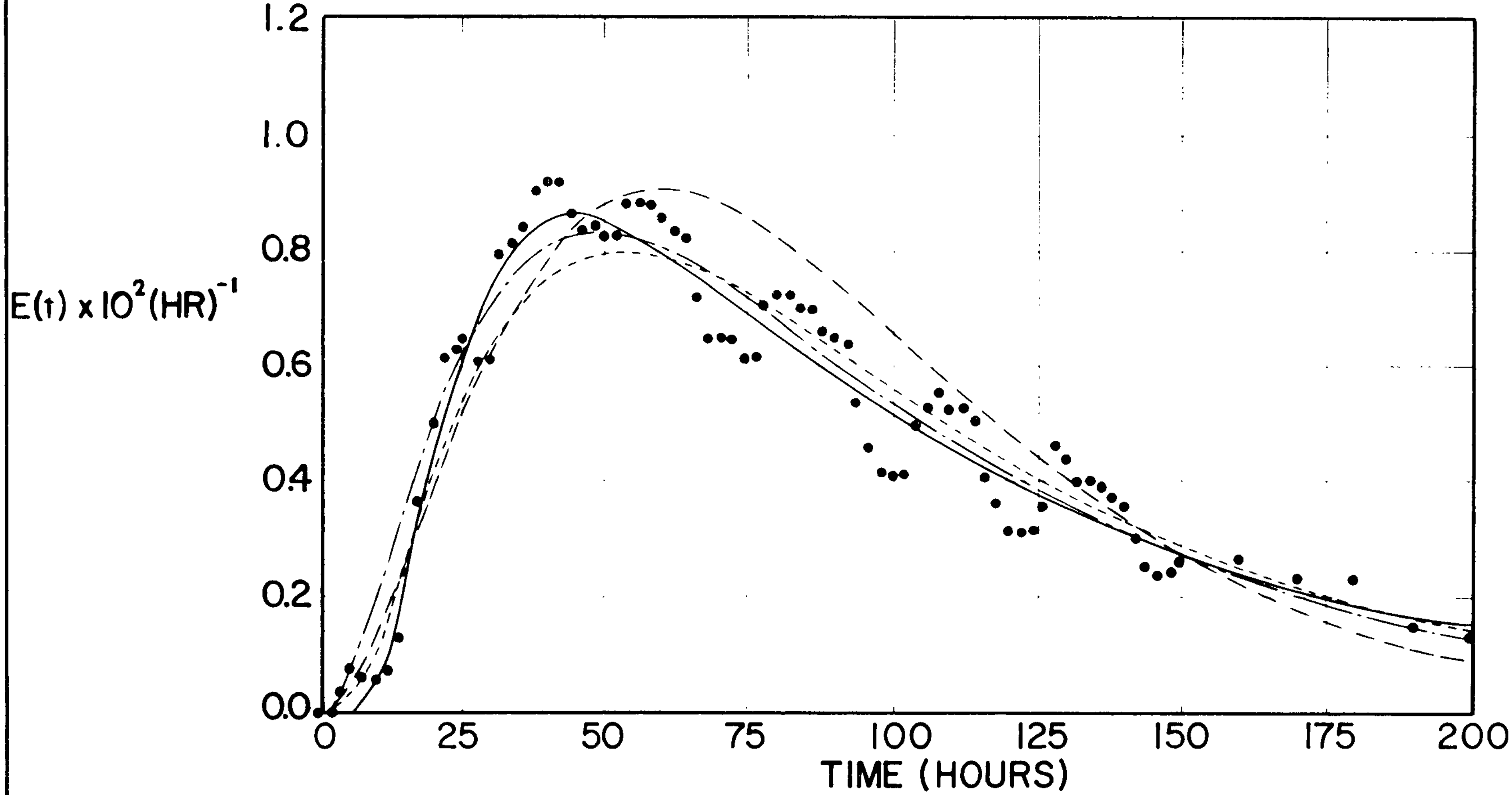


FIG. 15

RESIDENCE TIME DISTRIBUTION RUN H-4

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY RD DATE 17-3-72
DWG NO A4015-15

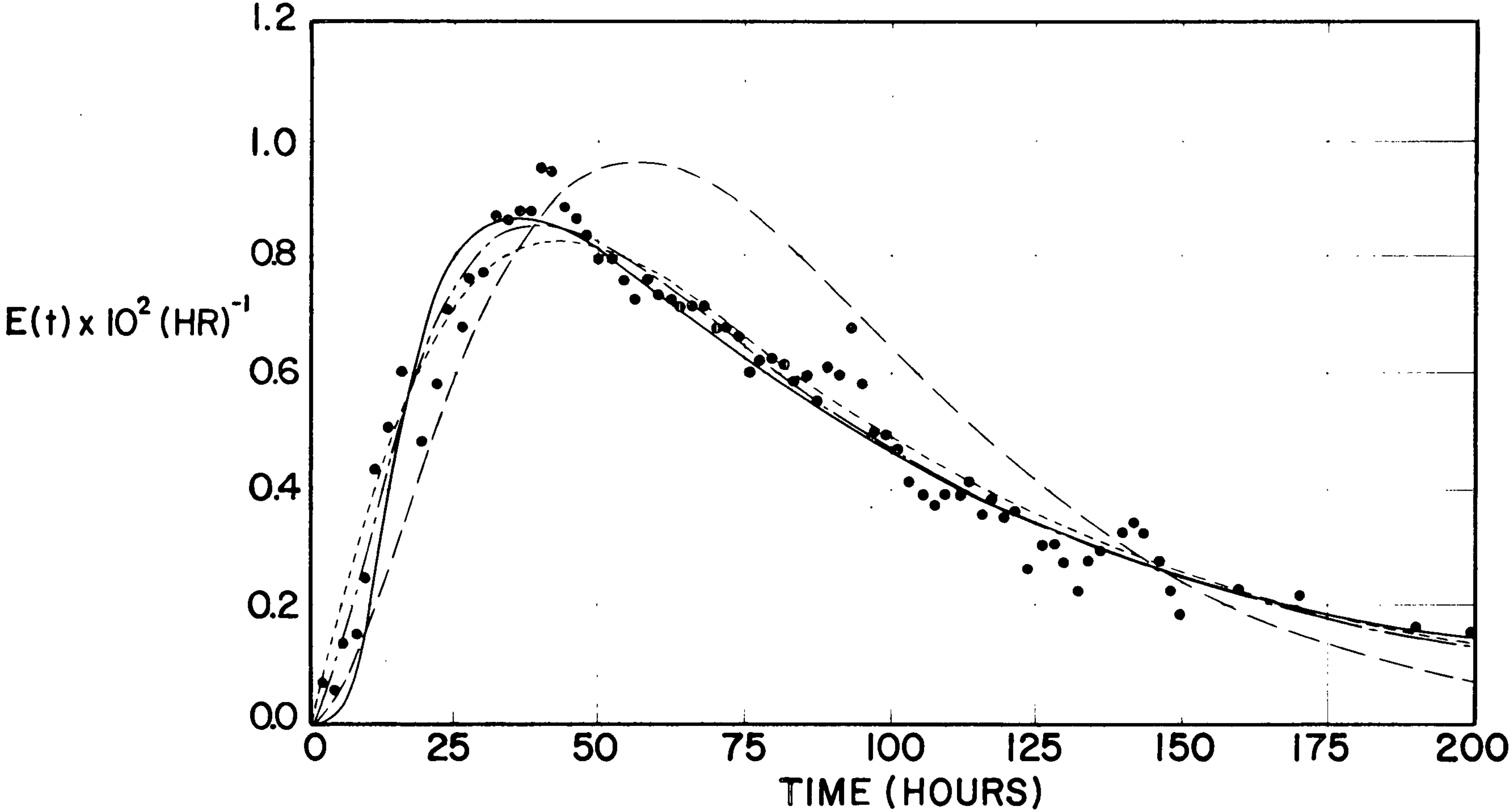


FIG. 16

RESIDENCE TIME DISTRIBUTION RUN H-5

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY RD DATE 17-3-72

DWG NO A4015-16

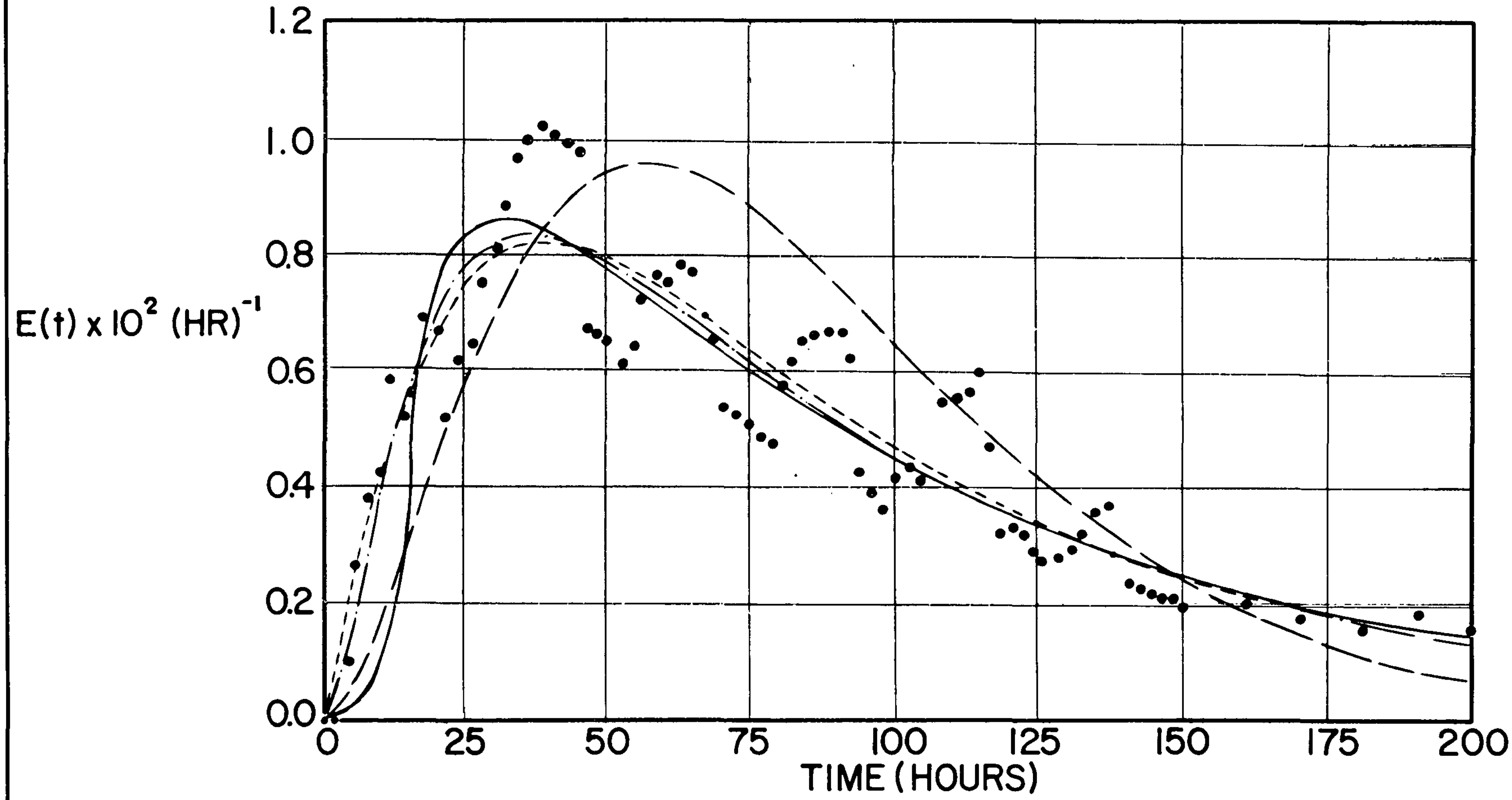


FIG. 17

RESIDENCE TIME DISTRIBUTION RUN H-6

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17-3-72
DWG NO A4015-17

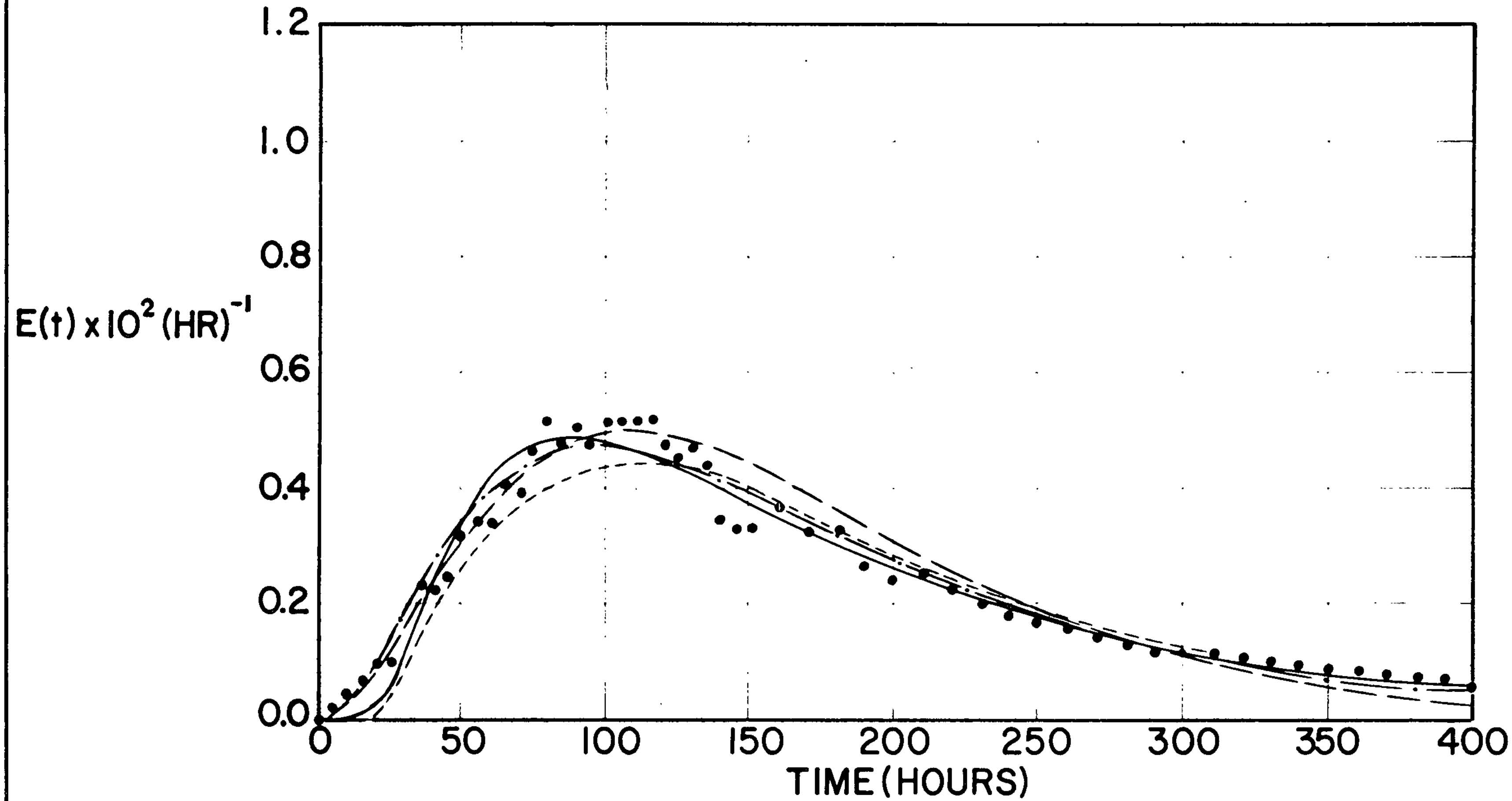


FIG. 18

RESIDENCE TIME DISTRIBUTION RUN A-1

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS. RD DATE 17-3-72 DWG NO A4015-18

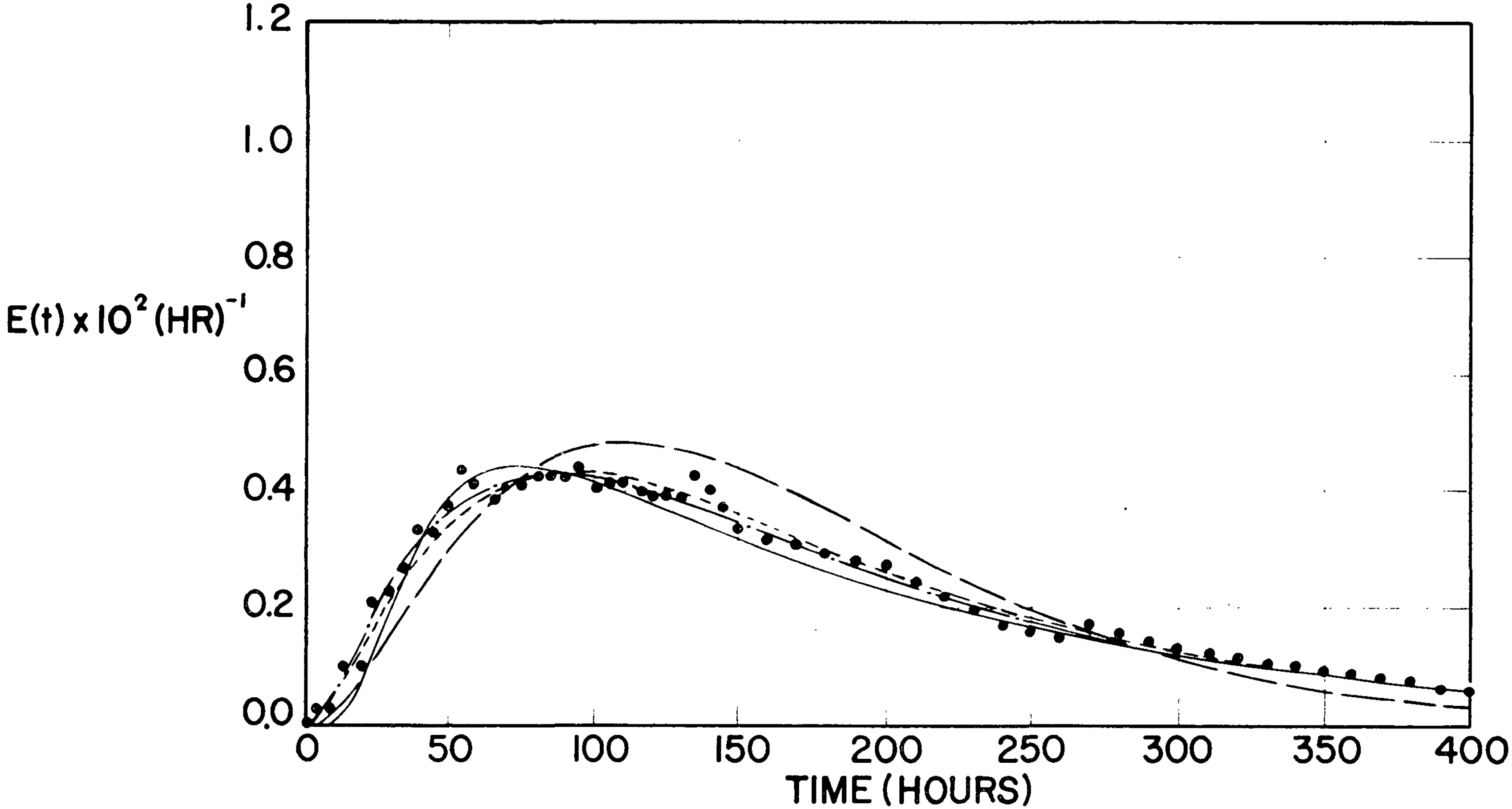


FIG. 19
RESIDENCE TIME DISTRIBUTION RUN A-2

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17·3·72
DWG NO A4015-19

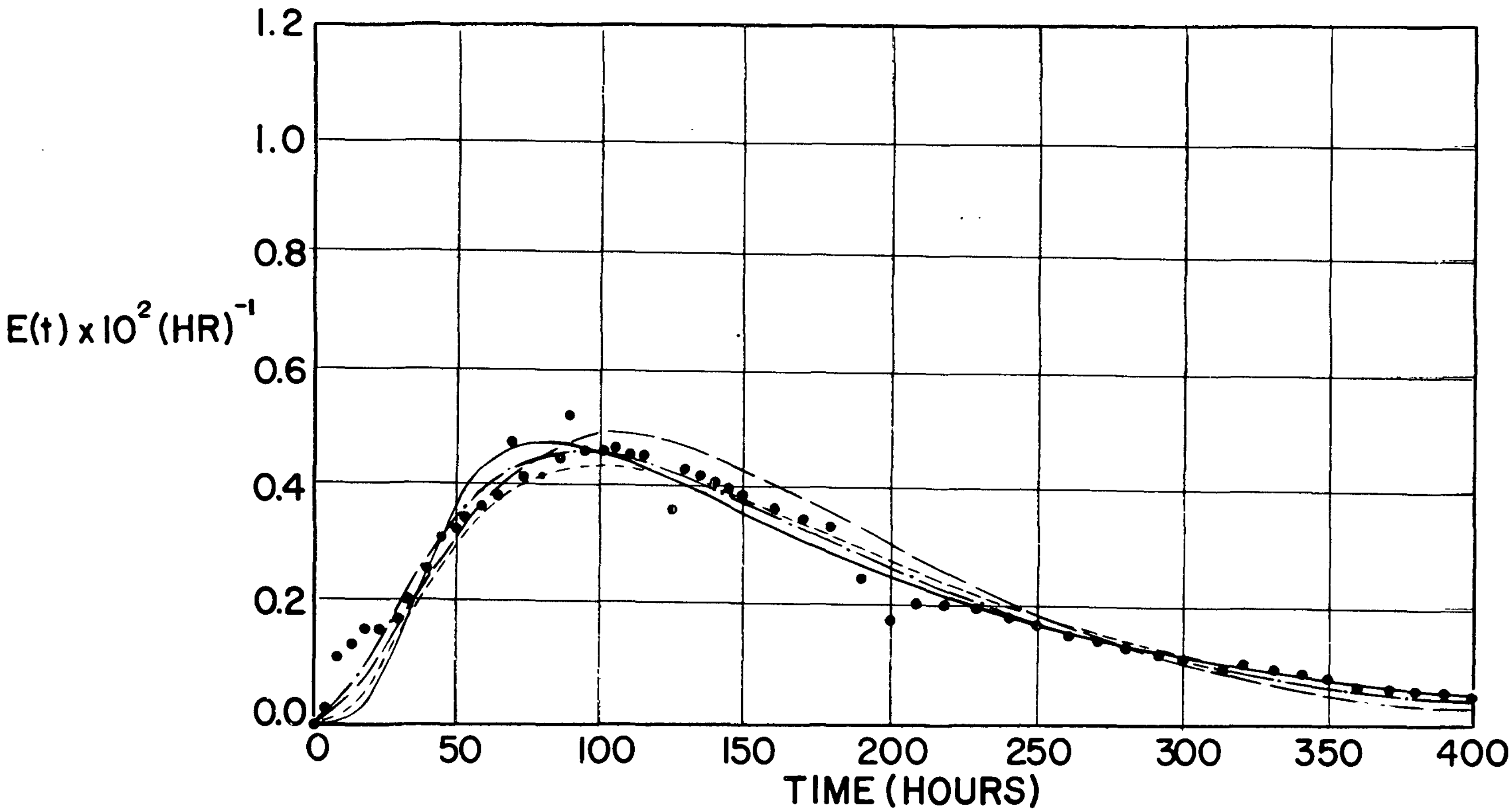


FIG. 20

RESIDENCE TIME DISTRIBUTION RUN A-3

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS. RD DATE 17-3-72 DWG NO A4015-20

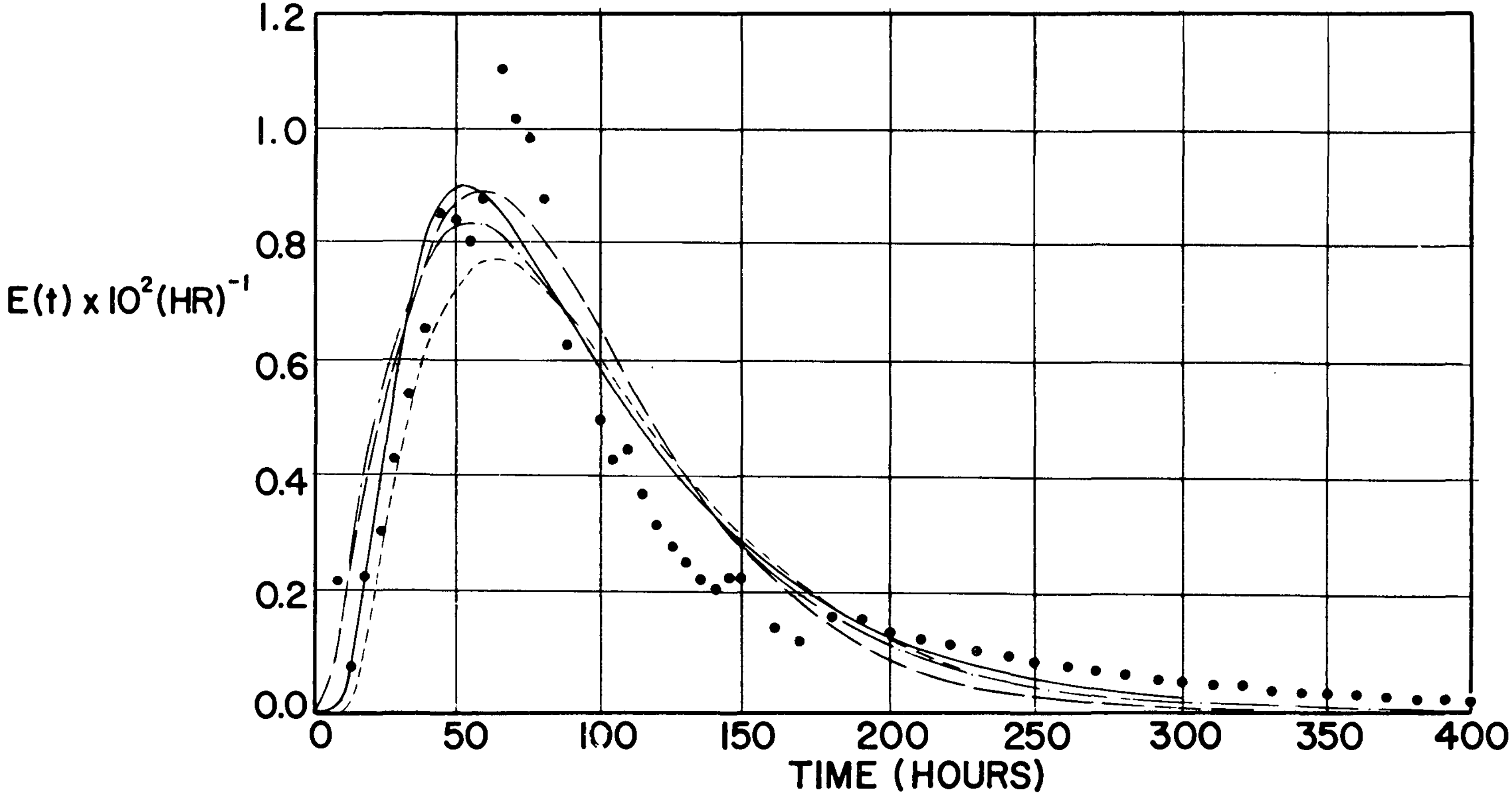


FIG. 21

RESIDENCE TIME DISTRIBUTION RUN A-4

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17-3-72

DWG NO A4015-21

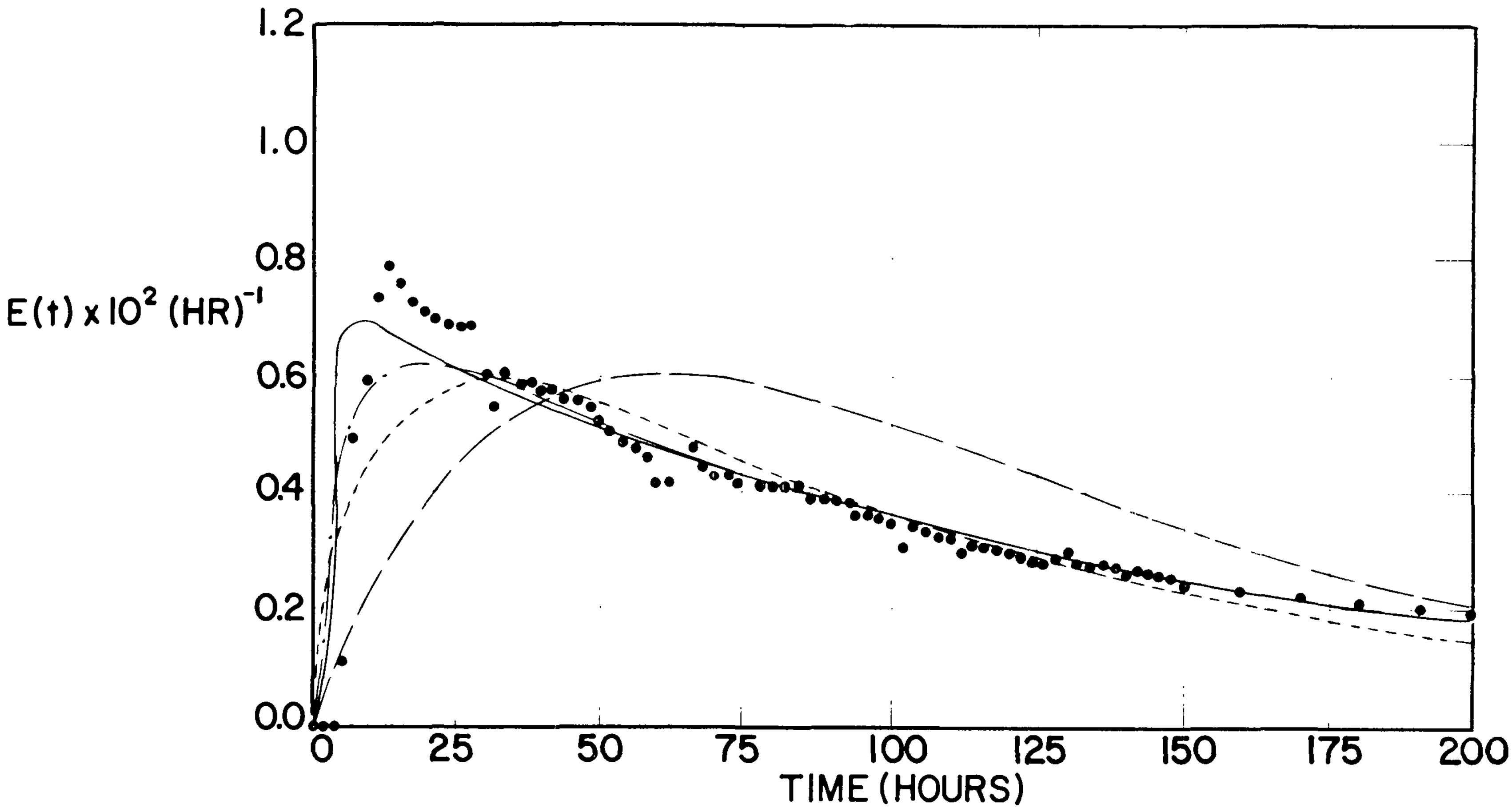


FIG. 22

RESIDENCE TIME DISTRIBUTION RUN E-1

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS. RD DATE 17-3-72
DWG NO A4015-22

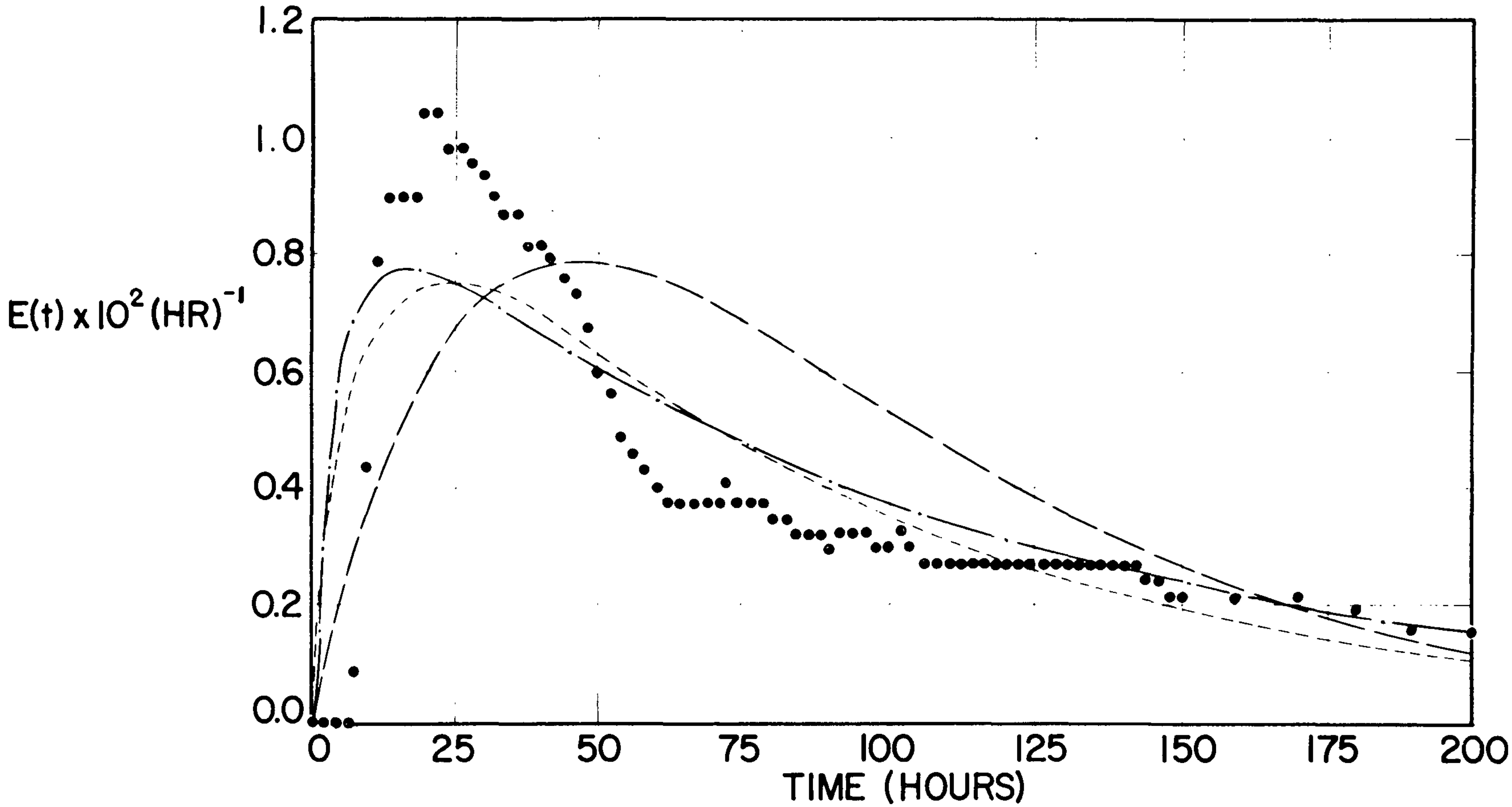


FIG. 23

RESIDENCE TIME DISTRIBUTION RUN E-2

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17-3-72
DWG NO A4015-23

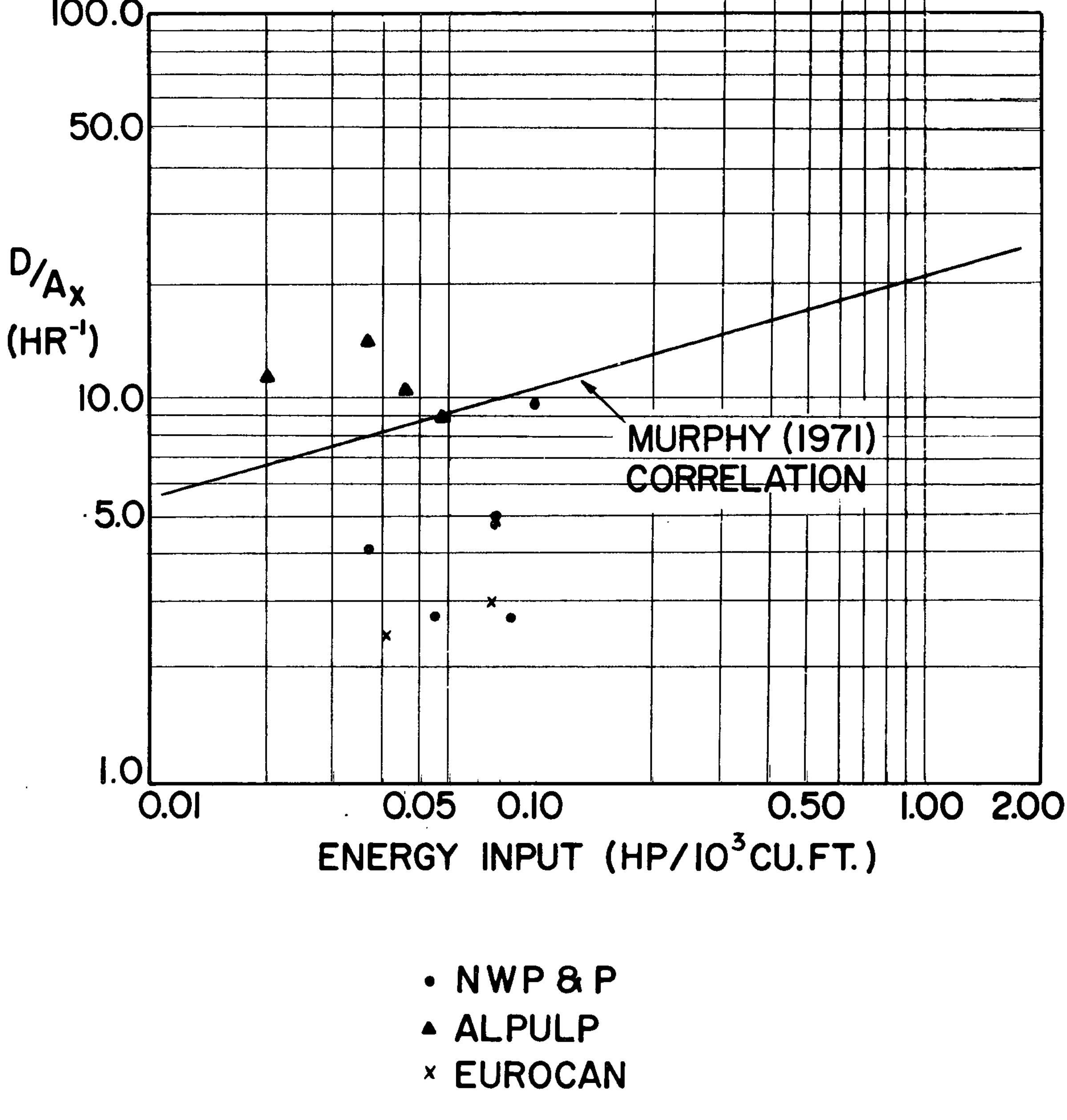


FIG. 24
EFFECT OF AERATION ENERGY INPUT ON D/A_X

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-24	

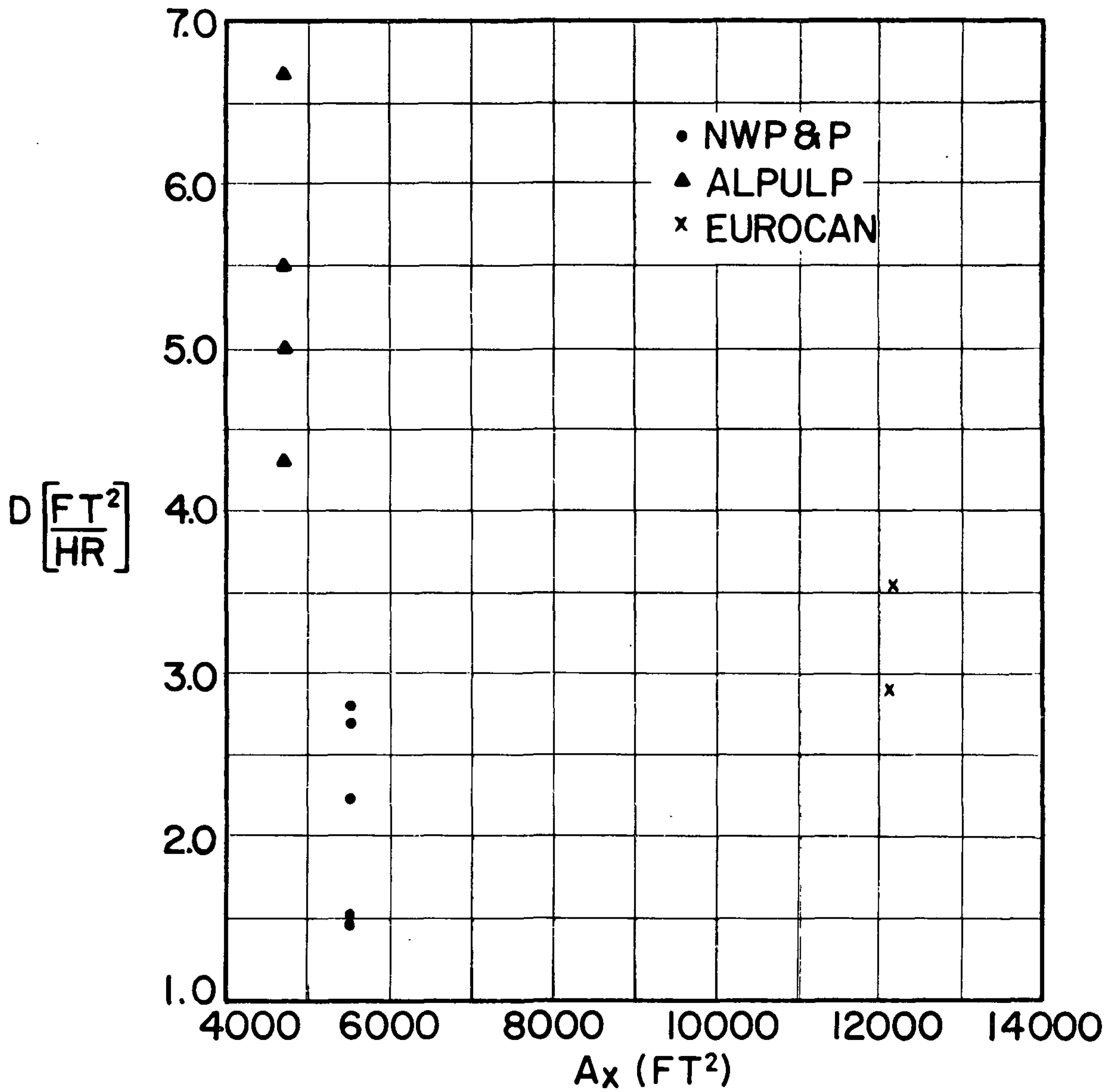
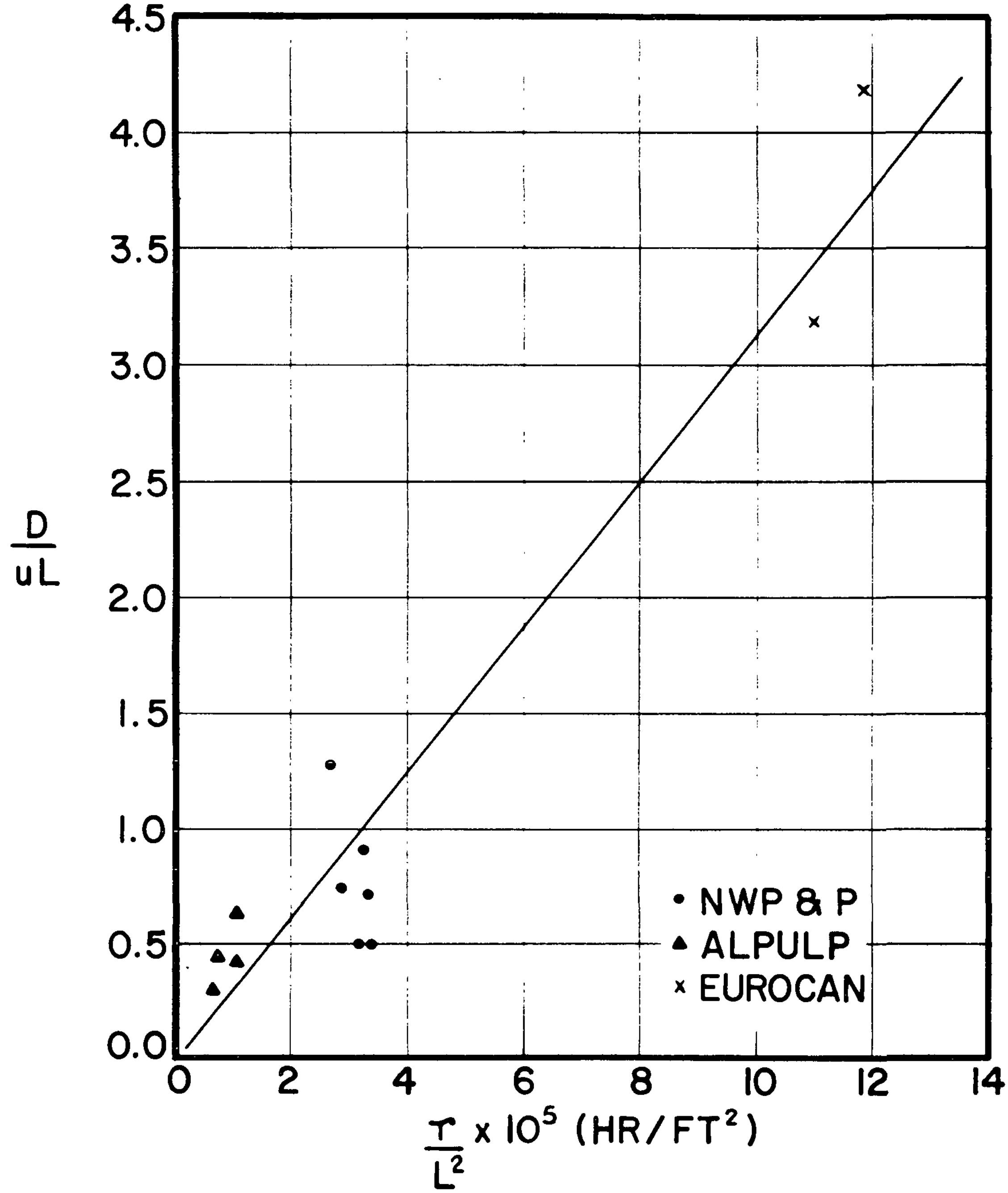


FIG. 25
PLOT OF DISPERSION COEFFICIENT 'D'
V's
CROSS-SECTIONAL AREA 'A'$_X$

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-25	



SLOPE = 0.310×10^5 CORRELATION COEFFICIENT = 0.960

FIG. 26
CORRELATION BETWEEN DISPERSION NUMBER & GEOMETRICAL PARAMETERS

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD DATE 17-3-72 DWG NO A4015-26

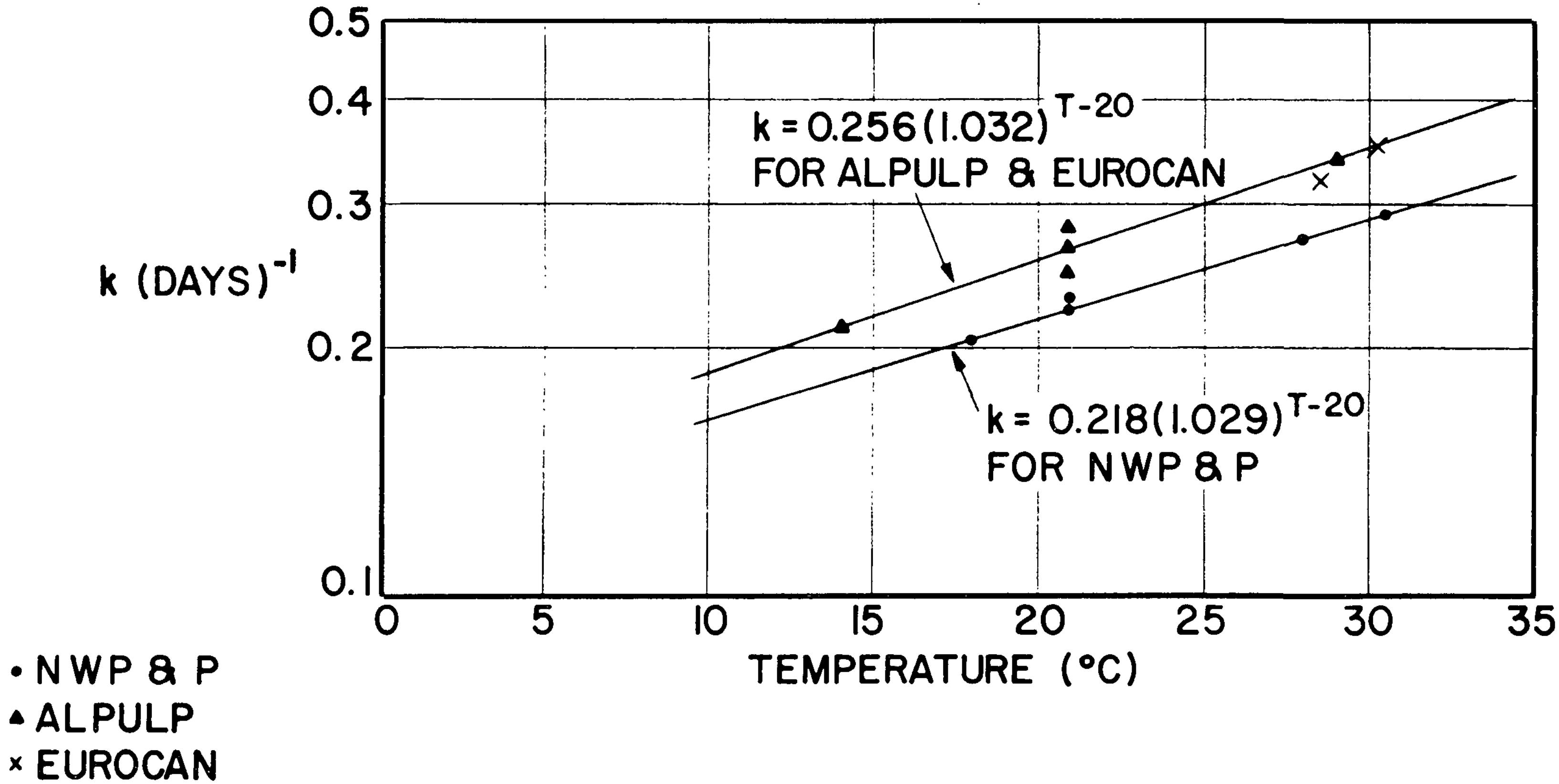


FIG. 27 — EFFECT OF TEMPERATURE ON FIRST ORDER B.O.D$_5$ REMOVAL RATE CONSTANT

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	B DS.RD DATE 17-3-72 DWG NO A4015-27

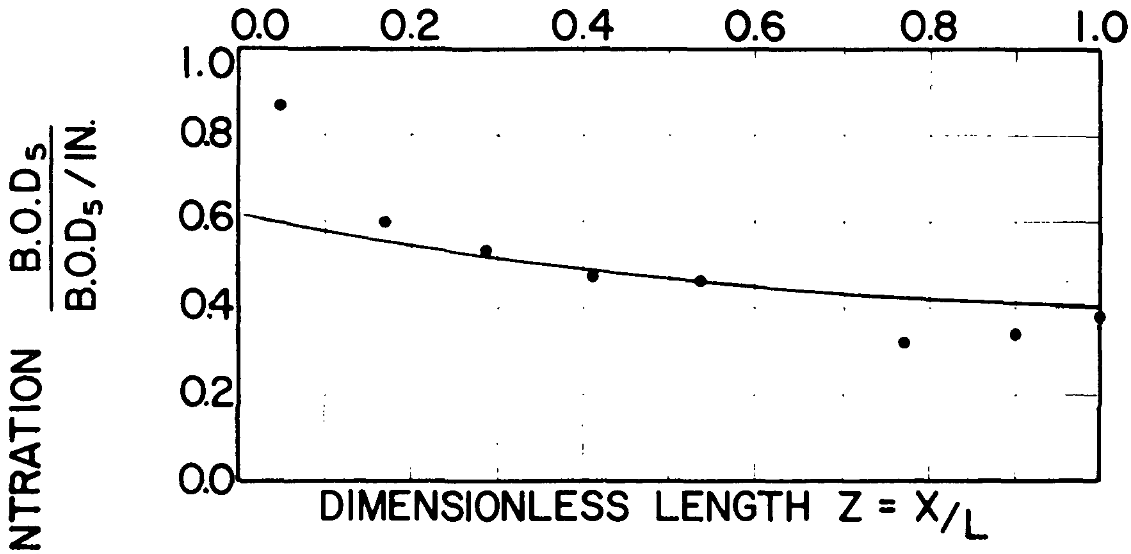


FIG. 28 – MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN H-1

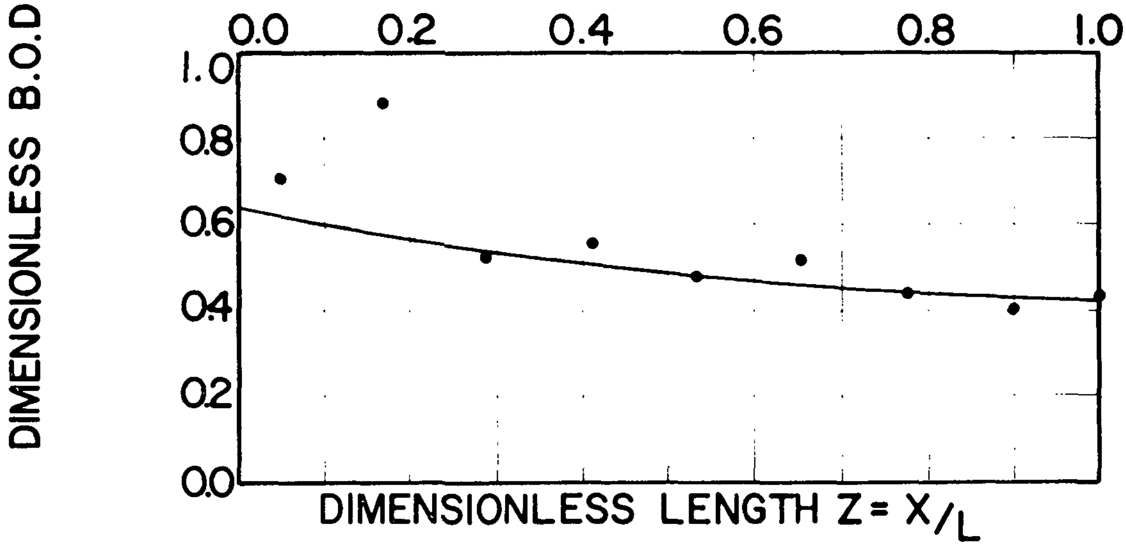


FIG. 29 – MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN H-2

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-28

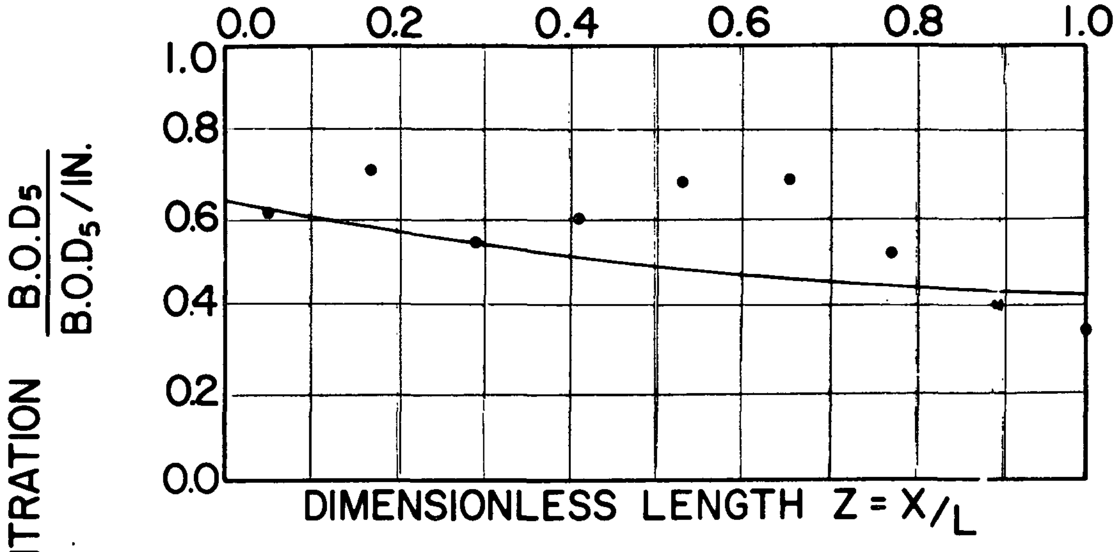


FIG. 30 – MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN H-3

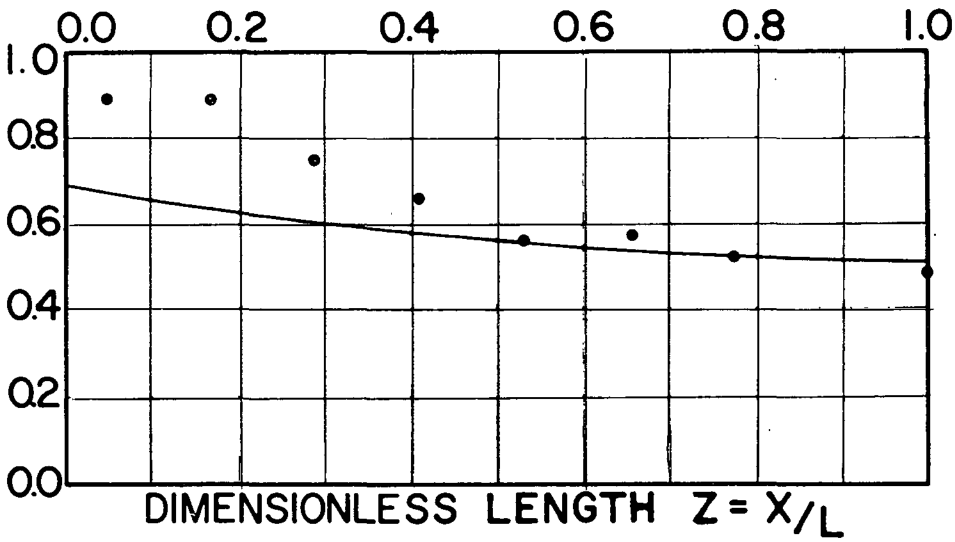


FIG. 31 – MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN H-6

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-30	

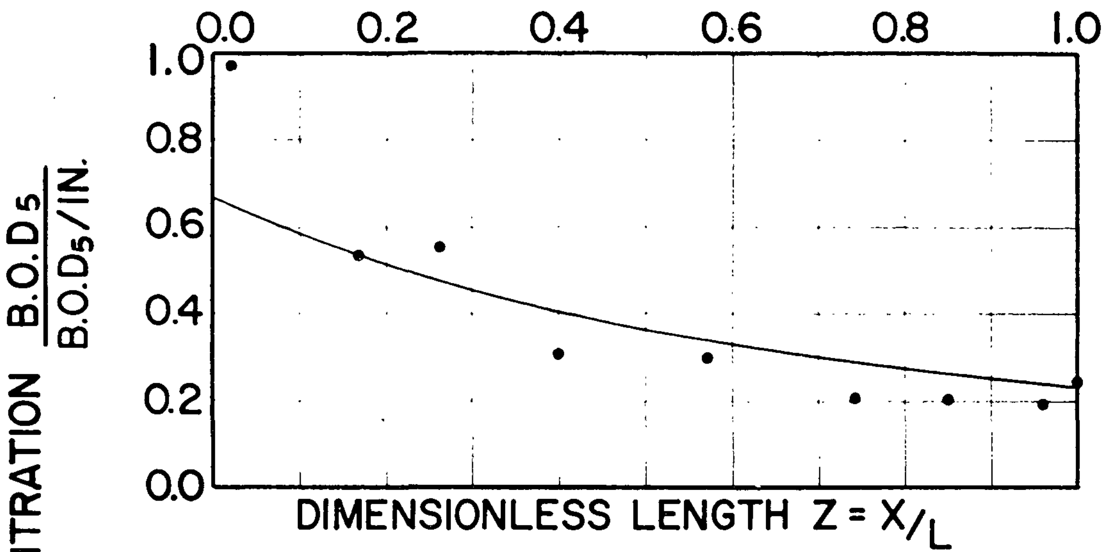


FIG. 32 - MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN A-1

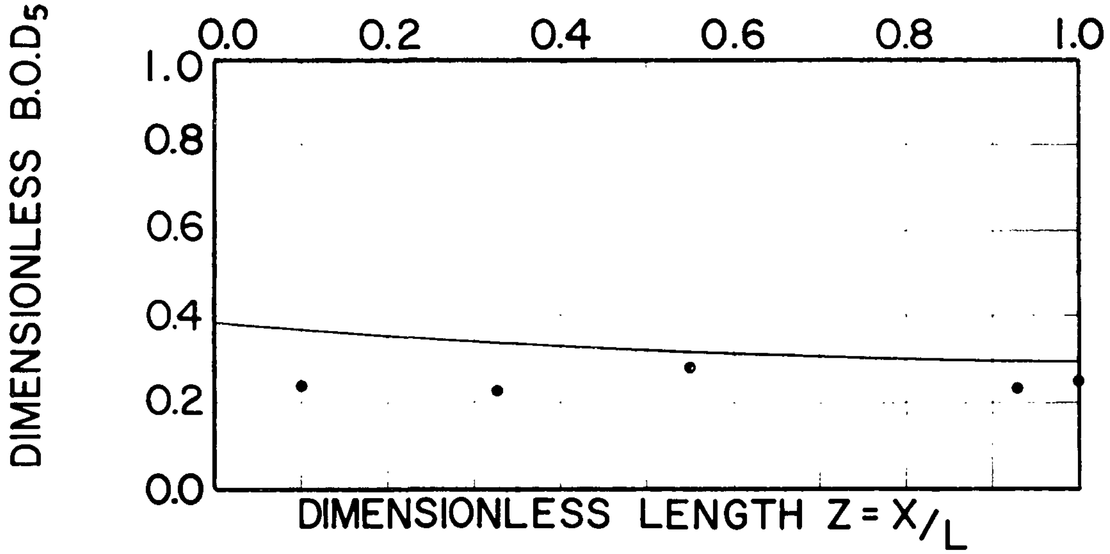


FIG. 33 - MEASURED & PREDICTED $B.O.D_5$ PROFILES RUN E-1

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-32	

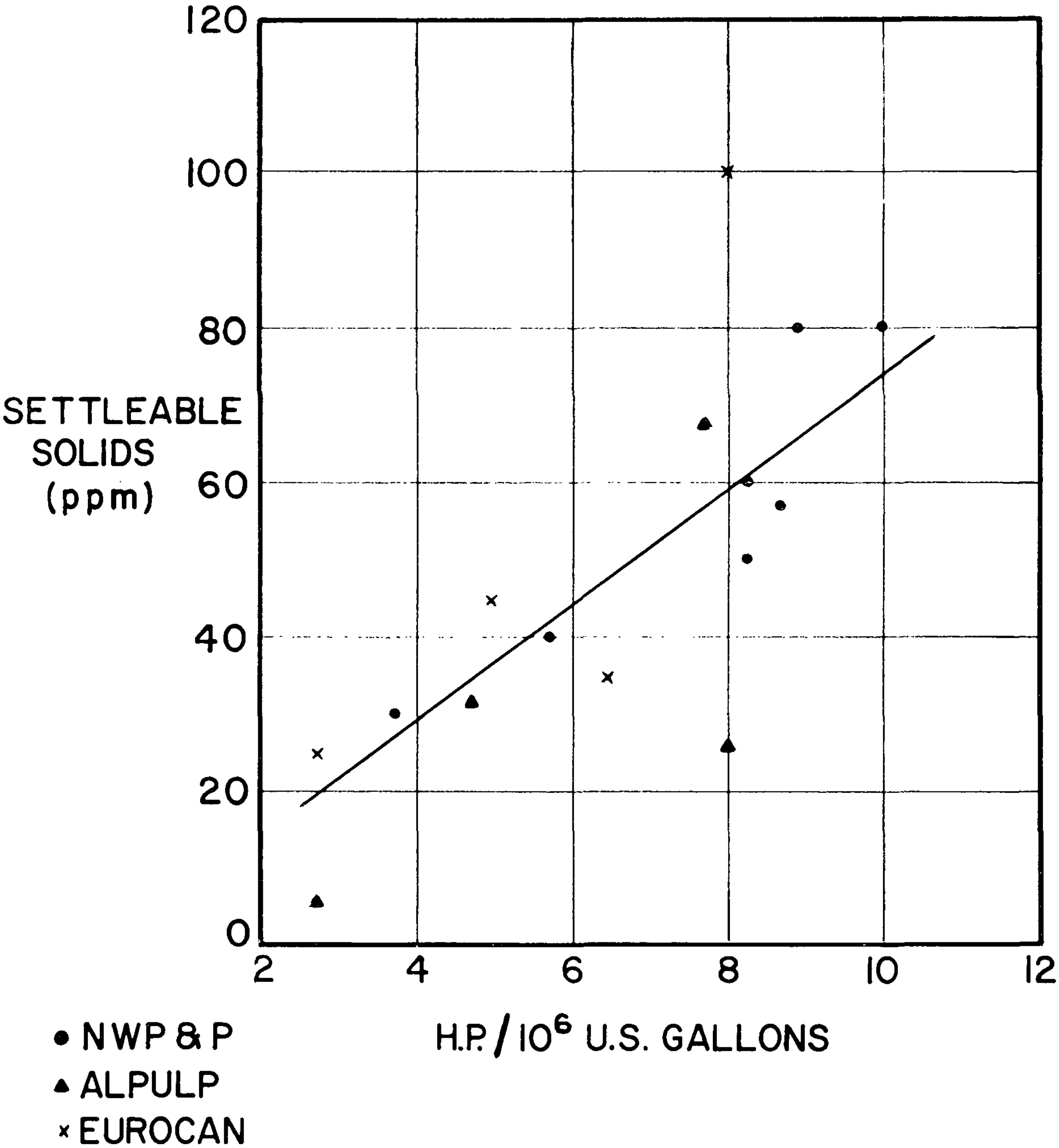


FIG. 34 — SETTLEABLE SOLIDS DEPENDENCY ON AERATION H.P.

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD DATE 17-3-72 DWG NO A 4015 -34

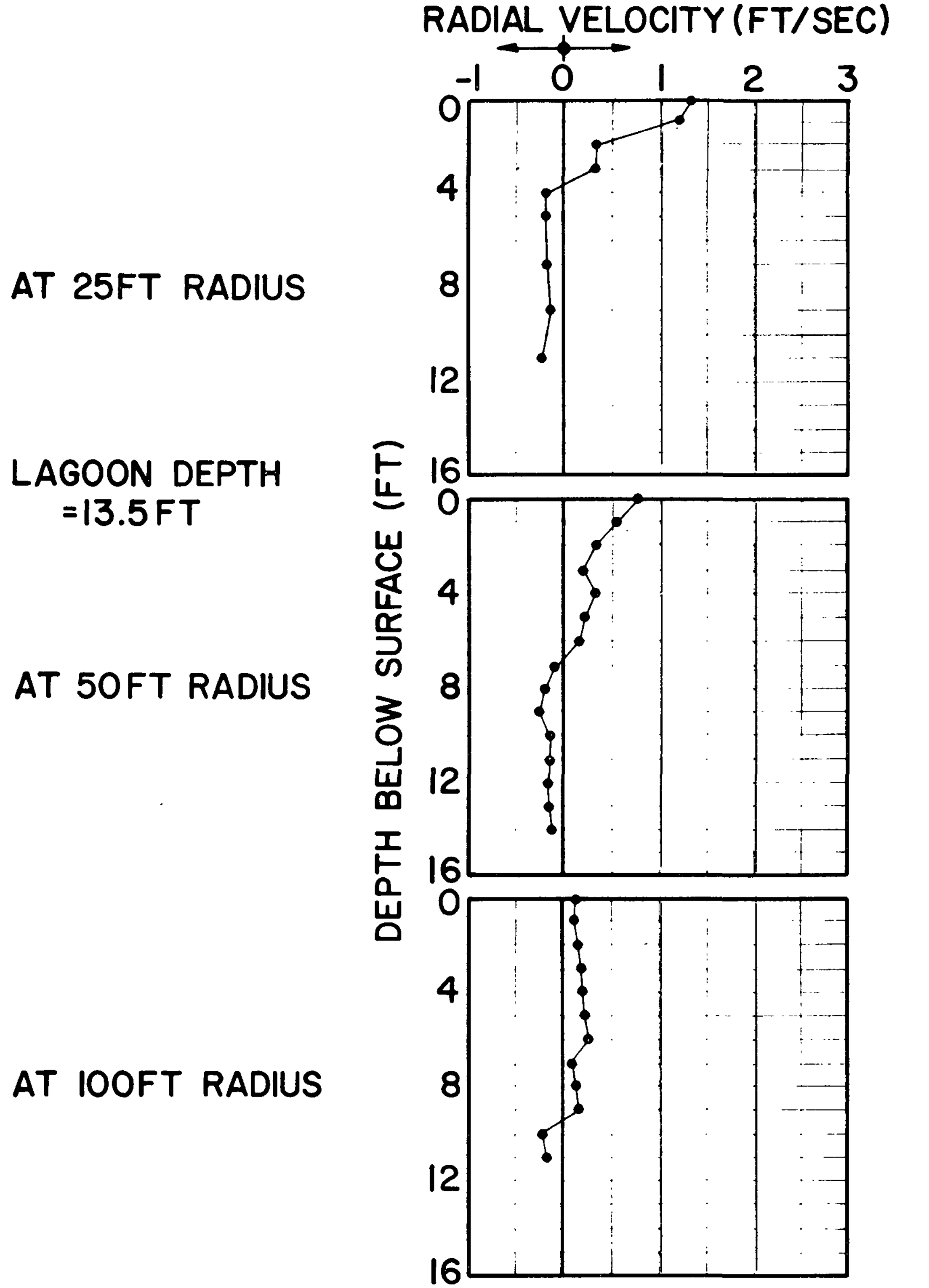


FIG. 35 — VELOCITY PROFILES ABOUT A 50H.P. LOW SPEED AERATOR

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-35

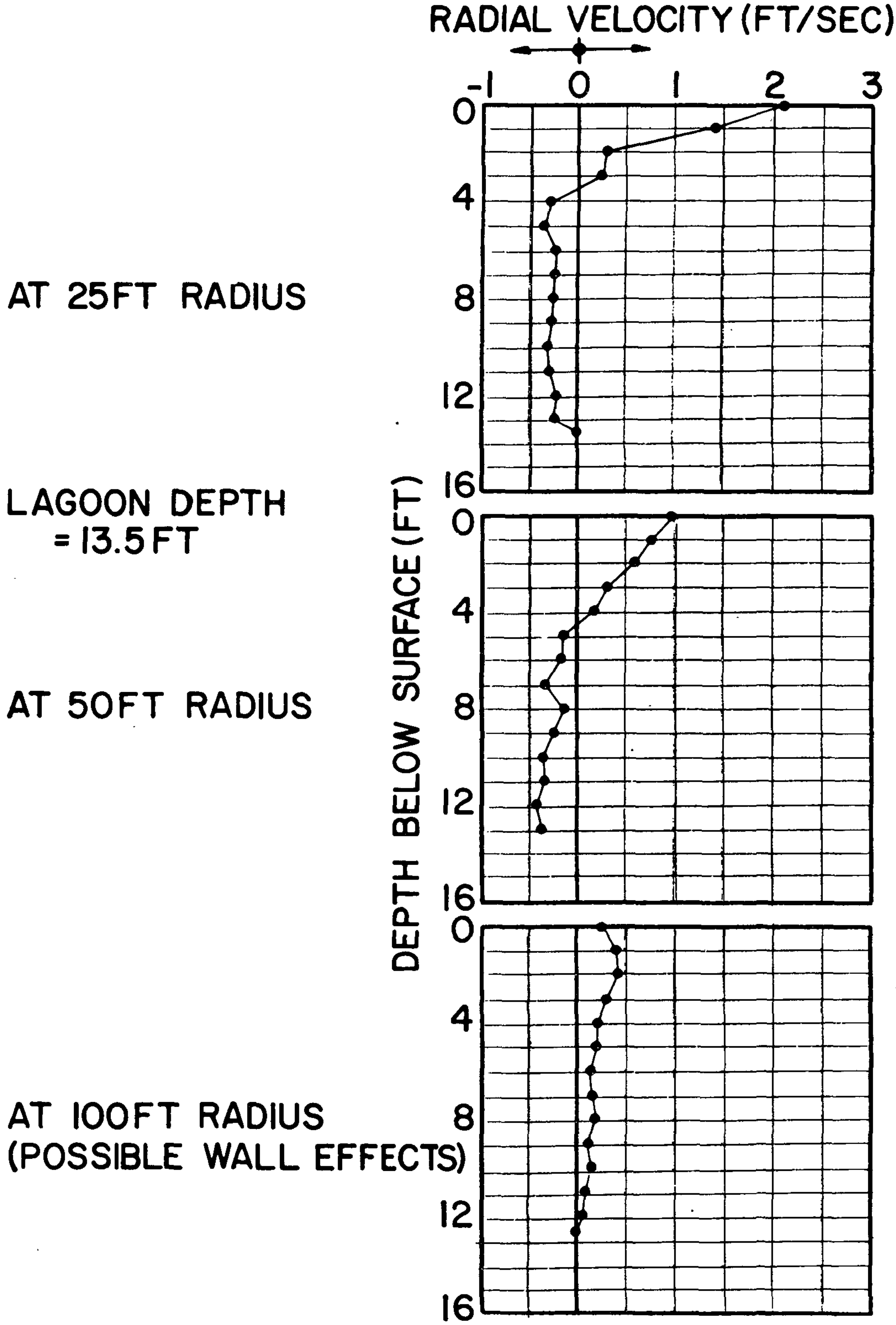


FIG. 36 — VELOCITY PROFILES ABOUT A 75 H.P. HIGH SPEED AERATOR

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-36	

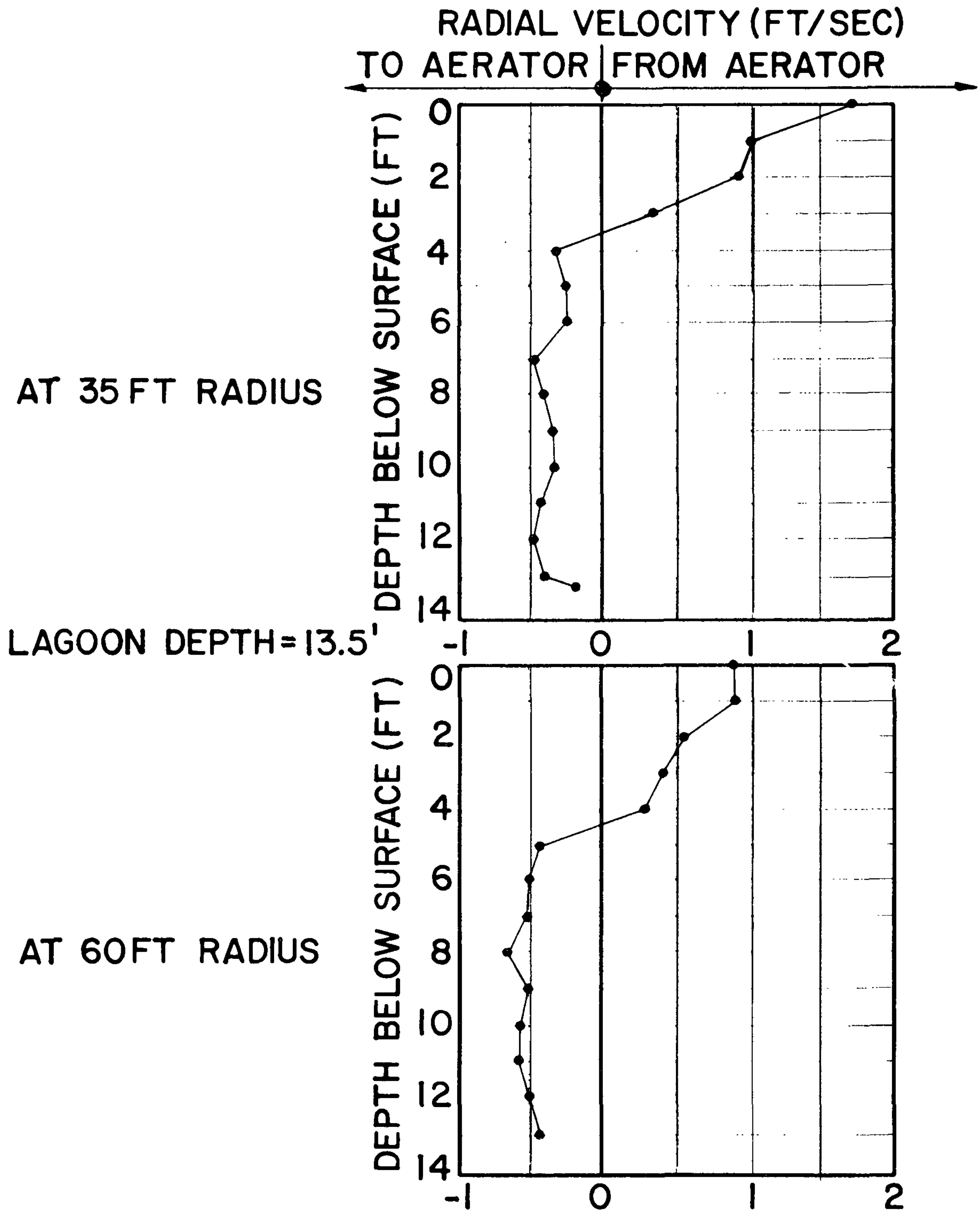


FIG. 37 — VELOCITY PROFILES ABOUT A 100H.P. LOW SPEED AERATOR

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-37

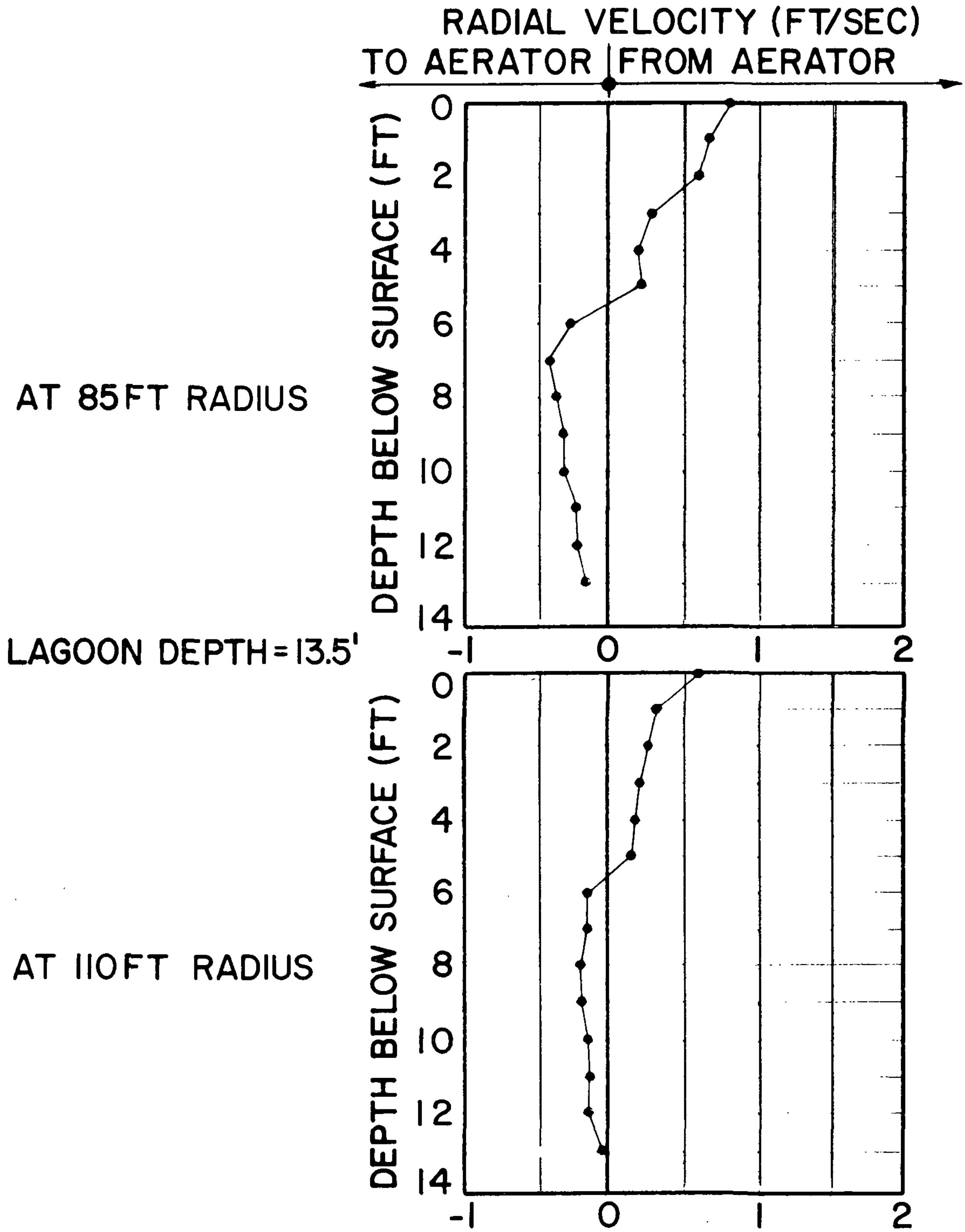
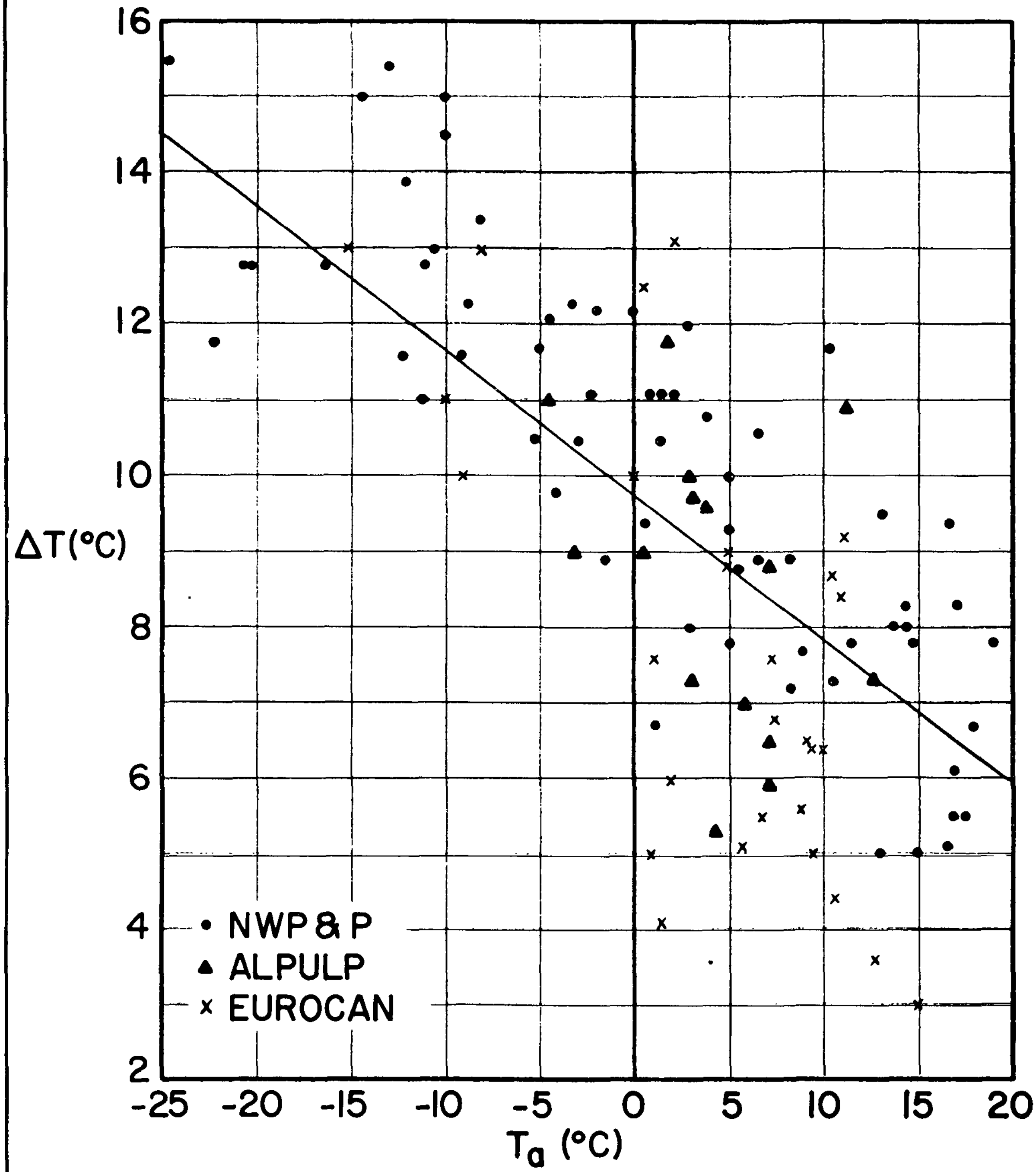


FIG. 38 — VELOCITY PROFILES ABOUT A 100H.P. LOW SPEED AERATOR

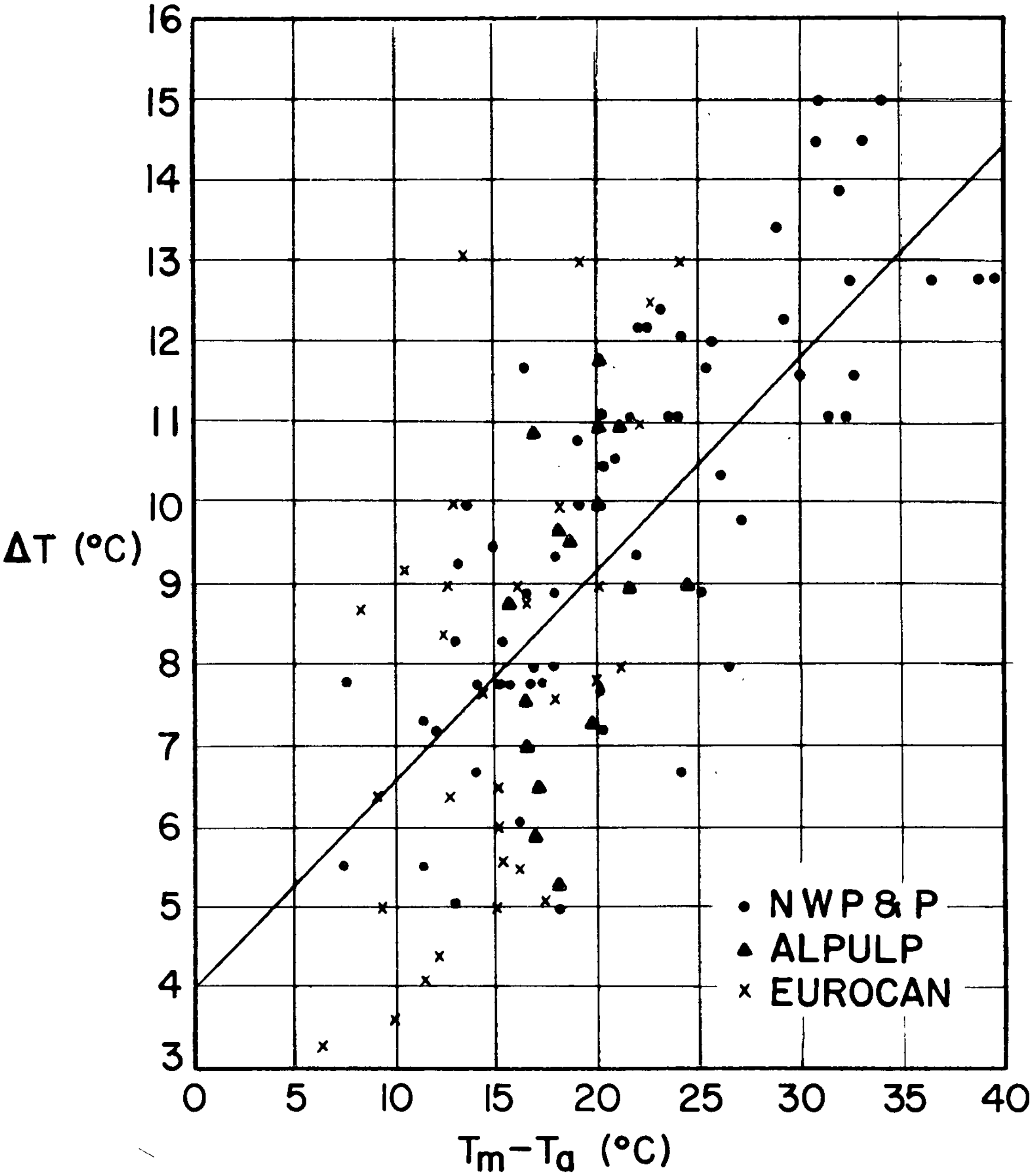
GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-38



SLOPE = -0.190 CORRELATION COEFFICIENT = 0.711

FIG. 39 — TEMP. DECREASE THRU LAGOONS V's AMBIENT TEMP.

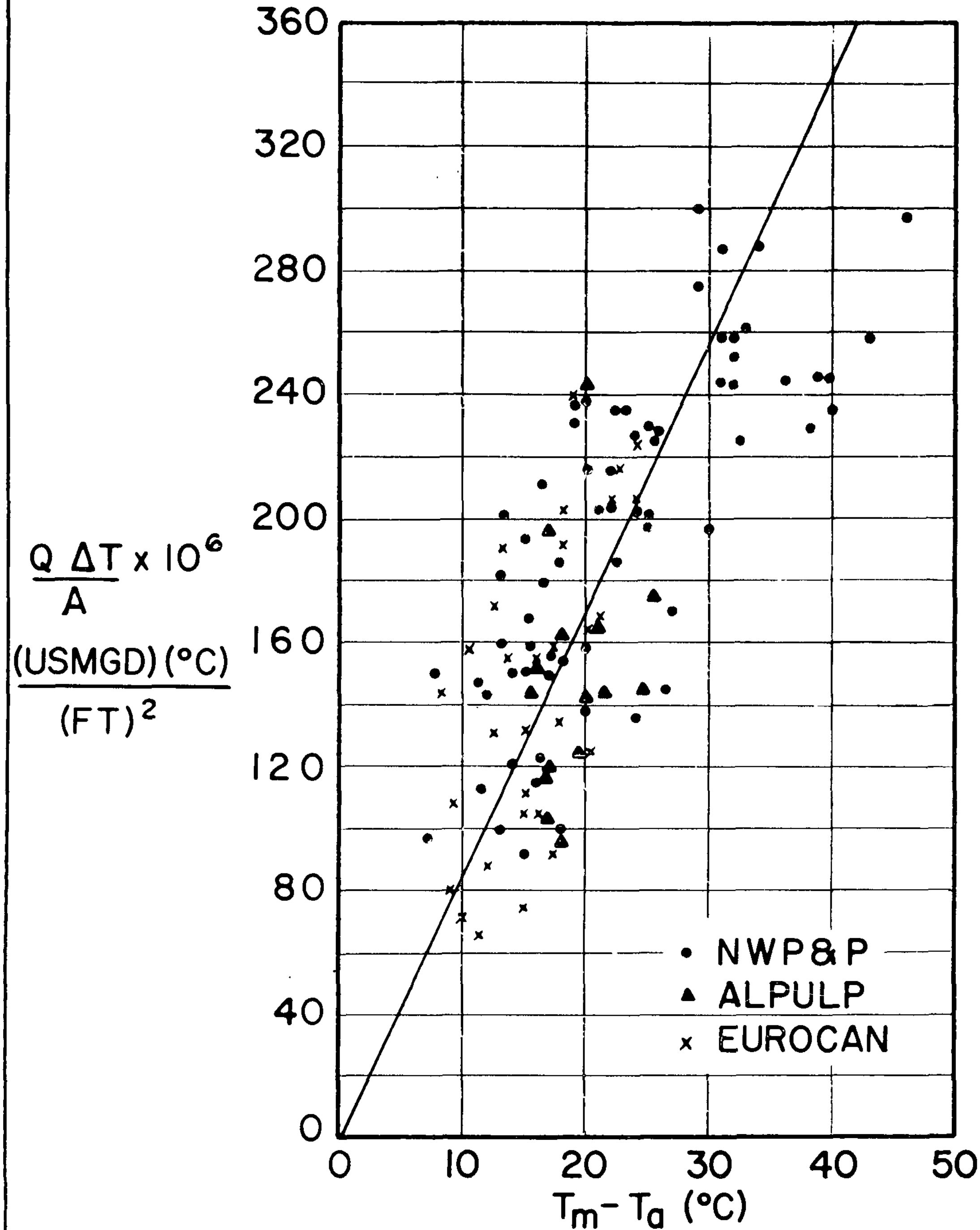
GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-39



SLOPE = 0.26 CORRELATION COEFFICIENT = 0.738

FIG.40 – TEMP. LOSS V's MEAN LAGOON TEMP. – AMBIENT TEMP.

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17-3-72 DWG NO A4015-40



SLOPE = 8.66×10^{-6} CORRELATION COEFFICIENT = 0.757

FIG. 41 — HEAT LOSS V's MEAN LAGOON TEMP. — AMBIENT TEMP.

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD DATE 17·3·72 DWG NO A4015-41

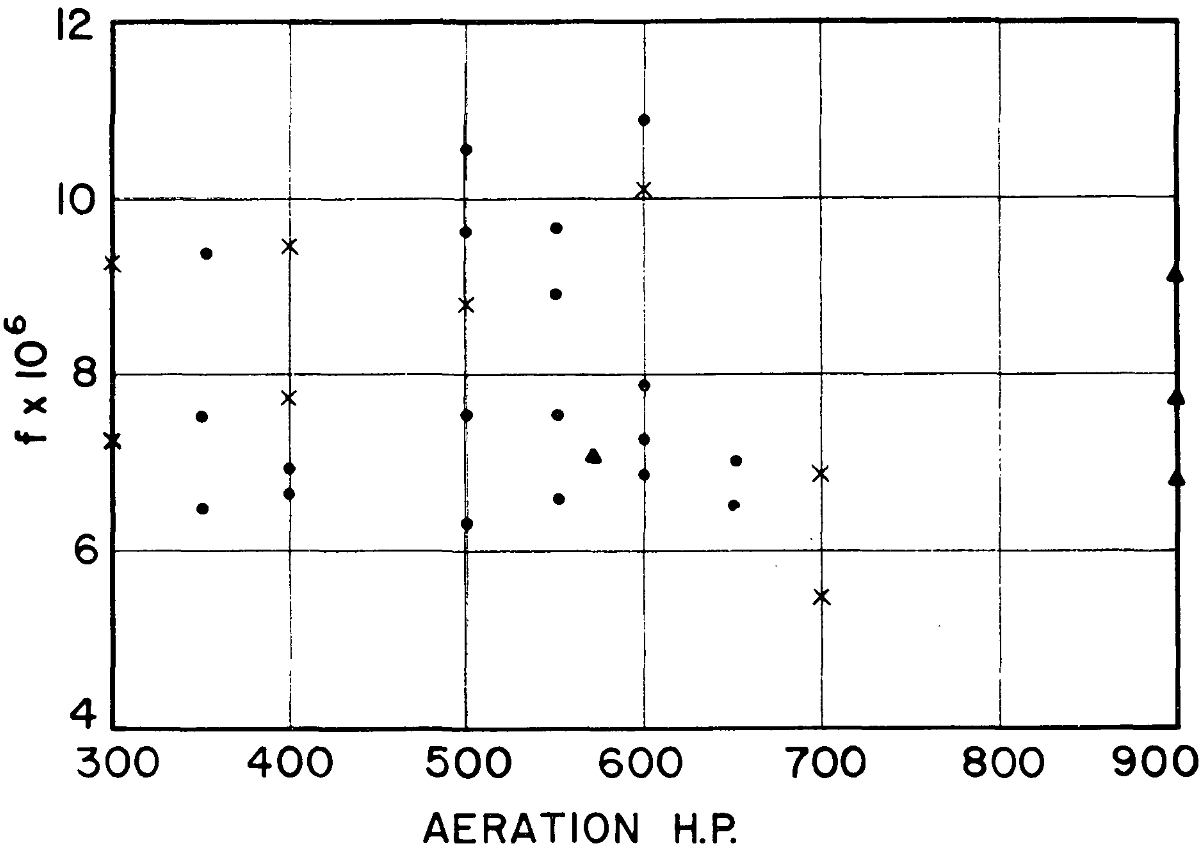


FIG. 42
EFFECT OF AERATION H.P. ON f

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD	DATE 17-3-72
		DWG NO A4015 -42	

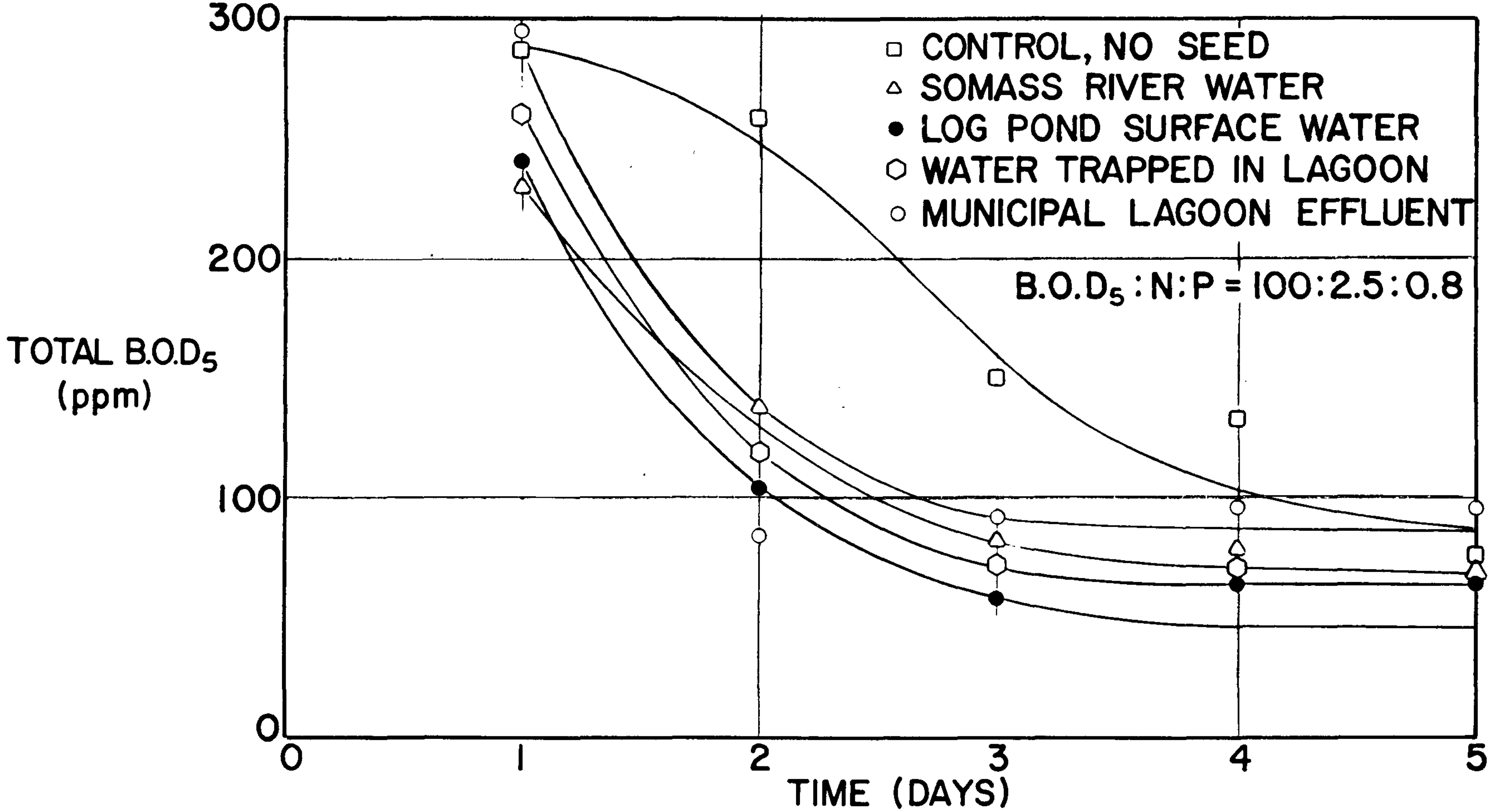


FIG. 43 — ALPULP BATCH TREATMENT STUDY
EFFECT OF 10% SEED

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS.RD	DATE 17-3-72
		DWG NO A4015-43	

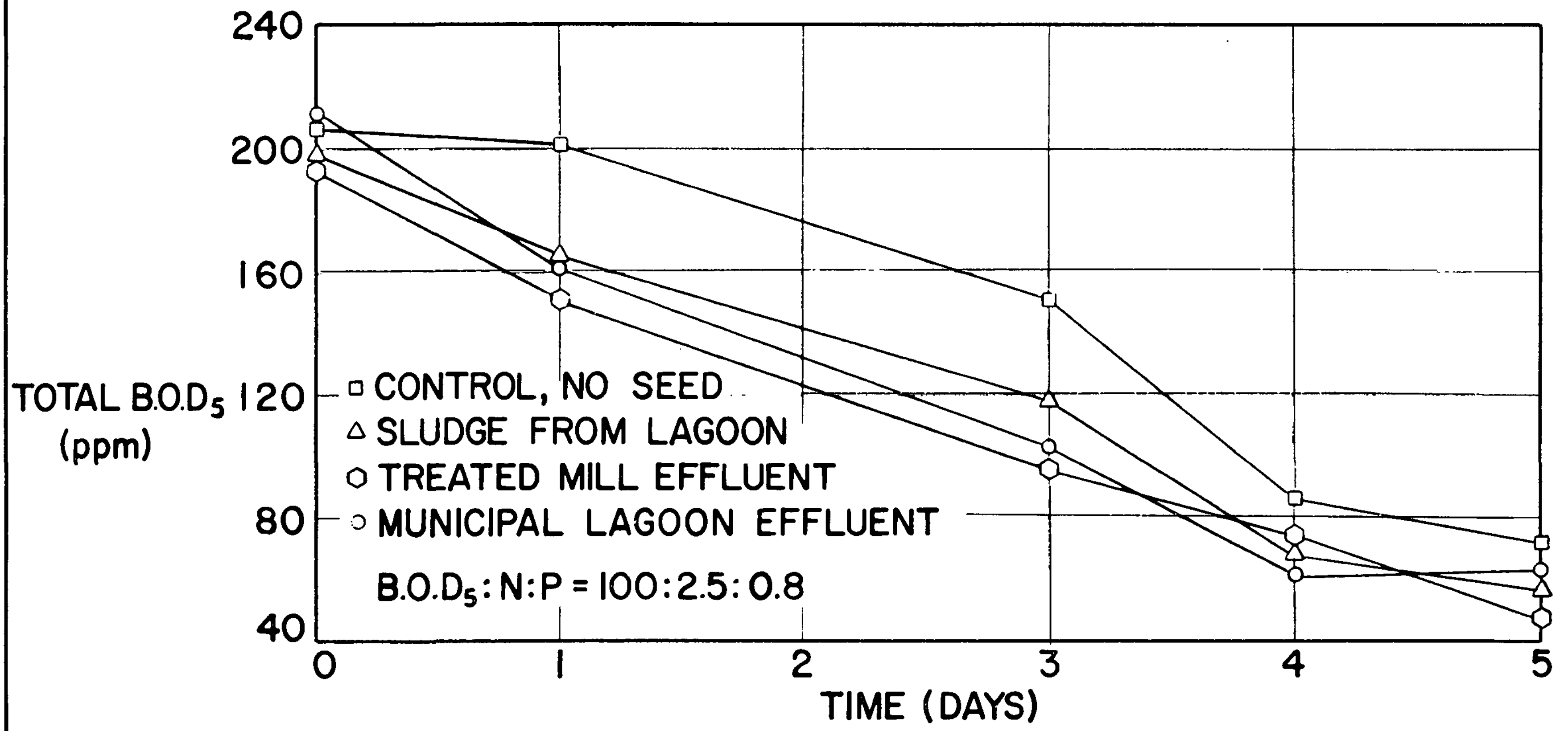


FIG. 44 — EUROCAN BATCH TREATMENT STUDY
EFFECT OF 10% SEED

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY RD	DATE 17-3-72
		DWG NO A4015-44	

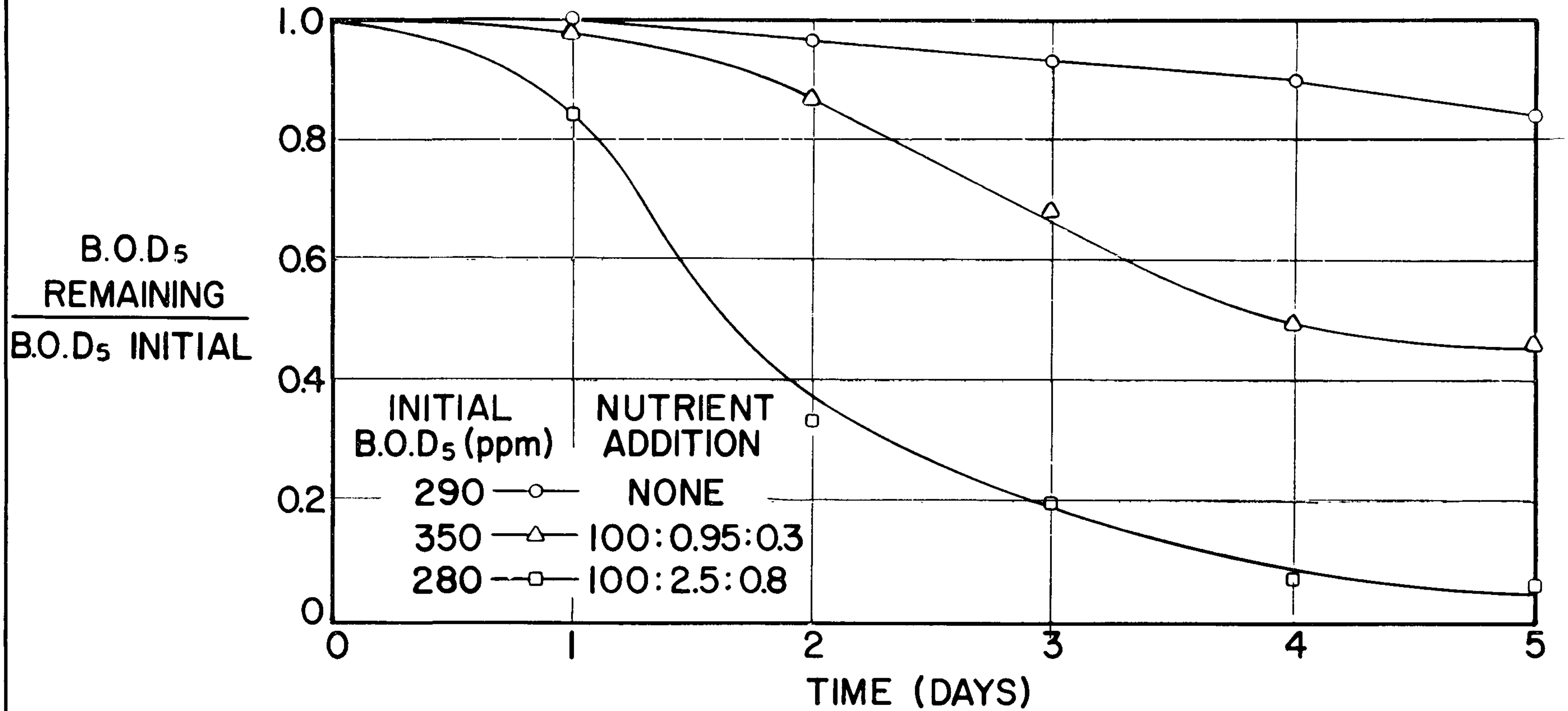


FIG. 45 — ALPULP BATCH TREATMENT STUDY EFFECT OF NUTRIENT CONCENTRATION

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17-3-72
DWG NO A4015-45

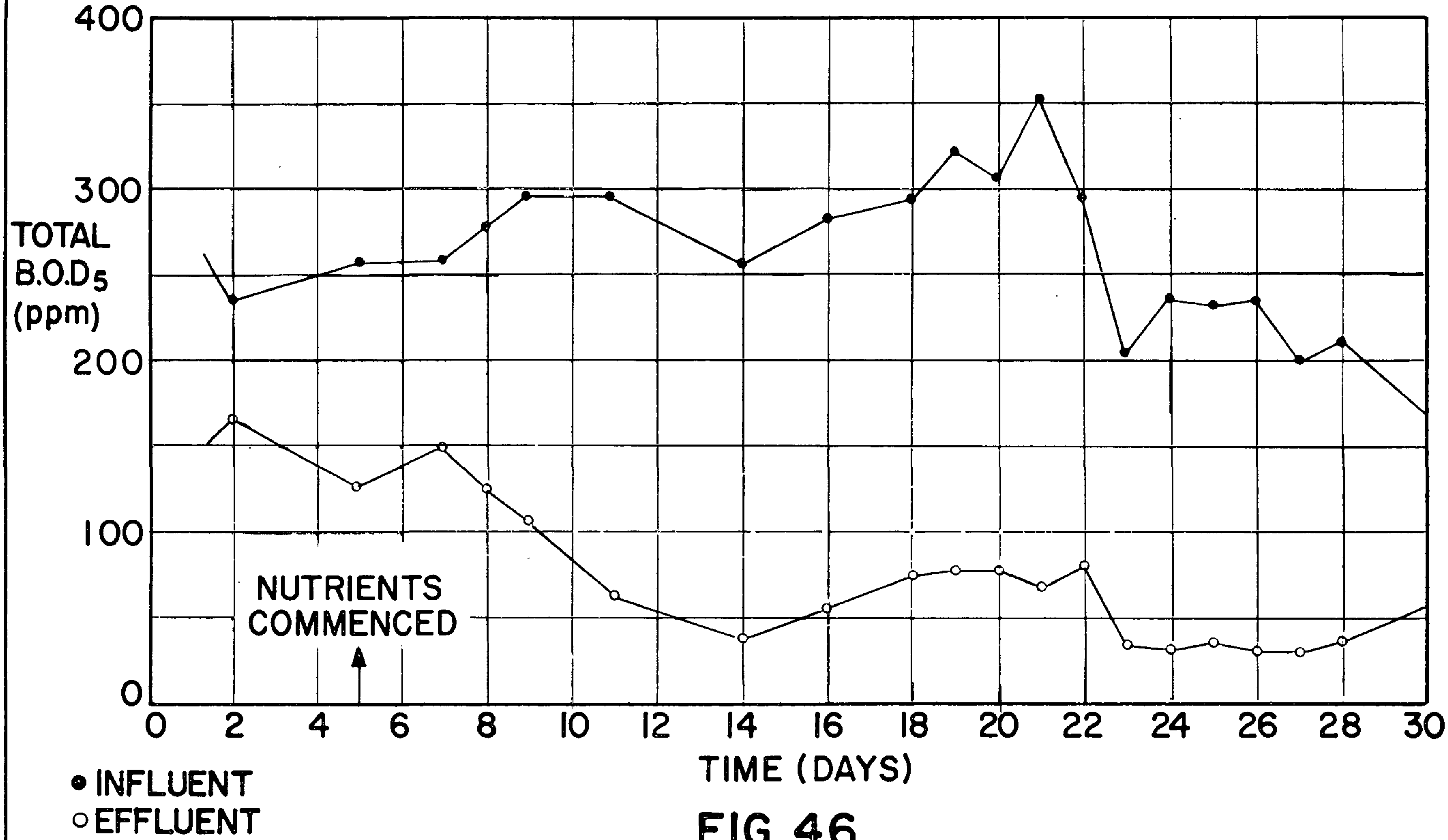


FIG. 46

ALPULP B.O.D_5 VARIATION & EFFECT OF NUTRIENTS

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY DS. RD DATE 17-3-72 DWG. NO A4015-46

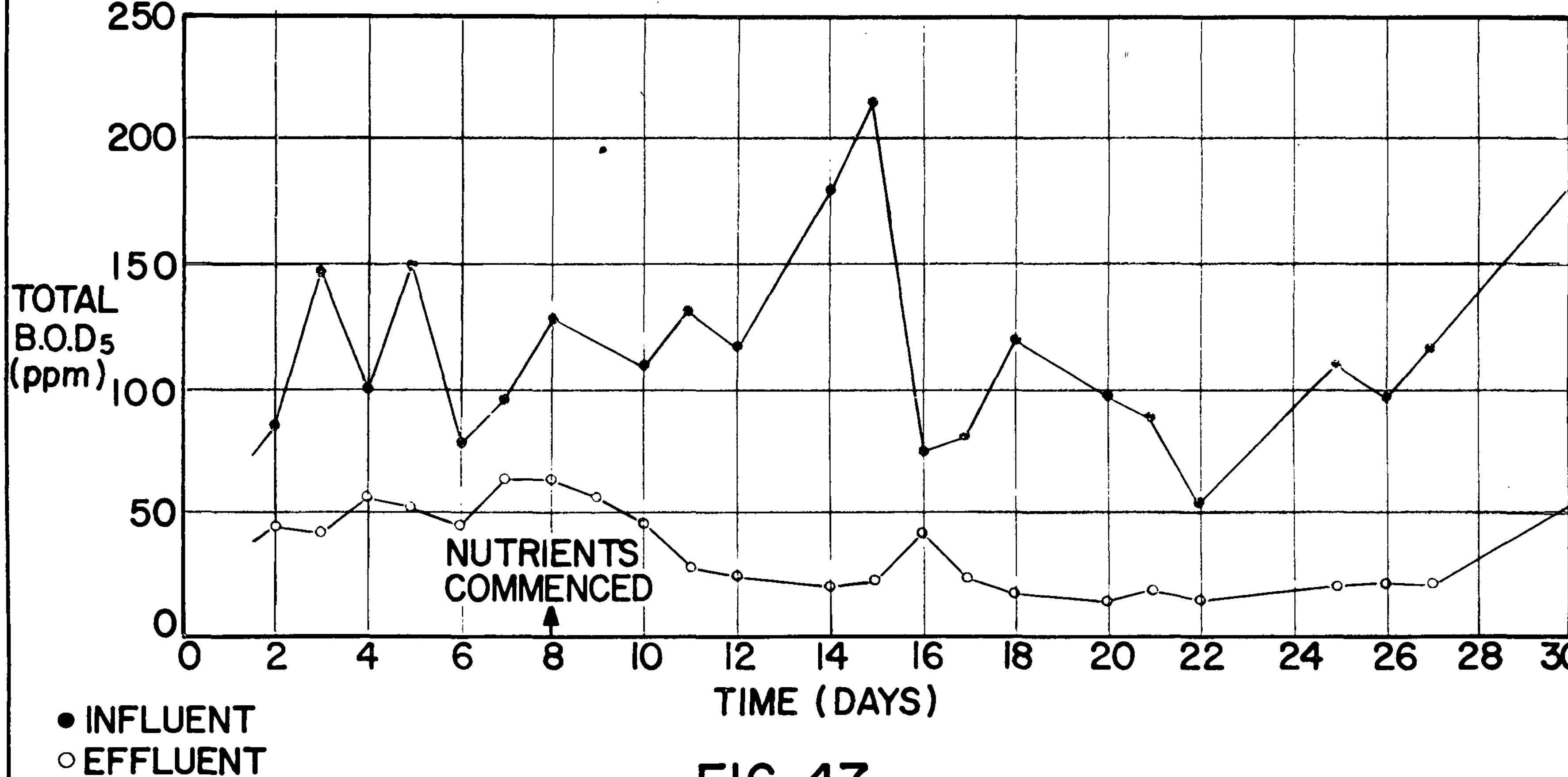


FIG. 47

EUROCAN B.O.D$_5$ VARIATION & EFFECT OF NUTRIENTS

GOVERNMENT OF CANADA OTTAWA ONTARIO BIOLOGICAL TREATMENT STUDY	BEAK	BY SR.RD	DATE 17-3-72
		DWG NO A4015-47	

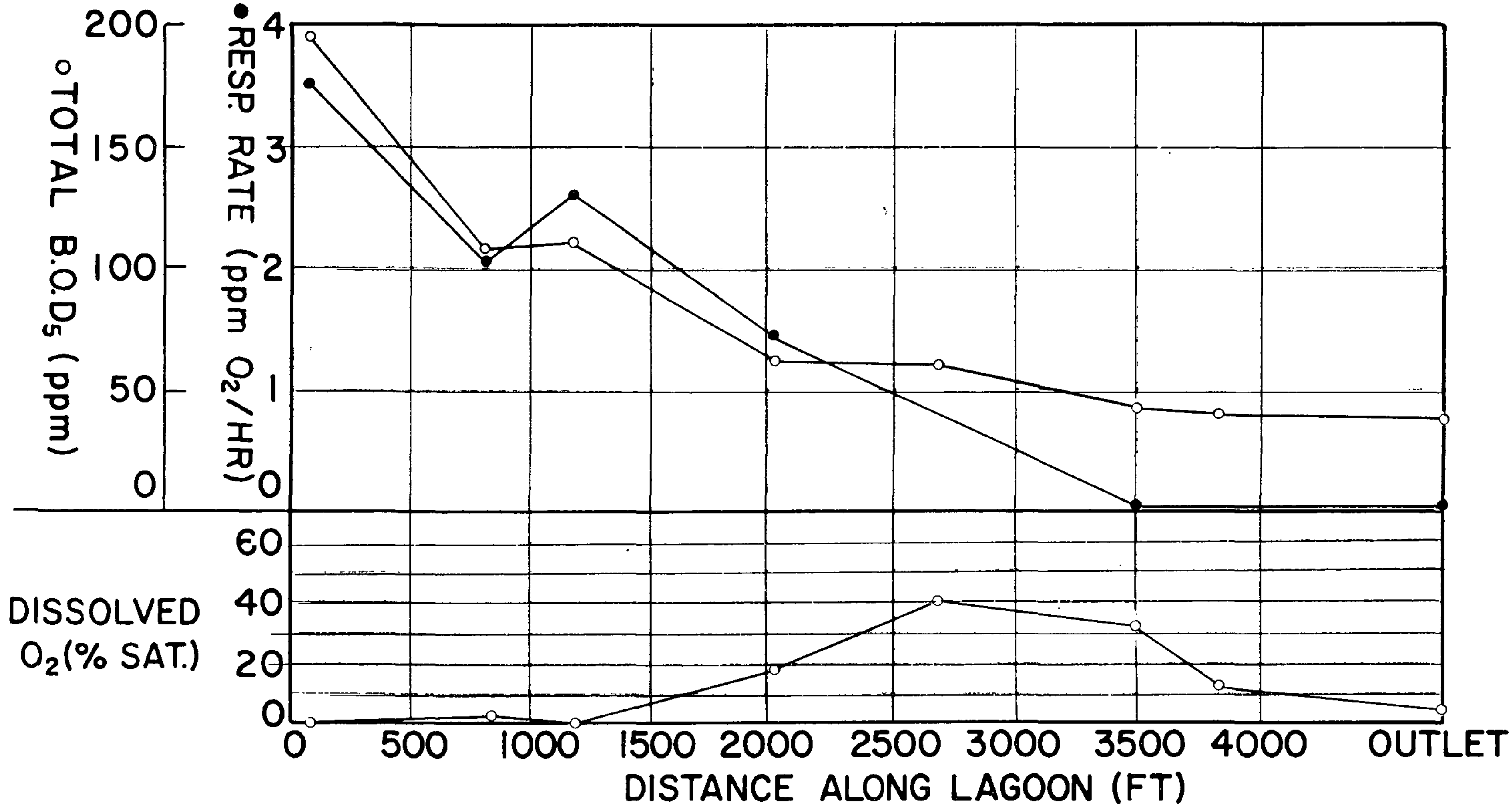


FIG. 48 – PROFILE OF ALPULP LAGOON

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY DS.RD DATE 17-3-72
DWG NO A4015-48

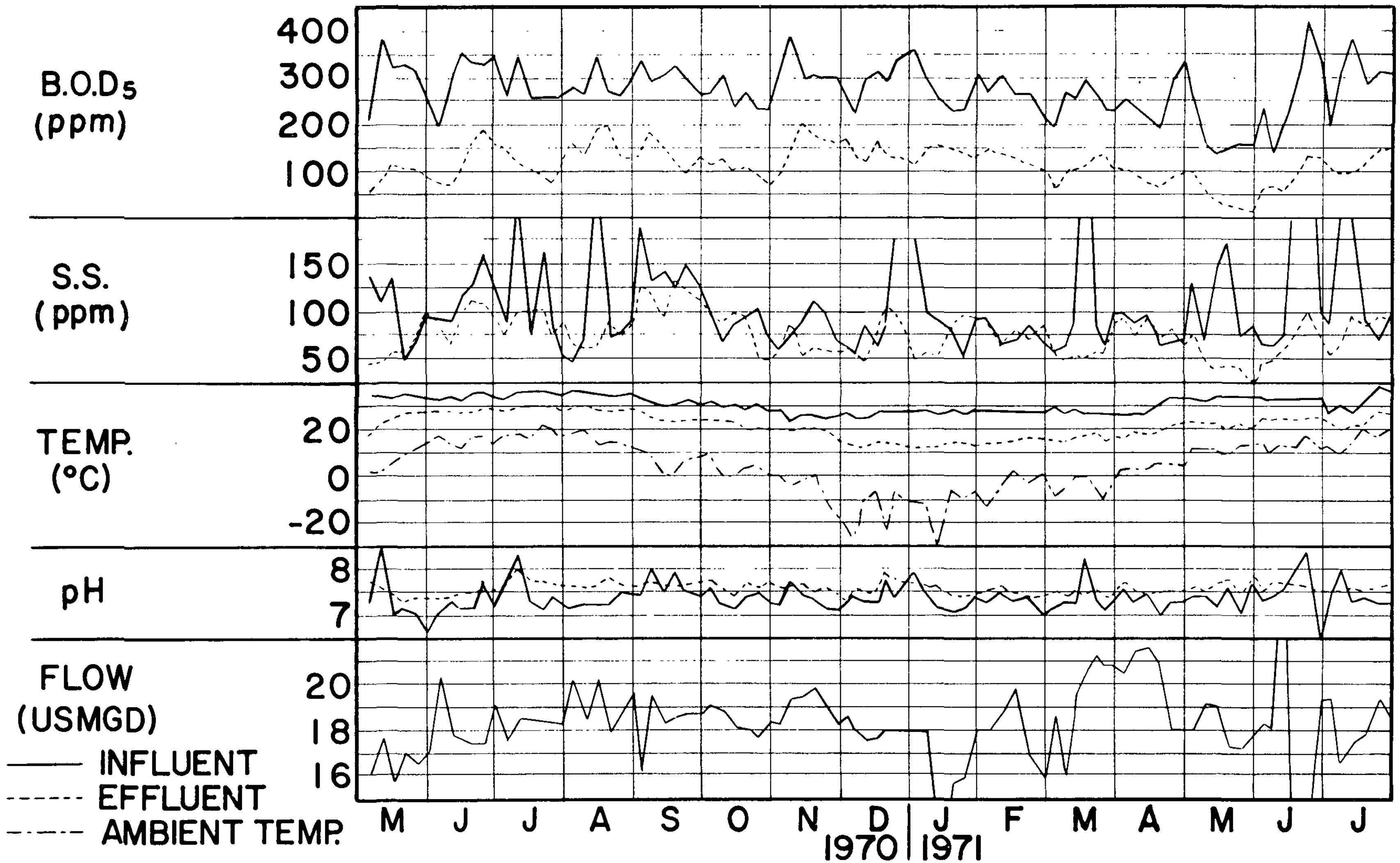


FIG.49 — NWP&P OPERATING DATA

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY SR. RD DATE 17-3-72
DWG NO A 4015-49

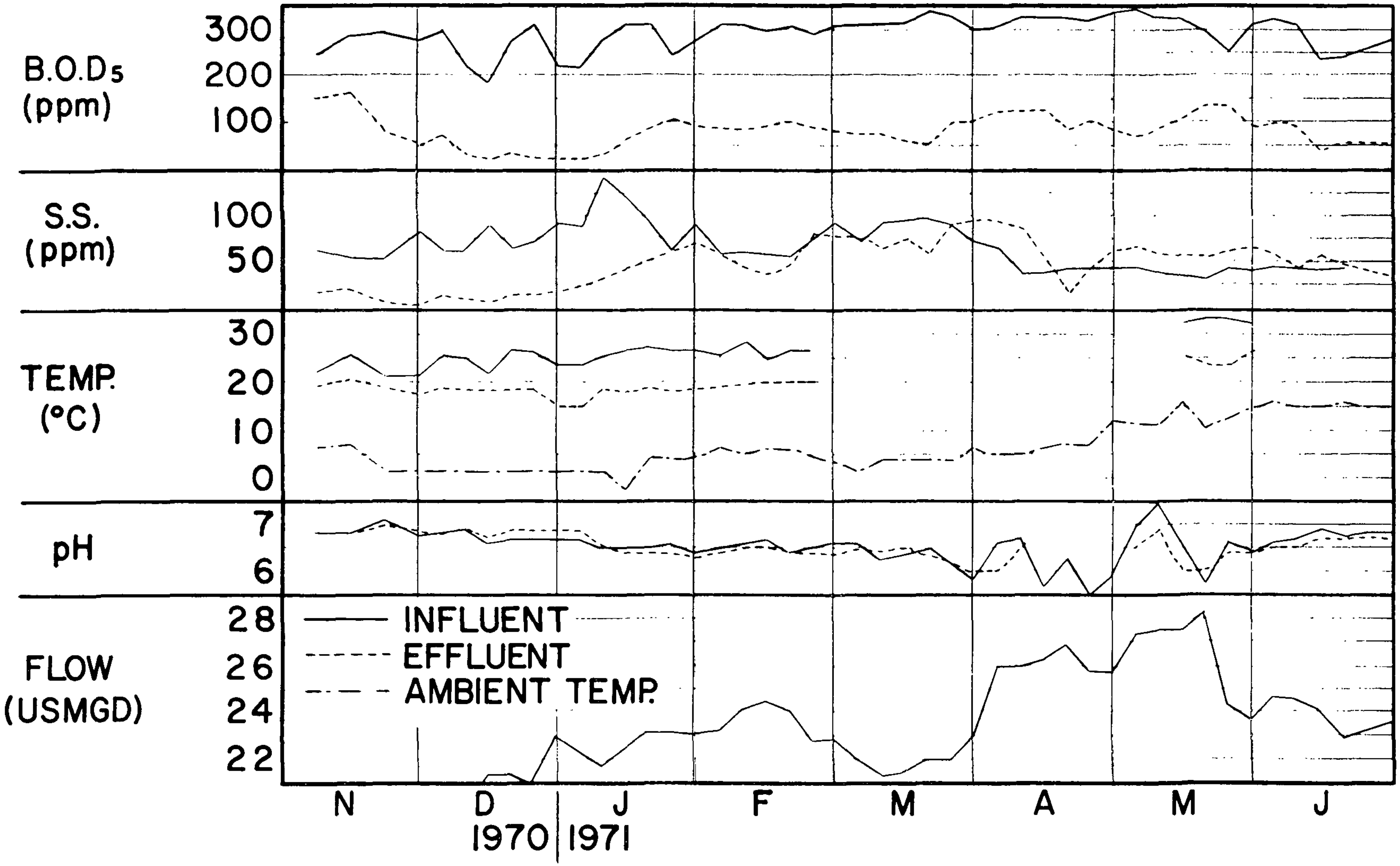


FIG. 50 — ALPULP OPERATING DATA

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY RD DATE 17-3-72
DWG NO A4015-50

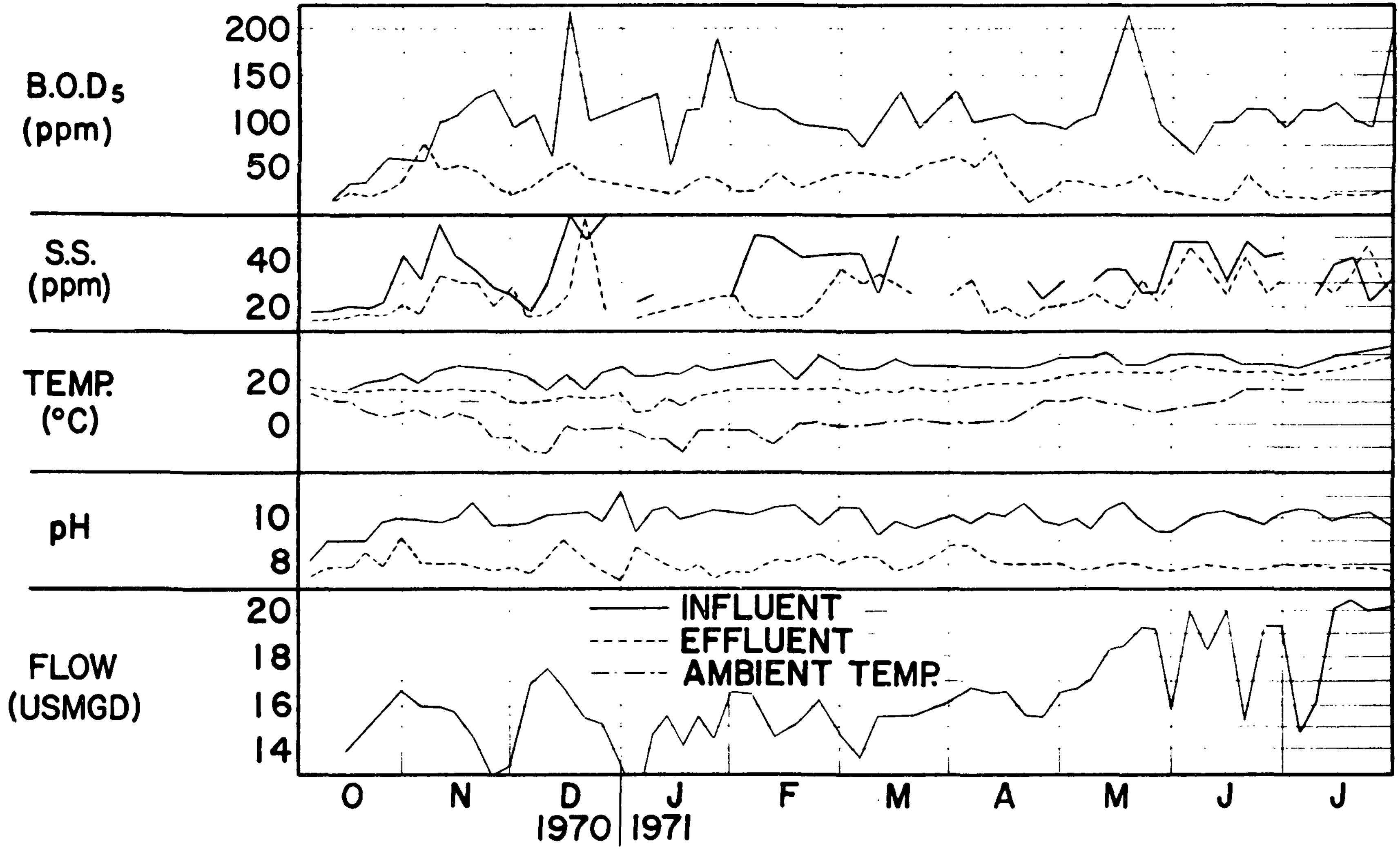


FIG. 51 — EUROCAN OPERATING DATA

GOVERNMENT OF CANADA
OTTAWA ONTARIO
BIOLOGICAL TREATMENT STUDY

BEAK

BY RD DATE 17-3-72
DWG NO A 4015-51

APPENDIX 1

APPENDIX 1

WASTE TREATMENT SYSTEM DESCRIPTIONS

DATE: SEPTEMBER 1972

APPENDIX 1

WASTE TREATMENT SYSTEM DESCRIPTIONS

NWP&P

The waste treatment facilities at the NWP&P mill in Hinton, Alberta, were designed to treat the total pulp mill and woodroom effluents, except for the bleach plant acid wastes. In addition to the mill waste, municipal sewage from the town of HINTON is also treated in the aerated lagoon.

The waste streams to receive biological treatment are clarified in a 200 foot diameter primary clarifier. Portions of the bleach plant acid waste are used for pH control. Prior to clarification the pH is trimmed to 7.5 and immediately before the aerated lagoon the pH is adjusted by an automatic controller to 7.0.

The U-shaped aerated lagoon is divided into two sections; an aeration zone and a quiescent zone. The aerated section, with a surface area of approximately 10 acres and an operating depth of about 21 feet provides a retention time of three and one-half days at the average waste flow rate of 18 USMGD Fourteen, 50-horsepower Welles, floating, high speed mechanical aerators, spaced throughout the aerated section provide aeration and mixing. The quiescent section of the lagoon has a surface area of about 10 acres and an average depth of about 6 feet providing a retention time of about one and one-half days. The treated waste combines with the untreated acid waste and is discharged into the Athabasca River through a submerged diffuser.

The nutrients, nitrogen and phosphorous are added to the clarified waste in the form of urea (46-0-0) and mono-ammonium phosphate (11-48-0) by two dry chemical feeders.

The untreated waste is sampled by a timer operated pump and the treated waste from the lagoon is sampled by a chain and bucket type sampler. The waste flowrate is measured by a weir at the lagoon outlet.

ALPULP

The waste water treatment facilities at ALPULP are designed to process wastes with high solids and BOD_5 content in a system consisting of collector sewers, a clarifier for sedimentation, and an aerated lagoon for biological oxidation. The effluents receiving treatment comprise about 50 per cent of the total waste flow and contain about 85 per cent of the total volatile suspended solids and about 60 per cent of the total BOD_5 from the mill.

The average flow rates of the main waste streams treated are shown in Table 1-1. Waste streams that do not receive biological treatment, including streams from the kraft bleach plant, recausticizing, paper machines and chemical recovery areas, are combined with the treated effluent before discharge to Alberni Inlet.

TABLE 1-1 WASTES RECEIVING BIOLOGICAL TREATMENT (ALPULP)

Stream	Average Flow (USGPM)	
Stone groundwood grinders and screens	800	
Stone groundwood bleach	3,000	
Refiner groundwood bleach	800	
Kraft caustic extraction washer	1,200	
No. 3 and 4 paper machine	4,500	
Paper machine and refiner groundwood	3,000	
Woodmill	3,000	
Average flow to Aerated Lagoon	16,300	(23 USMGD)

The mill effluents for treatment, except those from the wood mills, are combined and flow by gravity to a pumping station which lifts the effluent to the 200 foot diameter primary clarifier. The woodmill wastes are clarified in an 80 foot diameter clarifier and pumped to the primary clarifier overflow. The combined effluents then flow by gravity to the aerated lagoon.

The nutrients, nitrogen and phosphorus, in the forms of urea (46-0-0) and mono-ammonium phosphate (11-48-0) are introduced to the effluent at the primary clarifier overflow. These are separately metered into small solution tanks and dissolved in water before entering the system.

The aerated lagoon has a surface area of approximately 35 acres and an operating depth of about 13.5 feet, with a mean residence time of 5.5 days. Thirteen 75-horsepower Welles, floating, high speed, mechanical aerators and one 50-horsepower Lightnin, floating, low speed, mechanical aerator are spaced throughout the lagoon to provide aeration and mixing. At the lagoon inlet the aerators are relatively closely spaced in order to disperse the influent rapidly and to supply oxygen to satisfy the higher demand of the waste there, whereas the aerators near the outlet of the lagoon are more widely spaced because the oxygen demand of the waste is less in that region. The wider spacing also provides quiescent zones for sedimentation of any settleable material before the waste is discharged from the lagoon.

Waste flow rates are monitored throughout the system. Flows of the contributory streams are measured by Parshall flumes in the mill, and the total combined flow to the 200 foot diameter clarifier is recorded by a magnetic flow meter. The wood mill clarifier overflow is measured in a Parshall flume.

Chain and bucket type samplers are used to sample the aerated lagoon influent and effluent continuously. Many of the in-mill sewers are also sampled on a continuous basis at the Parshall flumes.

EUROCAN

The treatment facilities at EUROCAN are designed to treat the total effluent from the pulp mill and woodmill. Two sewers, a general mill sewer and a toxic sewer carry the effluents to the biological treatment system. Waste streams likely to have a high solids but low chemical content, which include sewers from the woodroom, washing and screening area, paper machine, and stock preparation areas, are collected in a general sewer and settled in a 100 foot diameter primary clarifier.

Effluents likely to have a high chemical content, including wastes from the digester area, water treatment, chemical recovery and recausticizing areas of the mill are collected in a toxic sewer which bypasses the primary clarifier. In the event of an upset or chemical spill in the mill, the toxic sewer flow is automatically diverted to a spill basin.

During normal operation, the toxic and general sewers combine and flow by gravity to one of two settling ponds. The settling ponds, which have a retention of about eight hours, are used alternately to facilitate solids removal.

The settling pond effluent overflows into the aerated lagoon, which has a surface area of approximately 23 acres, an operating depth of 13.5 feet, and a retention time of five days at the average waste flow rate of 20 USMGD. Nine, 100 HP Simon-Carves, floating, low speed, mechanical aerators spaced evenly throughout the lagoon provide aeration and mixing. A wooden dike, about 150 feet from the side of the lagoon, creates a quiescent zone before the outlet where any settleable material is removed. The treated effluent then overflows a Cipoletti Weir and flows by gravity to a submerged diffuser in the Kitimat River.

phosphate (11-48-0), are added to the combined effluent before the settling ponds. Both are added directly as aqueous solutions. The ammonium phosphate is metered by a solids feeder into a dissolving tank and the anhydrous ammonia is vaporized and metered, as gaseous ammonia, through a water ejector.

Extensive instrumentation provides for efficient operation of the effluent system. Operation of the spill basin is automatically controlled by the conductivity and pH measurements. The pH and waste flowrate into the settling pond are recorded continuously with visual readout in the central control room. In case of spills, there are high conductivity alarms on many of the in-mill sewers.

Effluent flowrates are recorded in Parshall flumes through the mill. The combined waste flow is measured by a Pitot tube before the settling pond and by a level recorder before the Cipoletti weir at the aeration lagoon outlet.

The in-mill sewers are sampled by flow-proportional, pneumatic samplers on a continuous 24 hour basis. The aerated lagoon influent and effluent are sampled continuously by automatic, bucket type composite samplers.

APPENDIX 2

APPENDIX 2

DESCRIPTION AND EVALUATION OF TESTING PROCEDURES

APPENDIX 2

DESCRIPTION AND EVALUATION OF TESTING PROCEDURES

(1) Biochemical Oxygen Demand (BOD_5)

The BOD_5 analysis procedure followed closely the method outlined in the 12th Edition of Standard Methods.

At each mill an acclimatized seed was cultured continuously in the laboratory by aerating and feeding a waste sample with small daily increments of the mill waste. Each day the seed was settled for about one hour and approximately 4 litres was siphoned off, part of which was used as the seed material.

Dilution water, containing 0.5 percent seed at NWP&P and 1.0 percent seed at ALPULP and EUROCAN, was made daily. Seed correction and dilution water control samples were prepared with each set of analyses. Sufficient dilutions of each sample were incubated so that the recorded result was the average of at least two readings in the required dissolved oxygen depletion range.

Dissolved oxygen (D.O.) measurements were made using a membrane electrode and meter, which was standardized immediately before readings were taken. The D.O. meter was calibrated periodically using the Winkler method.

In Table 2-1 the results of reproducibility testing are summarized for the three mills.

TABLE 2-1 - REPRODUCIBILITY OF BOD_5 TESTS

Sample	NWP&P Mean ppm	NWP&P $\pm \bar{s}$ ppm	EUROCAN Mean ppm	EUROCAN $\pm \bar{s}$ ppm	ALPULP Mean ppm	ALPULP $\pm \bar{s}$ ppm
Lagoon Influent-Total	312	22.9	145	28.1	279	24.6
Lagoon Influent-Filtered	283	19.4	112	16.3	256	22.7
Lagoon Effluent-Total	132	11.4	38	6.8	107	11.8
Lagoon Effluent-Filtered	124	8.9	35	7.1	98	10.9
Glucose-Glutamic Acid Stand.	202	5.8	199	13.4	218	12.3

The mean standard deviation ($\pm \bar{s}$) is an average value of the standard deviations calculated for triplicate and duplicate samples over the period of detailed testing at each mill.

(2) Suspended Solids

At NWP&P, suspended matter concentrations were determined by filtration through an asbestos mat in a Gooch crucible as outlined in the 12th Edition of Standard Methods. A 50 ml sample was used. The standard deviation (s) of the test at NWP&P was $\pm$12.5 ppm at a mean suspended solids concentration of 105 ppm.

Because the Gooch crucible method required a rather long period for filtration and because of the large standard deviation of the results, this method was not used at the other two mills. At ALPULP and EUROCAN glass fiber filters with a sample size of at least 200 ml were employed. A comparison between the Gooch method and the glass fiber filters showed similar results. The standard deviation (s) of the suspended solids test at ALPULP and EUROCAN was $\pm$ 7.4 ppm at a mean suspended solids concentration of 104 ppm.

At ALPULP a quantitative filter paper was normally used for routine suspended solids analyses (as recommended by the Technical Section CPPA). A comparison between the glass fiber filters and the quantitative filter papers showed that the glass fiber filter media produced substantially higher results. For the untreated waste the suspended matter concentration averaged 18 percent greater, while for the treated effluent from the five-day aerated lagoon, the concentration of suspended matter averaged 55 percent higher using the glass fiber filters. A summary of these test results is presented in Table 2-2.

(3) Oxygen Uptake Rate

The oxygen uptake rate, a measure of how quickly the dissolved oxygen in a waste sample is depleted, was used to estimate the state of biological activity in the waste. At NWP&P a sample was aerated for thirty minutes, following which the dissolved oxygen concentration was continuously recorded until the depletion was at least three to four ppm. The uptake rate was reported as ppm oxygen depleted per hour.

This procedure was modified at the other two mills to allow a more rapid method of determining the oxygen uptake rate. The waste sample was shaken in a large bottle for about one minute immediately after sampling. The sample, which had a D.O. concentration of 4 to 5 ppm, was then transferred to a standard BOD bottle and the dissolved oxygen concentration was recorded over a sufficient length of time to allow a D.O. depletion of at least 2 ppm, usually about 15 to 20 minutes. During the

TABLE 2-2 SUSPENDED SOLIDS DETERMINATION USING TWO FILTER MEDIA

Aeration Lagoon Influent			Aeration Lagoon Effluent		
934-AH* (ppm)	No. 40** (ppm)	Difference (%)	934-AH* (ppm)	No. 40** (ppm)	Difference (%)
65	53	20.4	32	8	120.0
80	63	23.8	20	2	163.7
89	62	35.8	15	10	40.0
64	52	20.7	21	13	47.0
68	64	6.3	22	9	83.8
68	50	30.5	27	25	7.7
86	75	13.7	21	10	71.0
54	35	42.2	37	20	59.6
91	72	23.4	48	31	43.0
77	59	26.5	55	34	48.3
77	63	20.0	185	144	25.0
86	55	43.9	65	48	30.1
100	96	4.1	64	44	37.0
95	83	13.5	66	50	27.6
138	120	14.0	64	37	53.5
172	168	2.4	71	45	44.8
190	184	3.2	78	34	78.6
60	43	33.0	88	63	33.1
226	204	10.2	86	58	38.9
117	117	0			
110	96	13.6			
99	92	8.7			
139	110	23.3			
128	102	22.6			
109	88	21.3			
178	171	4.0			
102	100	2.0			
106	92	17.9%	56	36	55.4%

* Reeve Angel glass fiber filter No. 934-AH

** Whatman No. 40 filter paper

test, the samples were placed in a temperature controlled bath maintained at the waste temperature at the time of sampling. Approximately 5 minutes elapsed between the actual sampling time and the time of sealing the BOD bottle at the start of the test.

(4) Alpha Value

The alpha value determinations were conducted in the laboratory according to the procedure recommended by Eckenfelder and Ford (1970). A sample of waste was placed in a four gallon container equipped with a constant speed agitator. The liquid was deoxygenated either by purging the system with nitrogen or by chemical oxidation using sodium sulfite. The rate of re-aeration of the sample was then measured by a D.O. probe while the sample was aerated either by a diffused air bubbler or by a surface agitator. Samples of normal tap water were run after each waste sample.

The reproducibility of the alpha value test was extremely poor, thus only a minimum of testing was performed to establish a relative comparison between the three mill wastes.

(5) First Order BOD_5 Removal Rate

The BOD_5 removal rate was determined from batch tests in the laboratory under simulated prototype conditions. A four gallon sample of mill effluent was inoculated with acclimatized seed and appropriate quantities of nutrients. It was then aerated by means of a sintered glass diffuser for 5 days. Frequent samples were taken for BOD_5 analysis.

The seed material was obtained by taking a sample of aerated lagoon contents and allowing it to settle in a container for one hour. Following this the supernatant was decanted and 1000 ml of the remaining "sludge" was used as the seed inoculum.

The temperature dependence of the reaction rate could be determined by placing the batch reactor in a water bath pre-set at any desired temperature.

(6) Velocity Measurements with Decca Current Meter

The velocity magnitudes are determined by a freely rotating impeller equipped with a magnetic counter, on the impeller shaft. It is capable of an accuracy of ± 5 percent over a range of 0.0656 to 3.0 feet/second. To determine the direction of flow, the current meter was allowed to rotate freely until a large vertical vane attached to the back of the meter, aligned itself with the direction of flow. The direction of flow was recorded with respect to the radial line from the sample point to the aerator shaft.

The sensor of the current meter was attached to a long handle and lowered from the stern of a rowboat to a specific depth. The boat was secured to one of the three aerator anchor cables at distances measured from the aerator shaft which were marked on the cable. Velocity magnitudes and directions were recorded from 2 inches below the surface, at 1 foot depth intervals, to the lagoon bottom. During some of the testing, dissolved oxygen concentrations at various depths were measured. Amperages drawn by the aerators were recorded and the actual drawn horsepower of the aerators determined.

APPENDIX 3

APPENDIX 3

LAGOON SAMPLING TECHNIQUES

APPENDIX 3

LAGOON SAMPLING TECHNIQUES

At NWP&P, lagoon sampling was performed using a remotely controlled raft. The raft was floated to the desired location and the sample bucket, a standard D.O. and BOD sampler as described in the 12th Edition of Standard Methods, was lowered to a predetermined depth. After sampling the bucket was raised and the raft pulled to shore. Dissolved oxygen and temperature readings were recorded immediately and the remaining sample was transferred to a polyethylene container.

One of the cross-sectional profiles at NWP&P was taken using a permanent, steel cable clothesline across the lagoon. A two-litre D.O. and BOD sampler was transported on the clothesline, lowered to collect the sample and retrieved along the clothesline.

At ALPULP, the cross-sectional profiles were taken using a clothesline sampler similar to the one at NWP&P. The longitudinal profiles were taken from a rowboat. D.O. and temperature readings were recorded in situ and the oxygen uptake rate determinations were performed at the lagoon immediately after sampling. Lagoon sampling at EUROCAN was performed using a boat in the same manner as at ALPULP.

TABLE 4-1

TRACER INPUT AND OUTPUT LOCATIONS

PROJECT	TRACER INPUT LOCATION	TRACER OUTPUT LOCATION
NWP&P	At open Manhole just before pond inlet	At end of aeration zone as flow proceeds into the quiescent settling zone.
ALPULP	In primary clarifier overflow.	Beside primary clarifier where 36" dia. pipe discharges to an open ditch and flows to Somass River.
EUROCAN	Tracer poured into overflow weir separating settling pond and lagoon.	Immediately ahead of Cipoletti weirs in effluent overflow structure.

APPENDIX 4

APPENDIX 4

TRACER MONITORING TECHNIQUES

APPENDIX 4

TRACER MONITORING TECHNIQUES

Following a comparative evaluation of several alternatives, rhodamine-WT was selected as the inert tracer. Its conservative properties were verified in batch laboratory tests by aerating an aliquot of the lagoon contents containing approximately 50 ppb tracer. The test was performed in an open container exposed to sunlight over a period of 4 to 6 weeks. No significant degradation of the tracer was detected.

For each experimental run, about 100 to 140 lbs. (3 to 4 containers) of 20% rhodamine-WT solution (Dupont) was used. This was adequate to yield a peak effluent concentration of approximately 50 ppb, well above the background fluorescent level. The location of the tracer input injection and output monitoring points for each treatment system is listed in Table 4-1.

The monitoring equipment, common to all tracer runs, consisted of a G.K. Turner Model 111 fluorometer fitted with a continuous-flow sampling door. A telethermometer was used to monitor the effluent stream temperature. The fluorescence and temperature levels were continuously recorded on a dual channel strip-chart recorder. An effluent sampling pump, connected to the discharge side of the fluorometer sampling door, maintained a continuous sampling flow of approximately 10 gpm.

Calibration of the fluorometer was performed using effluent samples containing a known tracer concentration. Fluorescence is temperature dependent, and therefore the calibrations were made over a temperature range varying from 20 to 35°C. In addition, periodic spot calibrations were performed throughout an experimental run to check for instrument drift.

TABLE 4-1

TRACER INPUT AND OUTPUT LOCATIONS

PROJECT	TRACER INPUT LOCATION	TRACER OUTPUT LOCATION
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ALPULP	In primary clarifier overflow.	Beside primary clarifier where 36" dia. pipe discharges to an open ditch and flows to Somass River.
EUROCAN	Tracer poured into overflow weir separating settling pond and lagoon.	Immediately ahead of Cipoletti weirs in effluent overflow structure.

APPENDIX 5

APPENDIX 5

MATHEMATICAL MODELLING

APPENDIX 5

MATHEMATICAL MODELLING

TABLE 5-1 THE IDEAL PLUG FLOW AND IDEAL COMPLETELY MIXED MODELS

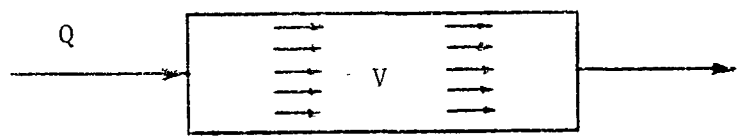
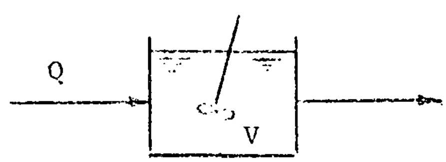
THE PLUG FLOW MODEL	 residence time = τ = V/Q
RESIDENCE TIME DISTRIBUTION	$E(t) =$ $E(t) = \delta(t-\tau)$ where δ signifies the Dirac-Delta function or unit impulse function.
TRANSFER FUNCTION	$G(s) = \exp(-\tau s)$
THE COMPLETELY MIXED MODEL	 residence time = $\tau = V/Q$
RESIDENCE TIME DISTRIBUTION	$E(t) = \frac{1}{\tau} \exp(-\frac{t}{\tau})$
TRANSFER FUNCTION	$G(s) = \frac{1}{1 + \tau s}$

TABLE 5-2 THE AXIAL DISPERSION MODEL (CLOSED/CLOSED BOUNDARY CONDITIONS)

THE MODEL	 L = length of vessel u = avg. fluid velocity in vessel D = axial dispersion coefficient Pe= Peclet number = uL/D
RESIDENCE TIME DISTRIBUTION	$E(t) = \frac{Pe}{4} \exp\left[\frac{Pe}{4}(2 - t)\right] \sum_{k=1}^{\infty} \left\{ \left[\frac{\lambda_k \sin(2\ _k)}{\lambda_k^2 + \frac{Pe}{4}^2 + \frac{Pe}{4}} \right] \exp\left[\frac{-4 \lambda_k^2 t}{Pe}\right] \right\}$ $+ \exp\left[\frac{Pe}{4}(2-t)\right] \sum_{k=1}^{\infty} \left\{ \frac{4 \lambda_k^2}{Pe} \left[\frac{\lambda_k \sin(2\lambda_k)}{\lambda_k^2 + \frac{Pe}{4}^2 + \frac{Pe}{4}} \right] \exp\left[\frac{-4 \lambda_k^2 t}{Pe}\right] \right\}$ where λ_k are the positive non-trivial roots of the transcedental equation : $\tan(2\lambda) = \frac{\lambda Pe}{2(\lambda^2 - \frac{Pe}{4})}$ These may be obtained by defining $\beta_n = \lambda_{2n-1}$ and $\gamma_n = \lambda_{2n}$ where the β_n and γ_n are the positive roots of the transcedental equations: $\tan \beta = \frac{Pe}{4\beta}$ and $\cot \gamma = -\frac{Pe}{4\lambda}$

TABLE 5-3 THE EQUAL TANKS -IN- SERIES MODEL

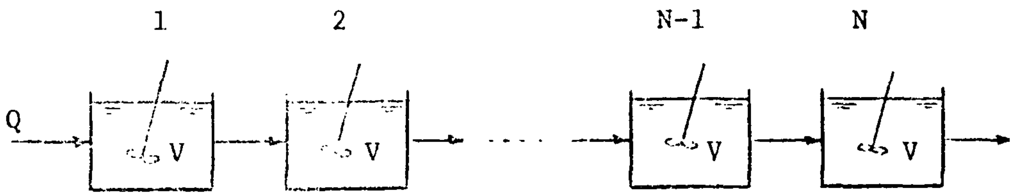
THE MODEL	 Q = flowrate V_T = total volume = N V individual vessel residence time = τ = V/Q overall mean residence time $= \tau_T = N\tau$
RESIDENCE TIME DISTRIBUTION	$E(t) = \dfrac{N^N \left[\dfrac{t}{\tau_T}\right]^{N-1}}{(N-1)!} \exp\left[\dfrac{-N t}{\tau_T}\right]$
TRANSFER FUNCTION	$G(s) = \left[\dfrac{1}{1 + \tau s}\right]^N$

TABLE 5-4 THE UNEQUAL TANKS - IN - SERIES MODEL

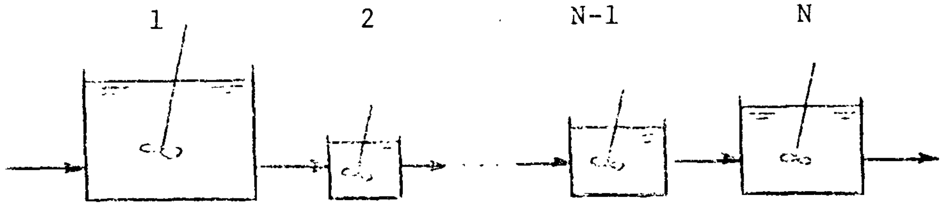
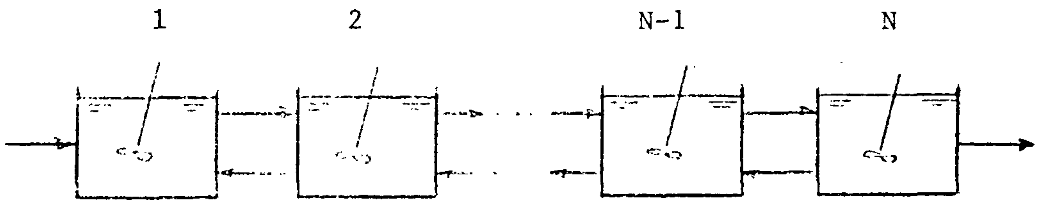
THE MODEL	 Q = flowrate V_i = volume of i'th vessel V_T= total volume = $\sum_{i=1}^{N} V_i$ τ_t = overall mean residence time = V_T/Q τ_i = residence time of i'th vessel = V_i/Q
TRANSFER FUNCTION	$G(S) = \prod_{i=1}^{N} \left[\frac{1}{1 + \tau_i s} \right]$
RESIDENCE TIME DISTRIBUTION	This may be obtained by Inverse Laplace Transformation of the Model transfer function. Its functional form will be dependent upon the value of N and whether or not two or more of the hypothetical vessels in the model have equal residence times.

TABLE 5-5 THE BACKFLOW CELL MODEL

THE MODEL	 Q = net forward flowrate q = backflowrate τ = individual vessel residence time = V/Q τ_T = total residence time = $N\tau$ Define $\alpha = \sqrt{1 + \frac{Q}{q}}$
RESIDENCE TIME DISTRIBUTION	$E(t) = \frac{1}{\tau} \frac{2\alpha^{N+1}}{(\alpha^2-1)} \sum_{i=1}^{N} \left[(-1)^{i+1} \frac{\sin^2\psi_i}{(1-N\tau s_i)} \exp(s_i t) \right]$ where Ψ_i are the roots of the transcedental equation: $\psi_i (N+1) + 2 \tan^{-1} \left[\frac{\sin\psi_i}{\alpha - \cos\psi_i} \right] = i\pi$ and $s_i = -\frac{1}{\tau} \left[1 + \frac{2(1-\alpha\cos\psi_i)}{\alpha^2 - 1} \right]$
TRANSFER FUNCTION	$G(s) = (\alpha^2-1)\alpha^N \sum_{i=1}^{N} \left[\frac{A_i}{s - s_i} \right]$ where $A_i = \frac{2\alpha}{(\alpha^2-1)^2} (-1)^{i+1} \frac{\sin^2\psi_i}{(1 - N\tau s_i)}$

RESIDENCE TIME DISTRIBUTION DATA ANALYSIS AND RESULTS

For each tracer run, concentration and temperature data were recorded continuously for about 10 days (250hrs.) thereby covering 2 to 2.5 pond residence times. Generally, this was adequate to recover better than 80% of the tracer added to the input stream. For purposes of data analysis, the remainder of the residence time distribution was obtained by plotting the available tail portion (≥150 hrs.) on semilogarithmic paper and linearily extrapolating to essentially zero tracer concentration. This occurred at approximately 500 hours.

The residence time distribution data was transcribed to computer cards for hourly intervals up to about 150 hrs. and then for 10 hourly intervals on the tail portion of the curve. Each complete curve was then numerically Fourier transformed from the time into the frequency domain and the transformed data was re-plotted to determine the complexity of the system. The mixing models were fitted in the frequency domain by a non-linear least squares parameter estimation routine using the rigorous statistical criterion recommended by Clements (1969). The procedures used for transforming the data and fitting the models have been described in detail by Wilson (1971).

Having fitted each mixing model to each transformed residence time distribution, the best model for a given run was selected as that one having the least residual sum of squares of the deviations between the experimentally observed and the predicted model responses. A numerical search routine (Rosenbrock (1960)) was used to minimize this statistic.

The dimensionless output reactant concentration for the unequal CSTR's -in-series model undergoing a first order reaction is :

$$\frac{BOD_5/out}{BOD_5/in} = \prod_{i=1}^{n} \left[\frac{1}{1 + k\tau_i} \right] \qquad (5\text{-}1)$$

where k is the first order rate constant (base e $hours^{-1}$) and τ_i is the residence time of the i'^{th} vessel in series (hours).

The dimensionless reactant concentration profile along a vessel as defined by the axial dispersion model is given by WEHNER and WILHELM (1956)as:

$$\frac{BOD_5}{BOD_5/in} = \frac{2 \exp\left(\frac{uL}{D}\frac{z}{2}\right) \left\{ (1+A) \exp\left[\frac{A}{2} \frac{uL}{D} (1-z) \right] - (1-A) \exp\left[\frac{A}{2} \frac{uL}{D} (z-1) \right] \right\}}{(1+A)^2 \exp\left(\frac{A}{2}\frac{uL}{D}\right) - (1-A)^2 \exp\left(-\frac{A}{2}\frac{uL}{D}\right)} \qquad (5\text{-}2)$$

(5-2)

where $A = \sqrt{1 + 4k\,\tau(D/uL)}$

D/uL = dimensionless dispersion number

D = axial dispersion coefficient (ft^2/hour)

u = mean axial velocity (ft /hour)

L = axial length (ft)

and z = dimensionless axial distance = x/L

APPENDIX 6

APPENDIX 6

OPERATING VARIABLE PROBABILITY PLOTS

FIGURE 6-1 - PROBABILITY OF INFLUENT AND EFFLUENT BOD_5 - NWP&P

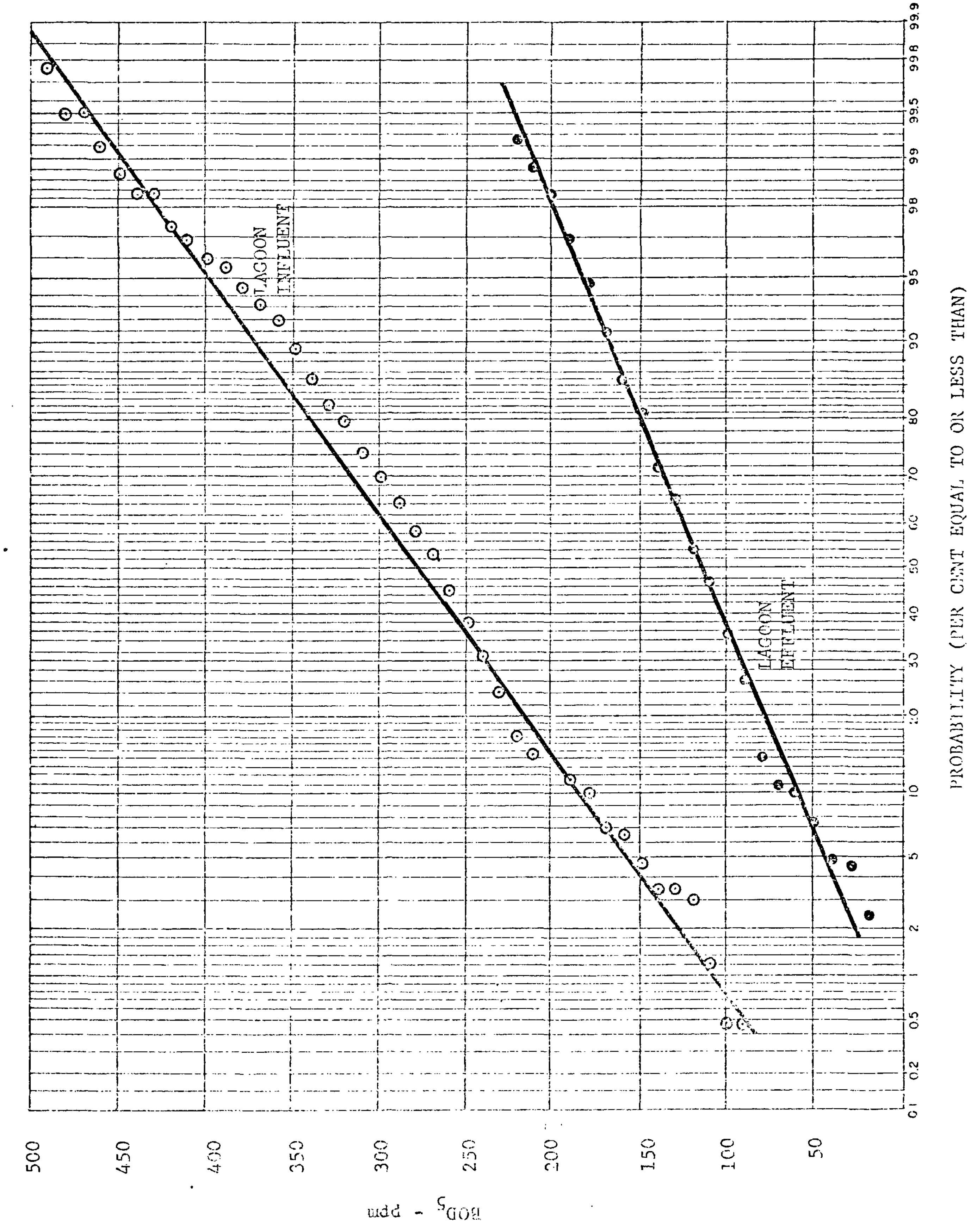


FIGURE 6-2 - PROBABILITY OF INFLUENT AND EFFLUENT BOD_5 - ALPULP

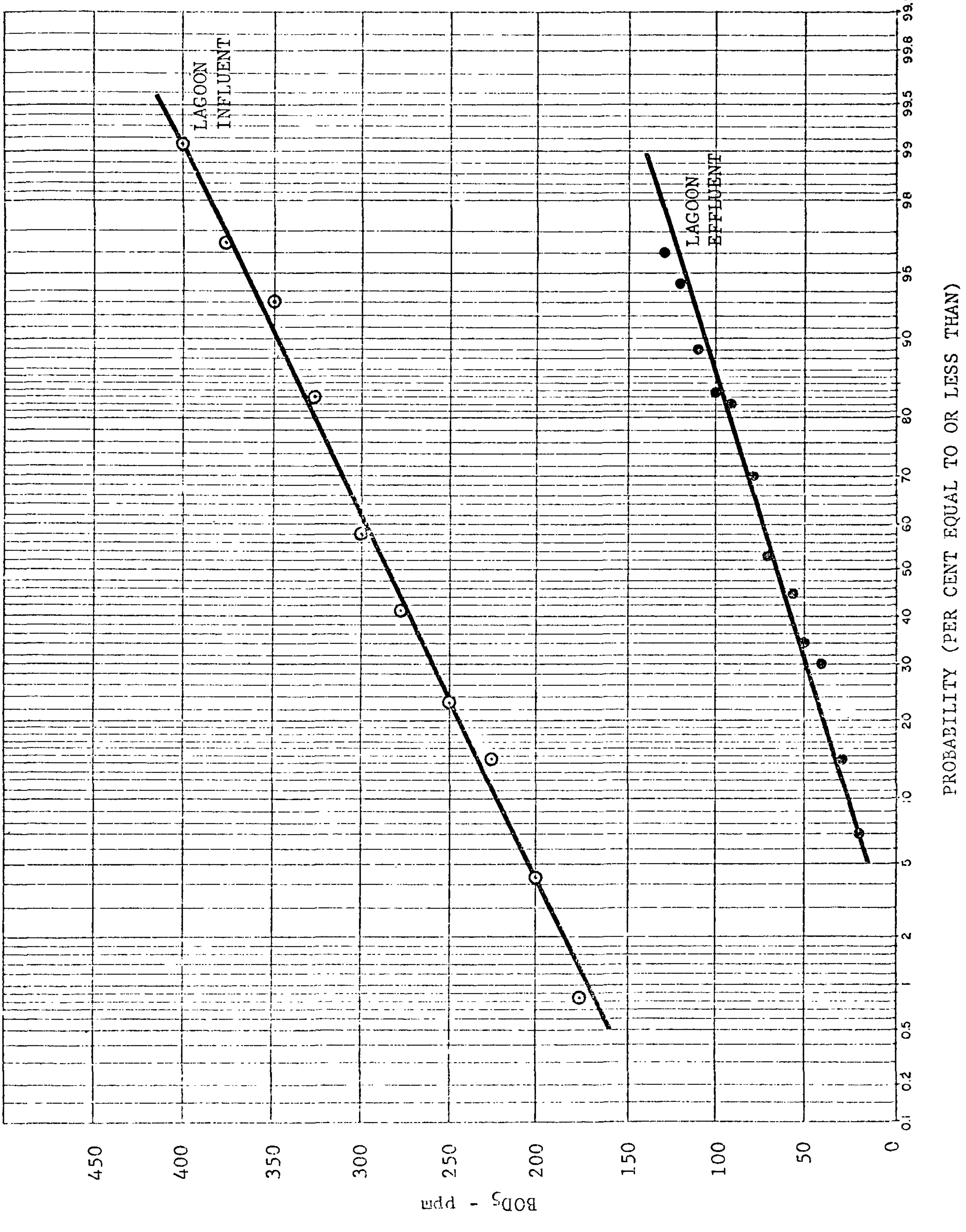


FIGURE 6-3 - PROBABILITY OF INFLUENT AND EFFLUENT BOD$_5$ - EUROCAN

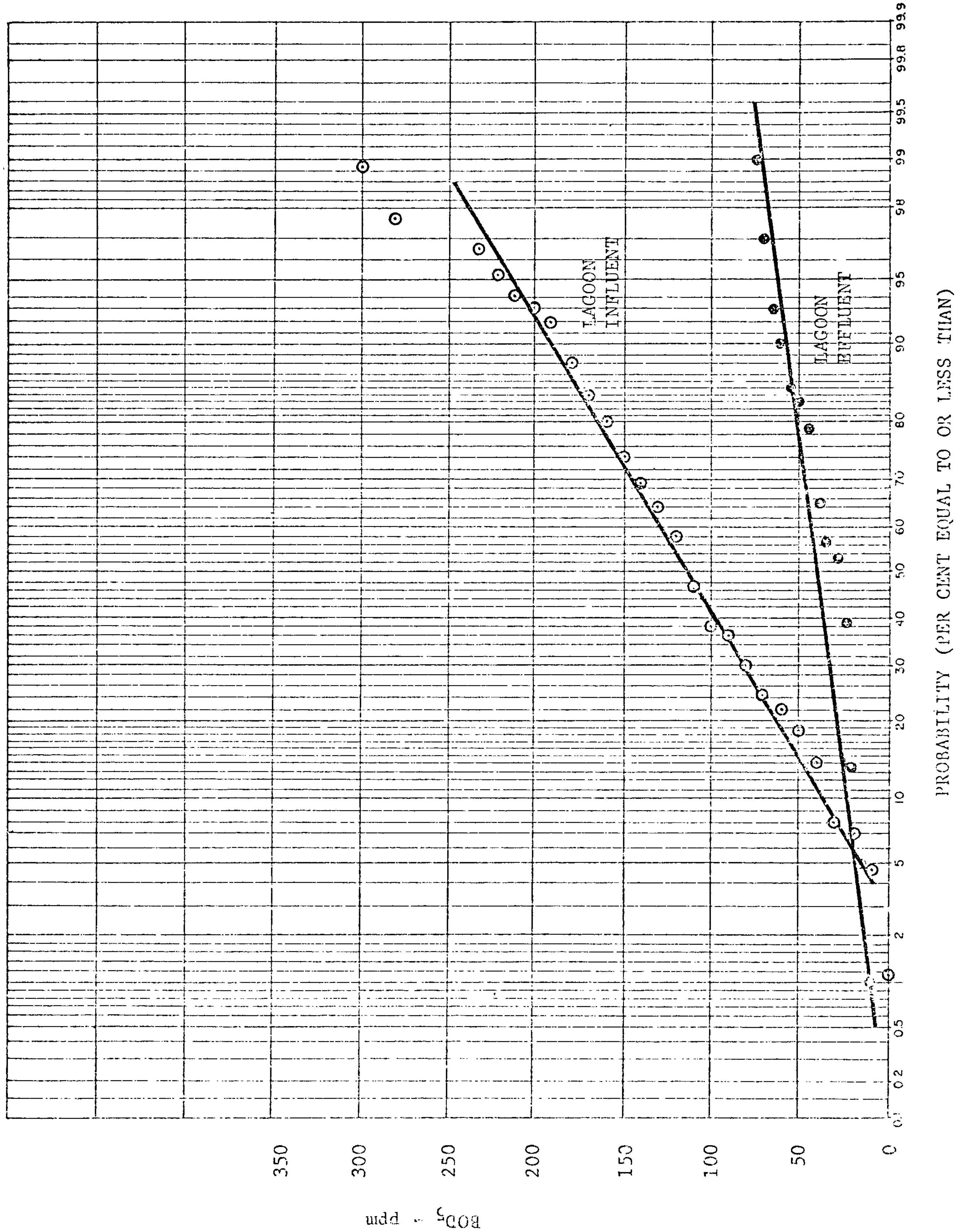


FIGURE 6-4 - PROBABILITY OF INFLUENT AND EFFLUENT SUSPENDED SOLIDS - NWP&P

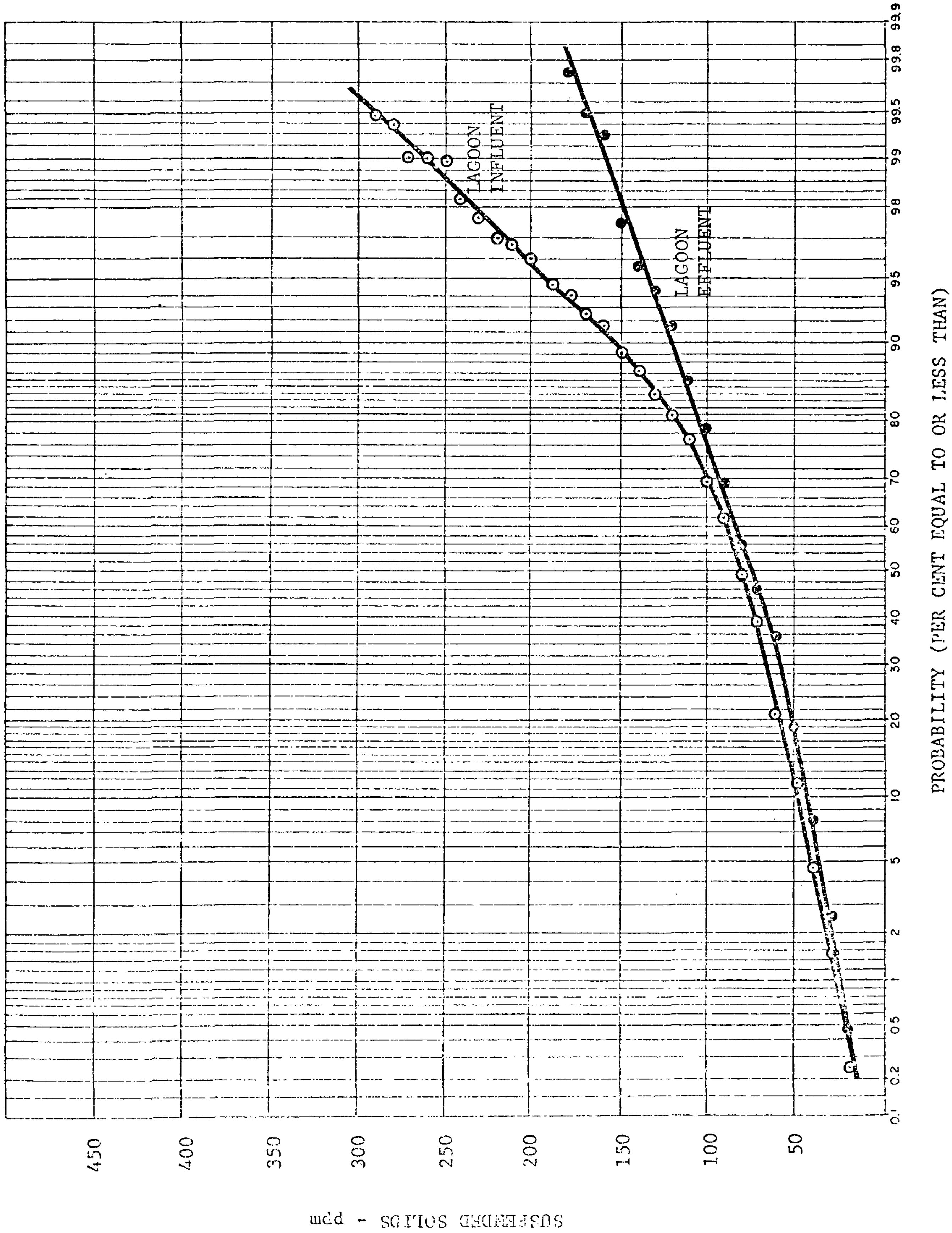


FIGURE 6-5 - PROBABILITY OF INFLUENT AND EFFLUENT SUSPENDED SOLIDS - ALPULP

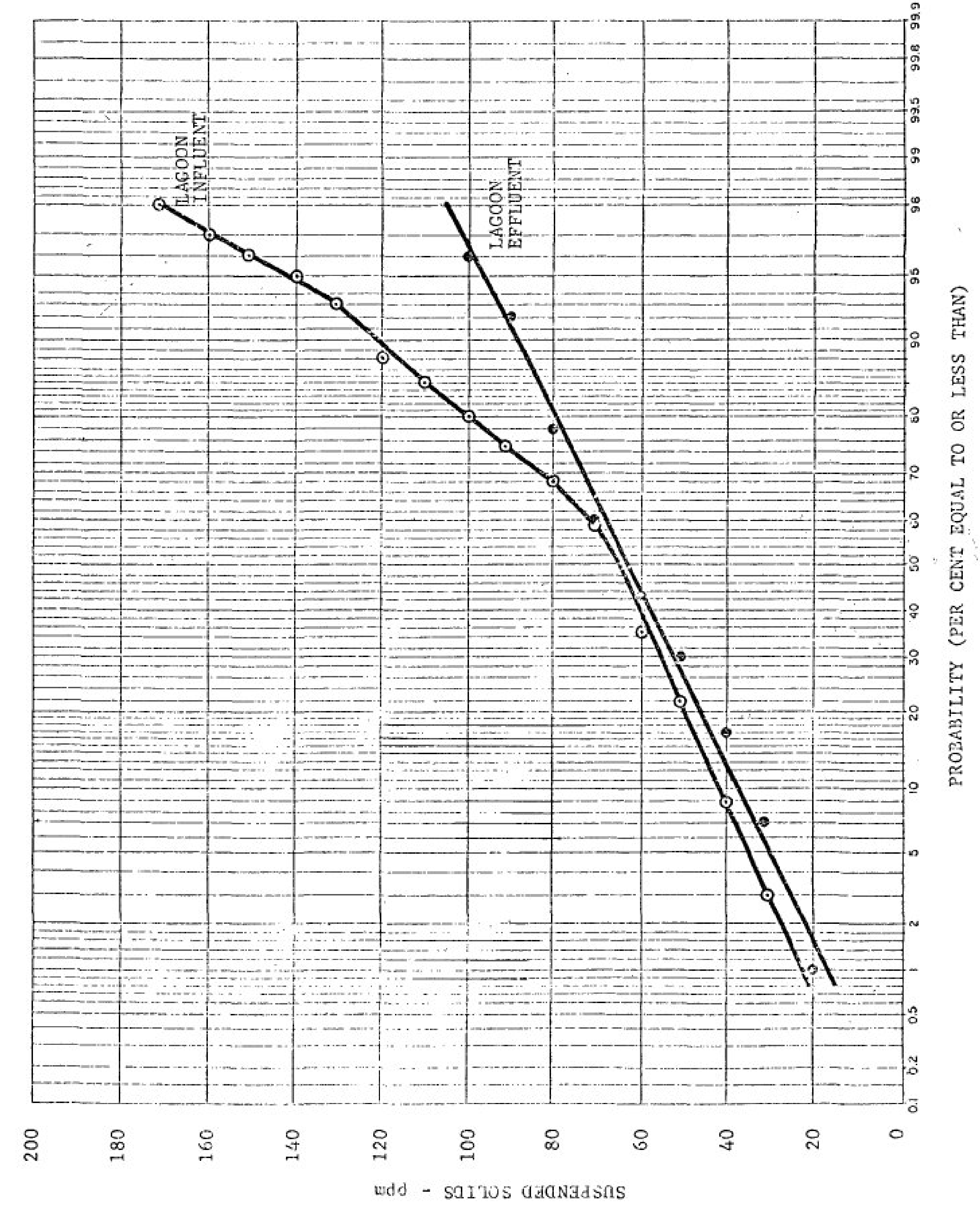


FIGURE 6-6 - PROBABILITY OF INFLUENT AND EFFLUENT SUSPENDED SOLIDS - EUROCAN

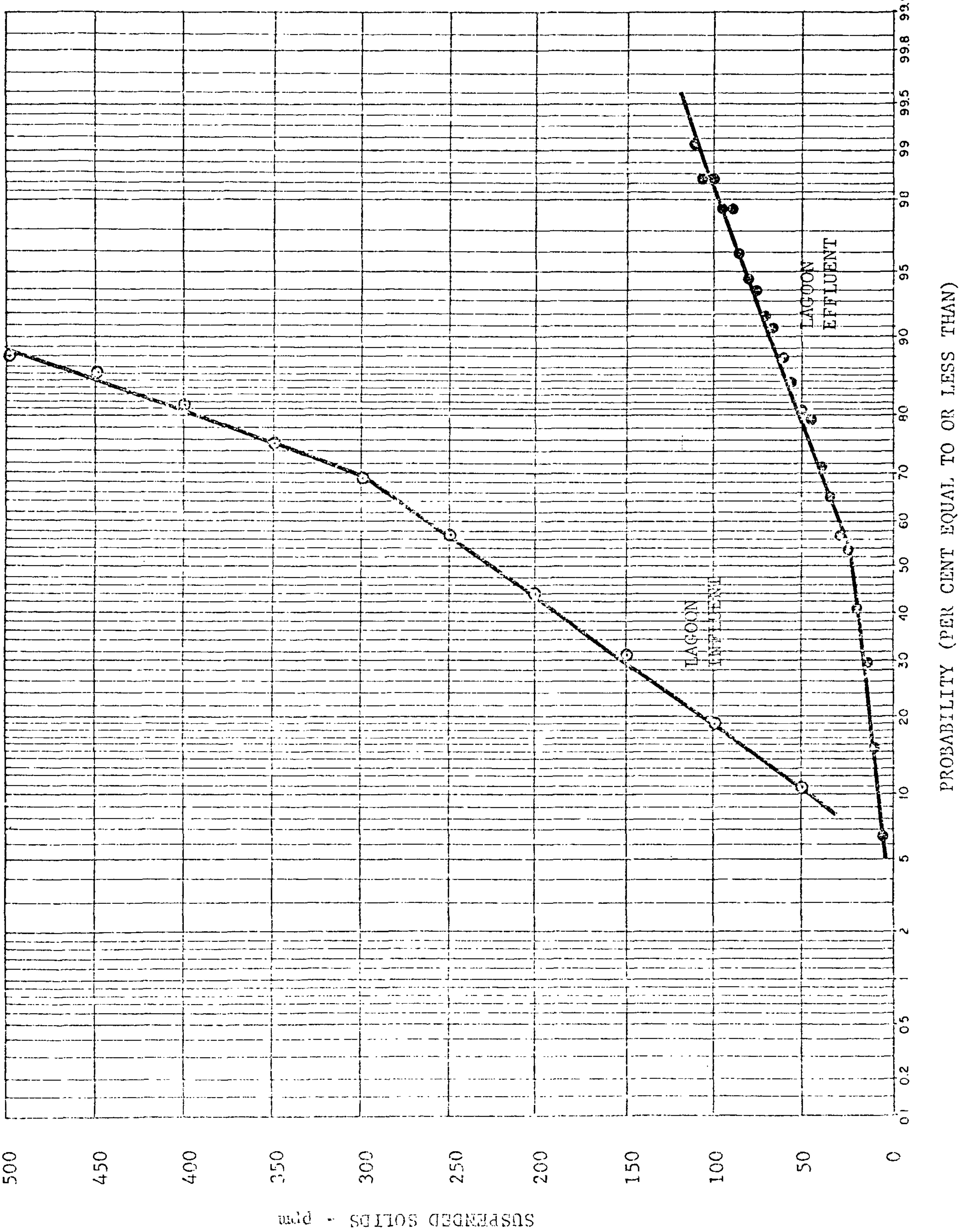


FIGURE 6-7 - PROBABILITY OF INFLUENT AND EFFLUENT TEMPERATURE - NWP&P

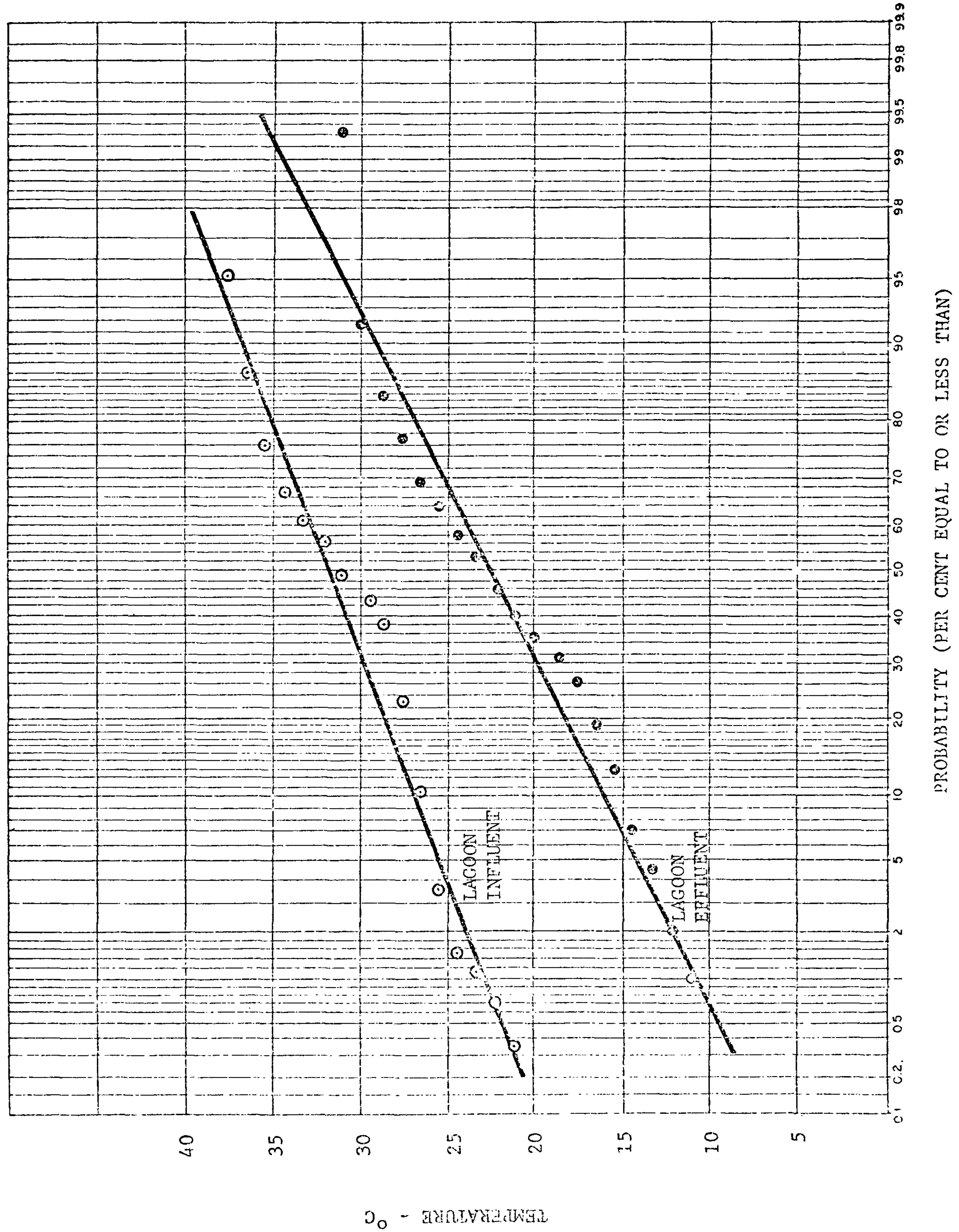


FIGURE 6-8 - PROBABILITY OF INFLUENT AND EFFLUENT TEMPERATURE - ALPULP

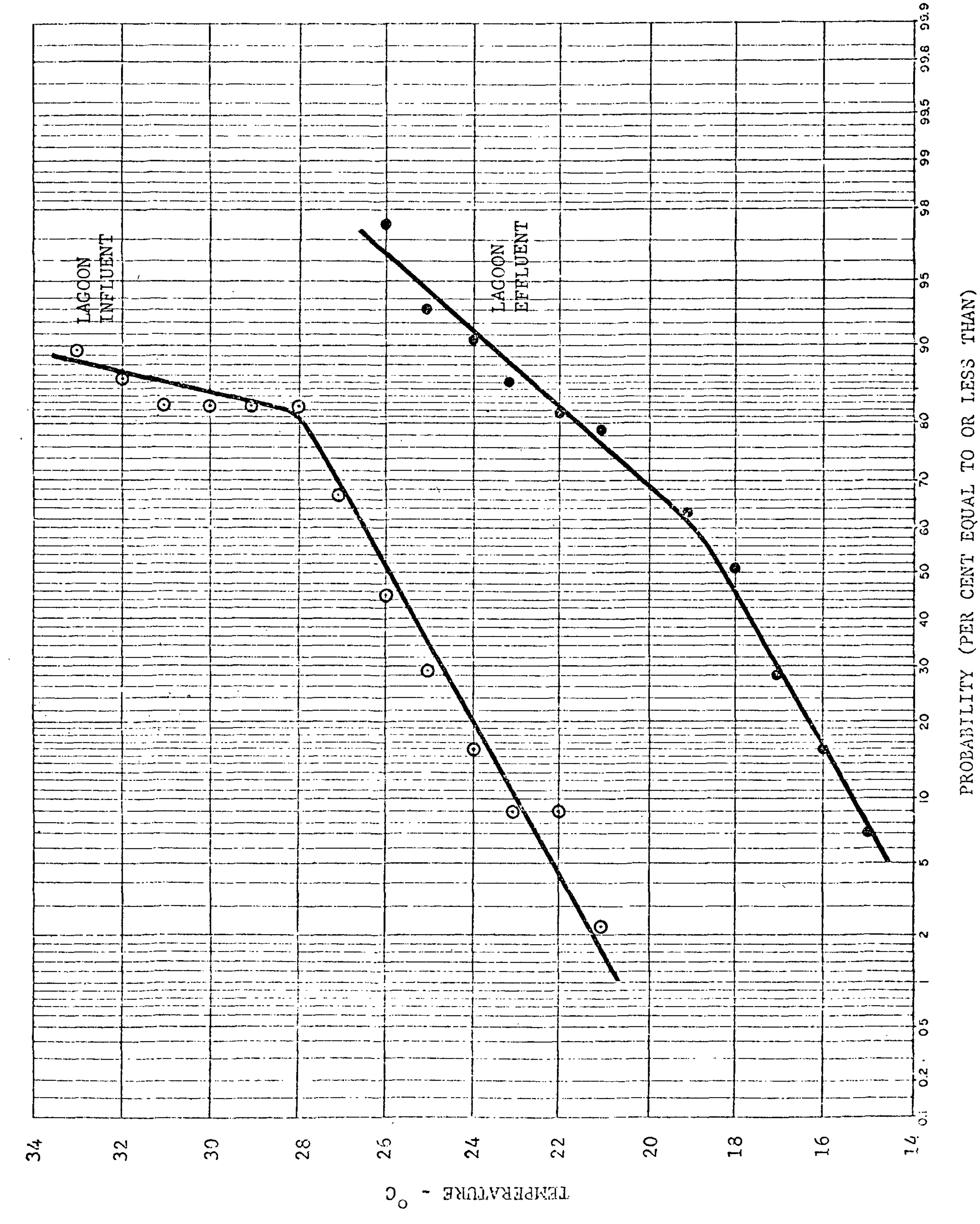


FIGURE 6-9 - PROBABILITY OF INFLUENT AND EFFLUENT TEMPERATURE - EUROCAN

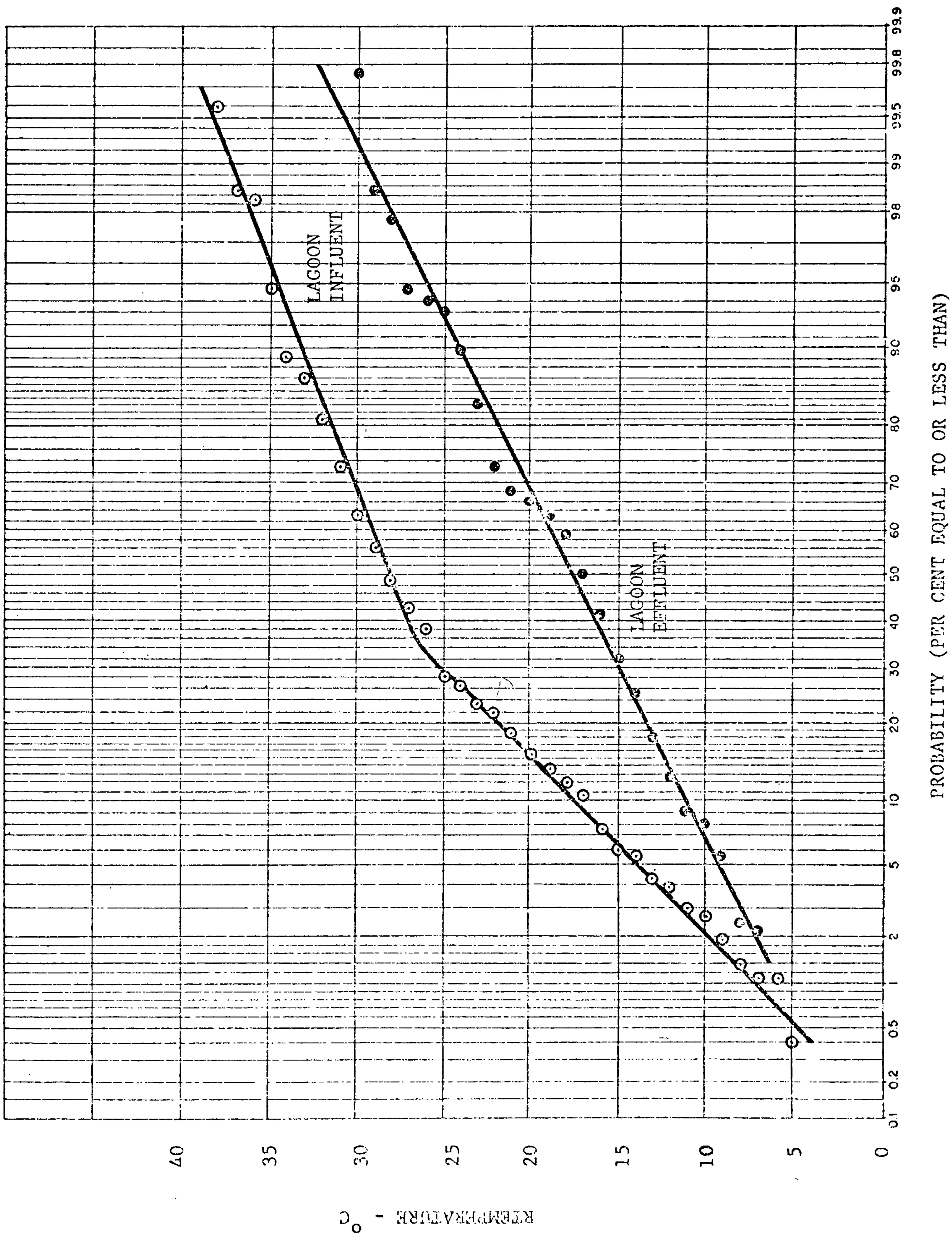


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FIGURE 6-10 - PROBABILITY OF INFLUENT AND EFFLUENT pH - NWP&P

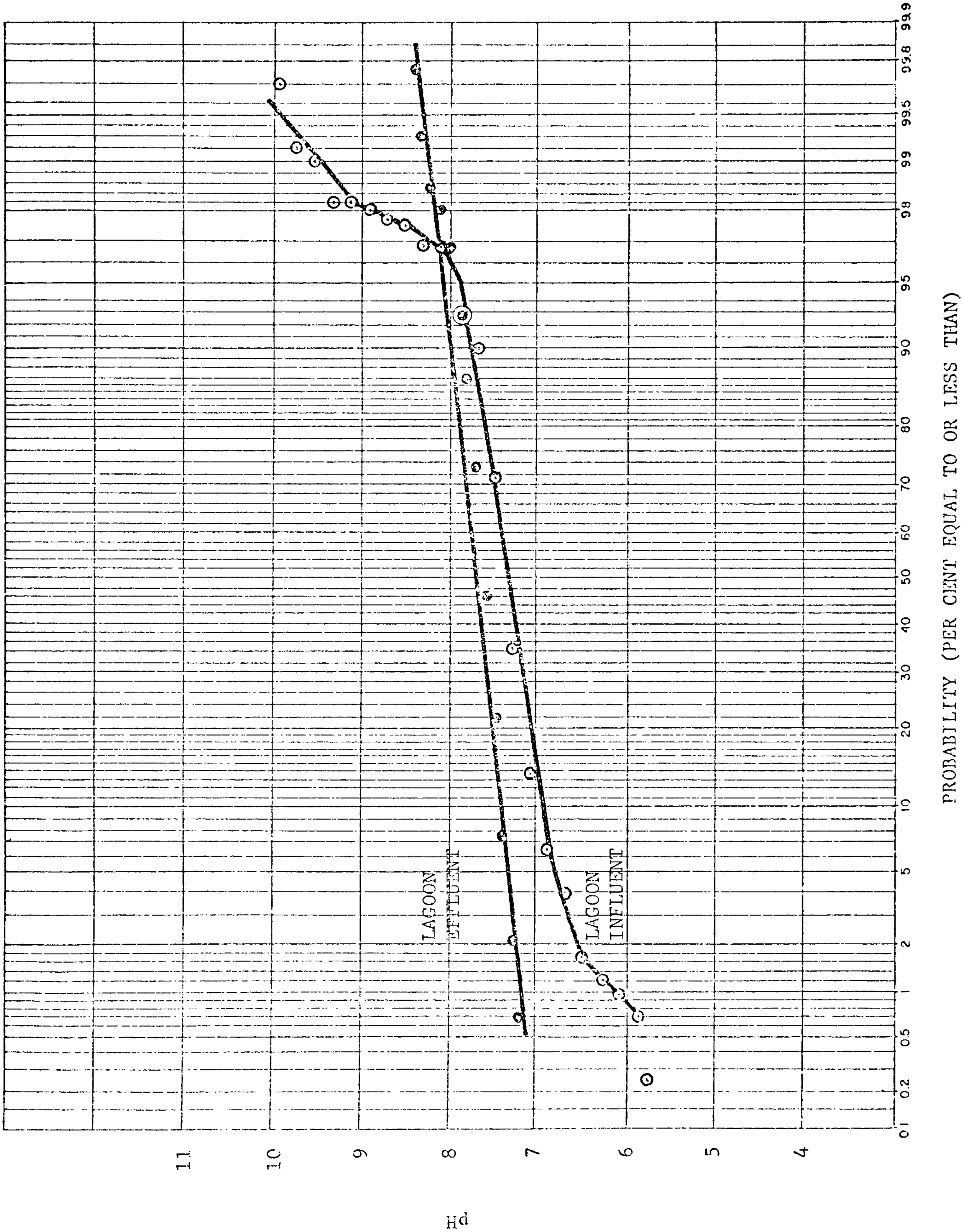


FIGURE 6-11 - PROBABILITY OF INFLUENT AND EFFLUENT pH - ALPULP

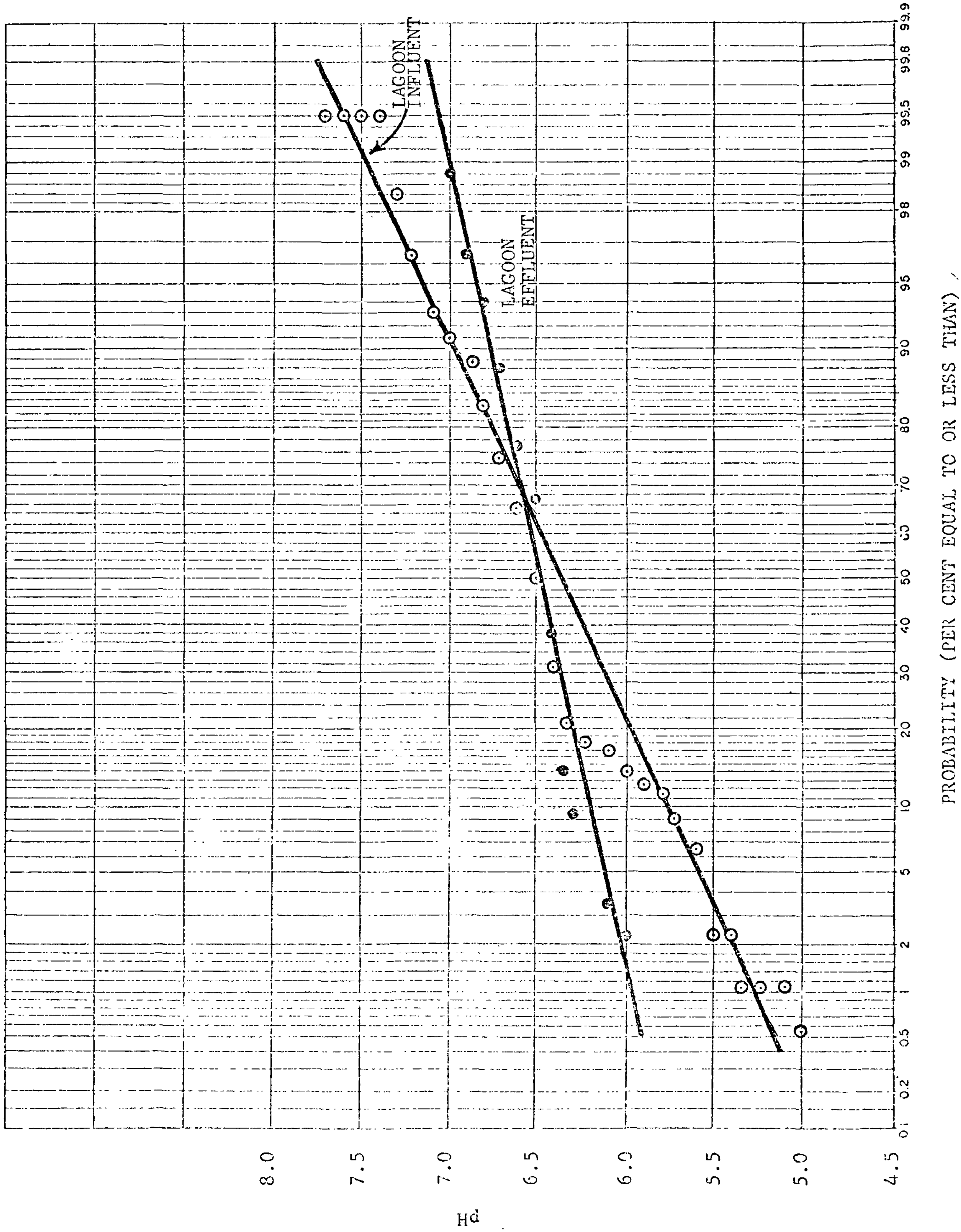


FIGURE 6-12 - PROBABILITY OF INFLUENT AND EFFLUENT pH - EUROCAN

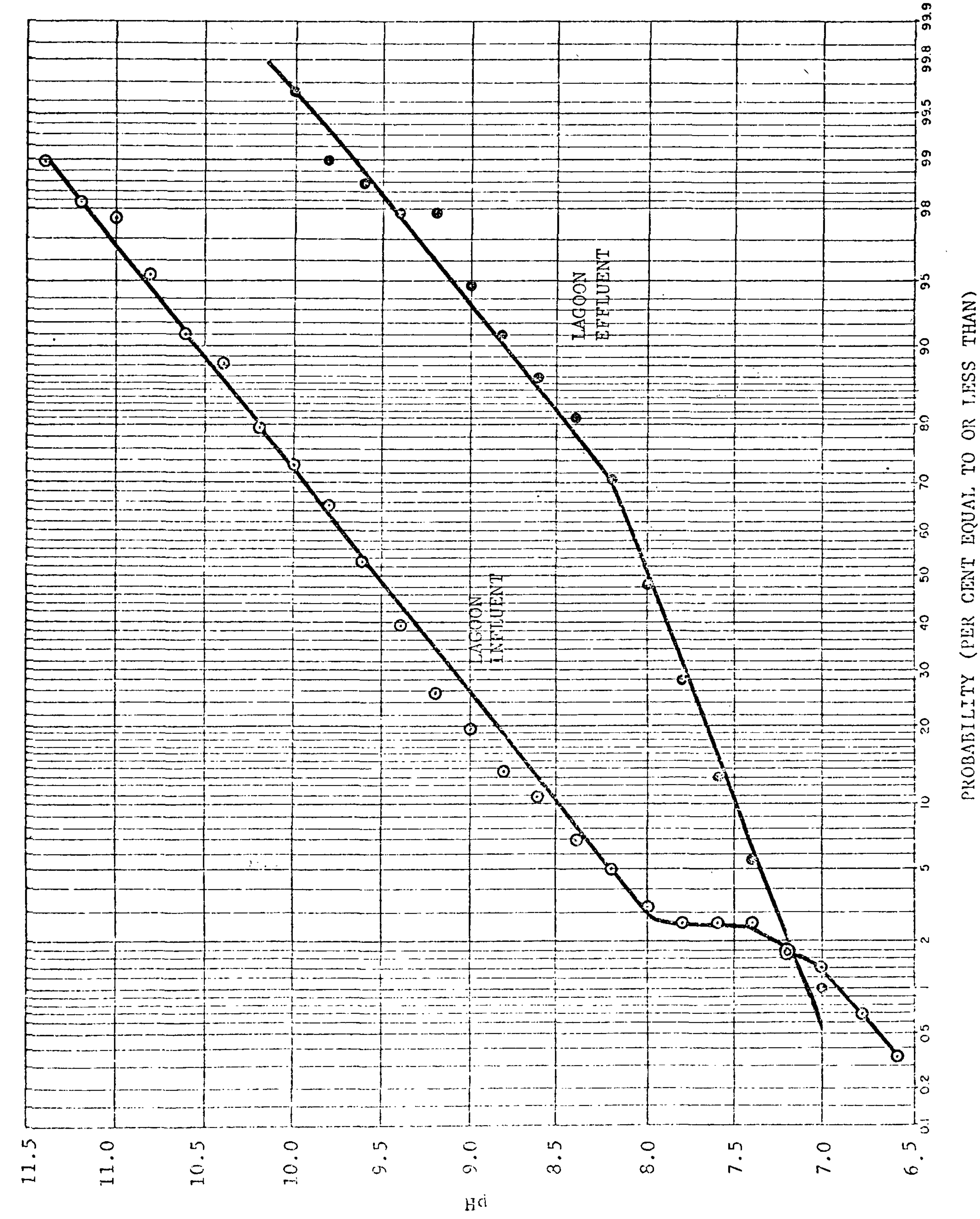


FIGURE 6-13 - PROBABILITY OF INFLUENT FLOWRATE - NWP&P

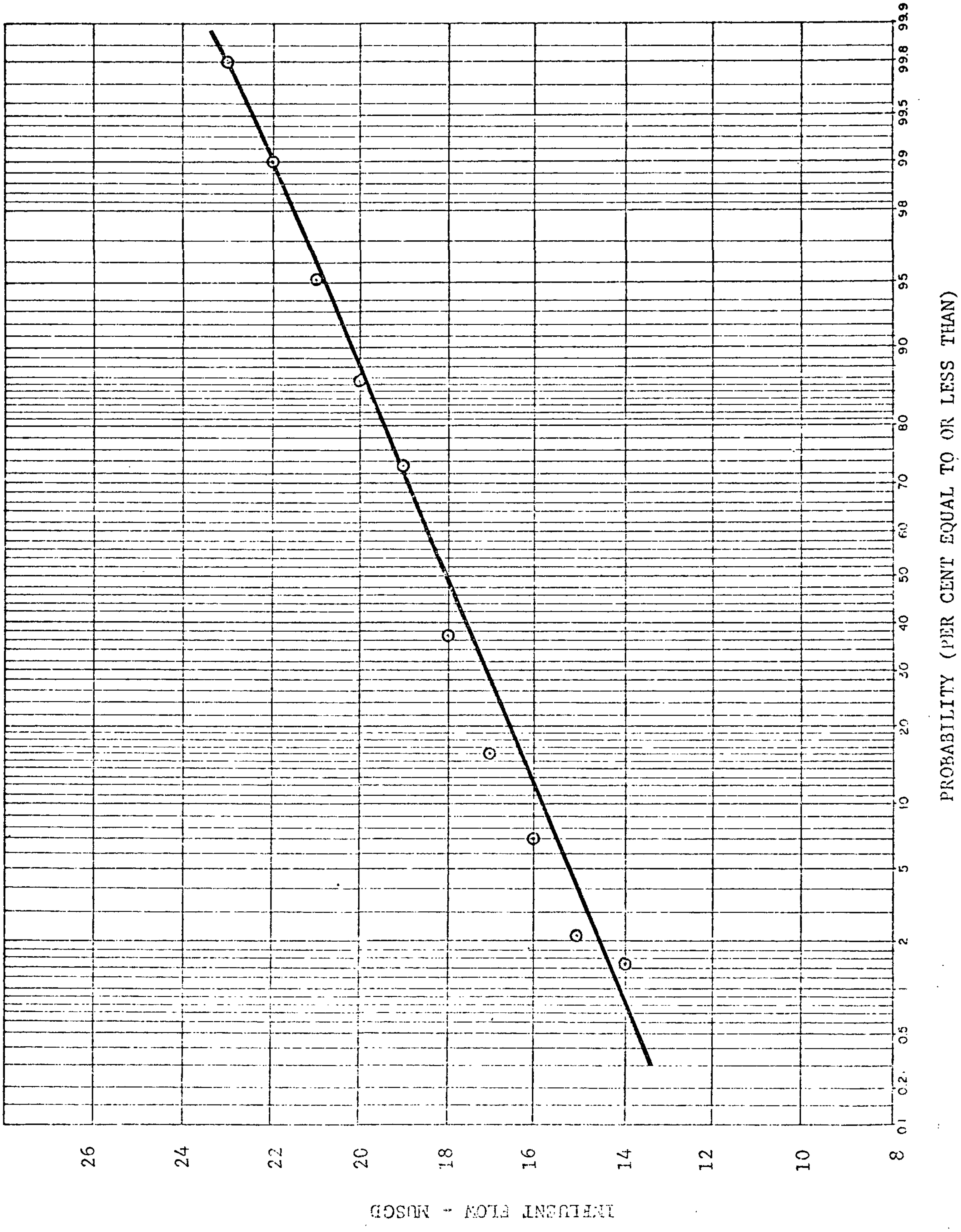


FIGURE 6-14 - PROBABILITY OF INFLUENT FLOWRATE - ALPULP

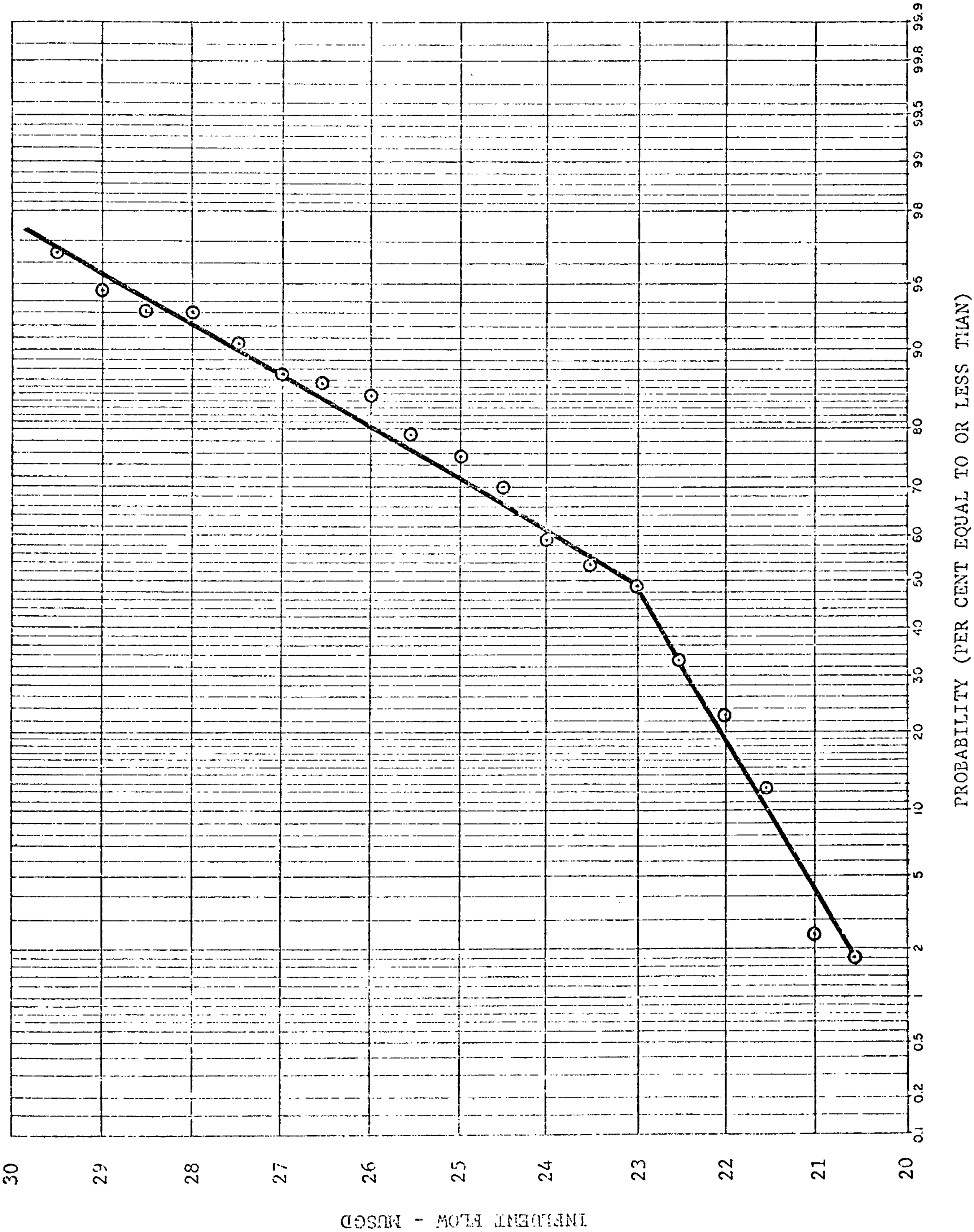
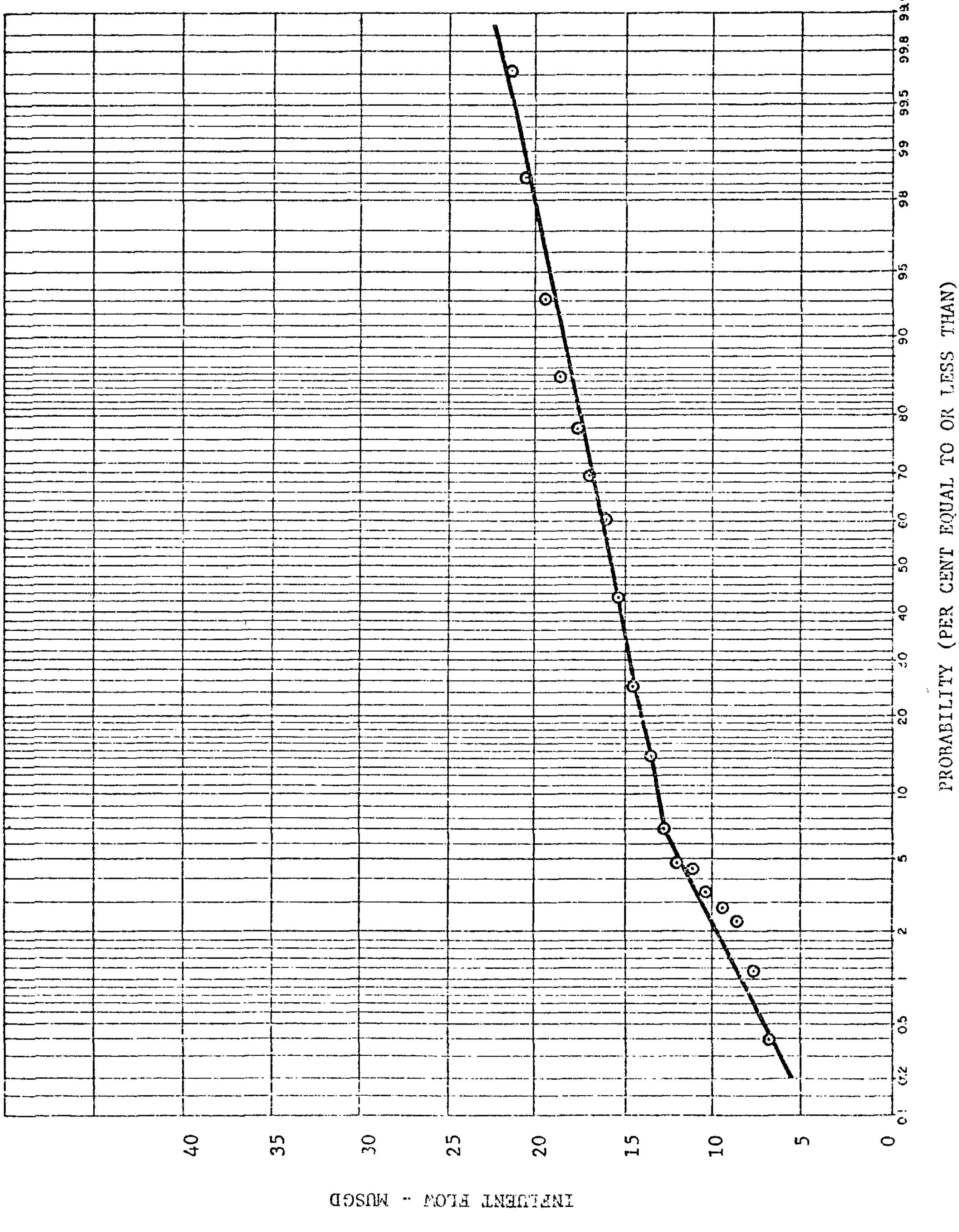


FIGURE 6-15 PROBABILITY OF INFLUENT FLOWRATE - EUROCAN



Toxicity Study

PROJECT K4015
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TOXICITY STUDIES
ADDENDUM TO ORIGINAL REPORT

DATE: 28 MAY 1973

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ADDENDUM TO ORIGINAL REPORT

DATE: 28 MAY 1973

INTRODUCTION

The biological treatment study of three kraft mill aerated lagoons was completed and a report submitted to the Department of the Environment during 1972. This report was published by Environment Canada, Inland Waters Directorate, Water Quality Branch.

After the laboratory investigations and fieldwork for this study were underway, the importance of effluent toxicity in the light of the new Federal Government pulp and paper effluent regulations became apparent. Consequently, the fieldwork was extended and toxicity testing of the effluents of each kraft mill involved in the study was performed. This addendum to the original report presents the results of these toxicity studies.

ABSTRACT

Bioassay tests were conducted on pulp and paper mill effluents from three kraft mills in western Canada. Toxicity was measured, using the 96 hour median tolerance limit (TLm 96) test, on both untreated mill wastewaters and on the effluents after they had received five-day biological treatment in aerated lagoons.

It was not possible to establish definite relationships between the wastewater toxicity and other variables such as BOD_5, COD, dissolved solids, etc. Also, no relationship was found between BOD_5 removal (treatment efficiency) and toxicity reduction in the five-day aerated lagoons. However, a definite and similar relationship was found to exist between toxicity and both the zinc and resin acid soap concentrations in the effluents.

MILL AND TREATMENT SYSTEM DESCRIPTIONS

NORTH WESTERN PULP & POWER LTD. (NWP&P)

The NWP&P mill, situated in Hinton, Alberta, on the Athabasca River, produces approximately 600 TPD of fully bleached kraft pulp utilizing a CEHDED six stage bleaching sequence. The wood furnish at NWP&P is approximately 60 percent spruce and 40 percent pine, hauled to the mill by land.

The waste treatment system, completed in 1967, was designed to treat the total pulp mill and woodroom effluents except the bleach plant acid waste. It consists of primary clarification, nutrient additions, pH adjustment, and biological treatment in a five-day aerated lagoon.

MACMILLAN BLOEDEL LTD., ALBERNI PULP & PAPER DIV. (ALPULP)

The ALPULP mill, situated in Port Alberni, B.C., at the head of Alberni Inlet, is an integrated mill complex producing approximately 900 tons per day (TPD) of kraft pulp and 1000 TPD of groundwood. About 300 TPD of the kraft pulp is bleached utilizing a CEH sequence. The wood furnish at ALPULP is about 80 percent hemlock and balsam, 10 percent fir, and 10 percent cedar. Zinc hypochlorite was used for groundwood brightening.

The waste treatment facilities comprise collector sewers, primary clarification and a five-day retention aerated lagoon. Approximately 50 percent of the total mill waste flow receives treatment. The groundwood mill effluents, the first stage caustic extraction liquor from the bleach plant and the woodroom effluent are treated. This accounts for about 85 percent of the total volatile suspended solids and about 60 percent of the total BOD_5 from the mill. Nutrients are added to the waste stream to promote efficient biological treatment.

EUROCAN PULP & PAPER COMPANY LTD. (EUROCAN)

The EUROCAN mill, situated in Kitimat, B.C., on the Kitimat River, consists of an unbleached kraft mill producing linerboard, sack paper and pulp, and a sawmill. The mill, with a design production rate of 915 TPD of kraft pulp and 130,000 Mfbm/A of sawn lumber, was brought on-stream in early October, 1970. The wood furnish at EUROCAN is about 30 percent hemlock, 22 percent balsam, 30 percent lodgepole pine, 11 percent spruce and 7 percent miscellaneous. It is transported to the mill both by water and land.

The waste treatment facilities were designed to treat the total effluent from both the pulp mill and the wood mill. A clarifier, an emergency spill basin, tandem settling ponds and a five-day retention aerated lagoon are the principal components of the treatment process. Nutrients are also added to the waste stream.

TOXICITY STUDIES

Toxicity of a wastewater sample may be expressed in several ways. One common method is to define it in terms of the 96 hour median tolerance limit (TLm 96). This is defined as the percent of wastewater in water solution that will result in 50 percent survival (or 50 percent mortality) of the test fish after 96 hours. The 96 hour TLm test method was selected because it provides a direct means of comparing the toxicity of various effluent samples.

The toxicity tests reported here were all batch or static studies carried out in accordance with the procedures recommended in Standard Methods (1971). Fresh effluent samples were obtained by the mill personnel and shipped directly to the testing laboratories. Most of the samples arrived at the laboratory within 24 hours of sampling. Biological and chemical testing was performed at the mills following Standard Methods (1971) procedures.

The complete test results for the TLm 96 for the three mill wastewaters are presented in Tables 1 to 5. A condensed listing of the results, along with the zinc and resin acid soap concentrations are shown in Table 6.

Alpulp Results

The average TLm 96 of the ALPULP combined effluent (treated and untreated wastewater streams) was 68 percent, with a low value of 41 percent and a high value of no mortality at 100 percent effluent concentration. The ALPULP combined wastewaters comply with the British Columbia provincial Level A, toxicity standard for marine water discharge, which requires a 50 percent survival after 96 hours in a 45 percent effluent solution in water. The Test No. 5 combined effluent sample, Table 5, was non-toxic at 100 percent concentration while the Test No. 4 sample, Table 4, showed only a 5 percent mortality at 75 percent concentration. Both of these samples had lower resin acid soap and zinc concentrations, averaging 3.2 and 2.9 respectively, than the other combined waste samples.

The resin acid soap levels were generally low in all of the ALPULP waste streams, ranging from 1.1 ppm to 3.5 ppm. The effluents treated in the aerated lagoon contained less than 1.6 ppm of resin acid soaps. The untreated effluents which included the kraft mill streams also contained low resin acid soap levels because of the dilution by the groundwood and other process streams.

The zinc levels in the mill waste streams originated from the groundwood brightening process where zinc hypochlorite was used. The groundwood mill effluents contained in excess of 30 ppm zinc, while the zinc concentration in the effluent streams receiving biological treatment averaged 24 ppm. The zinc concentration was reduced approximately 60 percent to 10 ppm in the five-day aeration lagoon, probably due to reduction and precipitation of the zinc complexes in the lagoon.

Through the ALPULP five-day lagoon, the wastewater toxicity was reduced from 5.4 percent TLm 96 in the influent, to 23 percent TLm 96 in the treated effluent. This reduction is somewhat lower than might be expected after five-day biological treatment achieving greater than 80 percent BOD_5 removal, but is probably due to the relatively high (10 ppm) zinc concentration in the treated effluent.

The combined treated and untreated wastes, which contained lower levels of zinc, were much less toxic with an average TLm 96 of approximately 70 percent.

Eurocan Results

The treated effluent from the EUROCAN aerated lagoon was consistently non-toxic at 100 percent concentration. The untreated mill wastewater showed a 96 hour median tolerance limit of 18 to 68 percent, the lower value occuring during severe upset conditions in the mill which resulted in the loss of black liquor to the sewers. The mill wastewater was less concentrated than that normally expected because the kraft pulp production during the testing period was about 40 to 50 percent of design capacity of the mill.

The BOD_5 of the mill effluent averaged 140 ppm which was reduced to about 25 ppm after primary and secondary treatment. The concentration of resin acids in the waste was low, averaging 3.0 ppm in the untreated waste and 2.0 ppm in the biologically treated effluent.

NWP&P Results

The TLm 96 of the combined effluent streams from the NWP&P bleached kraft pulp mill averaged 26 percent, ranging from 42 to 13.5 percent. The untreated mill wastewater streams that receive biological treatment in the five-day retention aerated lagoon had a TLm 96 of 13.5 percent. The effluent toxicity was reduced to 26 percent TLm 96 after treatment in the lagoon. The residual toxicity in the lagoon effluent appeared to be of the same magnitude as that of the untreated bleach plant acid effluent, although in some of the tests there was a slight reduction in toxicity when these two streams were combined.

The resin acid soap concentration in the NWP&P effluent averaged 28.5 ppm considerably higher than at the other two mills, probably due to the different wood furnish used by NWP&P. The resin acid soap levels were reduced approximately 60 percent through the aerated lagoon, averaging 11.6 ppm in the treated effluent.

TOXICITY RELATIONSHIP TO WASTE CONSTITUENTS

It was not possible to establish definite relationships between the wastewater toxicity and other variables such as BOD_5, COD, dissolved solids, etc. The pulp and paper mill effluents, both treated and untreated, used in this study, indicated that there was no relationship between toxicity and BOD_5, COD, etc., nor was there a relationship between biological treatment efficiency (BOD_5 removal) and toxicity reduction in the aerated lagoons.

However, a general relationship was found between toxicity of the effluents and both the zinc concentrations (for the Alpulp wastes) and the resin acid soap levels. This relationship is shown in Figure 1. The effluent TLm 96 toxicity values show a similar relationship to both the zinc and resin acid soap concentrations in the treated and untreated wastewaters.

Comparison of toxicity of lagoon influent and effluent at EUROCAN and NWP&P with resin acid soap concentrations, indicates that these are only partially responsible for toxicity. At EUROCAN, the influent with only 3 ppm resin acid soaps was toxic (TLm 96, 18-68%), and this toxicity was entirely removed in the lagoon although resin acid soaps fell to 2 ppm. In NWP&P the resin acid soaps fell from an average of 28 ppm to 11.6 ppm through the aerated lagoon and TLm 96 changed from 13.5 percent to 26 percent. This would suggest that the toxicity at EUROCAN may be due to a biodegradable material other than resin acid soaps, whereas the remaining non-biodegraded resin acid soaps at NWP&P cause the residual toxicity.

RESULTS OF TOXICITY BIOASSAY TESTS

TABLE 1 - TOXICITY TEST NO. 1

NWP&P

Sample	pH	Threshold of toxicity	96 hour TLm
Lagoon Influent	7.0	10%	13.5%
Lagoon Effluent	7.0	10%	13.5%
Combined Effluent	3.6	10%	24.0%

ALPULP

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of Toxicity	3.2%	10%	32%
96 hour TLm	5.6%	29%	53%
BOD_5 total/filtered-ppm	334/329	79/82	125/125
COD total/filtered-ppm	527/477	204/194	338/199
pH at mill/as received	7.0/6.6	6.8/6.7	7.0/7.1
Suspended Solids - ppm	35	44	206
Total Solids - ppm	707	438	729
Temperature (at mill) - °C	33	32	30
Dissolved Oxygen (at mill) - ppm	4.1	2.7	3.3
Zinc - ppm		2.15	

EUROCAN

Parameter	Lagoon Influent	Lagoon Effluent
Threshold of Toxicity	32%	100%
96 hour TLm	68%	nontoxic at 100%
BOD_5 total/filtered - ppm	178/172	26/17
COD total/filtered - ppm	298/249	189/151
pH at mill/as received	10.1/9.8	7.7/7.5
Suspended Solids - ppm	48	62
Total Solids - ppm	412	476
Temperature (at mill) - °C	30	28
Dissolved Oxygen (at mill) - ppm	2.4	1.0

TABLE 2 - TOXICITY TEST NO. 2

NWP&P

Sample	pH	Threshold of Toxicity	96 hour TLm	Resin Acid Soap
Lagoon Influent		10%	13.5%	28.0
Lagoon Effluent		10%	18.0%	15.6
Combined Effluent			24.0%	9.3

ALPULP

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of Toxicity	3.2%	0%	10%
96 hour TLm	5.9%	40%	41%
BOD_5 total/filtered - ppm	331/294	54/48	107/92
COD total/filtered - ppm	495/412	236/217	481/439
pH at mill/as received	6.8/	6.7/	6.0/
Suspended solids - ppm	30	25	235
Total solids - ppm	712	515	746
Dissolved oxygen (at mill) ppm	4.1	4.9	4.6
Zinc - ppm	21.0	9.2	5.24

EUROCAN

Sample	pH	Threshold of Toxicity	96 hour TLm
Lagoon Influent	11.2	10%	18%
Lagoon Effluent	7.2	100%	non-toxic at 100%

TABLE 3 - TOXICITY TEST NO. 3

MacMillan Bloedel - Alberni Pulp and Paper Division

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of Toxicity	1%	-	32%
96 hour TLm	4.2%	14%	64%
BOD_5 total/filtered - ppm	354/344	29/28	206/176
COD total/filtered - ppm	825/480	188/166	484/314
pH at mill/as received	6.8/6.9	7.0/6.9	9.9/10.0
Suspended solids - ppm	262	19	185
Total solids - ppm	954	452	1029
Temperature (at mill) - °C	35.6	23.3	32.2
Dissolved oxygen (at mill) - ppm	1.4	5.6	0.6
Zinc - ppm	31.0	15.0	8.0

Note: Aerated lagoon was being by-passed at time of sampling, thus lagoon influent sample is unclarified (high solids) and lagoon effluent has received greater treatment than normally.

TABLE 4 - TOXICITY TEST NO. 4

NWP&P

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of toxicity	10%	18%	18%
96 hour TLm	13.5%	37%	42%
pH as received	7.1	7.2	4.7
Acid resin soaps - ppm	26	9.8	10.5
BOD_5 - ppm	472	175	-
Zinc - ppm	0.04	0.24	0.17

ALPULP

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of toxicity	1.0%	7.5%	56%
96 hour TLm	4.6%	16%	5% mortality at 75% conc.
BOD_5 total/filtered - ppm	343/334	28/24	124/107
COD total/filtered - ppm	573/519	234/183	345/289
pH at mill/as received	6.8/6.9	6.7/6.7	7.4/7.4
Suspended solids - ppm	38	32	189
Total solids - ppm	779	532	822
Temperature (at mill) - °C	37	25	27
Dissolved oxygen (at mill) - ppm	2.4	2.5	3.8
Zinc - ppm	24.8	14.6	2.6
Acid resin soaps - ppm	1.1	1.2	2.9

EUROCAN

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
96 hour TLm	5% mortality at 100% conc.	non-toxic at 100%	

TABLE 5 - TOXICITY TEST NO. 5

NWP&P

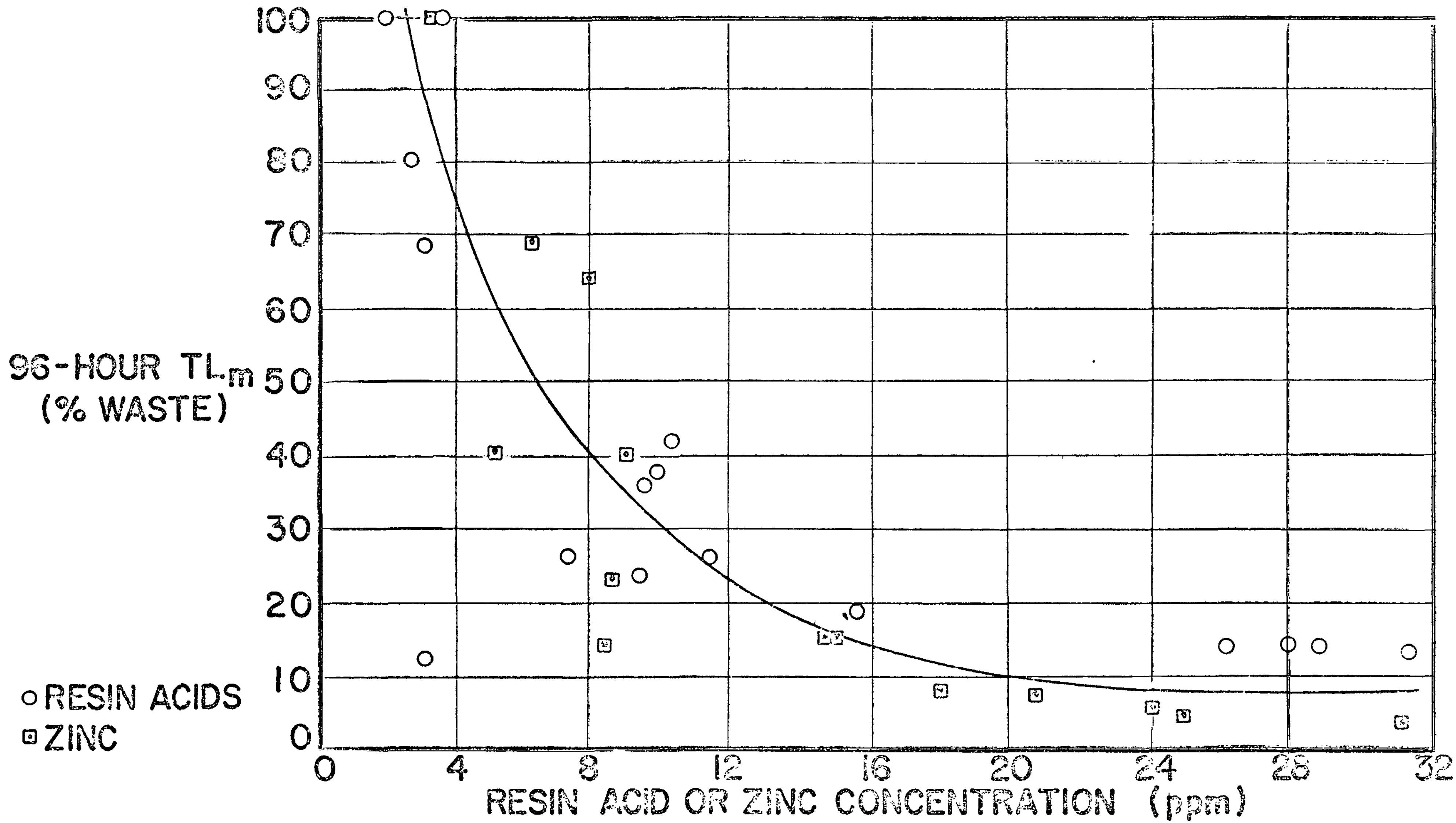
Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of toxicity	3.2%	18%	10%
96 hour TLm	13%	35%	13.5%
Zinc - ppm	0.10	0.05	0.06
Resin Acid Soap - ppm	31.5	9.3	3.1
pH	7.4	7.3	2.7

ALPULP

Parameter	Lagoon Influent	Lagoon Effluent	Combined Effluent
Threshold of toxicity	3.2%	10%	100%
96 hour TLm	6.8%	14%	100%
BOD_5 total/filtered - ppm	345/335	45/42	120/125
COD total/filtered - ppm	542/541	209/205	368/252
pH at mill/as received	6.8/6.9	6.7/6.8	8.6/8.8
Suspended Solids - ppm	7	5	182
Total Solids - ppm	749	499	903
Temperature (at mill) - °C	36	24	29
Dissolved oxygen (at mill) - ppm	2.1	2.8	2.4
Zinc - ppm	18.1	8.4	3.2
Resin Acid Soap - ppm	1.6	1.1	3.5

TABLE 6 - SUMMARY OF TOXICITY BIOASSAY RESULTS

Test	LAGOON INFLUENT			LAGOON EFFLUENT			COMBINED EFFLUENT		
	Zinc ppm	RAS ppm	TLm96 %	Zinc ppm	RAS ppm	TLm96 %	Zinc ppm	RAS ppm	TLm96 %
NWP&P									
1	-	-	13.5	-	-	13.5	-	-	24
2	-	28.0	13.5	-	15.6	18	-	9.3	24
3	0.04	26.0	13.5	0.24	9.8	37	0.17	10.5	42
4	0.10	31.5	13	0.05	9.3	35	0.06	3.1	13.5
AVERAGE	0.07	28.5	13.5	0.15	11.6	26	0.12	7.3	26
ALPULP									
1	-	-	5.6	2.2	-	29	-	-	53
2	21.0	-	5.9	9.2	-	40	5.3	-	41
3	31.0	-	4.2	15.0	-	14	8.0	-	64
4	24.8	1.1	4.6	14.6	1.2	16	2.6	2.9	(80)
5	18.1	1.6	6.8	8.4	1.1	14	3.2	3.5	100
AVERAGE	24.0	1.4	5.4	9.9	1.2	23	4.8	3.2	68
EUROCAN									
1	-	-	68	-	-	100			
2	-	-	18	-	-	100			
3	-	-	non-toxic at 32% conc.	-	-	100			
AVERAGE	-	3.0		-	2.0	100			



RESIN ACID & ZINC CONCENTRATION Vs EFFLUENT TOXICITY

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