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RECEIVING STREAMS RESPONSE TO EFFLUENT FROM BIO-OXIDATION PONDS

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RECEIVING STREAMS RESPONSE TO EFFLUENT

FROM BIO-OXIDATION PONDS

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ABSTRACT

This study considered the receiving stream as an integral part of the bio-oxidation pond method of treatment with the objective being to provide a better understanding of the bio-oxidation pond - receiving stream system. As representative of this "real world" situation with all of its variables, five existing central Oklahoma bio-oxidation ponds which had diverse loadings and designs were utilized. By observing these systems under varying climatic conditions, the effects of the bio-oxidation pond nutrients along with other pollutional parameters which were discharged into intermittent receiving streams were evaluated.

Except for scouring, bio-oxidation ponds and bio-oxidation pond - receiving streams were found to behave essentially the same as the streams became a continuation of the pond. In addition to making biochemical adjustments, the streams lost much of their biological identity and assumed characteristics more closely associated with the biological loadings from the pond effluent. The most persistent algae in the systems were the flagellates (Euglenophyta) and the blue-green algae (Cyanophyta) as these plankters had little difficulty making the transition from their acclimated life in the pond to the stream.

The long established criteria for evaluating waste treatment techniques (cost analyses based on percent removal of soluble biochemical parameters) excludes any regard for the conversion of mass or shuffling of constituents which takes place within the system. In order to

equitably make an economic comparison between the bio-oxidation pond and the other conventional sewage treatment processes, more attention must be given to the bio-oxidation pond - receiving stream combination.

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CHAPTER I

INTRODUCTION

Educators, employers, governmental officials and the general public are increasingly evidencing a greater awareness to stream sanitation and waste treatment. Words such as "eutrophication", "water quality standards", "in-stream" conditions, and other terms which were, in the not too distant past, spoken only in technical groups, are now appearing frequently in newspaper editorials and public speeches. There is a general concern for watercourse improvement and more emphasis is being placed on providing adequate wastewater treatment. Oklahoma is an excellent example of a state where there is a concerted effort to abate pollution and where there is a wide-spread and increasing use of a particularly economical and useful device, the bio-oxidation pond[1] for complete, secondary, or tertiary wastewater treatment. The influent wastewater, reduced in volume by evaporation and seepage, is returned to the stream, essentially greatly reduced in bio-degradable strength, but still requiring dilution. In

[1]A bio-oxidation pond is an impoundment for natural stabilization of liquid wastes through the symbiotic action of bacteria and algae. They are sometimes referred to as sewage lagoons, oxidation ponds, waste stabilization ponds, polishing ponds, or photosynthesis ponds.

Oklahoma and related areas where intensified re-use of streamwater is a certainty in the future, the reduced flows available as stream dilution water will be more and more at a premium. The prognosticated conditions of congestion demand a better understanding of the behavior and impact of these treated pond effluents upon the receiving lotic environment, as this is essential in evaluating any water resource system and selected treatments.

A comparison of removal efficiencies for the various other conventional processes available to that of the bio-oxidation pond is shown in Table 1. Present treatment of domestic wastes abates for the most part, pathogenic organisms and oxygen demanding organic loads. Despite some categorical reductions, the finished effluent contains soluble materials, total dissolved solids (TDS), which are not readily amenable to conventional sewage treatment practices. These materials provide a nutritious source of nitrogen (N), and phosphorous (P), and could promote latent biological activity within the receiving waters, called nutritional pollution.

TABLE 1

A COMPARISON OF REMOVAL EFFICIENCIES FOR VARIOUS CONVENTIONAL MUNICIPAL SEWAGE TREATMENT PROCESSES

TREATMENT PROCESS	PERCENT (%) REMOVAL					
	SOLIDS		ORGANIC	NUTRITIONAL		BACTERIOLOGICAL
	TDS	SS	BOD	N	P	COLIFORMS
Trickling Filter	5-10	70-85	75-90	15-35	2-20	90-95
Activated Sludge	10-15	80-95	85-95	40-60	30-40	90-98
Bio-oxidation Pond	0-25	0-45	70-99	30-95	30-95	88-90+

Research in the field of wastewater treatment has shifted from considering organic oxygen depleting substances as a main removal objective, to an emphasis on nutrients. This has been the case with bio-oxidation ponds, the subject of this study. Table 1. illustrates the striking difference in nitrogen and phosphorous removals by the bio-oxidation pond as comparied to the other biological treatment processes. Bio-oxidation ponds may be as much as 40-50 per cent more efficient in removing N and P because carbon is not limiting. Consequently, their operation has been subjected to intense study since the first engineered pond in the late forties and a working knowledge of operating conditions has evolved through both macro and micro research on existing and simulated bench-scale ponds. The studies to date, all have the common denominator of viewing bio-oxidation ponds as self-contained entities.

The influence of the bio-oxidation treatment and waste disposal method does not end at the pond, except in the case of the complete retention system (retention time = ∞). In most cases a drainage exists which contains wholly or in part the effluent, which further alters in character with time and distance, so the pond and the receiving stream both work to improve the quality of the waste. In fact, the pond and receiving stream should be treated as a single system with the development of an optimal, and not merely a sequential relationship.

The system as shown in Figure 1, is schematically simplified. It is presented in greater detail in the following section, however, for initial illustrative purposes, the sewage influent (Q_o) is characterized by its biochemical oxygen demand (BOD_o), nitrogen (N_o), phosphorous (P_o), and bacterial flora (B_o). The effluent (Q_1) which remains after losses due to evaporation and seepage, has, in addition to the other parameters, plankton (Pk_1), which is discharged into a similarly identified stream.

The downstream volume (Q_3) is comprised of the effluent plus the stream's volume with unknown chemical and biological characteristics. The greenish, plankton laden effluent is evidence that much more occurs within a bio-oxidation pond than simple settling and the carbon, nitrogen, and phosphorous removal as detected in liquid effluent. There is a definite mass conversion which is passed on the receiving waters.

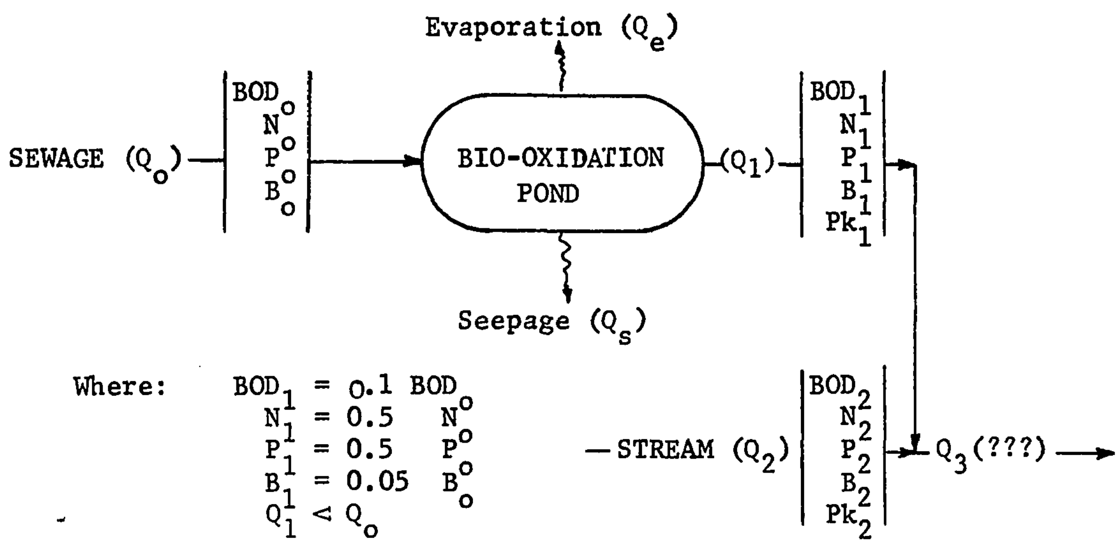


Figure 1. Bio-oxidation Pond -- Receiving Stream System

In the Southwest, evaporation is high and intermittent stream flows provide minimum dilution for the pond effluent. In recognizing this situation, it is the purpose of this study to consider the influence and fate of the nutrients, biodegradable-oxygen-demanding constituents, and biological concentrations remaining in the effluent once they are released to the stream, thus providing a better understanding of the Bio-oxidation pond-Receiving Stream System. The two components of this system can be identified and characterized individually through a study of the state of the art.

State of the Art

Bio-oxidation Pond

As compared to the other wastewater treatment processes available, construction costs for bio-oxidation ponds are minimal. They require very little attention, thus, operation and maintenance costs are low. The low total costs make them financially attractive to the small southwestern city faced with the problem of producing an acceptable effluent that can be released to surface waters.

Thorough studies on these ponds, since their recent introduction, have contributed toward a better understanding of the physical, chemical, and biological processes which take place when domestic wastewater (sewage) is retained for natural stabilization. Untreated sewage contains a rich and frequently imbalanced source of nutrients in both macro and micro levels, and is capable of supporting planktonic and other microscopic growth. It has been shown that stabilization of sewage is accomplished within a bio-oxidation pond through the symbiotic actions of heterotrophic and autotrophic bateria and algae (Oswald, 1957).

Soluble organic matter is reduced to cellular constituents and energy. As cell growth increases, nitrogen, phosphorous and other elements are incorporated into the cell. Carbonaceous material is utilized as an energy source with the resultant by-products of carbon dioxide (CO_2) and shortened chained carbonaceous materials. Photosynthetic planktonic organisms (algae) utilize the CO_2 released by the bacteria, maintain their own nutritional balance, produce additional algal cells, and in the process, liberate molecular oxygen (O_2). This symbiotic relationship is diagramatically simplified in Figure 2.

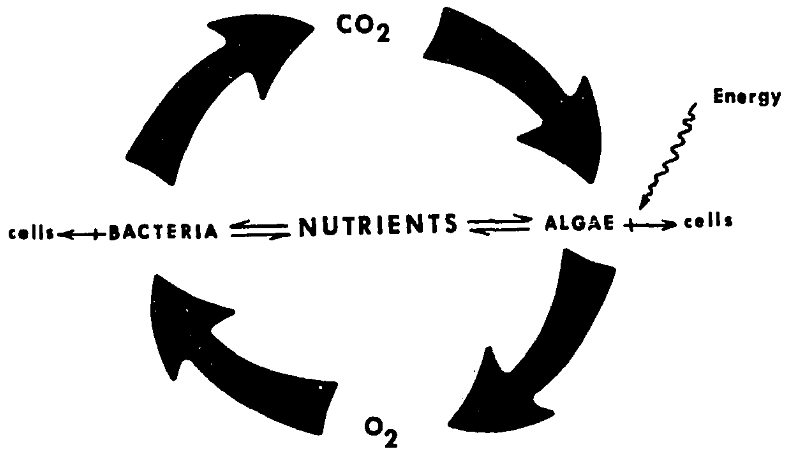


Figure 2. Bacteria - Algae Symbiosis In a Bio-oxidation Pond

As this cyclic decomposition scheme proceeds, the biochemical oxygen demand (BOD) is reduced and biomass growth is prolific. If one were to attempt an input-output balance on a bio-oxidation pond, the results could be pictorially represented as Figure 3. Variations in climatic conditions cause the major fluctuations in pond performance. Soil conditions, sunlight, and littoral vegetation may be considered constants if a long enough time interval is placed on the system, so that seasonal effects of climatic variables may be considered parameters. This is usually possible because of the long retention times within the ponds. Climatic conditions, which are seasonally induced, have both direct and indirect effects on pond

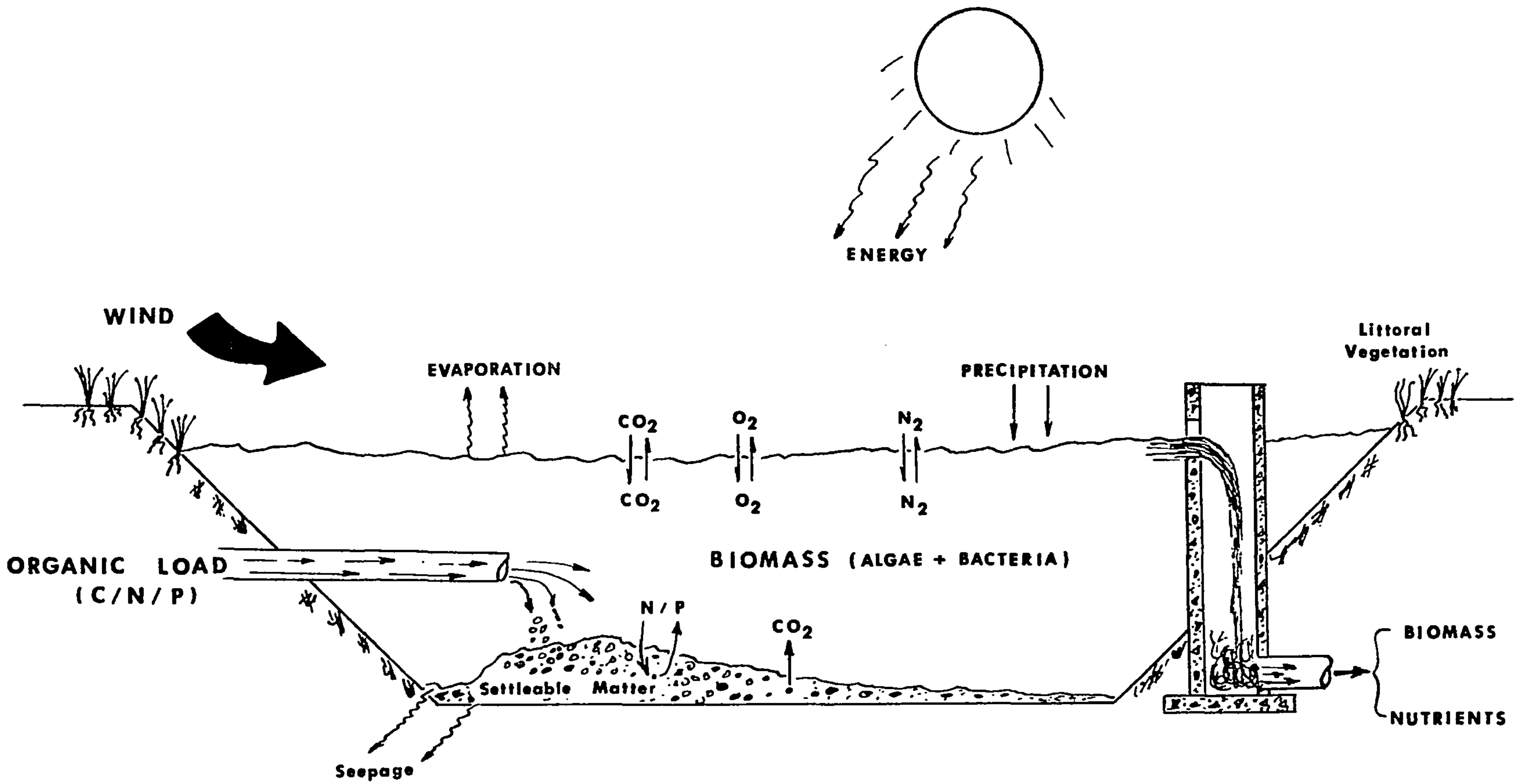


FIGURE 3: SOURCES OF GAINS AND LOSSES (INPUT-OUTPUT) FOR A BIO-OXIDATION POND MASS BALANCE.

behavior. Wind actions affect oxygen and other gas transfers, along with having a direct influence on evaporation. Evaporation tends to concentrate dissolved material where rainfall, even though it contains some particulate matter and dissolved gasses, dilutes the ponds contents. The major influence of these external factors, as will be seen later, is one of governing the extent of mass conversion, which initially is dependent on the nature of the raw sewage.

The relative concentrations of nutritional elements in raw sewage have been steadily changing over the years. Average ratios of carbon (C) to nitrogen (N) to phosphorous (P) (C/N/P) which once were 60/7/1 in raw domestic sewage, are now approximately 14/2/1, due to increasing discharge of detergents containing phophates (Reid, et al., 1967). The overabundance of nutrients becomes apparent when considering the BOD/N/P combining ratio, proposed for ideal biological assimilation, is 100/6/1 (Helmers, et al., 1951). It follows that the oxygen demand is greatly reduced, but the biomass is increased. From an input-output balance, there is merely a "shuffling" of elements and little net change. The losses within a bio-oxidation pond are due to retained settleable and precipitated solids (since sludge is not physically removed, these losses are minimal as many of these solids undergo additional stabilization then become accountable), and limited losses due to seepage, littoral vegetation, and atmospheric transfer. Net gains, as will be seen later can also occur, due to a relative overabundance of phosphorous (P), related to nitrogen (N) and carbon (C) and the possibility of adding N from the atmosphere and C from photosynthesis.

Heukelekian (1960) observed the photosynthetic transfer of such inorganic materials as ammonia, phosphate, and CO_2 into cellular material, and felt that algae should be labeled "producers" rather than "destroyers" of organic matter. This point may be illustrated by the following recent example. After a year of periodic sampling on a single cell bio-oxidation pond in Iowa, Raschke (1970) reported maxium per cent reductions in total and volatile solids of 30 and 39 per cent respectively; however, examination of his data reveals that net increases in total and volatile solids through the pond were 38 and 31 per cent respectively, and occurred predominately in the summer and fall, concurrently with maximum algal concentrations. The literature abounds with discussions on reductions in dissolved and soluble materials within a bio-oxidation pond, but what most researchers fail to consider is that these materials are not truly removed, but simply discharged in a different form.

The ideal ultimate solution would be harvesting the algal crop; thus, removing this biomass from the effluent before it reaches the receiving waters. In experimental feeding of harvested sewage-grown algae (predominantly *Scenedesmus* and *Chlorella*), Hintz, et al., (1966) have shown that these algae contained over fifty per cent crude protein plus significant amounts of phosphorous, calcium, carotenes, and trace minerals. The problems associated with harvesting algae are evident in that it must be concentrated, dewatered, and dried before it can be stored and handled, processes generally too expensive for small installations where bio-oxidation ponds are used.

Since algae, at present, is not amendable to economical harvesting techniques, it is included in the effluent but not counted in the calculation of the pond efficiency in removing BOD, N, and P. Upon leaving the pond, these organisms have to adjust to an ecosystem within the stream which includes different hydraulic and soil conditions, littoral shading, and chemical and biological quality variations.

Streams

There are many characteristics which make streams quite different from bio-oxidation ponds. The temperature in a stream closely follows the air temperature where the temperature in a pond will lag, and not respond abruptly to ambient changes. Another feature unique to a stream is the current and flow is in one direction. In effect, all physical, chemical, and biological conditions gradually change with distance with suspended or dissolved materials being transported downstream unable to return.

Streams are dynamic and continously changing physical features because of friction and resultant erosion. In elevation view the vertical velocity gradient within a stream is semi-parabolic in shape with the lowest velocity, due to friction, being at the bottom of the channel. In plan view the stream assumes configuration commonly called meanders, which Leopoid and Langbien (1966) described as sine-generated curves which result when a stream, because of total friction, wants to change directions in a manner which conserves the most energy and minimizes total work.

The nature of the channel bottom and the velocity of flow determine not only the character and rate of erosion and subsequent sediment transport, but largely influence the biotic distribution. Selective and non-uniform degradation of bottom materials in a small stream creates alternating pools and riffles which provide two distinct types of habitats. Since availability of basic food materials is a major factor controlling biological productivity, the habitat and biotic discussion which follows is of a general nature confined to streams which are small and not subject to nutritious point loads, as this will be discussed later.

Pools and areas where stream velocity is reduced predominantly provide a habitat for rooted aquatic plants, attached filamentous algae, and the higher aquatic animals such as fish. The riffles, on the other hand, exhibit a habitat almost exclusively for benthic animals as the higher velocity not only provides continuous conveyance of food materials, but gas transfers are accelerated at the liquid-air interface of the riffle, with resultant increased oxygen adsorption to meet the zoo-benthic oxygen demand.

Plankton is not typically found abundant in streams and in some instances it may be completely absent. When plankton is present, the phytoplankton most frequently consists of diatoms and green algae, rotifers and protozoa being the principal zoo-plankters.

Streams depend on the surrounding watershed area, not only for flow contributions, but almost entirely for nutritional subsistence. Land-use practices on the watershed largely govern the nature and concentrations of basic food materials which enter the stream and, consequently, the stream must sometimes cope with redundant or vestigial materials and other sources of nutritional pollution.

Receiving Streams (Systems)

In the broadest sense, all streams could probably be considered receiving streams because of the impurities which are accrued during travel from the stream's headwaters to its mouth; however, in water pollution control the term is reserved for those streams which receive discrete controllable point loads such as sewage.

A healthy stream has been described as one in which "the bio-dynamic cycle is such that conditions are maintained which are capable of supporting a variety or organisms" (Patrick, 1949, after Welch, 1952). When an unstable organic load, such as raw or poorly treated sewage, is introduced into a clean healthy stream, a succession of physical, chemical, and biological changes take place. Some of these effects will be discussed, as many of them will be shown later to be equally applicable to streams receiving "highly" treated sewage.

The streams biotic response to induced pollutants follows two principles of ecology: (1) the Law of the Minimum Supply, and (2) the Law of Tolerance (Odum, 1953). If suspended material is present, aquatic vegetation has it energy source, sunlight, reduced and thus the process of photosynthesis is retarded and in extreme cases, stopped. The resulting nutritional imbalance causes an increase in scavenging organisms to cope with the increased food supply. Higher aquatic forms which are motile (nekton), can sometimes migrate to locations with more favorable environmental conditions. Those aerobic organisms being less tolerant to physical and chemical stresses and unable to relocate, succumb, and are replaced by facultative organisms. In summary, a variety of species existing in relatively low numbers (a balanced population) are replaced by relatively large numbers of organisms with little species diversification. These conditions are temporary, however, because as flow proceeds downstream, surface reareation offsets deoxygenation, suspended materials begin settling, and the flora and fauna again approach balanced diversified populations. An example of these effects is shown in Figure 4. In the zone of recovery and clean water zone, the oxygen demand is greatly reduced; however, nutrients remain abundant.

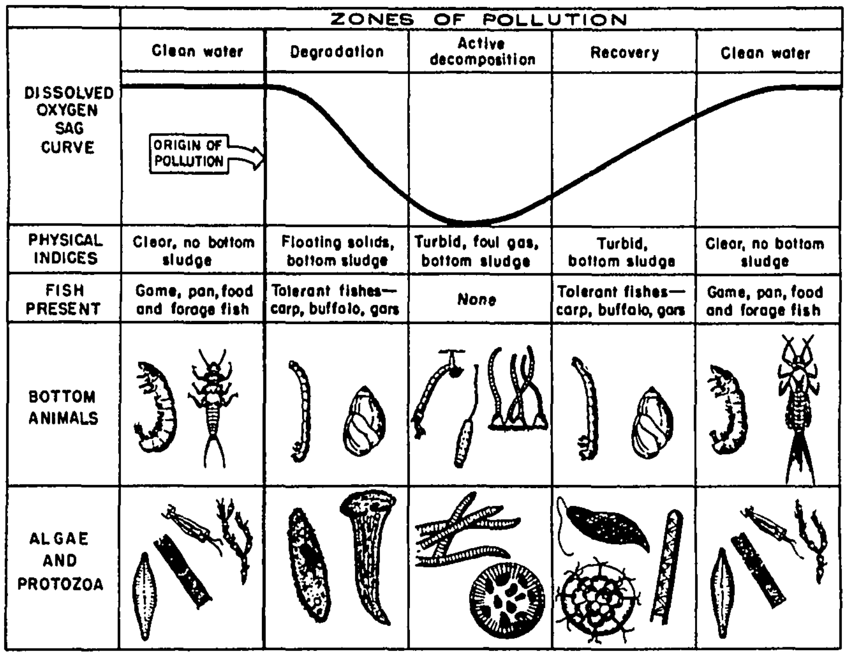


Figure 4: Pictoral diagram showing some examples of streamlife before and after discharge of organic wastes (after Ingram, McKenthun, and Bartsch (1966), p.49. Reproduced by permission of the Federal Water Quality Administration).

The simulataneous interplay between stream re-aeration and deoxygenation, termed the oxygen economy in a stream, was empirically described over 40 years ago (Streeter and Phelps, 1925). At that time much sewage was either being discharged without treatment or at most given primary treatment, and the initial oxygen demand transferred to the receiving stream was justifiably of principal concern because of the resulting biotic disruptions. The oxygen demand maybe currently a lesser problem because virtually all sewage now receives either primary or secondary treatment. Primary treatment is becoming increasingly less acceptable to water pollution control authorities because it is relatively ineffective in reducing colloidal matter and the biochemical oxygen demand (BOD). Secondary treatment is capable of reducing most of the BOD remaining in primary effluent and, although it is relatively ineffective in reducing nitrogen and phosphorous (Table 1), it is now considered as the minimum acceptable degree of treatment for sewage discharged into not only most streams but also most lakes and bays. It can be seen why sewage treatment plants have sometimes been likened to "several miles of river" as the oxygen demand is greatly reduced, leaving an overabundance of nitrogen and phosphorous (nutrients) much like the chemical quality of the downstream recovery and clean water zones of the earlier example.

Excessive nutrients in a water source can have varying degrees of effects. Lackey (1958), after studying receiving water fertilization, concluded that the ill effects from the admission of treated sewage may seem to outweight the benefits. The most troublesome problem with an overabundance of nutrients is the accelerated euthrophication indicated by the production of algae, referred to as nutritional pollution.

Algae is renown for its aesthetic degradation of recreational areas, as well as its role in altering impounded water quality and affecting overall limmological productivity. If the water affected is used as a raw water source for a municipal water supply, some genera of algae interfer with water treatment operations by clogging intake screens and filters along with forming slimy coatings on raw water transmission lines, settling basins and filter walls. Production of taste and odors in finished water is another nuisance problem linked to certain algae; thus, operation costs at the treatment plant are increased as additional disinfectants are needed; taste and odor controls have to be implemented; more in-plant maintenance is required; and filter runs are shortened (Palmer, 1962).

Several genera of blue-green algae pose a potential threat to humans, livestock, and fish by either being toxic or producing toxic by-products during "bloom" conditions (Ingram and Prescott, 1954; Gorham, 1962; Echlin, 1966). The reasonsfor algal "blooms" are still being sought. Rand and Numerow (1964) compiled an annotated bibliography with 193 references that deal with the subject of nutrients and their relationship to the growth of algae. As reported, accurate and precise predictions of when and where "bloom" conditions might occur are shrouded by the biological fact that some species are capable of fixing atmospheric nitrogen, while others have luxurious uptakes of phosphorous, the element which is known to be critical and thought to be limiting to growth. Consequently, algae may propagate prolifically under conditions which seem adverse because of nutritional imbalances and conversely, growth may not occur under seemingly ideal conditions.

On the other hand, additional nutrients and resultant algae might be beneficial by inhancing a receiving waters productivity. Spirogyra for example, has been described as a polluted water alga , yet it is known to harbor invertebrate species. Additionally, certain mayflies, caddisflies, and midges inhabit a wide variety of algal types (Neel, 1968). Ingram, et al., (1966, p.71) describe benthic flora as a "miniature jungle in which animals of many kinds prey upon each other with the survivors growing to become eventual fish food." Morris, et al. (1963) looked at the effects of extended aeration plant effluent in small streams and found that after the first 300 to 700 feet below the effluent outfall, the stream became clear, supported additional attached algal growth, and the numbers and varieties of benthic organisms and fish were subsequently increased. The significance of these observations is that an optimum system relationship can be established. The sewage treatment plant reduces the oxygen demand and the receiving stream biota utilizes the induced nutrients resulting in effective sewage disposal and an ecological improvement.

The downstream effects due to a high oxygen demanding waste with relatively low nutrients are well understood, <u>but many unknowns remain about the effects of the converse--a low oxygen demanding effluent with relatively high nutrients</u>. Consequently, general practice of water pollution control has focused primarily on providing treatment which reduces the BOD and until recently, lesser emphasis was placed on removing nutrients. One device which reduces both the BOD and the nutrients in the liquid effluent (in exchange for algal biomass and possibly more total mass) is the bio-oxidation pond. There is however, a lack of information on the overall effectiveness of the pond with relation of the receiving stream (the system), and in particular, small intermittent receiving streams. These systems are found in Oklahoma and are the nature of this study although ponds are found most everwhere.

Specifically, the objectives of this study are to provide a better understanding of the bio-oxidation pond and receiving stream system by evaluating the effects of bio-oxidation pond nutrients along with other pollutional parameters which are discharged into intermittent receiving streams. Observations were made under varying climatic conditions on existing bio-oxidation ponds which had diverse loadings and designs, rather than a single controllable pond.

CHAPTER II

THE STUDY BIO-OXIDATION PONDS AND RECEIVING STREAM SYSTEMS

The study area, central Oklahoma, generally lies in what is physiographically classified as the Central Redbed Plains, characterized by its low rolling hills, suitable for livestock pasture land and limited agriculture. The rural farming communities and towns, many of which act as a "bedroom" for the Greater Oklahoma City Metropolitan Area, are operated on restrictive budgets; thus, bio-oxidation ponds are being extensively used to satisfy waste treatment needs.

Of the more than 100 bio-oxidation ponds now in use in Oklahoma, at least 15 are located with a 50 mile radius of the City of Norman. It was decided to select several ponds from those available which would provide a variety of loadings and effluent flows, rather than constructing a single, controllable pond. In addition to economic considerations, this procedure of selecting existing ponds provided excellent data in a previous study by Assenzo and Reid (1965). Figure 5 shows the relative locations of the five selected systems -- Lexington, Maysville, Blanchard, Quail Creek, and Bluff Creek.

BIO-OXIDATION PONDS

The selected ponds which individually constituted one part of the system (see Table 2) served populations ranging from 1,200 to 20,000

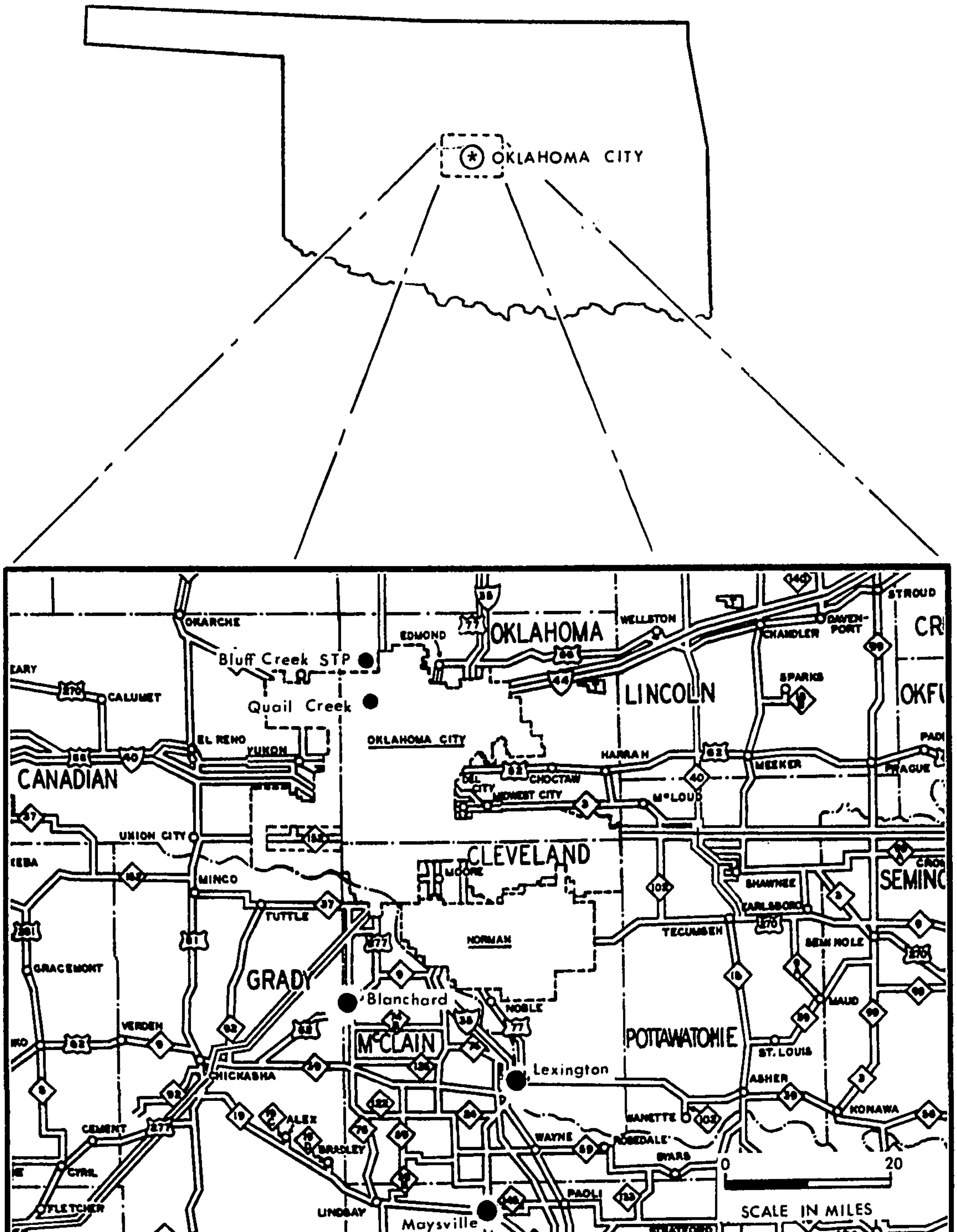


FIGURE 5: LOCATION OF STUDY BIO-OXIDATION POND - RECEIVING STREAM SYSTEMS

and represented the two predominant types of ponds found in Oklahoma, namely the raw and the tertiary bio-oxidation ponds locally referred to as sewage lagoons and polishing ponds respectively. These ponds ranged from single cell to multicelluar units with varied designs. Examples of these are shown in Figure 6.

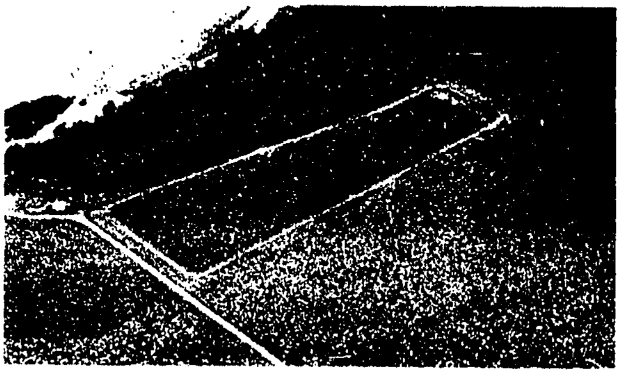
TABLE 2

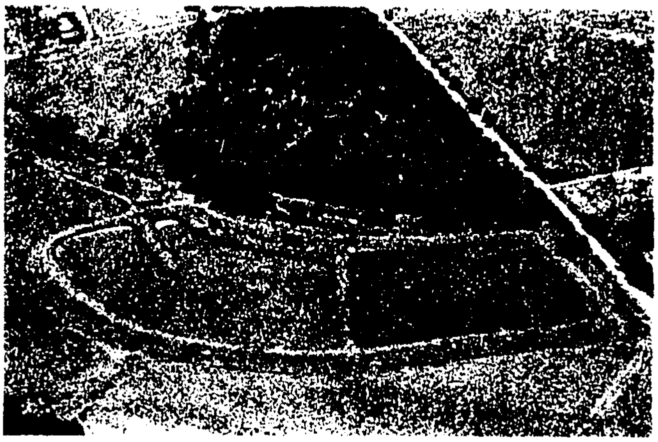
STUDY BIO-OXIDATION PONDS

POND	POPULATION SERVED	NO. OF CELLS	SIZE, ACRES	TYPE	AVERAGE EFFLUENT FLOW, MGD
Lexington	1,200	1	2.9	Raw	0.07
Maysville	1,500	2	8.7	Raw	0.03
Blanchard	1,400	2	10.0	Raw	0.04
Quail Creek	2,500	1	11.2	Raw	0.24
Bluff Creek	20,000	2	10.5	Tertiary	2.00

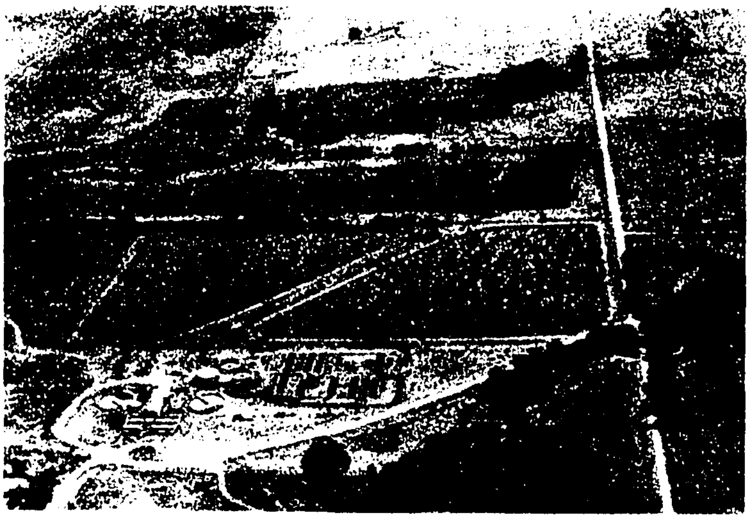
In addition to design variation, there were also wide variations in the operation and maintenance of these ponds. For example, the Lexington pond was often operated on a "fill-and-draw" basis during the winter season and during periods of blue-green algae blooms; sodium nitrate was on occasion, added to the Blanchard pond during the winter to chemically assist in the bio-oxidation process; sewage was frequently by-passed at the Maysville facility because of intermittent malfuctions at the lift station. Because of these operation anomalies, the portion of the study which included the Lexington and Maysville systems was limited to their

Right: Single-cell Raw Pond (Lexington)





Left: Multicellular-Raw Pond (Blanchard)



Above: Tertiary Pond (Bluff Creek)

FIGURE 6: PREDOMINANT TYPES OF BIO-OXIDATION PONDS IN THE CENTRAL OKLAHOMA STUDY AREA

respective transport streams (flow consisted entirely of pond effluent).

The Blanchard, Quail Creek, and Bluff Creek bio-oxidation ponds experienced very minimal effluent flow variations. Present day domestic water uses have tended to minimize extreme day-to-day flow fluctuations. Although hourly influent flow variations definitely occurred, the ponds dampened their effects. During the summer months, evaporation from these ponds was apparently largely offset by the increased influent flow due to increased domestic water usages during the warmer weather.

Seasonal influences are reflected in the chemical and biological quality of the effluent. The effluent biochemical oxygen demand (BOD), the present day yardstick for pond performance, ranged from a minimum average of 7 mg/l during the summer months at Quail Creek to a maximum average of 54 mg/l during the spring at Blanchard. The maximum and minimum seasonal average BOD, N, and P for the effluent from each individual pond is shown in Table 3 along with the biological characteristics. These values are seasonal averages based on numerous individual analyses and do not represent the recorded maximum or minimum individual values found in the pond effluent.

The biological activity, or biomass, within the ponds, experienced seasonally cyclic maximum and minimum concentrations. In the Quail Creek and Bluff Creek effluents, maximum biomass occurred during the summer months (peroid of minimum BOD). The winter season, contrary to theory, produced the most prolific biomass concentrations at the Blanchard and Lexington ponds. Although Fitzgerald (1961) concluded after a two year study on oxidation ponds that there were considerable periods during the year which might be considered optimum for algal growth, yet there was

TABLE 3

BIOCHEMICAL AND BIOLOGICAL CHARACTERISTICS[1] OF THE

EFFLUENT FROM THE STUDY BIO-OXIDATION PONDS

	LEXINGTON		MAYSVILLE		BLANCHARD		QUAIL CREEK		BLUFF CREEK	
	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average
BOD, mg/1	27(W)	8(S)	21(F)	10(W)	54(Sp)	21(S)	40(W)	7(S)	32(W)	8(F)
KJEL NITROGEN, mg/1 as N	52.6(W)	11.8(S)	3.4(S)	7.6(F)	29.7(W)	7.4(Sp)	12.9(W)	4.0(Sp)	57.2(Sp)	29.9(F)
T - PHOSPHATES, mg/1 as P	19.59(W)	6.70(S)	11.90(W)	2.5(S)	12.76(S)	2.15(F)	12.24(W)	5.75(S)	19.00(Sp)	15.50(S)
COLIFORMS, Colonies x 10^3/100ml	270(W)	52(F)	290(S)	6(F)	1600(W)	150(S)	460(S)	59(F)	380(S)	40(F)
PLANKTON ASU's x 10^3/ml	162(Sp)	107(F)	100(Sp)	9(W)	176(W)	59(F)	190(S)	76(W)	283(S)	23(W)

(W) = Winter
(Sp) = Spring
(S) = Summer
(F) = Fall

[1]These are seasonal averages of approximately 10 - 20 individual analyses.

very little algal development, it is felt that operational procedures at these two ponds explain the seasonal growth anomalies.

The phytoplankton populations in the effluent from the selected ponds were comprised generally of planktonic single cell green algae, Chlorophyta (Chlorella, Scenedesmus, Ankistrodesmus, Chlorococcum), and a few short filamentous and colonial blue-green algae, Cyanophyta, (Arthrospira, Oscillatoria, Anacystis). Population shifts from Chlorophyta to Cyanophyta were evident during the summer months, particularly in the Quail Creek effluent. The relative seasonal distribution of predominant phytoplankton from the various ponds is shown in Figure 7.

Receiving Streams

The study bio-oxidation ponds discharged into streams (see Figure 8, page 31) which were small, some were intermittent, and all were relatively inaccessible except where county section roads crossed the streambeds. The stream banks were incised due to erosion and eluviation during spring runoff from high intensity, short duration rainfalls which are characteristic to central Oklahoma. In general, streamflow was minimal during the winter months, reached its peak in the spring, then subsided during the summer and fall as is shown in Table 4.

Seasonally, the average BOD of these streams and tributaries ranged from less than 1 mg/l to 7 mg/l, the nitrogen (N) ranged from 0.4 mg/l to 7.6 mg/l, and the phosphates (P) ranged from 0.16 mg/l to 3.46 mg/l. For most of these parameters the maximum concentrations occurred during the winter and minimum concentration during the summer and fall (see Table 5). The reason for the substantial background levels of nitrogen and phosphorous (nutrients) found in these streams could be attributed

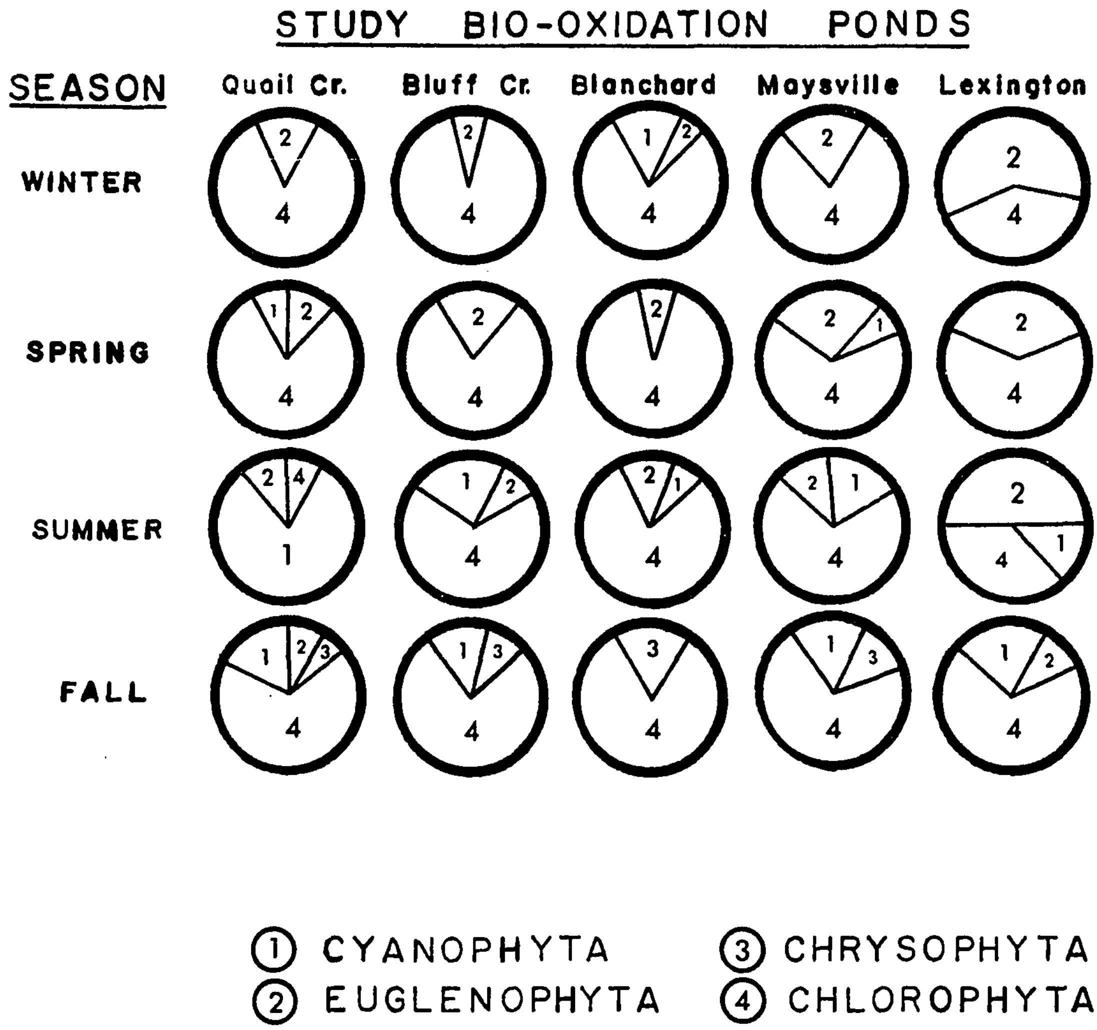


FIGURE 7 : RELATIVE SEASONAL DISTRIBUTION OF PREDOMINANT PHYTOPLANKTON IN THE EFFLUENT FROM THE STUDY BIO-OXIDATION PONDS

TABLE 4

DISCHARGES OF THE STUDY

RECEIVING STREAMS AND TRIBUTARIES

	SEASONAL AVERAGE FLOW, MGD			
	WINTER	SPRING	SUMMER	FALL
DRY CREEK	0.0	0.0	0.20	0.15
BLUFF CREEK	0.48	2.62	1.50	0.90
DEER CREEK	0.69	1.92	1.25	0.75
BERRY CREEK	0.024	0.40	0.14	0.08
NORTH FORK WALNUT	0.10	1.95	0.68	0.39
SOUTH FORK WALNUT	0.11	1.80	0.43	0.25
BUFFALO CREEK	0.015	0.38	0.13	0.07

to upstream use.

Dry Creek, the receiving stream for the Quail Creek pond, drained a golf course, and during the winter and spring, the only sustained flow within Dry Creek was bio-oxidation effluent (no available dilution for effluent, see Table 4) because natural stream flow was retained by an impoundment within the golf course. When flow was released during the summer and fall (height of golfing season), it not only had high N and P concentrations but, as can be seen in Table 5, the biomass was prolific. The flow in Dry Creek could more accurately be described as regulated rather than intermittent.

Bluff Creek, which ultimately received the Dry Creek flow as well as the effluent from both the Quail Creek and Bluff Creek ponds, had its headwaters near the sludge ponds of a lime-softening water treatment plant. In the summer when the water treatment plant activities were accelerated to meet the increased domestic water demands, the supernatant

TABLE 5

BIOCHEMICAL AND BIOLOGICAL CHARACTERISTICS[1] OF THE

RECEIVING STREAMS AND TRIBUTARIES

	BOD, mg/L		KJELDAHL NITROGEN mg/L AS N		TOTAL PHOSPHATES mg/L AS P		COLIFORMS X 10^3/100 ml		PLANKTON ASU'S X 10^3/ml	
	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average	Maximum Average	Minimum Average
DRY CREEK[2]	4(F)	1(Su)	3.7(F)	2.0(Su)	1.78(Su)	1.26(F)	15(Su)	2.5(F)	225(Su)	25(F)
BLUFF CREEK	5(W)	1(F)	2.6(F)	0.5(W)	1.59(Su)	0.83(W)	25(Su)	3.5(F)	54(Su)	1(Sp)
DEER CREEK	7(W)	1(F)	4.0(Sp)	0.9(W)	3.46(Sp)	1.60(F)	5(Su)	2.5(W)	7(Su)	1(W&Sp)
BERRY CREEK	4(F)	1(Su)	7.6(F)	0.8(Su)	1.45(W)	0.16(F)	13.6(W)	0.2(Su)	3(F)	1(W)
NO. FORK WALNUT	5(W)	1(Su)	3.4(W)	0.4(Su)	1.44(W)	0.15(F)	4.5(W)	0.1(Su)	4(Sp)	1(Su)
SO. FORK WALNUT	3(F)	1(Su)	2.5(W)	0.7(Su)	1.45(Sp)	0.18(F)	5(W)	0.05(Su)	39(Sp)	1(Su)
BUFFALO CREEK	2(W)	1(F)	5.0(W)	0.6(Su)	1.30(W)	0.71(Su)	40(Sp)	0.04(Su)	37(Sp)	1(Su)

(W) = Winter
(Sp) = Spring
(Su) = Summer
(F) = Fall

[1]These are seasonal averages of approximately 10 - 20 individual analyses.

[2]Values listed for Dry Creek are for Summer and Fall only, as this stream did not flow during the Winter and Spring.

from these sludge ponds frequently overflowed into Bluff Creek, this was reflected in the in-stream phosphate levels which were maximum during the warm weather (Table 5).

Deer Creek had upstream tributaries which received domestic wastewater plus agricultural runoff. The average phosphate concentrations during the spring were 3.46 mg/l as P. This is a substantial residual considering the streams in the Blanchard area (Berry, Walnut, Buffalo) had phosphate concentrations less than 1.5 mg/l, most of this being attributable to agricultural runoff and the livestock which watered at these streams during the winter and spring.

The natural phytoplankton in the streams near the Blanchard pond were limited to a few genera of Chrysophyta (Nitschia, Navicula, Cymbella) and on occasion planktonic green algae. Algal densities rarely exceeded 1,000 ASU/ml during the summer. On the other hand, Chlorophyta and Cyanophyta were more naturally predominant in the streams near the Quail Creek pond particularly during the summer when average planktonic densities reanged between 7,000 to 225,000 ASU/ml (Table 5). Benthic filamentous algae enjoyed a lucrative growth in all the streams except Dry Creek (possibly because flow was intermittent). Minnows and occasionally larger fish (mostly blue-gill) could be seen darting in and out of these benthic habitats at various times during the course of the study.

CHAPTER III

SAMPLE COLLECTION AND ANALYTICAL DETERMINATIONS

Field Techniques

Sampling was initiated in the winter of 1966 and continued on a bi-weekly basis through the winter of 1968. "Grab" samples were collected in polyethylene bottles at the effluent weir of each bio-oxidation pond and at subsequent downstream stations, dual samples being collected at tributary confluents as shown in Figure 8. In addition to the ponds and the effluent sampling stations, the Maysville and Lexington Systems (not shown) included only the transport stream which was one mile long at Maysville and sampling stations were located at the middle and end, where the Lexington transport stream was 800 feet long and was sampled only at the end.

Effluent discharge and corresponding specific conductivity were measured at the overflow weirs of each pond. These values along with the specificity conductivity of the receiving stream, both before and after mixing, provided a simple means of estimating streamflows. This indirect method is rapid and was necessary because of the time involved in the collection and analysis of samples (additionally, an attempt for direct streamflow measurements with 90° v-notch weirs installed in the streams proved unsuccessful because of public vandalism and damage suffered during periods of elevated streamflows).

Ambient conditions along with the streams aesthetic appearance and observed higher aquatic flora and fauna were also recorded before the samples were transported to the University of Oklahoma Sanitary Engineering Laboratory, Norman, Oklahoma.

Laboratory Procedures

The effluent from the bio-oxidation ponds and the receiving stream samples were analyzed for the following parameters in accordance with Standard Methods for the Examination of Water and Wastewater, Twelfth Edition (1965):

(a) biochemcial oxygen demand (BOD)

(b) total kjeldahl nitrogen (N)

(c) ammonia nitrogen

(d) total phosphates (P)

(e) orthophosphates

(f) plankton

(g) coliform and plate count

(h) detergents (MBAS)

(i) nitrates

The membrane filter (MF) technique was used for determining the 35^{o} plate count and for quantifying total coliform organisms. the MF technique has some limiting characteristics, particularly when employed for wastewater or water with high trubidity, as there is a tendency for bacterial growth to be suppressed or retarded should a bacterium come to rest above or below detritus which is entrapped on the filter. Consequently, relying on individual results as absolute measures of bacterial concentrations in turbid samples is unwise. Bacteriological

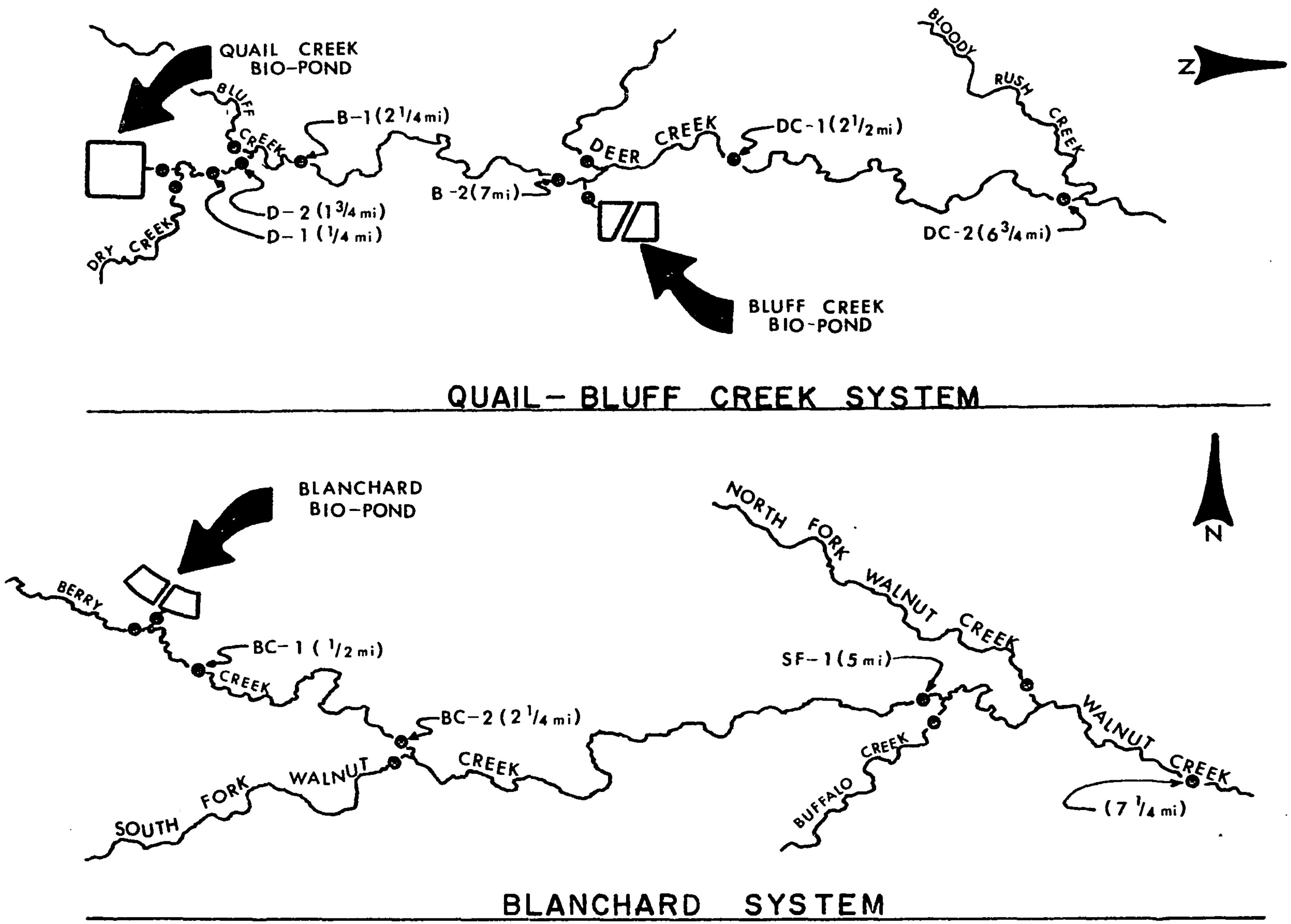


FIGURE 8: STUDY BIO-OXIDATION POND-RECEIVING STREAM SYSTEMS AND SAMPLING STATIONS.

trend, however, can be gleaned by comparing relative results among samples, provided bacterial densities are sufficient for detection after serial dilution to minimize the effect of turbidity. This was the case with these pond and stream samples; thus, the MF technique provided supplemental information on ecological conditions both with the ponds and the receiving streams.

In the initial stages of this project, both methylene blue active substances (MBAS) and nitrates were included in the laboratory determinations. The reasons for their initial inclusion and subsequent removal for the analytical list are given in the following brief discussion on both parameter.

Methylene Blue Active Substances (MBAS)

The methylene blue active substances (MBAS) in sewage predominately consist of detergents. Detergents, as previously mentioned, contain components of complexed phosphates and additionally can cause unsightly and aesthetically unpleasing frothing and foaming when their concentration in surface waters exceeds 1 mg/l. The alkyl benzene sulfonates (ABS) or non-biodegradable detergents were removed from the consumers market a few months before this project began and were replaced by bio-degradable detergents, linear alkyl sulfonates (LAS). Because of the product conversion, little information was available on the efficiency of bio-oxidation ponds with regard to degrading LAS. In a comprehensive four week special study (which included two, twenty four hour composite samples at the Quail Creek pond), the MBAS concentrations in raw sewage were found to range between 1.9 - 11.0 mg/l (average 5.7), while effluent MBAS residual concentrations averaged less than 0.5 mg/l

(DeMarta, 1966). Because of these low effluent and subsequent negligible concentration after downstream dilution, the analytical procedure for MBAS was discontinued.

Nitrates

Nitrogen (N) in aquatic environments may be found as ammonia nitrogen, organic nitrogen, nitrites, or nitrates, depending on its initial form and the amount of oxidation or reduction to which it is subjected. In raw or untreated sewage the predominant forms are organic and ammonia nitrogen. As sewage becomes stabilized under aerobic conditions, the relative concentrations of nitrites, and subsequently nitrates, increase. This condition is referred to as nitrification. As a nitrogen source, algae can apparently utilize either ammonium salts or nitrates, the former being preferable if light intensity (energy) is limited (Syrett, 1960, after Lewin, 1962). By means of polargraphic techniques, nitrogen concentrations in the form of nitrates were found to be insignificant in the study ponds and streams as compared to the ammonia and organic nitrogen concentrations. The nitrate determinations were therefore not continued and only the prevalent forms of nitrogen (ammonia and organic) were monitored.

Data Preparation

Under natural stream and bio-oxidation pond conditions, volumes as well as parameter concentrations vary but there is a comparative product, concentration times the flow and a constant. The simplest and most meaningful approach to normalizing data for comparative purposes is by incorporating flows and concentrations and arriving at total loading. The data now become directly additive and influences are more distinct.

For the Quail Creek, Buff Creek, and Blanchard Systems the parameter concentrations were easily converted to total loadings (#/Day = MGD x mg/l x 8.34), as the flows were expressed in million gallons per day (MGD). This is the most common and widely used means of expressing chemical data, however, normalizing biological data varies.

Methods for dealing with bacteriological data range from the quantity unit (Q.U) proposed by Frost and Streeter (1924) to the bacterial population equivalent (B.P.E.) suggested by Kittrell and Furfari (1963). The Q.U. is the product of a discharge of 1 cubic foot per second (cfs) and a bacterial concentration of 1000/ml. The B.P.E. relates the Q.U. to the sewered population by incorporating a per capita contribution. For comparative purposes, the bacteriological data collected in this study was converted to milligrams per liter using 4×10^{-10}mg/ cell, the average weight of a bacterium as suggested by Sarles, et al (1956). The data could then be directly converted to pounds per day (loading) by incorporating flow as is shown in the following equation:

$$\text{Bacteria, pounds/day} = F\ (4 \times 10^{-10}\text{mg/cell})\ (\text{Number of cells/ml})\ (10^{3}\text{ml/l})$$

where: F = Flow, MGD x 8.34

The plankton data was similarly converted to pounds per day using 500,000 ASU/ml = 1000 mg/l (Gearheart, 1969).

CHAPTER IV

PRESENTATION OF FINDINGS

The data collected over the two year study period were grouped by quarters and averaged in order to represent the seasonal effluent quality of the bio-oxidation ponds as well as the quality of the streams both before and after receiving the 'treated' wastewater. These data shown in Tables 6 , 7 , and 9 in the Appendix demonstrate the quality fluctuations during the year. Selected data were presented in Chapter II to supplement the individual description of the study ponds and streams. This chapter presents the findings and observations downstream. This first section segregates those ponds which discharge into dry streambeds (transport streams). The second section includes the remaining systems which had available dilution water.

Transport Streams

During the course of this study, the bio-oxidation ponds at Lexington, Maysville, and Quail Creek (for two seasons out of the year) discharged into streambeds which flowed varying distances without receiving any dilution. The findings regarding the transport streams are of interest because they reflect the transitional effects of the effluent going from lenic to lotic conditions, without added variables from dilution water.

The most significant immediate change in the effluent as it progresses undiluted downstream was found to be the increase in coliform organisms. For example, the Lexington transport stream was only 800 feet long, but coliform densities more than doubled within this short distance. This, however, is not too surprising as other investigators have found the same to be typical when either raw sewage or sewage treated by other conventional means is discharged into receiving water (Kittrell and Furfari, 1963). It has been shown in the literature, and will be shown later, that die-off of coliform bacteria is rapid when dilution is available.

Coliform die-off was found to be rapid between stations D-1 and D-2 (a net 50 percent reduction after a threefold increase between the effluent and station D-1) in the Quail Creek system for the two seasons when dilution was not available. On the other hand, after one mile of travel downstream from the Maysville pond (station M-2) increases in coliforms found during the spring and fall offset the reductions found at the station during the winter and summer, the net annual effect being a persistency of coliforms. Increases in plankton were also found at station M-2 after an initial 45 per cent reduction between the effluent and station M-1.

Figure 9 illustrates the annual average concentrations of the oxygen demand and nutritional components (BOD, N and P) in the Maysville effluent and at the two subsequent downstream stations. Reductions in pond effluent BOD, N and P averaged 36 per cent, 18 per cent and 7 per cent, respectively at a distance of one mile below the pond although most of this reduction occurred within the first one half mile of flow. Although there were no annual nitrogen (N) reductions, BOD reductions of 12 per cent and phosphate (P) reductions of 2 per cent were found in the effluent at station L-1 (terminas of transport stream, 800 feet from the pond) in the Lexington System. The BOD, N and P reduction in Quail Creek pond effluent during the winter and spring (the two seasons of undiluted pond effluent flow in Dry Creek) averaged 40 per cent, 27 per cent and 34 per cent respectively at station D-2, 1 3/4 miles downstream from the Quail Creek pond.

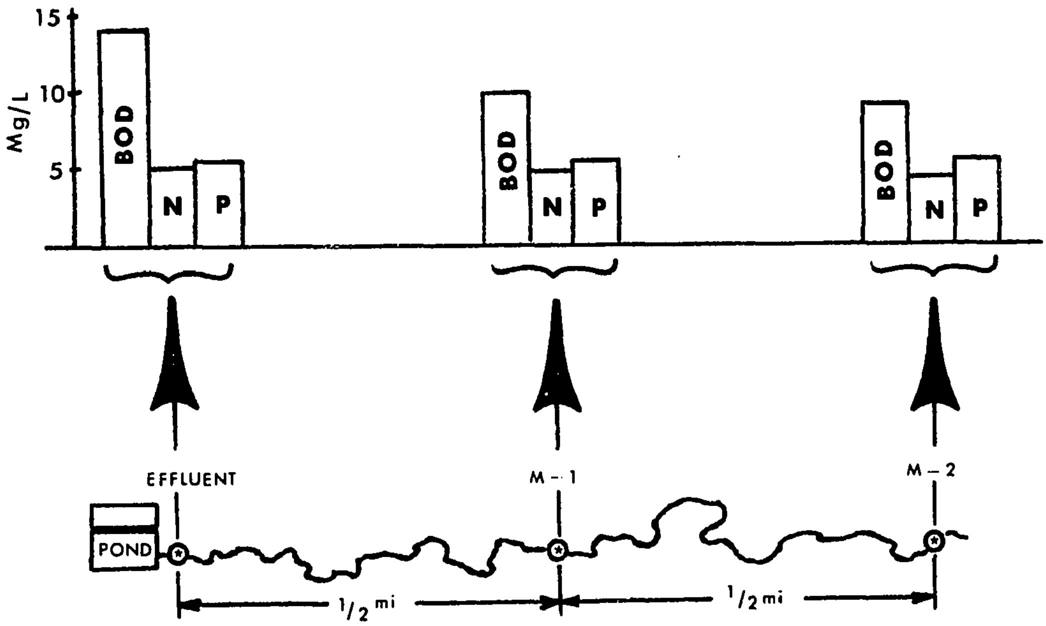


FIGURE 9: GRAPHICAL PRESENTATION OF THE AVERAGE BIOCHEMICAL PARAMETERS DISCHARGED FROM THE MAYSVILLE POND AND SUBSEQUENT DOWNSTREAM CONCENTRATION IN THE TRANSPORT STREAM (UNDILUTED FLOW)

Flowing Receiving Streams

Biochemical Parameters

During this study the bio-oxidation ponds at Blanchard, Bluff Creek, and Quail Creek (during the Summer and Fall) discharged directly into small flowing streams. As streamflows and concentrations varied seasonally, loadings were calculated. A complete summary of the normalized data is shown in Tables 8 and 10, in the appendix; however, for comparitive purposes the minimum and maximum seasonal and annual average BOD, total Nitrogen (N) and total Phosphate (P) loadings from the ponds were:

	BOD, lbs/Day			N, lbs/Day			P, lbs/Day		
POND	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Blanchard	7	11	18	3.1	5.0	9.8	0.71	2.38	4.20
Quail Creek	15	43	81	8.2	16.2	25.9	11.50	17.52	24.48
Bluff Creek	137	332	575	532.	662.	960.	258.	297.	315.

When these loads were applied to similarly characterized streams, it was found that the resultant parameter levels were largely dependent on whether or not the stream was periodically scoured. During the seasons when streamflows were insufficient to produce scouring (summer, fall and winter) the BOD, N and P showed a marked reduction (as much as 60 per cent) within the first two miles below the outfalls, with similar effects following downstream tributary confluents. Within the longer reaches studied (distances varied from five to seven miles), the initial BOD and N reductions were succeeded by slight increases, however, the net reductions in the BOD ranged from 44 per cent to 56 per cent, the reductions in nitrogen (N) ranged from 29 per cent to 55 per cent, and the phosphate (P) reductions ranged from 30 per cent to 50 per cent.

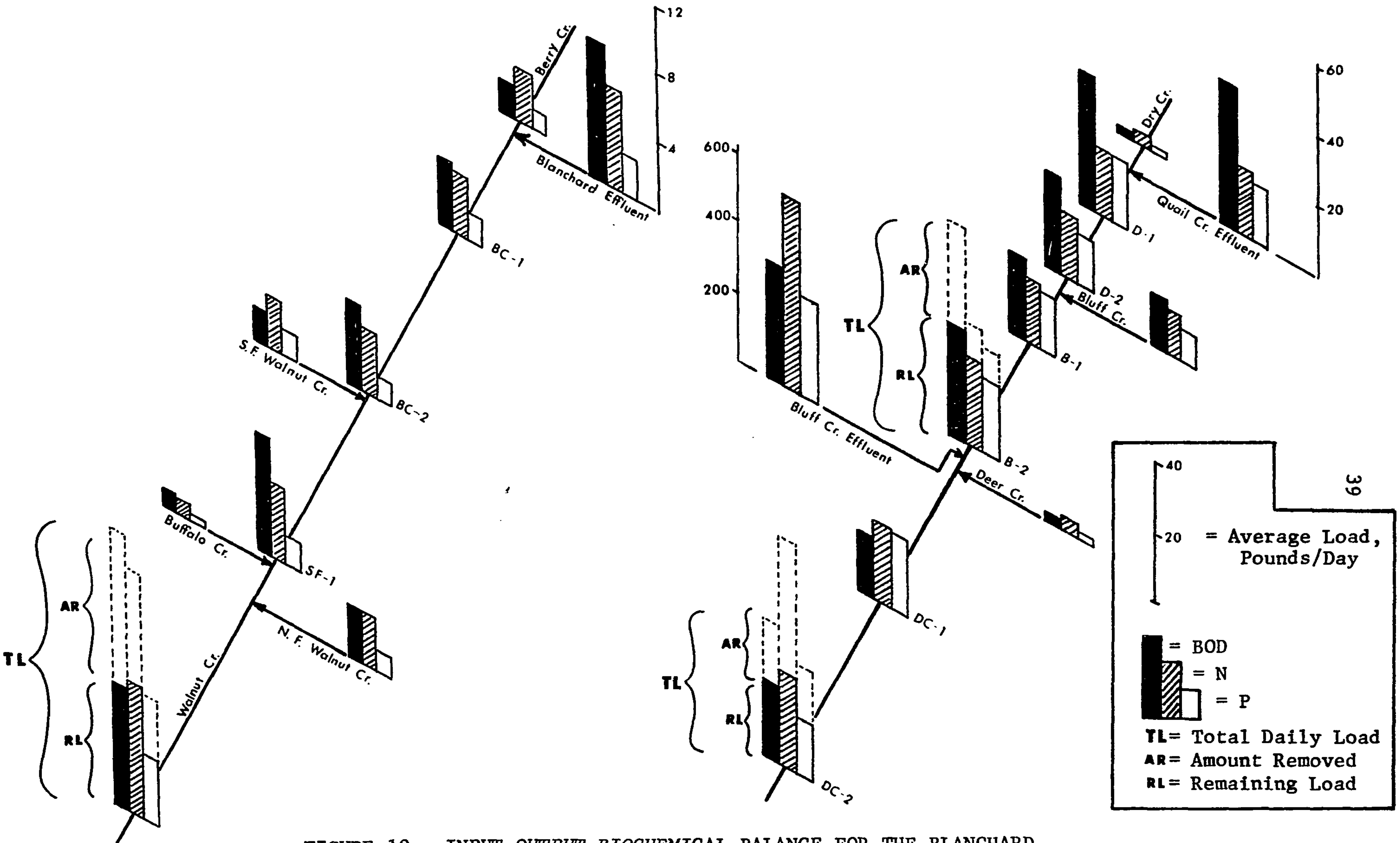


FIGURE 10: INPUT-OUTPUT BIOCHEMICAL BALANCE FOR THE BLANCHARD AND QUAIL-BLUFF CREEK SYSTEMS BASED ON AVERAGE DAILY LOADINGS DURING NON-SCOURING PERIODS (SUMMER, FALL AND WINTER)

The average applied and instream BOD, N and P loadings during the seasons when streamflow was non-scouring is graphically presented in Figure 10.

During the spring season when streamflow is maximum, the observed in-stream loadings were quite different from those found during the other seasons. The increased springtime streamflows which are necessary for supplementing downstream uses also perform nature's cleaning. Some stream reaches may be completely scoured within a matter of minutes following the high intensity, short duration rainfalls which are common to the central Oklahoma area during the spring.

One such event was recorded during a spring thunderstrom on Berry Creek, one-quarter of a mile below the Blanchard bio-oxidation pond outfall. The rainfall was localized and totaled over three inches during the two hour storm. The analytical data collected show that there is a successive order of eluviation (see Figure 11). Peak concentrations of nitrogen and phosphates slightly lead the maximum chemical oxygen demand[2] (COD), which in turn leads the peak turbidity. The most logical interpretation of this data is that nitrogenous and phosphate containing materials are deposited in the upper streambed layers, thus, most succeptable to scouring. The more firmly attached aquatic flora is next to yield, leaving the channel less protected and subject to further erosion. The flora detached from the streambed, pass as a 'slug' as the stream if flushed. This slug load must stress the ecosystem in the quiescent reaches downstream. As this estranged flora is thrashed about, many

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[2]Chemical oxygen demand (COD) was substituted for BOD because sufficient BOD bottles were not available at the time of this particular storm. The COD measures the amount of oxygen consumed in the oxidation of organic and inorganic matter by dichromate and values are comparable to the ultimate BOD.

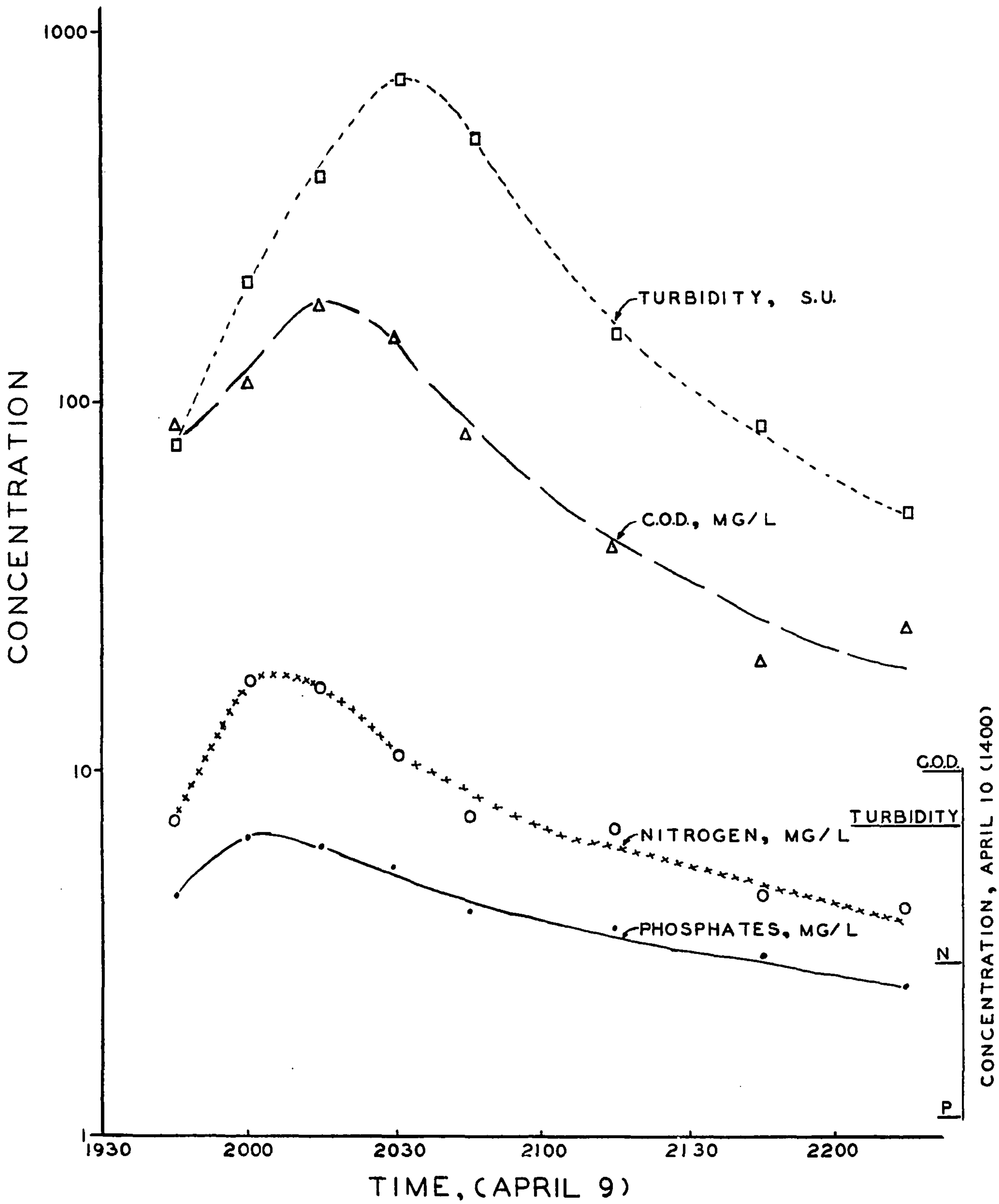

FIGURE 11: SCOURING EFFECTS OF RAINFALL RUNOFF--BERRY CREEK, BLANCHARD, OKLAHOMA

cells are undoubtedly lysed then subjected to reduced sunlight from the highly turbid runoff water.

During the spring season, there was at least partial scouring in all of the streams, and more pronounced in the Blanchard system and the section of Bluff Creek above the Deer Creek-Bluff Creek confluents. The normal elevated spring flows were found to elutriate most of the materials which accumulated throughout the summer, fall and winter. Consequently, on an annual basis, some BOD and soluble N and P reductions were experienced, however, nearly all of the total N and P inputs were accounted for in an input-output balance (see Figure 12) for the stream reaches. In the Blanchard system, the average daily BOD, N and P reductions were found to be 27 per cent, 4 per cent and 2 per cent respectively. In the Quail Creek system (from the Quail Creek pond to the Bluff Creek pond, a distance of seven miles) the average daily nitrogen input was not reduced although the BOD and P were reduced 11 per cent and 5 per cent respectively. The portion of Deer Creek below the Bluff Creek pond dampened increased flows and at approximately seven miles below the Bluff Creek pond, 24 per cent of the average daily input BOD, 44 per cent of the nitrogen, and 35 per cent of the phosphates could not be accounted for (see Figure 12).

Biological Parameters

Besides the threat of chemical flush-out, the instream biomass is another seasonal variable to contend with. Coliform bacteria were found to multiply within the first quarter of a mile below the ponds outfalls and also below the downstream tributary confluents. The amount of

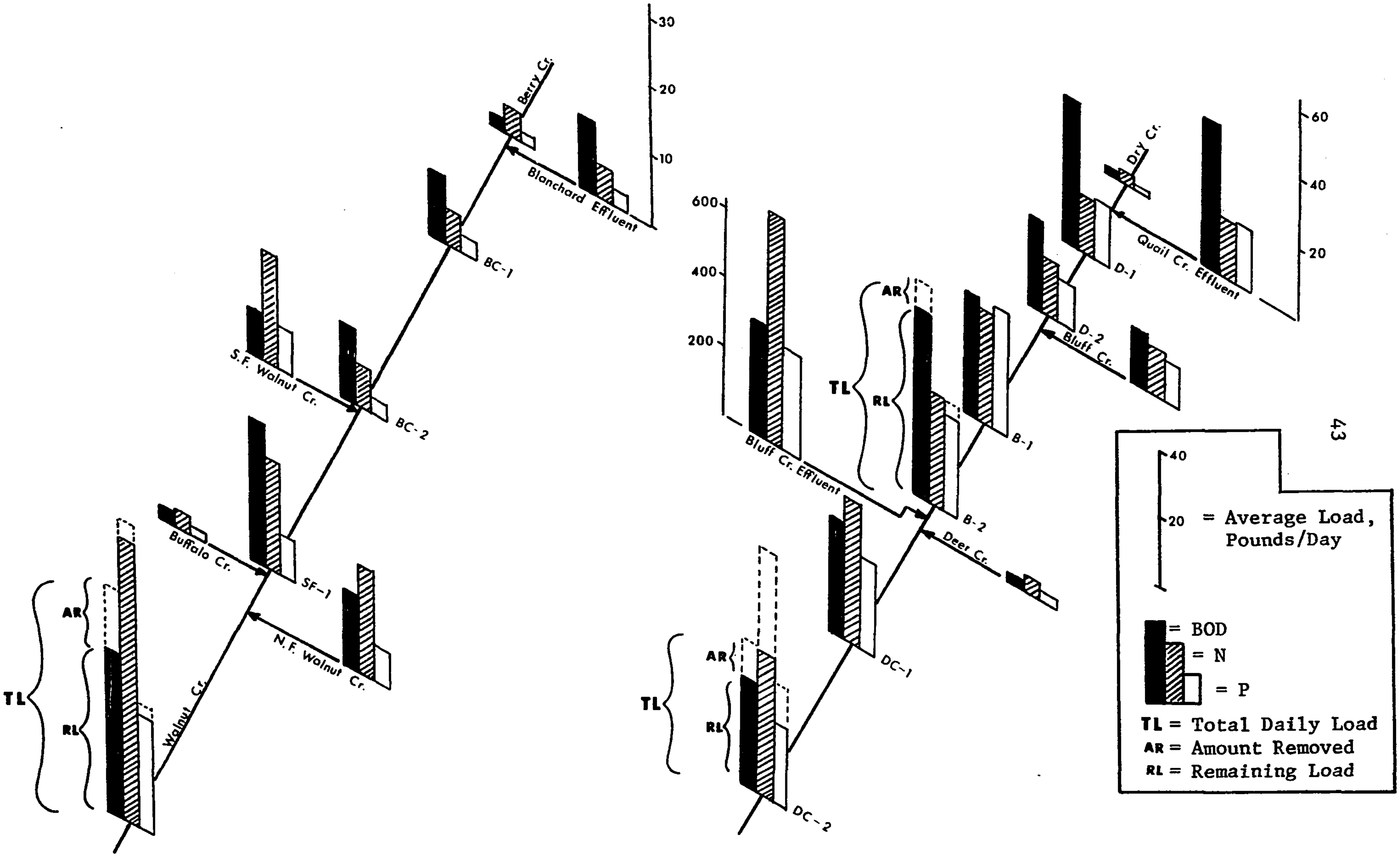

FIGURE 12: INPUT-OUTPUT BIOCHEMICAL BALANCE FOR THE BLANCHARD AND QUAIL-BLUFF CREEK SYSTEMS BASED ON AVERAGE DAILY LOADINGS.

regrowth ranged between 50 per cent and 100 per cent over the input levels, but coliform die-off followed these initial increases in all the systems. For example, the annual average coliform levels found one-forth mile downstream from the Quail Creek pond were 50 per cent higher than the sum of effluent plus the upstream levels; yet one and one half miles further downstream the levels had decreased 75 per cent.

The coliform densities remaining (residuals) at any point in the system are significant from a public health standpoint as these organisms are widely used as indicators of contamination. The use of "reduction percentages" when dealing with bacteriological data may leave the unwary individual with a false sense of security. Reduction percentages approaching 100 per cent imply excellent treatment when in fact the bacterial quality may continue to be a potential health hazzard. For example, Reid and Wilcomb (1963) found that the raw sewage from several small Oklahoma communities had an average coliform concentration of approximately 14,000,000/100ml. With this influent concentration it follows that a bio-oxidation pond (or any other method of treatment) having an impressive 99.9 per cent coliform removal efficiency would still leave a staggering 14,000/100 ml coliform residual in the effluent.

In addition to reporting coliform residuals it would perhaps be more meaningful to express coliform removal in terms of logarithmic (log) reductions.[3] For instance, the study ponds had average seasonal

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[3]This follows a long established water works practice of looking at log densities (U. S. Public Health Service, 1927); also practiced by Fair (Fair and Geyer, 1954) on bacteria reduction through filters,

coliform residuals in the effluent which ranged from 40,000/100 ml to 3,800,000/100 ml. Based on an influent coliform concentration of 14, 000,000/100 ml, the coliform removal efficiency of the study ponds expressed as log reductions would be between 8 per cent and 36 per cent. In the preceeding example (Quail Creek system) where there was a 75 per cent reduction in coliforms (log reduction of 10.8 per cent), the coliform residual still averaged 92,000/100ml! It was only during the summer and at a distance of 7 1/4 miles below the Blanchard pond that average coliform densities below 1000/100 ml were found.

Plankton (alage)

The streams were clear both above and below the ponds during the fall and winter and the channel bottoms supported growths of benthic algae, the habitat of bottom dwelling organisms. The phytoplankton (algae) loadings applied to the systems were found to initially undergo reductions similar to those described for the chemical parameters. During the winter, phytoplankton reductions of over 90 per cent were found in some of the longer stream reaches sampled, Walnut Creek being the one exception.

Walnut Creek (7¼ miles below the Blanchard pond) sustained increased Chlorophyta populations (predominately *Chlorella*) not only during winter, but also during the spring and fall. This was an area where the channel had been leveled for flood control measures; consequently, the stream flow was very shallow and completely exposed to sunlight, conditions ideal for algal propagation.

Relative to the overall annual effects, the plankton reductions during the fall and winter, as with the chemical parameters, were only temporary. In addition to algae becoming resuspended from the scoured zones during the spring, secondary algal blooms were found downstream from both the Quail Creek and Blanchard ponds during the summer. Because of these increases, the average algal levels in the Blanchard system exceeded the total average daily input loadings by 60 per cent. In the Quail Creek system, at a distance of 7 miles below the pond, the amount of instream planktonic algae was more than twice the total input loadings.

In all cases where subsequent plankton increases were found, it was predominately Cyanophyta (blue-green algae). Specifically, _Arthrospira_ blooms were observed at a distance of 7 miles below the Quail Creek pond, and _Anacystis_ blooms occurred at 2¼ miles and again at 7¼ miles downstream from the Blanchard pond. Both _Arthrosira_ and _Anacystis_ are characterized as "polluted water algae", with _Anacystis_ further linked with taste and odor problems and reknown as a filter clogging alga (Palmer, 1962). Additionally, during the summer the attached filamentous growths (benthic algae) disappeared from the channel in the areas where plantonic growth florished and the streams, instead of being clear, assumed the greenish appearance of the bio-oxidation pond effluent.

The seasonal plankton data in Figures 13 to 16 are presented to illustrate the general trends in algal predominance within the systems. This particular example is data taken from the 7 mile section of receiving stream below the Quail Creek bio-oxidation pond. It is typical of the other systems in that it reflects the seasonal competition within the mixed algal populations. Although instream flucuations did occur, the Euglenophyta and Cyanophyta populations (indigenous bio-oxidation pond plankton) prevailed in the enriched systems.

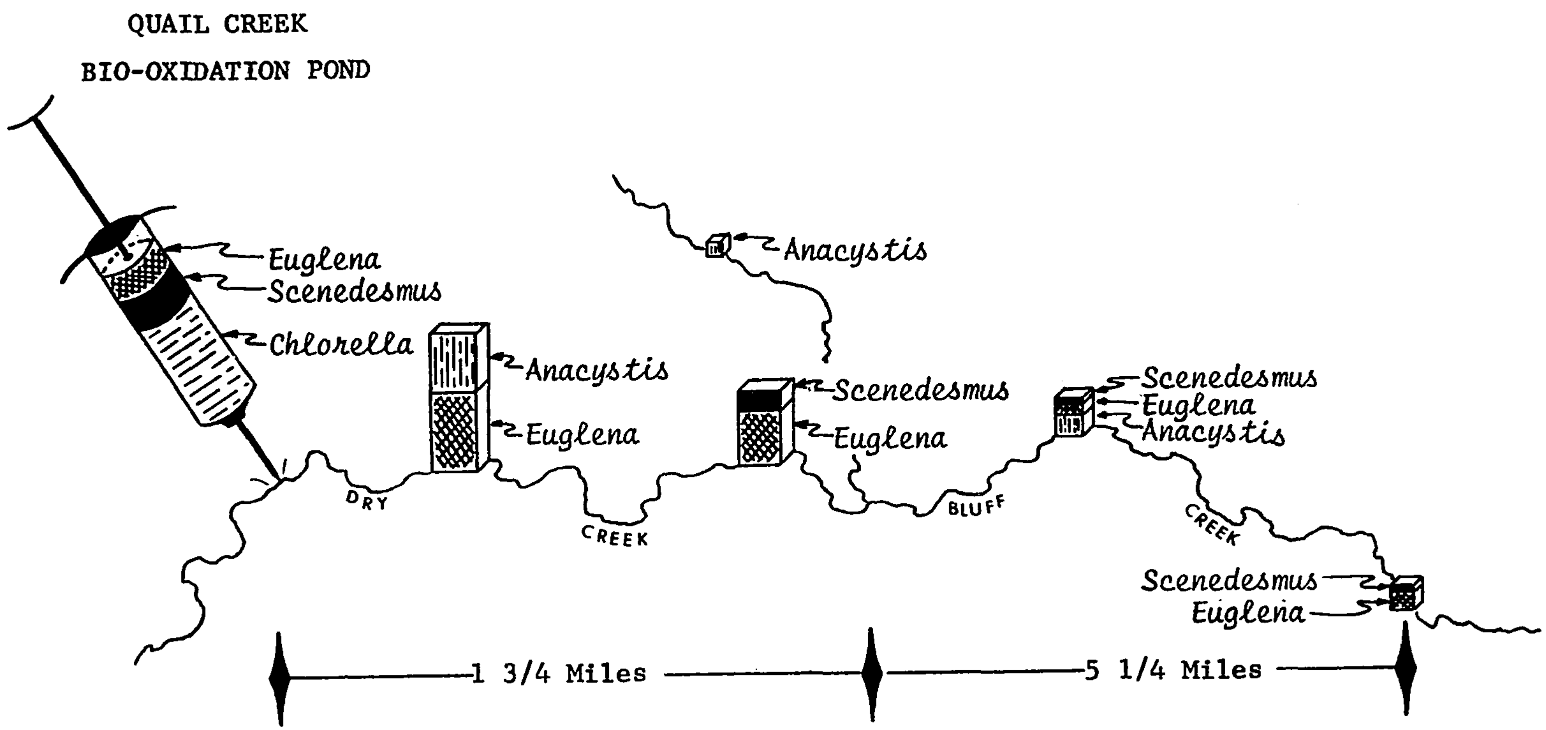

FIGURE 13: EXAMPLE OF RELATIVE PREDOMINANCE OF POND AND STREAM PHYTOPLANKTON (WINTER)

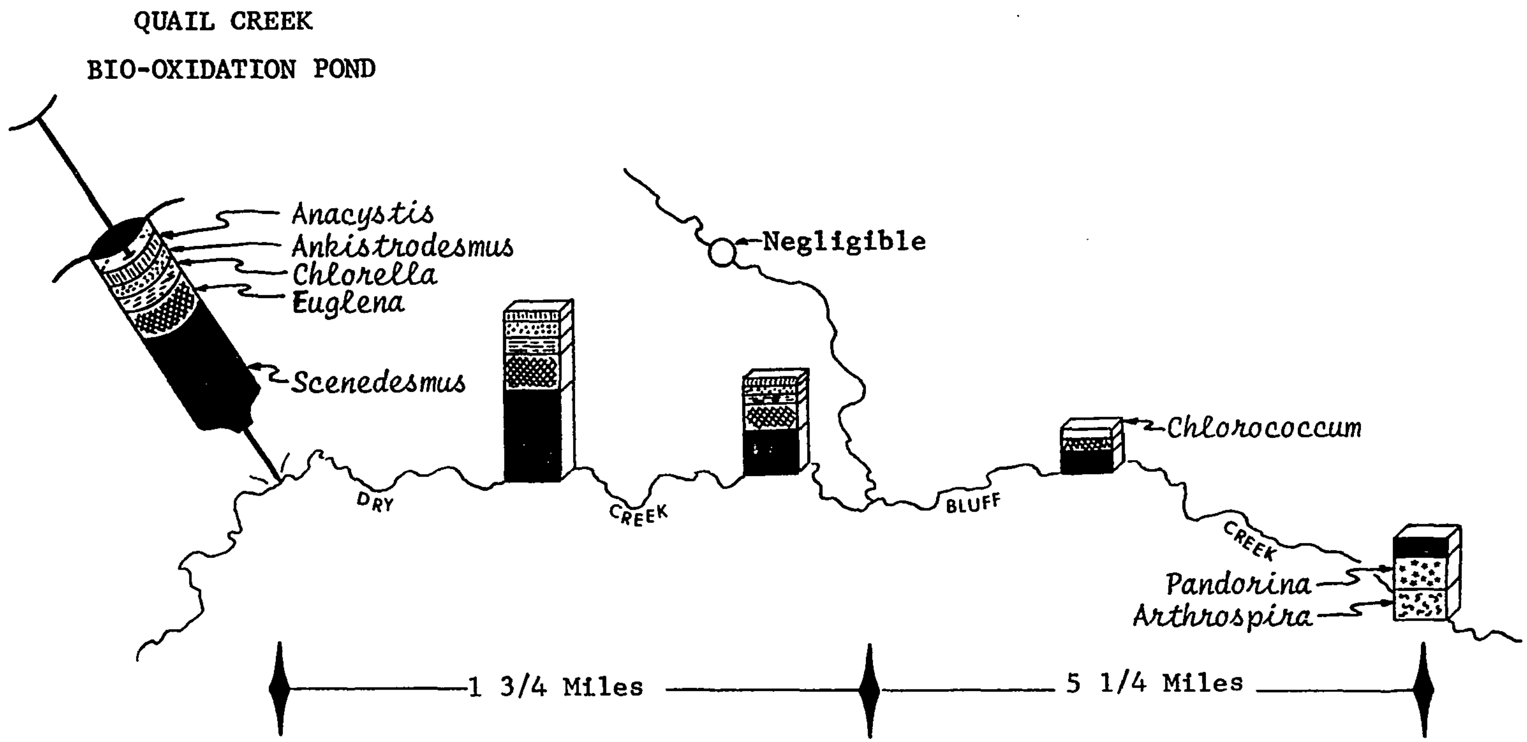

FIGURE 14: EXAMPLE OF RELATIVE PREDOMINANCE OF POND AND STREAM PHYTOPLANKTON (SPRING)

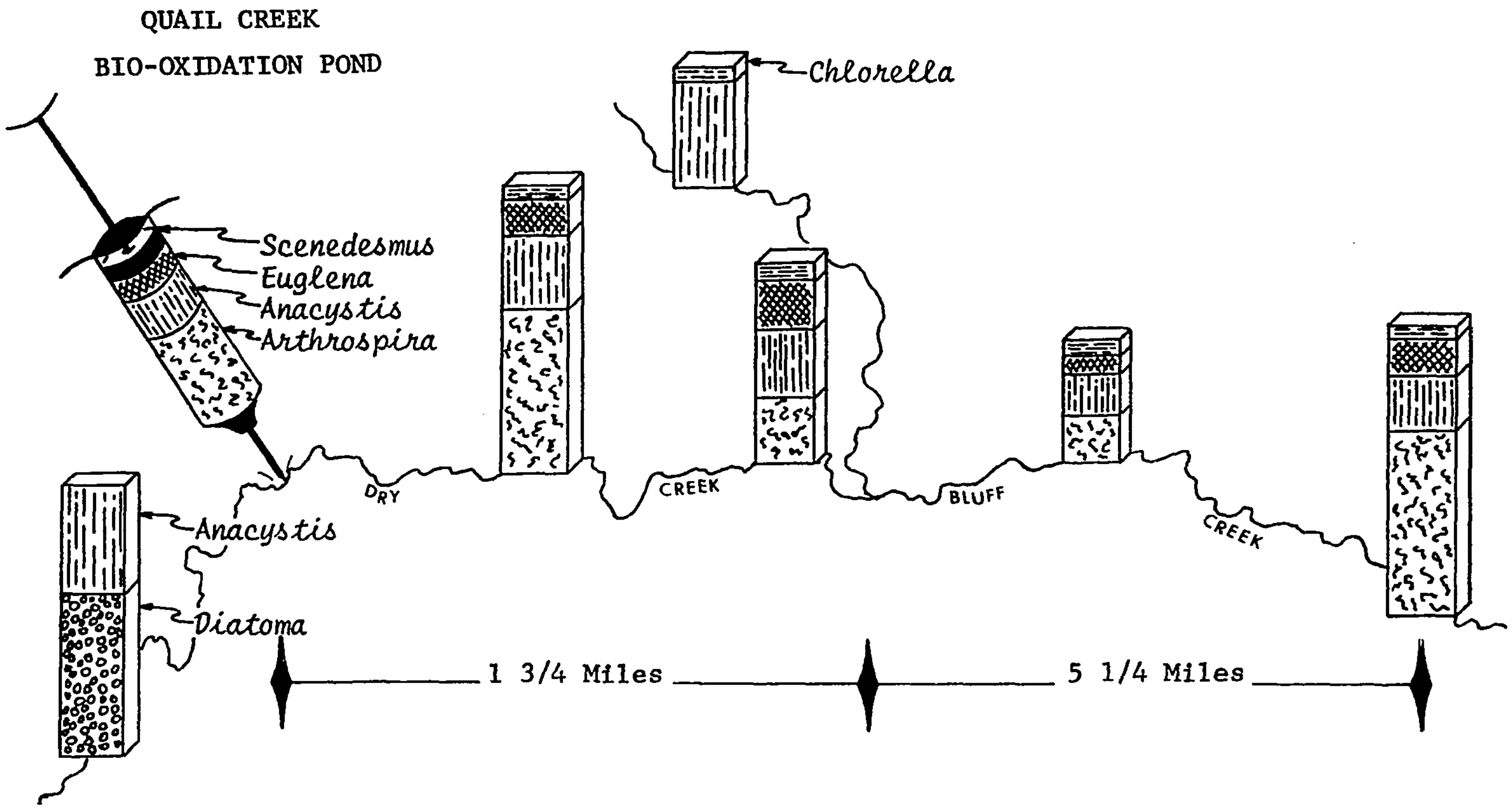

FIGURE 15: EXAMPLE OF RELATIVE PREDOMINANCE OF POND AND STREAM PHYTOPLANKTON (SUMMER)

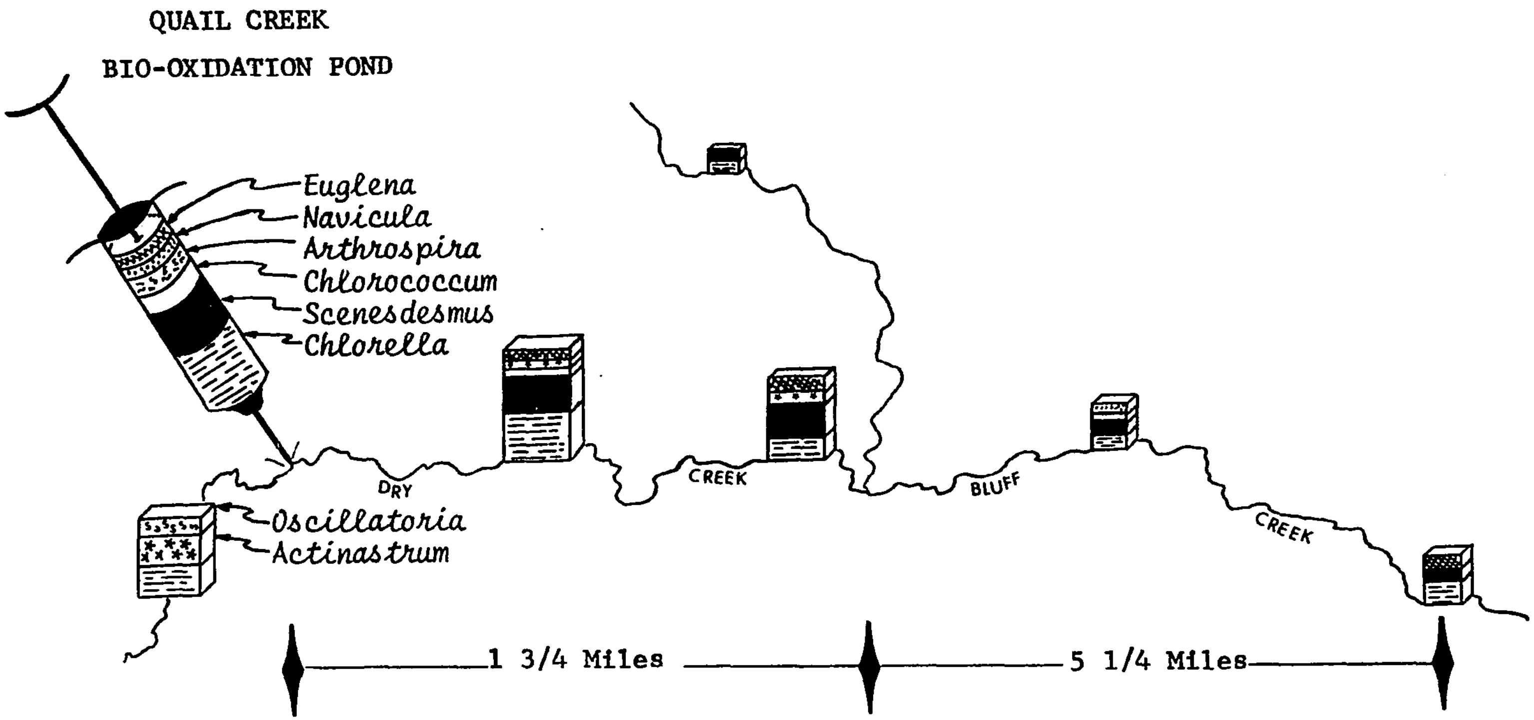

FIGURE 16: EXAMPLE OF RELATIVE PREDOMINANCE OF POND AND STREAM PHYTOPLANKTON (FALL)

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion

The oxygen demand (BOD) of a wastewater has long been the desired parameter to reduce before the wastewater could be considered effectively treated and discharged. Within the past few years, other biochemical parameters such as nitrogen and phosphorous (nutrients) have been included on the growing list of removal objectives. In an attempt to abate pollution by the most economical means, bio-oxidation ponds are increasingly being used to meet wastewater treatment needs of developing residential areas and towns, or as tertiary devices (polishing ponds) because of their efficient capability of removing BOD, and nitrogen and phosphorous from the liquid effluent. While concentrating on removing biochemical parameters there has been little regard for the conversion of mass, or shuffling of constituents which takes place within a pond and even less attention has been given to the downstream effects of the "shuffled" pond effluent. So, treatment technics have been evaluated by criteria that are not comparable. The end products developed in and discharged from a bio-oxidation pond being quite different from those coming from other conventional waste treatment methods yet the same guidelines and performance criteria -- percent removal and costs (dollars)-- are used in evaluating all methods. Unlike other sewage treatment methods where sludge removal is practiced, there are essentially little or no mass losses within a bio-oxidation pond, other than a small percentage of settleable inert materials which are retained within the pond. Additionally, the degree of treatment preceeding a pond seemingly has little effect on the average concentration of biomass (suspended solids) discharged. As an example, the one tertiary installation in the systems studied (Bluff Creek ponds which followed an activated sludge plant) was found to discharge an effluent with an average algal concentration of 230 mg/L. Upstream, and on the same system, the Quail Creek pond received raw sewage (no prior treatment) yet the average algal concentrations discharged were approximately the same (238 mg/L).

It has been shown that sewage treated by other conventional methods and discharged into small intermittent streams can have minimal adverse effects and can ultimately be beneficial to the stream by increasing productivity. Because of the nature of treated sewage from conventional plants (frequently an imbalance of nutrients), there is always a possibility of nutritional pollution but the stream responds by making adjustments in competitive organisms which discourages complete domination by individual species. If algae does appear downstream, it is usually dispersed filamentous growths which provide additional benthic habitats, or a progressive development of planktonic algae constantly being challanged by competitive organisms within the stream. The effects of bio-oxidation pond effluent on the streams are quite different.

It was demonstrated in this study that when bio-oxidation pond effluent was discharged into small intermittent streams, with the exception of scouring, the effluent responded to the stream, rather than the stream responding to the effluent. In essense, the streams were a continuation of the ponds. For example, the effluent from the Blanchard pond caused the BOD-to-nitrogen-to-phosphorous (BOD/N/P) ratio of Berry Creek (the receiving stream) to change from 1/3/1 to 4/2/1, a ratio more closely related to the pond's effluent ratio (BOD/N/P ratio of 5/2/1). In the Quail Creek system, Dry Creek's BOD/N/P ratio of 2/2/1 changed to 2/1/1 after receiving the Quail Creek pond effluent with its BOD/N/P ratio of 3/1/1.

In addition to the biochemical adjustments, the streams lost much of their biological identity and assumed characteristics more closely associated with the biological loadings from the pond effluent. Ironic as it may seem, the types of algae which are dreaded downstream from other conventional sewage treatment plants were the very types which are being discharged continuously from bio-oxidation ponds. The most persistent algae in the systems were the Euglenophyta and Cyanophyta as these plankton had little difficulty making the transition from their acclimated life in the pond to the stream. Once these plankters gained a "foothold", indigenous stream plankton seemingly afforded little competition. In the extreme cases such as during the summer months when blue green algae (Cyanophyta) dominated various downstream areas, even the benthic algae could not compete and they too subsequently disappeared.

In summary, the following events occurred when a bio-oxidation pond effluent was discharged into a stream: The effluent plankton was initially reduced for reasons not well understood. It is conjectured that this reduction was due to particle sorption or possibly a loss of bouyancy during the transitional turbulance. A reduction in nitrogen

(N), phosphorous (P), and BOD accompanied the plankton reduction. After settling, some of the plankton was retained on the bottom (probably dormant), other plankters may have been lysed, while some persisted in the streamflow. When cell lysing occurs some N and P is released and becomes available for assimilation by aquatic vegetation. Additionally, some phosphates may be chemically precipitated depending on the pH and other chemical parameters. However, with the reductions in mixed plankton populations the competitive balance is upset and the hardy and persistent plankters prevail, but with less available N and P. These series of events may have been the reason why the plankton in the receiving stream increased downstream, yet overall concentration of N and P were reduced.

The discharge of coliform organisms from a bio-oxidation pond is a subject which needs further research from a control standpoint. Bio-oxidation ponds are by no means unique in discharging coliform organisms, as all sewage treatment processes discharge varying coliform concentrations. However, with other treatment processes, disinfection (primarily chlorination) of the effluent has been shown to be quite effective in reducing coliform residuals to nondetectable levels. Chlorination of pond effluent needs to be evaluated from the standpoint of (1) effectiveness, and (2) downstream effects, as it would appear that much of the plankton would be equally susceptible to any disinfectant.

Conclusions

This study considered the receiving stream as an intergral part of the bio-oxidation pond method of treatment and studies were conducted over a two year period on five ponds and their associated receiving streams. A variety of ponds and streams (systems) provided a means of observing and comparing seasonal trends and recognizing some of the effects of the effluent, a subject long overlooked. This study affords a better understanding of the system and most important, it represents a "real world" situation with all of its variables. Specifically, it is concluded that:

1. A bio-oxidation pond plus a transport stream (undiluted flow of effluent) can remove from one to eleven per cent more of the biochemical oxygen demand (BOD) than a pond alone. Total nitrogen (N) and total phosphates (P), conservative parameters in a bio-oxidation pond, can be reduced as much as eighteen per cent and seven per cent, respectively by the stream. Biological characteristics (plankton and coliform levels) remain essentially unchanged.

2. A bio-oxidation pond plus a receiving stream which is seasonally scoured can remove from one to nine per cent more BOD, from less-than one per cent to four per cent more N, and two to five per cent more P than a bio-oxidation pond alone.

3. Control of streambed scouring could effect in raising the efficiency of the bio-oxidation pond - receiving stream system to where approximately one to thirteen per cent more BOD, twenty-nine to fifty-five per cent more N, and thirty to fifty per cent more P could be removed than in a pond alone. Scouring control would also reduce concentrated downstream loadings after intense rainfall.

4. Except for scouring, bio-oxidation ponds and bio-oxidation pond - receiving streams behave essentially the same. The pond therefore, does not ecologically improve the receiving stream and the criteria presently used to evaluate the effectiveness of waste treatment (BOD, N and P) do not identify sufficiently the difference in pond and pond-plus-stream performance.

5. The receiving stream must be considered an integral part of the bio-oxidation pond method of treatment (other than the self-contained evaporative ponds). Until an economical means of harvesting the effluent algae becomes a reality, the installation and use of bio-oxidation ponds should be carefully considered with their impact on the stream.

6. The composite evaluation of conventional sewage treatment processes (trickling filter, activated sludge) against a bio-oxidation pond, must be made against the (bio-oxidation pond - receiving stream) combination to justly demonstrate an economic comparison.

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APPENDIX

TABLE 6

SUMMARY OF AVERAGE SEASONAL DATA -- LEXINGTON AND MAYSVILLE SYSTEMS (1966 - 1968)

Location	Season	Parameters, Concentrations: BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x 10^3/100ml	Plankton, ASU x 10^3/ml
Lexington Bio-ox. Pond Effluent	Winter	27	52.6	32.00	19.50	16.40	107	2700	158
	Spring	18	21.5	5.52	11.45	6.90	52	1400	162
	Summer	8	11.8	3.00	6.70	5.50	46	1100	133
	Fall	13	17.5	15.76	8.33	6.93	16	52	107
Station L-1	Winter	23	56.0	48.00	17.30	16.42	113	8200	155
	Spring	14	24.0	4.45	10.90	7.25	38	3000	265
	Summer	8	11.8	3.70	8.05	6.20	49	1200	97
	Fall	13	12.9	6.64	8.53	4.60	20	40	52
Maysville Bio-ox. Pond Effluent	Winter	10	6.0	1.50	11.90	6.00	30	35	9
	Spring	11	3.6	0.99	2.80	1.66	3	50	100
	Summer	13	3.4	0.75	2.50	1.40	13	290	51
	Fall	21	7.6	0.64	4.85	4.78	66	6	9
Station M-1	Winter	7	7.1	1.16	10.70	5.02	35	30	9
	Spring	5	6.0	1.36	2.75	1.88	9	100	32
	Summer	3	2.8	1.05	2.30	1.90	13	200	43
	Fall	23	6.2	0.69	4.98	4.91	29	10	6
Station M-2	Winter	5	3.0	1.04	9.98	3.80	30	10	13
	Spring	7	2.9	1.14	2.70	2.00	5	250	125
	Summer	1	1.8	1.75	2.31	1.20	9	220	29
	Fall	21	9.0	1.35	5.60	5.56	51	35	1

TABLE 7

SUMMARY OF AVERAGE SEASONAL DATA -- QUAIL CREEK
AND BLUFF CREEK SYSTEMS
(1966 - 1968)

		Parameters, Concentrations							
Location	Season	BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x 10^3/100ml	Plankton, ASU x 10^3/ml
	Winter	40	12.9	5.50	12.24	10.16	17	300	76
Quail Creek	Spring	24	4.1	3.87	8.52	7.34	24	100	118
Bio-ox. Pond	Summer	7	6.3	3.90	5.75	4.02	458	460	190
Effluent	Fall	15	9.1	5.00	8.54	6.43	15	50	92
	Winter	No Flow							
Dry Creek	Spring	No Flow							
	Summer	1	2.0	0.59	1.78	0.33	1310	150	225
	Fall	4	3.7	1.80	1.26	0.67	61	25	25
	Winter	42	14.0	7.26	10.96	7.68	55	950	56
Station	Spring	27	5.8	4.80	7.47	6.87	112	400	89
D-1	Summer	5	5.2	3.92	4.85	1.41	96	100	206
	Fall	4	3.0	1.40	5.32	1.68	15	30	40
	Winter	28	8.9	6.37	8.70	5.53	4	50	26
Station	Spring	11	3.6	2.37	4.67	3.68	9	150	42
D-2	Summer	2	5.6	3.14	3.28	0.74	41	145	157
	Fall	6	5.9	1.62	4.32	3.97	30	25	22

TABLE 7 -- Continued

Location	Season	BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x 10^3/100ml	Plankton, ASU x 10^3/ml
		Parameters, Concentrations							
	Winter	5	0.5	0.35	0.83	0.08	2	50	1
Bluff Creek	Spring	1	0.8	0.57	0.86	0.17	5	40	$<$ 1
	Summer	2	1.4	0.27	1.59	0.16	32	250	54
	Fall	1	2.6	1.00	0.93	0.35	6	35	2
	Winter	7	1.4	1.17	3.55	1.95	8	45	3
Station	Spring	3	3.1	1.47	3.67	0.75	26	450	15
B-1	Summer	2	1.4	0.80	0.99	0.28	113	50	90
	Fall	1	2.6	1.02	1.88	0.97	6	25	8
	Winter	7	2.1	0.96	2.00	1.83	3	40	2
Station	Spring	5	2.4	1.69	2.32	0.56	23	100	44
B-2	Summer	2	2.4	1.58	2.15	0.67	82	50	272
	Fall	2	2.2	1.65	1.42	0.77	2	18	6
	Winter	35	31.9	29.50	18.87	14.50	28	900	23
Bluff Creek	Spring	17	57.2	40.10	19.00	16.33	11	450	112
Bio-ox. Pond	Summer	20	39.5	28.56	15.50	11.66	720	3800	283
Effluent	Fall	8	29.7	17.25	17.80	16.73	13	40	40

TABLE 7 -- Continued

Location	Season	BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x 10^3/100ml	Plankton, ASU x 10^3/ml
		Parameters, Concentrations							
Deer Creek	Winter	7	0.9	0.56	2.52	0.20	4	25	< 1
	Spring	4	4.0	3.64	3.46	0.87	8	40	< 1
	Summer	1	8.3	0.28	2.20	0.13	187	50	7
	Fall	1	2.0	1.68	1.60	0.53	7	35	3
Station DC-1	Winter	9	10.1	9.42	7.18	6.37	14	50	2
	Spring	15	12.4	10.10	7.10	5.40	5	250	16
	Summer	3	6.6	3.85	4.60	3.00	210	1150	211
	Fall	4	13.0	7.89	8.53	7.56	2	25	17
Station DC-2	Winter	11	13.2	11.65	6.05	5.78	3	17	1
	Spring	10	12.9	9.73	7.57	5.50	12	30	19
	Summer	4	3.9	2.31	1.62	1.06	227	50	152
	Fall	5	11.0	8.02	7.50	6.84	6	20	9

TABLE 8

SUMMARY OF AVERAGE SEASONAL LOADINGS BASED ON AVERAGE CONCENTRATIONS AND FLOWS -- QUAIL CREEK AND BLUFF CREEK SYSTEMS (1966 - 1968)

		Loading, Lbs/day							
Location	Season	BOD	Kj-N, as N	NH_3, as N	T-PO_4, as P	O-PO_4, as P	Plate Count, x 10^{-2}	Coliforms, x 10^{-3}	Plankton
	Winter	81	25.9	11.00	24.48	20.30	1.4	2.4	304
Quail Creek	Spring	47	8.2	7.74	17.04	14.68	1.9	0.8	470
Bio-ox. Pond	Summer	15	12.7	7.80	11.50	8.04	36.7	3.7	761
Effluent	Fall	30	18.1	10.01	17.08	12.86	1.2	0.4	367
	Winter	No Flow							
Dry Creek	Spring	No Flow							
	Summer	2.2	3.4	0.98	2.97	0.84	85.5	1.0	750
	Fall	7.1	6.2	3.00	2.10	1.12	3.0	0.1	62
	Winter	83	28.1	14.52	21.92	15.36	4.4	7.6	224
Station	Spring	55	11.5	9.60	14.94	13.74	8.9	3.2	354
D-1	Summer	18	19.1	14.39	17.80	5.17	14.1	1.4	1510
	Fall	15	9.6	4.55	17.29	5.46	19.5	0.4	260
	Winter	56	17.9	12.74	17.40	11.06	0.3	0.4	103
Station	Spring	22	7.2	4.74	9.34	7.36	0.7	1.2	167
D-2	Summer	7	20.4	11.52	12.03	2.71	6.0	2.1	1151
	Fall	20	19.0	5.26	14.07	12.90	3.8	0.3	140

TABLE 8 -- Continued

		Loading, Lbs/day							
Location	Season	BOD	Kj-N, as N	NH_3, as N	T-PO_4, as P	O-PO_4, as P	Plate Count, x 10^{-2}	Coliforms, x 10^{-3}	Plankton
	Winter	20	1.8	1.20	3.32	0.32	0.3	0.8	10
Bluff Creek	Spring	24	17.0	14.78	18.75	3.70	0.4	4.4	< 1
	Summer	19	17.5	3.38	19.87	2.00	16.2	16.	1351
	Fall	7	19.7	7.50	6.98	2.62	1.8	1.0	32
	Winter	42	8.2	7.02	20.30	11.70	2.2	1.1	40
Station	Spring	69	74.2	34.99	87.35	17.85	24.8	43.	726
B-1	Summer	25	22.1	12.94	16.00	4.52	73.3	4.3	2902
	Fall	6	27.4	10.97	20.21	10.43	2.6	1.2	180
	Winter	44	12.6	5.76	12.00	10.98	0.6	1.0	20
Station	Spring	124	57.6	40.22	55.21	13.32	22.0	9.6	212
B-2	Summer	29	38.3	25.56	34.76	10.83	53.4	3.0	8824
	Fall	25	23.1	17.73	15.26	8.28	0.8	0.8	118
	Winter	575	532.	494.	315.	242.	18.7	61.	774
Bluff Creek	Spring	290	960.	675.	317.	273.	7.4	29.	3750
Bio-ox. Pond	Summer	327	660.	476.	258.	245.	480.4	253.	9440
Effluent	Fall	137	496.	288.	297.	269.	9.0	2.8	1339

TABLE 8 -- Continued

Location	Season	Loading, Lbs/day BOD	Kj-N, as N	NH_3, as N	T-PO_4, as P	O-PO_4, as P	Plate Count, x 10^{-2}	Coliforms, x 10^{-3}	Plankton
	Winter	40	5.	2.	14.	1.	9.2	0.6	<1
Deer Creek	Spring	67	64.	59.	56.	14.	51.1	2.3	<1
	Summer	12	87.	3.	23.	1.	77.6	2.1	147
	Fall	4	12.	10.	10	3.	17.5	1.4	43
	Winter	261	284.	272.	202.	181.	15.	5.4	128
Station	Spring	870	700.	570.	403.	304.	11.	55.0	1790
DC-1	Summer	130	286.	167.	199.	130.	364.	20.1	19100
	Fall	138	440.	265.	287.	255.	2.	3.5	1134
	Winter	338	375.	332.	172.	164.	3.	2.2	57
Station	Spring	600	730.	550.	428.	310.	27.	15.3	1100
DC-2	Summer	150	170.	100.	70.	50.	394.	8.7	13300
	Fall	175	372.	270.	252.	233.	8.	2.7	634

TABLE 9

SUMMARY OF AVERAGE SEASONAL DATA -- BLANCHARD SYSTEM
(1966 - 1968)

		Parameters, Concentrations							
Location	Season	BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x10^3/100ml	Plankton, ASU x 10^3/ml
	Winter	30	29.7	11.22	6.73	4.15	80	1600	176.4
Blanchard	Spring	54	7.4	4.87	7.26	5.84	76	1300	134.7
Bio-ox. Pond	Summer	21	13.9	3.67	12.76	8.68	69	150	142.5
Effluent	Fall	25	9.3	1.05	2.15	2.07	26	350	59.4
	Winter	<1	1.9	0.72	1.45	0.47	2	140	<0.1
Berry	Spring	1	2.5	0.74	1.02	0.19	10	40	1.4
Creek	Summer	<1	0.8	0.52	0.84	0.13	3	<1	0.9
	Fall	4	7.6	0.37	0.16	0.09	2	100	3.0
	Winter	3	4.7	0.66	1.73	0.67	76	700	32.5
Station	Spring	7	2.8	1.07	1.52	0.90	17	500	152.6
BC-1	Summer	4	2.9	0.90	2.44	2.28	45	13	20.2
	Fall	5	4.5	0.53	0.43	0.21	2	50	8.0
	Winter	2	3.8	0.56	1.89	0.40	57	50	13.1
Station	Spring	8	3.5	2.18	1.65	1.08	19	470	78.8
BC-2	Summer	3	2.6	0.77	2.11	1.67	20	45	30.0
	Fall	10	5.1	0.62	0.39	0.35	7	40	5.0
	Winter	2	2.5	0.60	1.15	0.30	1	35	2.0
South Fork	Spring	2	3.6	0.84	1.45	0.09	2	40	38.8
Walnut Creek	Summer	<1	0.7	0.62	0.82	0.03	<1	<1	<0.1
	Fall	3	2.1	0.37	0.18	0.10	2	25	1.9

TABLE 9 -- Continued

Location	Season	BOD, mg/l	Kj-N, mg/l as N	NH_3, mg/l as N	T-PO_4, mg/l as P	O-PO_4, mg/l as P	Plate Count, x 10^3/ml	Coliforms, x10^3/100ml	Plankton, ASU x 10^3/ml
		Parameters, Concentrations							
Station SF-1	Winter	2	2.6	0.44	1.31	0.28	18	30	9.2
	Spring	3	2.7	0.75	1.23	0.25	7	200	32.2
	Summer	1	0.6	0.34	0.46	0.43	12	5	4.0
	Fall	4	2.3	0.67	0.19	0.09	7	15	1.3
Stream A	Winter	2	5.0	0.80	1.30	0.34	9	50	1.0
	Spring	1	2.0	0.67	1.02	0.10	17	400	36.9
	Summer	2	0.6	0.52	0.71	0.03	<1	<1	<0.1
	Fall	1	2.8	0.30	0.15	0.08	8	17	1.0
North Fork Walnut Creek	Winter	5	3.4	0.85	1.44	0.43	1	45	3.7
	Spring	2	3.3	0.82	1.01	0.12	11	20	4.2
	Summer	1	0.4	0.40	0.45	0.05	5	1	0.8
	Fall	4	1.2	0.60	0.16	0.09	1	25	2.2
Walnut Creek	Winter	1	1.1	0.68	1.28	0.40	10	40	9.5
	Spring	2	3.5	0.73	1.38	0.12	4	100	30.8
	Summer	1	0.7	0.51	0.53	0.01	3	<1	18.3
	Fall	2	1.8	0.35	0.19	0.09	5	18	2.0

TABLE 10

SUMMARY OF AVERAGE SEASONAL LOADINGS BASED ON AVERAGE CONCENTRATIONS AND FLOWS -- BLANCHARD SYSTEM (1966 - 1968)

		Loading, Lbs/day							
Location	Season	BOD	Kj-N, as N	NH_3, as N	T-PO_4, as P	O-PO_4, as P	Plate Count, x 10^{-2}	Coliforms, x 10^{-4}	Plankton
	Winter	10	9.8	3.70	2.22	1.37	1.0	2.0	117
Pond	Spring	18	2.4	1.58	2.40	1.93	1.0	1.7	89
Effluent	Summer	7	4.6	1.21	4.20	2.86	0.9	0.2	94
	Fall	8	3.1	0.34	0.71	0.58	0.4	0.5	39
	Winter	< 1	3.8	1.44	2.90	0.94	< 0.1	0.1	< 1
Berry	Spring	3	8.4	2.46	3.38	0.63	1.3	0.5	9
Creek	Summer	< 1	0.9	0.61	0.98	0.15	0.1	< 0.1	2
	Fall	3	5.2	0.25	0.11	0.06	< 0.1	0.3	4
	Winter	2	2.5	0.35	0.93	0.36	1.6	1.5	34
Station	Spring	27	10.0	3.92	5.55	3.30	2.5	8.0	1120
BC-1	Summer	5	4.3	1.35	3.60	3.42	2.7	0.1	61
	Fall	5	4.5	0.53	0.43	0.21	0.3	0.2	16
	Winter	1	2.0	0.30	1.00	0.21	1.2	0.1	14
Station	Spring	30	13.0	8.00	5.98	3.98	2.8	6.8	578
BC-2	Summer	4	4.0	1.15	3.16	2.50	1.2	< 0.1	90
	Fall	10	5.2	0.62	0.39	0.35	0.3	0.2	10
	Winter	2	2.3	0.55	1.06	0.27	< 0.1	0.2	37
South Fork	Spring	24	54.5	12.60	21.80	1.35	1.3	2.4	1164
Walnut Creek	Summer	< 1	2.5	2.23	2.95	0.10	0.1	< 0.1	< 1
	Fall	3	4.5	0.77	0.37	0.18	0.1	0.1	79

TABLE 10 -- Continued

Location	Season	BOD	Kj-N, as N	NH , as N	T-PO4, as P	O-PO4, as P	Plate Count, x 10^{-2}	Coliforms, x 10^{-4}	Plankton
		Loading, Lbs/day							
Station SF-1	Winter	3	3.8	0.64	1.90	0.41	0.7	0.1	17
	Spring	62	50.2	14.00	23.00	4.66	4.1	1.2	966
	Summer	6	2.8	1.74	2.34	2.18	1.7	< 0.1	29
	Fall	13	7.0	2.10	0.59	0.27	0.5	0.2	5
Stream A	Winter	< 1	0.6	0.09	0.15	0.04	< 0.1	< 0.1	<1
	Spring	4	6.2	2.12	3.23	0.32	2.1	5.0	234
	Summer	2	0.6	0.56	0.77	0.03	< 0.1	< 0.1	<1
	Fall	1	1.6	0.17	0.87	0.05	0.2	0.1	1
North Fork Walnut Creek	Winter	4	2.8	0.70	1.20	0.35	< 0.1	0.2	6
	Spring	36	53.6	13.20	16.30	1.95	7.0	1.0	137
	Summer	1	2.4	2.24	2.55	0.28	1.1	< 0.1	9
	Fall	3	3.8	1.30	0.52	0.26	0.1	0.2	14
Walnut Creek	Winter	3	2.7	1.62	3.08	0.95	1.0	0.2	45
	Spring	74	145.0	30.00	56.60	4.90	7.4	16.5	2538
	Summer	12	7.8	6.05	6.30	1.18	1.4	< 0.1	434
	Fall	6	11.9	2.33	1.26	0.60	1.2	0.5	27