EFFECT OF NUTRIENT ENRICHMENT FROM AGRICULTURAL RUNOFF ON MACROINVERTEBRATES IN SALT CREEK, A PRAIRIE STREAM IN NORTH CENTRAL OKLAHOMA

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1982

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 1988

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ACKNOWLEDGMENTS

I wish to express sincere appreciation to my thesis advisor, Dr. Jerry Wilhm, for his guidance, encouragement, and friendship throughout my graduate program at Oklahoma State University. I am also grateful for the support and recommendations of Drs. Sterling Burks, David Francko, and Ronald McNew, who served on my graduate committee.

To Allen Ratzlaff and Richard Hartman who aided in field collections, I extend sincere thanks. This project would not have been possible without their help. I appeciate the permission granted by Mr. Reed and Mr. Weaver to access the portion of Salt Creek on their ranches.

I am endebted to my parents, Dick and Pat Bryant, for their encouragement and inspiration, and to my wife, Rebecca, for her understanding, encouragement, and support. I also extend thanks to Dr. James Gore for helping me to realize my potential and Sherry Ham for her support and friendship.

Finally, I would like to thank Dr. Norman Durham and Beth McTernan of the University Center for Water Research. The Presidential Fellowship that I received from them allowed me to improve the quality of my dissertation research.

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NOMENCLATURE

AFW	ash-free weight
AOV	analysis of variance
APOM	allochthonous particulate organic matter
CHL_b	chlorophyll concentration of attached algae
CHL_s	chlorophyll concentration of suspended algae
COL	collector macroinvertebrates
CPOM	coarse particulate organic (> 1mm)
$CPOM_b$	CPOM sedimentation rate
DDW	demineralized distilled water
DO	dissolved oxygen
E	equitability portion of diversity
FPOM	fine particulate organic matter (63 - 1000um)
$FPOM_s$	suspended FPOM
GRA	grazer macroinvertebrates
H'	diversity
N	nitrate-nitrite nitrogen
N/P	nitrate-nitrite nitrogen to orthophophate ratio
P	orthophosphate
P'	primary production
P/R	primary production to respiration ratio
PAR	photosynthetically active radiation
PAR_b	PAR at substrate surface
PAR_s	PAR at water surface

PRED	predator macroinvertebrates
POM	particulate organic matter
RCC	river continuum concept
S	richness portion of diversity
SHR	shredder macroinvertebrates
UPOM	ultra-fine particulate organic matter (0.5 - 63um)
$UPOM_S$	suspended UPOM

CHAPTER I

INTRODUCTION

Longitudinal variation of structure and function of stream ecosystems has been a central issue of running water ecology. The river continuum concept (RCC) considers stream ecosystems as predictably organized units and provides a conceptual framework of their organization (Vannote et al. 1980). The RCC predicts that communities respond to changes in certain geomorphic, physical, and biotic variables to achieve a state of dynamic equilibrium. Based on the predicted responses, lotic communities are classified into three broad areas: headwaters (orders 1-3), mid-reaches (orders 4-6), and large rivers (orders >6). The transition between each area involves changes in producers (algae and macrophytes), microconsumers (primarily bacteria and fungi), and macroconsumers (primarily macroinvertebrates and fish). The changes involved are based on energy input, use, and conversion such that downstream communities depend on the inefficiency of energy use in upstream communities (Cummins 1980). Recent research indicates that the stream order designations are not always as originally proposed (Minshall et al. 1983, Bott et al. 1985, Bruns & Minshall 1985). These studies indicate that the RCC can be adjusted using a "sliding scale" such that the stream order designations associated with predicted trends are different for different biomes (Minshall et al. 1983).

Since the RCC was largely developed from studies in eastern woodland streams in the United States, it emphasizes the contributions of large allochthonous material such as leaf litter in stream energetics (Cushing et al. 1983). In streams without a headwater canopy, input of large allochthonous material may not be as important as finer allochthonous inputs and primary production. Macroinvertebrate assemblages in systems without a headwater canopy are generally dominated by grazer/scrapers and collector/gathers (Rounick et al. 1982, MacFarlane 1983, Lowe et al. 1986). Shedders are relatively sparse since little coarse particulate organic matter enters the stream from the terrestrial environment. Streams without a headwater canopy can exhibit higher rates of primary production and community respiration and in many cases algal assemblages are dominated by green algae rather than diatoms (Kownacki 1982, Duncan & Brusven 1985a,b).

Although the RCC was developed for unperturbed streams, it should accommodate many unnatural disturbances such as nutrient enrichment (Vannote et al. 1980). Nutrient enrichment in streams is generally associated with increased localized algal biomass and productivity which decrease downstream (Cooper & Wilhm 1975, Aizaki 1978, Kurata 1983, Puncochar 1983). Effects on macroconsumers include an initial increase in biomass, compositional reorganization, and then a biomass decrease (Gammon et al. 1983). These effects may be more pronounced in streams without a headwater canopy since algal growth appears to be nutrient rather than light limited (Moore 1977, Lowe et al. 1986).

No studies have yet been performed to test the applicability of the river continuum concept, as a whole, to grassland prairie streams lacking headwater canopies. The objectives of the first phase of this

study were to develop and test a set of assumptions and hypotheses based on the RCC for Salt Creek, a prairie stream in Osage County, Oklahoma. The second phase of this study was to analyze the effects of nutrient enrichment from agricultural runoff on the longitudinal relationships determined in the first phase.

CHAPTER II

LITERATURE REVIEW

Introduction

Prior to the mid-1960's, ecological research in running waters emphasized the association between organisms and abiotic factors (Minshall et al. 1983). These studies were primarily limited to first through third-order streams and focused on periphyton, macro-invertebrates, or fish. Few attempts treated stream systems holistically or viewed them as discrete ecological units (Cummins 1975). Knowledge of the structure and function of streams reached a stage by the early 1970's that allowed general theories to be constructed which related large rivers to the more frequently studied smaller streams. Until recently few such unifying concepts have been proposed.

Three reasons for the sparcity of unifying concepts in streams are (1) the complex nature of stream ecosystems, (2) the recognition of the functional biotic unit in streams, and (3) the historic use of ecological models (Cummins et al. 1983). Due to the complex nature of flowing-water systems, it is more difficult to visualize streams of different sizes within a drainage basin as being one ecosystem than it is to visualize a lake or forest as being a discrete system (Pennak 1971, Rzoska 1978). Once the stream system is viewed holistically, the second major impediment to the construction of generalized theories has

been the traditional basis for ecological studies. Most ecological research has been based on taxonomic inventories of species assemblages. As long as species have been assumed to be the basic ecological unit, the incomplete state of taxonomic knowledge has been a major constraint (Cummins 1974). Finally, once an ecological model is presented, it may not be generally accepted due to misuse. Many models are used without modification to describe specific systems rather than as a framework for building individualized descriptions.

The River Continuum Concept

In the early 1900's, it was recognized that functional roles were filled by different taxa occupying similar habitats that were spatially separated. Shelford (1914,1937) discussed analagous species groups in spatially separated aquatic systems. Lindemann (1942) categorized biological associations on the basis of nutritional habits and Cummins (1974) devised a classification of aquatic organisms based on feeding behavior or functional group. The use of functional groups to describe stream communities was the key to constructing the current theories of lotic system structure and function.

Several researchers theorized that streams possess species assemblages whose distributions reflect the existing physical gradients (Shelford 1911, Thompson & Hunt 1930, Ricker 1934, Burton & Odum 1945, Minshall 1968, Platts 1979). Including functional relationships of organisms with this idea allowed development of a basic framework describing biotic communities along a river system (Vannote 1975, Cummins 1975). The concept proposed that understanding biotic structure and function along a river requires the consideration of physical

gradients formed by the drainage system. Vannote and Cummins based their theory on the fluvial principle of dynamic equilibrium. The dynamic equilibrium concept was proposed to describe statistically the relationship among stream width, depth, velocity, and sediment load (Leopold & Maddock 1953, Currey 1972). This concept was later used to describe the system in terms of energy inputs and use efficiency (Leopold et al. 1964, Langbein & Leopold 1966).

Vannote (1975) and Cummins (1975) formulated the hypothesis that structural and functional characteristics of lotic communities distributed along a river system were selected to conform to the mean state of the physical stream at each location. Refinement of their early ideas led to the River Continuum Concept (RCC) which classified lotic communities into headwaters, medium-sized streams, and large rivers (Vannote et al. 1980). Stream communities followed an ecological transition from headwaters to lower reaches which involved changes in producers (algae and vascular macrophytes), microconsumers (primarily bacteria and fungi), and macroconsumers (invertebrates and fish). This theory was based on energy input, use, and conversion where downstream communities depended on the inefficiency or "leakage" of food resources from upstream communities (Cummins 1980).

The RCC originally described streams in deciduous forest watersheds. In these watersheds, headwater streams are influenced by riparian vegetation which reduces autochthonous production by shading and which contributes large amounts of allochthonous detritus, especially coarse particulate organic matter (CPOM, particles > 1mm) (Fig. 1). After CPOM enters the stream, it is quickly colonized by microconsumers and then shredders which consume the CPOM/microconsumer

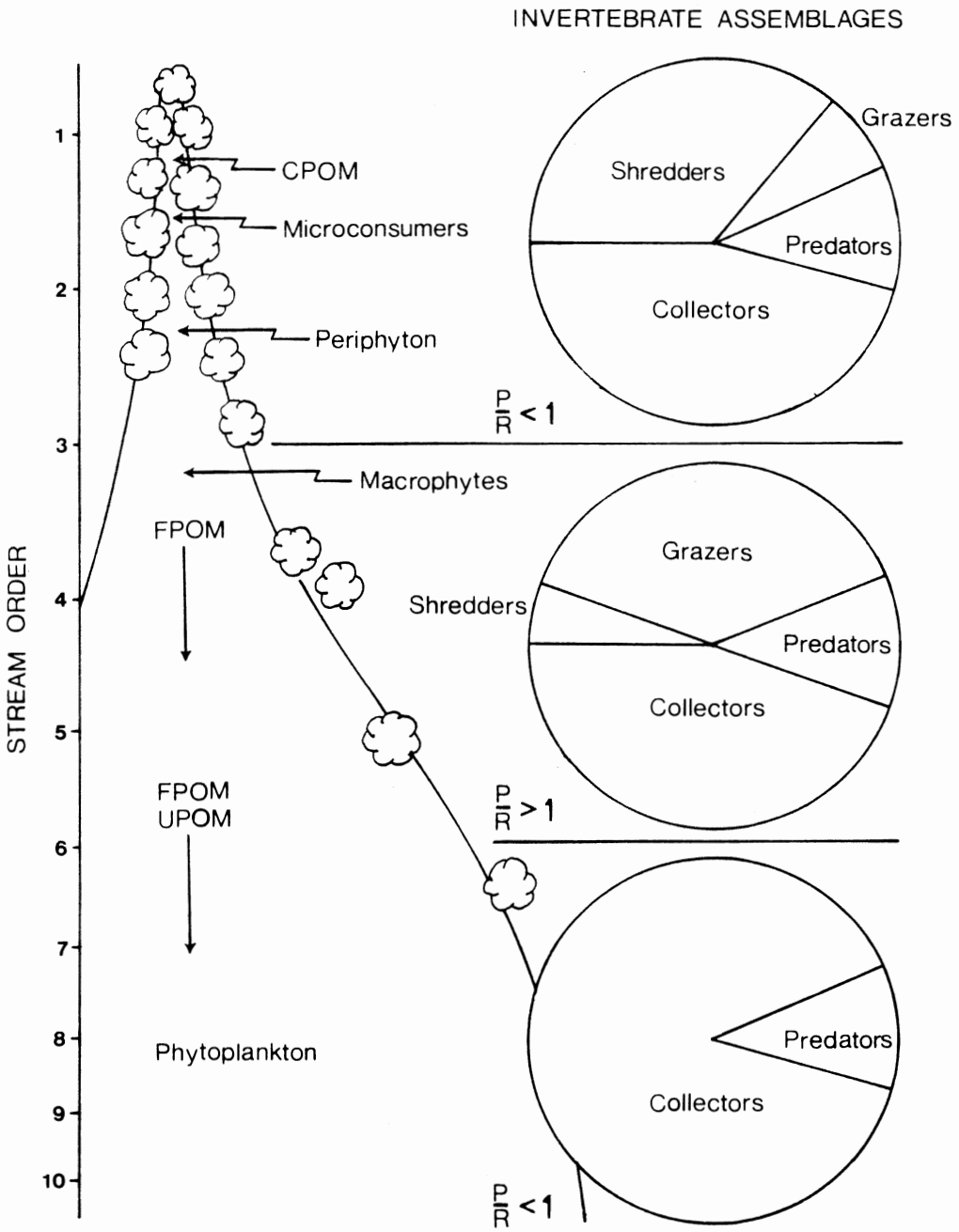


Figure 1. Diagram of the River Continuum Concept (adapted from Cummins 1975 and Vannote et al. 1980).

matrix. CPOM is tranformed into fine POM (FPOM, particles 63 - 1000 um) in the form of shredder feces and feeding fragments which are carried downstream. The production of FPOM allows the headwaters to support collector/gatherers (FPOM consumers) which transform the FPOM into finer FPOM which is also carried downstream. The headwater regions can be described as CPOM-microconsumer-shredder-FPOM-collector/gatherer systems.

Medium-sized rivers are more dependent on organic production by photosynthetic algae and macrophytes coupled with FPOM from upstream sources than on terrestrial inputs (Fig. 1). The point at which the stream dynamics change from heterotrophic to autotrophic primarily depends on the degree of shading by terrestrial vegetation. The increased primary producer biomass supports an increased biomass of grazer/scrapers (primary producer consumers) which transform producers into FPOM. With decreased dependence on terrestrial inputs, a corresponding decrease in shredders is predicted. Although the relative biomass of collector/gatherers in the mid-reaches should not change significantly from that of the headwaters, a taxa shift may be noted due to the continuous downstream transformation of FPOM into smaller particles. FPOM may also be transformed into ultra-fine POM (UPOM, particles 0.5 - 63 um) in the mid-reaches and carried downstream. The intermediate sized streams can be described as producer-grazer-FPOM(UPOM)-collecter/gatherer systems.

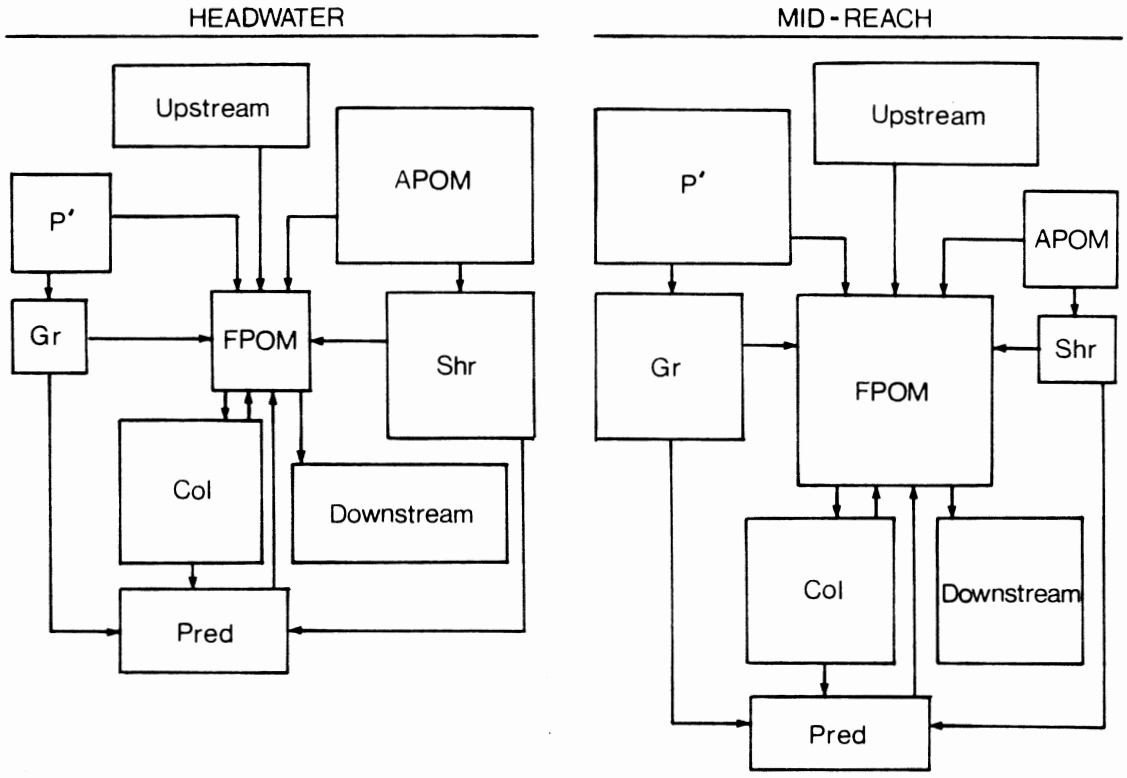
Large rivers tend to be turbid with heavy sediment loads, the culmination of all the upstream processes. The large quantity of FPOM and UPOM available in this load should support a relatively high biomass of collecter/gatherers. The turbidity will also limit primary

production within the system which would reduce the relative biomass of grazers. As in intermediate sized streams, the energy input from riparian vegetation is small so shredder biomass should be low. Thus, these are FPOM(UPOM)- collecter/gatherer systems.

The predator component relies on the availability of the other functional groups instead of on fundamental changes in allochthonous and autochthonous energy sources. Due to the level of dissociation between the predators and the changing energy inputs, the RCC predicts little change in the relative biomass of predators along the stream gradient.

Assumptions and Hypotheses

The river continuum concept views streams as longitudinally linked systems in which energy flow dynamics in downstream areas are linked to in-stream processes in upstream areas (O'Neill et al. 1979). This approach leads to useful generalizations concerning spatial and temporal variation of the energy inputs, conversions, outputs, and the resulting structure of the biotic community (Cummins et al. 1983). Describing an entire river system as a continuum of communities with their associated biotic and abiotic interactions may be illustrated using a simplified nine component model of the headwaters and mid-reaches of a woodland stream (Fig. 2). The relative size of each component (e.g. AFW) is represented by the size of the boxes. The differences between the two systems are the relative size of components and the rates of transfer among components. An entire river system can be veiwed as a series of such plans along the continuum. The RCC's conceptualization of a typical forest watershed (Fig. 1) can be



Gr - Grazers
Shr - Shredders
Col - Collectors
Pred - Predators

P' - Primary Producers
APOM - Allochthonous Particulate Organic Matter
FPOM - Fine Particulate Organic Matter

Figure 2. Simplified Component Models for Two Hypothetical Stream Ecosystems. The Size of Each Component Corresponds to its Relative Importance (adapted from Fisher & Likens 1973, Cummins et al. 1973, and Minshall et al. 1983).

described using three component models. The relationships between successive downstream components can be partitioned into four sets of hypotheses, grouped under the following assumptions (Cummins et al. 1983):

(1) If the POM at one location in a stream is determined by what occurs upstream and if the biotic component exploits this, then (a) a gradual reduction in particle size occurs as the material is metabolized and fragmented within each segment, and (b) a reduction in the organic content of the particles occurs as they are transported downstream.

(2) Given the assumption in (1) and if the relative contribution of CPOM from the terrestrial environment decreases downstream, then (a) the coarse to fine particulate size ratio will decrease downstream, and (b) the relative proportion of particulates produced by instream processes will increase downstream.

(3) If stream channel morphology changes from narrow, shallow, and shaded to wide, deep, and open, then (a) a shift from heterotrophic to autotrophic processes will occur as adequate light becomes available followed by a shift back to heterotrophic processes as the channel deepens, and (b) a shift from community metabolism dominated by benthic processes to metabolism dominated by water column processes will occur.

(4) Given assumptions (1) - (3), then (a) the proportion of organisms dependent on CPOM will decrease from headwaters to lower reaches, (b) organisms dependent on FPOM increase downstream, and (c) organisms dependent on primary producers increase from headwaters to mid-sized streams and then decrease.

Testing of the Model

The RCC was proposed to provide a framework for integrating biotic features of flowing waters systems with the physical environment and was developed specifically to define average conditions in unperturbed streams (Minshall et al. 1983). Most of the problems associated with the river continuum concept stem from inflexibility in its use to describe individual systems (Bott et al. 1985). To fit the stream under study, the model assumptions and/or hypotheses needed to be altered but the components used to describe each stream segment and the linkages between successive segments did not need to be changed.

Shifts from heterotrophic headwaters to autotrophic midreaches occurred in forested watersheds of Michigan, Pennsylvania (Bott et al. 1985), and Idaho (Cushing et al. 1983). The transition between trophic states occurred at different locations on each stream and during different seasons due to site specific factors. In general, changes in particulate organic matter, community production and respiration, CPOM breakdown rates, and macroinvertebrate functional feeding group compositions along each stream supported the RCC (Cummins 1981, Minshall et al. 1983). In a 200 km segment of an eighth order stream, the dominance of filter-feeders and lack of shredders supported the RCC, while a consistently high proportion of scrapers suggested that the importance of autotrophic production in large rivers was more important than originally assumed (Bruns & Minshall 1985).

Detritus is a major food source for macroinvertebrates and their role in processing this material has been extensively analyzed (Anderson et al. 1978, Anderson & Sedell 1979, Cummins & Klug 1979,

Kirby et al. 1983, Merritt et al. 1984a). Fresh deciduous leaf litter is not readily consumed by stream invertebrates but requires days to weeks of microconsumer conditioning to render it usable by shredders (Kaushik & Hynes 1971, Barlocher & Kendrick 1974, Merritt et al. 1984b). However, the leaves from coniferous trees require months of conditioning prior to invertebrate colonization (Peterson & Cummins 1974, Triska et al. 1975, Sedell et al. 1975). The use of coniferous needles in detrital food chains appears to be minimal due to the slow rate of conditioning and high rate of export prior to use. In these systems, the predominant source of CPOM is woody material and most of the shredders are replaced by borers and gougers (woody CPOM consumers) (Anderson et al. 1978, Naiman & Sedell 1979, Triska & Cromack 1980, Melillo et al. 1983).

Rivers in New Zealand are short, low-order streams which are typically fast-flowing and turbulent, and the unstable substrates have poor debris-retention characteristics (Winterbourn et al. 1984). Shredders, borers, and gougers are poorly represented or absent in New Zealand headwaters (Winterbourn et al. 1981,1984; Anderson 1982, Rounick & Winterbourn 1983). A general prediction of the RCC is that the detrital base shifts from a predominance of CPOM in the headwaters to FPOM and UPOM downstream (Vannote et al. 1980). In North American streams, this shift is generally facilitated by high amounts of debris retention in the headwaters which allows rapid biotic conversion of CPOM to smaller sizes (Bilby & Likens 1980). Apparently, in New Zealand, CPOM is rapidly converted to FPOM by mechanical activity which does not allow the CPOM-using biota to colonize and the entire stream system represents only the middle reaches described in the RCC.

Although the importance of tributaries on the predictions of the RCC has received little attention, a variety of effects have been postulated (Vannote et al. 1980, Minshall et al. 1983, Bruns et al. 1984). A small tributary may provide a sustained input of CPOM into a larger order stream which would result in maintenance of biotic structure and function similar to upstream reaches. Conversely, at a point where the canopy prevents an autotrophic community, the joining of two stream segments may allow such a community to exist. Tributaries in an Oregon coniferous forest stream increased the CPOM to FPOM ratio, but did not significantly alter the relative proportions of functional groups (Minshall et al. 1983), primary production, or respiration (Bott et al. 1985). In an Idaho stream, small tributaries entering small streams tended to change the structure of the stream to that of higher orders, while small tributaries entering larger streams reset the structure to that of lower orders (Bruns et al. 1984).

In natural stream systems, both living and detrital food bases are processed continuously, but seasonal shifts in the relative importance of autotrophic production and detrital processing occur (Vannote et al. 1980). Autotrophic communities often form the major food base during spring and summer (Minshall 1978). Detritus is often the major food base during autumn and winter, and provides a fine particulate base during other seasons (Kaushik & Hynes 1971, MacKay & Kalff 1973, Sedell et al. 1974). In the South Saskatchewan River system (Alberta, Canada), the longitudinal trends in macroinvertebrate funtional groups generally followed the predictions of the RCC (Culp & Davies 1982). However, these trends were not always consistent among seasons. Only the fauna of the headwater region remained longitudinally distinct. The fauna of

the middle and lower reaches shifted seasonally as the relative importance of the autotrophic and detrital energy pathways shifted. Similarly, the fauna in an eighth order river changed in an orderly fashion as predicted by the RCC in autumn but not in summer (Bruns & Minshall 1985). The nonconformity in summer was attributed to more dependence on primary production than originally hypothesized by the RCC. In a third to fourth order stream in Colorado, shredders were most abundant upsteam and collectors more abundant in the mid-reaches as predicted by the RCC (Canton & Chadwich 1983). The observed trends were highly seasonal, with shredders being abundant only in spring and collectors only in summer.

Habitat and food limitation of biotic assemblages ("bottom-up" regulation) is assumed by the RCC (Bowlby & Roff 1986). Benthic macroinvertebrate densities have been correlated to microcommunity production and biomass (Hawkins & Sedell 1981, Taylor & Roff 1982) and trout biomass has been correlated with benthic macroinvertebrate biomass (Murphy et al. 1981). However, in southern Ontario streams, it has been demonstrated that regulation by predation ("top-down" regulation) best explains trophic structure patterns (Bowlby & Roff 1986). The effect of a trophic level on the next lowest level was more pronounced at high trophic levels and decreased down the food chain having the least effect at the microcommunity level. Plecopteran predator limitation of prey assemblage biomass has also been demonstrated in streams (Peckarsky & Dodson 1980, Walde & Davies 1984).

The RCC, developed for unperturbed streams, should accommodate many unnatural disturbances such as impoundment and nutrient enrichment (Vannote et al. 1980). Regulation of streams by dams and reservoirs has

typically resulted in breaking the river continuum into an alternating series of lentic and lotic reaches. The RCC does not yet predict interrupted continua dynamics, but the serial discontinuity concept predicts that physical conditions and biotic assemblages below a reservoir will reset the community structure to that of lower order streams (Ward & Stanford 1983). Reservoirs appeared to reset many physical and chemical parameters and macroinvertebrates along the Arkansas River (Gore & Bryant 1985). However, reservoirs did not reset forage fish assemblages but instead acted as distributional barriers.

Nutrient Enrichment

Several studies have considered the effects of nutrient enrichment along river continua. Rapid removal of inorganic nutrients by periphyton downstream of sewage inputs has resulted in high primary productivity immediately below the inputs and decreasing productivity downstream (Cooper & Wilhm 1975, Aizaki 1978, Sladeckova et al. 1983). Overall biomass of algae (Kurata 1983) and benthic heterotrophic bacteria (Puncochar 1983) also decreased downstream as inorganic nutrient availability decreased. The increase in heterotrophic bacteria as well as other microconsumers may be associated with the reported increases in breakdown of CPOM associated with nutrient enrichment (Fairchild et al. 1984). The effects of nutrient enrichment on macroinvertebrates is generally an increase in standing crop prior to a reduction in assemblage diversity (Wilhm & Dorris 1968, Reger & Kevern 1981).

In Polish grassland streams receiving nutrients from fertilized pastures, algal development was poor with green algae dominating in

spring and blue-green algae dominating in summer and fall as nutrient levels declined (Kawecka 1983). Ditches in the Netherlands receiving agricultural runoff exhibited marked orthophosphate and ammonia gradients which were inversely correlated with distance from source (Klapwijk et al. 1983). Algal biomass was positively correlated and algal diversity was negatively correlated with both nutrients. An intensive study of the effects of agricultural runoff on stream fauna in central Indiana reported three phases of effects (Gammon et al. 1983). Initially, the biomass of macroinvertebrates and fish increased without a compositional change. As agricultural inputs increased, chironomids assumed a dominant role while other benthic groups became secondary in importance. Finally, the fish assemblages changed from insectivorous and piscivorous to detritivorous and herbivorous. The change in fish composition was accompanied by overall decreases in fish and macroinvertebrate biomass. Increased chironomid and decreased mayfly and stonefly biomass has also been reported for Polish streams heavily impacted by agricultural runoff (Kownacki 1982).

The RCC in Prairie Streams

In contrast to the woodland streams generally studied in conjunction with the RCC, prairie streams in midwestern North America lack headwater canopies. Allochthanous inputs are mainly derived from surrounding plains or croplands and the CPOM fraction of this input may be relatively low. In streams without a headwater canopy, the transition to autotrophic dominance may be in first order rather than in third or fourth order streams as predicted for canopied watersheds (Vannote et al. 1980).

The fauna of small streams in recently clearcut catchments exhibited increased use of autochthonous materials in response to canopy removal and flushing of forest derived organic materials from the streams (Rounick et al. 1982). Logged headwaters in southern Alaska had higher densities of benthic macroinvertebrates and higher rates of primary production and community respiration than unlogged headwaters (Duncan & Brusven 1985a, 1985b). Logged streams exhibited an increase in the proportions of scraper/grazers and collector/gatherers, while shredders were a minor group. As new canopies developed, shredders became more common and scraper/grazers were only abundant in summer. Changes of algal assemblages from dominance by diatoms to filamentous green algae has also been associated with forest clear-cutting (Lowe et al. 1986). Nutrient limitation appeared to control algal growth in clearcut streams, while light availability was the control in adjacent forested watersheds.

Energy use in small grassland streams in New Zealand consisted of both autochthonous and allochthonous materials, while only allochthonous materials were used in forested headwaters (Rounick et al. 1982). In Poland, a greater number of algal and macroinvertebrate taxa occurred in grassland streams than in forested streams (Kownacki 1982). Additionally, macroscopic aggregations of green algae occurred only in grassland streams. Since the predominant allochthonous input in the headwaters of a midwestern plains stream was FPOM, shredders were reduced and collectors dominated (MacFarlane 1983). Further downsteam, CPOM input and the relative importance of shredders increased. Grazer/scapers were not a dominant group at any location on the stream due to the shifting unstable substrates which decreased periphyton

availability. Shredder colonization of CPOM was also low in a tallgrass prairie stream in Kansas (Smith 1986). CPOM processing was attributed to the microcommunity and macroconsumers appeared to use this material for habitat. In the middle reaches of Otter Creek, a stream in the Oklahoma mixed-grass prairie, the diversity, equitability, and number of algal taxa increased with increased stream order, while chlorophyll *a* and algal biomass decreased (Seyfer & Wilhm 1977). The maximum numbers of benthic macroinvertebrates in Otter Creek occurred in fourth order streams and minimum numbers in sixth order (Harrel & Dorris 1968). Annual numbers of species and diversity increased from third to fifth order reachs and decreased in the sixth order reach as predicted by the RCC.

Objectives

The objectives of the first phase of this study were to develop a set of assumptions and hypotheses based on the RCC for prairie streams and to test these hypotheses in Salt Creek, Osage County, Oklahoma. The second phase of this study was to analyze the effects of nutrient enrichment from agricultural runoff on the longitudinal relationships determined in the first phase. Since it has been reported that primary production in streams without headwater canopies is nutrient-limited rather than light-limited, a system such as Salt Creek should be more responsive to nutrient manipulation. This study was designed to analyze the following:

(1) General physical and chemical characteristics of Salt Creek from the headwaters to higher orders.

(2) Longitudinal and seasonal changes in selected biotic assemblages of Salt Creek.

(3) The applicability of the RCC to the physical, chemical, and biotic patterns and relationships identified.

(4) The effects of localized agricultural nutrient enrichment on the physical, chemical, and biotic patterns and relationships, and the applicability of the RCC.

CHAPTER III

DESCRIPTION OF STUDY AREA

Salt Creek is located in the tallgrass prairie of Osage County, Oklahoma (Fig. 3). Its headwaters are at Grainola OK near the Kansas-Oklahoma border. From this point, it flows southerly through Shidler and Fairfax OK and enters the Arkansas River 12 km south of Fairfax. It is the largest stream in Osage County, draining 628 km^2 along an 89 km length. The Salt Creek basin averaged 86 cm of precipitation per year with peaks in February, May, and October (NOAA 1986). The mean annual air temperature was 16.4 ^oC.

The terrestrial habitat bordering Salt Creek varied from pasturelands with riparian vegetation dominated by non-woody plants and small shrubs to forested canopies of ash, elm, and hackberry. Dominant herbacious vegetation included Ammania coccinea, Cyprus acuminatus, C. aristatus, C. esculentus, Echinochloa crusgalli, Juncus torreyi, J. diffussimus, Pasplum floridanum, Polygonum bicorne, P. hydropiperoides, and Setaria viridis. Dominant shrubs included Amorpha fruticosa, Apocynum cannabium, Cassia fasciculata, and Cephalanthus occidentalis, and the dominant trees were Celtis sp., Fraxinus quadrangulata, Populus deltoides, Salix nigra, and Ulmus americana.

Five sites were sampled along Salt Creek (Fig. 3, Table 1). Stream order and drainage area were determined according to methods described by Lind (1979). Link number was determined according to the methods of Shreve (1966). No sample sites were chosen below Fairfax

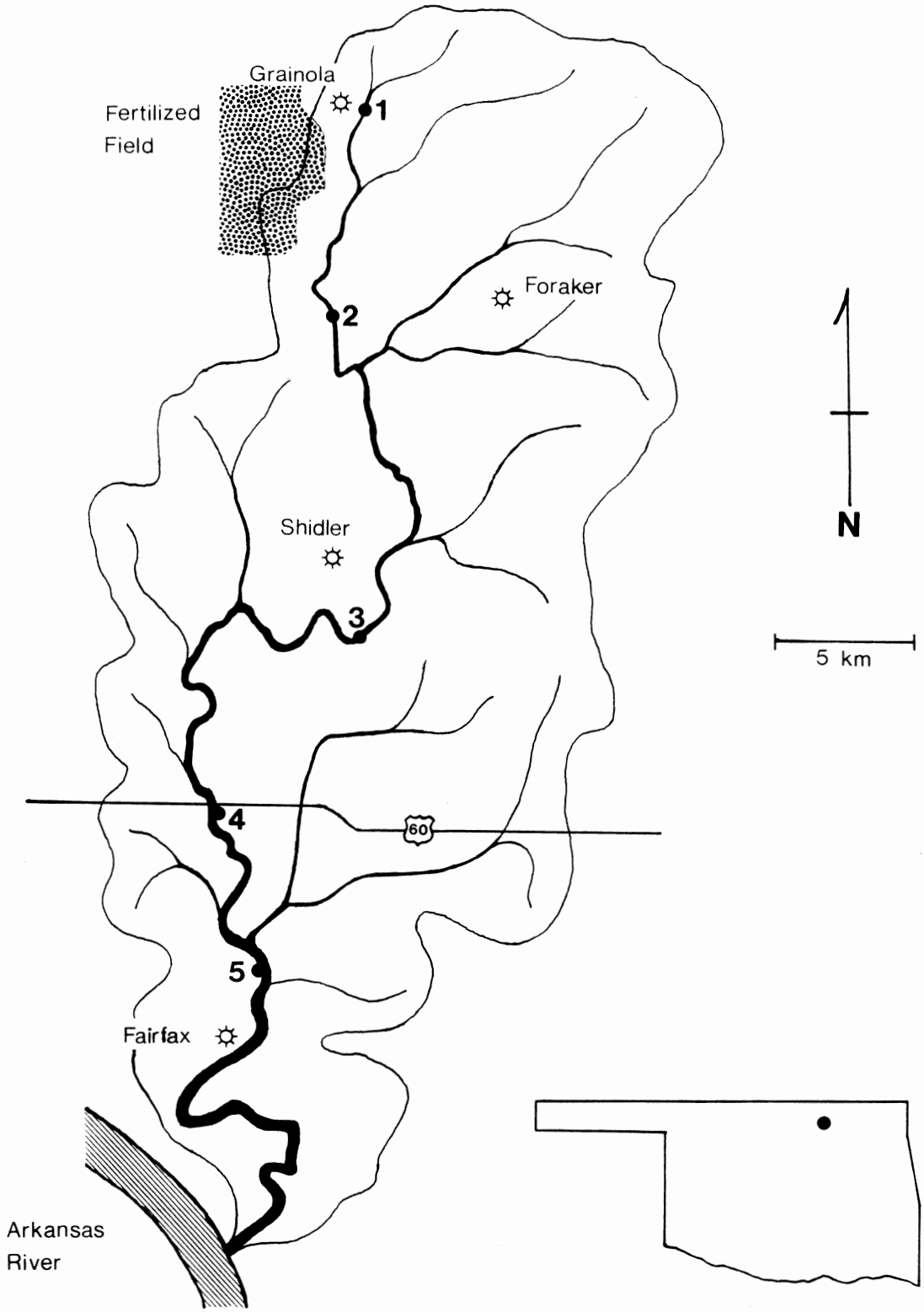


Figure 3. Location of Sampling Stations (1-5) and the Fertilized Milo Field in the Salt Creek Drainage Basin (Osage County, Oklahoma).

TABLE 1

DESCRIPTION OF SAMPLING STATIONS LOCATED ON SALT CREEK, OSAGE COUNTY, OKLAHOMA

	Station				
	1	2	3	4	5
Location	R6E T29N SEC 34	R6E T28N SEC 33	R6E T26N SEC 10	R5E T26N SEC 36	R5E T25N SEC 19
River km	6.5	15.0	37.5	57.0	62.5
Elevation (m)	358	338	306	274	258
Stream Order	2	3	4	4	4
Link Number	2	3	9	13	19
Drainage Area (km^2)	35	132	351	530	628
Habitat	Riffle, some Pool	Riffle, Pool	Pool, Riffle	Pool, some Riffle	Pool, some Riffle
Substrate	Silt, small to medium Cobble, Bedrock	small to medium Cobble, Bedrock	small to large Cobble, small Boulders	medium to large Cobble, Boulders	medium to large cobble, small boulders
Riparian Vegetation	Herbaceous, small Shrubs	Herbaceous, Shrubs, few well spaced trees	Herbaceous, Shrubs, Trees limited to banks	Herbaceous, few Shrubs, Wider, denser tree canopy	Herbaceous, few shrubs, Riparian Forests
Notes	Pasture	Pasture Hackberry Ash	Pasture Hackberry Ash, Elm Dogwood	Pasture Hackberry Ash, Elm Dogwood Willow	"Canyon Effect" Hackberry Ash, Elm Dogwood Willow

due to the extent of human impact on the stream. No flow existed in the upper portions of Salt Creek during summer, leaving only permanent pools upstream from station 1. A large cultivated field located south and east of Grainola was fertilized in early summer with anhydrous ammonia (Fig.3) . During precipitation, a small portion of the runoff from this field entered Salt Creek through a small tributary approximately 3 km upstream from Station 2.

CHAPTER IV

LONGITUDINAL MODEL FOR PRAIRIE STREAMS

Each community along the prairie stream continuum can be described using a component model (Fig. 4) which is an expansion of that presented in Fig. 2 and a modification of the one described for the RCC (Cummins 1974, Vannote et al. 1980, Cummins et al. 1983). The model is presented in five sections including gross energy/matter input, modification, net energy/matter, use and conversion, and output from the stream reach. Arrows connecting the upper and lower sides of components represent matter and/or energy flow. Horizontal arrows represent modifiers of available energy. The model was modified to include regional slope, vegetation quality and quantity, and stream dimensions as described by Higler and Mol (1984) and Statzner and Higler (1986). Benthic algal material was added to the possible diets of shredders as an additional CPOM source (Young et al. 1978, Peckarsky 1980, Winterbourn et al. 1981, 1984, Merritt & Cummins 1984). The added nutrient pathways follow those presented by Wetzel (1983).

In order to assess longitudinal changes in Salt Creek, the assumptions and hypotheses presented by Cummins et al. (1983) were modified to account for the lack of a headwater canopy. Hypotheses about seasonal change and nutrient enrichment effects were included based on the literature review. Since my study was limited to headwaters and middle stream reaches, hypotheses pertaining to large rivers were not included nor were meteorological influences such as

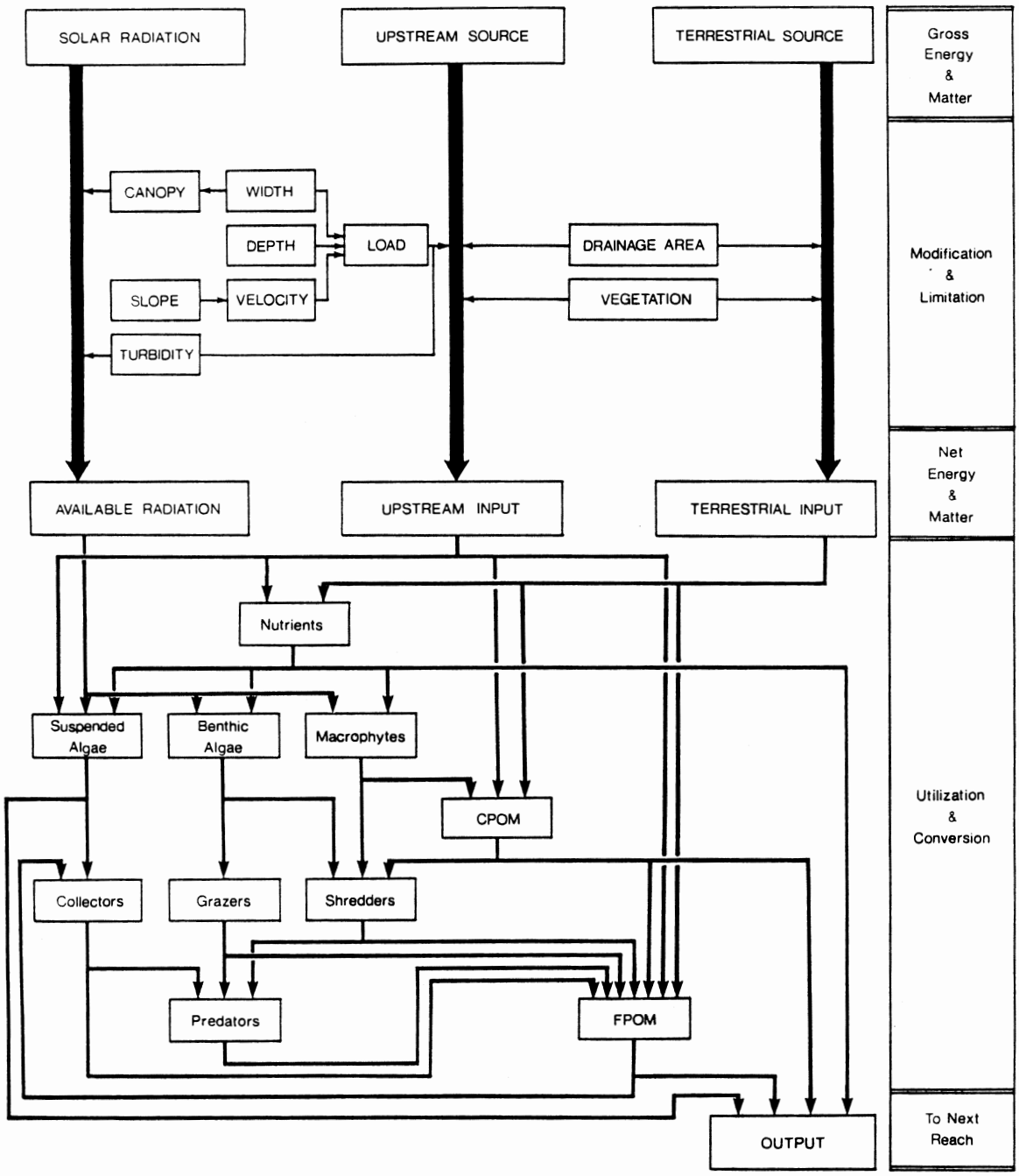


Figure 4. Component Model for Prairie Stream Segments. Component Size does not Relate to the Relative Importance of each Component. Arrows Connecting Upper and Lower Sides of Components Represent Matter and/or Energy Flow. Arrows Connecting Right and Left Sides of Components Represent Modifiers of Available Energy.

precipitation. The hypotheses for Salt Creek were classified under the following assumptions:

(1) If the amount of allochthonous POM entering the stream at any location depends on drainage area and the quality and quantity of vegetation within the drainage area, then (a) FPOM entering the stream increases as drainage area increases and (b) CPOM entering the stream increases as vegetation changes from pasture to riparian forest.

(2) If stream channel morphology changes from narrow, shallow, and open to wide, deep, and shaded, then a downstream shift occurs from (a) autotrophic to heterotrophic processes and (b) community metabolism dominated by benthic processes to metabolism dominated by water column processes.

(3) Given the assumptions in (1) and (2) and if the biotic components exploit these changes in energy source, then (a) the relative proportion of organisms dependent on primary producers decreases downstream and (b) the relative proportion of organisms dependent on FPOM and CPOM increases downstream.

(4) Given (3) and if the biotic components exploit both energy from upstream processes and terrestrial inputs, then (a) available energy and (b) overall biomass of consumers increases downstream.

(5) If the riparian canopy is dominated by deciduous vegetation, then (a) low, sustained allochthonous inputs occur in spring and summer, (b) increased inputs occur in fall during senescence, and (c) greatly reduced inputs occur in winter.

(6) If autocthonous production is related to solar radiation, then production (a) increases in summer and (b) decreases in winter.

(7) Given (5) and (6), then less pronounced seasonal changes in autocthonous production occur in areas with more developed riparian canopies due to the canopies greatly blocking solar radiation in summer but not in winter. This results in smoothing of the seasonal fluctuations of solar energy reaching the water.

(8) Given (5) to (7) and if the biotic components exploit these changes in energy sources, then (a) an overall reduction in consumers occurs during winter as total energy availability decreases and (b) the relative proportion of organisms dependent on FPOM and CPOM increases in autumn.

(9) Given (1) to (8) and if primary production in headwaters without riparian canopies is primarily nutrient limited and if localized nutrient enrichment from agricultural runoff occurs in these segments during spring and summer, then (a) increased primary production occurs immediately downstream of the nutrient input, (b) primary production decreases downstream as the riparian canopy becomes more developed reducing solar radiation and as nutrients are diluted or removed from the water column, (c) increased relative proportions of macroconsumers dependent on primary producers and FPOM (e.g. suspended algae) occurs immediately downstream of input and then decreases further downstream, and (d) overall macroconsumer biomass also increases immediately downstream of input and then decreases furthur downstream due to increased energy availability.

CHAPTER V

MATERIALS AND METHODS

Each of the five stations consisted of a 100 m reach. This area ensured that all habitat types present would be represented (Minshall et al. 1983). Six sets of physical, chemical, and biotic data were collected from July, 1986 to August, 1987 using a 6-week schedule for each (Table 2). The beginning dates were 7 July, 20 September, and 6 December 1986 and 7 March, 2 May, and 11 July 1987. The 6-week sequence of sampling allowed some estimation of temporal variation within each time of year studied as well as ensured similar environmental conditions for variables assumed to be correlated.

Physical and Chemical Characteristics

A Hydrolab model 4000 was used to measure conductivity (S cm^{-1}), dissolved oxygen (mg l^{-1}), pH, and temperature (^{o}C). Each sensor was calibrated prior to and after field use according to the procedure provided with the Hydrolab. Three random replicate measurements were made at 0.6 depth for each variable at each station.

Carbonate and bicarbonate alkalinities were determined by titration of a 50 ml water sample with 0.020 N sulfuric acid using phenolphthalein and brom cresol green - methyl red indicators (Kopp & McKee 1979). Total alkalinity in mg l^{-1} was calculated as 20 times the total milliliters of sulfuric acid used. Determinations were performed for three random samples taken at 0.6 depth.

TABLE 2

SEQUENCE OF SAMPLING FOR VARIABLES MEASURED IN SALT CREEK WHERE WEEK 0 INDICATES THE INITIATION OF SAMPLING AND X INDICATES THE WEEK OF MEASUREMENT

	Week		
	0	3	6
Alkalinity, Conductivity, pH Dissolved Oxygen, Temperature	X		X
Water Flow Rates, Volume	X		X
Invertebrate Colonization Baskets	Set		Collect
Periphyton Colonization Tiles	Set	Collect	
Periphyton Chlorophyll, Biomass		X	
Periphyton ^{14}C Assimilation		X	
Phytoplankton Chlorophyll		X	X
Diel DO Curve		X	
Nutrients		X	
Photosynthetically Active Radiation		X	
Benthic POM Collecting Jars		Set	Collect
Suspended POM		X	X

Mean depth, mean velocity, and discharge were calculated for each station using the techniques described by Eckblad (1978). A transect was established across the width of the stream. The transect was divided into 1 m segments and the depth (cm) and the mean segment velocity (velocity at 0.6 depth; m s^{-1}) were measured at the center of each segment. Velocity was measured with a Pigmy Gurley Current Meter. Mean depth and velocity were calculated as the averages of the segment

depths and segment mean velocities, respectively. The discharge of each segment (R) was calculated as follows:

$$R_i = W_i D_i V_i$$

where W_i = width of segment (1 m), D_i = depth of segment, and V_i = mean velocity of segment. Total discharge in $m^3\ s^{-1}$ was calculated by adding the segment discharges (R_i).

Nutrients

Two randomly located 500 ml water samples were collected from a depth of 5-10 cm at each station for orthophosphate, ammonia nitrogen, and nitrite-nitrate nitrogen analyses. Each sample was field filtered through HA Millipore filters (0.45 um pores) and stored in 500 ml glass BOD bottles which had been rinsed in 1:1 hydrochloric acid and demineralized distilled water (DDW) (Kopp & McKee 1979). The samples were transported in ice to the laboratory and stored at 4 ^{o}C until analyzed. All nutrient analysis was performed within 24 h of sample collection as per E.P.A. guidelines (Kopp & McKee 1979).

Orthophosphate was determined by the amino acid method as described in Standard Methods (A.P.H.A. 1976) using the technique of standard additions (Hach 1979). For each water sample, 0.4, 0.8, and 1.2 mg l^{-1} of orthophosphate was added to three of five 25 ml subsamples using 0.1, 0.2, and 0.3 ml of 100.0 mg l^{-1} phosphate standard (Hach Chemical Co.), respectively. To each subsample, 1 ml of ammonium molybdate and 1 ml of amino acid reagent (Hach Chemical Co.) were added. The ammonium molybdate combined with the orthophosphate to form molybdophosphoric acid which was reduced by the amino acid reagent to the colored complex, molybdenum blue. After 10 min of color

development, percent transmittance was measured on a Baush & Lomb spectronic 501 spectrophotometer set at 530 nm and zeroed with a water sample with no reagents added. To determine orthophosphate concentration of the original sample, a linear regression was performed using the amount of standard added versus percent transmittance of the four subsamples. The predicted concentration (mg l^{-1}) at 100% transmitance was used as the estimated sample concentration.

Ammonia nitrogen was determined potentiometrically using an Orion model 95-10 ammonia selective electrode and an Orion model 407A specific ion meter as described by E.P.A. (Kopp & McKee 1979). The electrode was cleaned and recharged prior to use for each sample set. For calibration and sample determination, the ammonia electrode was placed in 100 ml of standard or sample and 1.0 ml of 10 N sodium hydroxide was added while mixing. The sodium hydroxide raised the solution pH above 11, allowing the ammonia to diffuse into the electrode and change the electrode's internal pH. The difference between the ammonia electrodes internal pH and that of the reference electrode was proportional to the ammonia concentration. The meter was calibrated using 0.1, 1.0, 10.0 mg l^{-1} ammonium chloride standards such that the ammonia concentration was determined in mg l^{-1} by directly reading the specific ion meter scale. The ammonia concentration of two replicates per sample was determined.

Nitrite-nitrate nitrogen was determined by a modified cadmium reduction-diazotization Method (A.H.P.A. 1976) using the technique of standard additions (Hach 1979). For each water sample, 1.0, 2.0, and 3.0 mg l^{-1} of nitrate was added to three of five 25 ml subsamples using 50, 100, and 150 ul of 500.0 mg l^{-1} nitrate standard (Hach Chemical

Co.), respectively. To each subsample, cadmium, sulfanilic acid, and gentisic acid were added in the form of a Hach NitraVer V powder pillow. The cadmium reduced the nitrate nitrogen to nitrite nitrogen which then reacted with the sulfanilic and gentisic acids to form a reddish purple azo. After 10 min of color development, percent transmittance was measured on a Baush & Lomb spectronic 501 spectrophotometer set at 500 nm and zeroed with a water sample to which no reagents had been added. Nitrite-nitrate nitrogen concentrations were determined by linear regression as described for orthophosphate.

Photosynthetically Active Radiation

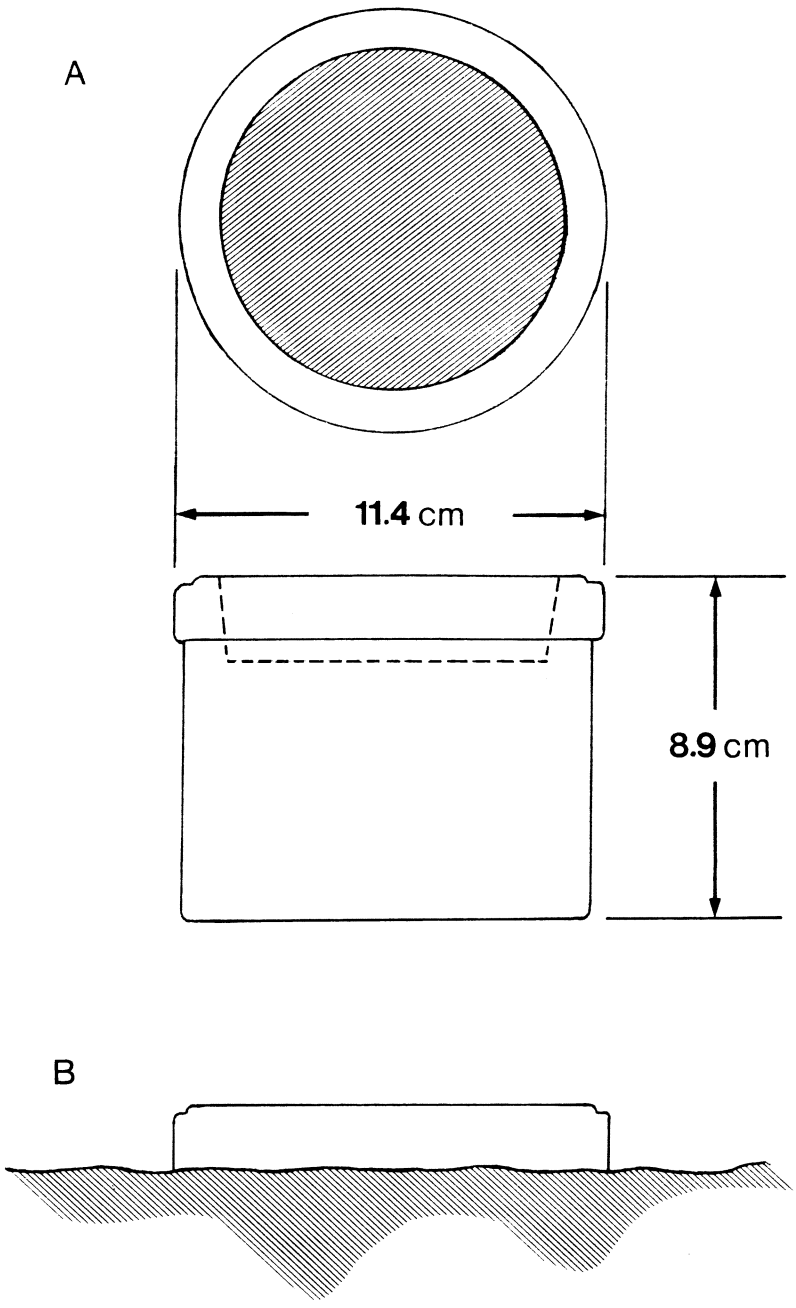
Photosyntheticaly active radiation (PAR) in uE m^{-2} s^{-1} was measured using a Licor model LI-188B integrating photometer and model LI-193SB spherical quantum sensor (400-700 nm quantum response). The stream was divided into three segments of equal length across a transect at each station. PAR was measured at the surface and on the substrate at the center of each segment at quarter-day, midday, and three-quarter day. PAR was assumed to be below detection limits before dawn and after dusk. PAR measurements for all stations were taken within a 2 h interval at each time period. Mean water column PAR was calculated from all surface and benthic measurements. Polar planimetry (Lind 1979) was used to calculate total-daily PAR in E m^{-2} d^{-1} as the area under the PAR by time-of-day curve.

Particulate Organic Matter

Benthic particulate organic matter was collected using a modification of lentic sediment trap methodology (Kirchner 1975).

Sediment traps estimated the rate at which new POM reached the substrate per unit area rather than the amount in the water column or already present on the substrate. The POM trap was constructed from an 11.4 cm diameter by 8.9 cm tall plastic jar with a screw-on lid containing a funnel with a 7.6 cm diameter minimum opening (Figure 5). Two traps were placed at each sample station at the locations from which the periphyton colonization tiles were removed. The traps were filled with stream water so no air bubbles where present, weighted with a small steel bar for neutral buoyancy, and placed in the substrate with 1 cm of the trap exposed above the substrate. After 21 d, the traps were lifted from the substrate, the funnel lids removed, and solid lids screwed on the traps. On the shore, the material collected in the traps was filtered through 1 mm and 63 um Nitex sieves to collect CPOM and FPOM, respectively (Minshall et al. 1983). The filtrate was then filtered through HA Millipore filters (0.45 um pore size) to collect UPOM. The vacuum differential applied did not exceed 0.3 atm (Wetzel & Likens 1979). POM on the Nitex screens were washed with DDW into vials and the Millipore filters were placed in DDW for transporting to the laboratory. In the laboratory, the biomass of each POM fraction was determined as mg l^{-1} using the AFW procedure described by Wetzel and Likens (1979). Each POM fraction was placed in a crucible, dried at 105 ^{o}C for 24 h, and weighed on a Mettler model H20T analytical balance. The material was then ashed at 550 ^{o}C for 1 h, the ash rewetted, redried at 105 ^{o}C for 24 h, cooled in a dessicator, and reweighed. The biomass in mg was calculated as the difference in the two weights.

Two randomly selected 500 ml water samples were collected from 0.6



Fiqure 5. Particulate Organic Matter Sedimentation Devices (A) and Placement in Stream Substrate (B).

depth at each station for suspended POM analysis (Minshall et al. 1983, Bruns & Minshall 1985). Each water sample was field filtered through 1mm, 0.63 um Nitex sieves and 0.45 um Millipore filters and the biomass of each POM fraction was determined as mg l^{-1} using the procedures described for benthic POM.

Primary Production and Respiration

Unglazed 15.2 x 15.2 cm clay tiles were used as artificial substrates for periphyton colonization (Lamberti & Resh 1983, 1985). Prior to use, the tiles were conditioned in stream water for 21 d, scrubbed to remove attached material, and sterilized in an autoclave (Lamberti & Resh 1985). Two sets of four tiles were randomly placed on the substrate at each station in 2 x 2 grids. After 3 wk of colonization, two tiles were randomly selected from each group of four, lifted from the substrate, and placed on 63 um mesh Nitex sieves. All periphyton samples from a tile were collected in the shade within 5 min of its removal from the substrate as suggested by Wetzel & Likens (1983). Two, 16.0 cm^2 periphyton scrapings were taken from each selected tile using a 4.0 x 4.0 cm template and glass microscope slides. One scraping from each tile was preserved in basic methanol (4.0 ml 1 N sodium hydroxide l^{-1}; Holm-Hansen 1978) to extract chlorophyll (Francko 1986). The second set of scrapings were preserved in 2% formalin buffered to pH 7.0 with sodium hydroxide for biomass determinations (Wetzel & Likens 1979). Chlorophyll and periphyton biomass samples were transported in ice to the laboratory and stored at $4^{o}C$ until analyzed. Two 8.0 cm^2 scrapings for carbon assimilation analysis were also taken from each selected tile using a 4.0 x 2.0 cm

template. One scraping from each tile was combined to produce two, 16.0 cm^2 scrapings per tile set and four per station. Each combined scaping was placed in 100 ml of stream water which had been filtered with HA Millipore filters (0.45 um pore size).

Periphyton biomass in mg m^{-2} was determined as AFW using the technique described for POM. Chlorophyll a, b, and c and phaeopigment concentrations were determined using the trichromatic method (Strickland & Parsons 1968, Wetzel & Likens 1979). All determinations were made with a Baush & Lomb Spectronic 501 within 24 h of collection. The periphyton material was ground for 2 min in 5 ml of basic methanol using a teflon grinder and centrifuged at 3 - 4000 rpm for 5 - 7 min. The supernatant was removed and brought to a total volume of 10.0 ml with basic methanol. The percent absorption of each sample was measured at 750, 665, 645, and 630 nm wavelengths. At each wavelength the spectrophotometer was zeroed using basic methanol. To each 10.0 ml sample, 0.1 ml of 4 N hydrochloric acid was added and percent absorption was remeasured at 750, and 665 nm wavelenghts. The concentration of chlorophyll a, b, and c and phaeopigments were calculated as follows:

$$Chl_x \text{ (mg } m^{-2}) = (C_x \; v) / (A \; Z)$$

$$\text{Phaeopigments (mg } m^{-2}) = (P_a \; v) / (A \; Z)$$

$$\text{Total Chl. Corrected (mg } m^{-2}) = Chl_a + Chl_b + Chl_c - \text{Phaeopigments}$$

where v was the volume of extract (10.0 ml), A was the area of scraping (0.0016 m^2), Z was the light path length through extract (1.0 cm), and C_a, C_b, C_c, and P_a were calculated as

$$C_a = 11.6 \; E665_o - 1.3 \; E645_o - 0.14 \; E630_o$$

$$C_b = 20.7 \; E645_o - 4.34 \; E665_o - 4.42 \; E630_o$$

$$C_c = 55\ E630_o - 4.64\ E665_o - 16.3\ E645_o$$

$$P_a = 45.39\ E665_a - 26.7\ E665_o$$

where

$E665_o$ = absorbance at 665 um - absorbance at 750 um

$E645_o$ = absorbance at 645 um - absorbance at 750 um

$E630_o$ = absorbance at 630 um - absorbance at 750 um

$E665_a$ = absorbance at 665 um after acidification - absorbance at 750 um after acidification.

Periphyton carbon assimilation rates were determined by the carbon-14 method as first used by Steemann Neilsen (1951, 1952) and modified by Strickland (1966) and Vollenweider (1969). Carbon assimilation rate determinations were carried out concurrently with chlorophyll, nutrient, and PAR determinations to ensure similar environmental conditions. The four combined scrapings in the 100 ml of filtered stream water were thoroughly mixed to disperse periphyton clumps. One slurry from each tile set was placed in clear 250 ml glass BOD bottles and the other in 250 ml glass BOD bottles covered with black plastic tape and covered with aluminum foil to prevent light penetration. A micropipette was used to add 0.4 uC (1.5×10^2 Bq) of carbon-14 as $NaH^{14}CO_3$ into each bottle and to a control scintillation vial filled with 20 ml of liquid scintillation cocktail (Budget-solve; RPI Corp.). The radiolabeled carbon was introduced beneath the fluid surface. The sample bottles were filled with filtered stream water such that no air was trapped in the bottles when capped and then inverted several times to mix. One light and one dark bottle for each tile set were placed in the stream at the locations from which the tiles were removed and incubated for 1 h. After incubation, two 20 ml aliquots

were removed from each bottle and filtered through separate Millipore HA filters (0.45 um pore size). The filtration pressure differential was kept below 0.5 atm to prevent cell breakage (Funk & Gaufin 1971). The filters were placed in scintillation vials prefilled with 150 ul of perchloric acid, placed in the dark for 15 min to allow unincorporated carbon-14 to escape as CO_2, capped, and placed in ice for transporting to the laboratory. Unused material from each incubation bottle was collected and taken to the laboratory for disposal.

In the laboratory, 20 ml of scintillation cocktail was added to each vial within 24 h of incubation. The vials were placed in the dark for 12 h to dissolve fully the filter paper and reduce background chemoluminescence (Francko 1986). Sample and control vials were analyzed for incorporated radioactivity using a Beckman model 7500 scintillation counter in counter channel 2 (LL 397, UL 655) using program 3. Carbon-12 assimilation rates as mg cm^{-2} h^{-1} were calculated as

$$^{12}C_{as} = {}^{12}C_{av} \left({}^{14}C_{as} / {}^{14}C_{av} \right) k_1$$

where $^{12}C_{as}$ is the assimilation rate of carbon-12 in mg cm^{-2} h^{-1}, $^{12}C_{av}$ is the amount of carbon-12 available in mg l^{-1}, $^{14}C_{as}$ is the assimilation rate of carbon-14 in uC h^{-1}, $^{14}C_{av}$ is the amount of carbon-14 available in uC, and K_1 is the conversion factor to convert from mg l^{-1} h^{-1} of water in the incubation bottle to mg cm^{-2} h^{-1} of substrate which was determined to be 0.015625 as follows:

(1) $^{12}C_{as}$ / 4 = $^{12}C_{as}$ per 250 ml (incubation bottle volume)

(2) $^{12}C_{as}$ per 250 ml = $^{12}C_{as}$ per 16.0 cm^2 substrate

(3) $^{12}C_{as}$ per 16.0 cm^2 substrate / 16 = $^{12}C_{as}$ per 1.0 cm^2 substrate

The amount of carbon-14 available in uC was calculated as

$$^{14}C_{av} = k_2 \ (\ v \ / \ V \ )$$

where k_2 is the amount of carbon-14 introduced into each incubation bottle (0.4 uC), v is the volume of sample filtered for analysis (20.0 ml), and V is the total volume of the incubation bottle. The assimulation rate of carbon-14 in uC h^{-1} was calculated as

$$^{14}C_{as} = ((\ LB - DB \ ) \ / \ CN \ ) \ K_3 \ K_4$$

where LB and DB are the scintillation counts for the light and dark bottle vials, respectively; CN is the scintillation counts for the control vial, K_3 is the amount of carbon-14 introduced into the control vial (0.4 uC), and K_4 is the isotopic correction factor (1.06). Subtracting dark bottle from light bottle counts corrected for background interferences such as dark fixation, absorption, and natural radiation. Dividing by the control vial counts and multiplying by the amount of carbon-14 introduced into the control vial enabled calculating the amount of carbon-14 present in the sample while correcting for disintegrative losses and scintillation counter efficiency. The isotopic correction factor theoretically corrected for the slower assimilation of the heavier carbon-14. The amount of carbon-12 available in mg l^{-1} was calculated as

$$^{12}C_{av} = (\ \text{Total Alkalinity} \ )(\ \text{pH Factor} \ )$$

where total alkalinity is the phenolphthalein and brom cresol green - methyl red alkalinity in mg l^{-1} and the pH factor was determined from pH and temperature of the water used in the incubation bottles using Table 8-1 in Wetzel & Likens (1979).

Two randomly selected 500 ml water samples were collected from 0.5 cm below the water surface at each station for suspended chlorophyll

analysis (Wetzel & Likens 1979). Each water sample was filtered using HA millipore filters (0.45 um pore size) at less than 0.5 atm pressure differential. The filters were placed in basic methanol and transported in ice to the laboratory. The suspended chlorophyll concentrations were determined within 24 h of collection using the trichromatic method as described for periphyton. Equational changes were (1) V was the volume of water filtered (500 ml) rather than the area of substrate scraped and (2) the resulting concentrations were expressed in mg l^{-1}.

The ratio of primary production to respiration (P/R) was estimated using the simplified diel oxygen method developed by McConnell (1962). The stream was divided into six segments of equal length along a transect established across the width of the stream. Temperature (^{o}C) and dissolved oxygen (mg l^{-1}) were measured at the center of each segment within 1 h of dusk of one day, and of dawn and dusk of the next day. Primary production, respiration, and P/R of each segment were determined by graphical extrapolation as described in Lind (1979).

Macroinvertebrates

Five rock baskets (Mason et al. 1973) for macroinvertebrate colonization were randomly placed within Salt Creek at each location. Each basket, constructed of 7.9 mm mesh galvanized hardware cloth, was 20cm long by 15cm in diameter. Substrata, collected from the streambed near the location where the baskets were to be placed, was scrubbed to remove all macroinvertebrates prior to placement in the basket. Once filled, the baskets were placed on the stream bed, attached to the shore, and allowed to colonize for 6 weeks as suggested by Mason et al. (1971, 1973). When collected, each basket was brought to the surface,

placed on a U.S. Standard No. 30 sieve and emptied into a bucket partially filled with water. The basket and each rock were scrubbed to remove macroinvertebrates and debris which were then separated from the water with a 63 um mesh Nitex plankton net with an attached collecting bag. The collecting bags were field preserved in 10% formalin. In the laboratory, the samples were elutriated (Magdych 1981), hand sorted, and the macroinvertebrates were enumerated and identified to the lowest possible taxon.

Consumer composition as predicted by the RCC is based on the biomass of functional groups (Vannote et al. 1980). The functional group of each macroinvertebrate taxon was determined using data published by other authors (e.g. Merritt & Cummins 1984). Biomass was determined as ash-free weight (AFW) using the procedure described for benthic POM. AFW determinations of macroinvertebrate biomass are not significantly affected by 10% formalin (Leuven et al. 1985).

Richness (S), equitability (E), and an approximation of Shannon-Weaver diversity (H') were calculated for each macroinvertebrate sample to aid in the analysis of longitudinal and temporal changes in assemblage composition. These values were calculated as follows:

$E = H'/\ln(S)$ (Mcnaughton & Wolf 1979)

$H' = \Sigma n_i/n \ln (n_i/n)$ (Emlen 1973)

Where S was the number of taxa represented in the sample and n_i was the number of individuals in the i-th taxa in the sample and n was the total number of individuals in the sample.

QUAL2E Computer Simulations

The EPA stream water quality model, QUAL2E , was used as a

deterministic model to estimate nitrate, phosphate, and chlorophyll a concentrations along Salt Creek (Brown & Barnwell 1985). The microcomputer version 3.3 of QUAL2E was used. The QUAL2E model of Salt Creek consisted of five reaches with two to four 5.0 km segments per reach (Fiq. 6). The nutrient input from the tributary draining the milo field was modeled as a point source input in segment 1 of reach 2. The options used to model Salt Creek where the trapezoidal cross-section calculation of discharge, Monod half-saturation and Leibig's law of the minimum limitations of photosynthesis, hourly solar radiation based on total daily radiation and an assumed sine function, and algae with an equal preference for ammonia or nitrate nitrogen. In this study, light was measured in quantum energy. To convert to radiometric energy required for QUAL2E, all energy measured was assumed to be at 550 nm. In the PAR sensitivity range, 550 nm represents the median wavelength of surface solar flux (Wetzel 1979) and sensor sensitivity (Licor 1980).

Initial calibration was performed using the data set collected from 20 September to 1 November 1986. Since this was this first data set with no apparent nutrient enrichment, the model was calibrated with no point source influence. A summary of the QUAL2E input data set for September, 1986 is presented in Appendix D. All other data sets from periods with no apparent nutrient enrichment were then simulated using the calibrated model, changing only the following variables: day of year to be simulated, number of daylight hours, amount of solar radiation, water temperature, DO concentrations, and flow rates. Results from these simulations were used to fine-tune the model at times of no apparent enrichment. The datasets from times of nutrient

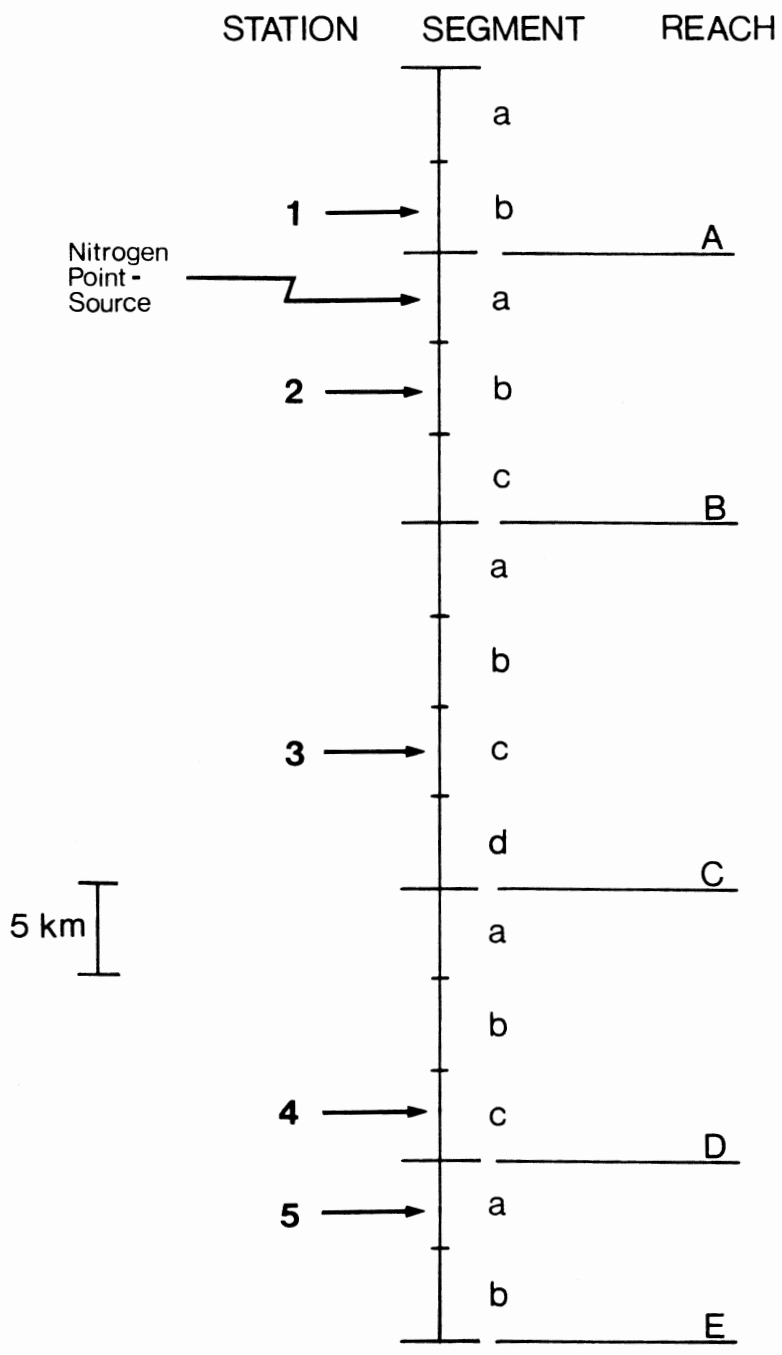


Figure 6. QUAL2E Network Diagram of Segments and Reaches Used to Describe Salt Creek with the Approximate Locations of each Sampling Station.

enrichment were modeled by adding the point source input variables to the simulations. A summary of the QUAL2E input dataset for July, 1986 is presented in Appendix D. The point source coefficients were then calibrated. Once all simulations were adequately predicting the concentration of each variable at each station for each dataset, the differences between the measured concentrations and the QUAL2E predicted concentrations were used to calculate residual mean square as an estimate of the quality of the QUAL2E predictions. The residual mean square was used to calculate 95% prediction intervals for nitrate and orthoposphate for each simulation. To predict variable concentrations in the absence of nutrient enrichment (baseline concentrations), the excess nitrogen load was removed from the point source input while no other variables were adjusted. In using the QUAL2E program in this fashion, an estimate of the amount of nitrogen entering Salt Creek during eutrophication could be made.

Two additional data sets for model verification were collected using the 6-week schedule and the methods presented previosly. The starting dates for these collections were 12 September and 14 November 1987. Algal biomass, carbon assimilation rates, and P/R were not analyzed for these data sets. Verification involved using the calibrated QUAL2E model to predict nitrate-nitrogen, orthophosphate, and chlorophyll a concentrations for each verification dataset. Predicted nitrate-nitrite nitrogen and orthophosphate concentrations were then compared to the field collected data using t-tests.

Statistical Analysis

All statistical analysis was performed with SYSTAT version 3

(Wilkinson, 1987). Linear regressions were used to relate PAR and POM change along Salt Creek. The experimental units of this study were each station at each time period. Since there was no replication of experimental units, a two-way analysis of variance using individual observations was used to determine if temporal data could be used as replicates. As indicated in the Prairie Stream Model, PAR was expected to increase in summer and decrease in winter. Coarse POM was expected to increase greatly in fall and decrease in winter and early spring. Fine and ultra-fine POM were expected to exhibit a similar pattern to CPOM but the amount of seasonal change was expected to be lower. FPOM and UPOM were also expected to increase during eutrophication due to increased algal biomass. If temporal differences were determined in the two-way AOV, then Duncan's multiple range test was used to determine if the hypothesized temporal groupings occured. Individual regressions were then performed for each group using the means of each sample trip as replicates. In each regression, tests were made for lack-of-fit and for the regression parameters being different from zero.

Simple and multiple regressions were used to relate variables to each other as defined by the Prairie Stream Component Model. Periphyton and suspended chlorophyll were related to available light, nitrogen, and phosphorus using the multiplicative and inverse additive nutrient limitation hypotheses (Brown & Barnswell 1985) as follows:

$$Chl = f(PAR) \times f(N) \times f(P) \qquad \text{Multiplicative}$$

$$Chl = f(PAR) \,/\, [\, f(1/N) + f(1/P) \,] \qquad \text{Inverse Additive}$$

where chl was the chlorophyll concentration in mg m^{-2} (periphyton) or ug l^{-1} (suspended), f(PAR) was a function of total daily PAR reaching the substrate (periphyton) or water surface (suspended) in E m^{-2} d^{-1},

f(N) was a function of nitrate-nitrite nitrogen concentration in mg l^{-1}, and f(P) was a function of orthophosphate concentration in mg l^{-1}. An inverse relationship with mean water velocity (m s^{-1}) was also used in the suspended chlorophyll analysis.

Two relationships between collector biomass and UPOM, FPOM, and suspended chlorophyll were analyzed. The first assumed that the collectors were able to discriminate between UPOM and FPOM, while the second assumed that they could not. In the nondiscriminatory hypothesis UPOM and FPOM were combined prior to analysis. Similarly, the relationship between predator biomass and the biomass of the other functional groups was analyzed with both discriminatory and non-discriminatory assumptions. In the nondiscriminatory analysis, the biomass of the grazers, collectors, and shredders were combined.

CHAPTER VI

RESULTS

Physical and Chemical Characteristics

The physical and chemical data for each station are presented in Appendix A. Mean water depth, velocity, and discharge increased downstream during this study. Mean depth ranged from 12.5 to 24.5 cm at Station 1 and from 31.0 to 41.1 cm at Station 5. Mean water velocity ranged from 1.3 to 1.5 m s^{-1} at Station 1 and from 11.1 to 18.5 m s^{-1} at Station 5. The discharge at the time of lowest flow was 0.1 m^3 s^{-1} at Station 1 and 27.9 m^3 s^{-1} at Station 5. At highest flow, the discharges were 1.2 and 57.4 m^3 s^{-1} at stations 1 and 5, respectively.

Alkalinity ranged from 96 to 216 mg l^{-1}. Three different downstream trends were evident for alkalinity. Values increased downstream during May and July at all stations except for a decrease at Station 2 in July (Fig. 7a). Alkalinity decreased downstream during other sampling times. Conductivity ranged from 195 to 660 S cm^{-1}. Values generally increased downstream although a decrease was observed at Station 2 in July (Fig. 7b). Conductivity was higher in March and May than during other sampling trips. No difference existed in pH among stations or sampling trips except pH was higher at Station 2 in July of both years (Fig. 7c). Values ranged from 6.1 and 8.0.

Measurements of dissolved oxygen taken at dawn and dusk ranged from 3.2 at Station 3 in July, 1986, to 18.4 at Station 2 in July, 1987

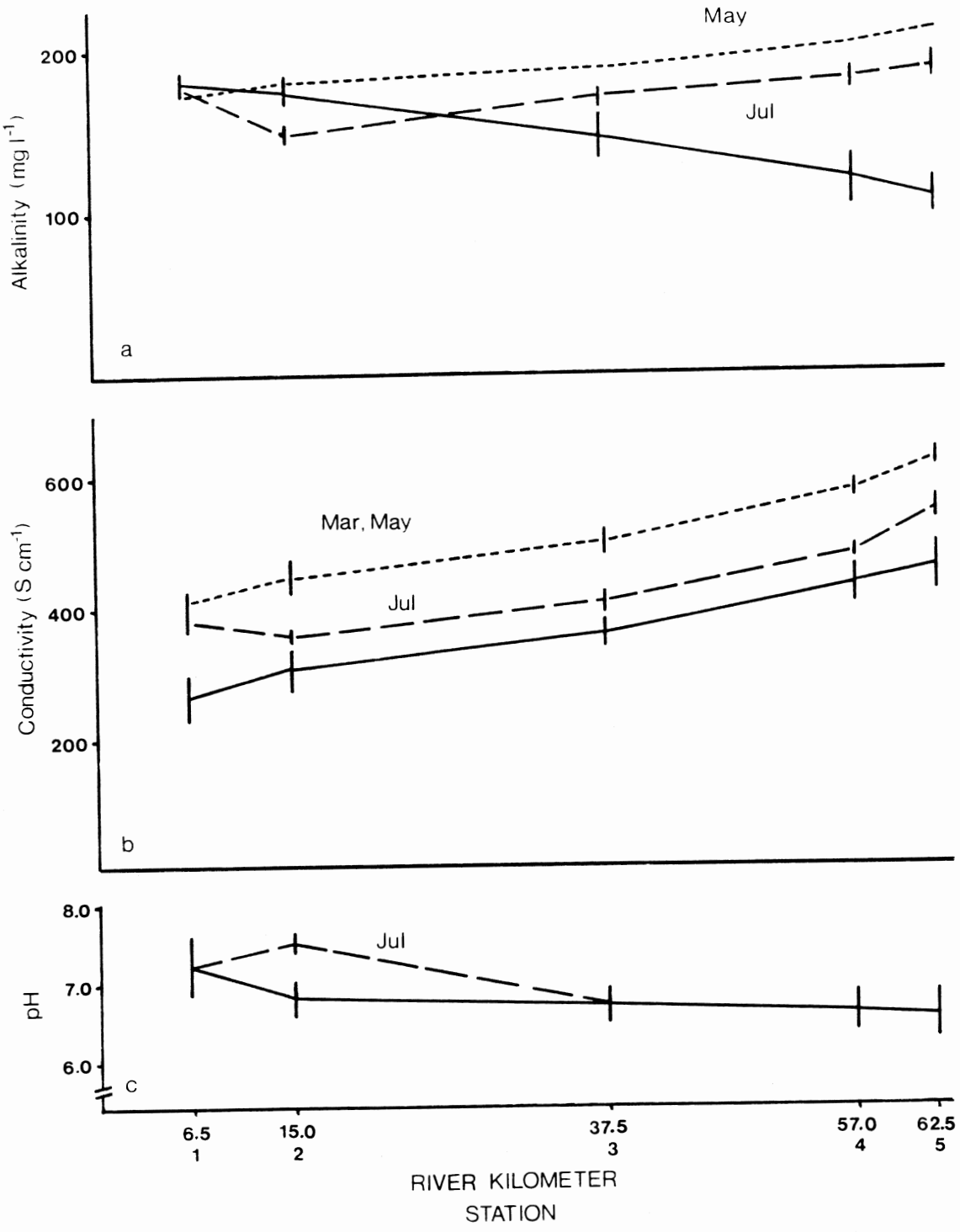


Figure 7. Alkalinity, Conductivity, and pH at the Sampling Stations in Salt Creek. Vertical Bars Indicate 95% Confidence Intervals. Solid Lines Represent all Sample Times Except Those Labeled and Data Collected for Model Verification.

(Table 3). The largest dawn to dusk fluctuations in DO were 11.8 and 12.5 mg l^{-1} which occurred at Station 2 in July, 1986 and 1987, respectively. At all other times, the daily range in DO was less than 2.2 mg l^{-1}. In general, daily DO fluctuations were largest at Station 1 and decreased downstream. Water temperature varied from 4.4 °C in December, 1986, to 29.8 °C in July, 1986.

TABLE 3

DIEL VARIATION IN DISSOLVED OXYGEN CONCENTRATION AT FIVE STATIONS IN SALT CREEK, OKLAHOMA FROM JULY, 1986 TO NOVEMBER, 1987

DATE	STATIONS 1	2	3	4	5
Jul 1986	3.8- 6.0	6.1-17.9	3.2- 5.2	4.9- 5.6	6.4- 8.6
Sep 1986	7.6- 9.8	7.4- 9.1	6.3- 7.8	5.0- 6.4	5.0- 6.2
Dec 1986	12.5-13.6	12.3-13.3	12.1-13.0	12.1-12.8	12.0-12.5
Mar 1987	8.8-10.2	8.8-10.0	6.6- 9.8	8.4- 9.2	7.8- 8.9
May 1987	7.4- 8.9	7.3- 8.6	7.1- 8.3	7.0- 8.1	6.7- 7.8
Jul 1987	4.2- 6.5	5.9-18.4	4.3- 5.7	4.6- 6.2	5.7- 7.1
Sep 1987	6.4- 8.5	6.1- 8.0	6.0- 7.6	5.4- 6.9	5.4- 6.5
Nov 1987	10.5-11.7	11.4-11.5	10.2-11.1	10.1-10.9	9.9-10.5

Nutrients

No measurable concentration of ammonia nitrogen existed at any station on any trip. The detection limit for ammonia was 0.09 mg l^{-1}. Values of nitrate-nitrite nitrogen and orthophosphate ranged from 0.29 to 3.01 mg l^{-1} and from below detection limits to 0.71 mg l^{-1},

respectively. The detection limits were 0.05 mg l^{-1} for nitrate-nitrite nitrogen and 0.08 mg l^{-1} for orthophosphate. Nitrate-nitrite and orthophosphate concentrations decreased downstream except in July of both years (Fig. 8). In July, nitrate-nitrogen concentrations peaked at Station 2, while no detectable concentration of orthophosphate existed at either station 2 or 3. No difference existed over time in nitrate-nitrite and orthophosphate concentrations at stations 1, 4, or 5.

Summaries of each QUAL2E simulation are presented in Appendix E. Mean QUAL2E predicted concentrations of nitrate-nitrite nitrogen and orthophosphate were not different from observed means for both the enriched and nonenriched data sets. QUAL2E predictions for each data set were within the 95% confidence intervals obtained from individual observations for the respective data sets.

Nitrate-nitrite : orthophophate ratios varied from 2.41 at Station 1 to 0.84 at Station 5 (Table 4). The N:P ratio values decreased downstream. In July, N:P ratios could not be determined at stations 2 and 3 because no detectable orthophosphate existed.

Photosynthetically Active Radiation

Photosynthetically active radiation reaching the water surface and the substrate ranged from 39.7 to 83.3 and 22.0 to 54.6 E m^{-2} d^{-1}, respectively. Water surface PAR consistently decreased from station 1 to station 5 ($P < 0.03$) (Fig. 9). Although, the pattern of downstream decrease was similar for all sampling times, three significantly different rates of downstream decrease in water surface PAR were measured ($P = 0.05$) which corresponded to the summer, spring and autumn, and winter groups hypothesized in the prairie stream model.

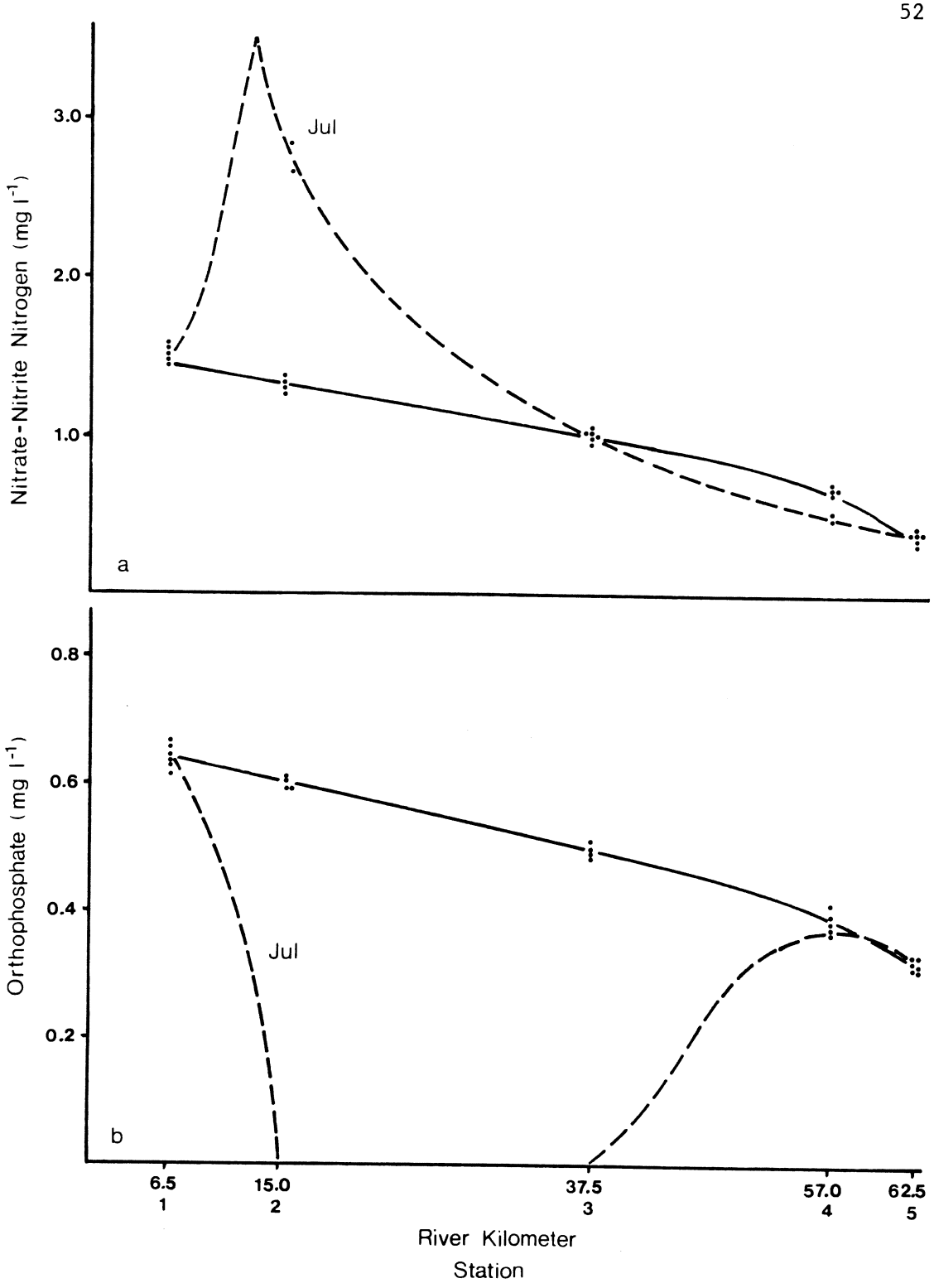


Figure 8. Nitrate-Nitrite Nitrogen and Orthophosphate Concentrations at the Sampling Stations in Salt Creek. Data Points are Observation Means for Each Sampling Trip. Solid Lines Represent Mean QUAL2E Predictions for all Sample Times Except Those Labeled and Data Collected for Model Verification.

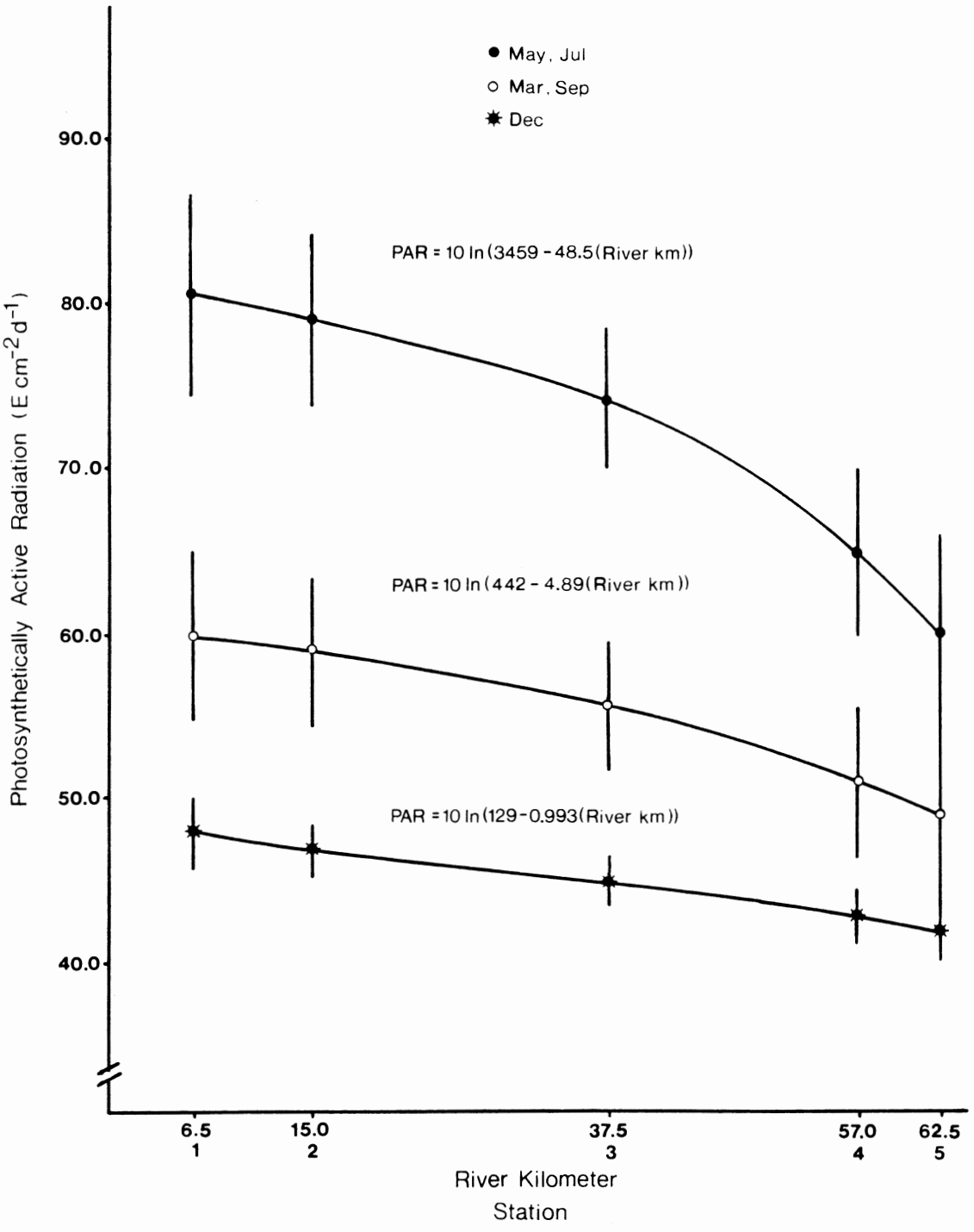


Figure 9. Photosynthetically Active Radiation Reaching the Water Surface at the Sampling Stations in Salt Creek. Vertical Bars Indicate 95% Confidence Intervals.

TABLE 4

NITRATE-NITRITE NITROGEN : ORTHOPHOSPHATE RATIOS
AT FIVE STATIONS ON SALT CREEK

DATE	STATIONS 1	2	3	4	5
JUL 1986	2.14	-	-	1.17	0.84
SEP 1986	2.18	2.09	1.78	1.61	1.17
DEC 1986	2.41	2.28	1.94	1.50	1.09
MAR 1987	2.11	2.02	1.94	1.67	1.32
MAY 1987	2.16	2.03	1.96	1.72	1.10
JUL 1987	2.27	-	-	1.18	1.11

Seasonal variability in water surface PAR was highest at Station 1 and decreased downstream. At Station 5, no significant difference existed in PAR over time ($P > 0.45$).

The PAR reaching the substrate was related to water surface PAR as follows:

$$PAR_b = 1.970 \times [\ PAR_s / \ln (z)\ ] \qquad r^2 = 0.92$$

where PAR_b and PAR_s were the amount of PAR (E m^{-2} d^{-1}) reaching the substrate and the water surface, respectively, and z was the water depth in centimeters.

Particulate Organic Matter

Suspended UPOM ranged from 14.3 to 27.2 mg l^{-1} and suspended FPOM from 8.9 to 24.7 mg l^{-1}. Both increased significantly downstream ($P < 0.05$) except in July, 1986 and 1987 (Fig. 10). During July of both years, suspended UPOM and FPOM peaked at Station 2. Although UPOM

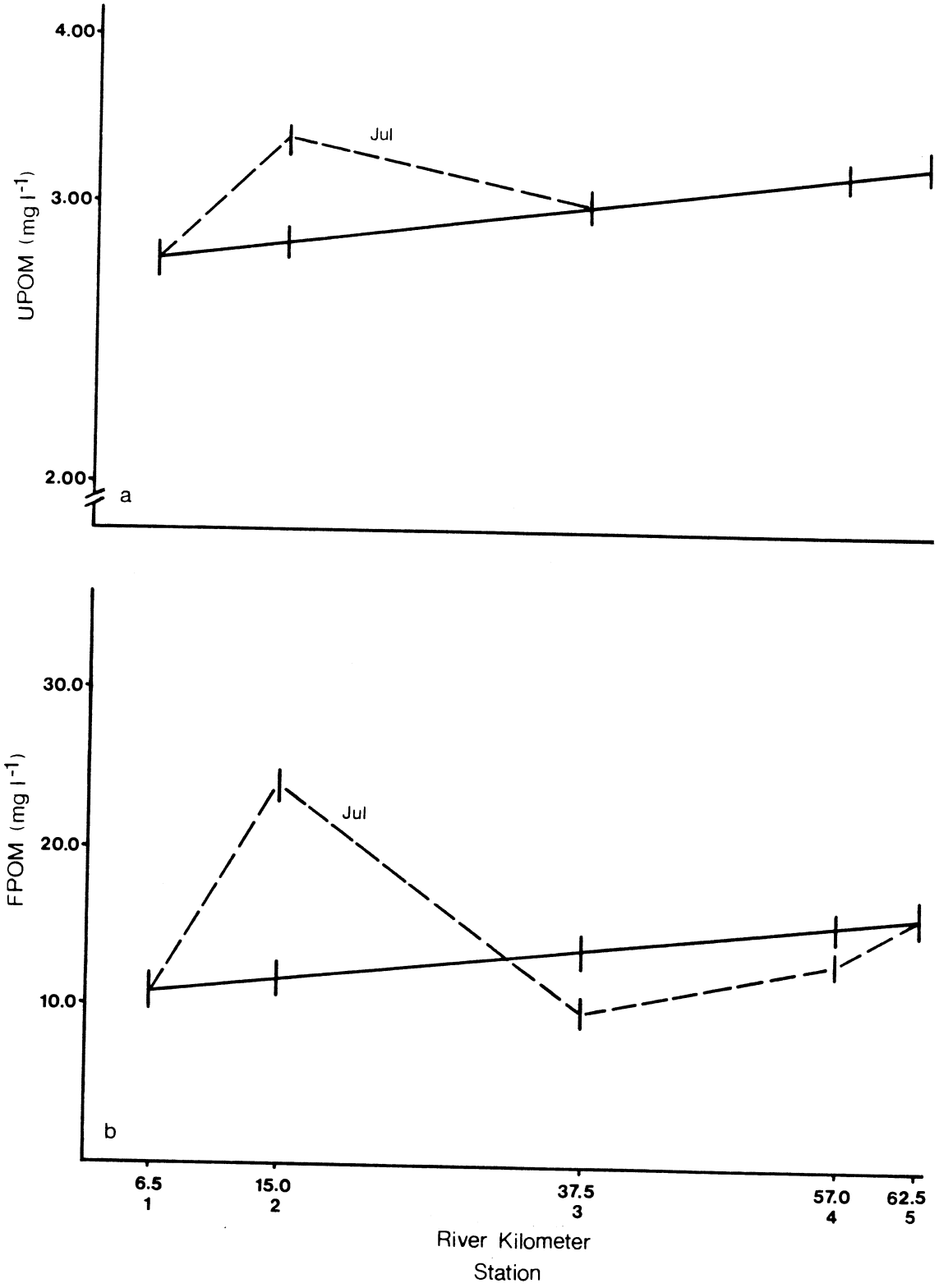


Figure 10. Suspended UPOM and FPOM at the Sampling Stations in Salt Creek. Vertical Bars Indicate 95% Confidence Intervals. Solid Lines Represent all Sample Times Except Those Labeled and Data Collected for Model Verification.

concentrations in July were not different from other times at any other station, FPOM was reduced at stations 3 and 4.

The relationships between suspended UPOM and FPOM and location along Salt Creek at all sampling times except July, 1986 and 1987 were as follows:

$$\ln (\text{UPOM}) = 2.720 + 0.006 (\text{River km}) \qquad r^2 = 0.89$$

$$\text{FPOM} = 10.40 + 0.09 (\text{River km}) \qquad r^2 = 0.91$$

where UPOM and FPOM were particulate concentrations in mg l^{-1}. No measurable amounts of suspended CPOM were measured during this study.

Sedimentation rates of UPOM, FPOM, and CPOM ranged from 55.5 to 136.1, 49.8 to 290.1, and 47.5 to 460.1 mg l^{-1}, respectively. The downstream changes in UPOM and FPOM sedimentation were similar to that presented for suspended UPOM and FPOM except no differences existed in FPOM between July and other times at stations 3 and 4 ($P < 0.05$).

The relationships between UPOM and FPOM sedimentation rates and location along Salt Creek for all sampling trips except July, 1986 and 1987 were as follows:

$$\ln (\text{UPOM}) = 4.04 + 0.010 (\text{River km}) \qquad r^2 = 0.91$$

$$\ln (\text{FPOM}) = 3.87 + 0.023 (\text{River km}) \qquad r^2 = 0.96$$

where UPOM and FPOM were the sedimentation rates in mg m^{-2} h^{-1}.

CPOM sedimentation rates also increased significantly downstream ($P < 0.01$). The amount of increase in sedimentation downstream did not change with time ($P > 0.32$) but the rate of sedimentation at each site was higher in September and lower in March as hypothesized ($P < 0.01$). The relationship between CPOM sedimentation rates and location in Salt Creek at all sampling times except March and September was as follows:

$$\ln (\text{CPOM}) = 3.70 + 0.033 (\text{River km}) \qquad r^2 = 0.92$$

where CPOM was the sedimentation rate in mg m^{-2} h^{-1}. Although the slopes of the equations relating CPOM in March and September to location were not different from the equation for other sampling times, the intercepts were 3.60 and 3.85, respectively.

Primary Production and Respiration

Considerable variation existed among stations in attached algal biomass, total chlorophyll concentrations, and carbon assimilation rates. Ranges were from 5.05 to 155.66 mg cm^{-2}, 1.6 to 25.4 mg m^{-2}, and 0.34 to 3.14 mg C cm^{-2} h^{-1}, respectively. Three distinct trends of a downstream decrease in attached algal chlorophyll concentrations were determined for Salt Creek. Chlorophyll concentrations at stations 1 to 4 were higher in May, 1987, and in July of both years than at all other times sampled (Fig. 11a). Concentrations in July of both years were higher than those in May at stations 2 and 3 but not at stations 1 and 4. No difference existed in chlorophyll concentration over time at Station 5.

The multiplicative hypothesis best described the relationship between attached algal chlorophyll and the amount of PAR reaching the substrate, nitrate-nitrite nitrogen, and orthophophate as follows:

$$\ln (chl_b) = -3.024 + 1.415 \ln (PAR_b) + 0.459 \ln (N) \quad r^2 = 0.87$$

where chl_b was the attached chlorophyll concentration in mg m^{-2}, PAR_b was the amount of PAR reaching the substrate in E m^{-2} d^{-1}, and N was the nitrate-nitrite nitrogen concentrations in mg l^{-1}. Othophosphate concentration was determined to be unnecessary in describing this reltionship.

Total chlorophyll concentrations of the attached algae were

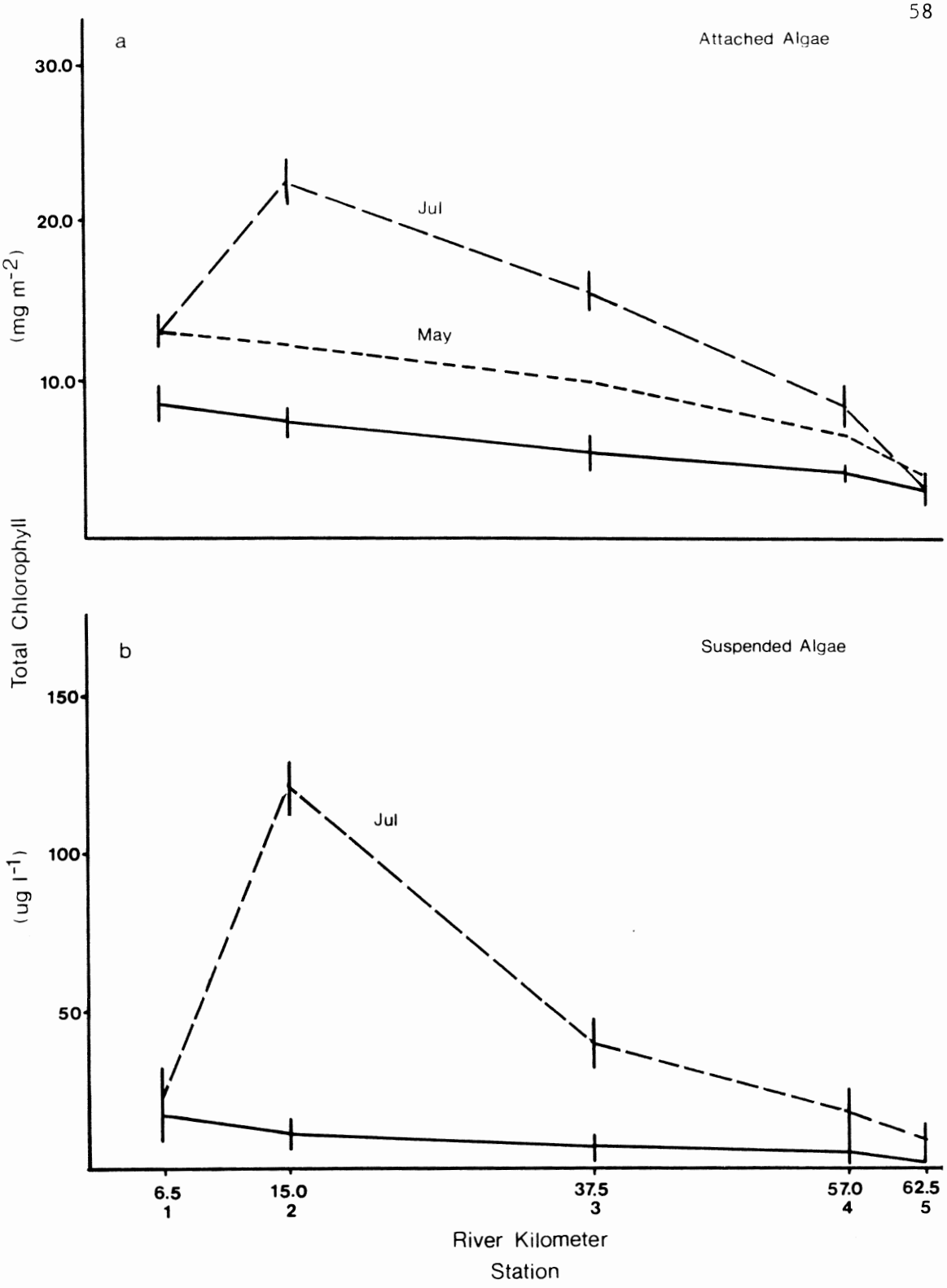


Figure 11. Chlorophyll Concentrations of Attached and Suspended Algae at the Sampling Stations in Salt Creek. Verticle Bars Indicate 95% Confidence Intervals. Solid Lines Represent All Sample Times Except Those Labeled and Data Collected for Model Verification.

linearly correlated with carbon assimilation rates (Fig. 12). No spatial or temporal patterns were determined for this relationship. The relationship between chlorophyll and biomass for the attached algae was as follows:

$$Chl_b = 0.0149\ (Biomass_b) \qquad r^2 = 0.78.$$

where chl_b and $biomass_b$ were the attached algal chlorophyll and biomass in mg m^{-2}.

Suspended chlorophyll concentrations ranged from 2.1 to 129.2 ug l^{-1}. Variations among stations in suspended chlorophyll were slight except in July of both years (Fig.11b). Concentrations in July of both years were higher at stations 2 and 3 but not at other stations.

The inverse additive nutrient limitation hypothesis best described the relationship between suspended algal chlorophyll and the amount of PAR reaching the water surface, nitrate-nitrite nitrogen, and orthophophate as follows:

$$\ln (chl_s) = -7.967 + 2.653 \ln (PAR_s) - 0.591 \ln (1/N + 1/P)$$

$$r^2 = 0.84$$

where chl_s was the attached chlorophyll concentration in mg m^{-2}, PAR_s was the amount of PAR reaching the substrate in E m^{-2} d^{-1}, and N and P were the nitrate-nitrite nitrogen and orthophosphate concentrations in mg l^{-1}, respectively. Mean water velocity was determined to be unneccessary in describing this relationship.

Primary productivity and respiration as determined by the diel oxygen method ranged from 0.12 to 1.97 and 0.13 to 1.60 g O_2 m^{-3} d^{-1}, respectively. The P/R decreased from an average of 1.83 at Station 1 to 0.92 at Station 5.

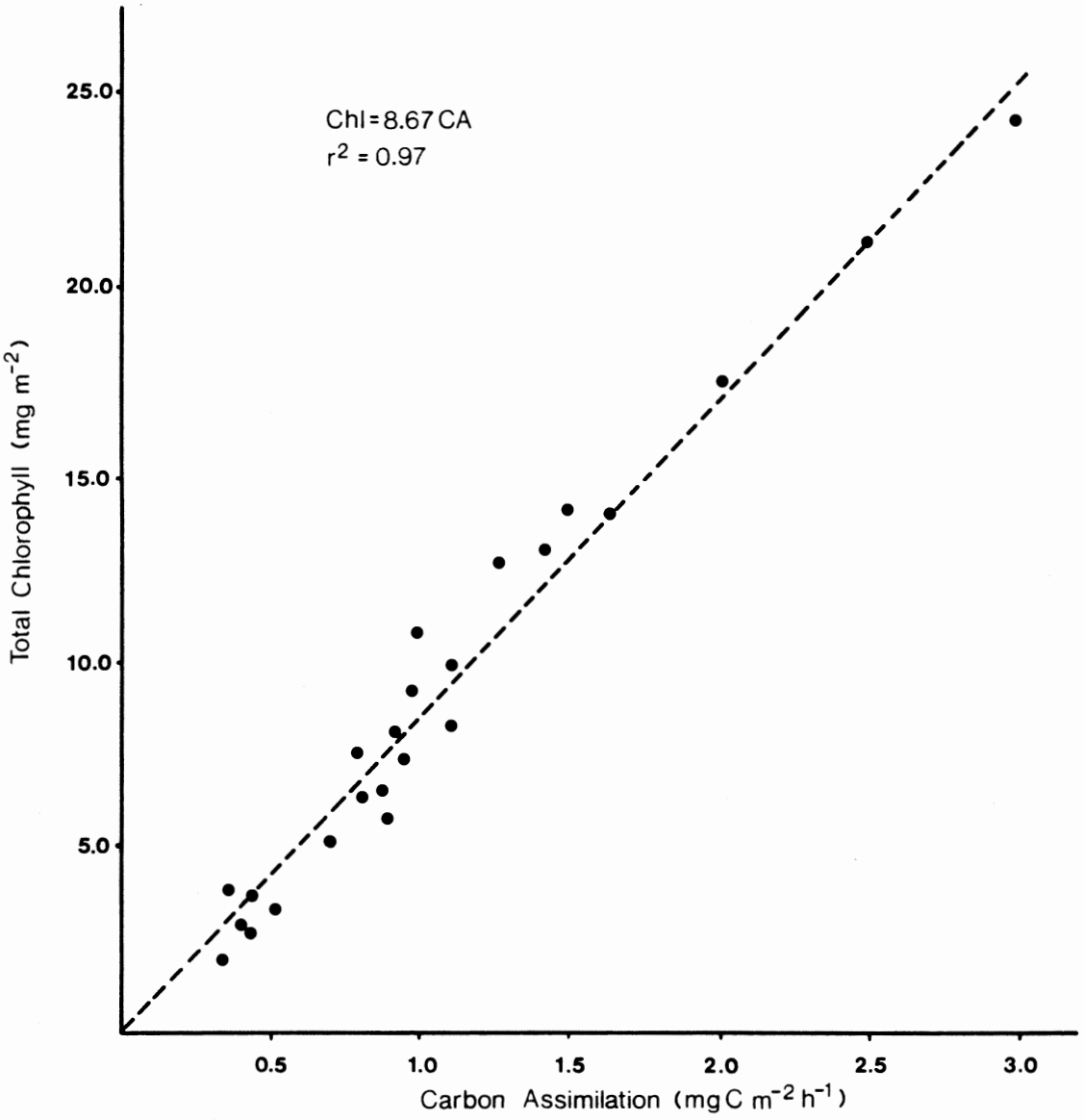


Figure 12. Total Chlorophyll Concentration Versus Carbon Assimilation Rate for Attached Algae.

Macroinvertebrates

The biomass of grazer macroinvertebrates ranged from 0.35 to 4.67 mg $trap^{-1}$. Three distinct temporal trends of downstream decrease were determined for grazer biomass (Fig. 13a). The biomass of grazers was higher in May, 1987, and July of both years at stations 1 through 3 than during other sample dates. The biomass was higher in July than in May at stations 2 and 3. No seasonal difference existed in grazer biomass at stations 4 and 5.

The component model indicated that grazer biomass should be related to the amount of periphytic algae available. This relationship was determined to be as follows:

$$GRA = 0.1924\ (Chl_b) \qquad r^2 = 0.99$$

where the grazer biomass was in mg m^{-2} and chl_b was the chlorophyll concentration of the attached algae in mg m^{-2}.

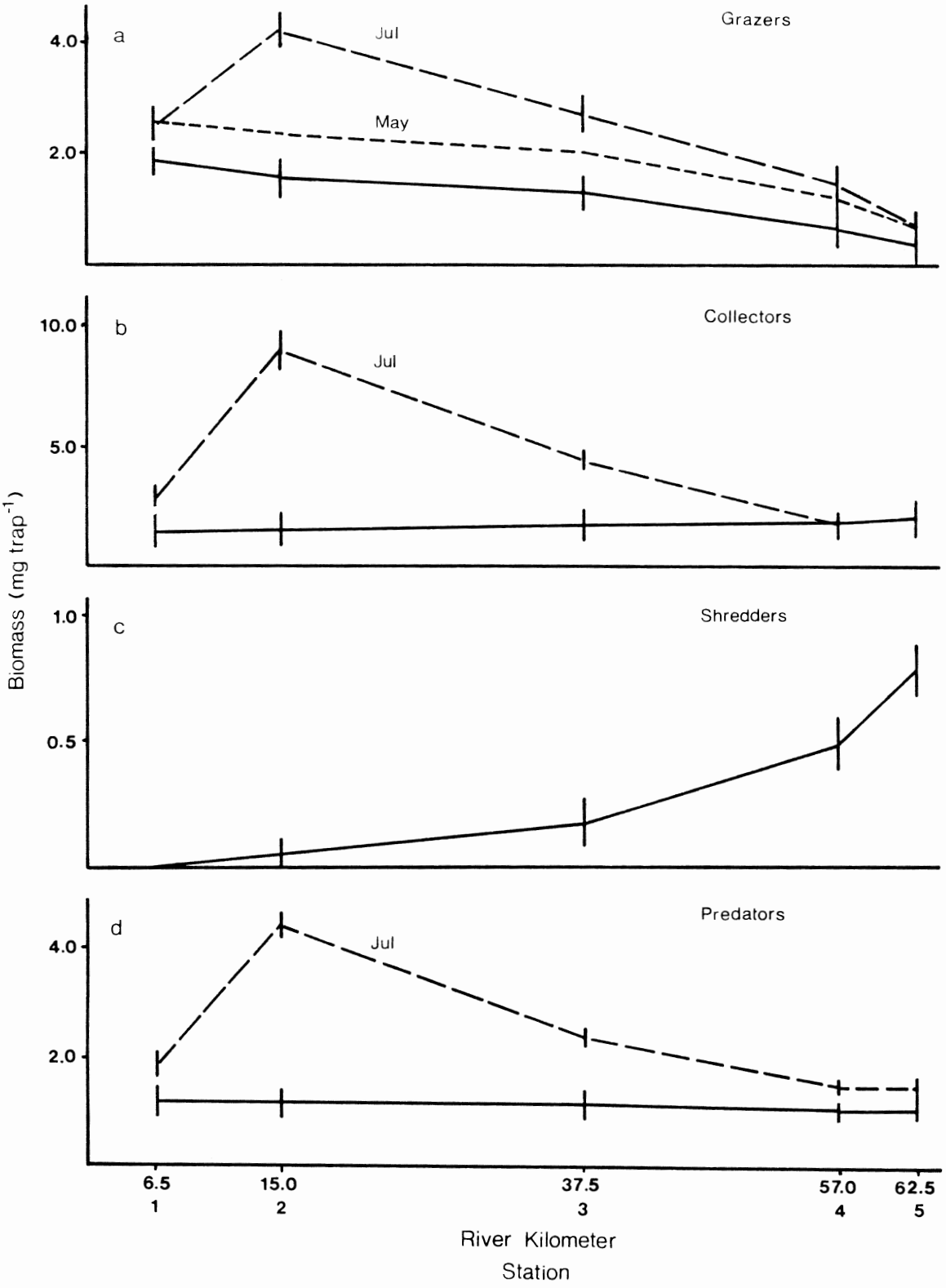
Collector biomass ranged from 1.60 to 10.88 mg $trap^{-1}$ and did not change along Salt Creek except in July of both years when it was higher at stations 1 through 3 (Fig. 13b).

The analysis of the discriminatory hypothesis indicated that UPOM and FPOM were too closely related and that either one could be used in a regression equation but not both simultaneously. The maximum correlation coefficent (r^2) obtained was 0.81. The result of the analysis of the nondiscriminatory hypothesis was as follows:

$$COL = 0.0532\ (UPOM_s + FPOM_s) + 0.0587\ (Chl_s) \qquad r_2 = 0.98$$

where collector biomass was in mg m^{-2}, $UPOM_s$ and $FPOM_s$ were the biomass of suspended UPOM and FPOM in mg l^{-1}, and Chl_s was the suspended chlorophyll concentration in ug l^{-1}.

Shredder biomass ranged from 0.00 to 0.85 mg $trap^{-1}$. Shredder



Fiqure 13. Macroinvertebrate Biomass at the Sampling Stations in Salt Creek. Vertical Bars Indicate 95% Confidence Intervals. Solid Lines Represent All Sample Times Except Those Labeled and Data Collected for Model Verification.

biomass increased downstream and did not change over time (Fig. 13c). The relationship between shredder biomass (mg m^{-2}) and CPOM sedimentation rates (mg m^{-2} h^{-1}) was as follows:

$$SHR = 0.00207\ (CPOM_b) \qquad r^2 = 0.90$$

However, no shredders existed at station 1 or any other station until CPOM exceeded 60 mg m^{-2} h^{-1}. When samples with CPOM less than 60 mg m^{-2} h^{-1} were not used the relationship became,

$$SHR = 0.00187\ (CPOM_b) \qquad r^2 = 0.97.$$

Predator biomass ranged from 0.92 to 5.18 mg $trap^{-1}$ and was not different among sampling stations except in July of both years (Fig. 13d). In July, 1986 and 1987, predator biomass was higher than during other times at all stations except Station 5.

The relationship between the predators and prey using the discriminatory assumption was

$$PRED = 0.341\ (GRA) + 0.421\ (SHR) + 0.320\ (COL) \qquad r^2 = 0.97$$

and for the nondiscriminatory was

$$PRED = 0.332\ (GRA + SHR + COL) \qquad r^2 = 0.97$$

where PRED, GRA, SHR, and COL were the biomass in mg m^{-2} of the predators, grazers, shredders, and collectors, respectively. The coefficient of variation was 0.063 for the discriminatory and 0.064 for the nondiscriminatory equation.

The total numbers by taxa of benthic macroinvertebrates collected are presented in Appendix B. The numbers, richness (S), evenness (E), and diversity (H') of each sample collected are presented in Appendix C. The numbers of macroinvertebrates collected increased downstream except in July of both years. Numbers ranged from 63 at station 1 to 245 at station 5 during non-enriched periods and peaked at Station 2

during enriched periods with a maximum of 328. The number of taxa represented in each sample (richness) ranged from nine at Station 1 and increased downstream to 26 at Station 5. In July of both years, richness increased at Station 2 by two to four taxa. Evenness also increased from stations 1 to 5 ranging from 43% at Station 1 to 90% at Station 5. Diversity ranged from 1.15 at Station 1 and increased downstream to 2.74 at Station 5. Downstream trends in evenness and diversity did not change seasonally.

Baseline Predictions

QUAL2E predictions of nitrate nitrogen and orthophosphate in the July, 1986 and 1987, simulations in the absence of the nitrogen point-source input (i.e. baseline) are presented in Table 5. The predicted mean nitrate and orthophosphate concentrations were within the ranges of the data collected at all other times. The predicted amount of nitrate nitrogen entering Salt Creek during enrichment was 9.9 mg l^{-1}.

Predicted baseline concentrations of chlorophyll, and macroinvertebrate biomass for July, 1986 are presented in Table 6. These were calculated from the statistical relationships determined from the component model. The quantity of PAR was assumed to be unchanged and UPOM and FPOM concentrations used were taken from the regression lines for times other than July. Since predicted values for July of both years were similar, only values for 1986 are presented.

The predicted chlorophyll concentrations and macroinvertebrate biomass for July, 1986, in the absence of nutrient enrichment were most similar to those measured in May, 1987 before enrichment. Predicted suspended chlorophyll was higher and attached chlorophyll was lower

TABLE 5

PREDICTED CONCENTRATIONS OF NITRATE NITROGEN AND ORTHOPHOSPHATE AT FIVE STATIONS ON SALT CREEK IN JULY, 1986 AND 1987 IN THE ABSENCE OF NITROGEN ENRICHMENT

		Concentration (mg l^{-1})				
		Station				
Date	Nutrient	1	2	3	4	5
1986	Nitrate nitrogen	1.39	1.22	0.92	0.69	0.44
	Orthophophate	0.67	0.58	0.52	0.44	0.35
1987	Nitrate Nitrogen	1.46	1.28	0.95	0.68	0.43
	Orthophosphate	0.65	0.57	0.51	0.44	0.34

TABLE 6

PREDICTED CHLOROPHYLL CONCENTRATIONS AND MACROINVERTEBRATE BIOMASS AT FIVE STATIONS ON SALT CREEK IN JULY, 1986 IN THE ABSENCE OF NITROGEN ENRICHMENT

	Station				
Component	1	2	3	4	5
Chlorophyll					
Suspended (ug l^{-1})	25.74	20.32	17.77	10.41	5.12
Attached (mg m^{-2})	13.9	10.6	8.6	6.3	3.9
Macroinvertebrates (mg m^{-2})					
Grazers	2.62	2.04	1.65	1.21	0.75
Collectors	2.89	2.63	2.69	2.47	2.43
Shredders	0.00	0.14	0.28	0.58	0.94
Predators	1.83	1.59	1.53	1.41	1.37

than that measured in May. Predicted collector and shredder biomass wassimilar to that measured during nonenriched periods with the predicted values being higher for collectors at stations 1 to 3 and for shredders at stations 4 and 5. Predicted predator biomass was higher

than that measured for non-enriched periods at all stations.

Verification of Model

The measured values of depth, velosity, discharge, water temperature, pH, conductivity, and alkalinity in the verification data collected in September and November, 1987, were similar to those measured in September and December, 1986, respectively. The QUAL2E predictions of nitrate-nitrite nitrogen and orthophosphate were within the 95% confidence intervals of the individual observations at all five stations for both the September and November verification data sets. The predicted and the mean of the observed values for PAR, POM, chlorophyll, and macroinvertebrate biomass for the September data are presented in Table 7 and for the November data in Table 8.

No apparent difference existed in the predicted and mean observed values in September for PAR, suspended POM, suspended chlorophyll, and collector and shredder biomass. The predicted sedimentation rates of POM were lower than observed rates at Station 5. The predicted attached chlorophyll concentration and grazer biomass were higher at stations 1 and 2 than observed and predator biomass was higher at Station 1.

The predicted values for the November data set were not different from mean observed values for water surface PAR, suspended POM, UPOM sedimentation rates, and collector, shredder, and predator biomass. Predicted substrate PAR was lower than observed at all five stations. Predicted FPOM sedimentation was higher at Station 4 and lower at Station 5 than observed and predicted CPOM sedimentation was lower at Station 5 than observed. Chlorophyll concentrations and grazer biomass predictions were lower at stations 1 and 2 than observed.

TABLE 7

PREDICTED AND MEAN OBSERVED VALUES (IN PARENTHESES) OF PAR, POM, CHLOROPHYLL CONCENTRATIONS, AND MACROINVERTEBRATE BIOMASS AT FIVE STATIONS ON SALT CREEK, SEPTEMBER 1987

Variable	Station 1	2	3	4	5
PAR (E m^{-2} d^{-1})					
Water surface	60.2	59.1	55.6	51.0	49.2
	(61.1)	(58.3)	(53.3)	(48.9)	(45.1)
Substrate	42.3	40.1	32.3	29.4	28.1
	(42.3)	(40.1)	(34.1)	(28.8)	(25.8)
POM					
Suspended (mg l^{-1})					
UPOM	15.7	16.5	18.7	20.8	21.5
	(14.7)	(16.2)	(17.2)	(19.2)	(21.4)
FPOM	11.0	11.8	13.8	15.5	16.0
	(11.8)	(12.0)	(13.8)	(15.2)	(16.3)
Sedimentation (mg m^{-2} h^{-1})					
UPOM	60.7	66.1	82.6	101.1	*106.8
	(67.2)	(69.3)	(82.3)	(100.6)	(132.1)
FPOM	55.6	67.5	111.5	175.8	*199.4
	(57.2)	(68.1)	(114.3)	(163.4)	(248.9)
CPOM	58.3	77.2	160.0	315.2	*371.9
	(57.1)	(77.7)	(143.1)	(293.3)	(400.3)
Chlorophyll					
Suspended (ug l^{-1})	14.2	10.5	8.2	4.5	3.1
	(12.3)	(10.4)	(8.5)	(4.0)	(2.9)
Attached (mg m^{-2})	*11.6	*10.0	6.6	4.8	3.5
	(9.5)	(8.3)	(6.3)	(4.5)	(3.3)
Invertebrates (mg $trap^{-1}$)					
Grazers	*2.23	*1.92	1.26	0.92	0.67
	(1.99)	(1.68)	(1.16)	(0.84)	(0.74)
Collectors	2.25	2.12	2.21	2.20	2.18
	(2.17)	(2.25)	(2.14)	(2.09)	(2.28)
Shredders	0.0	0.14	0.30	0.59	0.70
	(0.0)	(0.20)	(0.29)	(0.53)	(0.82)
Predators	*1.49	1.38	1.24	1.23	1.18
	(1.60)	(1.30)	(1.31)	(1.25)	(1.27)

* Outside 95% confidence interval of observed data.

TABLE 8

PREDICTED AND MEAN OBSERVED VALUES (IN PARENTHESES) OF PAR, POM, CHLOROPHYLL CONCENTRATIONS, AND MACROINVERTEBRATE BIOMASS AT FIVE STATIONS ON SALT CREEK, NOVEMBER 1987

Variable	Station 1	2	3	4	5
PAR (E m^{-2} d^{-1})					
Water surface	48.1	47.4	45.2	42.8	42.0
	(52.5)	(50.6)	(49.1)	(45.3)	(44.7)
Substrate	*30.1	*25.8	*25.4	*24.2	*22.9
	(33.9)	(29.3)	(28.6)	(28.5)	(27.6)
POM					
Suspended (mg l^{-1})					
UPOM	15.7	16.5	18.7	20.8	21.5
	(16.5)	(17.9)	(19.9)	(21.2)	(23.2)
FPOM	11.0	11.8	13.8	15.5	16.0
	(11.5)	(13.4)	(13.9)	(15.8)	(17.1)
Sedimentation (mg m^{-2} h^{-1})					
UPOM	60.7	66.1	82.6	101.1	106.8
	(60.7)	(64.5)	(73.0)	(90.1)	(112.6)
FPOM	55.6	67.5	111.5	*175.8	*199.4
	(58.9)	(71.5)	(102.3)	(156.2)	(223.2)
CPOM	50.1	66.5	140.0	266.9	*320.2
	(52.8)	(71.7)	(114.5)	(241.9)	(402.5)
Chlorophyll					
Suspended (ug l^{-1})	*6.3	*5.7	4.3	3.3	2.6
	(7.4)	(6.5)	(4.8)	(3.8)	(2.9)
Attached (mg m^{-2})	*7.2	*5.5	4.9	3.7	2.9
	(7.9)	(6.7)	(5.2)	(4.2)	(3.0)
Invertebrates (mg $trap^{-1}$)					
Grazers	*1.39	*1.06	0.94	0.71	0.55
	(1.61)	(1.40)	(1.00)	(0.78)	(0.61)
Collectors	1.79	1.84	1.98	2.12	2.20
	(1.62)	(1.75)	(1.83)	(2.09)	(2.21)
Shredders	0.0	0.12	0.26	0.50	0.60
	(0.0)	(0.14)	(0.24)	(0.46)	(0.68)
Predators	1.06	1.00	1.06	1.11	1.11
	(1.00)	(1.02)	(0.97)	(1.10)	(1.19)

* Outside 95% confidence interval of observed data.

CHAPTER VII

DISCUSSION

Physical and Chemical Characteristics

Values of physical and chemical variables measured in Salt Creek were generally within the ranges described for Otter Creek, an Oklahoma mixed-grass prairie stream (Harrel & Dorris 1968, Harrel 1969) and Skeleton Creek, another north central Oklahoma stream (Cooper & Wilhm 1975). Alkalinity of Otter and Skeleton creek averaged 40 and 65 mg l^{-1} higher, respectively, than Salt Creek. Alkalinity in all three streams decreased downstream except in May and July when downstream increases occurred in Salt Creek. The daily variation in dissolved oxygen in the summer was also higher in Skeleton Creek, primarily due to large volumes of domestic wastes entering the headwaters which increased primary production. Conductivity in Otter and Skeleton creeks decreased downstream, probably because of dilution and incorporation of compounds by algae (Cooper & Wilhm 1975), while conductivity in Salt Creek increased downstream except during enrichment when it decreased downstream.

Nutrients

The concentration of nitrate-nitrite nitrogen measured in Salt Creek was within the range of values reported for forested watersheds in Idaho, Michigan, and Pennsylvannia (Bott et al. 1985). However,

phosphorous concentrations in these streams averaged an order-of-magnitude lower than in Salt Creek. Nitrogen concentrations in the streams in Idaho and Michigan decreased downstream as in Salt Creek. During enrichment, the nitrate-nitrite concentration at Station 2 in Salt Creek was twice the total dissolved nitrogen reported in streams receiving agricultural runoff in the Netherlands (Klapwijk et al. 1983). Orthophosphate values near the enrichment source were four times higher in the Netherlands than the maximum measured in Salt Creek.

Using QUAL2E to estimate nitrogen and phosphorous concentrations along Salt Creek should have provided better estimates than using simple spatial variation as was done for PAR and POM. QUAL2E predictions were based on numerous instream processes, many of which were independent of location. In the QUAL2E simulations, nitrogen, phosphorous, and chlorophyll a concentrations were predicted but chlorophyll was included only to increase the quality of the simulations. The QUAL2E chlorophyll estimates were not used in further modeling because suspended and attached algal chlorophyll could not be separated as was done in the statistical analysis. Predicting all three variables indicated that the rate functions used in the simulations were estimated adequately and that the model was mimicking the processes occurring in Salt Creek. Only the nitrogen and phosphorous predictions were used in further modeling. During enrichment, the values of nitrogen and phosphorous predicted when the point source was removed were not different from the values during nonenriched periods. Since no other seasonal variability existed in either nutrient, these results indicated that the point-source was adequately modeled.

Primary production in streams without a headwater canopy are

generally nutrient-limited rather than light-limited (Moore 1977, Lowe et al. 1986). The headwaters of Salt Creek appeared to be nitrogen-limited. The N:P was below 2.41 except during enrichment from agricultural runoff. During enrichment, adding the predicted 9.9 mg l^{-1} of nitrate nitrogen entering Salt Creek to the mean concentration at all other times resulted in an N:P of 18.5. This indicated that nitrogen was probably no longer limiting during enrichment and that phosphorous was most likely the limiting nutrient since it declined to below detection limits. Streams in the Netherlands receiving agricultural wastewater were nitrogen-limited when not enriched and also during enrichment because orthophosphate as well as nitrogen concentrations were elevated (Klapwijk 1983). In Salt Creek, 48 km downstream from the nutrient input, nutrient concentrations during enriched periods were not different from other periods. Concentrations similar to those measured 48 km downstream of enrichment in Salt Creek were measured 2.3 km downstream from enrichment in the Netherlands. However, no recovery distance was presented in the latter study.

Photosynthetically Active Radiation

The amount of light reaching the water surface in the headwaters of Salt Creek was an order-of-magnitude greater than that reported for canopied headwaters in Idaho, Michigan, Oregon, and Pennsylvania (Bott et al. 1985). Photosynthetically active radiation at the canopied Station 5 in Salt Creek was approximately the same as that reported for these streams. Open canopied streams in southeast Alaska received three to five times the amount of light received by dense canopied streams (Duncan & Brusven 1985) and similar comparisons were presented for

streams in New Zealand (Rounick et al. 1982). The amount of PAR reaching the water surface in the open-canopied headwaters of Salt Creek was one to 1.5 times that of the canopied, higher order reaches.

The downstream decrease and seasonal changes in PAR corresponded to the hypothesis presented in the prairie stream model. The seasonal variabilty in PAR was greatest in open canopied areas and decreased as canopy development increased. Surface PAR modeling was based on spatial and temporal variation because the current lack of understanding of the processes which affect PAR distributions in stream systems did not allow empirical predictions. In fact, the QUAL2E estimates of hourly PAR used to predict algal growth were based on an empirically derived sine function. In Salt Creek, the daily PAR curve was sinusoidal in the open-canopied headwaters but was Gaussian in canopied downstream reaches.

Benthic PAR was related to surface PAR and mean water depth. Although this relationship assumed uniform turbidity along Salt Creek and through time, this was not the case. Particulates per unit volume increased downstream. During enrichment, suspended algal biomass at Station 2 produced a deep-green color which decreased visibility. In Skeleton Creek, another north central Oklahoma stream, light transmission decreased downstream, except in winter, due to erosion of adjacent cultivated lands which increased suspended particulates (Cooper & Wilhm 1975).

Particulate Organic Matter

The amount of suspended UPOM and FPOM in Salt Creek were higher than the amounts reported for forested streams in Idaho (Minshall et

al. 1982), Michigan, Oregon, and Pennsylvania (Minshall et al. 1983) and the concentration of FPOM was 50 times higher than that reported for Bear Brook in New Hampshire (Fisher & Likens 1973). Some of the differences may have been due to differences in techniques. My samples were not collected from all water depths nor for long periods of time. Concentrations of suspended CPOM were appreciable in all of the above streams except Salt Creek. Suspended CPOM was also collected along the Great Lakes drainage basin (Cummins et al. 1981). The lack of any measurable suspended CPOM in Salt Creek did not indicate that no CPOM was present. CPOM was present in the sedimentation traps. In order to be in these traps, CPOM must have been in the water column.

The downstream increase in suspended UPOM and FPOM were as expected in the prairie stream model. However, the lack of seasonal variation was not expected. In Salt Creek, no increase occured in suspended particulates after senescence of riparian vegetation, perhaps because of flushing of particulates by above average flows that occurred during record rainfall in late September, 1986. Further, the lack of seasonal changes in UPOM and FPOM may have been because these particulates were derived primarily from the pasture soils and thus less influenced by the seasonal development of the riparian vegetation (Cooper & Wilhm 1975, MacFarlane 1983). Increased concentrations at Station 2 during enrichment were most likely because of increased concentrations of suspended algae since suspended chlorophyll concentrations increased approximately the same degree as particulates.

Benthic POM determinations from my study were not directly comparable to those of other studies. Many investigators collect accumulated particulates from the substrate with nitex screens

(Minshall et al. 1983) or with suction pumps (Naiman & Sedell, 1979). These techniques provide information about the total amount of particulates present at a given time but permit only rough estimates of accumulation rates. The rate of sedimentation should be more important in reestablishing macroinvertebrates after high flows and in long term maintenance of macroinvertebrate assemblages in stream systems. I estimated the rate of sedimentation using particulate traps and not the total amount of accumulated particles within the substrate. The advantages of my technique were reproducibility and obtaining rate functions. The disadvantages included problems with water flow and particulate export. Placement of the trap within the substrate changed the texture of the substrate from that of rock and cobble to an open hole. This altered water movement over the trap and may have biased the sedimentation rate, a bias that may not have been uniform among particle sizes. Additionally, the funnel design of the trap may have altered natural export of sedimented particles.

In Salt Creek, the sedimentation rates of all three size ranges of benthic particulates increased downstream as hypothesized. In streams with canopied headwaters, UPOM and FPOM increased downstream and CPOM decreased downstream (Cummins et al. 1981, Minshall et al. 1983, Bott et al. 1985). Hypothesized seasonal changes in benthic UPOM and FPOM did not did occur. The lack of seasonal changes in the sedimentation rates of UPOM and FPOM corresponded to the lack of seasonal changes in the suspended particulates. Sedimentation rates for CPOM were lower in spring and higher in fall as hypothesized in the prairie stream model.

The prairie stream model predicted little change in CPOM:FPOM since both FPOM and CPOM should increase downstream. In Salt Creek, the

CPOM:FPOM increased from 0.9 at Station 1 to 1.6 at Station 5. The RCC predicts a downstream decrease in CPOM:FPOM in forested watersheds. However, a downstream increase was reported for a forested watershed in Oregon (Naiman & Sedell 1979).

The predictions of PAR and POM were closer to the observed values in the September than in the November verification dataset. The statistical model predicted mean concentrations at a sample site for a given season. Thus, the annual variability would account for some of the differences between predicted and measured concentrations. Additionally, some temporal changes in PAR and POM are expected to occur within each season. The use of PAR and POM temporal data as replicates in the statistical model may have allowed for the variation of these variables in both verification datasets. Better predictions for the September than the November dataset may have been because the former were based on data from the previous September, while the latter were based on the previous December.

Primary Production and Respiration

Three techniques were used in this study to estimate attached algal photosynthesis: total chlorophyll, carbon assimilation rates, and biomass. Although estimating carbon assimilation rates using radio-labeled carbon is generally the preferred technique (Lind 1979), this technique can be time consuming and impractical if many stations are established. Both algal biomass and chlorophyll concentrations are widely used alternatives (Wetzel & Likens 1979). Generally, monochromatic determinations of chlorophyll _a_ concentrations are performed using spectrophotometric or fluorescence techniques. However,

streams are commonly dominated by diatoms which contain high amounts of chlorophyll c (Lowe et al. 1986, Noel et al. 1986). Thus, the spectrophotometric trichromatic method which estimates chlorophylls a, b, and c was more suitable for my study.

Total chlorophyll and carbon assimilation rate measurements provided similar estimates of photosynthesis (Fig. 12). Field collection times for chlorophyll samples were less than 10 min per station, while 1 to 1.5 h were required for incorporating of radio-labeled carbon. Laboratory times for each technique were similar. Attached algal biomass measurements were confounded with nonalgal particulates which were entrained by the algae, especially the thick filamentous green mats formed during enrichment. Additionally, suspended algal biomass was not determined because algal particles could not be separated from nonalgal particles. For these reasons, total chlorophyll was used to estimate photosynthesis in the regression analysis of the prairie stream model.

The range of attached algal chlorophyll concentrations in Salt Creek was similar to those reported in several Great Plains streams in Kansas and Oklahoma (Seyfer & Wilhm 1977, Gelroth & Marzoff 1978, Wilhm et al. 1978) as well as in streams in many agricultural fields around the United States (Nelson & Scott 1962, Naiman 1983, Bott et al. 1985). Little data has been published on the chlorophyll concentrations of suspended algae in streams. The concentrations of suspended chlorophyll from an eighth order stream reach were 5 to 100 times that measured in Salt Creek (Bruns & Minshall 1985). Concentrations in the Columbian River Estuary were in the same range as those measured in Salt Creek, except during enrichment when chlorophyll concentrations at Station 2

in Salt Creek were higher. In two, third-order streams in California, suspended chlorophyll was 10 to 100 times lower than in Salt Creek (Lamberti & Resh 1987).

Suspended chlorophyll did not appear to exhibit seasonal changes in concentration as hypothesized. In Cascade Mountain streams, suspended chlorophyll increased in summer in a canopied first-order stream but no seasonal change occurred in a canopied third-order stream (Naiman & Sedell 1979). In an open-canopied fifth-order stream, suspended chlorophyll concentrations increased in autumn. Suspended chlorophyll in two third order California streams peaked in summer when light availability was high and water current was low (Lamberti & Resh 1987).

Attached chlorophyll concentrations increased in summer as hypothesized but appeared to be constant through the rest of the year. In forested watersheds of Idaho, Michigan, Oregon, and Pennslyvannia, attached algal chlorophyll concentrations were constant throughout most of the year but were generally higher in spring or autumn (Bott et al. 1985). Chlorophyll concentrations of attached algae in Otter Creek, Oklahoma, peaked in the spring in a third order reach and in summer in fourth through sixth order reaches (Seyfer & Wilhm 1977).

The downstream decrease in both suspended and attached algal chlorophyll concentrations were as hypothesized as was the response to nitrogen enrichment. The downstream pattern of chlorophyll response to enrichment was similar to that presented in other studies of agricultural runoff as well as for studies of sewage inputs (Cooper & Wilhm 1975, Seyfer & Wilhm 1977, Aizaki 1978, Gammon et al. 1983, Klapwijk et al. 1983, Sladeckova et al. 1983, Morgan 1987).

Although velocity was not statistically significant in the regression equation determined for suspended chlorophyll, it still influenced suspended algal accumulation. At Station 2 in Salt Creek, the water contained such a large density of suspended algae during enrichment that the creek was pea-green in color and suspended chlorophyll concentrations were four to five times higher than at other times. Enrichment occurred during the low summer flows. If enrichment had occurred during high flows, much of the algae that accumulated at Station 2 in Salt Creek would have been transported downstream.

Phosphorus was determined not to be important in the regression relationship between attached algal chlorophyll concentrations and light and nutrients. Although phosphorus may have been a biologically important nutrient, especially during enrichment, once nitrogen was accounted for in the regression relationship the amount of additional variability accounted for by phosphorus was insignificant. Furthermore, the periphyton assemblage may have obtained sufficent phosphorus from the underlying substratum during times of low dissolved phosphorus in the water column (Pringle 1987). Finally, the formation of dense suspended algal assemblages at stations 2 and 3 during enrichment may have blocked sufficent light such that the attached algae became light-limited before they were phosphorus-limited. Light limitation by phytoplankton is well documented in lakes and reservoirs (Wetzel 1983).

The downstream changes in P/R were as predicted in the prairie stream model and in the original description of the RCC by Vannote et al. (1980). The simple method used to predict P/R in my study generally underestimates net primary production (Bott et al. 1978). However, estimates of gross productivity and community respiration compare

favorably with values obtained from complex in-situ enclosed chamber techniques. The range of gross primary production and community respiration in Salt Creek were similar to estimates reported for many agricultural and plains streams (Bott et al. 1985).

Macroinvertebrates

Since colonization devices were used, densities and biomass estimates of macroinvertebrates collected in Salt Creek are not directly comparable to those collected in other studies. However, the colonization devices provided a uniform substrate which increased the reproducibility (Mason et al. 1971, 1973; Lamberti & Resh 1983, 1985). Although colonization devices present the possibility of not collecting taxa which are highly substrate specific, this bias should not have varied among stations.

The RCC predicted that primary producers should be more important as a food source in prairie than in forested headwaters. The proportions of grazers in the headwaters of Salt Creek were much higher than those reported for forested headwaters in Idaho, Michigan, Oregan, and Pennsylvania (Minshall et al. 1983). However, the proportions of grazers in canopied downstream stations in Salt Creek were similar to the values reported for the headwaters of the forested watersheds. The proportion of grazers in Salt Creek was higher than that reported for plains streams in Minnesota (MacFarlane 1983) and Kansas (Smith 1986).

The grazer biomass decreased downstream and increased in summer as hypothesized in the prairie stream model. The downstream and seasonal pattern of grazers (Fig. 13) corresponded to the pattern of the attached algal chlorophyll (Fig. 11). In forested watersheds, grazers

generally increased from headwaters to midreaches as light and hence primary producers increased (Cummins et al. 1981, Minshall et al. 1982, 1983). However, in forested watersheds in Idaho and Pennsylvania, summer grazer biomass peaked in the headwaters and decreased downstream as in Salt Creek (Minshall et al. 1983). During winter, no grazers were collected in the headwaters and the peak biomass was in the midreaches. Grazer biomass increased downstream during all seasons in a tallgrass prairie stream in Kansas (Smith 1986).

The proportion of collectors was lower in Salt Creek than in plains streams in Minnesota (MacFarlane 1983) and Kansas (Smith 1986). In New Zealand streams, collectors consumed a large proportion of the available algal material which effectively increased their relative proportion while decreasing the proportion of grazers (Rounick et al. 1982). The proportion of collectors in forested streams of Idaho, Michigan, Oregon, and Pennsylvannia were within the ranges for Salt Creek (Minshall et al. 1983).

Collector biomass did not change along Salt Creek or seasonally. Collector biomass was higher in third order than in second order plains streams in Minnesota (MacFarlane 1983) and increased downstream during all times of the year in a tallgrass prairie stream in Kansas (Smith 1986) as well as in forested watersheds in many locations in the United States (Minshall et al. 1983). In the prairie stream model, collector biomass was hypothesized to increase downstream and during autumn because of increases in UPOM and FPOM. FPOM and UPOM did increase downstream; however suspended algae decreased downstream. Since the regression coefficients were approximately the same for combined UPOM-FPOM and suspended algae, equal preference for these two food sources

was indicated and the algal decrease counteracted the POM increase. The nondiscriminatory hypothesis was used to relate collector biomass to particulates and to suspended algae. Since longitudinal and seasonal patterns of UPOM and FPOM were highly correlated, they could not be used simultaneously in a regression equation. The RCC predicts that longitudinal taxonomic changes may occur in collectors as smaller particulates dominate downstream (Vannote et al. 1980). Taxa persist that can consume the smaller particle sizes. Since the dominant collectors in Salt Creek were similar at all stations, little change should have existed in the particle sizes selected by the invertebrates suggesting that the nondiscriminatory hypothesis should be used. However, smaller individuals within a taxa also consume smaller particulates (Allen 1982, Hauer & Stanford 1982). In Salt Creek, the collector biomass did not change downstream but the numbers of collectors increased. Thus, the size of each individual was smaller downstream and smaller particle sizes may have been selected suggesting that the discriminatory hypothesis should have been used.

The proportion of shredders in Salt Creek was similar to the proportions reported in prairie streams in Minnesota (MacFarlane 1983) and Kansas (Smith 1986). The proportions of shredders were lower in Salt Creek than in the streams of Michigan, Oregon, and Pennsylvania and higher than in streams in Idaho (Minshall et al. 1983). Shredders collected in Idaho were less than 1 % of the total assemblage biomass which was similar to the headwaters of Salt Creek. In New Zealand streams, shredders consumed a large proportion of the available algal material which effectively increased their relative proportion while decreasing the proportion of grazers (Rounick et al. 1982).

Shredder biomass increased downstream as hypothesized, but did not decrease in spring or increase in autumn. In other prairie streams, shredder biomass also increased downstream (MacFarlane 1983) and was higher in autumn and winter (Smith 1986). In forested watersheds, shredders generally decrease downstream as the relative amount of allochthonous CPOM decreases. No shredders were collected at Station 1 and few at Station 2. The primary CPOM at these stations were grass stems which are generally resistant to decomposition (Bird & Kaushik 1987) and primarily used as habitat by macroinvertebrates (Smith 1986).

Several studies have indicated that attached algae can be a significant portion of shredder diet (Young et al. 1978; Peckarsky 1980; Winterbourn et al. 1981,1984; Rounick et al. 1982). This did not appear to be the case in Salt Creek. When analyzing the shredder portion of the prairie stream component model, attached algae was not a significant contributor to the regression equation suggesting that shredders were consuming relatively little periphyton. The lack of attached algal consumption was further evidenced by the lack of shredder response to the increase in available algae during enrichment.

Predator biomass did not change along Salt Creek or seasonally. Predator biomass in a plains stream in Minnesota was lower in a second order reach than in a third order reach (MacFarlane 1983). Predators in forested watersheds in Pennsylvannia decreased downstream during both winter and summer, while those collected in Idaho and Oregon decreased downstream in summer and increased downstream in autumn (Minshall et al. 1983). In forested watersheds in Michigan, predators decreased from headwaters to midreaches and then increased further downstream. The RCC and prairie stream model did not predict longitudinal or seasonal

changes in predator biomass except to state that it was dependent on the biomass of the other functional groups. Although the relative proportions of functional groups along Salt Creek changed, the total biomass did not change longitudinally or seasonally.

Macroinvertebrate predators are usually considered generalists, pursuing any potential prey that is large enough to be noticed but small enough to be consumed (Chutter 1961, Pritchard 1964, Thompson 1978, Johnson & Crowley 1980, Bryant 1987) suggesting that the non-discriminatory hypothesis should be used. However, many macro-invertebrates prefer specific habitats within a stream reach (Hart 1981, Mittlebach 1981, Gore 1983). Predators within these specific habitats may be more likely to consume one functional group than another suggesting that the discriminatory hypothesis should be used. Additionally, different functional groups are relatively more abundant in different stream reaches and therefore more likely to be consumed. The regression equations from both hypotheses explained equally well the relationship between the predators and the other functional groups. Since the nondiscriminatory hypothesis was the simplest, it was used in the model of Salt Creek.

During enrichment, grazer, collector, and predator biomass increased immediately below the nutrient input source and then decreased downstream as hypothesized in the prairie stream model. Collector response was primarily because of increases in suspended algae which again indicated the importance of algae as a food source. The increase in predators occured because of increases in grazer and collector biomass. Shredders did not respond to enrichment.

Total macroinvertebrate biomass did not change seasonally or

increase downstream as hypothesized but remained constant. Since the numbers of macroinvertebrates collected increased downstream, the average biomass of individuals was higher in the headwaters than in the downstream stations. Richness, equitability, and diversity also increased downstream. In Otter Creek, a mixed-grass prairie stream in Oklahoma, richness increased from third to fifth order reaches and diversity increased from third to fourth order reaches and then decreased from fourth to sixth order reaches (Harrel & Dorris 1968). During eutrophication in Salt Creek, macroinvertebrate densities and richness increased while equitability and diversity remained unchanged. Macroinvertebrates in a plains stream in Indiana receiving agricultural runoff also exhibited an increase in density without a compositional reorganization (Gammon et al. 1983). However, as agricultural inputs continued, the macroinvertebrate assemblage in the Indiana stream became dominated by chironomids which resulted in a decrease in equitability and diversity. Finally, after inputs continued for a period of time, total macroinvertebrate density decreased sharply.

Although the RCC as modified in the prairie stream model appeared to be applicable to Salt Creek, several hypotheses in the model were not evident in the data. No seasonal variation existed in the sedimentation rates or the amount of suspended UPOM and FPOM. The lack of predicted seasonal changes was also evident in suspended chlorophyll concentrations. Attached algal chlorophyll concentrations increased in summer as expected but were constant during the rest of the year. As a result of the lack of seasonal changes in suspended particulates and chlorophyll, collector biomass did not undergo expected seasonal changes. Collector biomass did not increase downstream as expected

because of decreased suspended algae downstream. The response of chlorophyll concentrations and macroinvertebrate biomass during enrichment were generally as hypothesized in the prairie stream model. However, attached algae was not a significant food source for shredders. Thus, shredder biomass did not respond to enrichment.

The combined use of QUAL2E to estimate nitrogen and phosphorous concentrations, and statistical relationships to estimate biotic variables adequately predicted most variables in the verification datasets. Most differences between observed and predicted values were because of the models used to describe PAR and POM. Both PAR and POM predictions were based only on spatial and temporal variation because the current lack of understanding of the processes which affect their distributions in streams did not allow the use of more complex empirical equations.

CHAPTER VIII

SUMMARY

The longitudinal changes observed in Salt Creek are summarized in Figure 14. The first two sections of this figure correspond to the first section presented for deciduous forest watersheds (Fig. 1) while the last section of this figure corresponds to the second section presented for forested watersheds. The headwaters of Salt Creek were not shaded by a riparian canopy which resulted in high primary production and thus a high proportion of grazer macroinvertebrates. The adjacent pastures supplied the primary source of UPOM and FPOM which supported a high proportion of collecters during the study. The primary form of CPOM was grass stems which were resistant to decomposition and primarily used for habitat. Thus, few shredders were present.

Downstream, the riparian canopy blocked more PAR which resulted in a decrease in primary production and in grazers. Although UPOM and FPOM increased downstream, the proportion of collectors remained unchanged because of decreases in suspended algae. The primary form of CPOM shifted from grass stems to deciduous leaf and a concomitant increase in shredder biomass. The total macroinvertebrate biomass did not change downstream even though POM increased significantly, since autochthonous production decreased downstream.

During enrichment, the algae were no longer nitrogen-limited and primary production increased immediately below the nutrient input and then decreased downstream. The increase in attached algae supported an

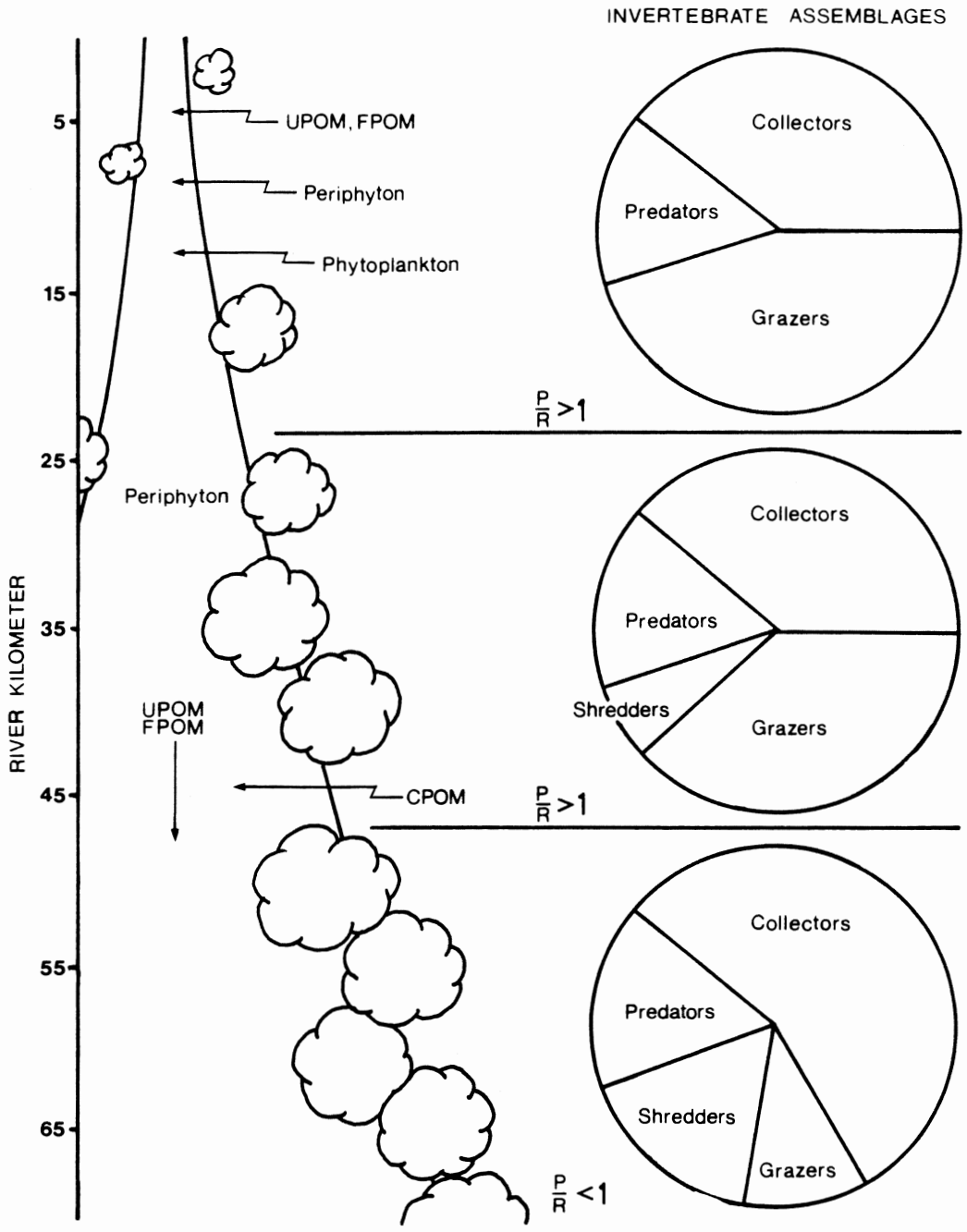


Figure 14. Modification of the RCC Diagram (Fig. 1) as Determined in Salt Creek.

increase in grazers. The increase in suspended algae was reflected in the increased biomass values determined for UPOM and FPOM. Increases in suspended chlorophyll and POM supported increased biomass of collectors. No response was observed by the shredders during eutrophication and predator biomass increased due to increased grazer and collector biomass.

The predicted concentrations of nitrate and orthophosphate by QUAL2E were within the 95% confidence intervals of the observed values for each sampling trip. The relationships described in the prairie stream model were determined to exist in the samples collected from Salt Creek with minor changes. Shredders in Salt Creek did not appear to consume filamentous algal mats, and I could not determine if collectors and predators were discriminatory or not. Predicted values from the relationships determined from the prairie stream model were generally within the 95% confidence intervals of the observed values in the verification datasets. Estimates of attached algal chlorophyll and grazers in the headwaters were higher than observed in September 1987. In November, 1987, estimates of suspended and attached chlorophyll, and grazer biomass in the headwaters were lower than observed.

Recommendations

Continued research needs to be performed to understand the longitudinal processes in prairie streams as well as the effects of nutrient enrichment on these processes. Some specific problems that need to be studied include the following:

1) The effect of algal and nonalgal turbidity on the relationship between water surface and substrate PAR.

2) The relationships between allochthonous POM and drainage basin size, morphology, and vegetation type and quantity.
3) Determing the function of grass stems in relation to macro-invertebrate habitat and CPOM use.
4) The relationship between POM sedimentation rates and total accummulated POM on the substrate including variables most important to short and long-term stability of the macroinvertebrates.
5) The effects of nutrient and PAR availability on primary production such that the effects of downstream nutrient dillution are not confounded with decreased PAR availability.
6) The effects of water current on the presence, productivity, and biomass accumulation of suspended algae.
7) Collector and predator feeding preferences to determine if they are discriminatory or not in prairie streams.
8) Enhancing the QUAL2E simulations by including BOD, COD, DO simulations as well as performing dynamic simulations.

Additional studies of the relationships among biotic and abiotic factors within streams may enable describing a hiearchial framework of assumptions and hypotheses similar to those of the RCC that describes longitudinal patterns in several types of stream systems.

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APPENDIX A

ALKALINITY, CONDUCTIVITY, DISSOLVED OXYGEN, pH, TEMPERATURE, DEPTH, VELOCITY, DISCHARGE, NITRITE-NITRATE NITOGEN, ORTHOPHOSPHATE, PHOTOSYNTHETICALLY ACTIVE RADIATION, CHLOROPHYLL, PERIPHYTON BIOMASS PERIPHYTON CARBON ASSIMILATION, PARTICULATE ORGANIC MATTER, P/R, AND INVERTEBRATE BIOMASS

TABLE 9

ALKALINITY CONCENTRATIONS (mg l^{-1})

DATE	STATION	REPLICATE 1	2	3	4	5	6
Jul 1986	1	188	192	194	-	-	-
	2	158	160	162	-	-	-
	3	164	164	164	-	-	-
	4	170	170	172	-	-	-
	5	182	184	186	-	-	-
Sep 1986	1	186	188	188	162	164	164
	2	154	154	154	141	145	145
	3	134	140	140	122	124	124
	4	114	116	116	98	102	104
	5	110	110	110	96	96	96
Dec 1986	1	176	178	180	182	184	184
	2	160	162	162	164	166	168
	3	134	133	134	136	144	144
	4	106	106	108	118	120	120
	5	102	102	102	116	116	118
Mar 1987	1	180	184	184	182	184	182
	2	188	188	188	186	185	188
	3	190	192	196	195	196	192
	4	200	206	208	205	205	208
	5	210	212	214	212	216	216
May 1987	1	180	182	182	180	180	180
	2	184	184	186	182	184	184
	3	188	188	188	190	188	188
	4	200	202	204	202	200	200
	5	214	214	212	216	210	212
Jul 1987	1	182	184	182	182	180	184
	2	164	162	164	164	160	160
	3	178	178	180	180	182	180
	4	190	190	190	192	194	192
	5	214	214	216	212	210	210
Sep 1987	1	186	184	184	186	188	184
	2	182	180	182	184	182	180
	3	176	176	176	174	174	174
	4	170	172	170	170	172	174
	5	166	166	164	162	164	164

TABLE 9 (Continued)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Nov 1987	1	172	176	176	180	182	184
	2	160	162	164	166	168	164
	3	146	146	148	146	140	146
	4	126	124	124	124	120	120
	5	112	114	114	118	118	120

TABLE 10

CONDUCTIVITY (S cm^{-1})

DATE	STATION	REPLICATE 1	2	3	4	5	6
Jul 1986	1	375	378	380	-	-	-
	2	353	353	353	-	-	-
	3	379	380	381	-	-	-
	4	508	509	509	-	-	-
	5	531	534	547	-	-	-
Sep 1986	1	215	216	220	195	196	200
	2	313	313	315	320	320	320
	3	337	343	344	300	306	309
	4	397	398	400	365	368	370
	5	397	412	420	370	370	372
Dec 1986	1	290	292	292	280	286	292
	2	363	365	365	380	380	380
	3	407	414	416	391	396	399
	4	481	485	487	454	463	463
	5	472	472	480	466	470	474
Mar 1987	1	399	401	414	405	411	418
	2	402	414	429	416	418	422
	3	482	482	484	484	485	485
	4	594	596	596	594	598	598
	5	630	632	632	628	628	632
May 1987	1	420	425	418	432	425	430
	2	490	494	492	494	496	499
	3	531	525	530	542	540	544
	4	580	578	576	584	584	588
	5	642	644	641	657	655	660
Jul 1987	1	390	396	400	394	392	392
	2	362	364	368	371	374	375
	3	400	410	414	408	412	410
	4	490	491	494	488	496	492
	5	575	578	580	571	570	568
Sep 1987	1	300	301	305	315	314	315
	2	360	358	364	362	362	368
	3	400	410	402	412	414	416
	4	440	442	441	450	450	454
	5	490	492	495	499	491	492

TABLE 10 (Continued)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Nov 1987	1	220	218	222	230	232	232
	2	280	278	270	280	284	294
	3	340	330	334	342	348	344
	4	380	378	376	384	384	386
	5	400	402	406	402	404	404

TABLE 11

DISSOLVED OXYGEN (mg l^{-1})

DATE	STATION	REPLICATE 1	2	3	4	5	6
Jul 1986	1	4.2	4.3	4.4	-	-	-
	2	8.8	8.8	9.4	-	-	-
	3	4.5	4.6	4.6	-	-	-
	4	6.2	6.2	6.3	-	-	-
	5	8.0	8.1	8.6	-	-	-
Sep 1986	1	7.8	7.9	8.0	7.7	7.7	7.9
	2	7.7	7.9	8.1	7.8	7.8	8.2
	3	6.7	6.9	7.2	6.5	6.7	6.8
	4	5.2	5.3	5.6	5.5	5.7	5.7
	5	5.1	5.2	5.3	6.0	6.1	6.2
Dec 1986	1	12.8	12.9	12.9	12.8	12.9	13.0
	2	12.6	12.7	12.7	12.7	12.8	12.9
	3	12.2	12.4	12.4	12.1	12.3	12.5
	4	12.1	12.2	12.3	12.2	12.2	12.2
	5	12.0	12.0	12.1	12.1	12.1	12.1
Mar 1987	1	9.5	9.6	9.7	9.0	9.1	9.1
	2	9.3	9.3	9.5	8.8	8.9	9.0
	3	8.9	9.0	9.6	8.5	8.5	8.6
	4	8.7	8.8	9.8	8.4	8.4	8.4
	5	7.8	8.2	8.0	8.0	8.3	8.4
May 1987	1	7.8	7.6	7.7	7.7	7.8	7.6
	2	7.6	7.5	7.5	7.4	7.4	7.4
	3	7.3	7.3	7.1	7.2	7.4	7.4
	4	7.1	7.1	7.3	7.2	7.2	7.2
	5	6.9	6.8	6.8	6.7	6.7	6.7
Jul 1987	1	5.1	5.0	5.0	5.2	5.1	5.0
	2	9.4	9.8	9.1	8.9	9.3	9.7
	3	4.9	4.8	4.7	4.8	4.8	4.7
	4	5.7	5.6	5.8	5.3	5.5	5.3
	5	6.9	6.8	6.0	7.0	6.9	6.9
Sep 1987	1	6.8	6.7	6.5	6.7	6.7	6.9
	2	6.7	6.6	6.6	6.4	6.3	6.2
	3	6.4	6.3	6.2	6.4	6.4	6.5
	4	6.2	6.1	6.1	6.4	6.3	6.4
	5	6.0	6.0	6.1	6.2	6.2	6.2

TABLE 11 (Continued)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Nov 1987	1	11.1	11.2	11.4	11.6	11.7	11.7
	2	10.9	10.8	10.9	11.1	11.1	11.2
	3	10.7	10.6	10.5	10.9	11.0	11.0
	4	10.5	10.4	10.3	10.6	10.6	10.6
	5	10.4	10.3	10.3	10.4	10.4	10.4

TABLE 12

pH

DATE	STATION	REPLICATE 1	2	3	4	5	6
Jul 1986	1	6.6	6.7	6.7	-	-	-
	2	7.5	7.5	7.5	-	-	-
	3	6.7	6.7	6.8	-	-	-
	4	6.5	6.4	6.4	-	-	-
	5	6.1	6.4	6.2	-	-	-
Sep 1986	1	6.7	6.7	6.8	6.5	6.6	6.7
	2	6.4	6.4	6.6	6.5	6.5	6.6
	3	6.3	6.3	6.5	6.4	6.3	6.5
	4	6.2	6.2	6.3	6.4	6.4	6.4
	5	6.2	6.2	6.2	6.6	6.6	6.6
Dec 1986	1	7.0	7.0	7.1	6.8	6.9	6.9
	2	6.7	6.7	6.7	6.8	6.8	6.9
	3	6.5	6.7	6.9	6.7	6.8	6.9
	4	6.4	6.4	6.5	6.7	6.7	6.7
	5	6.5	6.5	6.5	6.8	6.9	7.0
Mar 1987	1	7.7	7.7	8.0	7.5	7.6	7.7
	2	7.0	7.1	7.3	7.0	7.1	7.2
	3	6.5	6.6	6.7	6.5	6.5	6.6
	4	6.3	6.4	6.7	6.6	6.7	6.8
	5	6.2	6.4	6.5	6.3	6.4	6.4
May 1987	1	7.3	7.3	7.2	7.3	7.2	7.1
	2	6.9	6.8	6.8	6.7	6.6	6.6
	3	6.5	6.5	6.5	6.5	6.4	6.3
	4	6.4	6.4	6.3	6.3	6.3	6.3
	5	6.3	6.2	6.2	6.2	6.1	6.1
Jul 1987	1	6.9	6.8	6.8	6.7	6.7	6.7
	2	7.4	7.4	7.3	7.3	7.3	7.3
	3	7.0	6.9	6.9	6.9	8.0	8.0
	4	6.7	6.7	6.7	6.6	6.6	6.6
	5	6.5	6.4	6.4	6.3	6.3	6.3
Sep 1987	1	7.1	7.1	7.0	7.0	7.0	7.0
	2	7.0	7.0	7.0	6.9	6.9	6.9
	3	6.9	6.9	6.8	6.8	6.8	6.8
	4	6.8	6.7	6.7	6.6	6.6	6.6
	5	6.7	6.6	6.6	6.5	6.4	6.4

TABLE 12 (Continued)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Nov 1987	1	7.2	7.2	7.1	7.1	7.1	7.0
	2	7.1	7.1	7.0	7.0	7.0	6.9
	3	6.9	6.9	6.9	6.8	6.8	6.7
	4	6.8	6.8	6.7	6.7	6.6	6.6
	5	6.6	6.6	6.5	6.4	6.4	6.4

TABLE 13

TEMPERATURE (^{o}C)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Jul 1986	1	29.6	29.7	29.8	-	-	-
	2	29.2	29.5	29.6	-	-	-
	3	28.6	28.7	28.6	-	-	-
	4	28.0	28.5	28.6	-	-	-
	5	29.2	29.5	29.6	-	-	-
Sep 1986	1	28.9	29.0	29.1	21.0	21.1	21.1
	2	25.7	25.8	26.6	21.5	21.6	21.6
	3	25.4	25.6	25.7	22.1	22.1	22.2
	4	24.7	24.7	24.7	22.9	23.0	23.0
	5	24.6	24.7	24.7	23.6	23.7	23.9
Dec 1986	1	5.1	5.2	5.2	4.7	4.7	4.7
	2	5.0	5.0	5.0	4.5	4.6	4.6
	3	4.9	4.9	4.9	4.4	4.5	4.5
	4	4.8	4.8	4.8	4.5	4.5	4.6
	5	4.7	4.7	4.7	4.4	4.4	4.4
Mar 1987	1	14.3	14.4	14.8	13.7	13.7	13.7
	2	12.5	12.7	12.7	12.2	12.2	12.3
	3	12.2	12.2	12.4	11.7	1.7	11.8
	4	11.5	11.6	11.7	11.2	11.2	11.3
	5	11.3	11.3	11.3	10.9	10.9	10.9
May 1987	1	23.4	23.3	23.3	24.3	24.5	24.5
	2	22.8	22.6	22.4	22.4	22.4	22.4
	3	22.4	22.3	22.3	21.7	21.9	22.0
	4	22.0	21.9	21.9	22.0	22.0	21.9
	5	21.8	21.7	21.6	21.6	21.6	21.6
Jul 1987	1	28.8	28.7	28.6	27.5	27.4	27.4
	2	28.4	28.3	28.2	27.9	27.9	27.9
	3	27.6	27.5	27.5	27.1	27.1	27.2
	4	27.0	27.1	27.2	27.0	27.1	27.1
	5	26.1	26.3	26.3	25.7	25.8	25.8
Sep 1987	1	22.4	22.3	22.3	22.0	22.0	22.0
	2	21.6	21.5	21.5	20.7	20.7	20.8
	3	21.1	21.1	21.2	20.8	20.7	20.7
	4	20.5	20.5	20.5	20.1	20.1	20.2
	5	20.2	20.2	20.1	19.8	19.9	20.0

TABLE 13 (Continued)

DATE	STATION	REPLICATE 1	2	3	4	5	6
Nov 1987	1	7.9	7.9	7.7	7.5	7.4	7.4
	2	7.8	7.8	7.8	7.6	7.6	7.6
	3	7.8	7.7	7.6	7.3	7.3	7.3
	4	7.7	7.6	7.6	7.2	7.2	7.2
	5	7.6	7.6	7.6	7.1	7.1	7.1

TABLE 14

MEAN DEPTH (cm), MEAN VELOCITY ($m\ s^{-1}$), AND DISCHARGE ($m^3\ s^{-1}$)

		DEPTH		VELOCITY		DISCHARGE	
DATE	STATION	REP 1	2	1	2	1	2
Jul 1986	1	22.7	23.2	1.4	1.4	0.1	0.2
	2	37.6	28.4	4.4	4.6	2.3	2.9
	3	32.4	33.1	6.5	6.5	14.1	19.1
	4	33.9	34.8	10.9	11.4	30.5	42.9
	5	35.6	36.8	12.1	12.3	36.9	52.6
Sep 1986	1	12.5	18.5	1.4	1.4	0.1	0.3
	2	18.4	26.4	2.9	3.5	1.5	2.1
	3	32.3	44.8	6.2	7.3	6.3	15.2
	4	34.8	52.1	11.4	15.4	19.4	28.7
	5	32.0	41.1	13.2	18.5	39.3	57.4
Dec 1986	1	21.9	22.4	1.4	1.4	1.2	1.1
	2	26.3	27.2	3.0	3.1	4.3	3.9
	3	30.2	31.4	6.3	6.5	17.7	16.2
	4	32.2	33.7	10.7	11.1	40.1	38.4
	5	33.4	37.7	12.7	13.3	55.2	51.5
Mar 1987	1	15.0	15.0	1.4	1.4	0.3	0.3
	2	27.5	30.4	3.1	3.2	1.7	1.9
	3	35.2	36.0	6.7	6.9	13.3	14.5
	4	44.7	46.2	12.1	13.4	21.7	25.3
	4	38.7	40.6	15.3	17.0	47.0	54.8
May 1987	1	24.1	24.5	1.4	1.5	0.2	0.3
	2	35.6	38.2	4.1	4.4	2.8	3.2
	3	33.7	44.1	6.3	6.4	15.3	17.2
	4	33.5	33.9	10.9	11.1	30.5	34.7
	5	34.7	35.1	11.7	11.9	44.1	46.4
Jul 1987	1	18.4	19.2	1.4	1.4	0.3	0.3
	2	19.7	19.9	2.1	2.5	1.5	1.6
	3	30.4	31.0	5.4	5.4	6.7	6.9
	4	30.6	30.8	9.9	10.1	18.4	19.0
	5	31.1	31.4	11.6	11.7	34.5	37.1
Sep 1987	1	16.5	17.0	1.3	1.3	0.2	0.2
	2	17.8	17.9	1.9	2.0	1.3	1.2
	3	29.7	29.9	4.8	5.0	5.4	5.2
	4	30.1	30.4	9.7	9.8	12.7	13.1
	5	31.0	31.4	11.1	11.1	27.9	28.2

TABLE 14 (Continued)

DATE	STATION	DEPTH REP 1	DEPTH 2	VELOCITY 1	VELOCITY 2	DISCHARGE 1	DISCHARGE 2
Nov 1987	1	23.7	24.0	1.4	1.4	0.9	1.0
	2	37.3	36.8	3.9	4.1	3.6	3.4
	3	33.2	33.5	6.6	6.8	16.2	16.5
	4	32.7	33.1	11.1	11.8	37.1	38.0
	5	36.6	37.5	12.2	12.9	50.1	51.4

TABLE 15

NITRITE-NITRATE NITROGEN (mg l^{-1})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	1.36	1.37	1.41	1.43
	2	2.62	2.64	2.71	2.74
	3	0.88	0.90	0.91	0.93
	4	0.44	0.47	0.50	0.51
	5	0.29	0.29	0.30	0.31
Sep 1986	1	1.40	1.42	1.44	1.45
	2	1.25	1.25	1.28	1.30
	3	0.90	0.90	0.94	0.95
	4	0.64	0.66	0.66	0.69
	5	0.38	0.38	0.41	0.41
Dec 1986	1	1.47	1.49	1.50	1.50
	2	1.30	1.30	1.32	1.32
	3	0.98	1.00	1.02	1.02
	4	0.62	0.64	0.64	0.65
	5	0.35	0.38	0.39	0.40
Mar 1987	1	1.45	1.47	1.49	1.52
	2	1.25	1.26	1.29	1.33
	3	0.97	0.99	0.99	1.04
	4	0.63	0.67	0.69	0.71
	5	0.39	0.40	0.41	0.41
May 1987	1	1.43	1.44	1.45	1.45
	2	1.24	1.25	1.25	1.25
	3	1.00	1.01	1.03	1.03
	4	0.70	0.70	0.72	0.73
	5	0.40	0.40	0.41	0.41
Jul 1987	1	1.44	1.45	1.47	1.47
	2	2.81	2.84	2.99	3.01
	3	0.98	0.99	1.01	1.02
	4	0.50	0.52	0.53	0.53
	5	0.34	0.36	0.38	0.39
Sep 1987	1	1.42	1.44	1.48	1.48
	2	1.25	1.27	1.26	1.26
	3	0.96	0.97	0.97	0.97
	4	0.66	0.66	0.66	0.66
	5	0.39	0.40	0.41	0.41

TABLE 15 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	1.47	1.49	1.51	1.51
	2	1.31	1.31	1.34	1.35
	3	1.00	1.01	1.01	1.02
	4	0.68	0.69	0.70	0.71
	5	0.38	0.39	0.39	0.40

TABLE 16

ORTHOPHOSPHATE (mg l^{-1})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	0.61	0.61	0.68	0.70
	2	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00
	4	0.37	0.43	0.42	0.42
	5	0.32	0.36	0.38	0.38
Sep 1986	1	0.63	0.65	0.66	0.68
	2	0.60	0.60	0.61	0.62
	3	0.50	0.51	0.53	0.53
	4	0.40	0.40	0.42	0.43
	5	0.32	0.33	0.35	0.35
Dec 1986	1	0.61	0.61	0.62	0.63
	2	0.58	0.59	0.59	0.59
	3	0.51	0.51	0.52	0.53
	4	0.42	0.43	0.42	0.43
	5	0.31	0.41	0.33	0.34
Mar 1987	1	0.69	0.70	0.71	0.71
	2	0.63	0.63	0.64	0.64
	3	0.48	0.51	0.53	0.54
	4	0.39	0.39	0.41	0.42
	5	0.29	0.31	0.31	0.31
May 1987	1	0.65	0.65	0.68	0.69
	2	0.60	0.61	0.62	0.62
	3	0.51	0.51	0.53	0.53
	4	0.40	0.41	0.42	0.42
	5	0.34	0.36	0.38	0.39
Jul 1987	1	0.63	0.63	0.65	0.66
	2	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.00
	4	0.43	0.43	0.45	0.45
	5	0.32	0.32	0.34	0.35
Sep 1987	1	0.61	0.62	0.63	0.63
	2	0.58	0.58	0.59	0.60
	3	0.51	0.52	0.53	0.53
	4	0.41	0.42	0.42	0.42
	5	0.36	0.37	0.39	0.40

TABLE 16 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	0.63	0.64	0.66	0.67
	2	0.58	0.59	0.61	0.62
	3	0.50	0.50	0.51	0.51
	4	0.40	0.42	0.43	0.43
	5	0.35	0.36	0.36	0.38

TABLE 17

PHOTOSYNTHETICALLY ACTIVE RADIATION (E m^{-2} d^{-1})

DAILY TOTAL: WATER SURFACE

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	80.9	76.4	70.5	62.4	51.7
	2	81.2	77.3	71.0	65.4	53.3
	3	83.3	77.8	72.7	68.2	56.1
Sep 1986	1	58.9	55.7	51.6	48.1	44.3
	2	59.3	56.4	52.1	49.4	46.1
	3	60.1	56.8	52.3	49.6	47.6
Dec 1986	1	47,8	46.6	44.8	42.5	39.7
	2	47.9	47.3	45.6	43.3	42.0
	3	48.8	47.8	46.1	44.6	42.5
Mar 1987	1	62.5	60.9	57.9	52.3	48.4
	2	62.9	61.3	58.4	52.9	48.9
	3	63.3	61.8	59.1	53.8	49.9
May 1987	1	79.0	75.1	73.3	67.8	54.6
	2	80.1	75.2	74.7	68.3	55.8
	3	80.9	76.4	75.1	69.1	58.1
Jul 1987	1	79.6	78.1	72.3	61.5	52.2
	2	80.1	78.9	73.5	63.1	54.1
	3	80.4	79.3	74.1	65.4	56.7
Sep 1987	1	60.2	57.4	52.2	47.5	43.6
	2	61.1	57.8	52.8	48.2	44.3
	3	61.3	58.3	53.3	48.9	45.1
Nov 1987	1	52.4	50.4	49.1	45.3	44.9
	2	52.5	50.6	49.9	45.9	44.7
	3	52.9	51.5	49.6	46.3	45.6

TABLE 18

PHOTOSYNTHETICALLY ACTIVE RADIATION (E m^{-2} d^{-1})

DAILY TOTAL: SUBSTRATE SURFACE

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	49.4	42.1	39.8	35.0	27.0
	2	51.6	43.5	41.4	36.5	28.8
	3	52.2	44.7	42.0	37.0	29.9
Sep 1986	1	42.5	37.0	29.0	27.7	23.9
	2	42.5	37.3	29.5	28.1	24.5
	3	42.7	37.7	30.2	28.6	24.9
Dec 1986	1	31.3	28.0	25.2	24.4	22.0
	2	31.3	28.1	25.3	24.6	22.3
	3	31.6	28.3	25.4	24.8	22.5
Mar 1987	1	47.7	36.0	32.0	28.0	25.5
	2	48.1	36.8	32.1	28.4	26.1
	3	48.5	37.6	32.6	28.8	26.5
May 1987	1	48.5	43.1	40.4	38.1	31.2
	2	49.1	44.0	40.9	38.8	31.7
	3	49.7	44.9	41.8	39.6	32.4
Jul 1987	1	54.0	51.6	41.8	36.0	30.0
	2	54.3	52.1	42.0	36.2	30.4
	3	54.6	52.7	42.3	36.4	30.9
Sep 1987	1	42.0	39.8	34.1	28.2	25.5
	2	42.3	40.1	34.4	28.4	25.6
	3	52.7	40.3	34.6	28.8	25.8
Nov 1987	1	33.9	29.3	28.6	28.5	27.6
	2	34.0	29.4	28.8	28.5	27.8
	3	34.0	29.5	28.8	28.5	27.9

TABLE 19

CHLOROPHYLL: BENTHIC (mg m^{-2})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	10.1	10.4	10.7	12.1
	2	21.6	23.1	-	-
	3	13.6	13.8	14.3	14.4
	4	7.3	7.5	7.7	7.7
	5	2.5	2.6	2.9	3.1
Sep 1986	1	8.6	8.8	9.0	9.0
	2	7.3	7.4	8.1	8.3
	3	6.0	6.0	6.1	6.2
	4	-	-	-	-
	5	2.6	2.8	2.8	3.0
Dec 1986	1	7.4	7.5	7.6	7.8
	2	6.4	6.5	6.7	6.8
	3	5.5	5.6	5.7	5.8
	4	3.3	3.3	3.5	3.6
	5	1.6	1.7	1.9	2.1
Mar 1987	1	8.9	9.1	9.7	9.9
	2	7.8	8.0	8.3	8.5
	3	7.0	7.0	7.2	7.3
	4	5.0	5.1	5.4	5.4
	5	3.4	3.7	3.9	4.0
May 1987	1	14.1	14.3	14.0	14.5
	2	12.3	12.5	12.4	12.7
	3	9.5	9.9	10.1	10.4
	4	6.5	6.8	6.6	7.1
	5	3.5	3.7	3.9	4.0
Jul 1987	1	12.4	13.0	13.3	13.9
	2	24.0	24.6	24.9	25.4
	3	17.1	17.3	17.4	17.8
	4	8.7	9.1	8.9	9.5
	5	3.6	3.7	3.9	4.0
Sep 1987	1	9.0	9.3	9.7	10.1
	2	8.1	8.3	8.3	8.4
	3	6.0	6.2	6.4	6.5
	4	4.3	4.4	4.5	4.7
	5	3.1	3.3	3.3	3.6

TABLE 19 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	7.9	8.0	8.1	8.3
	2	6.7	6.7	6.9	7.1
	3	5.1	5.3	5.3	5.3
	4	4.2	4.3	4.4	4.5
	5	3.0	3.0	3.1	3.2

TABLE 20

CHLOROPHYLL: SUSPENDED (ug l^{-1})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	24.1	24.3	27.7	27.9
	2	112.3	120.1	-	-
	3	35.0	37.6	37.7	38.2
	4	16.3	17.1	17.7	19.1
	5	3.3	3.2	3.5	3.7
Sep 1986	1	9.6	10.3	10.9	11.0
	2	8.6	8.6	9.1	9.6
	3	5.2	6.1	7.1	7.4
	4	-	-	-	-
	5	3.0	3.0	3.3	3.3
Dec 1986	1	7.4	7.4	7.6	8.0
	2	6.3	6.7	7.0	7.3
	3	5.3	5.4	5.7	6.2
	4	3.3	3.4	3.4	3.7
	5	2.1	2.3	3.1	3.1
Mar 1987	1	14.1	14.2	14.4	14.6
	2	11.3	11.5	12.0	12.1
	3	6.4	7.0	7.3	7.7
	4	4.0	4.3	5.1	5.1
	5	2.3	2.7	2.7	2.7
May 1987	1	24.7	25.1	25.1	25.3
	2	19.0	19.4	19.8	20.3
	3	12.9	13.1	13.3	13.9
	4	8.4	9.0	9.1	9.3
	5	4.1	4.9	5.3	5.5
Jul 1987	1	28.4	28.8	29.2	30.1
	2	119.9	124.1	127.8	129.2
	3	39.0	41.0	41.5	42.3
	4	10.9	10.7	10.1	10.0
	5	4.0	4.1	4.5	4.1
Sep 1987	1	12.0	11.7	12.5	12.9
	2	9.9	10.4	10.4	10.9
	3	7.9	8.4	8.7	9.1
	4	3.4	3.7	4.0	4.7
	5	2.5	2.7	3.0	3.2

TABLE 20 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	7.4	7.9	7.3	7.9
	2	6.0	6.7	6.9	6.5
	3	4.8	4.1	4.4	4.7
	4	3.8	3.1	3.5	3.9
	5	2.5	2.8	3.1	3.4

TABLE 21

PERIPHYTON BIOMASS (mg cm^{-2})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	30.25	31.53	33.00	36.55
	2	143.09	151.89	-	-
	3	42.59	44.27	46.14	47.63
	4	23.44	24.58	25.74	26.19
	5	7.71	7.95	8.32	8.45
Sep 1986	1	25.43	26.52	28.18	28.89
	2	21.60	22.36	23.34	23.91
	3	19.03	20.33	21.70	22.31
	4	-	-	-	-
	5	7.31	7.67	7.99	8.34
Dec 1986	1	22.35	23.13	23.42	25.64
	2	19.20	19.68	19.82	21.42
	3	16.52	16.70	17.46	17.96
	4	9.92	9.99	10.07	10.14
	5	5.05	5.32	5.45	5.51
Mar 1987	1	26.77	27.09	28.93	27.75
	2	22.44	22.90	25.70	25.52
	3	19.64	21.06	21.62	21.22
	4	10.81	11.94	14.13	12.88
	5	10.22	10.43	11.59	12.10
May 1987	1	31.19	31.66	31.84	32.25
	2	24.40	24.91	24.99	25.73
	3	20.47	21.55	21.89	22.27
	4	13.88	13.91	14.13	14.86
	5	11.21	11.49	11.63	11.97
Jul 1987	1	30.40	30.69	31.97	33.02
	2	124.02	137.10	141.19	155.66
	3	39.93	41.14	43.32	46.29
	4	19.49	21.20	22.04	22.77
	5	9.91	10.49	10.75	11.82

TABLE 22

PERIPHYTON CARBON ASSIMILATION (mg cm^{-2} h^{-1})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	1.01	1.14	1.11	1.21
	2	2.48	2.59	-	-
	3	1.39	1.47	1.52	1.57
	4	0.80	0.84	0.89	0.93
	5	0.38	0.41	0.41	0.45
Sep 1986	1	1.04	1.14	1.11	1.18
	2	0.84	0.89	0.95	0.99
	3	0.78	0.82	0.88	0.93
	4	-	-	-	-
	5	0.43	0.47	0.45	0.49
Dec 1986	1	0.92	0.95	0.94	1.04
	2	0.70	0.79	0.82	0.91
	3	0.68	0.71	0.67	0.69
	4	0.45	0.49	0.43	0.47
	5	0.34	0.38	0.35	0.40
Mar 1987	1	-	-	-	-
	2	-	-	-	-
	3	-	-	-	-
	4	-	-	-	-
	5	-	-	-	-
May 1987	1	1.58	1.61	1.66	1.72
	2	1.31	1.34	1.32	1.38
	3	1.11	1.13	1.13	1.15
	4	0.78	0.81	0.86	0.91
	5	0.40	0.41	0.41	0.42
Jul 1987	1	1.35	1.38	1.49	1.54
	2	2.83	2.89	3.11	3.14
	3	1.92	1.99	2.01	2.12
	4	1.01	1.05	1.02	1.10
	5	0.43	0.45	0.42	0.48

TABLE 23

PARTICULATE ORGANIC MATTER: BENTHIC (mg m^{-2} h^{-1})

DATE	STATION	REP	ULTRA-FINE 1	ULTRA-FINE 2	FINE 1	FINE 2	COARSE 1	COARSE 2
Jul 1986	1		67.2	77.1	56.1	64.1	50.7	65.4
	2		101.3	106.3	137.0	138.4	64.1	73.1
	3		78.1	83.1	114.3	113.7	113.2	136.8
	4		97.1	101.1	168.1	172.1	278.1	280.3
	5		120.3	124.3	276.5	283.1	451.0	460.1
Sep 1986	1		69.1	73.1	58.3	52.2	53.1	58.7
	2		69.8	76.3	70.1	84.1	99.2	97.1
	3		85.4	86.8	118.9	116.8	149.4	142.2
	4		101.0	-	159.9	-	283.1	-
	5		134.1	136.1	281.0	286.3	422.1	429.4
Dec 1986	1		59.8	61.0	53.1	54.9	49.9	55.1
	2		63.3	68.1	65.1	70.3	64.9	68.3
	3		72.3	75.6	99.9	107.1	119.8	123.7
	4		88.1	91.0	149.9	155.4	239.3	243.3
	5		109.9	113.3	210.7	212.2	391.0	399.9
Mar 1987	1		57.7	58.4	49.8	52.1	47.5	50.5
	2		65.0	66.7	67.3	71.0	60.0	63.9
	3		70.1	71.5	104.3	106.7	100.8	105.4
	4		83.2	84.1	141.3	142.9	198.4	201.7
	5		105.2	106.2	181.9	183.8	368.4	373.0
May 1987	1		55.5	57.1	53.1	54.4	49.9	51.7
	2		61.0	62.2	66.6	68.2	66.2	67.4
	3		70.1	71.4	100.3	101.7	121.1	123.1
	4		85.3	88.1	152.3	154.2	241.0	244.1
	5		108.7	111.1	213.1	215.9	401.7	403.9
Jul 1987	1		59.9	62.7	57.1	58.8	60.1	61.2
	2		101.0	104.0	141.1	142.3	67.2	68.9
	3		88.1	91.1	114.4	115.8	134.4	135.9
	4		96.3	97.8	174.2	175.3	268.2	271.0
	5		120.0	121.8	288.1	290.1	410.0	412.3
Sep 1987	1		67.2	68.3	57.2	58.4	56.2	57.1
	2		69.3	71.1	68.1	68.9	77.2	78.8
	3		82.3	85.4	114.3	115.2	139.9	143.1
	4		100.0	101.8	162.1	163.4	291.1	293.3
	5		132.1	134.7	248.9	249.9	399.0	401.3

TABLE 23 (Continued)

DATE	STATION	REP	ULTRA-FINE 1	ULTRA-FINE 2	FINE 1	FINE 2	COARSE 1	COARSE 2
Nov 1987	1		60.2	61.7	58.2	59.8	52.1	53.7
	2		63.3	65.2	71.0	72.9	71.1	72.9
	3		72.3	73.7	101.1	104.4	113.4	115.5
	4		88.9	91.0	155.5	156.9	239.9	243.9
	5		112.1	113.3	222.2	224.2	400.2	405.7

TABLE 24

PARTICULATE ORGANIC MATTER: SUSPENDED (mg l^{-1})

DATE	STATION	REP	ULTRA-FINE 1	ULTRA-FINE 2	FINE 1	FINE 2	COARSE 1	COARSE 2
Jul 1986	1		15.4	16.2	11.0	11.7	0.0	0.0
	2		25.0	25.8	23.0	23.5	0.0	0.0
	3		17.9	18.3	8.9	9.3	0.0	0.0
	4		19.9	20.4	12.3	13.6	0.0	0.0
	5		21.7	22.4	17.9	18.7	0.0	0.0
Sep 1986	1		14.3	16.0	9.2	11.9	0.0	0.0
	2		14.9	17.0	11.1	11.3	0.0	0.0
	3		16.7	16.8	12.8	13.7	0.0	0.0
	4		18.2	-	14.1	-	0.0	-
	5		20.0	20.1	15.4	17.8	0.0	0.0
Dec 1986	1		16.5	17.2	10.5	11.5	0.0	0.0
	2		17.7	18.9	12.0	12.2	0.0	0.0
	3		19.9	20.6	13.2	13.6	0.0	0.0
	4		21.5	22.4	15.2	16.1	0.0	0.0
	5		24.4	24.6	15.1	16.7	0.0	0.0
Mar 1987	1		15.6	16.2	9.0	10.7	0.0	0.0
	2		15.9	16.4	11.1	11.7	0.0	0.0
	3		17.9	18.9	13.3	13.8	0.0	0.0
	4		19.9	20.7	14.4	15.2	0.0	0.0
	5		22.8	22.6	16.1	16.7	0.0	0.0
May 1987	1		15.4	15.9	10.1	11.0	0.0	0.0
	2		16.8	16.6	12.4	13.1	0.0	0.0
	3		17.2	17.9	14.0	14.6	0.0	0.0
	4		18.8	19.9	15.2	16.1	0.0	0.0
	5		22.8	23.9	15.5	16.6	0.0	0.0
Jul 1987	1		15.8	16.7	11.0	11.5	0.0	0.0
	2		26.1	27.2	24.1	24.7	0.0	0.0
	3		18.0	18.4	9.1	10.0	0.0	0.0
	4		19.9	20.6	12.7	13.3	0.0	0.0
	5		21.1	22.4	16.5	17.9	0.0	0.0
Sep 1987	1		14.3	15.1	10.5	13.3	0.0	0.0
	2		15.6	16.7	11.6	12.4	0.0	0.0
	3		17.0	17.4	13.5	14.1	0.0	0.0
	4		18.2	19.2	14.3	15.2	0.0	0.0
	5		20.2	21.4	15.9	16.7	0.0	0.0

TABLE 24 (Continued)

DATE	STATION	REP	ULTRA-FINE 1	ULTRA-FINE 2	FINE 1	FINE 2	COARSE 1	COARSE 2
Nov 1987	1		16.1	16.9	11.0	11.7	0.0	0.0
	2		17.7	18.8	13.0	13.9	0.0	0.0
	3		19.9	20.6	13.7	14.1	0.0	0.0
	4		21.0	21.4	15.3	16.2	0.0	0.0
	5		22.4	24.0	16.7	17.4	0.0	0.0

TABLE 25

PRIMARY PRODUCTION (g O_2 m^{-3} d^{-1}): DIEL OXYGEN METHOD

DATE	STATION	REPLICATE 1	2	3	4	5
Jul 1986	1	0.25	0.31	0.34	0.42	0.46
	2	1.73	1.85	1.87	2.11	2.28
	3	0.17	0.25	0.28	0.31	0.33
	4	0.19	0.23	0.24	0.26	0.30
	5	0.14	0.17	0.19	0.20	0.25
Sep 1986	1	0.24	0.27	0.28	0.35	0.39
	2	0.21	0.22	0.27	0.32	0.35
	3	0.15	0.18	0.23	0.30	0.32
	4	0.13	0.14	0.16	0.25	0.27
	5	0.10	0.13	0.14	0.16	0.19
Dec 1986	1	0.22	0.27	0.28	0.30	0.33
	2	0.16	0.19	0.21	0.25	0.27
	3	0.14	0.15	0.19	0.20	0.26
	4	0.13	0.16	0.17	0.22	0.23
	5	0.08	0.13	0.15	0.18	0.19
Mar 1987	1	0.25	0.27	0.27	0.29	0.26
	2	0.17	0.19	0.21	0.23	0.25
	3	0.18	0.19	0.20	0.25	0.25
	4	0.14	0.15	0.15	0.17	0.18
	5	0.10	0.11	0.12	0.12	0.14
May 1987	1	0.23	0.24	0.28	0.29	0.33
	2	0.18	0.19	0.19	0.19	0.22
	3	0.17	0.17	0.19	0.21	0.23
	4	0.15	0.16	0.18	0.18	0.21
	5	0.12	0.13	0.14	0.15	0.17
Jul 1987	1	0.27	0.29	0.34	0.35	0.39
	2	1.65	1.75	1.78	1.84	1.99
	3	0.25	0.29	0.30	0.30	0.31
	4	0.18	0.18	0.19	0.23	0.24
	5	0.15	0.16	0.19	0.21	0.21

TABLE 26

RESPIRATION (g O_2 m^{-3} d^{-1}): DIEL OXYGEN METHOD

DATE	STATION	REPLICATE 1	2	3	4	5
Jul 1986	1	0.11	0.13	0.16	0.19	0.21
	2	1.16	1.44	1.51	2.11	1.78
	3	0.08	0.14	0.17	0.18	0.18
	4	0.18	0.21	0.21	0.25	0.27
	5	0.18	0.19	0.23	0.24	0.27
Sep 1986	1	0.12	0.16	0.17	0.21	0.23
	2	0.13	0.12	0.14	0.17	0.22
	3	0.10	0.16	0.19	0.19	0.20
	4	0.12	0.14	0.15	0.21	0.25
	5	0.13	0.14	0.17	0.17	0.22
Dec 1986	1	0.13	0.17	0.19	0.21	0.23
	2	0.12	0.15	0.17	0.20	0.22
	3	0.11	0.13	0.14	0.19	0.21
	4	0.12	0.16	0.16	0.21	0.21
	5	0.09	0.14	0.14	0.18	0.19
Mar 1987	1	0.14	0.17	0.15	0.18	0.17
	2	0.12	0.14	0.14	0.16	0.20
	3	0.13	0.13	0.14	0.19	0.20
	4	0.11	0.13	0.12	0.13	0.14
	5	0.11	0.11	0.13	0.13	0.16
May 1987	1	0.14	0.12	0.15	0.15	0.18
	2	0.13	0.14	0.16	0.14	0.14
	3	0.14	0.14	0.16	0.17	0.17
	4	0.13	0.15	0.15	0.17	0.18
	5	0.11	0.14	0.16	0.15	0.15
Jul 1987	1	0.13	0.15	0.18	0.18	0.20
	2	1.19	1.26	1.24	1.18	1.33
	3	0.18	0.25	0.22	0.24	0.25
	4	0.19	0.17	0.18	0.21	0.21
	5	0.18	0.16	0.26	0.20	0.23

TABLE 27

P/R: DIEL OXYGEN METHOD

DATE	STATION	REPLICATE 1	2	3	4	5
Jul 1986	1	2.27	2.38	2.12	2.21	2.19
	2	1.49	1.29	1.24	1.27	1.28
	3	2.13	1.79	1.65	1.72	1.83
	4	1.06	1.10	1.15	1.04	1.11
	5	0.78	0.89	0.83	0.83	0.93
Sep 1986	1	2.00	1.69	1.65	1.67	1.70
	2	1.62	1.83	1.93	1.88	1.59
	3	1.50	1.13	1.21	1.58	1.39
	4	1.08	1.00	1.07	1.19	1.08
	5	0.77	0.93	0.82	0.94	0.86
Dec 1986	1	1.69	1.59	1.47	1.43	1.43
	2	1.33	1.27	1.24	1.25	1.23
	3	1.27	1.15	1.36	1.05	1.34
	4	1.08	1.00	1.06	1.05	1.10
	5	0.89	0.93	1.07	1.00	1.00
Mar 1987	1	1.78	1.59	1.80	1.61	1.53
	2	1.41	1.36	1.50	1.44	1.53
	3	1.38	1.46	1.43	1.32	1.25
	4	1.27	1.15	1.35	1.31	1.29
	5	0.91	1.00	0.92	0.92	0.88
May 1987	1	1.64	1.85	1.87	1.93	1.83
	2	1.38	1.36	1.19	1.35	1.57
	3	1.21	1.21	1.19	1.23	1.35
	4	1.15	1.06	1.20	1.06	1.17
	5	1.09	0.93	0.88	1.00	1.13
Jul 1987	1	2.08	1.93	1.89	1.94	1.95
	2	1.39	1.39	1.44	1.56	1.50
	3	1.39	1.16	1.36	1.25	1.24
	4	0.95	1.06	1.06	1.10	1.14
	5	0.83	1.00	0.95	1.05	0.91

TABLE 28

COLLECTOR BIOMASS (mg $trap^{-1}$)

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	2.53	2.59	2.86	2.90
	2	9.41	9.92	9.71	10.88
	3	3.79	4.01	4.05	-
	4	2.62	2.74	2.81	2.90
	5	3.51	3.52	3.55	3.56
Sep 1986	1	1.75	1.71	1.79	1.60
	2	1.80	1.81	1.81	1.76
	3	1.67	1.71	1.67	-
	4	-	-	-	-
	5	2.04	2.13	2.18	2.29
Dec 1986	1	1.96	1.91	1.85	1.99
	2	1.87	1.94	1.85	1.91
	3	2.11	2.05	2.03	1.99
	4	2.25	2.27	2.18	2.11
	5	2.48	2.54	2.62	2.63
Mar 1987	1	2.15	2.20	2.17	2.22
	2	2.25	2.29	2.31	2.33
	3	2.30	2.32	2.19	2.34
	4	2.39	2.41	2.34	2.42
	5	2.70	2.65	2.71	2.78
May 1987	1	2.10	2.13	2.15	2.20
	2	2.05	2.11	2.13	2.15
	3	2.07	2.13	2.14	2.17
	4	2.12	2.23	2.31	2.33
	5	2.89	2.44	2.47	3.10
Jul 1987	1	2.97	3.00	3.04	3.05
	2	9.61	9.73	9.79	10.11
	3	4.40	4.48	4.53	5.59
	4	3.41	3.48	3.50	3.54
	5	3.40	3.43	3.42	3.44
Sep 1987	1	2.14	2.20	2.17	2.22
	2	2.25	2.27	2.21	2.31
	3	2.09	2.14	2.20	2.12
	4	2.04	2.09	2.13	2.18
	5	2.21	2.23	2.29	2.37

TABLE 28 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	1.63	1.65	1.72	1.75
	2	1.74	1.74	1.75	1.76
	3	1.81	1.83	1.97	1.93
	4	2.06	2.09	2.14	2.18
	5	2.15	2.24	2.27	2.29

TABLE 29

GRAZER BIOMASS (mg $trap^{-1}$)

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	2.35	2.55	2.60	2.98
	2	3.83	4.00	4.07	4.19
	3	2.43	2.44	2.51	-
	4	1.29	1.17	1.32	1.35
	5	0.42	0.43	0.72	0.57
Sep 1986	1	1.88	1.93	1.98	2.10
	2	1.57	1.67	1.84	1.87
	3	1.55	1.58	1.60	-
	4	-	-	-	-
	5	0.55	0.64	0.60	0.69
Dec 1986	1	1.67	1.71	1.68	1.80
	2	1.44	1.33	1.53	1.55
	3	1.34	1.25	1.13	1.31
	4	0.75	0.78	0.80	0.81
	5	0.35	0.39	0.43	0.48
Mar 1987	1	1.70	1.74	1.82	1.87
	2	1.48	1.53	1.56	1.62
	3	1.21	1.33	1.30	1.39
	4	0.76	0.85	0.80	0.85
	5	0.60	0.65	0.71	0.73
May 1987	1	2.69	2.71	2.75	2.80
	2	2.42	2.46	2.47	2.53
	3	1.90	1.93	1.95	1.98
	4	1.32	1.37	1.39	1.47
	5	0.73	0.77	0.81	0.89
Jul 1987	1	2.43	2.44	2.49	2.51
	2	4.40	4.53	4.58	4.67
	3	2.99	3.10	3.13	3.15
	4	1.71	1.73	1.78	1.79
	5	0.77	0.78	0.81	0.84
Sep 1987	1	1.94	1.97	2.01	2.04
	2	1.64	1.64	1.71	1.72
	3	1.10	1.14	1.17	1.22
	4	0.83	0.84	0.84	0.86
	5	0.68	0.71	0.75	0.83

TABLE 29 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	1.61	1.67	1.67	1.69
	2	1.40	1.41	1.44	1.45
	3	0.98	1.01	1.02	1.05
	4	0.78	0.80	0.81	0.80
	5	0.61	0.64	0.65	0.67

TABLE 30

SHREDDER BIOMASS (mg trap^{-1})

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	0.00	0.00	0.00	0.12
	2	0.00	0.11	0.12	0.13
	3	0.20	0.22	0.22	-
	4	0.41	0.44	0.43	0.45
	5	0.72	0.74	0.71	0.77
Sep 1986	1	0.00	0.00	0.00	0.00
	2	0.21	0.20	0.22	0.22
	3	0.30	0.29	0.30	-
	4	-	-	-	-
	5	0.81	0.82	0.83	0.83
Dec 1986	1	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00
	3	0.23	0.24	0.26	0.23
	4	0.50	0.48	0.50	0.51
	5	0.79	0.81	0.80	0.81
Mar 1987	1	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00
	3	0.22	0.22	0.22	0.22
	4	0.40	0.41	0.39	0.39
	5	0.73	0.70	0.71	0.72
May 1987	1	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00
	3	0.28	0.29	0.30	0.30
	4	0.39	0.41	0.41	0.43
	5	0.70	0.71	0.74	0.77
Jul 1987	1	0.00	0.00	0.00	0.00
	2	0.00	0.00	0.00	0.00
	3	0.20	0.21	0.21	0.21
	4	0.40	0.41	0.42	0.43
	5	0.67	0.68	0.68	0.72
Sep 1987	1	0.00	0.00	0.00	0.00
	2	0.18	0.19	0.21	0.21
	3	0.28	0.28	0.29	0.30
	4	0.52	0.53	0.53	0.54
	5	0.80	0.82	0.83	0.85

TABLE 30 (Continued)

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	0.00	0.00	0.00	0.00
	2	0.14	0.14	0.14	0.15
	3	0.23	0.23	0.24	0.25
	4	0.49	0.40	0.41	0.42
	5	0.60	0.66	0.67	0.68

TABLE 31

PREDATOR BIOMASS (mg $trap^{-1}$)

DATE	STATION	REPLICATE 1	2	3	4
Jul 1986	1	1.75	1.85	1.99	2.11
	2	4.21	4.63	4.76	5.18
	3	2.25	2.30	2.51	-
	4	1.68	1.59	1.54	1.61
	5	1.53	1.49	1.67	1.73
Sep 1986	1	1.21	1.17	1.24	1.28
	2	1.25	1.25	1.26	1.22
	3	1.16	1.26	1.09	-
	4	-	-	-	-
	5	1.24	1.15	1.23	1.21
Dec 1986	1	1.26	1.25	1.27	1.22
	2	1.12	1.11	1.16	1.17
	3	1.22	1.27	1.26	1.25
	4	1.21	1.23	1.21	1.23
	5	1.10	1.25	1.17	1.31
Mar 1987	1	1.30	1.39	1.33	1.31
	2	1.26	1.21	1.30	1.26
	3	1.18	1.25	1.17	1.32
	4	1.27	1.22	1.30	1.25
	5	1.34	1.32	1.27	1.39
May 1987	1	1.58	1.63	1.69	1.72
	2	1.43	1.46	1.48	1.49
	3	1.48	1.48	1.53	1.59
	4	1.31	1.35	1.32	1.37
	5	1.42	1.53	1.47	1.49
Jul 1987	1	1.79	1.83	1.74	1.81
	2	4.40	4.49	4.53	4.69
	3	2.52	2.55	2.51	2.57
	4	1.80	1.78	1.79	1.84
	5	1.63	1.79	1.55	1.73
Sep 1987	1	1.65	1.67	1.57	1.66
	2	1.32	1.29	1.36	1.41
	3	1.31	1.25	1.40	1.32
	4	1.21	1.25	1.31	1.27
	5	1.27	1.24	1.27	1.29

TABLE 31

DATE	STATION	REPLICATE 1	2	3	4
Nov 1987	1	1.00	1.01	1.06	1.01
	2	1.00	1.01	1.05	1.00
	3	0.92	0.97	1.01	1.00
	4	1.07	1.09	1.11	1.13
	5	1.10	1.15	1.19	1.23

APPENDIX B

TOTAL NUMBERS OF BENTHIC MACROINVERTEBRATES COLLECTED IN BASKET SAMPLERS AT FIVE STATIONS IN SALT CREEK, OKLAHOMA

TABLE 32

MACROINVERTEBRATE NUMBERS: JULY, 1986

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	167	360	127	115	168
Haplophlebia sp.					29
Hexagenia sp.	5	9			
Isonychia sp.				25	84
Siphlonurus sp.	5	29	10	12	66
Stenonema tripunctatum	253	476	163	132	170
ODONATA					
Telebasis sp.		9	20	21	11
PLECOPTERA					
Hydroperla crosbyii					9
Taeniopteryx sp.					30
MEGALOPTERA					
Sialis sp.	9	19	7	3	5
TRICHOPTERA					
Chimmara sp.					22
Helicopsyche sp.					9
Hydropshyche sp.		61	106	124	87
COLEOPTERA					
Gyretes sp.					4
Hexacylloepus sp.		5	12	11	38
Microcylloepus sp.	2	4	11	16	40
Stenelmis markeli		5	11	8	34
DIPTERA					
Ceratopogonidae				8	
Chrysops sp.					4
Simulium sp.					4
Chironomidae					
Ablabesmyia sp.	4				
Chironomus sp.		4			
Cricotopus sp.	6				
Dicrotendipes sp.	4	62	39	14	5
Endochironomus sp.	7	4			
Glyptotendipes sp.	14				
Polypedilum convictum		31	11	21	47
P. fallax		7	3	4	
Pseudochironomus sp.	5			5	45
Strictochironomus sp.	13	6	3		
Thienemannimyia sp.		16	14	5	4
OTHER					
Lumbricidae			7		
Ancyliidae			4		
Physella sp.	1	18			
Hyalella azteca	8	13			

TABLE 33

MACROINVERTEBRATE NUMBERS: SEPTEMBER, 1986

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	94	67	35		
Haplophlebia sp.					4
Siphlonurus sp.		4	3		16
Stenonema tripunctatum	152	131	79		76
ODONATA					
Engallama sp.	8	5			
Telebasis sp.		13	16		22
PLECOPTERA					
Acroneuria sp.					11
Hydroperla crosbyii					1
Taeniopteryx sp.					33
MEGALOPTERA					
Corydalis cornutus		1	2		6
Sialis sp.	1				
TRICHOPTERA					
Chimmara sp.					4
Helicopsyche sp.					27
Hydropshyche sp.		40	58		108
COLEOPTERA					
Hexacylloepus sp.		9	11		43
Microcylloepus sp.		11	10		39
Stenelmis markeli					9
DIPTERA					
Chrysops sp.					8
Chironomidae					
Ablabesmyia sp.	13	4			
Chironomus sp.		4	2		
Cricotopus sp.	2				
Endochironomus sp.		1			
Glyptotendipes sp.	3	2	4		3
Pentaneura sp.					19
Polypedilum convictum		9	19		9
P. fallax		3	4		
P. illinoense					27
Pseudochironomus sp.	6	1	4		12
Strictochironomus sp.	6	15	7		14
Thienemannimyia sp.		9	5		14
OTHER					
Physella sp.	3	7			
Hyalella azteca	11	5	2		

TABLE 34

MACROINVERTEBRATE NUMBERS: DECEMBER, 1986

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	68	47	37	9	
Siphlonurus sp.			1	4	7
Stenonema tripunctatum	130	125	89	77	63
ODONATA					
Engallama sp.	9	13			
Telebasis sp.		7	13	23	22
PLECOPTERA					
Acroneuria sp.					15
Taeniopteryx sp.					31
MEGALOPTERA					
Corydalis cornutus			3	6	7
TRICHOPTERA					
Chimmara sp.					1
Helicopsyche sp.					5
Hydropshyche sp.		16	62	93	132
LEPIDOPTERA					
Crambus sp.					5
COLEOPTERA					
Berosus sp.					3
Hexacylloepus sp.			9	11	40
Microcylloepus sp.			10	20	39
Stenelmis markeli					4
DIPTERA					
Chrysops sp.					4
Chironomidae					
Ablabesmyia sp.	5	3			
Chironomus sp.			7	12	10
Cricotopus sp.	6	2			
Glyptotendipes sp.	4	8	3		
Pentaneura sp.			10	12	11
Polypedilum convictum		3			
P. fallax			17	32	8
P. illinoense				5	6
Pseudochironomus sp.	12				6
Strictochironomus sp.	19	12	2		
Thienemannimyia sp.		5	10	20	20
OTHER					
Physella sp.	5	7			
Hyalella azteca	24	14			

TABLE 35

MACROINVERTEBRATE NUMBERS: MARCH, 1987

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	135	145	186	232	250
Haplophlebia sp.					4
Hexagenia sp.		2	3	4	7
Isonychia sp.				3	12
Siphlonurus sp.	1	7	2	1	
Stenonema tripunctatum	193	240	268	276	280
ODONATA					
Engallama sp.				2	6
Telebasis sp.	6	8	16	26	33
PLECOPTERA					
Acroneuria sp.					15
Taeniopteryx sp.					31
MEGALOPTERA					
Corydalis cornutus			3	6	7
TRICHOPTERA					
Chimmara sp.					4
Hydropshyche sp.			9	17	39
Micrasema sp.				3	7
LEPIDOPTERA					
Crambus sp.			1		
COLEOPTERA					
Hexacylloepus sp.		3	1		
Microcylloepus sp.	4	2	1		
Phanocerus sp.				6	13
Stenelmis markeli		2	1		5
DIPTERA					
Nemotelus sp.					2
Chironomidae					
Ablabesmyia sp.	2				
Chironomus sp.			2	13	21
Cricotopus sp.	1				
Dicrotendipes sp.	4	17	12	5	
Endochironomus sp.	4	3			
Glyptotendipes sp.	3				
Pentaneura sp.			2	8	4
Polypedilum convictum		5	17	24	34
P. fallax		4	5	7	10
P. illinoense			2	10	12
Pseudochironomus sp.	11	6	3		24
Strictochironomus sp.	4	4	4	3	
Thienemannimyia sp.		7	5	6	7
OTHER					
Physella sp.	7	8	6	5	3
Hyalella azteca	32	37	18	7	

TABLE 36

MACROINVERTEBRATE NUMBERS: MAY, 1987

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	249	152	134	168	182
Haplophlebia sp.					9
Hexagenia sp.	3	2	1		
Isonychia sp.				2	43
Siphlonurus sp.	5	17	8	9	2
Stenonema tripunctatum	354	241	214	190	175
ODONATA					
Engallama sp.				3	2
Telebasis sp.		11	20	23	23
PLECOPTERA					
Acroneuria sp.					4
MEGALOPTERA					
Corydalis cornutus				3	3
Sialis sp.	6	9	13	6	2
TRICHOPTERA					
Chimmara sp.					33
Hydropshyche sp.		6	7	61	22
Micrasema sp.				11	12
LEPIDOPTERA					
Crambus sp.			2		
COLEOPTERA					
Hexacylloepus p.		7	9	7	4
Microcylloepus sp.	2	2	3	2	3
Stenelmis markeli		3	7	3	9
DIPTERA					
Chrysops sp.					2
Simulium sp.					4
Chironomidae					
Ablabesmyia sp.	4				
Chironomus sp.			2	5	6
Cricotopus sp.	3				
Dicrotendipes sp.	4	26	17	7	2
Endochironomus sp.	5	5			
Glyptotendipes sp.	5				
Pentaneura sp.				2	1
Polypedilum convictum		17	11	22	42
P. fallax		3	4	6	6
P. illinoense		10	4	5	4
Pseudochironomus sp.	8	2	2	1	30
Strictochironomus sp.	7	4	2	1	
Thienemannimyia sp.			9	4	5
OTHER					
Physella sp.	7	8	8	3	
Hyalella azteca	20	31	15	7	

TABLE 37

MACROINVERTEBRATE NUMBERS: JULY, 1987

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	186	345	157	127	162
Haplophlebia sp.					31
Hexagenia sp.	6	14	4		
Isonychia sp.				17	92
Siphlonurus sp.	7	40	11	7	67
Stenonema tripunctatum	251	553	205	151	147
ODONATA					
Telebasis sp.		12	21	22	14
PLECOPTERA					
Acroneuria sp.					1
Hydroperla crosbii					12
Taeniopteryx sp.					21
MEGALOPTERA					
Corydalis cornutus				8	10
Sialis sp.	13	24	7	2	3
TRICHOPTERA					
Chimmara sp.					20
Helicopsyche sp.					5
Hydropshyche sp.		56	126	131	98
Micrasema sp.				3	1
COLEOPTERA					
Gyretes sp.					3
Hexacylloepus p.		4	12	12	24
Microcylloepus sp.	1	2	15	15	42
Stenelmis markeli		5	10	5	31
DIPTERA					
Ceraropogonidae				9	4
Chrysops sp.					6
Simulium sp.					4
Chironomidae					
Chironomus sp.		2			2
Cricotopus sp.	4				
Dicrotendipes sp.	4	47	51	11	7
Endochironomus sp.	12	4			
Glyptotendipes sp.	17				
Polypedilum convictum		37	11	7	54
P. fallax		4	4	8	3
P. illinoense		2	1		
Pseudochironomus sp.	13	2	2		2
Strictochironomus sp.	17	4			
Thienemannimyia sp.		9	20	4	4
OTHER					
Physella sp.	4	18	9	3	
Hyalella azteca	17	19	10	5	

TABLE 38

MACROINVERTEBRATE NUMBERS: SEPTEMBER, 1987

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	976	65	54	39	19
Haplophlebia sp.				2	8
Isonychia sp.				9	31
Siphlonurus sp.		6	4	5	6
Stenonema tripunctatum	159	133	125	103	90
ODONATA					
Engallama sp.	9	4			
Telebasis sp.		12	25	7	21
PLECOPTERA					
Acroneuria sp.				3	10
Hydroperla crosbii				1	4
Taeniopteryx sp.				9	28
MEGALOPTERA					
Corydalis cornutus		2	5	5	6
Sialis sp.	4	3			
TRICHOPTERA					
Chimmara sp.				1	9
Helicopsyche sp.				11	27
Hydropshyche sp.		46	86	96	112
COLEOPTERA					
Berosus sp.				2	6
Hexacylloepus p.		9	15	19	38
Microcylloepus sp.		13	14	25	31
Stenelmis markeli				3	9
DIPTERA					
Ceraropogonidae					2
Chrysops sp.				3	12
Chironomidae					
Ablabesmyia sp.	10	4	5		
Chironomus sp.			2		
Cricotopus sp.	2				
Dicrotendipes sp.	1				
Endochironomus sp.	2	2			
Glyptotendipes sp.	4	4	4	4	4
Pentaneura sp.				6	19
Polypedilum convictum		9	21	11	9
P. fallax		5	4		
P. illinoense				7	35
Pseudochironomus sp.	5	2	4	4	6
Strictochironomus sp.	30	16	5	5	4
Thienemannimyia sp.		12	6	8	11
OTHER					
Physella sp.	7	8	3		
Hyalella azteca	19	14	8		

TABLE 39

MACROINVERTEBRATE NUMBERS: NOVEMBER, 1987

TAXA	STATION 1	2	3	4	5
EPHEMEROPTERA					
Caenis sp.	74	47	35	14	8
Isonychia sp.					3
Siphlonurus sp.				2	4
Stenonema tripunctatum	125	106	86	67	53
ODONATA					
Engallama sp.	11	14	5		
Telebasis sp.		8	12	23	31
PLECOPTERA					
Acroneuria sp.					3
Taeniopteryx sp.					22
MEGALOPTERA					
Corydalis cornutus			2	6	7
TRICHOPTERA					
Chimmara sp.					3
Helicopsyche sp.					6
Hydropshyche sp.		23	48	74	106
COLEOPTERA					
Berosus sp.					3
Hexacylloepus p.			9	12	43
Microcylloepus sp.			7	16	35
Stenelmis markeli					5
DIPTERA					
Chrysops sp.				1	4
Chironomidae					
Ablabesmyia sp.	7	3			
Chironomus sp.			4	11	10
Cricotopus sp.	7	4			
Glyptotendipes sp.	4	7	3		
Pentaneura sp.			9	22	8
Polypedilum convictum		4			
P. fallax			19	34	10
P. illinoense				8	11
Pseudochironomus sp.	11	4			4
Strictochironomus sp.	22	11	4		
Thienemannimyia sp.		7	12	19	30
OTHER					
Physella sp.	7	5			
Hyalella azteca	33	12	2		

APPENDIX C

NUMBERS, RICHNESS (S), EVENNESS (E), AND DIVERSITY (H') OF MACROINVERTEBRATES COLLECTED IN BASKET SAMPLERS AT FIVE LOCATIONS IN SALT CREEK, OKLAHOMA

TABLE 40

NUMBERS OF MACROINVERTEBRATES COLLECTED

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	144	257	134	125	217
	2	110	308	149	134	225
	3	116	292	129	137	208
	4	131	281	137	128	245
Sep 1986	1	81	91	80	-	108
	2	77	79	98	-	134
	3	96	91	83	-	118
	4	74	80	-	-	120
Dec 1986	1	80	72	65	77	97
	2	75	68	61	87	103
	3	64	58	71	93	107
	4	63	64	77	77	102
Mar 1987	1	105	133	137	164	194
	2	105	133	142	162	199
	3	104	120	144	165	181
	4	98	125	141	167	189
May 1987	1	148	128	115	128	126
	2	165	140	125	139	159
	3	177	135	134	145	138
	4	192	155	119	139	157
Jul 1987	1	139	265	162	138	212
	2	122	309	174	145	242
	3	135	328	163	133	241
	4	146	300	174	135	228
Sep 1987	1	91	94	86	98	129
	2	85	91	107	91	150
	3	86	91	102	104	139
	4	87	90	95	95	138
Nov 1987	1	71	61	60	84	104
	2	74	65	62	77	103
	3	76	64	72	72	120
	4	77	67	64	64	92

TABLE 41

MACROINVERTEBRATE RICHNESS (S)

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	12	17	15	15	21
	2	12	19	15	14	19
	3	13	18	15	16	21
	4	15	19	16	15	21
Sep 1986	1	9	17	15	-	20
	2	10	15	16	-	22
	3	10	17	14	-	20
	4	7	17	-	-	21
Dec 1986	1	9	12	12	13	18
	2	10	12	11	12	17
	3	10	11	12	12	18
	4	10	11	15	12	17
Mar 1987	1	11	14	16	17	20
	2	12	15	14	19	17
	3	11	17	16	18	19
	4	12	13	16	14	19
May 1987	1	15	15	18	20	23
	2	14	18	20	20	21
	3	13	17	18	20	23
	4	15	15	15	19	21
Jul 1987	1	15	18	16	19	26
	2	14	20	17	19	27
	3	13	18	15	19	25
	4	14	18	15	18	21
Sep 1987	1	12	18	17	22	26
	2	12	18	16	21	25
	3	11	18	18	23	26
	4	10	16	16	20	24
Nov 1987	1	10	14	15	12	22
	2	10	13	13	12	20
	3	10	14	14	14	20
	4	10	13	13	13	18

TABLE 42

MACROINVERTEBRATE EVENNESS (E)

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	0.52	0.62	0.71	0.70	0.90
	2	0.55	0.57	0.74	0.77	0.80
	3	0.57	0.58	0.73	0.73	0.82
	4	0.51	0.62	0.77	0.77	0.82
Sep 1986	1	0.64	0.70	0.78	-	0.82
	2	0.67	0.72	0.75	-	0.83
	3	0.66	0.73	0.80	-	0.90
	4	0.72	0.76	-	-	0.86
Dec 1986	1	0.69	0.70	0.82	0.82	0.77
	2	0.64	0.76	0.80	0.83	0.82
	3	0.73	0.68	0.78	0.83	0.78
	4	0.76	0.63	0.77	0.80	0.80
Mar 1987	1	0.59	0.56	0.56	0.57	0.63
	2	0.57	0.60	0.52	0.56	0.65
	3	0.58	0.56	0.51	0.56	0.65
	4	0.49	0.53	0.59	0.62	0.65
May 1987	1	0.48	0.65	0.62	0.64	0.78
	2	0.49	0.59	0.63	0.64	0.81
	3	0.45	0.58	0.62	0.66	0.75
	4	0.43	0.60	0.65	0.64	0.71
Jul 1987	1	0.54	0.59	0.71	0.69	0.80
	2	0.60	0.56	0.71	0.69	0.78
	3	0.62	0.56	0.76	0.70	0.83
	4	0.52	0.59	0.71	0.72	0.83
Sep 1987	1	0.62	0.73	0.76	0.74	0.84
	2	0.67	0.78	0.74	0.78	0.85
	3	0.64	0.77	0.73	0.76	0.88
	4	0.68	0.73	0.74	0.76	0.83
Nov 1987	1	0.58	0.77	0.78	0.88	0.80
	2	0.75	0.73	0.79	0.88	0.79
	3	0.69	0.80	0.79	0.84	0.77
	4	0.77	0.73	0.85	0.84	0.82

TABLE 43

MACROINVERTEBRATE DIVERSITY (H')

DATE	REPLICATE	STATION 1	2	3	4	5
Jul 1986	1	1.30	1.71	1.91	1.90	2.74
	2	1.37	1.61	2.01	2.05	2.37
	3	1.46	1.66	1.97	2.00	2.51
	4	1.37	1.83	2.08	2.08	2.49
Sep 1986	1	1.42	1.99	2.10	-	2.44
	2	1.55	1.96	2.07	-	2.57
	3	1.51	2.08	2.11	-	2.70
	4	1.41	2.14	-	-	2.61
Dec 1986	1	1.51	1.75	2.02	2.12	2.21
	2	1.48	1.90	1.93	2.06	2.32
	3	1.69	1.63	1.94	2.07	2.25
	4	1.74	1.50	2.08	1.99	2.27
Mar 1987	1	1.41	1.47	1.54	1.60	1.90
	2	1.43	1.62	1.38	1.65	1.83
	3	1.40	1.60	1.42	1.63	1.90
	4	1.22	1.35	1.62	1.64	1.92
May 1987	1	1.30	1.77	1.80	1.92	2.45
	2	1.29	1.72	1.90	1.93	2.45
	3	1.16	1.65	1.78	1.99	2.36
	4	1.15	1.63	1.77	1.88	2.15
Jul 1987	1	1.46	1.71	1.98	2.02	2.60
	2	1.59	1.68	2.02	2.04	2.58
	3	1.58	1.61	2.06	2.05	2.68
	4	1.38	1.70	1.91	2.08	2.51
Sep 1987	1	1.55	2.10	2.15	2.29	2.72
	2	1.66	2.25	2.05	2.36	2.72
	3	1.52	2.21	2.13	2.39	2.85
	4	1.57	2.02	2.04	2.29	2.64
Nov 1987	1	1.34	2.03	2.10	2.18	2.48
	2	1.73	1.87	2.02	2.18	2.35
	3	1.59	2.12	2.10	2.21	2.32
	4	1.78	1.88	2.17	2.17	2.38

APPENDIX D

SUMMARY OF INPUT DATASETS FOR JULY AND SEPTEMBER, 1986 QUAL2E SIMULATIONS

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1986

```
NO          CONSERVATIVE MINERAL   I
NO          CONSERVATIVE MINERAL  II
NO          CONSERVATIVE MINERAL III
NO          TEMPERATURE
NO          BIOCHEMICAL OXYGEN DEMAND IN MG/L
YES         ALGAE AS CHL-A IN UG/L
YES         PHOSPHORUS CYCLE AS P IN MG/L
YES         NITROGEN CYCLE AS N IN MG/L
NO          DISSOLVED OXYGEN IN MG/L
NO          FECAL COLIFORMS IN NO./100 ML
NO          ARBITRARY NON-CONSERVATIVE
NO          FLOW AUGMENTATION

STEADY STATE
TRAPEZOIDAL X-SECTIONS
PRINT SOLAR/LCD DATA
NO PLOT DO AND BOD
FIXED DNSTRM CONC(YES=1)=    .0      5D-ULT BOD CONV K COEF  =    .00
INPUT METRIC (YES=1)    =   1.0      OUTPUT METRIC (YES=1)   =   1.0
NUMBER OF REACHES       =   5.0      NUMBER OF JUNCTIONS     =    .0
NUM OF HEADWATERS       =   1.0      NUMBER OF POINT LOADS   =   0.0
TIME STEP (HOURS)       =            LNTH. COMP. ELEMENT (DX)=   5.00
MAXIMUM ROUTE TIME (HRS)=  20.0      TIME INC. FOR RPT2 (HRS)=
LATITUDE OF BASIN (DEG) =  36.00     LONGITUDE OF BASIN (DEG)=  96.0
STANDARD MERIDIAN (DEG) =  36.0      DAY OF YEAR START TIME  = 209.0
EVAP. COEF..(AE)        =  .0000050  EVAP. COEF..(BE)        =  .0000040
ELEV. OF BASIN (ELEV)   = 320.0      DUST ATTENUATION COEF.  =    .000

O UPTAKE BY NH3 OXID    =   3.500    O UPTAKE BY NO2 OXID    =   1.200
O PROD  BY ALGAE        =   1.600    O UPTAKE BY ALGAE       =   2.000
N CONTENT OF ALGAE      =    .085    P CONTENT OF ALGAE      =    .012
ALG MAX SPEC GROWTH     =   2.500    ALGAE RESPIRATION RATE  =    .100
N HALF SATURATION CONST =    .300    P HALF SATURATION CONST =    .040
LIN ALG SHADE CO        =    .0088   NLIN SHADE              =    .0540
LIGHT FUNCTION OPTION   =   1.0      LIGHT SATURATION COEFF  =    .030
DAILY AVERAGING OPTION  =   4.0      LIGHT AVERAGING FACTOR  =    .920
NUMBER OF DAYLIGHT HOURS=  14.0      TOTAL DAILY SOLAR RADTN = 600.0
ALGY GROWTH CALC OPTION =   2.0      ALGAL PREF FOR NH3-N    =    .500
ALG/TEMP SOLAR RAD FACT =    .500    NITRIFICATION INHIBITION=    .500

STREAM REACH     1.0RCH =1      FROM        .00    TO        10.00
STREAM REACH     2.0RCH =2.0    FROM      10.00    TO        25.00
STREAM REACH     3.0RCH =3.0    FROM      25.00    TO        45.00
STREAM REACH     4.0RCH =4.0    FROM      45.00    TO        60.00
STREAM REACH     5.0RCH =5.0    FROM      60.00    TO        70.00

FLAG FIELD RCH=  1.0   2.0     1.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  2.0   3.0     6.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  3.0   4.0     2.2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  4.0   3.0     2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  5.0   2.0     2.5.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
```

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1986 Continued

```
HYDRAULICS RCH=1.0  5.9  1.000000  1.000000   2.00000    .00540    .0330
HYDRAULICS RCH=2.0  5.9  1.000000  1.000000   5.00000    .00230    .0330
HYDRAULICS RCH=3.0  5.9  1.000000  1.000000   8.00000    .00140    .0500
HYDRAULICS RCH=4.0  5.9  1.000000  1.000000  12.00000    .00160    .0440
HYDRAULICS RCH=5.0  5.9  1.000000  1.000000  18.00000    .00370    .0440

N AND P  RCH=1.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=2.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=3.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=4.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=5.0   .250   .100   .150  2.000  1.000   .200   .100  1.000

ALG/OTHER COEF RCH=1.0    5.0   .050   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=2.0    5.0   .100   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=3.0    5.0   .150   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=4.0    5.0   .200   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=5.0    5.0   .250   .100  1.500   .000   .000   .000

INITIAL COND RCH=1.0  29.00   4.20   3.00    .00    .00    .00   .000
INITIAL COND RCH=2.0  29.00   9.00   3.00    .00    .00    .00   .000
INITIAL COND RCH=3.0  29.00   4.60   3.00    .00    .00    .00   .000
INITIAL COND RCH=4.0  29.00   6.20   3.00    .00    .00    .00   .000
INITIAL COND RCH=5.0  29.00   8.20   3.00    .00    .00    .00   .000

INITIAL COND-2 RCH=1.0  2.500   .000   .000   .000  1.000   .000   .450
INITIAL COND-2 RCH=2.0  3.500   .000   .000   .000   .850   .000   .450
INITIAL COND-2 RCH=3.0  1.750   .000   .000   .000   .600   .000   .450
INITIAL COND-2 RCH=4.0  1.000   .000   .000   .000   .350   .000   .350
INITIAL COND-2 RCH=5.0   .500   .000   .000   .000   .100   .000   .250

INCR INFLOW  RCH=1.0   .100  29.00  4.00  3.00   .00   .00   .00  .000
INCR INFLOW  RCH=2.0   .200  29.00  4.00  3.00   .00   .00   .00  .000
INCR INFLOW  RCH=3.0   .300  29.00  4.00  3.00   .00   .00   .00  .000
INCR INFLOW  RCH=4.0   .400  29.00  4.00  3.00   .00   .00   .00  .000
INCR INFLOW  RCH=5.0   .500  29.00  4.00  3.00   .00   .00   .00  .000

INCR INFLOW-2  RCH=1.0  1.000   .000   .000   .000   .800   .000   .450
INCR INFLOW-2  RCH=2.0  3.500   .000   .000   .000  1.000   .000   .450
INCR INFLOW-2  RCH=3.0  0.000   .000   .000   .000  0.500   .000   .450
INCR INFLOW-2  RCH=4.0  0.000   .000   .000   .000   .250   .000   .250
INCR INFLOW-2  RCH=5.0  0.000   .000   .000   .000   .050   .000   .200

HEADWTR-1 HDW=1.0  GRAINOLA  .100  29.00  4.10  2.00    .0    .0    .0
HEADWTR-2 HDW=1.0  .000  0.6  2.500  .000  .000  .000 2.000  .000  .900

POINTLD-1 PTL=1.0  FORAKER   .100  29.00  4.10  2.00    .0    .0    .0
POINTLD-2 PTL=1.0  .000  0.0   .000  .000  .000  .000 9.999  .000  .000
```

SALT CREEK (OSAGE COUNTY, OKLAHOMA) SEPTEMBER, 1986

```
NO          CONSERVATIVE MINERAL   I
NO          CONSERVATIVE MINERAL  II
NO          CONSERVATIVE MINERAL III
NO          TEMPERATURE
NO          BIOCHEMICAL OXYGEN DEMAND IN MG/L
YES         ALGAE AS CHL-A IN UG/L
YES         PHOSPHORUS CYCLE AS P IN MG/L
YES         NITROGEN CYCLE AS N IN MG/L
NO          DISSOLVED OXYGEN IN MG/L
NO          FECAL COLIFORMS IN NO./100 ML
NO          ARBITRARY NON-CONSERVATIVE
NO          FLOW AUGMENTATION

STEADY STATE
TRAPEZOIDAL X-SECTIONS
PRINT SOLAR/LCD DATA
NO PLOT DO AND BOD
FIXED DNSTRM CONC(YES-1)=    .0      5D-ULT BOD CONV K COEF  =    .00
INPUT METRIC (YES-1)    =   1.0      OUTPUT METRIC (YES-1)   =   1.0
NUMBER OF REACHES       =   5.0      NUMBER OF JUNCTIONS     =    .0
NUM OF HEADWATERS       =   1.0      NUMBER OF POINT LOADS   =   0.0
TIME STEP (HOURS)       =            LNTH. COMP. ELEMENT (DX)=   5.00
MAXIMUM ROUTE TIME (HRS)=  20.0      TIME INC. FOR RPT2 (HRS)=
LATITUDE OF BASIN (DEG) =  36.00     LONGITUDE OF BASIN (DEG)=  96.0
STANDARD MERIDIAN (DEG) =  36.0      DAY OF YEAR START TIME  = 284.0
EVAP. COEF..(AE)        =  .0000050  EVAP. COEF..(BE)        =  .0000040
ELEV. OF BASIN (ELEV)   = 320.0      DUST ATTENUATION COEF.  =    .000

O UPTAKE BY NH3 OXID    =   3.500    O UPTAKE BY NO2 OXID    =   1.200
O PROD  BY ALGAE        =   1.600    O UPTAKE BY ALGAE       =   2.000
N CONTENT OF ALGAE      =    .085    P CONTENT OF ALGAE      =    .012
ALG MAX SPEC GROWTH     =   2.500    ALGAE RESPIRATION RATE  =    .100
N HALF SATURATION CONST =    .300    P HALF SATURATION CONST =    .040
LIN ALG SHADE CO        =    .0088   NLIN SHADE              =    .0540
LIGHT FUNCTION OPTION   =   1.0      LIGHT SATURATION COEFF  =    .030
DAILY AVERAGING OPTION  =   4.0      LIGHT AVERAGING FACTOR  =    .920
NUMBER OF DAYLIGHT HOURS=  11.0      TOTAL DAILY SOLAR RADTN = 550.0
ALGY GROWTH CALC OPTION =   2.0      ALGAL PREF FOR NH3-N    =    .500
ALG/TEMP SOLAR RAD FACT =    .500    NITRIFICATION INHIBITION=    .500

STREAM REACH     1.0RCH =1      FROM          .00    TO         10.00
STREAM REACH     2.0RCH =2.0    FROM        10.00    TO         25.00
STREAM REACH     3.0RCH =3.0    FROM        25.00    TO         45.00
STREAM REACH     4.0RCH =4.0    FROM        45.00    TO         60.00
STREAM REACH     5.0RCH =5.0    FROM        60.00    TO         70.00

FLAG FIELD RCH=  1.0   2.0     1.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  2.0   3.0     2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  3.0   4.0     2.2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  4.0   3.0     2.2.2.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
FLAG FIELD RCH=  5.0   2.0     2.5.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.
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SALT CREEK (OSAGE COUNTY, OKLAHOMA) SEPTEMBER, 1986 Continued

```
HYDRAULICS RCH=1.0  5.9  1.000000  1.000000   2.00000    .00540    .0330
HYDRAULICS RCH=2.0  5.9  1.000000  1.000000   5.00000    .00230    .0330
HYDRAULICS RCH=3.0  5.9  1.000000  1.000000   8.00000    .00140    .0500
HYDRAULICS RCH=4.0  5.9  1.000000  1.000000  12.00000    .00160    .0440
HYDRAULICS RCH=5.0  5.9  1.000000  1.000000  18.00000    .00370    .0440

N AND P  RCH=1.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=2.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=3.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=4.0   .250   .100   .150  2.000  1.000   .200   .100  1.000
N AND P  RCH=5.0   .250   .100   .150  2.000  1.000   .200   .100  1.000

ALG/OTHER COEF RCH=1.0    5.0   .050   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=2.0    5.0   .100   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=3.0    5.0   .150   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=4.0    5.0   .200   .100  1.500   .000   .000   .000
ALG/OTHER COEF RCH=5.0    5.0   .250   .100  1.500   .000   .000   .000

INITIAL COND RCH=1.0  26.00   7.20   3.00    .00    .00    .00   .000
INITIAL COND RCH=2.0  26.00   7.00   3.00    .00    .00    .00   .000
INITIAL COND RCH=3.0  26.00   6.60   3.00    .00    .00    .00   .000
INITIAL COND RCH=4.0  26.00   6.20   3.00    .00    .00    .00   .000
INITIAL COND RCH=5.0  26.00   6.20   3.00    .00    .00    .00   .000

INITIAL COND-2 RCH=1.0  1.500   .000   .000   .000  1.000   .000   .450
INITIAL COND-2 RCH=2.0  1.250   .000   .000   .000   .850   .000   .450
INITIAL COND-2 RCH=3.0  1.000   .000   .000   .000   .600   .000   .450
INITIAL COND-2 RCH=4.0   .750   .000   .000   .000   .350   .000   .350
INITIAL COND-2 RCH=5.0   .500   .000   .000   .000   .100   .000   .250

INCR INFLOW  RCH=1.0   .100  26.00  5.00  3.00   .00   .00   .00   .000
INCR INFLOW  RCH=2.0   .200  26.00  5.00  3.00   .00   .00   .00   .000
INCR INFLOW  RCH=3.0   .300  26.00  5.00  3.00   .00   .00   .00   .000
INCR INFLOW  RCH=4.0   .400  26.00  5.00  3.00   .00   .00   .00   .000
INCR INFLOW  RCH=5.0   .500  26.00  5.00  3.00   .00   .00   .00   .000

INCR INFLOW-2  RCH=1.0   .600   .000   .000   .000   .800   .000   .450
INCR INFLOW-2  RCH=2.0   .400   .000   .000   .000  1.000   .000   .450
INCR INFLOW-2  RCH=3.0   .100   .000   .000   .000  0.500   .000   .450
INCR INFLOW-2  RCH=4.0   .100   .000   .000   .000   .250   .000   .250
INCR INFLOW-2  RCH=5.0   .200   .000   .000   .000   .050   .000   .200

HEADWTR-1 HDW=1.0  GRAINOLA     .100 26.00  6.10  2.00    .0    .0    .0
HEADWTR-2 HDW=1.0  .000  0.6  1.250  .000  .000  .000 2.000  .000  .900
```

APPENDIX E

SUMMARY OF QUAL2E SIMULATION OUTPUTS

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1986

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	14
ALGAE GROWTH RATE	3	13
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	3.71	9	77.53	17	.00
2	14.18	10	64.29	18	.00
3	29.61	11	47.34	19	.00
4	47.34	12	29.61	20	.00
5	64.29	13	14.18	21	.00
6	77.53	14	3.71	22	.00
7	84.78	15	.00	23	.00
8	84.78	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.59	1.39		
2	3.46	2.81	2.29	
3	1.63	1.15	.81	.64
4	.53	.47	.41	
5	.38	.36		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.67		
2	.45	.05	.06	
3	.04	.05	.08	.16
4	.28	.42	.37	
5	.34	.32		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.21	1.10		
2	1.97	2.35	2.01	
3	1.83	1.68	1.39	1.21
4	.98	.81	.62	
5	.43	.28		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1986 :BASELINE

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	14
ALGAE GROWTH RATE	3	13
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	3.71	9	77.53	17	.00
2	14.18	10	64.29	18	.00
3	29.61	11	47.34	19	.00
4	47.34	12	29.61	20	.00
5	64.29	13	14.18	21	.00
6	77.53	14	3.71	22	.00
7	84.78	15	.00	23	.00
8	84.78	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.59	1.39		
2	1.29	1.22	1.18	
3	1.07	.98	.92	.86
4	.76	.69	.63	
5	.52	.44		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.67		
2	.62	.58	.56	
3	.54	.53	.52	.51
4	.47	.44	.41	
5	.37	.35		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.21	1.10		
2	1.05	1.01	.96	
3	.90	.85	.79	.75
4	.71	.64	.59	
5	.54	.50		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) SEPTEMBER, 1986

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	14
ALGAE GROWTH RATE	3	11
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	6.70	9	50.00	17	.00
2	25.00	10	25.00	18	.00
3	50.00	11	6.70	19	.00
4	75.00	12	.00	20	.00
5	93.30	13	.00	21	.00
6	100.00	14	.00	22	.00
7	93.30	15	.00	23	.00
8	75.00	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.60	1.40		
2	1.29	1.23	1.19	
3	1.08	1.00	.94	.85
4	.74	.65	.60	
5	.59	.40		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.67		
2	.62	.58	.56	
3	.54	.53	.52	.51
4	.47	.44	.42	
5	.38	.35		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.06	.92		
2	.86	.83	.74	
3	.70	.67	.62	.66
4	.55	.48	.44	
5	.35	.30		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) DECEMBER, 1986

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	14
ALGAE GROWTH RATE	3	8
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	9.55	9	9.55	17	.00
2	34.55	10	.00	18	.00
3	65.45	11	.04	19	.00
4	90.45	12	.00	20	.00
5	100.00	13	.00	21	.00
6	90.45	14	.00	22	.00
7	65.45	15	.00	23	.00
8	34.55	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.60	1.44		
2	1.35	1.30	1.24	
3	1.19	1.08	1.00	.89
4	.79	.70	.62	
5	.51	.40		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.67		
2	.62	.58	.56	
3	.54	.53	.52	.51
4	.47	.44	.42	
5	.38	.35		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	.88	.76		
2	.70	.67	.61	
3	.61	.62	.63	.60
4	.55	.48	.43	
5	.39	.35		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) MARCH, 1987

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	14
ALGAE GROWTH RATE	3	12
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	5.25	9	62.09	17	.00
2	19.80	10	40.29	18	.00
3	40.31	11	40.31	19	.00
4	62.09	12	19.80	20	.00
5	80.14	13	5.25	21	.00
6	90.33	14	.00	22	.00
7	90.33	15	.00	23	.00
8	80.14	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.60	1.45		
2	1.36	1.31	1.25	
3	1.21	1.09	1.02	.91
4	.79	.71	.63	
5	.51	.42		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.70		
2	.67	.63	.58	
3	.56	.54	.53	.52
4	.46	.42	.38	
5	.35	.30		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	.94	.93		
2	.83	.80	.78	
3	.74	.73	.71	.66
4	.58	.50	.44	
5	.39	.36		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) MAY, 1986

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	13
ALGAE GROWTH RATE	2	11
ALGAE GROWTH RATE	3	1
ALGAE GROWTH RATE	4	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	3.86	9	80.76	17	.00
2	14.77	10	66.96	18	.00
3	30.85	11	49.31	19	.00
4	49.31	12	30.85	20	.00
5	66.96	13	14.77	21	.00
6	80.76	14	3.86	22	.00
7	88.31	15	.00	23	.00
8	88.31	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.60	1.43		
2	1.29	1.23	1.19	
3	1.08	1.05	1.00	.92
4	.80	.70	.64	
5	.53	.42		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.75	.67		
2	.62	.59	.56	
3	.54	.53	.52	.51
4	.46	.43	.40	
5	.38	.35		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.52	1.44		
2	1.35	1.25	1.16	
3	1.08	1.01	.95	.89
4	.81	.74	.63	
5	.50	.40		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1987

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	13
ALGAE GROWTH RATE	3	12
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	3.75	9	77.87	17	.00
2	14.23	10	64.45	18	.00
3	29.75	11	47.66	19	.00
4	47.66	12	29.75	20	.00
5	64.45	13	14.23	21	.00
6	77.87	14	3.75	22	.00
7	86.78	15	.00	23	.00
8	86.78	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.65	1.46		
2	3.58	2.94	2.22	
3	1.69	1.21	1.05	.83
4	.69	.58	.46	
5	.41	.35		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.73	.65		
2	.41	.02	.03	
3	.04	.05	.07	.18
4	.31	.45	.38	
5	.36	.34		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.34	1.26		
2	2.05	2.44	2.11	
3	1.99	1.88	1.71	1.56
4	1.21	.95	.71	
5	.54	.41		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) JULY, 1987 :BASELINE

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	14
ALGAE GROWTH RATE	2	13
ALGAE GROWTH RATE	3	11
ALGAE GROWTH RATE	4	2
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	3.75	9	77.87	17	.00
2	14.23	10	64.45	18	.00
3	29.75	11	47.66	19	.00
4	47.66	12	29.75	20	.00
5	64.45	13	14.23	21	.00
6	77.87	14	3.75	22	.00
7	86.78	15	.00	23	.00
8	86.78	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.65	1.46		
2	1.35	1.28	1.23	
3	1.11	1.01	.95	.85
4	.75	.68	.61	
5	.52	.43		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.73	.65		
2	.61	.57	.55	
3	.53	.52	.51	.50
4	.47	.44	.40	
5	.37	.34		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.34	1.26		
2	1.16	1.08	1.02	
3	.95	.89	.85	.80
4	.74	.67	.60	
5	.54	.45		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) SEPTEMBER, 1987

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	12
ALGAE GROWTH RATE	2	6
ALGAE GROWTH RATE	3	2
ALGAE GROWTH RATE	4	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	5	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	5.49	9	64.91	17	.00
2	20.70	10	42.14	18	.00
3	42.14	11	20.70	19	.00
4	64.91	12	5.49	20	.00
5	83.78	13	.00	21	.00
6	94.44	14	.00	22	.00
7	94.44	15	.00	23	.00
8	83.78	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.60	1.46		
2	1.34	1.25	1.19	
3	1.09	1.00	.91	.81
4	.73	.65	.55	
5	.46	.38		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.67	.64		
2	.62	.60	.57	
3	.55	.53	.51	.48
4	.45	.42	.40	
5	.38	.36		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	1.03	.98		
2	.91	.83	.77	
3	.72	.65	.59	.54
4	.50	.46	.42	
5	.38	.34		

SALT CREEK (OSAGE COUNTY, OKLAHOMA) NOVEMBER, 1987

OUTPUT SUMMARY

CONVERGENCE SUMMARY:

VARIABLE	ITERATION	NUMBER OF NONCONVERGENT ELEMENTS
ALGAE GROWTH RATE	1	11
ALGAE GROWTH RATE	2	4
ALGAE GROWTH RATE	3	1
ALGAE GROWTH RATE	4	0
NITRIFICATION INHIBITION	1	0
ALGAE GROWTH RATE	6	0
NITRIFICATION INHIBITION	2	0

HOURLY VALUES OF SOLAR RADIATION (LANGLEYS)

1	6.70	9	50.00	17	.00
2	25.00	10	25.00	18	.00
3	50.00	11	6.70	19	.00
4	75.00	12	.00	20	.00
5	93.30	13	.00	21	.00
6	100.00	14	.00	22	.00
7	93.30	15	.00	23	.00
8	75.00	16	.00	24	.00

NITRATE AS N IN MG/L

RCH/CL	1	2	3	4
1	1.66	1.50		
2	1.42	1.31	1.24	
3	1.14	1.06	.98	.86
4	.78	.68	.57	
5	.47	.41		

DISSOLVED PHOSPHOROUS AS P IN MG/L

RCH/CL	1	2	3	4
1	.67	.63		
2	.60	.58	.56	
3	.53	.50	.47	.45
4	.43	.41	.40	
5	.38	.36		

ALGAE AS CHL-A IN MG/L

RCH/CL	1	2	3	4
1	.86	.79		
2	.74	.67	.63	
3	.59	.54	.51	.49
4	.47	.45	.42	
5	.37	.32		

VITA

Richard Miles Bryant Jr.

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF NUTRIENT ENRICHMENT FROM AGRICULTURAL RUNOFF ON MACROINVERTEBRATES IN SALT CREEK, A PRAIRIE STREAM IN NORTH CENTRAL OKLAHOMA

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