THE EFFECT OF WASTE WATER LAGOON EFFLUENT
UPON A RECEIVING STREAM

by

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THE EFFECT OF WASTE WATER LAGOON EFFLUENT
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INTRODUCTION

Rapidly increasing population and industrialization has created a demand for more water of better quality and simultaneously produced larger volumes of wastes which pose an increasing threat to the purity of our water resources. Streams provide water for municipal water supplies, industrial use, agricultural use, fisheries, and recreation. Pollution of our streams must be prevented to protect the health and welfare of our population and to preserve this vital resource for all beneficial purposes. During the 19th and early 20th centuries, disposal of wastes to the nearest watercourse was common practice because of a lack of legal control and adequate knowledge of the consequences of pollution. Fortunately, there has been a great effort in recent years to reverse this policy by either prevention of the disposal of wastes into streams, or by requiring adequate treatment prior to discharge.

The construction, operation, and maintenance of a waste treatment plant is costly. Small communities and industries often find it difficult to finance conventional waste treatment processes. Oxidation lagoons are now being used for waste stabilization. They provide satisfactory biological treatment with a minimum of operating expense. The initial costs depend upon the value

of desirable land and the suitability of the soil.

The lagoon is normally 3 to 5 feet deep and may assume any geometrical shape. It is preferrably located so that it is exposed to the action of the prevailing winds and to the maximum available sunlight. Such a lagoon provides an excellent environment for the growth of algae. The treatment process in a lagoon can proceed without odor or nuisance under aerobic conditions. The required dissolved oxygen is supplied both by surface reaeration and by the photosynthetic process of the algae.

Lagoons were originally used in arid climates where evaporation was equal to or greater than the waste inflow, therefore an effluent did not result. Because of increasing popularity and the necessity of waste treatment by smaller communities and industries, lagoons are now being used in maritime regions where evaporation is insufficient to eliminate an effluent. The resulting effluent is normally discharged into a nearby stream or watercourse.

Object of this Thesis

The conditions resulting from the discharge of lagoon effluents into a receiving stream must be carefully considered. The creation of an environment favorable to algal growth can make a stream undesirable for recreational use and water supplies because of the resulting taste and odors. Water uses may require disinfection of lagoon

effluents prior to discharge. The death of algae cells resulting from disinfection will increase the amount of decomposable organic matter in the stream.

The object of this thesis is to investigate the conditions arising from the disposal of normal and disinfected lagoon effluents into a receiving stream.

DISCUSSION OF PROBLEM

The nature of the stream and the lagoon is of great importance. An examination of these systems and the factors affecting them is required.

A stream is a complex system with a state of dynamic balance existing within the biological community. A stable equilibrium cannot be expected because there are so many continually varying factors which affect the density of the existing populations (7, p. 200). The balance therefore is dynamic in that there are infinite combinations of circumstances for which the system will attain a temporary equilibrium. For example, when pollution is introduced into a stream, many changes take place. With the addition of organic material, bacterial populations and respiration rates will increase causing depletion of the oxygen in the stream. Anaerobic decomposition would result, with odors being produced. As oxygen is resupplied to the system, and nutrient concentrations decrease, aerobic conditions would develop. In each case,

a temporary balance between the biological population
and the environment exists.

The principle of biological balance in a stream also
applies to an oxidation lagoon and its effluent. The
relative concentrations of organic material, biologically
active components, and mixing currents are the primary
differences that exist between the two systems.

Factors Affecting System Balance

The factors which affect a waterborne biological
system are physical, chemical, and biological in nature.
Temperature is one of the major physical factors. Micro-
organisms can grow and carry on their life activities at
the optimum rate only within a rather limited temperature
range (6, p. 58). Biochemical reactions in general follow
the Van't Hoff rule of a doubling of reaction rate for a
10° C. increase in temperature over a restricted range
(11, p. 153). The amount of oxygen that may be dissolved
in water is primarily dependent upon temperature with
saturation values decreasing as temperature increases.
Biological activity of the organisms on the other hand
increases with an increase in temperature. Therefore,
within the range of the organisms, as temperature in-
creases, oxygen demand is greater, but the available
supply is less. This effect can be critical to the system
balance.

Sunlight is a source of energy which has an important influence on the water biological scheme. Algae utilize light energy and carbon dioxide in the synthesis of their organic food requirements. The oxygen given off in this process is often a major source for other organisms. Mixing action in a lagoon can be provided by the thermal currents produced by light energy.

Chemical factors may be divided into three groups. They are nutrition, hydrogen ion concentration (pH), and toxic effects (10, p. 132). Organisms must have some source of energy to utilize nutrients. This energy is obtained by the oxidation of organic compounds which are either taken from the system or synthesized by the organism. Some of the oxidizing agents employed in this process are oxygen, nitrates, nitrites, sulfates, and carbonates. The organic compounds are oxidized to carbon dioxide and water, and the oxidizing agents are reduced if the system is aerobic. Complex nitrogen compounds will be oxidized to ammonia.

Macronutrients and micronutrients are the terms given to mineral nutrients and refer to the amount required by living cells. For both animals and plants, the major macronutrients are sodium, chlorine, potassium, calcium, phosphorus, and magnesium. The principal micronutrients are iron, copper, manganese, and zinc (8, p. 8). Vitamins, often called growth factors, are necessary

nutritional elements. They are required in very small amounts and cannot be manufactured by cells that require them (8, p. 8).

The Hydrogen Ion Concentration (pH) is an important factor influencing the biological population. Every organism has a definite pH tolerance range (10, p. 132). This range varies for different organisms.

The primary sources of toxic materials in a water biological system are industrial waste and agricultural pesticides. Studies of the toxic effects of some wastes on biological treatment processes have been made. More information on this subject is needed.

Every organism in a biological system has a specific function. Some of these functions are well defined and easily visible whereas others are not. One of the principles of microbiology is that for every naturally occurring organic compound there is some microorganism that will metabolize it (10, p. 132). Higher biological forms feed upon bacteria and other lower forms. The available food supply controls the population.

Living organisms are divided into two groups based upon their food requirements. These are heterotrophs and autotrophs. Heterotrophs are incapable of manufacturing their own food (7, p. 197). They obtain their energy from organic compounds and require oxygen in their metabolism. In this respect, they are considered to be animal

like. The classification is subdivided into primary and
secondary groups. The primary heterotrophs feed on bac-
teria and small plants such as algae. Secondary hetero-
trophs feed on primary heterotrophs (10, p. 133).

Autotrophs are able to grow in a purely inorganic
medium. They utilize carbon dioxide and ammonia or
nitrate to synthesize their own food (8, p. 11). The
photosynthetic autotrophs of primary interest are algae.
They convert light energy into chemical energy in the
process of photosynthesis. One of the by-products of
their metabolism is oxygen.

Bacteria may be either heterotrophic or autotrophic.
Figure 1 is a simplified expression of the basic concept
of the life cycles in a water biological system such as
an oxidation lagoon.

The effects of the disposal of a lagoon effluent
upon the chemical and biological characteristics of a
stream are important. The condition resulting from a dis-
infected effluent would be different from that of the
regular effluent. For this reason, it is necessary to
consider disinfection.

Disinfection

The microorganisms in human wastes can survive the
oxidation lagoon treatment process. If a lagoon effluent
is discharged upstream from a public water supply or rec-
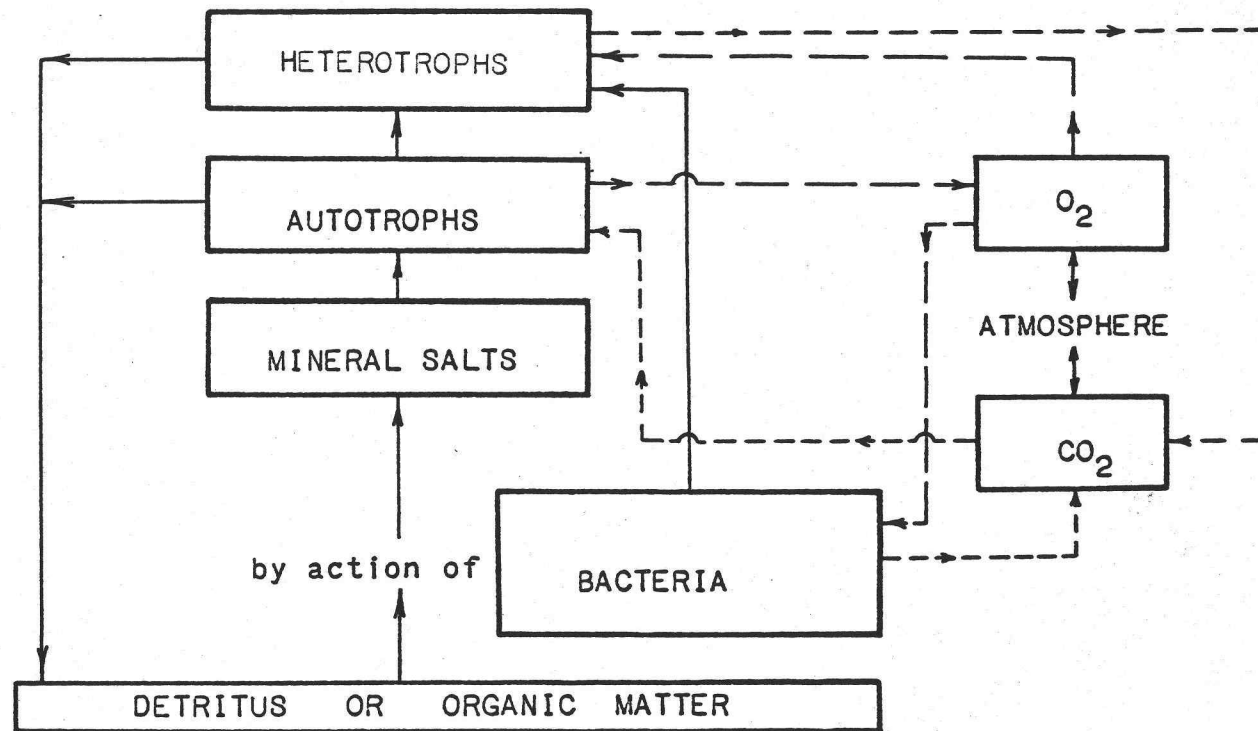reational area, disinfection will be required. The

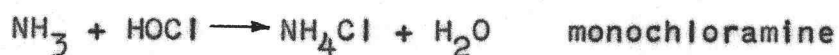Figure 1. Basic food cycle of a lagoon.

purpose of disinfection is to destroy any bacteria that may be pathogenic or capable of transmitting disease. Some of the disinfectants which may be used are ammonia, sulfur dioxide, ozone, silver compounds, ultraviolet light, bromine, and chlorine. Chlorine can be easily applied, is economical, and is the principal disinfectant used. Discussion will be limited to the use of chlorine.

Chlorine is one of the most active elements. It will readily combine with or oxidize many organic and inorganic compounds. Residual chlorine is measured in a water system as free available chlorine and combined available chlorine. Free available chlorine exists in water as Cl_2, HOCl, and as the OCl^- ion. The chemical reactions are as follows (11, p. 249):

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$
$$HOCl \rightleftharpoons H^+ + OCl^-$$
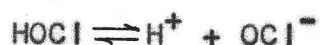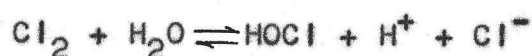
Below a pH of 5, chlorine will be present in the molecular form of Cl_2. Between 5 and 6, it exists almost entirely as HOCl. Above a pH of 6, OCl^- ions are present, becoming predominant above pH 7.5 (2, p. 205).

Combined available chlorine exists as ammonia compounds. Ammonia reacts with hypochlorous acid to form monochloramines, dichloramines, and trichloramines as follows (11, p. 249):

$$NH_3 + HOCl \longrightarrow NH_4Cl + H_2O \qquad \text{monochloramine}$$
$$NH_3 + 2HOCl \longrightarrow NHCL_2 + 2H_2O \qquad \text{dichloramine}$$

$$NH_3 + 3HOCl \longrightarrow NCl_3 + 3H_2O \quad \text{trichloramine}$$

Above a pH of 8.5 only monochloramine will exist. Between
8.5 and 4.5 both monochloramine and dichloramine will be
present. At pH 4.5, dichloramine will predominate, and
below 4.4, trichloramine will be produced (2, p. 215).

The cause of death as a result of chlorination is
not known. It is assumed that chlorine will combine with
protein substance in the cell wall of microorganisms,
interfering with reproduction and growth, and eventually
resulting in death of the organism. Another explanation
is that chlorine inhibits a key enzymatic process of the
cell and thus stops its metabolism (2, p. 209). Death of
microorganisms subjected to chlorination is not instan-
taneous at normal chlorine levels.

Organisms are known to have varying resistances to
the effects of chlorine. It has been well established
that pathogenic organisms are less resistant than non
pathogens (5, p.8). In one experiment, it was determined
that a 100% kill of 21 strains of E. Typhi was effected
by a 0.1 mg/l chlorine dose for 15 to 30 seconds. For
E. Coli organisms, under the same test conditions, 9
strains required a 0.15 mg/l dose, 10 strains required
0.2 mg/l, and 9 strains required 0.25 mg/l (5, p.14).
It is on the basis of such tests that the coliform bac-
teria is used as an indicator of pollution.

The effectiveness and speed of the bacterial kill is

dependent upon suspended solids concentration, pH, temperature, form of chlorine present, strength of dosage, and contact time. When suspended solids are present, complete kill requires time for chlorine to penetrate the solids. An increase in temperature and a decrease in pH will accelerate the chemical reactions. Free available chlorine will give faster results than combined available chlorine. Greater dosages will produce more rapid results. A longer contact time will insure a more effective kill. Under the most favorable conditions of no turbidity, a pH of 7.0, and a temperature of 20° C., 100% destruction of bacteria, with equal contact times, requires 25 times as much combined available chlorine as free available chlorine. Combined available chlorine will require a contact period 100 times that of free available chlorine to give the same kill with equal dosages (2, p. 219).

Chlorine is also used as an algicide. An indicated range of lethal dosages is 0.25 to 1.5 mg/l depending on the algae type (2, p. 112). A large number of the algae in a lagoon effluent would be killed under normal chlorination practices. Upon discharge into a stream, the dead cells would create an increased organic load subject to decomposition.

The normal practice in the chlorination of a waste is to add chlorine in quantities such that after a given

period of time a specified residual will remain. The
normal requirement by state health agencies is a 0.5 mg/l
residual after 30 minutes of contact. Under these circum-
stances, available chlorine will be discharged into the
stream receiving the waste. The chlorine may have adverse
effects upon the stream life as demonstrated by a reduc-
tion in the natural stream bacterial population. Chlorine
in quantities of 0.05 to 0.2 mg/l is reported to be toxic
to fish (7, p. 33).

METHOD OF STUDY

The effects of stream pollution will depend on the
distance below the disposal point. Organic bottom de-
posits will be maximum near the outfall unless stream
velocity is sufficient to carry solids away. Oxygen
depletion by bacteria may be critical at points downstream
as a result of bacterial growth characteristics. Algae
growth, promoted by the abundance of the proper nutrients,
will be most noticeable in slow moving waters below the
outfall. The conditions downstream are quite varied both
with respect to cause and effect.

The general objective of any study of stream pol-
lution would be to arrive at methods of evaluating stream
variables and conditions for the purpose of formulating
behavior prediction equations. Solar energy, temperature,
properties of the channel, composition of the waste,

bottom deposits, added dilution, and pollution--all of
these are variables. Many can be measured for today, or
evaluated for yesterday, but can not be easily predicted
for tomorrow.

This thesis is limited to the evaluation of para-
meters normally used to describe pollution, as they apply
to stream disposal of a lagoon effluent, with and with-
out chlorination.

It would be desirable to follow an 'element' of water
as it flows downstream and observe the changes that occur.
This was done through the use of a circulating device
which would provide conditions similar to those in a
stream. The 'element' of water was isolated from the
stream and analyzed for changes as time progressed.

Facilities

To obtain the necessary control for this study, a
device as shown in Figure 2 was constructed. It consists
of 4 water-tight channels with circulation of water pro-
vided by a constant speed paddle assembly. The velocity,
mixing action, and surface disturbances induced by the
paddles are assumed to be consistent. The model was
located in a room where temperature was constant ($14.5^{\circ} \pm 1^{\circ}$ C.) and ventilation adequate. Artificial lighting was
provided by five, four tube fluorescent light fixtures
suspended 15 inches above the average water surface in the
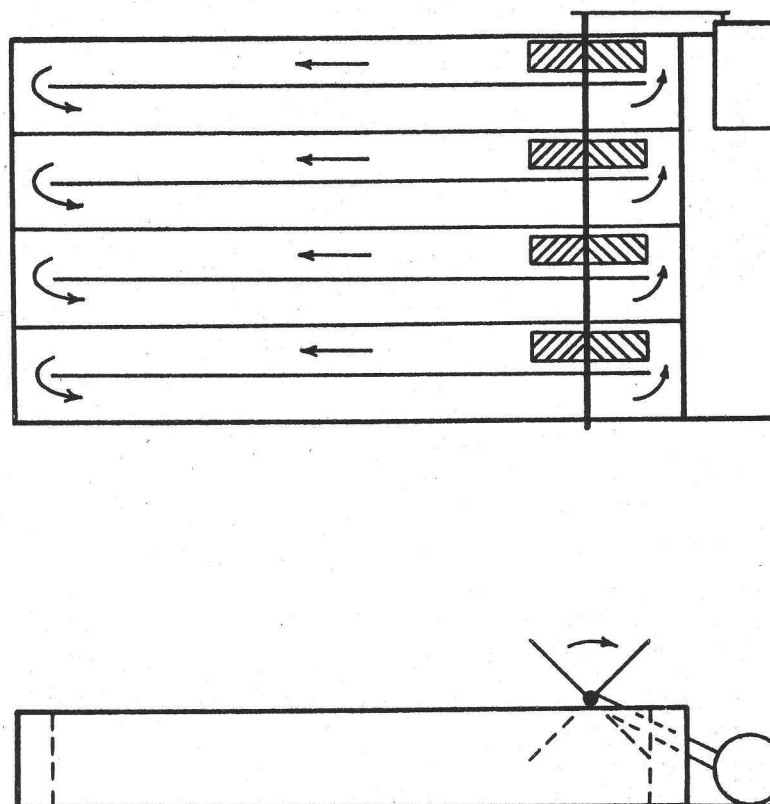
Channel Length = 7 feet

Channel Width = $5\frac{1}{4}$ inches

Channel Depth = $11\frac{1}{2}$ inches

Paddle Speed = 16 rpm

Material used = Wood

Coating = Fibre Glass Resin

Color = Medium Grey

Figure 2. Mixing device

channels. The intensity of light at the water surface
was approximately 550 foot candles. The lights were on
for a continuous period of 12 hours each day. No attempt
was made to reproduce natural stream bottom effects. The
model was constructed of wood and coated with a fibre
glass resin. A medium grey color was selected for the
coating so as to nearly approximate the absorptive and
reflective characteristics of natural stream banks.

Experimental Procedure

Two series of tests, designated Test Run No. 1 and
Test Run No. 2, were completed. The river water for both
was taken from the Willamette River at Corvallis, Oregon,
on March 1 and March 20, 1962. The lagoon effluent used
was obtained from the Experimental Waste Water Oxidation
Lagoon which is operated by the Oregon State University
Engineering Experiment Station in conjunction with the
City of Corvallis, Oregon.

For Test Run No. 1, the ratio of lagoon effluent to
river water was 1/5 for both the chlorinated and unchlor-
inated channels. A 1/10 dilution was used for Test Run
No. 2. An equal water surface level was maintained in
all channels throughout the tests. No water was added to
the system during any tests. The samples withdrawn con-
stituted less than 10% of the total volume within the
channel. Water lost to evaporation was not measured.

The chlorinated effluent was dosed at 3 mg/l as total available chlorine, with a hypochlorite solution. A 15 minute contact period was allowed prior to mixing with the river water. The 15 minute residual for Test Run No. 1 was 1.5 mg/l; 0.5 mg/l as free available chlorine and 1.0 mg/l as combined available chlorine. For Test Run No. 2, the 15 minute residual was 0.5 mg/l as combined available chlorine.

A 15 minute mixing time was allowed following the addition of the lagoon effluents before the first sample was taken. This sample was designated as the zero time sample. Three channels, one containing river water only, one with river water plus unchlorinated effluent, and one with river water plus chlorinated effluent were sampled periodically for 7 days. The fourth channel was filled with river water and used as needed for other tests.

Tests Performed

The Biochemical Oxygen Demand (BOD) test is a controlled laboratory measure of the oxygen required for stabilization of a waste product under aerobic conditions. Oxygen is utilized by bacteria and other organisms for their respiration requirements in the initial phases of the test. Since the results are dependent upon bacterial action, the procedures and conditions of the test are critical and must be interpreted in the analysis of data.

To obtain uniformity such that information from various sources can be compared and utilized to its fullest value, the American Public Health Association and other interested groups have suggested standard procedures for the performance of the BOD test. These are given in detail in the book Standard Methods for the Examination of Water and Wastewater, hereafter referred to as Standard Methods (1, p. 318).

Analysis of the reactions that take place during the BOD test indicate two distinct demands for oxygen. Dead organic matter is transformed into initial products of decomposition by bacterial action. Oxygen is used for bacterial respiration in this process. Initial products are then oxidized to intermediate and final products with oxygen being used in the formation of end products. These reactions can be characterized by the following word equations:

(a) Organic Matter $\xrightarrow[O_2]{Bact.}$ Initial products

(b) Initial Products + O_2 $\xrightarrow{Bact.}$ Intermediate products

(c) Intermediate Products + O_2 $\xrightarrow{Bact.}$ Final products

Specific equations for (b) and (c) above are as follows:

(d) $2NH_3 + 3O_2 \xrightarrow{Bact.} 2NO_2^- + 2H^+ + 2H_2O$

(e) $2NO_2^- + 2H^+ + O_2 \xrightarrow{Bact.} 2NO_3^- + 2H^+$ (11, p. 274).

The oxygen used for bacterial respiration in the BOD

reaction is termed First Stage BOD. This stage is mathe-
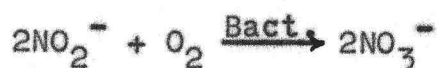matically characterized by the equation
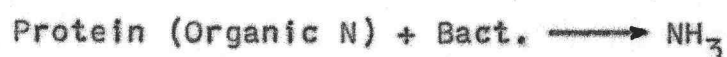
$$y = L_a (1 - e^{-Kt}) \tag{1}$$

in which L_a is the ultimate first stage BOD, y is the BOD
measured at time t, e is the natural log base, K is a
rate constant (4, p. 521). In the second or nitrification
stage, oxygen is being utilized for bacterial respiration
and for the formation of nitrites and nitrates. Mathe-
matical formulation of the nitrification stage is more
difficult and is generally not done.

BOD information is normally reported as either a 5
day BOD or an ultimate first stage BOD. The 5 day value
does not differentiate between first and second stage re-
actions. Its use stems from the general observation that
the 5 day BOD of ordinary domestic sewage is approximately
2/3 of the estimated ultimate first stage BOD. The ulti-
mate first stage BOD is calculated using equation 1.

There are several methods proposed for the calcula-
tion of the rate constant "K". Thomas (12, p. 123) has
proposed a method which is a simple graphical approxi-
mation for the evaluation of the constants of the BOD
curve. Moore, Thomas, and Snow (9, p. 1343) have sug-
gested a method involving a few calculations and the use
of a standard curve. This method is perhaps the most
convenient to use.

The BOD tests for this study were performed according to the procedures in Standard Methods (1, p. 318) at an incubation temperature 20° C. One, three, five and seven day BOD values were determined for each sample. Available incubator space prevented duplication of samples, therefore values are based on single bottle determinations. The data obtained for each sample were plotted and appear in the appendix. One, two, and three day values were read from the curves and used to calculate "K" and L_a by the method suggested by Moore, Thomas, and Snow (9, p. 1343). Values of "K" and L_a are plotted as functions of sample time in figures 3 and 4.

Compounds of nitrogen are important for plant and animal growth. They will exist in the organic state as proteins or in the inorganic state as ammonia, nitrites, and nitrates. Nitrogen, as it exists in wastes, will normally be in transition from the organic to inorganic states. The changes which take place can be characterized by the following relationships (11, p. 291):

$$\text{Protein (Organic N)} + \text{Bact.} \longrightarrow NH_3$$

$$NH_3 + 3O_2 \xrightarrow{\text{Bact.}} NO_2^- + H + H_2O$$

$$2NO_2^- + O_2 \xrightarrow{\text{Bact.}} 2NO_3^-$$

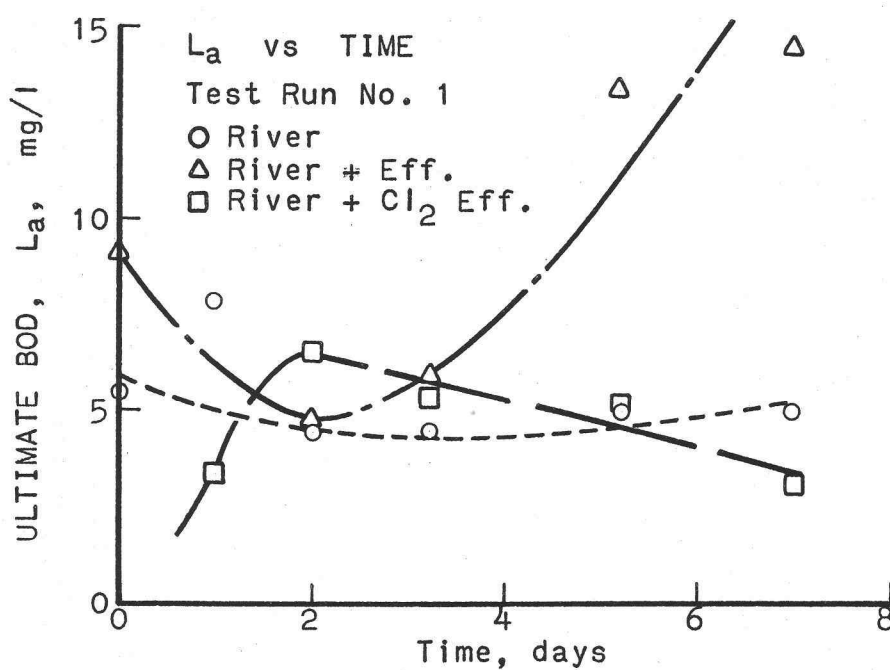Nitrogen is returned to the organic state by plants as follows (11, p. 290):
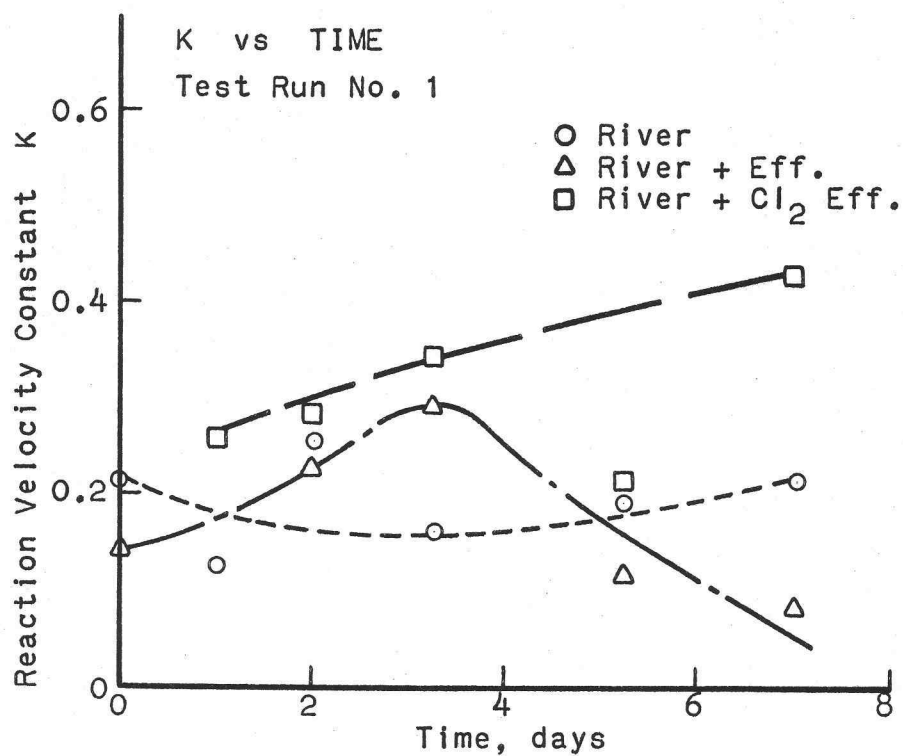
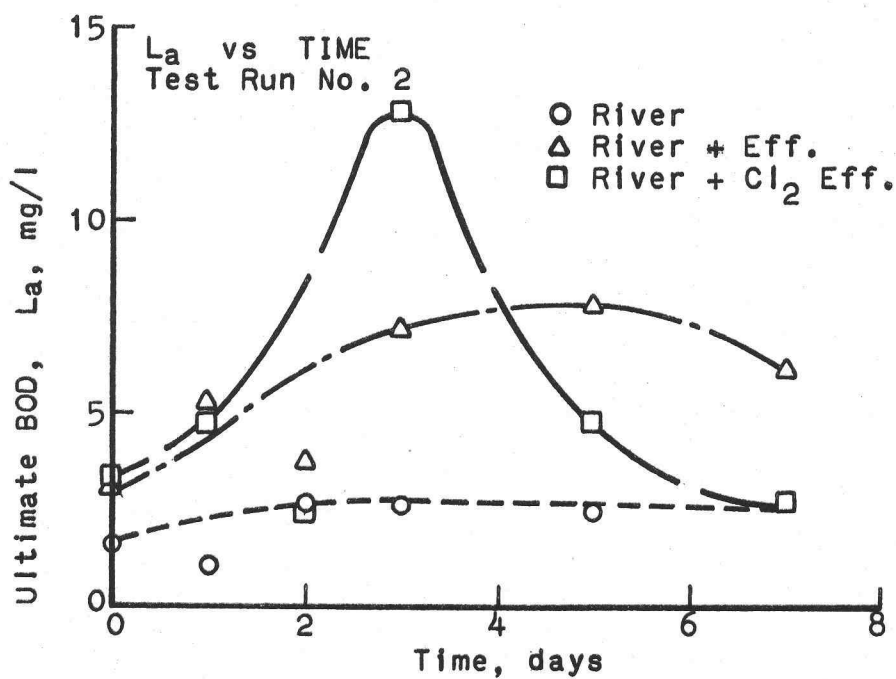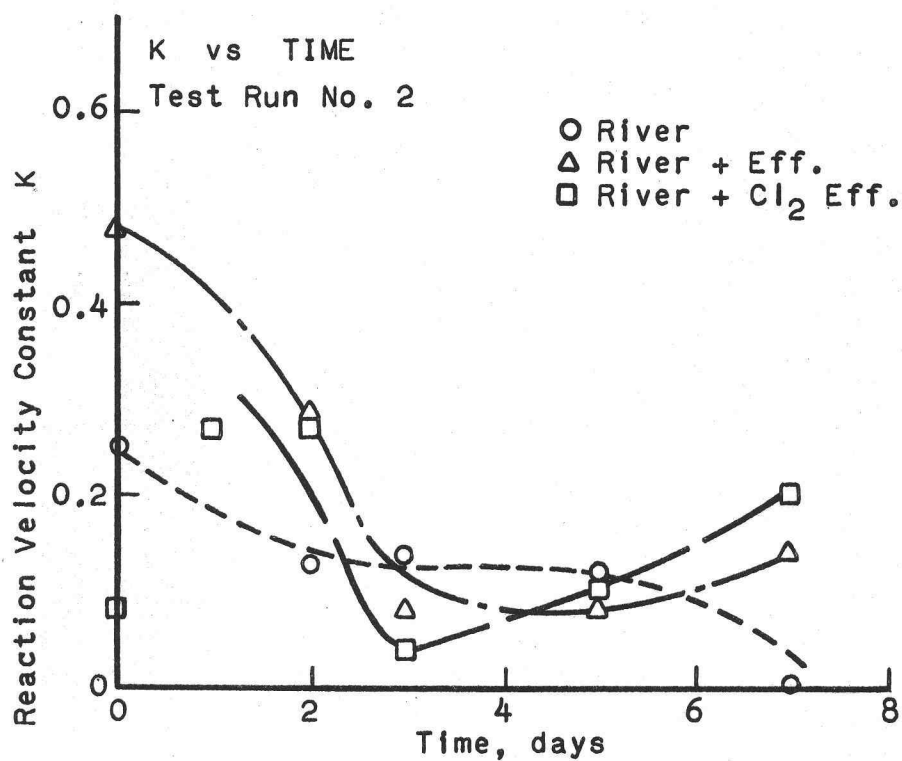Figure 3. L_a and K versus sample time for test run no. 1.

Figure 4. L_a and K versus sample time for test run no. 2.

$$NO_3^- + CO_2 + \text{Green Plants} + \text{Sunlight} \longrightarrow \text{Protein.}$$
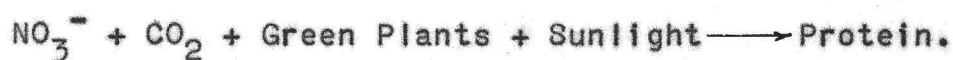
The relationships between nitrogen compounds present can be an indicator of pollution. High nitrate concentrations generally indicate a stable condition. High nitrite and ammonia concentrations are often accepted as an indicator of recent pollution and a highly unstable condition.

The nitrogen tests performed on the samples taken for analysis in this project were ammonia, nitrogen, nitrite nitrogen, and nitrate nitrogen. Colorimetric determination procedures were used with the aid of a spectrophotometer. Samples were filtered to remove turbidity. The first 50 milliliters of filtrate were discarded. A reagent blank was used in all determinations, with correction for sample color. Nitrogen determination methods were as follows: Ammonia by the Direct Nesslerization Method (1, p. 295), nitrite by the Diazotization Method (1, p. 303), and nitrate by the Tenative Brucine Method (1, p. 178). Results of the ammonia and nitrite nitrogen tests are shown in figures 5 and 6. Nitrate concentrations were zero in all tests.

Phosphorus determinations are essential in assessing the biological productivity potential of surface waters (11, p. 330). Algal blooms are attributed to an abundance of nitrogen and phosphorus. Phosphates and polyphosphates are the only inorganic phosphorus forms of importance.
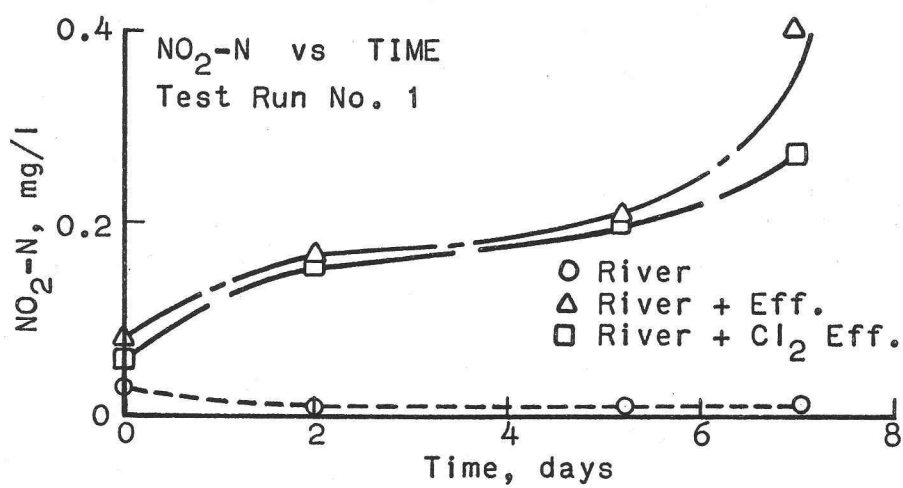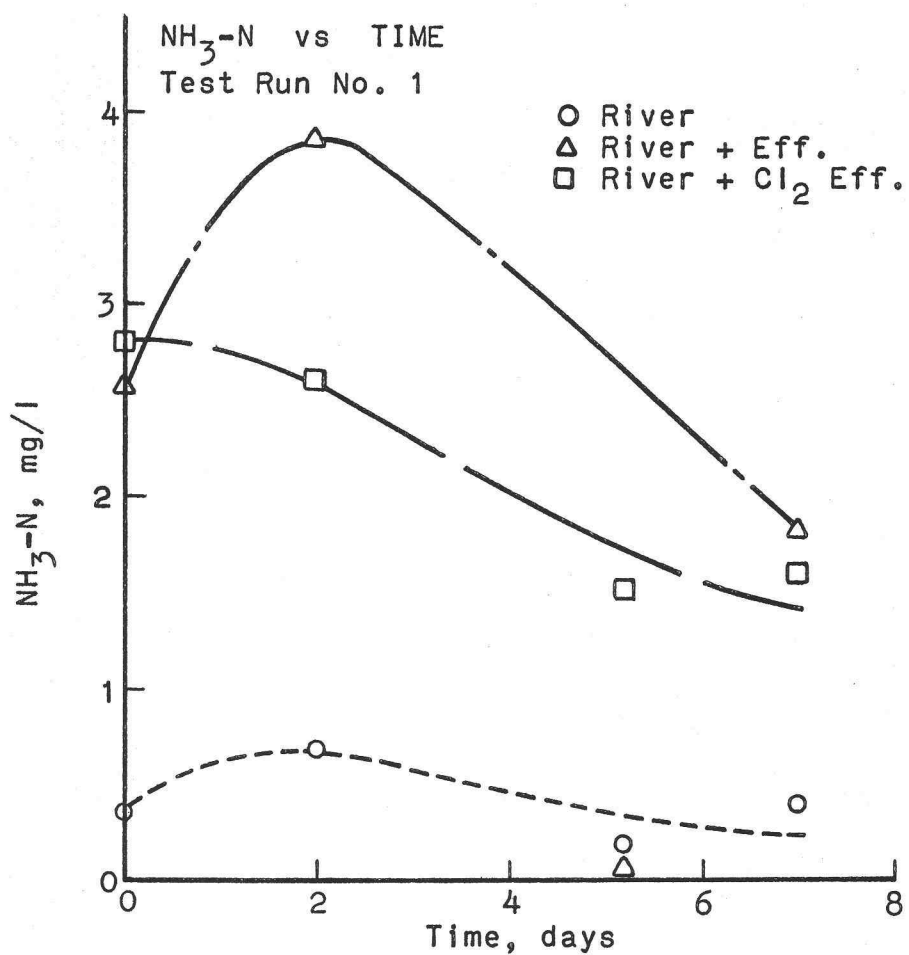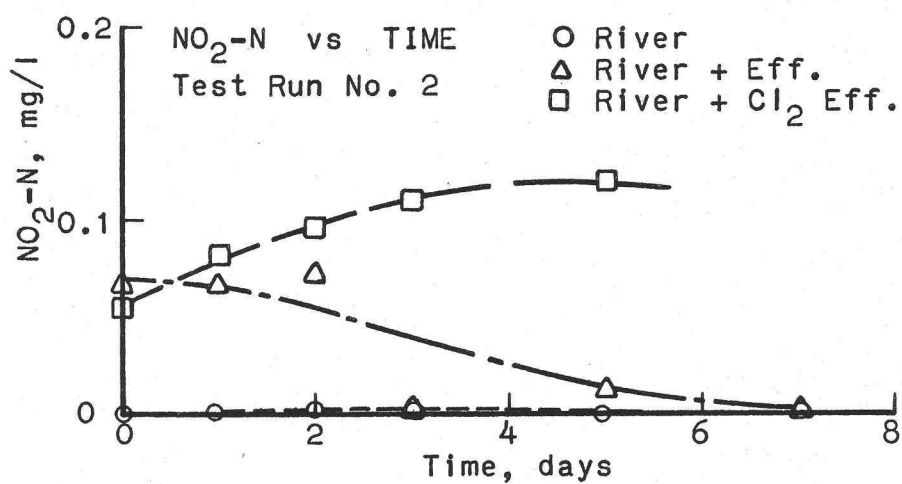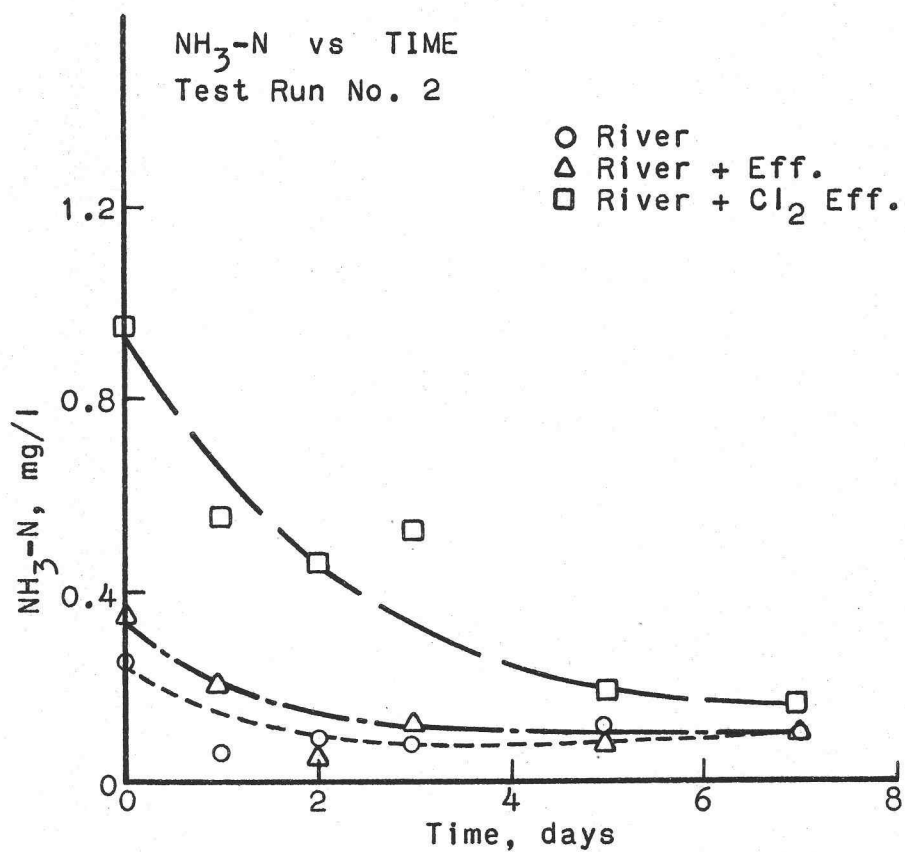
Figure 5. NH$_3$-N and NO$_2$-N versus sample time for test run no. 1.

Figure 6. NH$_3$-N and NO$_2$-N versus sample time for test run no. 2.

Organically bound phosphates are generally of minor con-
sideration (11, p. 325). Domestic wastes are normally
rich in phosphates, especially since the advent of syn-
thetic detergents which are compounds of phosphorous.

Colorimetric methods of analysis were used for the
determination of phosphates in this study. Samples were
filtered prior to determinations. The first 50 mil-
liliters of filtrate were discarded. A reagent blank was
used, and data were corrected for sample color. The
Stannous Chloride Method for determination of ortho-
phosphate (1, p. 202) and total phosphate (1, p. 204) was
used. Orthophosphate concentrations are plotted as a
function of sample time in figures 7 and 8. Polyphos-
phate concentrations equal to the total phosphate minus
the orthophosphate, are shown in table 2 in the appendix.

Algae concentrations were determined by microscopic
cell counts at 100 diameters magnification using a
counting cell 1 mm. in depth. Counts were recorded as
cells per cubic millimeter. The only cells counted were
those typical of the lagoon effluent. The dominant
species were Chlorella and Scenedesmus. Concentrations
are shown in figures 7 and 8. The concentration in the
river water was essentially zero.

Tests for the coliform organism were made using the
membrane filter technique as given in Standard Methods
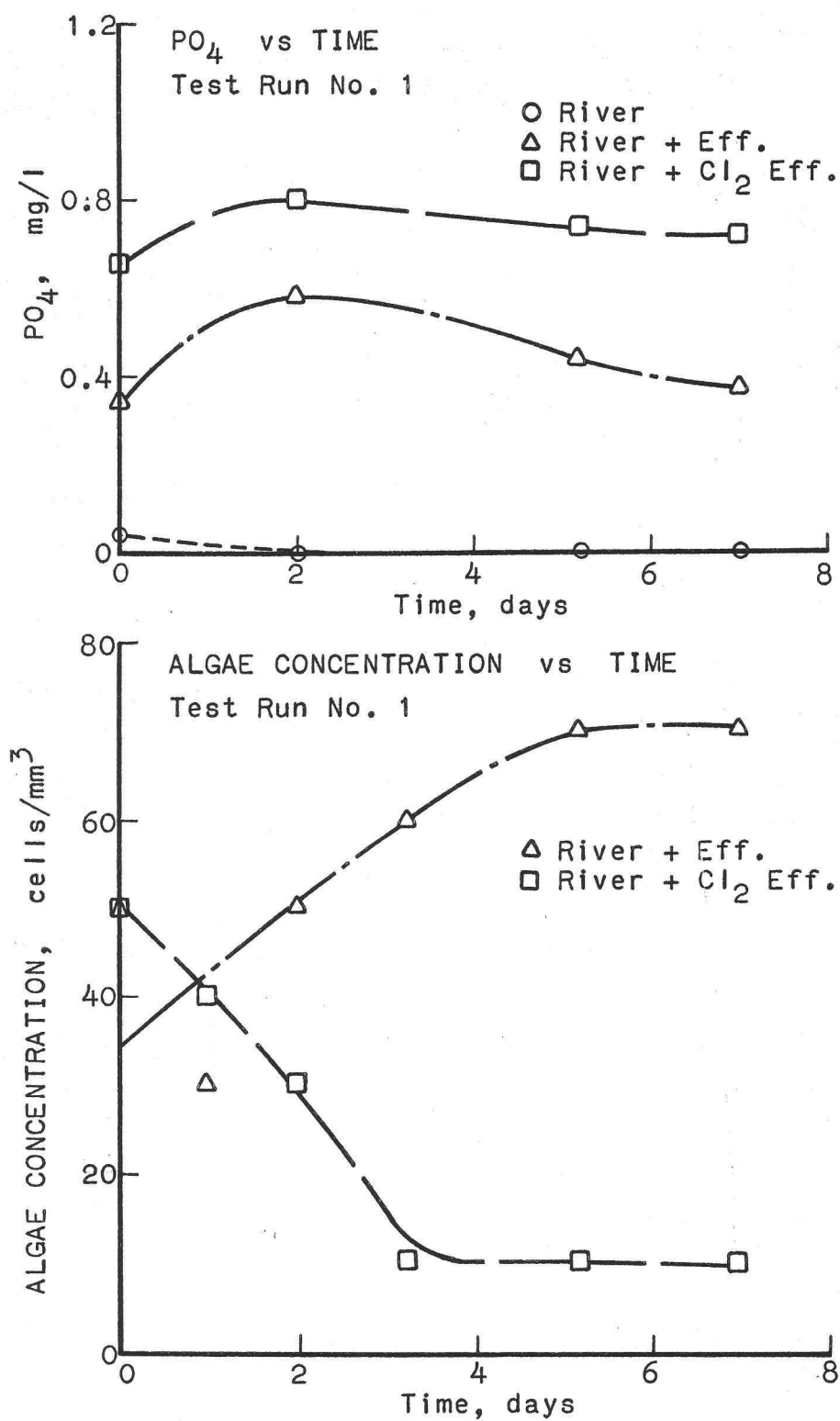(1, p. 508). A 47 mm type HA filter, grid marked, with

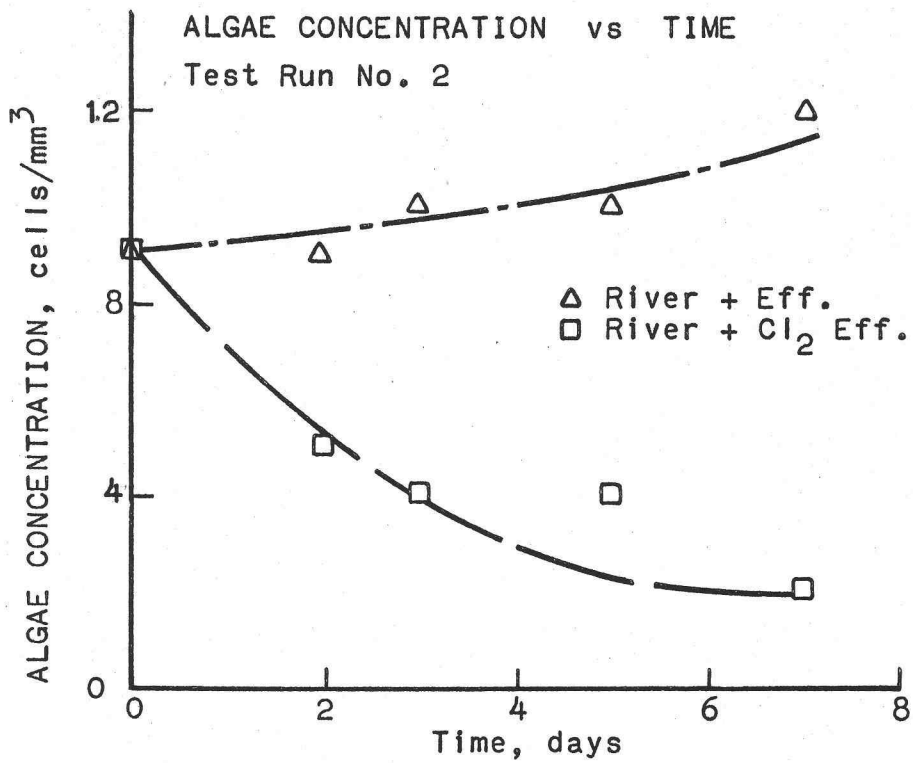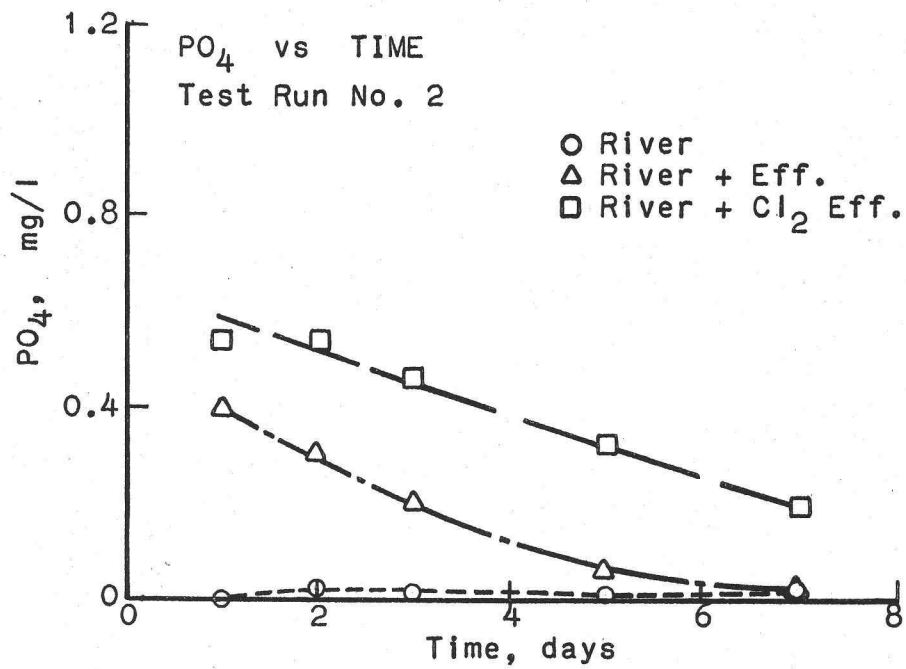Figure 7. PO$_4$ and algae concentration versus sample time for test run no. 1.

Figure 8. PO$_4$ and algae concentration versus sample time for test run no. 2.

0.45 micron pore openings was utilized together with M-Endo Broth M. F. 0749-01 as produced by Difco Laboratories. Metallic sheen colonies were counted and recorded as colonies per milliliter, with values rounded to the nearest significant digit. Counts less than 1/ml were recorded as zero, whereas a count of 11/ml would be recorded as 10/ml. Results are shown in table 2 in the appendix.

Chlorine residuals were determined within 10 minutes after samples were taken using an amperometric titrator as specified in Standard Methods (1, p. 94). Results appear in table 2.

Temperature was measured in the mixing device when samples were taken. The temperature remained between 13.5 and 15.5° C. at all times.

The hydrogen ion concentration (pH) was measured within 20 minutes after samples were taken using a glass electrode pH meter. The pH in all channels remained between 7.5 and 7.8 for both test runs.

The Dissolved Oxygen, as measured by the Winkler Method (Azide Modification) (1, p. 309), was near saturation in all samples taken during the test. No significant deficit or surplus of oxygen existed. The oxygen present at any time is equal to the quantity supplied by algae and surface reaeration minus that utilized for biological respiration. Excess oxygen may be lost through

the surface to the atmosphere. No attempt was made to measure this quantity since the required equipment was not available.

Stream reaeration studies indicate that when the oxygen demand is small, the oxygen transfer may be described by the equation;

$$\frac{\Delta D}{\Delta T} = -K_2 D$$

where D is the saturation deficit at time T and K_2 is a reaeration rate constant. Since $\Delta D = -\Delta DO$, the equation becomes

$$\frac{\Delta DO}{\Delta T} = K_2 D$$

where DO is the dissolved oxygen as measured. The following method was used to determine the possible rate of oxygen transfer from the atmosphere to the water in the circulating device.

The test was carried out during a dark cycle such that algal production of oxygen was zero. The oxygen concentration in the extra channel containing river water was depressed by the addition of Sodium Sulfite. The change in dissolved oxygen and the oxygen usage were then measured as a function of time. The oxygen supplied to the system during the time increment was equal to the measured increase in dissolved oxygen plus the oxygen utilized. The values obtained are as follows:

At T = 0, DO = 0.7 mg/l

At T = 5.25 hrs., DO = 1.9 mg/l and BOD = 0.1 mg/l

DO at Saturation (14.5° C.) = 10.3 mg/l

O_2 supplied = 1.9 - 0.7 + 0.1 = 1.3 mg/l

Average D = 10.3 - (1.9 + 0.7)/2 = 9.0 mg/l

K_2 = 1.3/(5.25)(9.0) = 0.0276/hr. = 0.66/day

The value of the rate constant as determined by this method is 0.66/day.

DISCUSSION OF RESULTS

Unstable conditions were encountered during the initial period of both test series, as indicated by the scatter of data points in figures 3 and 4. This may be attributed to environmental changes as reflected by the removal of the river water and lagoon effluent from their natural habitats, increasing their temperatures, and changing from natural to artificial light. Coliform bacteria were present in the lagoon effluent and river water in both test series (see Table 2). Chlorination produced a complete kill of these organisms in both the lagoon effluent and the river water. Coliform present in the unchlorinated channels disappeared gradually.

The chlorine residual in the lagoon effluent prior to mixing with the river water was higher than desired in Test Run No. I. The effect of this residual can be observed in the relationships of figure 5. Ammonia and nitrite nitrogen concentrations were less in the

chlorinated channel. A greater concentration would be expected as a result of reduced algal demand for these nutrients. The excess chlorine apparently retarded the nitrifying bacteria. The ammonia and nitrite concentrations in Test Run No. 2 were as expected. The chlorine dose was less, and nitrogen compounds were least in the unchlorinated channel where algal use was greater.

Algal concentrations were very low in the river water as a result of limited nitrogen and phosphate concentrations. Addition of lagoon effluent provided sufficient nutrients to support algal growth. This was indicated by significant concentration increases in the unchlorinated channel.

Several factors essential for the interpretation of BOD results, including the effects of nitrification, could not be measured. The BOD versus incubation time curves appearing in the appendix were plotted on the assumption that nitrification existed. All calculations dependent upon BOD data were made using the values from the first three days of the incubation period.

Studies by others (3, p. 177) (13, p. 157) indicate that the presence of algae has a definite effect upon the measured biochemical oxygen demand. An increase in the concentration of either live or dead algal cells will cause an apparent increase in BOD (3, p. 179). Test results show that on an ultimate demand basis, with equal

algal concentrations, the oxygen consumed in algal res-
piration under dark incubation is no greater than that
required for the aerobic oxidation of dead algal cells
(3, p. 178). Further tests indicate that although the
apparent ultimate BOD of live and dead cells is nearly
the same, the reaction velocity constant "K" was observed
to vary, with no consistent pattern developed. This was
attributed to the possible changes in the organic material
induced by the method employed to kill the algae (13, p.
162).

To aid in the evaluation of the biochemical oxygen
demand data, the general equation

$$KL = dL/dT$$

was evaluated for the condition $L = L_a$ where L_a is equal
to the ultimate BOD of the sample, L is the BOD re-
maining at time T, and K is the reaction velocity con-
stant. When K and L_a values are given, the equation
reduces to the expression

$$KL_a = \Delta L/\Delta T$$

where $\Delta L/\Delta T$ is the slope of the BOD versus incubation time
curve at the point where $L = L_a$. By definition, this
condition occurs when the incubation time $T = 0$. Since
the BOD satisfied in time T is directly proportional to
the oxygen used in the same period of time, the value of
$\Delta L/\Delta T$ can be called an oxygen use rate and designated "B"

TABLE I

OXYGEN USE RATE B

Test Run No. 1

Time	River K	River L	B	River + Eff. K	L	B	River + Cl$_2$ Eff. K	L	B
0	0.22	6.2	1.36	0.14	9.0	1.26			
1	0.20	5.2	1.04	0.19	6.2	1.18	0.26	3.5	0.91
2	0.17	4.3	0.73	0.24	4.7	1.13	0.29	6.5	1.89
3	0.16	4.3	0.69	0.29	5.5	1.6	0.33	5.8	1.92
4	0.17	4.5	0.76	0.25	7.5	1.88	0.35	5.3	1.86
5	0.18	4.7	0.85	0.18	10.0	1.80	0.38	4.8	1.82
6	0.2	5.0	1.0	0.10	13.0	1.30	0.4	4.0	1.60
7	0.23	5.3	1.22	0.05	16.0	0.8	0.43	3.5	1.51

Test Run No. 2

Time	River K	River L	B	River + Eff. K	L	B	River + Cl$_2$ Eff. K	L	B
0	0.25	1.2	0.3	0.47	3.0	1.41			
1	0.19	2.0	0.38	0.39	4.2	1.64	0.31	5.0	1.55
2	0.15	2.5	0.375	0.28	6.0	1.68	0.20	9.5	1.90
3	0.15	2.5	0.35	0.12	7.0	0.84	0.05	13.0	0.65
4	0.13	2.7	0.35	0.07	7.6	0.53	0.06	8.5	0.51
5	0.12	2.7	0.33	0.07	7.7	0.54	0.10	5.0	0.5
6	0.09	2.6	0.23	0.11	7.5	0.83	0.15	3.5	0.53
7	0.03	2.5	0.08	0.14	6.2	0.87	0.20	2.5	0.5

for convenience. The dimensions of B are mg/l/day when
K is on a per day basis. The values of K and L_a used
in calculating B were obtained from the trend curves in
figures 3 and 4. Values of B appear in Table I.

The basic relationship between the parameters K,
L_a, and B as they apply to the specific test data are
important. The values of K and L_a will uniquely define
the BOD versus incubation time curve. The value of B
indicates the rate of oxygen use in the sample at the
time it was taken, as determined by the BOD test. It
does not directly indicate an actual stream condition,
but can be used to interpret oxygen relationships in the
stream providing values are available for successive days.

Algae present in a BOD sample subjected to a dark
incubation test will produce a respirational oxygen de-
mand. If it is assumed that for the duration of the test,
the respiration rate of the cells present remains con-
stant, the indicated BOD due to algae alone could be
shown as a BOD curve with a constant slope. If this
curve were superimposed upon a standard BOD curve, the
observed effect would be a decrease in K and an increase
in BOD such that no ultimate value would be reached. How-
ever, the methods used to calculate the ultimate BOD
would establish a value for L_a. Therefore, it could be
said that the relative effect of the presence of algae in
a sample would be to increase the apparent value of L_a

and decrease K. The corresponding value of B would in-
crease. These considerations were used in the evaluation
of the BOD data.

An equilibrium condition in the river water used in
both tests is indicated by the consistency in the BOD
measured in successive samples. The lack of BOD depletion,
and the relatively constant values for K and B indicates
a balance between growth and death in the system.

The changes which took place in the channels con-
taining unchlorinated effluent differed in magnitude in
the two test runs, but followed similar trends. The re-
sults of Test Run No. 1 show a decrease in L_a and an in-
crease in K during the first 2 days. The BOD is appar-
ently being satisfied at an increasing rate. Algal
respiration effects on the measured values are probably
low but significant. After the second day, L_a increases
and K decreases. This indicates that the percentage of
the oxygen demand exerted by algal respiration is rapidly
increasing.

Significant algal respiration demands would normally
not be exerted in a stream or in the test model. Instead,
an excess of oxygen would be produced. Therefore, the
BOD test is an indication of the conditions existing in a
stream during total darkness and cannot be applied to
daylight conditions.

In Test Run No. 2, the unchlorinated samples displayed

an initial increase in L_a and a decrease in K for the first 4 days. This may be attributed to increased algal respiration resulting from measured algal growth. Following the 4th day, K increases, and L_a decreases. Although the cell count indicates an increase in the algae population, limited nutrients, as indicated by the near zero concentrations of phosphate and nitrite, would result in a decreased respirational rate and eventual death. This decreased respirational rate by the algae would produce the results indicated.

The trends experienced in the chlorinated channels were similar. The BOD results for the first few days in Test Run No. 1 were inhibited by the high chlorine dose. After the second day, the residual chlorine in the channel was dissipated, and biological activity was increasing. The high dosage of chlorine may have removed some of the potential BOD by direct oxidation and at the same time added decomposable organic matter as dead algae cells. After the second day, L_a decreased and the K increased. This would indicate that as time progressed, the biological breakdown of organic material becomes easier and a BOD reduction resulted.

The chlorinated results in Test Run No. 2 indicate an increase in L_a and a decrease in K during the first 3 days. The BOD increase can be related to the increase in organic matter being made available for aerobic

decomposition through the death of algae. Although the chlorine dosage was sufficient to affect the initial K value, the inhibiting effect upon the subsequent reactions was not as great as in Test Run No. I. After the third day, L_a decreased and K increased, indicating that the added organic matter is more readily degradable as time progresses and the remaining BOD is being satisfied more rapidly.

The oxygen use rates for the chlorinated and un-chlorinated samples within a test run are nearly the same (see Table I). This indicates that under dark conditions, similar to the BOD test, oxygen consumption will be nearly equal for chlorinated and unchlorinated samples. The value of B does not account for oxygen production by algae, therefore is not indicative of daylight conditions.

CONCLUSIONS

1. Coliform bacteria survive the lagoon treatment process, therefore disinfection prior to discharge into a stream may be required.

2. The nutrients and "seed" provided by a 1/10 dilution of unchlorinated effluent were sufficient to cause algal growth in the river water used.

3. Algal growth will result in an increase in the apparent BOD as measured by the standard dark incubation method, therefore this test will not indicate the true conditions in a stream high in green algae concentrations.

4. Chlorination increased the decomposable organic matter in the model, as measured by the BOD test, with a maximum value occuring after a 2 to 3 day lag.

5. Chlorination of the lagoon effluent resulted in a decrease in algae concentration.

6. The nutrients added to a stream with a chlorinated effluent are available for subsequent algal growth.

7. The differences in the oxygen use rates (B) of the chlorinated and unchlorinated samples are small, as measured by the dark incubation BOD test.

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APPENDIX

TABLE 2

GENERAL TEST DATA

Test	TIME days	RIVER	RIVER plus EFF.	RIVER plus Cl_2 EFF.
Test Run I	0	I	100	0
COLIFORM TEST Colonies/ml	2	I	20	0
Lagoon Effluent Count = 500/ml	7	0	0	0
Test Run 2	0	10	60	0
COLIFORM TEST	I	10	2	0
Colonies/ml	3	5	I	0
Lagoon Effluent	5	2	0	0
Count = 700/ml	7	0	0	0
Test Run I	0			0.5
Cl_2 RESIDUAL	I			0.15
Effluent Residual	2			0
1.5 mg/l at 15 min.	2			0
Total Available Cl_2	7			0
Test Run 2	0			0.3
Cl_2 RESIDUAL	I			0
Effluent Residual	2			0
0.5 mg/l at 15 min.	7			0
Test Run I	0	0.04	3.21	3.64
POLYPHOSPHATE	2	0	3.02	3.4
CONCENTRATION, mg/l	5.2	0	2.46	2.41
	7	0	2.13	1.88
Test Run 2	0			
POLYPHOSPHATE	I	0.04	4.01	3.86
	3	0.01	3.2	5.04
CONCENTRATION, mg/l	5	0.01	3.14	3.68
	7	0.02	0.4	0.15

Figure 9.

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Figure 10.

Figure 11.

BOD vs INCUBATION TIME
Test Run No. 1   2.00 Day
8:00 A.M.   March 3, 1962
o River Water Only
△ River Water + Effluent
□ River Water + Cl_2 Effluent

Figure 12.

Figure 13.

BOD vs INCUBATION TIME
Test Run No. 1   5.21 Day
1:00 P.M.   March 6, 1962
o River Water Only
△ River Water + Effluent
□ River Water + Cl_2 Effluent

Figure 14.

Figure 15.

BOD vs INCUBATION TIME
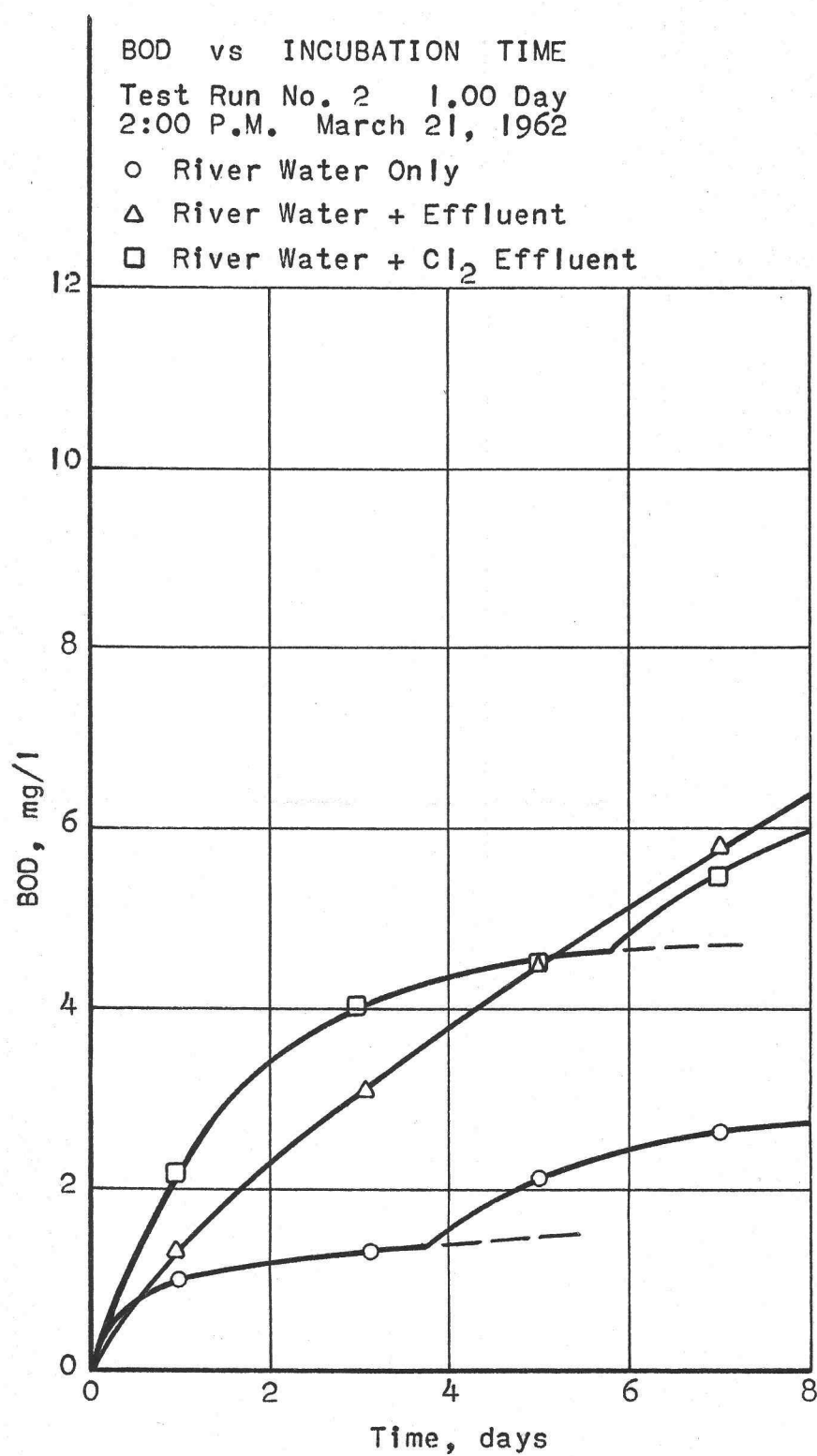Test Run No. 2
2:00 P.M. March 20, 1962
o Lagoon Effluent Only
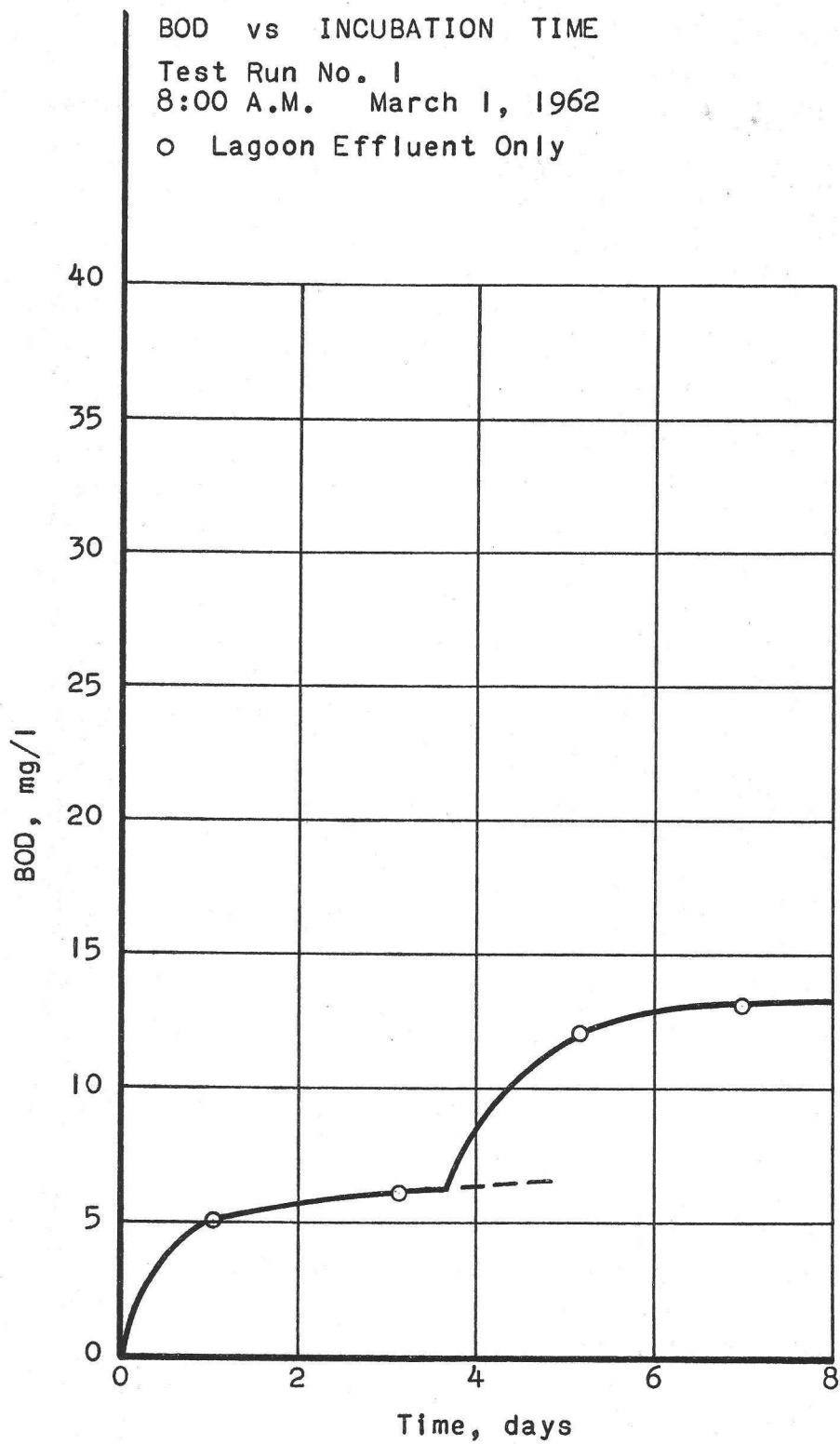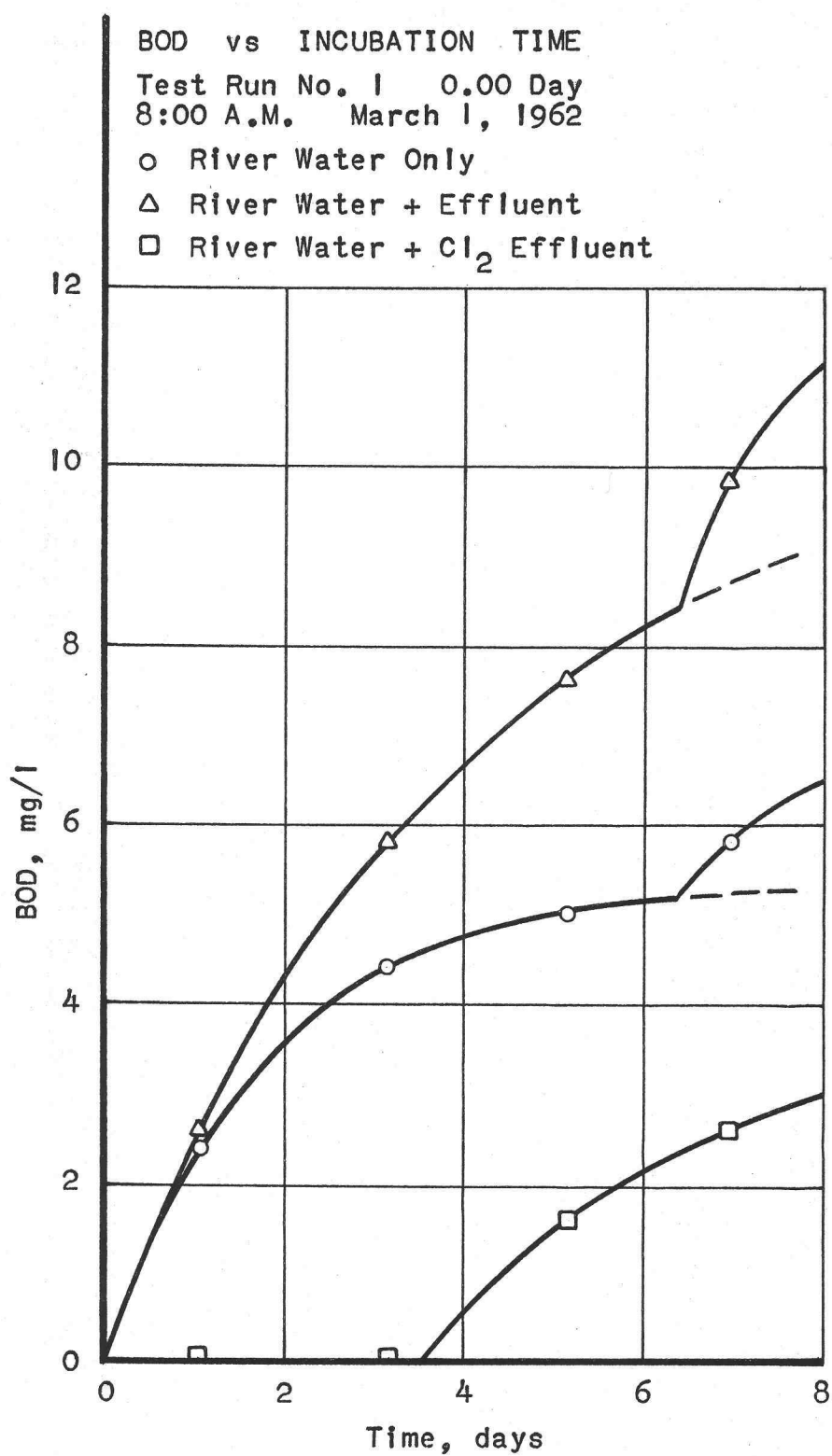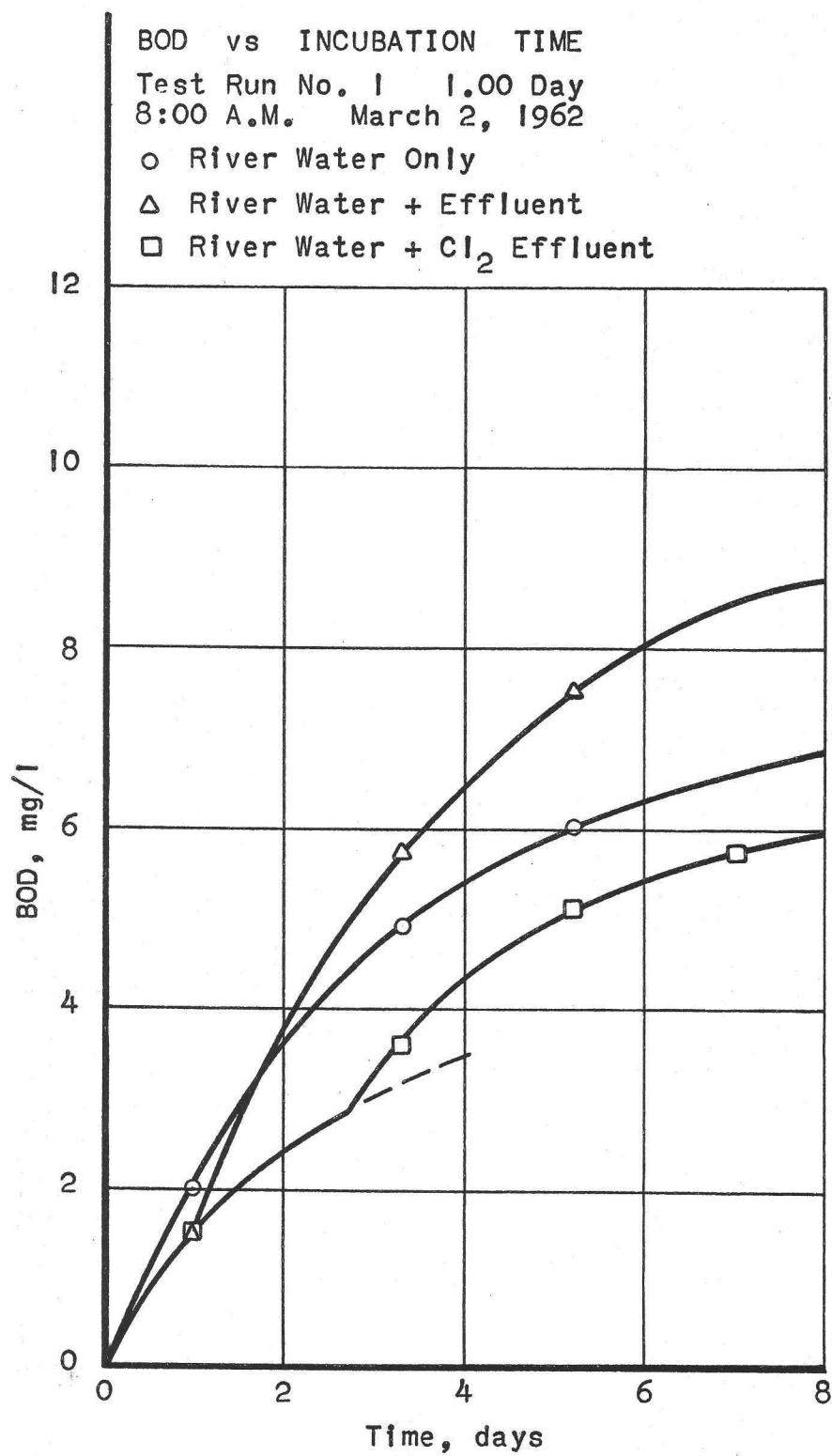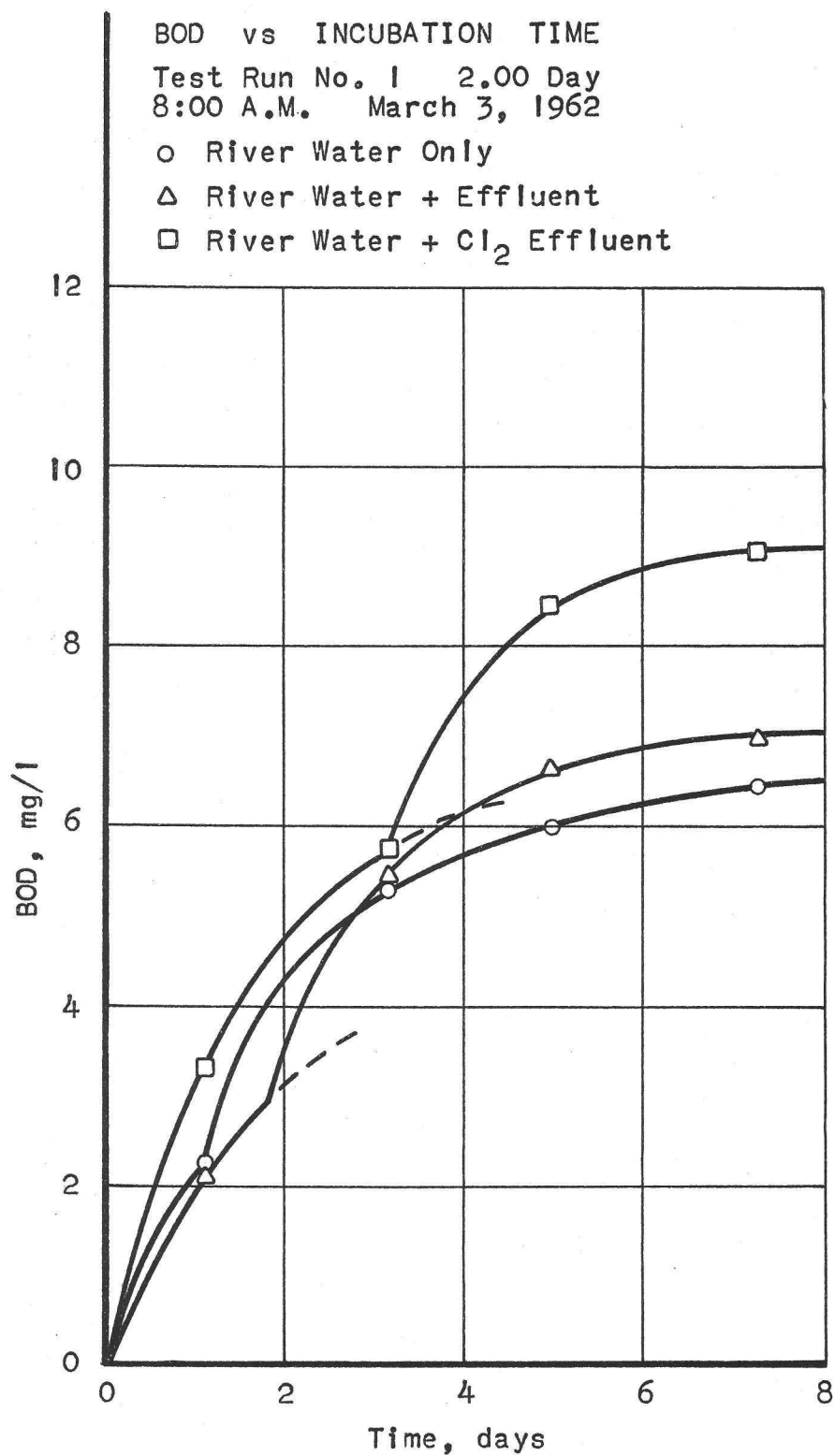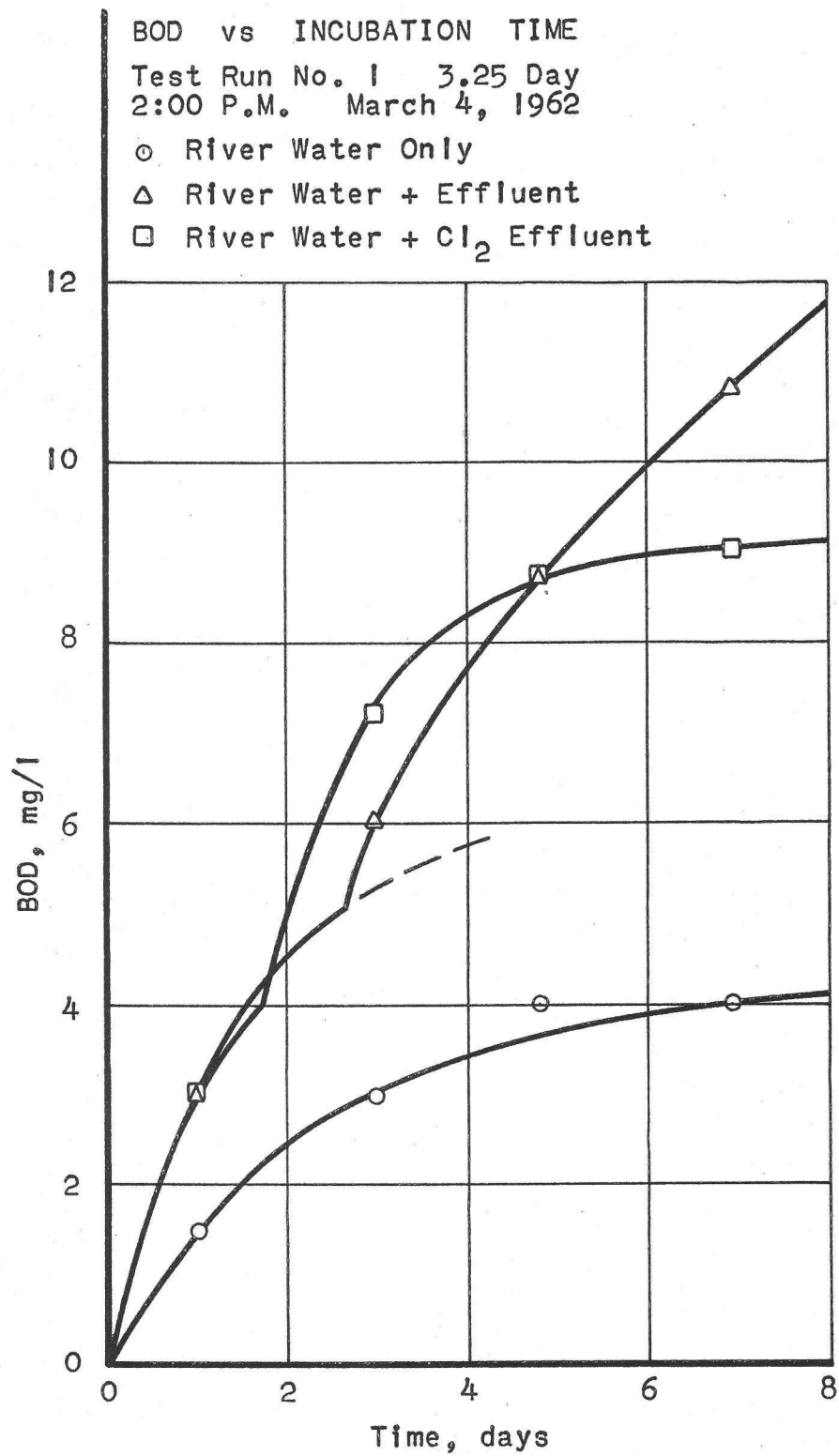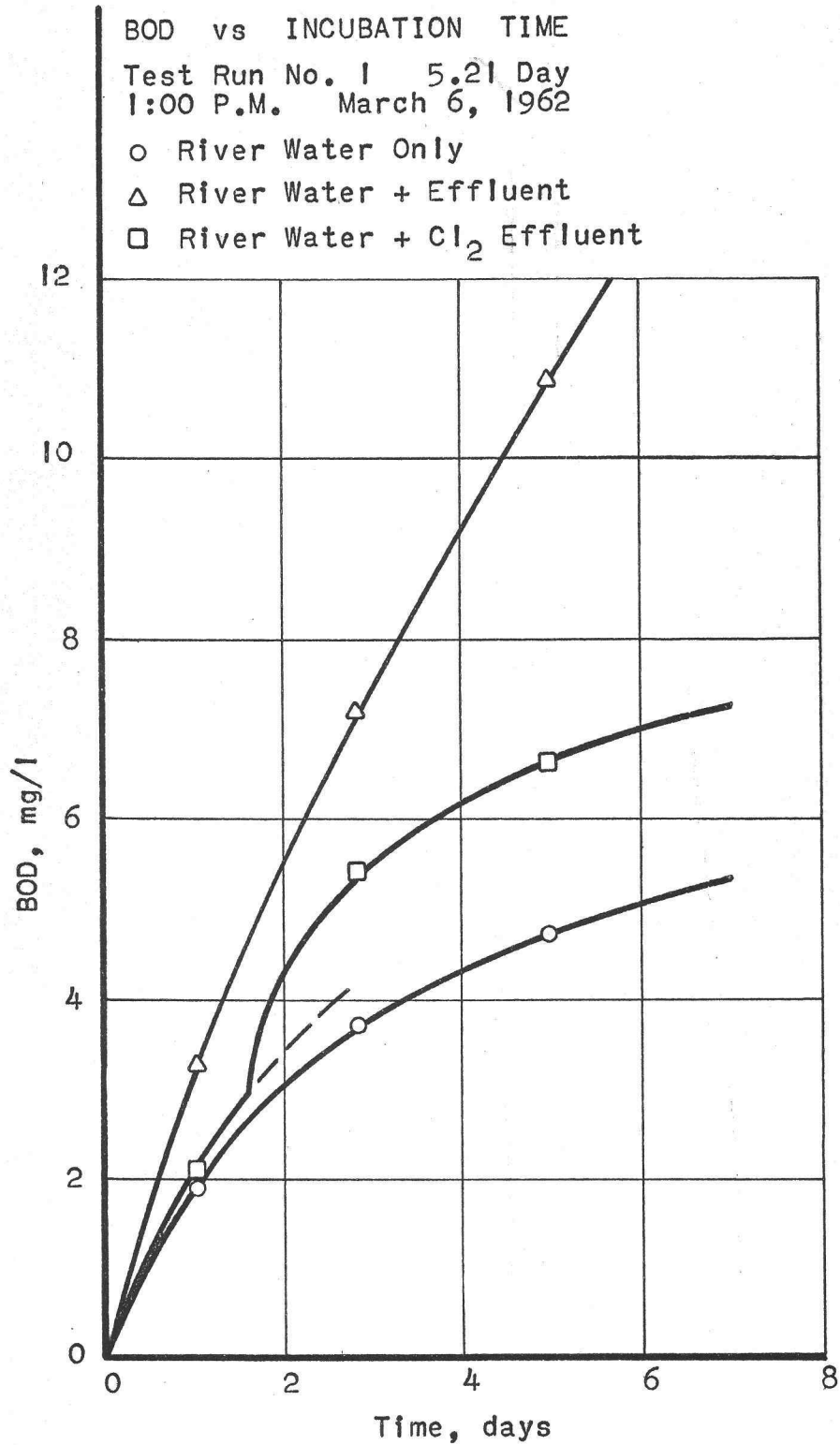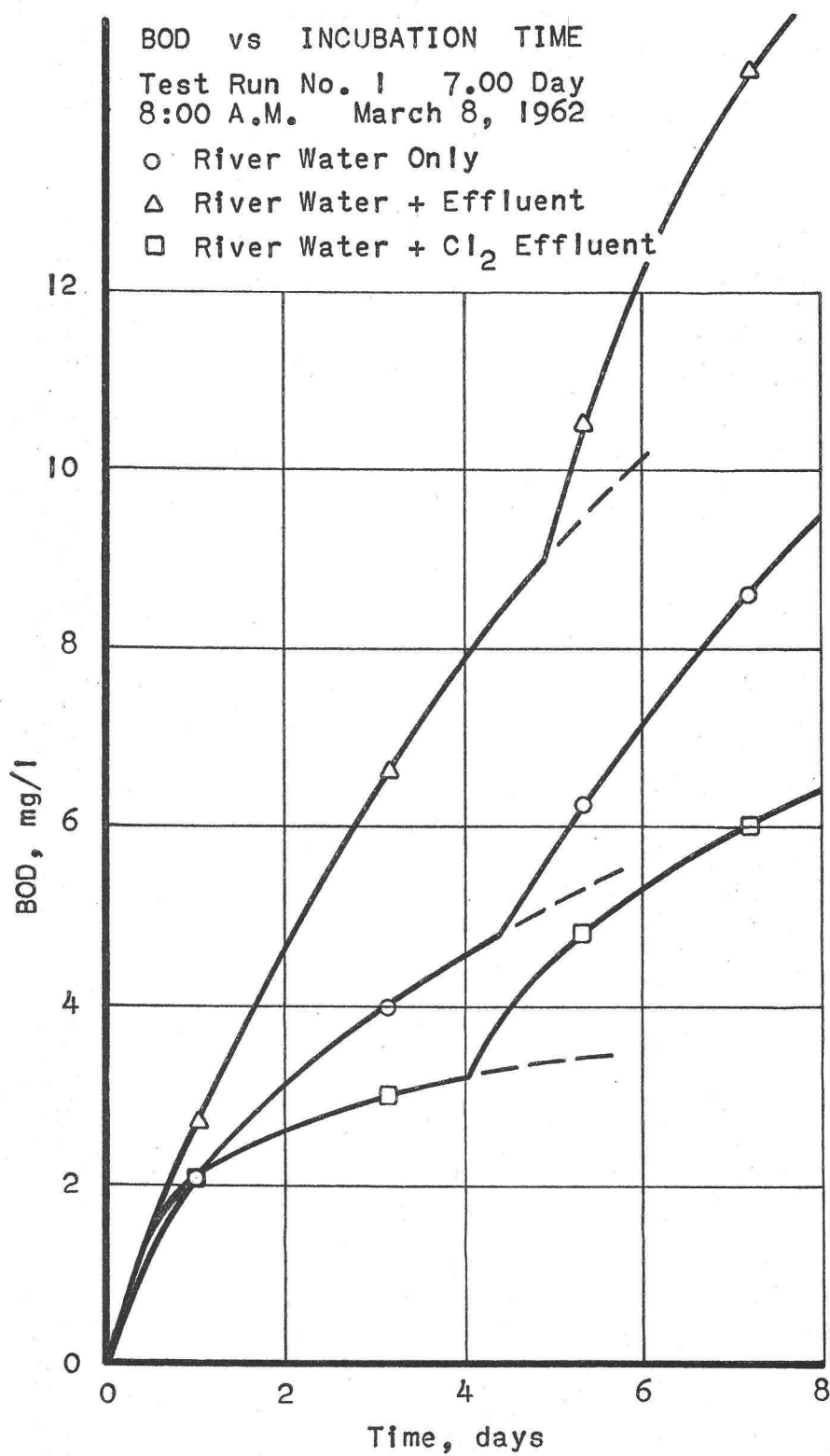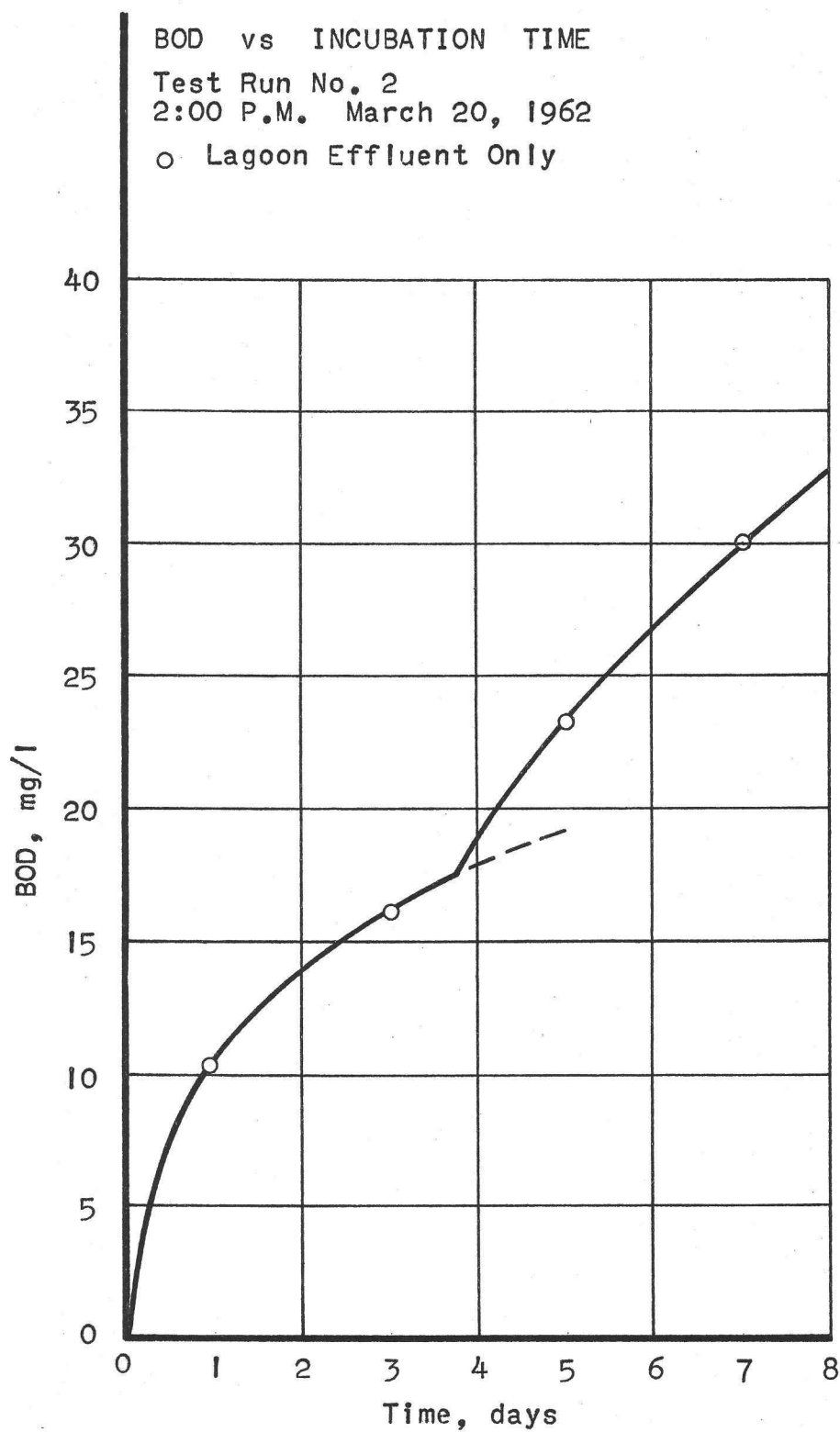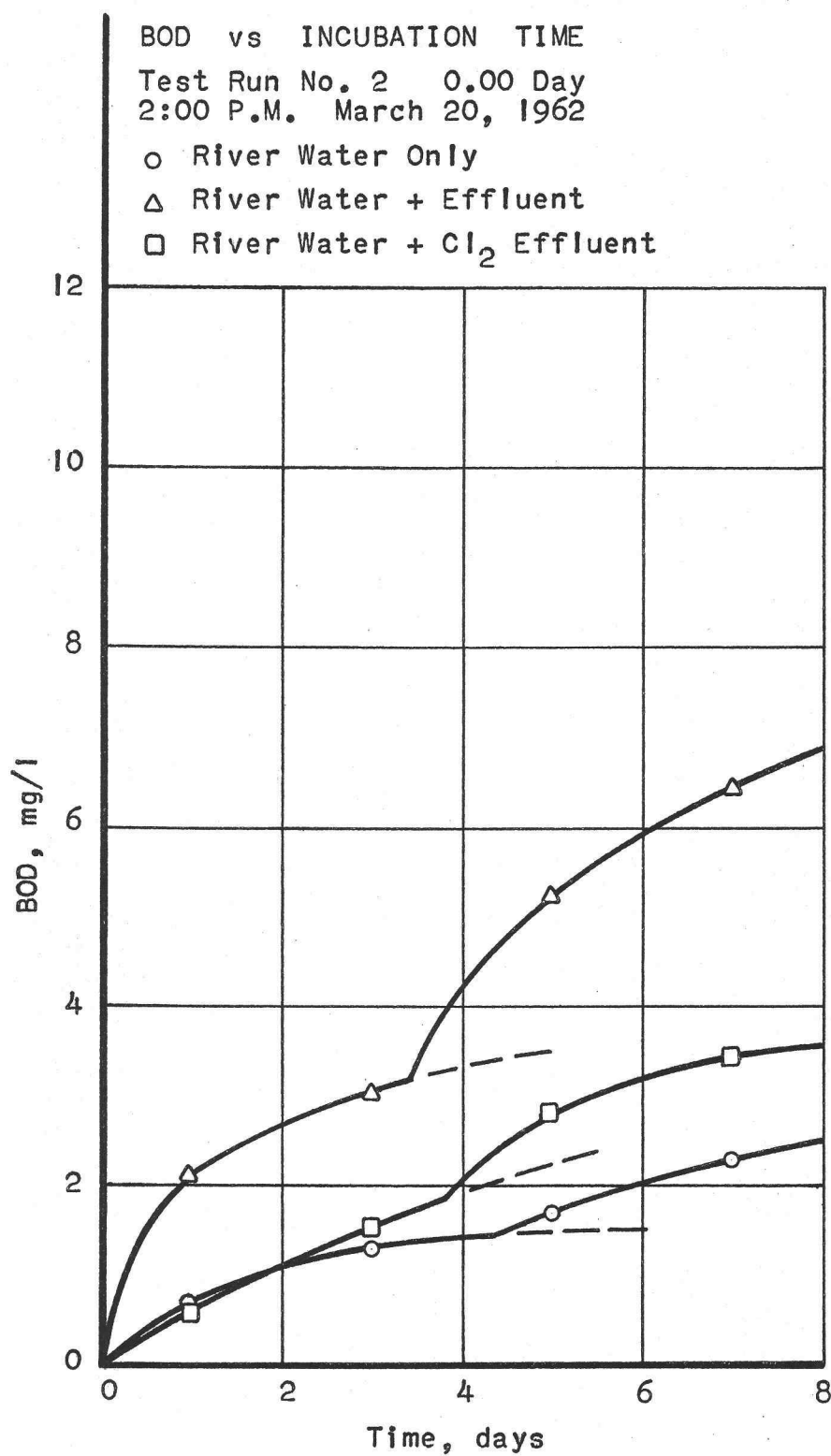
Figure 16.

Figure 17.

Figure 18.

Figure 19.

Figure 20.