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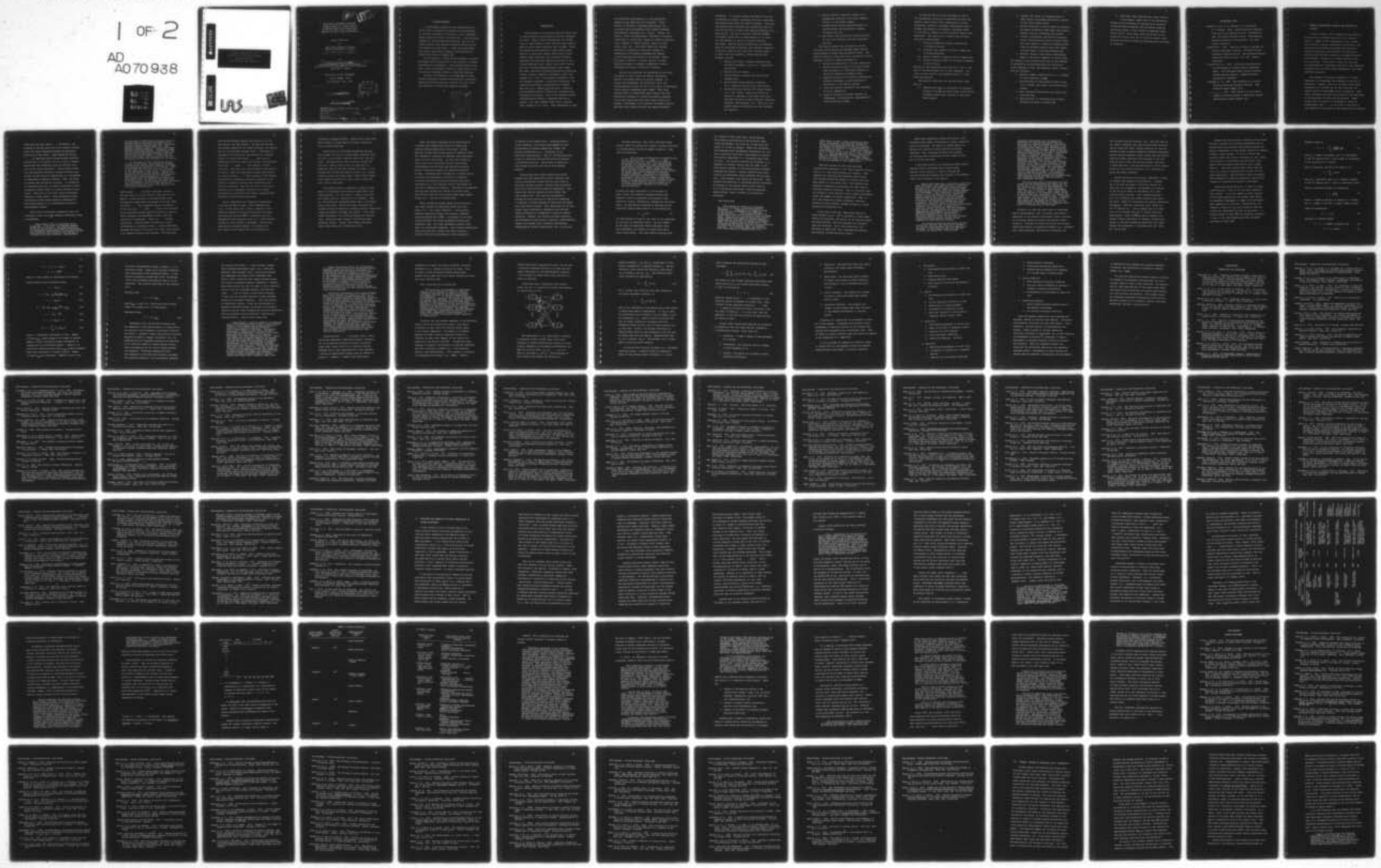

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ECOLOGICAL PARAMETERS PERTINENT TO DEVELOPMENT OF A WATER QUALITY ASSESSMENT MODEL FOR CLOVER CREEK McCHORD AIR FORCE BASE, WASHINGTON

Report Submitted

to

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I am extremely grateful to the United States Air Force Office of Scientific Research for the Mini-Grant to continue work begun in 1976 while I was a USAF/ASEE Summer Faculty Associate at Tyndall AFB. I am especially indebted to captain Mike Osborn and his staff for providing logistic and technical assistance during the on-site survey of Clover Creek. I must also acknowledge the earlier help given by Captain Steve Shelton and Colonel Emil Frein at Tyndall AFB.

As an ecologist, I found the environmental research, philosophy and the dedication of the personnel at Tyndall and McChord to be exemplary. With adequate support and time, those environmental scientists should help to mitigate the environmental effects of many USAF missions.

Finally, the USAFOSR is to be commended for maintaining cooperative programs with university scientists. Cooperative multidisciplinary research is a most effective approach to solving environmental problems.

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INTRODUCTION

Installations of the United States Air Force exist in vastly different environmental settings throughout the world. Many of these installations are located close to large bodies of water and have small lakes or ponds on and streams traversing their grounds. Numerous operations and missions at these installations directly or indirectly impact these surface waters. Impacts result from point and non-point effluents generated from technical/industrial operations (e.g., aircraft/AGE wash racks, vehicle wash racks, plating and metal finishing, photoprocessing, paint shops, NDI shops, degreasing heating/cooling/power generating plants); general "domestic" wastewater; runoff from runways (e.g., fuel, fire protection chemicals, foam for emergency landings), streets, and landscaping and construction projects; precipitation of airborne materials (e.g., exhaust from aircraft); landfills; and from modifications of vegetation surrounding and overhanging the waters. Some of the effluents contain substances having known or suspected toxicity to aquatic life (see, Lefebvre 1969, 1970; Doudoroff 1976; Cardwell et al. 1976). Other substances or their derivatives may bioaccumulate in food webs/chains leading to man where they may be harmful. Often effects of effluents, landscape modification, etc., are subtle and not detectable with standard bioassay/ toxicological techniques (e.g., LD_{50}'s). Minute, but chronic, levels of contaminants, increases in turbidity, alterations in stream flow, changes in substrate particle sizes, changes in thermal regimes, removal of vegetation cover, etc., can produce behavorial changes, reduction in fecundity or fertility, changes in sequencing of life history phenomena and changes in the energy-nutrient drives of the system. These may reduce a species' or several species' fitness, producing changes in community composition; overall consequence of which is difficult to predict.

The Air Force realizes its obligation to the letter and spirit of local, state and federal legislation inacted to mitigate impacts on natural systems. To fulfill this commitment, the Environics' Water and Solids Resource Division of the U.S. Air Force is developing a water quality assessment model (WQAM). This model should be able to predict and assess impacts and offer mitigative strategies for sound environmental planning of Air Force operations that could impact aquatic ecosystems. Development of an effective instrument requires much more than systems analysis and computer modeling technology. It requires working knowledge of structure and dynamics of aquatic ecosystems and their watersheds, and adequate data bases for specific systems. Biological subsystems within ecosystems are considerably more complex and difficult to model than physical dynamics (e.g., hydrological. Air Force personnel involved in ~~WQAM~~ water quality assessment model development should have an understanding of the structure and dynamics of aquatic ecosystems and their watersheds. Because aquatic systems vary considerably among eco-geographical regions, they should be cognizant of specific baseline data required to develop models of lentic and lotic dynamics. These baseline data minimally include:

1. Species and trophic (foodweb connectivities) structure throughout a year (i.e., aspectional succession).
2. Spatial array of species.
3. Life histories of species and factors that sequence them.
4. Relationship between physical structure (e.g., substrate particle size) and species.
5. Susceptability of various life history stages (i.e., egg, larval, immature and adult) of species to compounds in effluents (both LD_{50} - type data and data on subtle behavior, fertility, fecundity, developmental, etc., effects of compounds singly and combined as in the effluents are required).

4. Similar effects of physical factors (e.g., temperature, turbidity, flow rates, sedimentation) on life history stages.
5. Standard water quality characterization including thermal and hydrological regimes throughout the year.
6. Qualitative and quantitative characterization of point and non-point effluents throughout the year.

This report presents the continuation of work presented earlier during my USAF/ASEE Summer Faculty Associateship at Tyndall AFB (Fitzpatrick 1976). The specific purpose of that work was to introduce Air Force personnel involved in WQAM development to:

1. Nature and complexities of biotic communities.
2. Current primitive status of ecological knowledge and paucity of falsifiable theories at the biotic community-ecosystem levels.
3. Inherent difficulties of applying mathematical modeling techniques, so well-developed in engineering, to biological systems.
4. Local and regional variability and uniqueness of biotic communities.
5. Types of time-series studies required for development, interpretations, implementation, and verification of WQAM.

My approach was to review and summarize some of the contemporary literature on ecosystem structure and dynamics (specifically biotic communities in stream ecosystems), provide a reasonably comprehensive bibliography and construct a preliminary conceptual model for the biotic community in Clover Creek at McChord AFB, Washington. The report was to contain four sections, each with a bibliography:

I. General Contemporary Concepts and Theories in Community Ecology
II. Structure and Dynamics of Biotic Communities in Stream Ecosystems
III. General Comments on Modeling Biotic Communities
IV. General Conceptual Model of the Biotic Community in Clover Creek.

Because of time limitations only sections I and II, and part of the bibliography for III were completed. Sections III and IV were to be completed later if a Mini-Grant was received.

The specific objectives for the Mini-Grant study were to:

1. Complete the review of literature on ecological studies of streams and small lakes in the Pacific Northwest specifically relevant to the Clover Creek project.

2. Complete the review of techniques used to model aquatic ecosystems specifically relevant to the Clover Creek project.
3. Review literature on biotic effects of specific pollutants produced on USAF bases (particularly McChord) that are discharged into streams.
4. Conduct a preliminary qualitative and quantitative investigation of biota in Clover Creek. This will require 1-2 weeks of sampling Clover Creek to determine general biotic and trophic structure above, on and below McChord AFB.
5. Develop a general input-output compartmental model of the biotic community in Clover Creek.

The results of the proposed study were to help CEC/EVW to establish an on-site monitoring and time-series biotic sampling program, and laboratory study to determine the following:

1. Specific trophic connectivities (i.e., foodweb) of biota essential to WQAM.
2. Quantification of intertrophic fluxes of mass (e.g., biomass, and organic and inorganic compounds).
3. Rate (transfer) coefficients and factors that time-vary them.
4. Quantification of bioaccumulation of major pollutants produced at McChord AFB.

5. Toxicology (both LD_{50} and more subtle effects) of pollutants, singly and in the combination.

Because of the necessity for setting up an extensive integrated physico-chemical and ecological sampling/ monitoring regime, I have elected to emphasize objectives 4 and 5. Until good times-series data are obtained for Clover Creek for at least one annual cycle, detailed treatment of modeling techniques and toxicology is premature.

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I. GENERAL CONTEMPORARY CONCEPTS AND THEORIES IN ECOLOGY

In this section I wish to emphasize the relations between biotic community structure (e.g., spatial, species, trophic, niche) and dynamics (e.g., energy flow, material cycling, population fluctuations), and the growing controversy surrounding the diversity-stability hypothesis; particularly in reference to using species diversity indices as unbiased estimators of ecosystems "health" or to assess impacts of Air Force projects. I also wish to argue for the need for development of falsifiable theories at the community-ecosystem level and that studies designed to test them should be supported.

The concept of the biotic community (= living components of ecosystems) and ecosystem is not new to ecologists. However, there are divergent views among ecologists as to whether or not they represent the highest levels of functional biotic integration. Odum (1971) addressed this idea and pointed out the importance of the principle of functional integration. Essentially life is arrayed in a hierarchy of levels of organization, and ". . . no one level is any more or less important or any more or less deserving of scientific study than any other level . . . furthermore, the findings at any one level aid in the study of another level, but never completely explain the phenomena occurring at that level." Odum emphasized this as " . . . an important point because persons sometimes contend that it is useless to try to work on complex populations and communities when the smaller units are not yet fully understood." The principle infers that new properties develop or emerge (emergent properties) at each level of organization as a consequence of subsystems or sublevel coupling. Thus, the whole is greater than the sum of its parts. In attempting to understand one level, we must be cognizant of what knowledge of lower levels is trivial and what is pertinent. Often work at one level directs meaningful research at lower levels. Thus, ecologists working at different levels should maintain communication. Such advice applies to all disciplines involved in environmental studies.

Smith (1975) articulately summarized, and I believe put to rest, the often semantic dichotomous views on ecosystems.

> "Two extreme views of ecosystems can be recognized. In one view, an ecosystem emerges as the sum of its parts. Any understanding of the whole must derive from studies of the species. An evolutionary understanding of ecosystems follows from studies of the ecology of each species as a product of natural selection. Such studies

> are the heart of Evolutionary Ecology, based on intimate observations and experimentation in natural history, population dynamics, population genetics, behavior, physiology, etc. This approach includes studies of co-evolution among strongly associated species. Studies on enough species in an ecosystem will, collectively, provide an evolutionary understanding of the form and function of the system. In this view the species are unique. Any uniqueness of the ecosystem derives from the uniqueness of its species.
>
> In the opposite view, ecosystems are persistent organizations, constrained to workable configurations and therefore themselves strongly constraining the evolution of its species. Much of the evolution that does occur is irrelevant in the sense that it has little if any effect on the performance of the system. Indeed, one species or set of species may be substituted for another with little disruption of the whole. This implies that the uniqueness of species may contribute little or nothing to the uniqueness of the ecosystem. In this opposite view, ecosystems have uniqueness of their own that guides the evolution of species, rather than emerging from the evolution of species."

Smith argued ". . . that both views have validity, and that they are in less conflict than may at first appear." Using concepts of the hypervolume niche, interspecific competition and natural selection, Smith concluded ". . . that ecosystems emerge as products of the evolution . . . [and] . . . These same selective forces operating through connected systems of species, exert consistent and predictable effects upon the evolution of assemblages. These are . . . systems constraints. Learning about them will be a basic contribution to ecosystem science." Smith argued that although the species is the unit for study, each species in a community affects other species. "Not only does each species achieve balance, but they do so at the same time in the same systems. Through the food web, and through competition for other resources, one species' gain is often another species' loss." "The basic requirement of existence for each species is a general balance of inputs and outputs. . . . The array of adaptations affecting inputs and outputs is potentially very large . . . [and] . . . will usually involve trade-offs, improving some relationships at the expense of others. Thus, the equations of inputs and outputs are interconnected . . ." The relevance of the species' connectivity to modeling and systems analysis is the potential problem of solving many simultaneous differential equations. Not only do errors in one place generate errors throughout the model, but because each species is affected by all others, modeling their feedbacks is drastically complicated.

Biotic communities are composed of populations of species arrayed in space. Each community type (e.g., stream, pond, lake, forest, grassland, intertidal) has unique vertical and horizontal structure. Structure also varies within a community type over geographical and ecological space (e.g., fast mountain streams vs. slow streams in lowlands). Species are generally not arrayed randomly, (if random it is most likely to be Poisson) but are dispersed in a contiguous (clumped) fashion. Smith (1975) stated that the struggle to occupy space is a major organizing force in many ecosystems.

Populations are connected through the food web. This trophic structure is unique among community types and also varies within community types over time and space. Although species often interact outside the food web, trophic interactions are important for modeling; they are the input-output functions. It is through the food web that matter cycles (i.e., biogeochemical cycle) and energy flows. Smith (1975) argued that trophic interaction is also a major organizing force within ecosystems.

Each species within a community occupies a niche. There is considerable literature on niche theory and niche dynamics. For this report I equate niche with the trophic role of a species in its community. That is, the qualitative and quantitative ways it processes matter and energy. Niches have been segregated and refined through interspecific (between species) competition. Niches are dynamic on three time scales. First, they change according to life history changes of a species (e.g., larval and adult stages of butterflies have different niches). Second, they change seasonally. Third, they change over evolutionary time.

Thus, the biotic community can be envisioned as a dynamic three-dimensional matrix of niches that captures and processes matter and energy. Unlike physical systems that process matter or energy or both, the community's integrity is dependent upon continuous imput of matter and energy. In fact, the concept of energy flow as an organizing force in open system thermodynamics has directly and indirectly produced several "unifying concepts" in community-ecosystem ecology. Ecologists have searched for a unified theory to account for geographic variations in community structure (principally species diversity) and biotic succession (i.e., the apparent orderly replacement of one biotic community by another). According to Prigogine's theorem, open systems have maximal structural order and efficient material cycles when energy input equals output (i.e., they are in steady state).

Thus, ecological systems should evolve structure that comes closest to equalizing energy input and output (i.e., the climax community). Since physico-chemical constraints differ across space, community structure should also differ. Succession is the local process by which the climax assemblage develops over ecological time. One stage outcompetes another until there is a persistent community. This terminal association should have the most complex and stable structure, and most efficient biogeochemical cycles because it is closest to the steady state. Extending Smith's (1975) arguments, the internal development of this organization is through competitive trophic and spatial interactions (i.e., reciprocal or co-evolution) among species. That is, neo-Darwinian processes of adaptation and natural selection function in ecosystem evolution. The process is Markovian, each change constrains the set of next possible changes.

Observations that climax communities persist through time with apparently greater stability than earlier successional stages and that some forms of diversity (usually species) increase with succession have led to the diversity-stability hypothesis. This states that diverse systems are more stable than less diverse ones. This idea has persisted in ecology for some time and is a basis for laypersons to conceive of diverse systems as being more desirable than less diverse systems. Most guidelines for environmental impact statements, assessments and analyses require evaluation of ecosystems in terms of species diversity. However, the relations between diversity and attributes of persistence, stability, predictability, steady state energy flow, ecological efficiences, biogeochemical cycles, productivity, etc. are unclear.

Consider stability. May (1973) developed mathematical models of systems that suggest increased diversity is accomplished by increased dynamic fragility. Odum (1975) hypothesized

> " . . . that too much diversity can be destabilizing as well as too little. . . [and] . . . that optimum diversity is a function of the quality and quantity of energy flow. Low diversity may be optimum in ecosystems strongly subsidized by high quality auxillary energy flows and/or by large nutrient inputs, while a higher diversity may be optimum in ecosystems limited by the quality of energy input and/or dependent on internal nutrient recycling. Any positive correlation between diversity and stability is, therefore, a secondary rather than a primary relationship. Which is to say that quite stable systems in terms either of persistence in time or in terms of resistence to perturbation can have either a low or a high diversity, depending on the energy forcing function."

He based the above hypothesis on 150 censuses of major trophic and taxonomic components which have important roles in ecosystems representing a wide variety of natural, seminatural, managed and cultivated types. He used species diversity as measured by the reciprocal Simpson Index where Pi is the probability

$$1 - \Sigma \ (Pi)^2 \qquad (1)$$

for each species in terms of the ratio of its importance to the total of importance values. He used numbers as the basis for importance where individual sizes were comparable, but biomass or productivity where sizes varied widely. The index scales diversity from

0-1, where 0 is the lowest and 1 is the maximum. The frequency distribution of the diversity index values was bimodal, low (0.05-0.2) in one group and higher (0.7-0.85) in another. There were relatively few ecosystems with intermediate diversities (ca. 0.5) and no case where there were large numbers of species with similar importance (i.e., producing index close to unity). Low diversity systems were stressed (i.e., degraded) by external factors such as inputs to polluted aquatic systems, or were agriculturally managed croplands and forests. Systems receiving large high quality and predictable energy subsidies and nutrients (e.g., tidal marshes) also showed low diversity. High diversity was observed in ecosystems powered principally by sunlight (a low quality energy source relative to its utilization efficiency), such as grasslands, upland forests, lakes in stable or nutrient-poor watersheds.

Odum stated that

> "The strategy of nature is to diversity but not to the extent of reducing energetic efficiency . . . the quality of energy in terms of utility and low entropy is as important as the quantity . . . the optimum diversity is determined by both the kind and the level of energy input. When one or a few sources of high utility energy coupled with pumped-in growth-promoting substances are available in excess of maintenance needs, low diversity has its advantages; a concentrated and specialized structure is more efficient in exploiting the bonanza than is a dispersed structure. It is perhaps under such conditions that high diversity is destabilizing (i.e.,

> undesirable) as May's (1973) theoretical models show. High energy, low diversity systems can be quite stable both time-wise and in terms of resistance to perturbation if the input subsidies are regular or continual at the same level over long periods of time . . . . Under such conditions a low diversity of the order of 0.1-0.2 is optimum. But . . . such systems will tend to 'boom or bust' when the subsidies fluctuate irregularly where energy is limiting or of low . . . then a higher diversity of order of 0.7-0.8 appears to be optimum for the performance of the steady state."

Odum also pointed out that high diversity characterizes ecosystems in very stable physical environments (e.g., some ocean bottoms, wet tropics). This supports the stability-time hypothesis which states that diversity should be highest in regions that have been stable for the longest time. The stability-time hypothesis essentially articulates the other view of diversity-stability relations. That is, diversity does not precede or cause stability first; stable environments permit development of diverse communities. They, in turn, may become more stable internally, resisting invasion by exotic species, disease epidemics, violent population fluctuations, etc.

On the base of his data, Odum urged caution in using diversity as an index to pollution or other human effects on ecosystems; and stated "If the impacted system has high diversity, then most stresses will certainly lower the diversity. But if the system has a low diversity to begin with, then a man-made perturbation may actually increase diversity ratios."

Odum's data essentially accord with Smith's (1975) contention that trophic interaction is a major organizing force in ecosystems. The matrix of niches appears to develop as a function of energy and matter forcing functions. Thus, ecosystem structure as increased by diversity must be considered in the context of the set of forcing functions.

I have used diversity and stability without clearly defining them or discussing how to measure them. However, before doing so, I wish to conclude the diversity-stability argument with excerpts from Goodman's (1975) fine treatment of the subject

> "About twenty years ago, the belief, traditional among ecologists, that complex natural communities are more stable than simple ones was given formal expression in a way that seemed to offer promise of both precise empirical tests and further theoretical development. The elaboration of theoretical models at first yielded gratifying results suggesting reasons why complex ecological systems should indeed be more stable, but these models suffered from questionable analogies and the use of peculiar and unrealistic mathematical representations. The broad scope of the diversity-stability hypothesis, and its particular implications, elevated it to a position of importance in practical debates concerning resource management, pest control, and preservation of natural areas. Observational confirmation of the diversity-stability hypothesis never materialized . . . The social implications of the failure of diversity-stability theory involve both straightforward practical concerns and more subtle problems of conservationist ideology.
>
> The diversity-stability hypothesis has been trotted out time and time again as an argument for various preservationist and environmentalist policies. It has seemed to offer an easy way to refute the charge that these policies

> represent nothing more than the subjective preferences of some minority constituencies. The burden of evidence subsumed in this review indicates that this particular defense will not be possible much longer, since continued scientific support for an untenable theory would become an embarrassment to that spirit of detached empirical sobriety which so often is held up as an ideal of scientific comportment. From a practical standpoint, the diversity-stability hypothesis is not really necessary; even if the hypothesis is completely false it remains logically possible - and, on the best available evidence, very likely - that disruption of the patterns of evolved interaction in natural communities will have untoward, and occasionally catastrophic, consequences. In other words, although the hypothesis may be false, the policies it promotes are prudent. The troubling questions for the moment are how effectively these policies will be defended with scientifically more acceptable arguments, and how smoothly this transition can occur.
>
> The diversity-stability hypothesis may have caught the lay conservationists' fancy, not for the allure of its scientific embellishments, but for the more basic appeal of its underlying metaphor. It is the sort of thing that people like, and want, to believe. Thus, though better theories supplant it in scientific usage, we may be certain that the "hypothesis" will persist for a while as an element of folk-science. Eventually, that remnant, too, may vanish in light of discordant facts, and the essential imagery of this once-scientific hypothesis will recede to a revered position in the popular environmental ethic, where it doubtless will do much good."

Diversity can take two major forms in ecosystems: spatial heterogeneity (e.g., horizontal and vertical complexity of the physical environment, biotic structure as in foliage heights of plants) and species (niche) diversity. Although the former has direct and indirect stabilizing effects on population dynamics (e.g., predator-prey, herbivore-plant, parasite-host relations) and may influence species diversity (e.g., more bird species are found in woodlots with high foliage-height diversity than in those with less), species diversity is the more frequently used to measure community-ecosystem complexity. Because species represent niches (recall that one species' niche may change seasonally and according to the life history stage so that one species actually represents a "niche spectrum"), species diversity is a first approximation of, say, trophic diversity (i.e., diversity of matter and energy channels).

Species diversity has two major components, variety or richness and evenness or equitability. Richness has to do with the number of different species (S) that exist in a community, and evenness is a function of how the total number of individuals (N) is distributed among S species. Thus, maximum diversity for a 10 S community with 1000 N would be when each S has 100 N. Number of individuals per species essentially represents a numerical importance value (Ni/N) for the i^{th} species (S_i). Use of numbers may be suitable for a set of species that are of similar sizes and physiologies. Other variables such as biomass, bio-content (caloric equivalent of biomass), productivity (grams or calories produced by species per unit time), energy flow (production + respiration per unit time), etc. can be used.

Extreme care must be used in selecting the variable and set of species for diversity measurements and in deciding what the diversity index measures beyond the obvious "importance" of each species relative to numbers, biomass or some process. If it is to reflect the possible number and relative importance of, say, energy flow channels or intertrophic connectivities, then species must be grouped according to their trophic level(s). Since many species feed in more than one level on a daily or seasonal basis or both, this becomes complicated. This difficulty faces the modeler when attempting to construct equivalence input-output classes for compartmental models of ecosystems.

Before discussing diversity in terms of trophic connectivities, I wish to list the most frequently used indices. I will not comment on their relative merits beyond saying that the optimal index should be reasonably independent of sample size and measure both components of diversity. Shannon-Weaver and Simpson's indices are the most frequently used and satisfy the requirements as well as any others. It should be kept in mind that the biological relevance, if any, of the index depends upon what ecosystem attribute is being used.

Simpson's Index is

$$D = 1 - \sum_{j=1}^{S} \frac{Nj(Nj - 1)}{N(N - 1)} \quad (2)$$

where Nj - number (or biomass, etc.) of individuals in the j^{th} species and N = total number of individuals in the collection of S species.

Index of dominance (variation of number 2) is

$$C = \sum_{j=1}^{S} (nj/N) \quad (3)$$

where nj = importance value (e.g., numbers, biomass) of the i^{th} species and N = total of importance values.

Index of Similarity between two communities

$$S = \frac{2\ C}{A + B} \quad (4)$$

where A = number of species in community or a sample one, B = number in two and C = number common to both.

Index of Dissimilarity

$$D = 1 - S \quad (5)$$

Varietal or richness indices

$$D = S = \text{number of species only} \quad (6)$$

$$D = S / 1000\ N \quad (7)$$

$$D = (S - 1) / \log N \quad (8)$$

$$D = S / \sqrt{N} \quad (9)$$

where N = total number of individuals in S species.

Indices based on the Information Theory

$$I = \log_2 S \quad (10)$$

$$I = \log_2 \frac{(N - 1)!}{(N - S)!(S - 1)!} \quad (11)$$

$$I = \log_2 N! \quad (12)$$

$$I = \frac{1}{N} \log_2 \frac{N!}{N_1!N_2! \ . \ . \ . \ N_s!} \quad (13)$$

$$I = \log_2 (N^N) \quad (14)$$

$$I = N (\log_2 N - 1) \quad (15)$$

$$\bar{H} = - \sum_{i=1}^{S} Pi \log_2 Pi \quad (16)$$

where I = information (diversity) in bits. Number 10 gives I_{min}, based simply on the number of species. Number 11 gives information content (diversity) of knowing how N is distributed among S. Number 12 is Brillouin's index and gives total I_{max}, based on knowing where each individual is located in space. Number 13 gives I_{max} per individual. Numbers 14 and 15 use

Stirling's approximation ($\log_2 N! = N(\log_2 N - 1)$ of Brillouin's Index. Number 16 is the most frequently used index based on the Information Theory. It was recently discussed by Mulholland (1975) and Goodman (1975), who presented constrasting views as to its usefulness. The relative importance of each species is Pi.

Evenness Index

$$J = \bar{H} / \bar{H}_{max} \qquad (17)$$

where $\bar{H}_{max} = \log_2 S$ (i.e., when each S has an equal number (or biomass, etc.) of individuals.

Redundancy Index

$$b = \bar{H} / \bar{H}_{max} \qquad (18)$$

Mulholland (1975) stated that "Diversity and the complexity of food web structure, or connectivity, are central to the discussion of ecological stability and choice." Instead of simply using species diversity measured by numbers, biomass, biocontent, etc., he suggested that we "consider a definition of diversity as the effective number of choices between equally likely alternatives for the flow of energy through the ecosystem." Mulholland demonstrated that "the complexity of the food web structure, and hence the ecological stability, can be altered by changing the initial flow vector." I find the basic concept, which predates Mulholland's paper (e.g., Odum 1953; MacArthur 1955; Margalef 1963), intuitively pleasing and compatible with Odum's (1975) hypothesis and Smith's (1975) contention that energy-nutrient drives and trophic interaotion organize communities. However, Mulholland pointed out that "In order to be of practical use as a tool for ecosystem analysis, the stability index . . . must be tested in real world situations. It must also be evaluated relative to other proposed measures of ecological stability. And, with respect to theoretical studies, it must be investigated as a possible connection between the concept of ecological stability and the formal mathematical stability definition." Such an evaluation will be difficult, requiring considerable effort. Orians (1975) stated that

> "Unfortunately it will be difficult to establish causal relationships between stability and diversity because we must measure one or more concepts of stability in ecological systems differing only in some measure of diversity. The easiest ecosystems to compare cannot provide adequate proof because differences in diversity are usually associated with differences in the physical environment and other complicating factors. Rather than demonstrating greater stability in species-rich systems we may only be showing that species are more vulnerable to disturbances in marginal environments, or that environmental constancy facilitates diversity while reducing perturbations that might affect stability. In fact, we are confronted with the apparent paradox that stability in natural ecosystems seems to be associated with diversity whereas increasing the diversity of a variety of model ecosystems tends to reduce rather than enhance their stability (May, 1973).

> Another attractive option, the perturbation experiment, also confronts serious interpretational problems because the species in ecosystems are coevolved and removal or addition of one or more of the species not only changes the diversity of the system but many of the interaction parameters as well. Which of the changes should be attributed to differences in diversities and which should be attributed to changed interactive patterns is difficult to determine. If the species are allowed to adjust evolutionarily to the new association patterns, the final stabilities may be very different from the ones observed immediately after the perturbation.
>
> Theoretical developments face similar problems. Most formal analyses of concepts of stability are based on non-linear population equations. Given a system of these equations, equilibrium populations are determined by setting all growth rates equal to zero and then analyzing the effects of perturbations around the equilibrium. A common bond is the use of an m x m matrix, referred to as the interaction matrix, each element of which describes the effect of species j on species i near equilibrium. Analysis of an interaction matrix reveals whether or not the system is stable, i.e., if it returns to its original state after a perturbation, and the speed of return which can be estimated from the values of the elements. Most theoretical studies have focussed on local stability under deterministic environments and small perturbations. It is, however, also possible to construct matrices whose elements are random variables and to analyze responses to stronger perturbations (May 1973), or to considerable qualitative matrices in which only the signs of the interactions are known and not these values."

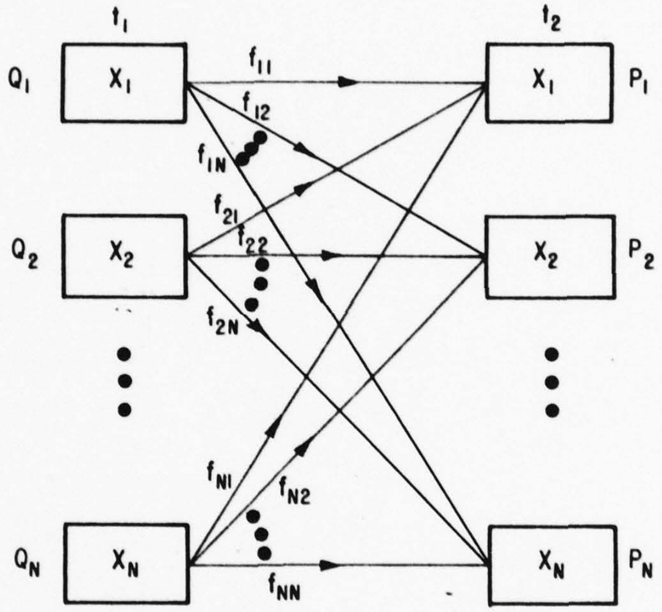
Mulholland used ". . . a piecewise linear, donor-controlled compartment type system [model]" developed for an International Biological Program (grassland biome study, Patten 1972) for a stability analysis. Although only a first approximation of this approach, I believe it demonstrated enough value for workers to pursue it. However, I suggest that simultaneous examination of other, more easily measured, diversity parameters (e.g., species diversity) be taken. Thus, if there is high correlation between Mulholland's pathway choice index and a more easily obtained attribute, the latter could be used.

Also, as pointed out by Mulholland

> "The diversity of throughput [= compartment content, say in calories x turnover] does not completely characterize the choice of pathways for energy flow and, as has been demonstrated experimentally . . . it cannot be used exclusively as a measure of stability. The choice of pathways for energy flow, and hence the ecological stability, depends not only on the diversity of throughput but also on the complexity of the food web structure. Complexity of the food web structure, or connectivity, refers to the degree and patterns of component interdependence in an ecosystem. Maximum complexity occurs when every compartment derives energy from every other compartment in equal amounts. A [linear] food chain represents minimum complexity or connectivity."

I believe that the maximum complexity is as Mulholland stated, but do not believe that there is any reason to believe a priori that this evenness should evolve in all climax communities. The number of throughput channels and their relative importance should be a function, as Odum (1975) argued, of the quality and quantity of the forcing functions. Considerable basic research is needed on the dynamics of food web complexity and their relations to inputs (i.e., their quantity, quality, and predictability). This research is essential to developing stream models (e.g., WQAM). However, because Mulholland's approach has merit, can be used to describe ecosystem diversity in another way and enables discussion of the Shannon-Weaver equation, I will present his model before going into what is meant by stability.

Mulholland used a compartment model (shown below; his Fig. 1) connected by energy flow channels to demonstrate his idea.



The compartments (i.e., populations of species in different trophic levels; again recall that occupancy of trophic positions by a species is time varying, something not considered by Mulholland, but must be in future work), x_1, x_2, . . . x_n, are shown at two times t_1, and t_2. The percentage of total energy flow through the system at t_1, passing through $x_i = Q_i$ and P_j = percentage of total energy throughput at t_2 passing through x_j. The percentage of total energy flow through x_i that passes to x_j between t_1 and $t_2 = f_{ij}$. The relations among these variables are described by

$$Pj = \sum_{i=1}^{N} fij\ Qi \qquad (19)$$

At t_1, without any structural food web information, the energy throughput diversity is

$$D = - \sum_{i=1}^{N} Q_i \log Q_i \qquad (20)$$

This is the uncertainty of how energy from given sources is apportioned among n compartments. If $\log_2$ is used the uncertainty can be thought of as the number of bits of information (i.e., number of yes-no questions that must be asked) necessary to determine with unit probability where the next unit of energy passing into x_i came from. Clearly, the maximum information is required where there is equal probability that the unit of energy came from each source. Mathematically this is, for n sources, $\log_2 n$. The minimum, zero, is when there is only one source possible.

If the food web structure is known (i.e., increased information base), a quantity known in information theory as the average mutual information, I, can be used to measure the uncertainty resolved by that knowledge.

$$I = \sum_{k=1}^{N} \sum_{j=1}^{N} f_{kj} Q_k \log [f_{kj} / \sum_{i=1}^{N} f_{ij} Q_i] \qquad (21)$$

The measure of the average remaining uncertainty about energy sources at t_2 is called conditional entropy, S, and is calculated as

$$S = D - I \qquad (22)$$

Mulhollan argued that S ". . . is equivalent to the effective choice of pathways for energy flow. Thus, a measure of the remaining uncertainty . . . [and] . . . a measure of effective choice, and hence a useful index of stability. It is also clear that the complexity of the food web reflects the opportunities for choice of path."

Orians (1975) listed seven meanings for stability. He pointed out that the terms were not intended as a classification system. These terms are:

1. Constancy - a lack of change in some parameter of a system . . .

2. Persistence - the survival time of a system or some component of it.

3. Inertia - the ability of a system to resist external perturbations.

4. Elasticity - the speed with which the system returns to its former state following a perturbation.

5. Amplititude - the area over which a system is stable (also known as global stability; the distance it can be displaced and still return).

6. Cyclic stability - the property of a system to cycle or oscillate around some central point or zone.

7. Trajectory stability - the property of a system to move towards some final end point or zone despite differences in starting points.

Stability of a system must be considered in terms of its environment. Ecosystems have evolved various mechanisms of stability relative to the sresses their species have encountered over evolutionary time. Thus, we should not expect stability when new forces are applied to our ecosystem (e.g., pollution).

I will conclude the comments on stability (Table 1; Orians 1975) of environmental factors and species characteristics that appear to increase stability.

A. Persistence
  1. Environmental heterogeneity in space and time
  2. Large patch sizes
  3. Constant physical environment
  4. High resource utilization thresholds of predators

B. Inertia
  1. Environmental heterogeneity in space and time
  2. Greater phenotypic diversity of prey
  3. Multiplicity of energy pathways
  4. Intraspecific variability of prey
  5. High mean longevity of individuals of component species (Frank, 1968)

C. Elasticity
  1. High density-dependence in birth rates
  2. Short life cycles of component species
  3. Capacity for high dispersal
  4. Strong migratory tendencies
  5. Generalized foraging patterns

D. Amplitude
  1. Weak density-dependence in birth rates
  2. Intraspecific variability of component species
  3. Capacity for long-distance dispersal

4. Broad physical tolerances
5. Generalized harvesting capabilities
6. Defense against predators not dependent on a narrow range of hiding places

E. Cyclic Stability

1. High resource-utilization thresholds
2. Long lag times in response of species to changes in resource availability
3. Heterogeneity of environment in space and time

F. Trajectory Stability

1. Strong organism-induced modifications of the physical environment
2. All factors increasing elasticity.

Even the simplest communities and ecosystems are extremely complex in structure and behavior. Structural and behavioral attributes are also time varying. Thus, complexity has both spatial and chronological components. Modern ecology is actively addressing functional attributes of ecosystems, but in most instances, our knowledge of structure is inadequate to support development of testable theories relating to function and structure. There are numerous concepts, but relatively few falsifiable theories at the community-ecosystem levels. Development of these theories and testing them are essential prerequisites for development of appropriate land planning and resource management strategies, and construction of predictive computer models (e.g., WQAM).

We must have time-varying baseline data on structure and dynamics of ecosystems collected under the time-varying regime of their forcing functions. The quantity, quality, and predictability of the inputs under which the systems have evolved must be studied simultaneously with the structure and behavior. Such studies should be conducted by personnel representing biological and physical sciences (e.g., chemistry, physics, hydrology, meteorology, geology), and engineering.

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II. STRUCTURE AND DYNAMICS OF BIOTIC COMMUNITIES IN STREAM ECOSYSTEMS

In this section I wish to discuss some of the known relations between structure and dynamics of lotic (flowing water) communities, and emphasize types of data and future stream research that are relevant to WQAM development. I will specifically focus on the energy/matter drives (i.e., forcing functions) on stream communities, because they appear to be principle organizers of lotic ecosystems. Recall from Section I that Odum (1975) argued that the quality, quantity, and predictability of energy inputs govern species diversity (= major component of biological organization), and Smith (1975) suggested that trophic interaction (internal energy transfer) is a major ecosystem organizer.

If the nature of stream biotic communities derives principally from energy/matter inputs, we should expect that alterations of these inputs (e.g., changing their time dimension, adding new energy sources or increasing or decreasing existing ones, adding physical or chemical pollutants that affect internal energy processing) should produce basic changes in that nature. Some of these changes will be temporary, others permanent. We should expect that stream communities will adjust more easily to changes in their inputs that have occurred naturally over evolutionary or ecological time (i.e., those "stresses" that the stream biota have "learned to live with"). Thus, we should expect that most activities associated with Air Force bases that alter the quality, quantity and predictability of energy/matter drives on streams traversing the bases will produce deliterious effects on stream biotic organization. The nature of these effects or how harmful they are is relative to the type of stream, its history and state prior to the impact(s). Prediction of these effects minimally requires the baseline data listed on pages 3 and 4 in the Introduction.

Much of our knowledge about stream ecology has come from taxonomic and life history studies. These have focused on the species. According to Cummins (1974) "Frequently, traditional ecological studies have been taxonomic inventories of biological communities - information of limited use in answering certain function - and process - oriented questions." Cummins argued that stream ecologists must focus beyond the species-recognition/taxonomic inventory level ". . . in order to address important process-oriented ecological questions." Of course basic taxonomic descriptive information is beneficial to stream ecology, but it is only a means (i.e., tool) and should not be considered as an end product in ecological research. Cummins essentially suggested that ecologists should focus on functional roles of organisms. Generally, functional roles are equated with trophic positions. However, these trophic assignments are frequently based on inadequate literature reports, seldom on sound empirical data. Also, exchange rates (i.e., energy/matter fluxes among species) are almost always approximated crudely, if at all. According to Cummins (1974) trophic categorization has generally failed to deal adequately ". . . with the functional roles concerning community metabolism of particulate (detritus) and dissolved organic matter" in stream ecosystems.

Because particulate organic matter (POM) and dissolved organic matter (DOM) represent significant energy drives in stream ecosystems, they have recently received considerable attention (see numerous citations in bibliography). The POM and DOM may be principally generated internally (autochthonous) or derived from the surrounding watershed(s) as inputs (allochthonous). Essentially, streams can be divided into two classes based on whether a majority of their energy is produced internally or in the terrestrial systems through which they flow. Generally, allochthonous-driven streams are those which flow through forested watersheds and are covered with canopies of vegetation which significantly reduce solar energy input. According to Cummins (1974) "the present status of our knowledge of stream ecosystem structure and function is based on a number of generalizations that have been tested to some degree - primarily in woodland streams of the temperate zone." Thus, our extant data base of stream biotic structure and dynamics is quite restricted. We must expand this data base to include temperate streams that do not flow in forested watersheds and streams in other climatic zones (e.g., subtropical, tropical, tundra) which flow through both forested and non-forested watersheds. The streams must also be representative of the various stream orders (i.e., first, second, third, . . . order). Such a broader data base should enable ecologists to test the applicability of Odum's (1975) theory that biotic diversity is a function of energy input to stream ecosystems. However, it is imperative to these studies and testing of theories similar to Odum's that the "proper" diversity parameter(s) is (are) used. I believe that diversity in terms of the number, connectiveness and relative importance (i.e., dimension and rates) of stream energy/matter processing channels should be used as principal parameters.

Because most of the process-oriented information available is for woodland streams, and much of it has been well-treated and summarized (e.g., Cummins 1974, Boling et al. 1975), I will focus on them in this section.

Cummins (1974) pointed out two major features of woodland streams:

> ". . . first, a dependence for the majority of their energy supply on the import of organic matter elaborated in the terrestrial system through which the stream flows (the watershed), and second, the utilization of a great deal of this organic input during the fall-winter period of lowest annual temperatures. That is to say, stream communities are heterotrophic (dependent upon food produced outside the stream) and temperature compensated (having organisms that can process organic matter at reasonable rates below "normal" temperature optima)."

Fisher and Likens (1973) reported Bear Brook (a first order New Hampshire stream) received 99% of its energy as allochthonous input, and mosses produced the remaining 1% by photosynthesis. The allochthonous drive was composed of 47% DOM and 53% POM. Of this, 34% was metabolized to CO_2, principally by microorganisms, and the rest exported downstream. Thus, a significant proportion of the input to Bear Brook was not assimilated and respired, but passed on to other portions of the lotic (and perhaps eventually to lentic systems) system. If this is the normal assimilative capacity, then increased organic inputs through human actions would probably be exported downstream and not metabolized. Sedell et al. (1973) reported that two small streams in the Oregon Cascades received 99% of their organic matter from the surrounding terrestrial ecosystems, but that about 67% was directly processed in situ with 33% apparently being exported. Apparently the biotic structure and process capabilities for DOM and POM have evolved under the high organic-energy inputs. Even though, an array of constraints apparently precludes the system from evolving a greater total assimilative capacity. What these constraints are (i.e., what limits energy processing) is an important question facing stream ecologists today. According to Cummins (1974), "Determination of the rates and efficiencies at which organic matter is processed (converted to CO_2 and nutrients) in running water systems and the factors regulating such rates and efficiencies probably constitutes the primary goal of the present stream research effort."

Fisher and Likens (1973) suggested ". . . that small streams, being among the most open ecosystems, have relatively low efficiency and high flow-through energy. Watershed management programs should take cognizance of stream ecosystem efficiency, especially where watersheds are situated above recreational waters of marginal quality."

With regard to processing organic matter, streams can be classified as heterotrophic (i.e., production/

respiration < 1) or autotrophic (i.e., P/R > 1) or in steady state (i.e., P/R = 1), and conduit (i.e., organic import/export < 1) or process (i.e., I/E > 1) or in inport/export steady state (i.e., I/E = 1). Production is generally measured by CO_2 consumption and O_2 production using a variety of methods (e.g., light-dark bottles, ^{14}C, diurnal curves). A discussion of these methods is beyond the scope of this section. The literature is repleat with papers discussing each method. The P/R and I/E ratios are time varying, changing with season, and spatially varying, changing with stream order (Cummins 1974) and undoubtably with climate and watershed vegetation (see Odum 1950, Fisher and Likens 1973). Detailed assessments of the relative importance of heterotrophic vs. autotrophic mode or inport vs. export mode requires "periodic assessment of the average detritus standing crop in a section of stream, primary production (in-stream photosynthesis), and community respiration . . ." (Cummins 1974). Cummins (1974) pointed out that

> ". . . the ratio of heterotrophy to autotrophy is controlled by light, temperature, organic and inorganic inputs, and flow, with lesser localized effects by invertebrate grazers (scrapers). Shifts from heterotrophy to autotrophy in streams usually involve conversion from the typical diatommoss (e.g., Fontinalis) community and, in some streams, also watercress (Nasturtium) beds around the springs, to filamentous green algae (e.g., Cladophora, Stigeoclonium, Ulothrix, etc.) and/or beds of rooted aquatic plants."

Thus, for comparative purposes among streams and within streams among seasons, "primary production should be measured against a back ground of light, temperature, and nutrient (especially P and N) . . . [and] cumulative measures of light and temperature, e.g., foot- or meter- candle-hours or days (1 m - cand. = 1 lumen/m^2) and degree days, should prove more useful than calendar time intervals" (Cummins 1974). Generally, low order (first-third) streams are more heterotrophic than higher order slower moving streams with less vegetational cover. However, human activities such as deforestation and landscaping practices that alter watershed runoff, construction of dams and pollution can alter this pattern.

Regardless whether a stream is principally autotrophic or heterotrophic it contains three major functional biotic categories. These are autrotrophs (e.g., algae or micro producers and vascular plants or macro producers), consumers (i.e., principally animals, both micro- and macroconsumers) and transformers (i.e., decomposers such as bacteria and fungi). The relative importance of these three groups in processing energy obviously varies within and among streams, both spatially and temporally. Because most published information on functional groups in stream ecosystems is for heterotrophic systems, I will limit my review to consumer organisms. These are generally divided into microconsumers (e.g., microbial organisms such as fungi and bacteria, also known as decomposers or transformers, and protozoa, diatoms and rotifers) and macroconsumers (e.g., microcrustaceans, nematodes, water mites, mollusks, insect larvae and crustaceans).

Microconsumers are rarely, if ever, separated from the non-living organic matter in streams because of the extreme difficulty. Thus, Cummins (1974) stated that ". . . consideration of these components [living organisms and non-living organic matter] as functionally separate compartments seems merely academic," and suggested that "at present, compartmentalization of organic substrate and associated microbes by particle size, which is clearly related to processing time, seems to be the most tractable approach." Table 1 on the following page gives a scheme for partitioning stream organic detritus according to size. This is taken from Table 2 in Cummins (1974).

Obviously, all organic matter forms a size continuum. However, the classification of organic matter in the table is operationally functional. In fact, Hynes (1963) and Ross (1963) have pointed out that POM inputs, principally autumnal leaf litter, have been major forces in the evolution of stream biota. Thus, supporting Odum's (1975) theory that

TABLE 1--Classification of Detritus Correlates for Aquatic Ecosystems

Detritus Categories		Acronym	Approximate size ranges (mm)	Dominant Constituents	Dominant animal detrital feeding group
General	Specific				
Coarse particulate organic matter (CPOM)	Large resistant particulate organic matter	RPOM	> 64	Logs, branches, large twigs large sections of bark (processing times > 1 year)	Detritus shredders
	Whole leaf organic matter	LVOM	> 16 < 64	Leaf litter (leaf packs)	Detritus shredders
	Leaf fragment organic matter	LFOM	> 4 < 16	Large leaf, twig, and bark fragments, fruits and nuts, large seeds, buds and flowers, conifer needles	Collector-macrogatherers
	Large particulate organic matter	LPOM	> 1 < 4	Small fragments of plant (and animal) parts	Collector-macrogathers Collector-macrofilterers
Fine particulate organic matter (FPOM)	Medium particulate organic matter	MPOM	> 0.25 < 1	Plant and animal fragments, feces of large invertebrates	Collector-macrofilterers Collector-microgatherers
	Small particulate organic matter	SPOM	> 0.075 < 0.25	Plant, animal, and fecal fragments of large invertebrates and feces of small invertebrates	Collector-microfilterers Collector-microgatherers
	Very small particulate organic matter	VPOM	> 0.0005 < 0.075	Very small detrital fragments and free microorganisms	Collector-microfilterers
Dissolved organic matter		DOM	< 0.0005	Organic matter in solution-leachate from plant and animal detritus, microbial and producer excretions	Little or none

quality and quantity of energy input is principal in organizing diversity in ecosystems.

In addition to directly metabolizing DOM (as do some of the autotrophs), the microbes, principally bacteria and fungi "condition" much of the larger POM making it suitable nutritionally for macroconsumers. In fact, some macroconsumers may actually feed directly on the microbial organisms, ingesting the non-living POM incidently. Because many pollutants are organic, both DOM and POM, and many other pollutants adsorb to POM, it is essential to understand dynamics by which streams process DOM and POM. This is an area of research necessary for WQAM development. We must understand to what extent sediment and water column subsystems operate dependently or independently in processing DOM and POM. Cummins (1974) essentially pointed out a need for future research in this area by stating

> "As new techniques are developed and more data gathered, microbial and biochemical differences which transcend particle size categories will certainly become apparent. In addition to direct observation of microorganisms (especially epifluorescence and scanning electron microscopy . . .), the isolation and identification of biochemical capabilities of microbial elements will provide critical additional resolution of functional roles. For example identification and quantification (probably through microcosm and tracer uptake studies) of cellulolytic and/or lignolytic activity of detrital bacteria in fungi in natural streams under normal stream temperature regimes should constitute a prime objective for lotic researchers. Fractionation of DOM by molecular weight should permit recognition of microbes

> associated with certain fractions and concomitant processing rates . . . Again, if stream studies are process-oriented, new microbial data will be most useful if related to rates at which conversions of coarse particulate to fine particulate to dissolved organics to CO_2 occur."

Aquatic microbiology appears to be an area for fruitful research and should be encouraged by the Air Force.

Macroconsumers in streams are generally dominated by insect larvae. They are extremely important in energy transfer and matter conversions because of their high densities and turnover rates. Studies of life history energetics and trophic relations are central to understanding roles of these macroconsumers in stream ecosystems. Because niches change with an organism's age, evolution of its function must be assessed over its life cycle (e.g., McDiffit 1970; Brown and Fitzpatrick 1978[1]). Essentially, an insect macroconsumer's life history energy budget can be summarized as follows:

[1] Brown, A. V. and L. C. Fitzpatrick. Life history and population energetics of the dobson fly _Corydallus cornutus_. Ecology. In Press.

Life History	Time			Process[a]				
Stage	Duration	C	F	U	A	R	Pg	Pr
OVUM								
Larval Instars								
1								
2								
3								
.								
.								
.								
N								
Pupa								
Adult								
	ΣT	ΣC	ΣF	ΣU	ΣA	ΣR	ΣPg	ΣPr

a. C = consumption, F = egesta, U = excreta, A = assimilation, R = respiration, Pg = production as gametes or offspring in mass (g dry or wet weight) or calories per unit time; $C - (F + U) = A$, $A - R = P$.

If demographic data and population densities are known, the data in the table can be extrapolated to the stream. Details on techniques of gathering life-history energetics data are beyond the scope of this section.

Cummins (1973) outlined a functional classification system for trophic relations of aquatic insects. The following (Table 2) is taken from his Table 1.

TABLE 2--Trophic Relations

General category based on feeding mechanism	General particle size range of food (microns)	Subdivision based on dominant food
Shredders	$>10^3$	Chewers and miners
		Chewers and miners
Collectors	$<10^3$	Filter or suspension feeders
		Sediment or deposit (surface) feeders
Scrapers	$<10^3$	Mineral scrapers
		Organic scrapers
Predatora	$>10^3$	Swallowers
		Piercers

Subdivision based on dominant food	North American aquatic insect taxa containing predominant examples
Herbivores, living vascular plant tissue	Trichoptera (Phryganeidae, Leptoceridae) Lepidoptera Coleoptera (Chrysomelidae) Diptera (Chironomidae, Ephydridae)
Detritivores (large particle detritivores): decomposing vascular plant tissue	Plecoptera (Filipalpai) Trichopter (Limnephilidae, Lepidostomatidae) Diptera (Tipulidae, Chironomidae)
Herbivore-detritivores: living algal cells, decomposing organic matter	Ephemeropter (Siphlonuridae) Trichoptera (Philopotamidae, Psychomyiidae, Hydropsychidae, Brachycentridae) Lepidoptera Diptera (Simuliidae, Chironomidae, Culicidae)
Detritivores (fine particle detritivores): decomposing organic matter	Ephermeroptera (Caenidae, Ephemeridae, Leptophlebiidae, Baetidae, Ephemerellidae Heptageniidae) Hemiptera (Gerridae) Coleoptera (Hydrophilidae) Diptera (Chironomidae Ceratopogonidae)
Herbivores: algae and associated material (periphyton)	Ephemeroptera (Heptageniidae Baetidae, Ephemerellidae) Trichoptera (Glossosomatidae, Helicopsychidae, Molannidae, Odontoceridae, Goreridae) Lepidoptera- Coleoptera (Elmidae, Psephenidae) Diptera (Chironomidae, Tabanidae)
Herbivores: algae and associated material (periphyton)	Ephemeroptera (Caenidae, Leptophlebiidae, Heptageniidae, Baetidae) Hemiptera (Corixidae) Trichoptera (Leptoceridae) Diptera (Chironomidae)
Carnivores: whole animals (or parts)	Odonata Plecoptera (Setipalpia) Megaloptera Trichoptera (Rhyacophilidae, Polycentropidae, Hydropsychidae) Coleoptera (Dytiscidae, Gyrinnidae) Diptera (Chironomidae)
Carnivores: cell and tissue fluids	Hemiptera (Belastomatidae, Nepidae, Notonectidae, Naucoridae) Diptera (Rhagionidae)

Cummins' (1973) summarized the knowledge concerning trophic relations of aquatic insects as follows:

> "Freshwater ecosystems of the temperate zone might be generalized as having a reasonably constant biomass of macrobenthic animals, dominated by aquatic insects (plus mollusks, annelids, and crustaceans), which is turning over at a rate controlled primarily by temperature, seasonal temperature adjustments being much less pronounced in running waters in which a very significant amount of feeding and growth occurs in the fall and winter. The temperature control of biomass turnover is mediated primarily through the positive correlation between temperature and feeding rate and temperature and respiation; thus, the ratio of feeding, or respiration, to growth is fairly constant. The aquatic insects are supplied with consistent and abundant food supplies of similar caloric and protein content. Their assimilative efficiency is independent of temperature over wide ranges and fairly constant over the broad range of food quality normally ingested (predators may have a higher efficiency than herbivore-detritivores, 70). Food resources are partitioned on the basis of particle size and whether active (prey), stationary (periphyton, vascular plants, deposited detritus), or in suspension (plankton and fine particle detritus in standing waters, particulate drift in streams and rivers). Within any general food compartment, specific utilization is determined by temporal and microspatial isolation of potential competitors - size (age) groups of a large number of species that are all trophic generalists within the particle size ranges that they are capable of ingesting. Although the data on aquatic insects are not extensive enough to determine the validity of all aspects of these generalizations, the information at hand supports the contention that most aquatic insects are best termed polyphagous or generalists and that availability, most frequently delineated by food particle size and texture, is the key to trophic relationships among aquatic insects."

The data in Cummins' (1973) Table 1 and his preceding statement represent only a beginnning in trophic analyses of stream ecosystems necessary to establish a data base for bioaccummulation studies, for pollution-effect studies and development of WQAM-type models.

In regard to management strategies of stream ecosystems, Cummins (1973) has well-articulated several:

> "The fundamental problem in stream management is clearly 'water quality,' in the broad sense meaning system quality. Regardless of definition, here lies the challenge-interfacing, in compatible fashion, the self-perpetuating structure and function of running water ecosystems with selfish, 'natureless' human goals. Water quality is, in fact, always defined in reference to these goals. For example: Will the system support a particular sport fishery? Will it be a habitat where noxious and pathogenic organisms will flourish? Will it decompose organic wastes or serve merely as an export conduit?
>
> From the data at hand, two points seem clear. First, the maintenance of water quality necessitates the continuance of certain relationships between CPOM, FPOM, and DOM together with the involvement of critical functional ecological groups of both micro- and macro-organisms. Second, unless about one third of the total organic matter input (about one half of the POM) is processed, i.e., converted to CO_2, annually by the stream system and unless in-stream plant growth remains subservient to terrestrial organic matter as the 'fuel' to drive the system, the stream in question probably has impared water quality.
>
> In general, the differences between relatively undisturbed woodland streams, characterized by high processing efficiency, and 'organically enriched' or 'polluted' running water systems of similar dimensions are the size distribution of the organic particles that enter the stream,

> timing of the inputs, POM retention characteristics of the system, temperature and nutrient regimes, and the presence of key functional groups of organisms. Where appropriate options exist, management strategies should be developed and implemented based on available stream ecosystem theory . . . 'Water quality' status should be monitored through recognition of the continued appropriate relationships between CPOM, FPOM, DOM, and micro- and macroorganisms.
>
> It is not presently known whether the efficiency with which organic matter is processed in streams can be increased above reported levels (Fisher and Likens 1973, Sedell et al. 1973). Since so few systems have been studied in a fashion permitting comparison, the range of natural efficiencies has yet to be established - clearly, comparison of streams at opposite ends of such a spectrum would be most instructive."

Cummins then suggested three management strategies that singly or in combination offer promise. These are:

1. changes in the physical nature of the running water system - light (e.g. artifical shading), temperature, aeration, POM retention characteristics, etc.,
2. changes in organic inputs, particularly particle size distribution; and
3. changes in the biota, for example shredder population densities.

Streams with a history of processing a particular regime of organic matter should not be expected to process a new regime and still maintain its present water quality in terms of ". . . natural organic matter processing rates" (Cummins 1974).

It is obvious to ecologists that stream ecosystems must be studied in terms of their physico-chemical characteristics, biotic diversity in spatial and species terms and nature of their organic inputs simultaneously. Such studies will give a data base of extant "natural" conditions of various order streams. These "natural" conditions represent extant stream quality and can be used to compare similar streams traversing Air Force bases to assess their quality. Also, such baseline data relating stream dynamics to inputs can be used in development of WQAM.

Essentially, defining stream quality is a problem facing ecologists, environmental engineers, various local, state and federal agencies, etc., involved in maintaining overall water quality. Rather strict standards exist for drinking water quality, water used for contact sports, etc., but "ecological water quality" standards are not yet set. Numerous workers have suggested using stream biota as indicators of pollution/water quality. The rationale for this was summarized by Goodnight (1973):

> "The determination of water quality by use of chemical and physical tests is widely used and has certain values. Such tests can give,

> among other facts, an immediate picture of whether or not oxygen is being depleted or if the pH of the water has been radically changed. Such data are of immediate value, but have their drawbacks, chief of which is the fact that they do not detect occasional pollution. Intermittent pollution, though not readily discernible by chemical and physical tests, does have its effect upon the aquatic biota.
>
> In general, animals and plants are much more sensitive to changes within their environment than are such tests; thus they may respond strongly to even very small amounts of pollutants.
>
> A single series of samples of the biota may give a summation of the water conditions over a past period of time (Hynes, 1963). A chemist, on the other hand must make a series of tests over several days, weeks, or even months to obtain average values. Even such average values are not as important as the extreme conditions which may occur and may be missed by periodic sampling. A toxic substance, impossible to find in a chemical analysis, will show its effects upon the animal community long after it has been carried downstream by the current.
>
> Like any type of tests, biological tests do have their limitations. The chief one is that often only a trained biologist can interpret the data with assurance. Such data, when obtained, also can not identify the specific chemical involved, though often the difference between organic and inorganic poisonous materials can be distinguished.
>
> Once it is decided that biological tests of water quality are superior to chemical or physical tests, the problem is one of deciding what members of the biota are most significant."

Wilhm (1967) and Goodnight (1973) and others have suggested that macroinvertebrates should be good indicators of stream pollution/water quality. Most benthic macroinvertebrates are less motile than, say, fish and ". . . their habitat preference . . .

cause them to be affected directly by substances which enter the environment. Chemical surveys indicate stream conditions only at the time of sampling, but benthic macroinvertebrate populations can be indicative both of present and past environmental conditions" (Wilhm 1967). Wilhm (1967; 1970) summarized species diversity indices used with macroinvertebrates to assess stream pollution/water quality. He discussed many of the indices I have listed on pages 21-23, and concluded in his 1967 paper that

> "Populations of benthic macroinvertebrates can be used to assess pollution in a stream receiving organic enrichment. Sampling stations should be established at various distances below the pollution outfall. For comparative purposes samples should be collected in clean areas either above the outfall or at a sufficient distance downstream. Sampling methods should be the same at each station. Also, it should be remembered that environmental conditions other than pollution influence the distribution or organisms.
>
> Data can be summarized clearly and briefly with a diversity index. The index selected should be independent of sample size and associated closely with the wealth of species. In the present study the index which had the highest coefficient of correlation with numbers of species and which most effectively distinguished between the stations was $(s - 1)/\ln N$. This equation is comparatively easy to use. If computer equipment is available, indices derived from information theory can be used. These models include numbers of individuals representing each species. Expressions of the wealth of species and of the abundance of one or more species are both available. Values obtained at the various stations can be compared for statistical differences with a multiple comparisons test such as Duncan's multiple range test . . . If a functional expression is desired, organic

> weights or calories of the various organisms can be related to numbers of species in a dimensionless diversity equation such as 6. Considerable information about longitudinal change in community structure also can be obtained from a coefficients of similarity table; however, more effort is required in computing coefficients than in calculating indices with (s - 1)/ln N."

Goodnight (1973) summarized and compared several of the biotic systems used to assess stream pollution/ water quality (Saprobien System, American-Modified Saprobien System, Patrick's Biodynamic Histograms, Wurtz' "Mode of Life," Beck's Biotic Index, Wilhm's Species Diversity Index, The Sequential Comparison Index, Relative Percentage of Oligochaetes to Total Biota). This paper should be consulted for a brief, but informative treatment of extant (as of 1973) biotic methods. The actual "ecological meaning" of these systems, especially the diversity indices used by Wilhm (1967; 1970) and Wilhms and Dorris (1968) returns us to the discussion in Section I; thus directing the way to future research in stream ecology and urging us to develop falsifiable theories in stream ecology.

The only reasonably comprehensive approach to stream modeling that is pertinent to the discussion presented here was by Boling et al. (1975). I will discuss it in Section III.

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III. GENERAL COMMENTS ON MODELING BIOTIC COMMUNITIES

Systems analysis and modeling have become well-developed in both theory and practice in ecology during the two decades since Odum (1957) constructed a general trophic model for Silver Springs. Ecologists have drawn extensively from engineers in developing modeling technologies for ecosystem dynamics. The large theoretical and technical base evolved by the engineers has greatly accelerated the success of modeling and systems analysis in ecology. Not only has technical information flowed between the engineering and ecological communities, but new "breeds" of environmental scientists and "ecological engineers" have emerged from this productive interface. Ecologists with appreciation for mathematics and modeling, and engineers with appreciation for the holism of ecological systems are now working in concert to produce sensitive analytical and predictive models for ecosystems that go far beyond the first generation compartmental, donor-controlled linear models. New generation models are available for simulation experiments, prediction of environmental impacts, resource management, etc., using highly sophisticated programming, both linear and non-linear mathematics, and deterministic and stochastic functions. The literature is repleat with articles and reports on ecological modeling and systems analysis. An excellent review of systems analysis and modeling of biotic components of ecosystems is the four-volume series edited by B.C. Patten (1971, 1972, 1975, 1976). The articles contained in the series cover a diversity of techniques and ecological systems, and collectively represent a "primer" which should be consulted by personnel involved in WQAM development. Two other publications (Canale 1976; Hall 1977) containing numerous articles on ecosystem modeling provide a wealth of information pertinent to WQAM development. The bibliography at the end of this section (by no means complete) attests to the proliferation of publications during this decade.

Prime movers in development of systems analysis and modeling of ecosystems have been the International Biological Program (specifically its biome studies) and the National Environmental Policy Act. Although ecologists have long appreciated the holistic approach (see Lindeman 1941 for example), the IBP and NEPA provided the political and economic leverage. Unfortunately, the emphasis and scientific merit of IBP research and NEPA-spawned studies have not always been exemplary. Politics and economics too frequently have played roles more important than scientific considerations.

As result of the original charges and/or objectives inherent in IBP, and NEPA and related acts, a dichotomy exists in ecological modeling and systems analysis. IBP-related studies have been oriented toward basic ecology, involving university scientists, the training of graduate students, etc. Comprehensive in nature, IBP biome studies focused on understanding nature as it exists on many levels of integration. However, what portended to be highly successful has been somewhat disappointing in the result-per-unit effort (see Watt 1975 for critique of IBP Biome Modeling). Despite exceptions, numerous NEPA-related modeling efforts have been relatively more successful in results-per-unit-effort. Patten et al. (1975) point out part of the reason for this when discussing the Lake Texoma Cove model: "What most distinguishes the model, perhaps, is the fact that it is a biologists' model, an ecosystem description drawn in a relatively short time from the minds and collective efforts of a relatively large number of scientists under conditions of prolonged, intensive interaction. As a result, there is more basic biology and ecology incorporated in the model than perhaps any other ecosystem model of comparative scope of the present time." Many IBP studies involved personnel separated by space and time, whereas those more successful modeling efforts (in terms of payoff per-unit-effort) have involved highly integrated and coordinated groups working intensively over shorter periods of time.

Having participated in the Texoma Cove project with Patten et al. and directed a smaller-scale project at

NTSU involving seven scientists, I strongly urge that all modeling efforts involve a team that literally "lives together." Successful holistic studies depend significantly on the esprit de corps of the personnel and whether or not they view the project as a "labor of love." A heterogeneous or multidisciplinary group with diverse technical skills, but a common holistic philosophy is a most effective instrument for doing ecosystem-level modeling. Group dynamics and psychology play important roles in the successful achievement of a model. Patten et al. (1975) perceptively stated about the Mayfield Cove project: "the group dynamics in this process would itself be of interest to social psychologists, and in a real sense the model structure which emerged represented the collective knowledge of the institute members as shaped by social forces."

It is very important that the modelers and system scientists recognize what experimental ecologists have long known about laboratory-abstractions of nature; there is a fundamental distortion of reality when a biological process/system is extracted from its environment. Again, Patten et al. (1975) addressed this relative to the Texoma project:

> "Despite the theoretical and technical achievements of the cove model, no illusions should be allowed to persist about what it represents in relation to the actualities of Mayfield Cove. The model reduces the intricate beauty and awesome complexity of a piece of living nature to what is by comparison a flat,

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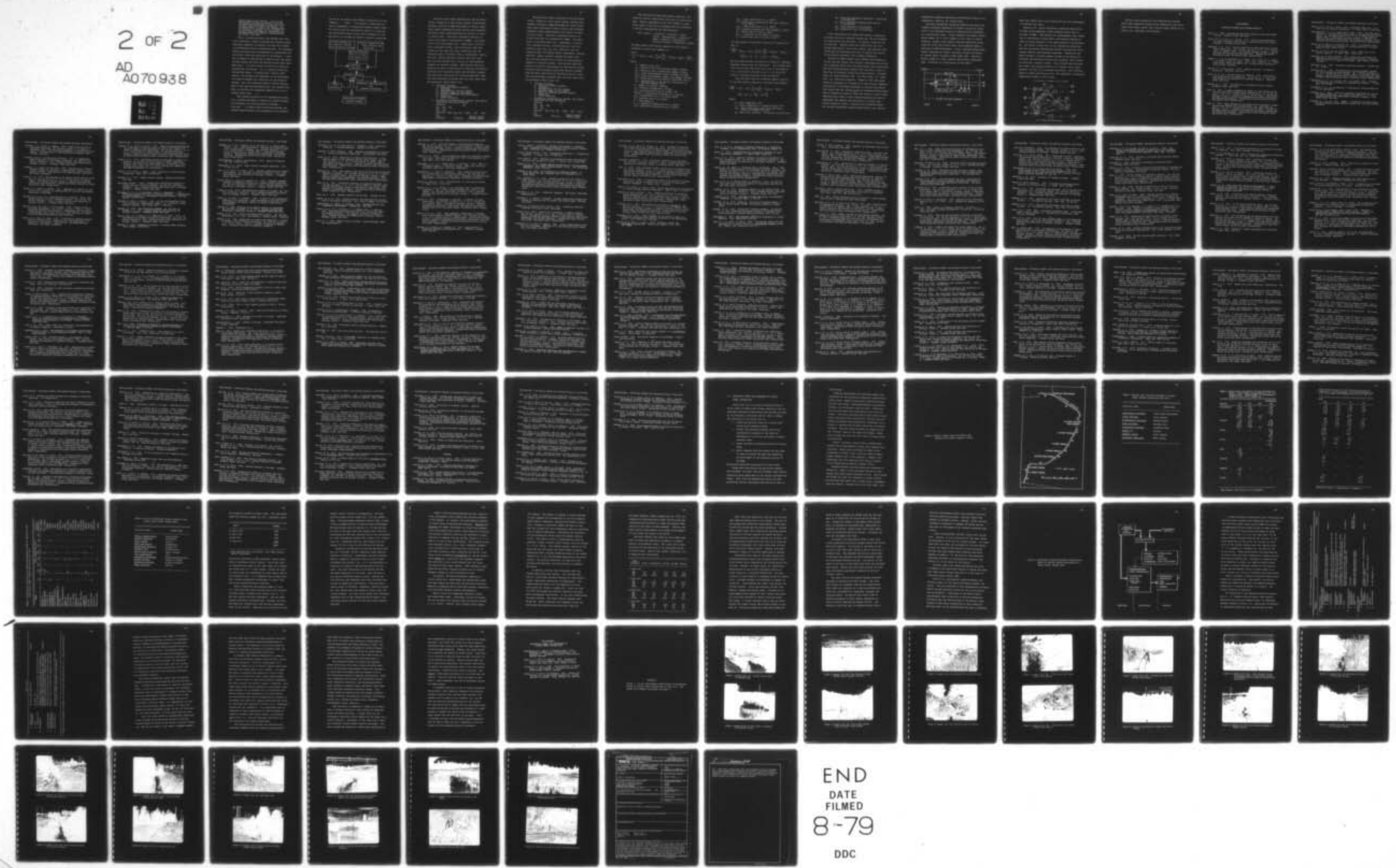

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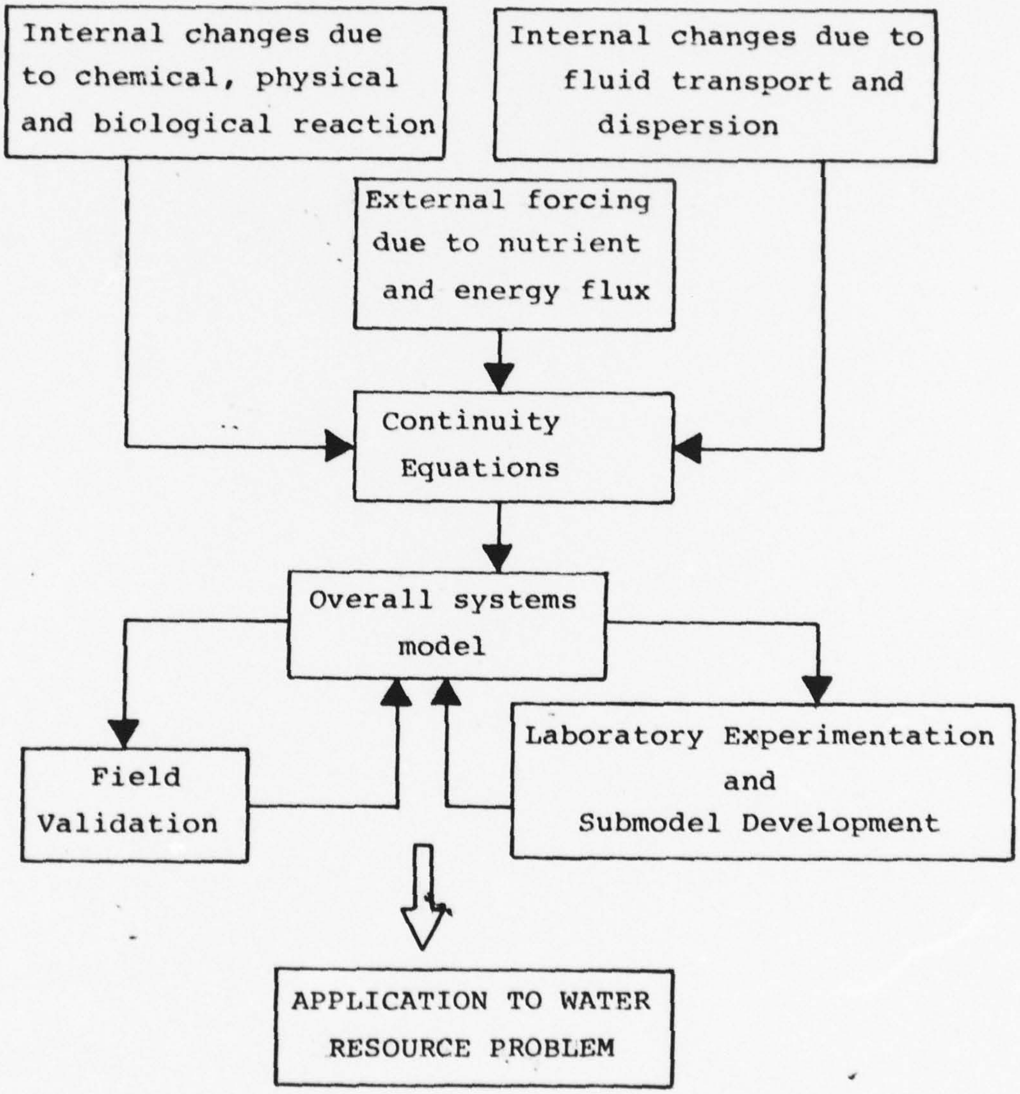
> pallid image of the reality. It is in the homomorphic character of models to do this, and ecologists would make a grave error ever to begin confusing image with reality. An ecosystem model, no matter how sophisticated or difficult to produce, is but a shadow of its prototype, and modeling, simulation, and systems analysis are means to understanding the latter, not ends."

After a multidisciplinary team blessed with technical competence, common philosophy and effective group behavioral dynamics is selected, the next major hurdle is establishing concrete goals/objectives. All personnel should contribute from the beginning in establishing the priorities, goals and objectives of the project. I have had a problem in contributing to WQAM in more than generalities because the goals and objectives have never been made clear. I am still unsure of why Clover Creek was selected for the project. Is it a typical stream traversing USAF bases? Is McChord AFB a typical base? Clearly, the interest and competence of the environmental group at McChord will contribute to the project's success. But, site selection needs to follow development of the team and goals/objectives, not precede them. Thus, my previous and subsequent comments will be of a general nature only.

"The ultimate objective of all mathematical models is to increase knowledge of systems and thereby advance the techniques for solving practical problems . . . [such as]. . .to design field monitoring programs that include identification of the parameters to be measured as well as the spatial and temporal structuring for the sampling . . . [and]. . .for purpose of addressing an aquatic management or engineering problem (Canale 1976)." The figure below was presented by Canale to illustrate the interactions among various steps necessary for the application of biochemical models to aquatic ecosystems.



The Boise River model developed by Chen and Wells (1976), though for a much larger system, contains many elements relevant to WQAM development at Clover Creek. Their model considered 24 water quality and biological parameters which compartmentally are similar to those in Clover Creek. (Obviously components peculiar to Clover Creek must be considered for WQAM). The parameters in the Boise Model are: temperature, toxicity, total suspended solids, coliform bacteria, BOD, dissolved O_2, NH_3, NO_2, NO_3, PO_4, alkalinity, pH, two floating algae, two benthic algae, zooplankton, insects, detritus, organic sediment, benthos and three fish. The river was divided into a series of interconnected segments of variable lengths. Mass balance equations based on the Law of Conservation of Mass and the Kinetic Principle were developed around each hydraulic segment. Chen and Wells identified the following physical, chemical and biological processes that can alter water quality parameters (their Table 7.4):

1. Physical Processes
    a. Advection between segments
    b. Diffusion
    c. Sedimentation from the segment
    d. External input to the segment
    e. Output to external from the segment
    f. Reaeration
    g. Solar insolation
2. Biochemical transformation, uptake, and release associated with the following:

Bacteria O_2

NH_3 NO_2 NO_3

BOD CO_2

Detritus NH_3, PO_4, CO_2 Algae 700. Fish

PO_4

Benthic Insect

Bacteria Detritus Benthic Algae

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    Benthic Insect

    Bacteria Detritus Benthic Algae

Chen and Wells divided mass balance equations into those for abiotic constituents and those for organic biomass. Abiotic components of the river exhibit a total change equal to the sum of processes that are considered to operate independently and simultaneously:

Total change = ± advection ± diffusion + input -
output ± sedimentation ± reaeration -
decay ± chemical transformation
biological uptake + respiration release

The mass balance differential equation for the abiotic components in each river segment is:

$$\frac{d(VC_1)}{dt} = Q_i C_{1i} - Q_o C_1 + \sum_{j=1}^{n} E_j A_j \frac{dC_1}{dx_j} + \Sigma Q_{in} C_{in} - \Sigma Q_{ou} C_1 - S_1 \frac{\bar{V}}{D} C_1$$

Where:

$\bar{V}$ = segment volume (m^3)
Q_i = advective flow from upstream segment (m^3/sec)
Q_o = advective flow to downstream segment (m^3/sec)
Q_{in} = local environmental input to segment (m^3/sec)
Q_{ou} = local environmental output from segment (m^3/sec)
C_1 = concentration of the quality constituent (mg/l)
C_{11} = concentration of the quality constituent in upstream segment (mg/l)
N = number of adjacent segments
E_j = diffusion coefficients (m^2/day)
A_j = cross-sectional area of segment (m^2)
dC_1/dxj = concentration gradient of C_1 (mg/l/m)
C_{in} = concentration of C_1 in inflow (mg/l)
S_1 = settling rate of C_1 (m/day)
D = mean depth (m)
$K_{r,1}$ = reaeration coefficient for C_1 (day^{-1})
$C_1{}^*$ = saturation concentration of C_1 (mg/l)

$K_{d,1}$ = decay coefficient of C_1 (day^{-1})
C_2 = constituent concentration that may transform to C_1 (mg/l)
$K_{d,2}$ = decay coefficient of C_z (day^{-1})
C_3 = organism concentration that consumer C_1 (mg/l)
M_3 = growth rate of biota C_3 (day^{-1})
$F_{3,1}$ = conversion factor between C_1 and C_3
R = respiration rate of biota C_3 (day^{-1})

The mass balance differential equation for organic biomass is:

$$\frac{d(\bar{V}C_1)}{dt} = Q_1C_{1i} - Q_oC_1 + \sum_{j=1}^{n} E_jA_j \frac{dC_1}{d_{xj}} + \Sigma Q_{in}C_{in} - \Sigma Q_{ou}C_1 - S_1\frac{\bar{V}}{D}C_1 + (\mu_1 - R_1 - \mu_1)\bar{V}C_1 - \mu_2\bar{V}C_2F_{2,1}$$

The two equations must be modified according to component examined; delete terms not applicable. Fish biomass equation will not have the first four terms in the equation (i.e., fish are not affected by advection, diffusion, inflow or outflow according to Chen and Wells).

Chen and Wells used the following equation similar to the mass balance equation to calculate heat budgets:

$$\frac{d(\bar{V}r)}{dt} = Q_iT_i - Q_oT + \sum_{j=1}^{n} E_jA_j\frac{dt}{dxj} + \Sigma Q_{in}T_{in} - \Sigma Q_{ou}T + (H_s + H_a \pm H_c - H_{br} - H_e)\frac{A_s}{\bar{V}}$$

Where:

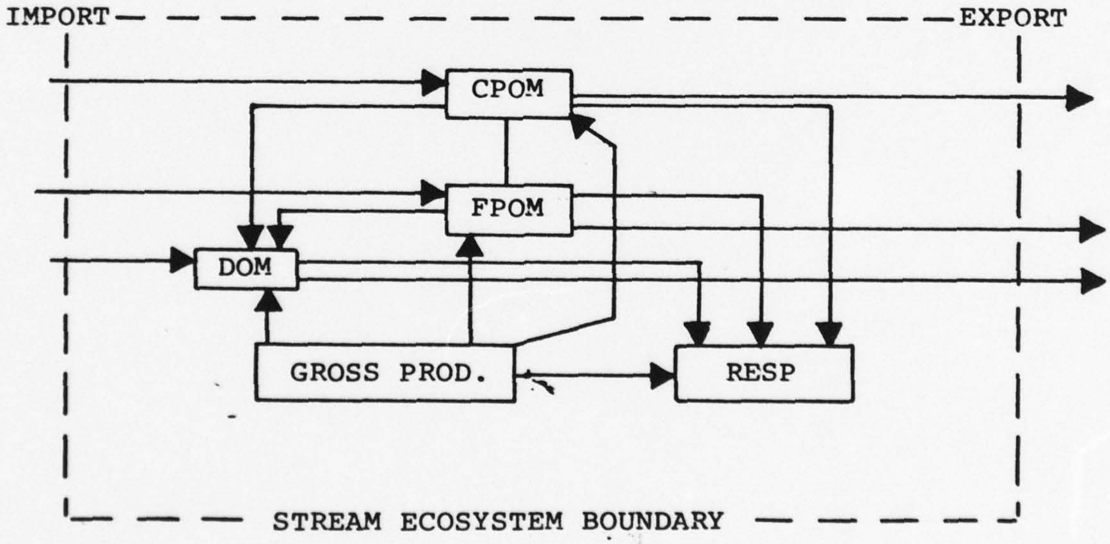
T = water temperature (^oC)
T_i = water temperature of upstream segment (^oC)
T_{in} = water temperature associated with local inflows to segment (Q_{in}; ^oC)
H_s = short wave radiation - reflection (k cal/m^2/sec)

H_a = long wave atmospheric radiation - reflection (k cal/m^2/sec)
H_c = heat conductance between water and air (k cal/m^2/sec)
H_{br} = back radiation (k cal/m^2/sec)
H_e = evaporation loss (k cal/m^2/sec)

Rate coefficients for temperature effects, reaeration, settling, mortality, hydraulic properties, and self-shading are detailed by Chen and Wells. In general, these are set as constants. However, many rate coefficients are time-varying functions of one or more factors, and specific algorithms must be constructed for each to capture the reality of the system's dynamics; and to enable simulation.

Because the WQAM probably will consider mass balance of various nutrient organic and inorganic substances and certain toxic compounds which enter and leave Clover Creek advectively and from point/non-point inflows, Chen and Wells' report to the Corps of Engineers (Boise River Water Quality - Ecologic Model for Urban Planning Study 1975 Tetra Tech, Inc. LaFayette, Ca.) should be consulted. Thoman's (1978) EPA report should be consulted for information on mass balance transport/accumulation of hazardous substances in aquatic food chains. That report does not consider toxicity threshold/effects which must be studied for specific biota and toxins in Clover Creek. Combined with a model of mass transfer/accumulation must be algorithms that capture the sensitivity of various life-history stages to toxins. Relevant toxic threshold levels for various life-history stages beyond LD-50's, etc. must be assessed for numerous synergistic environmental factors (e.g., temperature, salinity, pH, stream flow).

Pertinent information concerning modeling the biotic and organic-processing components of streams is given by Fisher (1977) in an excellent article on organic matter processing by a fourth-order river. Fisher considers the annual organic matter budget for a 1700 m segment of Fort River in Massachusetts. Though a much heavier riparian vegetation exists along the river than Clover Creek, the conceptual model is pertinent to WQAM development. Fisher considers meteorologic inputs, hydrological fluxes, biological fluxes and storage of organic matter fractions (CPOM, FPOM, DOM). Basically, Fisher's model is a mass transfer input-output compartment type. Following is a modification of the model:



=INPUT TOTAL OUTPUT=

Each flux (kg/m^2) has a rate coefficient and each compartment a "standing crop" mass.

Boling et al. (1975) presented an excellent description of steps toward modeling a small woodland stream that is relevant to WQAM. They present the developmental logic essential to developing a stream model, and discuss modeling in light of recent advances in the understanding of stream ecology. The value of their work is the information concerning detrital processing interactions between invertebrates (principally insects) and microbial organisms. Essentially the model considers a stream segment coupled to the abiotic environment and contiguous terrestrial ecosystem, and is based on functional (trophic) groups. They consider both allocthonous inputs and <u>in situ</u> production of organic matter (autocthonous) and how it is processed biotically. The following figure is taken from Boling et al. and represents a conceptual compartmental model of the stream:

R. H. BOLING, JR., R. C. PETERSEN, AND K. W. CUMMINS

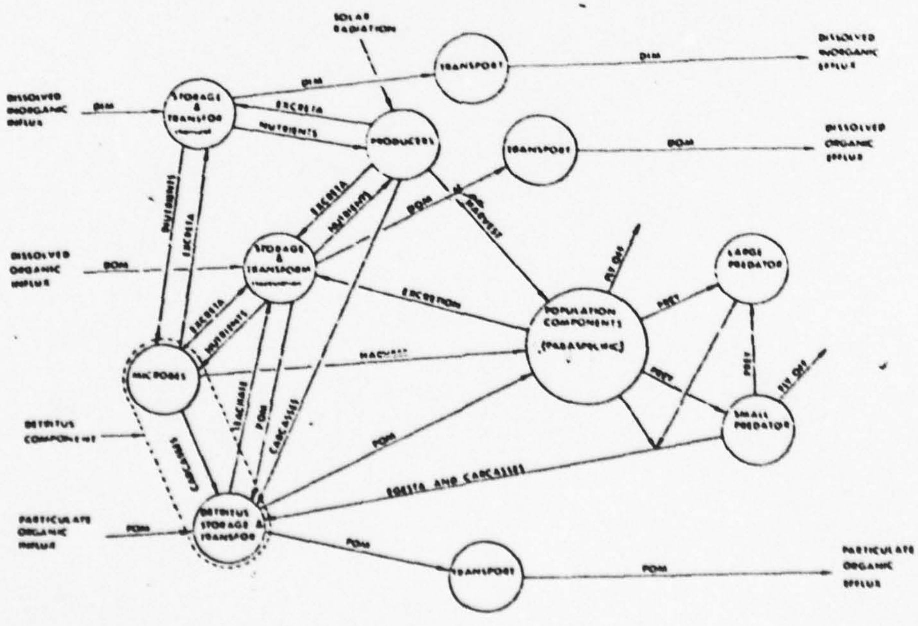


FIG. 4. Revised stream model system diagram.

Another highly successful lotic modeling and systems effort which should be consulted was conducted on the Willamette River Basin, Oregon (see citations under Rickert et al., Hines et al., Shearman, and Jennings).

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IV. ECOLOGICAL SURVEY AND ASSESSMENT OF CLOVER CREEK, McCHORD AFB

During July 1977 an on-site ecological survey of Clover Creek on McChord AFB, Tacoma, Washington and its watershed upstream and downstream from the base was made by the principal investigator and Mr. John L. Hughes. The objectives of the survey were to:

1. Locate and evaluate sites for a future time-series biotic sampling regime.
2. Collect and identify principal biota from representative segments of the creek for development of an initial qualitative trophic/taxonomic model.
3. Assess the general ecological quality of Clover Creek.
4. Obtain adequate data and insight for the creek in order to provide the USAF with guidelines for development of the ecological portion of the WQAM.

Qualitative Ecological Description of Clover Creek

Though both quantitative and qualitative samples were intended, low water flow and extremely dense aquatic vegetation which choked much of the channel precluded the former. Thus, data and descriptions herein are only qualitative and not presentable numerically on areal or volume basis.

Sampling methodology was relatively simple, but successful for the prevailing vegetative conditions of Clover Creek. Aquatic plants were collected by hand, dip nets and seines. Macroinvertebrates, principally benthos, were collected using kick nets. Additional macroinvertebrates were collected with dip nets and seines. Fish were collected with 10 and 20-foot seines. Dense vegetation made seining quite difficult and completely precluded using quantitative techniques (e.g., DeLury or catch-per-unit-effort) which were originally intended. The only areas favorable for sampling were the "riffles" close to and under the bridges. These areas yielded few fish, but were rich in certain macroinvertebrates.

Figure 1 is map of Clover Creek on McChord AFB showing the stream segments (1B-9B) where samples were collected. These sites correspond to sample sites referenced in Tables 2 and 3, and are shown in photographs (Plates 1-25) in the Appendix. Segment 2 was subdivided into four sampling sites ($2B_{1-4}$) because of its length and variability (Plates 3-9,11).

Results and data from the survey are presented in Tables 1-4. Table 1 lists the eight species of fish seined from Clover Creek according to site. Total length and weight are given for reference in future studies. We collected three game fish, rainbow trout, largemouth bass and sunfish. Rainbow trout (6-9" with some = 12")

Figure 1--Map of Clover Creek on McChord AFB Showing Nine Sample Segments (1B-9B).

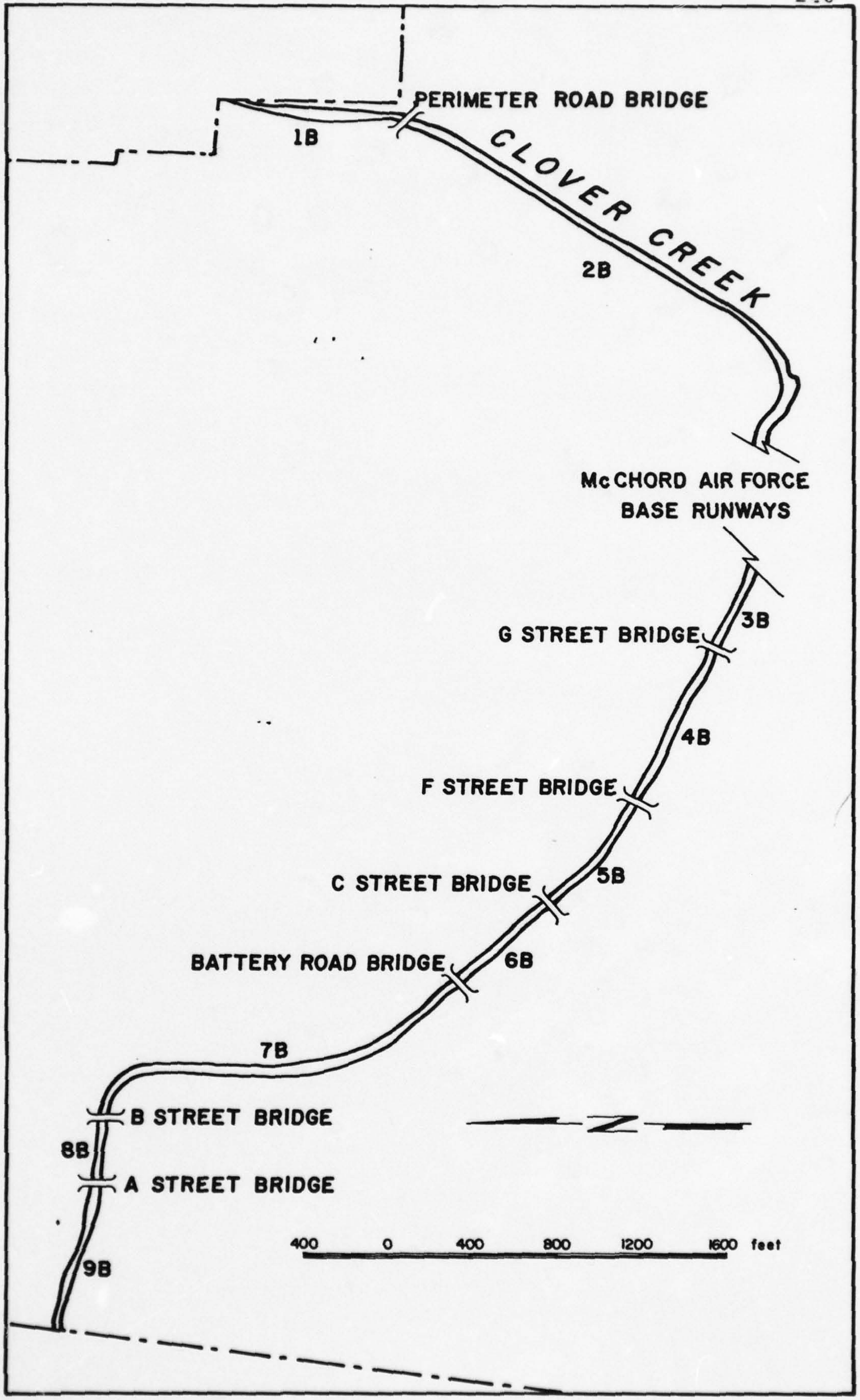
PERIMETER ROAD BRIDGE
1B
CLOVER CREEK
2B
McCHORD AIR FORCE BASE RUNWAYS
3B
G STREET BRIDGE
4B
F STREET BRIDGE
C STREET BRIDGE
5B
BATTERY ROAD BRIDGE
6B
7B
B STREET BRIDGE
8B
A STREET BRIDGE
9B
N
400 0 400 800 1200 1600 feet

TABLE 1--Species List for Fish Collected in Clover Creek, McChord AFB during July 1977.

Scientific Name	Common Name
Gasterosteus aculeatus	Three spine Stickleback
Cottus beldingi	Piute sculpin
Richardsonius balteatus	Redside shiner
Salmo gairdneri	Rainbow trout
Micropterus salmoides	Largemouth bass
Lepomis sp.	Sunfish
Lampetra ayresi	River lamprey
Catostomus commersoni	White sucker

TABLE 2--Qualitative Collections of Fish Collected in
Site*. First Number in parenthesis = N, fol-
Respectively. Second Number in Parenthesis =
lowed by their Total Weight (g).

				COLLECTION
Species	1B	$2B_1$	$2B_2$	$2B_3$
Stickleback	(23) 5.3± .44 2.1± .55	(39) 5.3± .38 1.9± .47	--	(5) 5.7± .59 2.6± .67
	(117) 25.2	(24) 6.6	(12) 4.0	--
Sculpin	(3) 8.4± 2.6 10.2± 8.5	(5) 8.3± 1.7 8.9± 4.22	-- 13.1	(6) 8.7± 3.04 15.6±
Shiner	--	--	--	(15) 7.9± .88 5.3± 2.0
Trout	--	--	--	(1) 13.1 -- 23.2 --
Bass	(2) 3.6± .35 .75± .21	--	--	--
Sunfish	--	--	--	--
Lamprey	(1) 8.5 -- 1.3 --	--	--	--
Sucker	--	--	--	--

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*See Figure 1 and Plates 1-25 in Appendix.

Clover Creek During July 1977 Listed by Collection
lowed by $\bar{x} \pm S_x$ Total Length (cm) and Body Weight (g)
N for three-spine Sticklebacks with TL $\gtrsim$ 3.8 cm, fol-

SITE			
$2B_4$	4B	7B	8B
(3) 5.1± 1.39 2.5± 1.64	(5) 5.0± .11 1.5± 1.64	(3) 5.6± .50 2.2±	(7) 4.1± .28 1.3±
--	(23) 9.5	(31) 16.0	--
(5) 7.9± .88 7.8± 2.4	(2) 5.1± 3.3 2.9± 3.2	(9) 5.4± 1.5 2.8± 2.0	(4) 6± 1.0 3.2± 1.3
(16) 10.3± 2.4 13.1± 8.3	--	(1) 11.7 -- 16.4 --	--
(1) 4.9 -- 1.7 --	(1) 15.7 -- 42.2 --	(1) 5.9 -- 2.8 --	--
--	--	--	--
(1) 7.0 -- 7.8 --	--	--	--
--	--	--	--
(1) 10.7 -- 12.5 --	--	--	(1) 19.7 -- 81.3 --

Subscripts refer to subdivision of segment 2.

TABLE 3--Qualitative Collections of Macroinvertebrates Listed By Sampling Site* From Clover Creek, McChord AFB during July 1977.

TAXON	TOTAL NUMBER PER SITE								Relative Abundance
	1B	2B1	2B2	2B3	2B4	4B	5B	8B	
Asellus sp.	1	>>>100	5	1	4	-	-	-	Very Common
Hyalella azteca	Z	>>100	2	4	59	3	-	-	Very Common
Crayfish sp.	1	12	1	1	1	-	-	-	Common
Dicosmoicus sp.	20	2	-	-	4	1	26		Common
Rhyacophila sp.	-	-	-	4	-	-	-	-	Rare
Other Trichoptera	-	1	-	1	4	-	-	-	Rare
Paraleptophelibia sp.	1	2	-	17	2	-	-	-	Common
Baetidae	-	5	-	-	-	-	-	-	Occasional
Other Ephemeroptera	-	1	-	-	-	1	-	-	Rare
Zapada sp.	-	3	-	98	-	-	-	-	Common
Chironomidae	3	>100	2	6	7	-	-	-	Very Common
Simulidae	-	2	-	12	-	-	-	-	Common
Other Diptera	-	-	-	1	-	-	-	-	Occasional
Promorsia sp.	-	5	-	9	-	-	-	-	Occasional
Plea sp.	-	3	1	2	4	-	-	-	Common
Other Hemiptera	-	1	-	-	-	-	-	-	Occasional
Ishnura sp.	-	4	1	-	5	-	-	-	Occasional
Planorbidae	-	7100	-	1	10	1	-	-	Common
Pysidae	-	32	-	-	-	-	-	-	Common
Pleuroceridae	10	4	4	2	-	11	2	-	Common
Hirudinia	-	1	-	-	-	-	-	1	Occasional
Lumbriculidae	-	1	-	18	-	-	-	-	Common

TABLE 4--List of Predominant Plants Growing in and Along Clover Creek, McChord AFB.

Scientific Name	Common Name
Robinia pseudo-acacia	Black Locust
Populus deltoides	Cottonwood
Salix rigida	Willow
Rubus spectabilis	Salmonberry
Tseudotsuga menziesii	Douglas fir
Myosotis laxa	Forget-me-not
Callitriche stagnalis	Water starwort
Iris pseudoacarus	Iris
Sparganium eurycarpum	Broad-fruited Burreed
Elodea nuttalii	Nuttall's Elodea
Spirodela polyrhiza	Greater Duckweed
Typha latifolia	Cattail

are regularly stocked in Clover Creek. The table below shows the stocking regime* for 1977. Apparently these

DATE	NUMBER
13 April 1977	3500
21 April 1977	3000
25 May 1977	3500
6 June 1977	2000
	12,000

are heavily exploited by USAF personnel, making Clover Creek a significant sports fishery. Two of the trout we collected were close to the lower range (6") stocked. The others were ca. 2" total length. Either the trout in Clover Creek are reproducing or trout smaller than 6" are stocked or both. It is doubtful that rainbow trout have become successfully established in Clover Creek and can be maintained without stocking.

Table 2 shows that the greatest number of fish (N = 146) were taken from the deep pool at the entrance of Clover Creek to McChord (1B; Plates 1 and 2). Of the four species 140 were stickleback. The only game species seined was largemouth bass. However, two boys had taken two rainbow trout from the pool immediately prior to our arrival. These were 17.9 and 19.8 cm total

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* Data supplied by Mr. Tom Bowie, local USAF environmental coordinator.

length, and 68.7 and 86.5 g respectively. The boys had also caught a white sucker (TL = 32.1 cm; weight = 425g). The second most productive station (2Bl); Plates 3 and 4) yielded 68 fish, of which 63 were stickleback. The most diverse site (6 species, N = 27) was the pool in front of the pipe under the runways (2B4; Plate 11). Stickleback was the most numerous fish in our collections (N = 292) followed by sculpin (34), shiner (32), rainbow trout (4), largemouth bass (2), white sucker (2) and lamprey (1) for a total of 367 fish and six species.

Because of the mobility of fish and the relatively few fish collected, further comparison among sampling stations is difficult. Stickleback, the most numerous species, showed no consistent trend in total length and weight with station (i.e., it is not meaningful to correlate or regress TL and BW with station at this time). The major difficulty in collecting fish was the dense vegetation in the creek. Only the pool at site $2B_4$ was relatively easy to seine. Perhaps the fish diversity and abundance would have increased were we able to sample more efficiently. With more data a clearer trend in diversity, abundance, condition factor, etc. may emerge along the length of Clover Creek traversing McChord. All that can be stated with confidence regarding fish is that segments 8B and 9B appear to be relatively poorer habitat for fish than those segments upstream.

Table 3 lists macroinvertebrates by taxa, sampling size, and presents their numbers and relative abundance in the samples. In general, the invertebrate community in Clover Creek is dominated by Crustacea. Ascellus and Hyalella are common "scavengers" in lentic and sluggish lotic environments that contain large amounts of detritus. The greatest taxonomic diversity and abundance of organisms were in samples from $2B_1$ and $2B_3$ (Plates 3, 4, 7, 8 and 9), 21 and 15 taxa respectively. This suggests either more favorable habitat (e.g., food, substrate, temperature) availability or less pollution or both than at the other collection sites, especially 8B and 9B. Prescence of the trichopteran Dicosmoicus sp. and the plecopteran Zapada sp. in the first five segments suggests that pollution is not severe because they are fairly intolerant of poor water quality. Their absence in segments 8B and 9B may indicate pollution due to organic/ sediment loading or toxic pollutants or both.

In general, the macroinvertebrate community is fairly diverse for a weed-choked and channelized stream with open canopy and some point and non-point pollution. Addition of sampling should yield more species, especially from the orders Odonata, Diptera and Hemiptera.

Table 4 lists the predominant vegetation within and along Clover Creek. Cottonwood, willow and Douglas fir are the major tree species along the channel (Plates 1, 2, 6, 12-19). However, their foliage rarely shades the channel. The channel is exposed to direct sunlight in most segments and consequently at low flow supports dense aquatic submergent, emergent and floating vegetation. Douglas fir partially shades the pools in segment $2B_3$ (Plates 8-9) and consequently they are relatively free of aquatic vegetation. Salmonberry and blackberry are the predominate shrubs along the channel (Plates 13-19). The aquatic flora is represented by cattails, duckweed, elodea, burreed, water starwort and iris (Plates 1-7, 11-17, 18-23). The exposed channel, clarity of the water and low flow permit the dense growth of aquatic vegetation which virtually choked portions of the channel (Plates 3-6, 11-14) and precluded quantitative efficient seining. The aquatic vegetation, as seen with fish and macroinvertebrates, declined markedly in segments 8B and 9B.

In general, flow was most noticeable under the bridges where water was shallow. The flow and presence of riffles made suitable habitats for macroinvertebrates, especially caddisflies (trichopterans). The highest quality habitat for fish appeared to be the pools below the riprap in segment $2B_3$. Water was cool (11-12°C) and shaded with minimal vegetation and abundant invertebrate food sources. It was also aesthetically the most pleasing. The lowest quality segments were 8B and 9B. Their substrates were somewhat varied, but often deep foul-smelling muck prevailed (Plate 23).

The heavy sediment, higher temperature (ca. 17°C) and summation of point/non-point runoff from the base may contribute synergistically to lower the general water quality of the creek in these segments. Clearly, the water quality deteriorates as it passes along segment 7B and reaches its lowest in 8B and 9B.

The water quality data below are from weekly samples collected and analysed by personnel in Captain Osborn's environmental group. The 8 July 1977 values coincide with the beginning of our ecological survey of Clover Creek. Time of day, weather conditions, etc. at sampling were unavailable.

Date/ Parameter	Inlet	Confluence	Culvert	Bridge	Outlet
1 June 1977					
pH	7.2	7.2	6.8	6.8	7.0
T°C	14	14	13	13	14
DO	10-11	11-12	9-10	9-10	10-11
6 June 1977					
pH	7.0	7.2	7.0	7.0	7.0
T°C	16.0	18.0	16.0	16.0	16.0
DO	8	9	7	8	8
% Sat.	67	77	57	67	67
13 June 1977					
pH	7.0	7.0	7.0	7.0	6.8
T°C	13	16	13	14	14
DO	8	9	5	8	8
% Sat.	75.4	90.4	50.2	77.1	77.1
8 July 1977					
pH	6.8	7.0	6.8	6.8	7.2
T°C	12	13	10	11	12
DO	10	6	8	11	13

Water level was reported as very low for the four-week sampling period prior to our survey. The data do not suggest any significant water quality change associated with station and the three parameters. Similar data, though lower water temperatures and high percent saturation of DO were reported for March and April. The only pollution event was reported for 24 March 1977 at approximately 1000h when foam from a fire truck was accidently discharged into Clover Creek near the west end of the North runway culvert. Whether this event produced a change in the biota downstream is unknown.

Considerably more data on the water quality and sediment/substrate quality are necessary before relations between biotic composition and stream quality can be drawn. However, as noted, there is a qualitative deterioration in the overall ecological quality of Clover Creek as it traverses McChord AFB. The deterioration is most dramatic in segments 8B and 9B (Plates 21-25), although changes are noticeable in segment 7B (Plate 20). Deterioration may result from several synergistic factors. Point and non-point inflows from streets, runways and several pipes. Evidence of oil being dumped along segment 5B near C-street was noted. Oil films were observed in several locations below the runway. A "milky" effluent from a pipe was noted between the runway culvert and 6-street bridge in segment 3B. Streamside shrubs and trees which shade the creek in other segments are absent from the last segment of 7B (Plate 20) and from 8B and 9B (Plates 21-24). Though not evident in the weekly water quality data, we observed an increased water temperature in segments 8B and 9B. During higher flow rates temperature differentials should be minimal. Turbidity was very low throughout the creek.

In general, we found Clover Creek to be a relatively productive and diverse aquatic system with fairly high water quality. The clarity of the water is due in part to the inlet pool (Plates 1 and 2) acting as a sediment trap. The sediments and muck are quite deep in the pool and combined with dense submergent vegetation precluded effective seining. The clarity of the water in the pool is much lower than below the Perimeter Road bridge. Runoff from the gravel parking lot probably contributes significant turbidity to the pool (Plates 1 and 2).

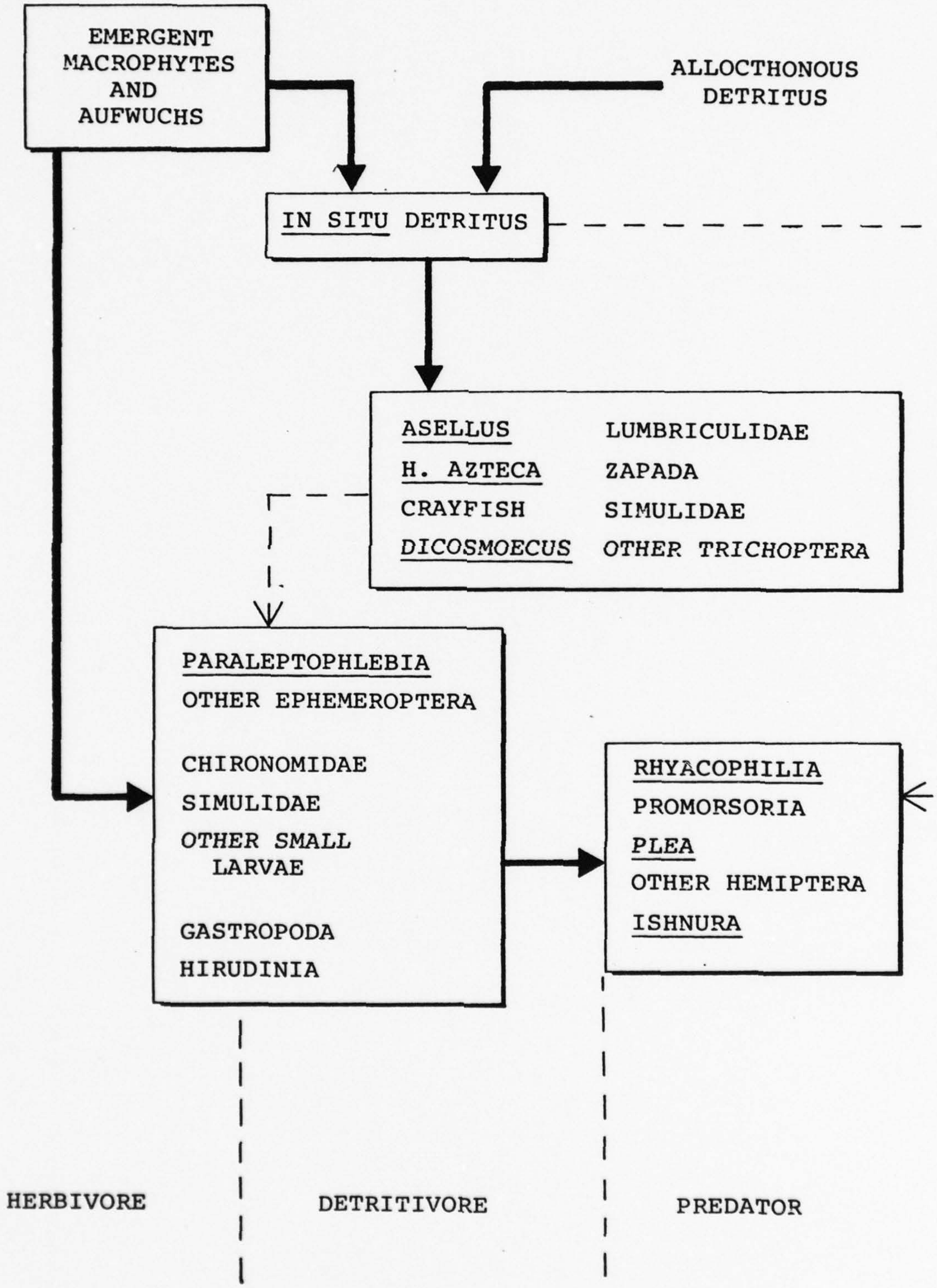
The water clarity and exposed channel permitted sunlight to penetrate the water column. The inlet pool acting as a sediment trap and the unobstructed solar input are conducive to a high autocthonous productivity, principally by submergent, emergent and floating plants. We believe that Clover Creek is driven principally by solar energy, especially between Perimeter Road and the Runway culvert. Production in the inlet pool is probably driven principally by allocthonous organic and inorganic nutrients from the upstream watershed. Nutrient runoff from McChord is probably trivial. However, runoff carrying turbidity is expected in segments 8B and 9B and the last part of 7B because of the reduced streamside vegetation.

Input from deciduous leaffall should occur during fall. However, in situ utilization of the input cannot be predicted at this time for several reasons: (1) Water depth and flow rates are not known for the fall-winter period; (2) Quantity and quality of nutrient/energy derived from input depend upon residence time which depends on number 1; (3) the suite of leaf-processor organisms available for the processing sequence (see Section II) is not known for fall-winter.

Nutrient input from canopy throughfall may occur in segments with significant borders of shrubs and trees. This input occurs during rains and is in the forms of dissolved organic matter (DOM).

Figure 2 is a preliminary trophic/taxonomic connectivity model for the macro-invertebrate benthic community. Fish are connected to the invertebrates at several points through predation activities and to one another, also by predation. Since many of the benthic macroinvertebrates feed on detritus or detritus-processing microbiota and fish feed and many of the benthic forms, trophic or food chain accumulation of toxic materials that may exist in the substrate/detrital pool is possible.

Figure 2--Preliminary Trophic/Taxonomic Connectivity Model for Benthic Macro-Invertebrates in Clover Creek, McChord AFB.


EMERGENT MACROPHYTES AND AUFWUCHS
ALLOCTHONOUS DETRITUS
IN SITU DETRITUS
ASELLUS
LUMBRICULIDAE
H. AZTECA
ZAPADA
CRAYFISH
SIMULIDAE
DICOSMOECUS
OTHER TRICHOPTERA
PARALEPTOPHLEBIA
OTHER EPHEMEROPTERA
CHIRONOMIDAE
SIMULIDAE
OTHER SMALL LARVAE
GASTROPODA
HIRUDINIA
RHYACOPHILIA
PROMORSORIA
PLEA
OTHER HEMIPTERA
ISHNURA
HERBIVORE
DETRITIVORE
PREDATOR

A trophic/taxonomic connectivity model identifying and depicting mass transfers with appropriate rate functions, and with high enough resolution for WQAM will require a sampling/analytical program lasting at least one year. Sampling sites for biota should correspond to those used in this study: (1) 1B at the inlet pool; (2) 2B midway between Perimeter Road and the rip rap; (3) the pools below the rip rap in 2B; (4) the pool in 2B in front of the culvert passing under the landing field; (5 - 11) midpoints in segments 3B - 9B; and (12) 9B at the outlet. These should reflect the heterogeniety of Clover Creek and biotic changes as it passes various facilities on McChord AFB. Frequency of sampling will vary according to season, but sampling should always be made to reflect potential effects of both environmental and man-induced events in Clover Creek (e.g., after a heavy rain, after an accidental pollution event).

Table 3 presents a tentative sampling regime recommended for consideration. Once regular time-series samples are taken and analyzed, the sampling/analysis regime will of course be subject to revision. Continual up-dating is essential.

The objectives of the sampling/analytical program are to: (1) identify existing biota, their spatial dispersion and food web connectivities; (2) determine seasonal changes in biota (i.e., aspectional succession); (3) determine fluxes and rate coefficients for mass

Table 3--Tentative Proposed Biotic Sampling/Analytical Program for Clover Creek, McChord AFB

Parameter	Method/Analytical Technique	Frequency*
I. Community Structure		
A. Taxonomic/Spatial/Biomass		
1. Aquatic Macrophytes		
a. Emergents	$0.5m^2$ clip quadrants in grid selected randomly;	monthly
b. Submergents	Biomass, wet and dry, gravimetrically	
c. Floating	Dipnets	
2. Phytoplankton	Transect plankton-net tows in flowing water and both tows and hauls in pools; Biomass gravimetrically	"
3. Microcrustacean Zooplankton	Transect plankton-net tows in flowing water and both tows and hauls in pools; Biomass gravimetrically	"
4. Benthic macro-invertebrates	$0.5m^2$ quadrants in grid selected randomly; kick nets, Surber and Hess samplers; drift nets; Biomass gravimetrically	"
5. Fish	Seining and electro fishing; length, weight condition factor; Biomass gravimetrically; demographic data	bi-monthly
B. Food Web Connectivities		
1. Microcrustaceans	Literature	Seasonally or when biota change
2. Benthic macro-invertebrates	Literature and stomach/intestine analysis	
3. Fish	Literature and stomach/intestine analysis	
II. Community Dynamics		
A. Production		
1. Aquatic Macrophytes		
a. Emergents	Clipping or cropping quadrats and determining biomass at successive intervals	monthly
b. Submergents		
2. Phytoplankton	^{14}C assimilation Light/dark bottles	"
3. Aufwuchs		
4. Microcrustaceans	see IBP Handbook No. 17	"

Table 3 cont.

5. Benthic macro-invertebrates	see Waters and Crawford 1973	monthly
6. Fish	see Ricker 1975	"
7. Community Level	Diurnal oxygen curve or pulse method; see Odum and Hoskins 1958	"
B. Decomposition	Gravimetric analysis of allocthonous organic decomposition; stabilization oxygen demand or ATP assay for in situ detritus; utilization or fixation of dissolved organic carbon through radioactive substrate assimilation; at different temperatures	seasonally
C. Food Web Transfers	Literature values and feeding studies at different temperatures	"
D. Bioaccummulation of specific pollutants	Bioassay of biota in food chains and laboratory uptake studies	"
E. Toxicity studies	Literature and laboratory work; LD 50's and more subtle effects (e.g., effects on growth, development and reproduction)	"

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* Frequency may be increased or decreased, but should always include special events (e.g., spates, pollution events).

transfer along food chains or web links; (4) measure effects of various pollutants on biota; (5) determine rates of trophic or bioaccummulation of various pollutants; (6) determine and measure external drives on the creek (e.g., solar input, allocthonous input); (7) determine detrital processing and decomposition rates; (8) measure effects of different environmental temperatures on rates and processes; (9) determine and measure exports from the creek; and (10) develop a compartmental input-output model which can be used for simulation, prediction and sensitivity analysis, and management purposes.

The biotic program must couple with the physico-chemical monitoring program and the hydrological analyses. In addition to monitoring for specific pollutants likely to enter the creek from McChord, the following parameters must be determined in frequency greater than the biotic measurements (recall from Section II that biota integrate physico-chemical events and are the "historical" result of them): (1) temperature; (2) dissolved and particulate organic matter; (3) total dissolved and total suspended solids; (4) pH; (5) dissolved O_2; (6) redox potential; (7) water depth and flow rate.

Leaf liter trays should be located where shrubs and trees overhang the creek during periods of leaffall. Screens should be placed at the outlet to collect leaves, etc. that do not remain in the creek. Sediment samples from the inlet pool should be taken regularly and after spate events to determine retention/accumulation of organic matter. The sediments in all pools should be measured and monitored relative to residence time, and effects of changing hydrological conditions.

In summary, DOM, CPOM and FPOM pools or compartments must be monitored together with nutrients, toxins and other inorganics, and biotic compartments in a coordinated fashion so as to reflect regular aspectional variation and chance events (e.g., spates). A strong data base is essential and possible for Clover Creek because of its relatively short length across McChord AFB. Identification of principal biological components and their various life history stages is essential. Each input-output group should represent an equivalence class whose dynamics can be modeled with a differential mass-balance equation with appropriate rate coefficients. The rate coefficients must be classified as constants or variables; the latter will require algorithms that allow for individual and synergistic effects (e.g., temperature, stream flow, pH, turbidity). All compartments must be connected to other compartments via mass transfers as fluxes of inorganic and organic matter, and external inputs from (i.e., forcing functions) and exports to the terrestrial environment established.

The creek should be divided into hydrologically functional segments that are connected advectively to each other and uniquely to their terrestrial environment so as to reflect the effects of various base activities/operations and events peculiar to them. The segments will probably correspond to 1B-9B on Figure 1 with possible subdivision of 2B and 7B; these should reflect spatial heterogeneity of the creek as well as the variation in input/forcing functions along it.

Mass balance/transfer of organic and inorganic matter advectively from above, within and below base, point and non-point input/output from/to the terrestrial (non-creek) environment must be coupled to toxic and stimulatory effects of chemical constituents. These will necessitate bio-toxicity and stimulatory studies under laboratory conditions, and bioaccumulation/bioassay studies on organism taken from Clover Creek regularly and after accidental pollution events. Such studies should go beyond LC-50's and assess threshold effects (positive and negative) on various life-history stages (e.g., effects on growth rates, fecundity, developmental rates, behavior).

Once the above is completed, a model can be developed to simulate chronic or acute effects of pollution events and base activities. A model could also be developed to maximize various aspects of the creek (e.g., trout fisheries). Obviously, if the right kind of data are collected, several models could be developed. Simply to assess the effects of various base activities on the ecology/water quality of Clover Creek is not enough. Hopefully, the effort will result in a water quality assessment model which can be used for both prediction/ simulation and management. Ideally, the intent should be to optimize the quality of Clover Creek. Since quality is relative, a decision must be made "up-front" as to the meaning of quality. Because Clover Creek connects advectively downstream, the possible definitions of quality are constrained by state, local and federal regulations. Compliance with these is minimal. The intent of NEPA-based legislation is to do more than the minimal. With the time and talent available to the USAF, a sound management tool can be developed through the WQAM program.

I recommend selecting a team of stream ecologists, hydrologists, water chemists, engineers and modelers/ systems scientists that can work well together, has enought time to spend on site together, etc. and let them set specific goals/objectives for the project. The team should have a common holistic philosophy based on sound ecological principles and knowledge of stream ecology in general and Clover Creek in specific. A clear charge from the USAF also is necessary. Thus, a statement of work with the general goals/objectives must be made by USAF and then responded to with proposals from the academic/scientific community.

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Odum, H. T. and C. M. Hoskin. 1958. Comparative studies on the metabolism of marine waters. Publs. Inst. Mar. Sci. Univ. Texas 5: 15-46.

Ricker, W. E. (ed.) 1968. Fish Production in Fresh Water. IBP Handbook 3. Blackwell Scientific Publications. Oxford, England

Waters, T. F. and G. W. Crawford. 1973. Annual production of a stream mayfly population: a comparison of methods. Limn. Oceanog. 18: 286-296.

APPENDIX

Plates 1 - 26 are photographs taken during the Ecological Survey of Clover Creek, McChord AFB in July 1977. The sample site numbers correspond to Figure 1.

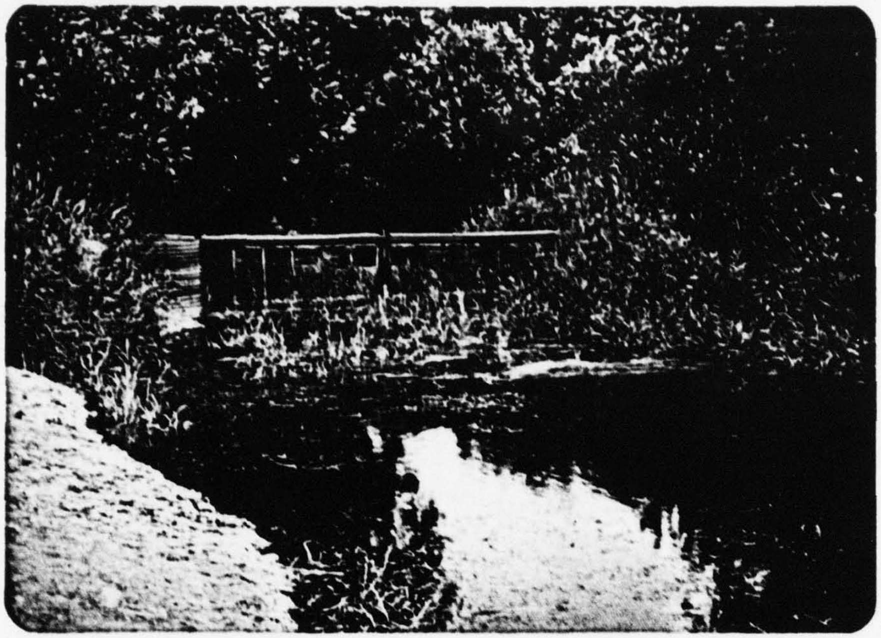

PLATE 1--Sample Site 1B. Clover Creek Inlet to McChord AFB.

PLATE 2--Sample Site 1B from Inlet to McChord to Perimeter Road.

PLATE 3--Sample Site $2B_1$ from Perimeter Road Bridge toward Runway culvert.

PLATE 4--Sample Site $2B_1$ from creek channel under Perimeter Road Bridge.

PLATE 5--Sample Site $2B_2$ Downstream view of Riprap.

PLATE 6--Sample Site $2B_2$ Upstream view of Riprap.

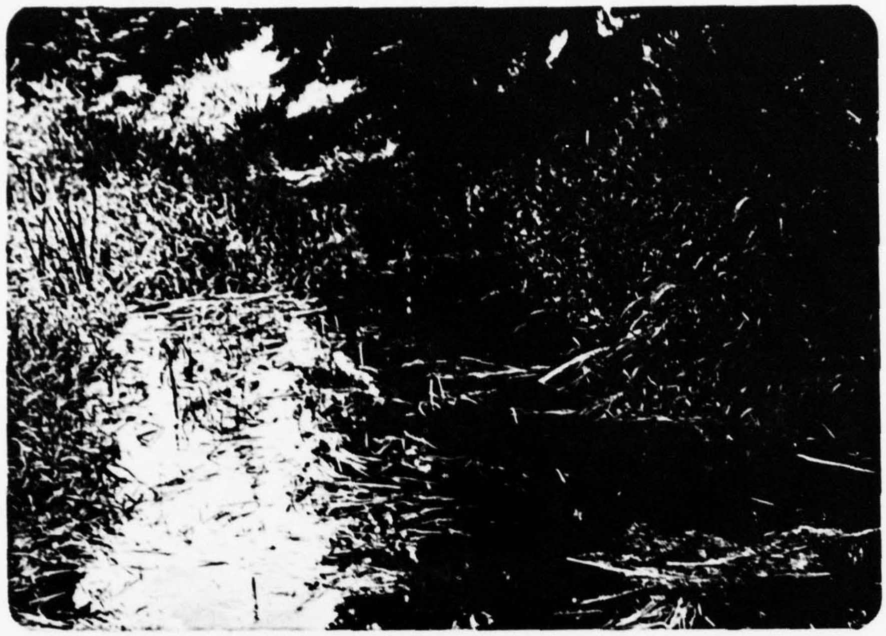

PLATE 7--Sample Site $2B_3$. First Pool area Downstream from Riprap.

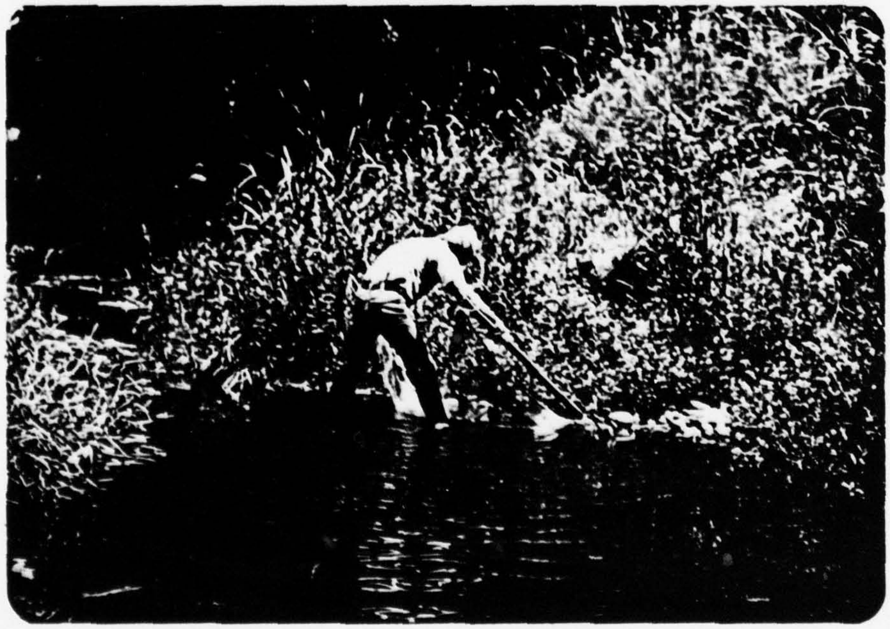

PLATE 8--Sample Site $2B_3$. Second Pool area Downstream from Riprap.

PLATE 9--Sample Site 2B3. Second Pool area Downstream from Riprap.

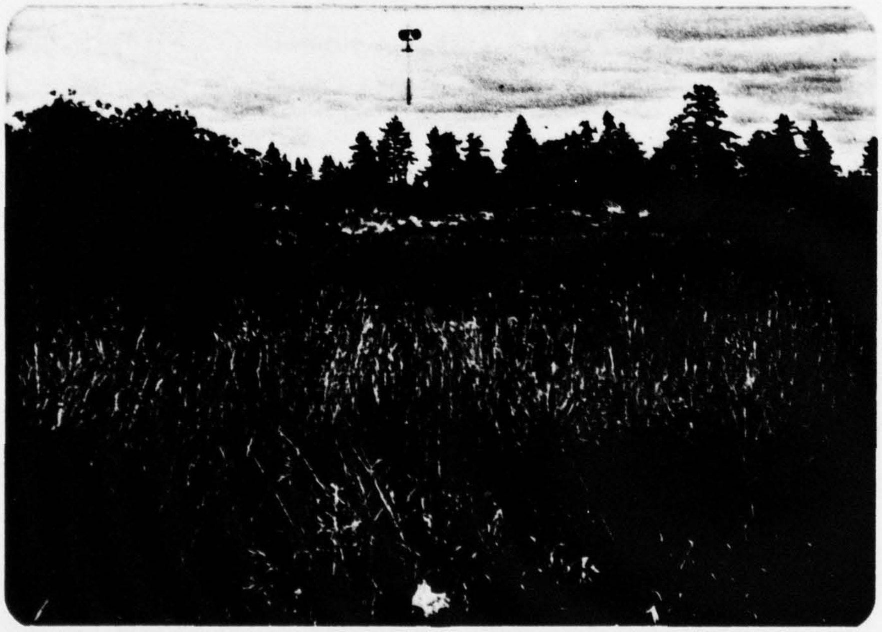

PLATE 10--Pond at Confluence of Morey and Clover Creeks.

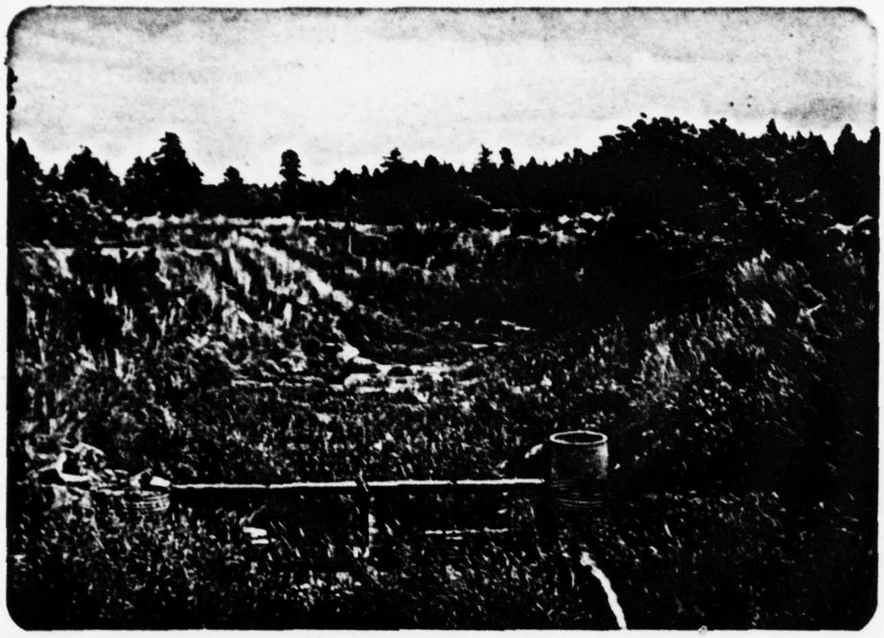

PLATE 11--Sample Site 2B4. Pool between screen and Runway Culvert from Runway Culvert to Spillway/wier for pond at More-Clover confluence.

PLATE 12--Sample Site 3B from G-Street Bridge to Runway Culvert

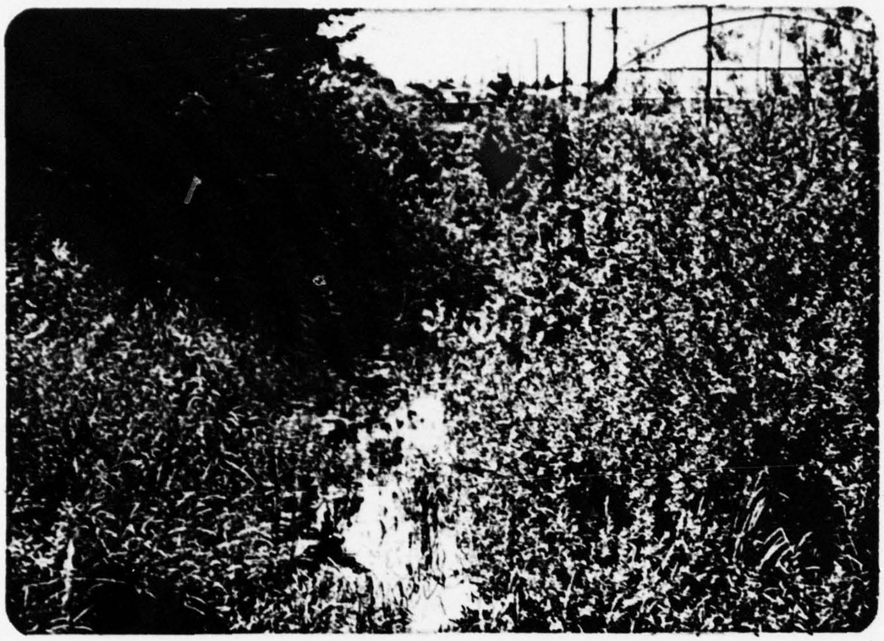

PLATE 13--Sample Site 3B from Runway Culvert to G-Street Bridge.

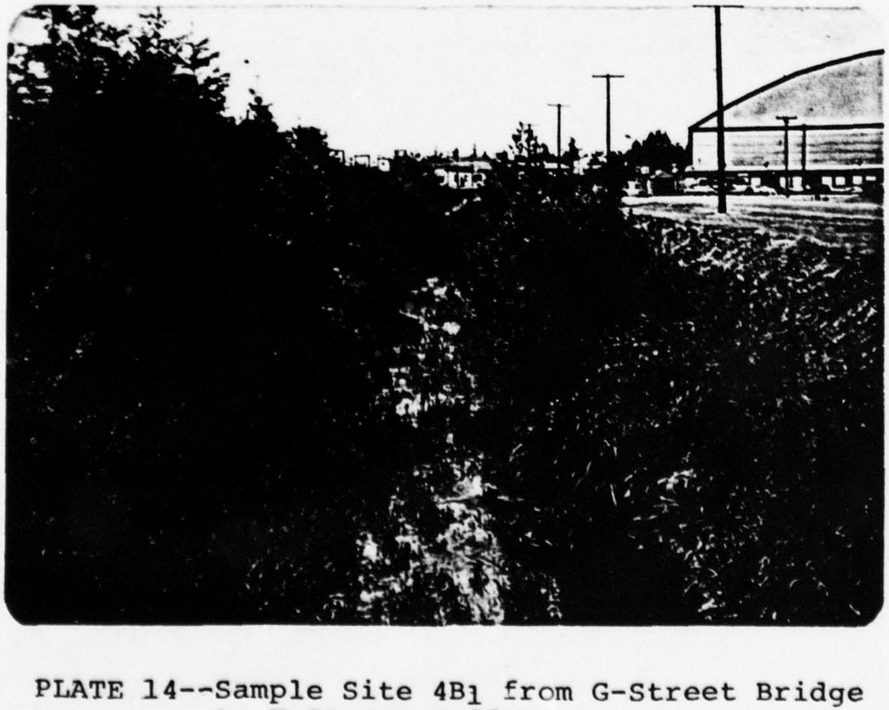

PLATE 14--Sample Site $4B_1$ from G-Street Bridge to F-Street Bridge.

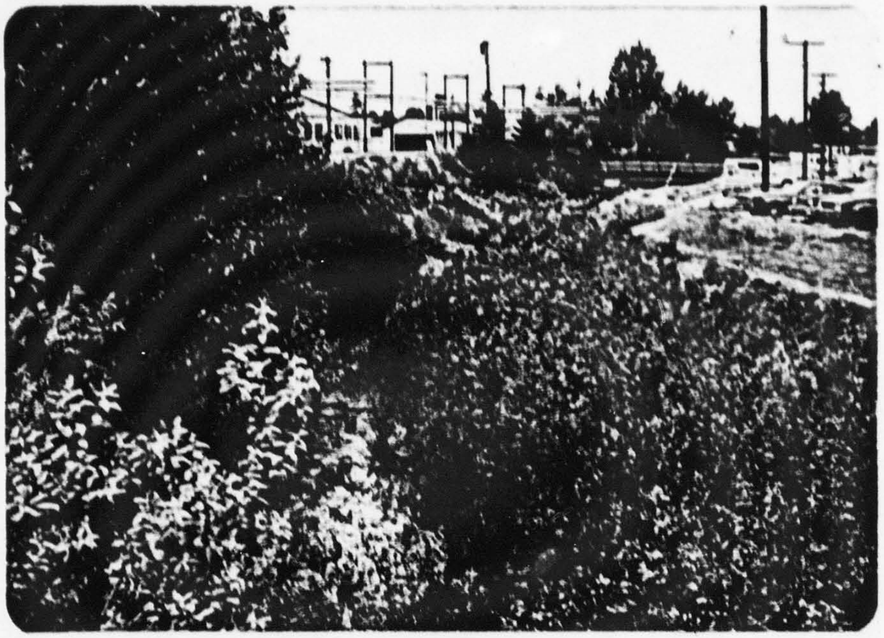

PLATE 15--Sample Site $4B_2$ from F-Street Bridge to C-Street Bridge.

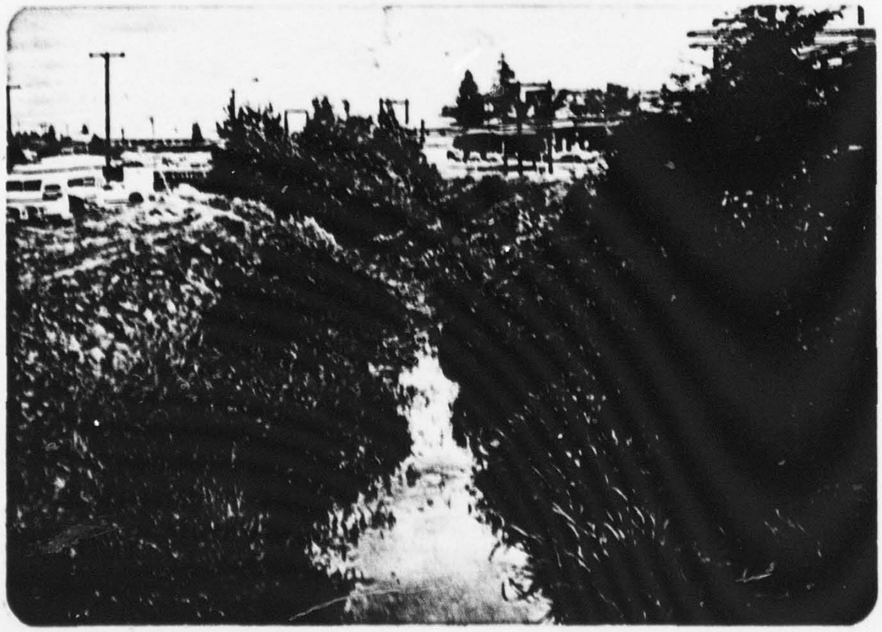

PLATE 16--Sample Site $4B_2$ from C-Street Bridge to F-Street Bridge.

PLATE 17--Sample Site 6B from C-Street Bridge toward Battery Road.

PLATE 18--Sample Site 7B, downstream view.

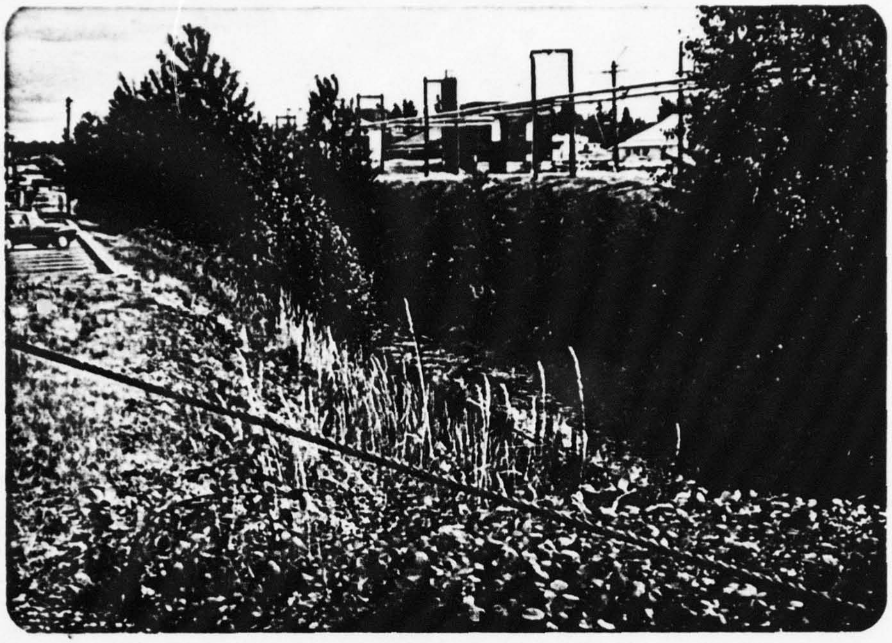

PLATE 19--Sample Site 7B, upstream view.

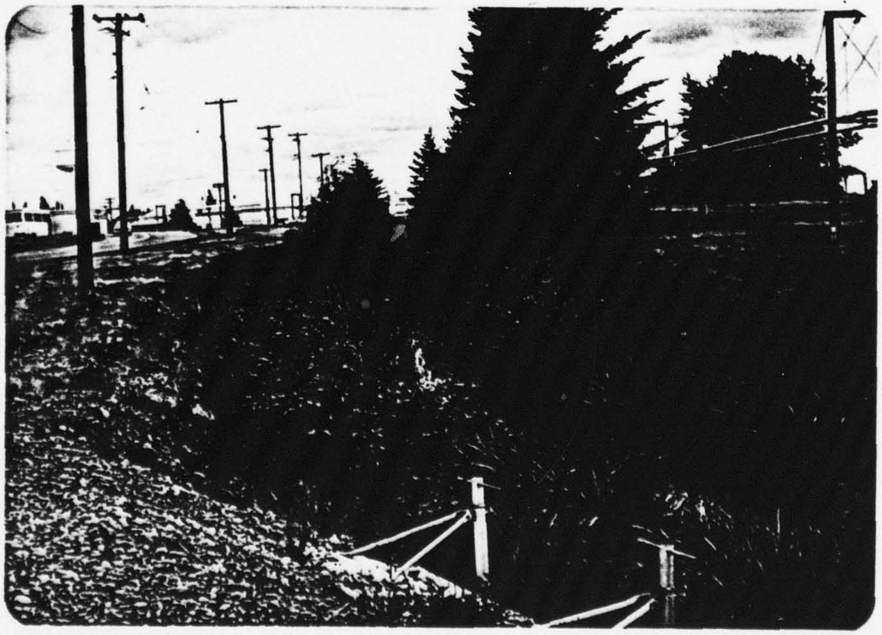

PLATE 20--Sample Site 7B near B-Street Bridge
toward Battery Road.

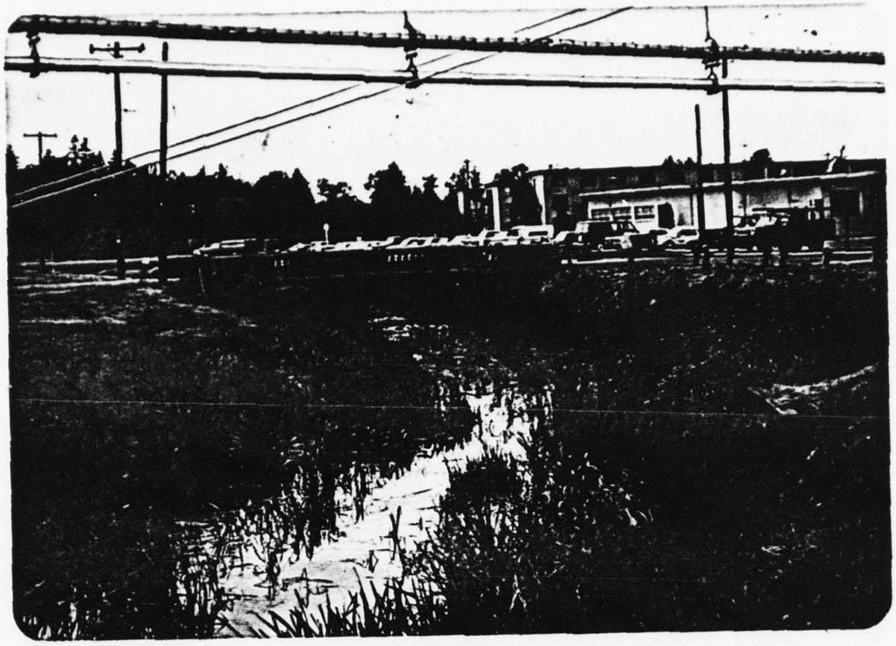

PLATE 21--Sample Site 7B from previous Location (Plate 20) toward B-Street Bridge.

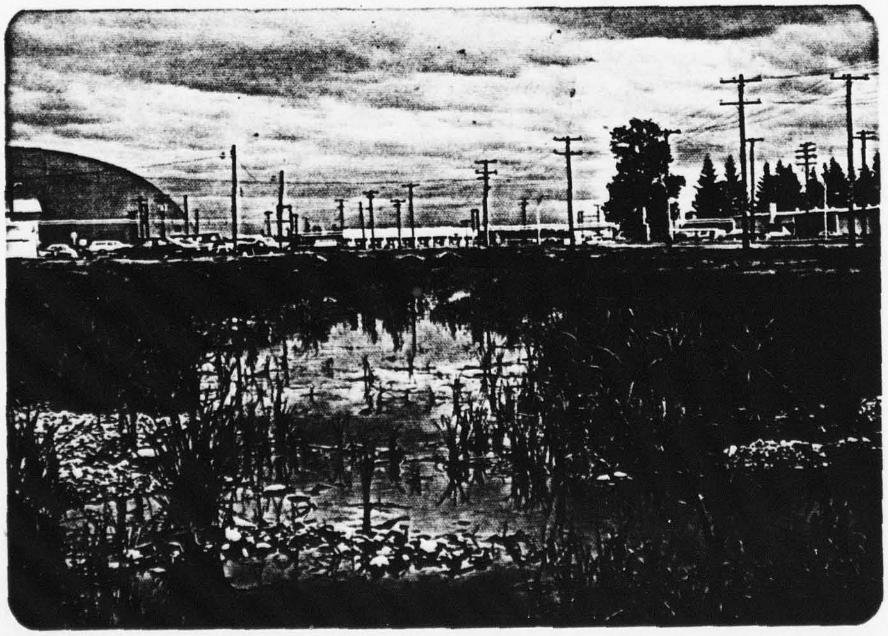

PLATE 22--Sample Site 8B from B-Street Bridge to A-Street.

PLATE 23--Sample Site 8B toward A-Street from bank.

PLATE 24--Sample Site 8B from bank.

PLATE 25--Sample Site 9B from A-Street to Outlet from McChord AFB.

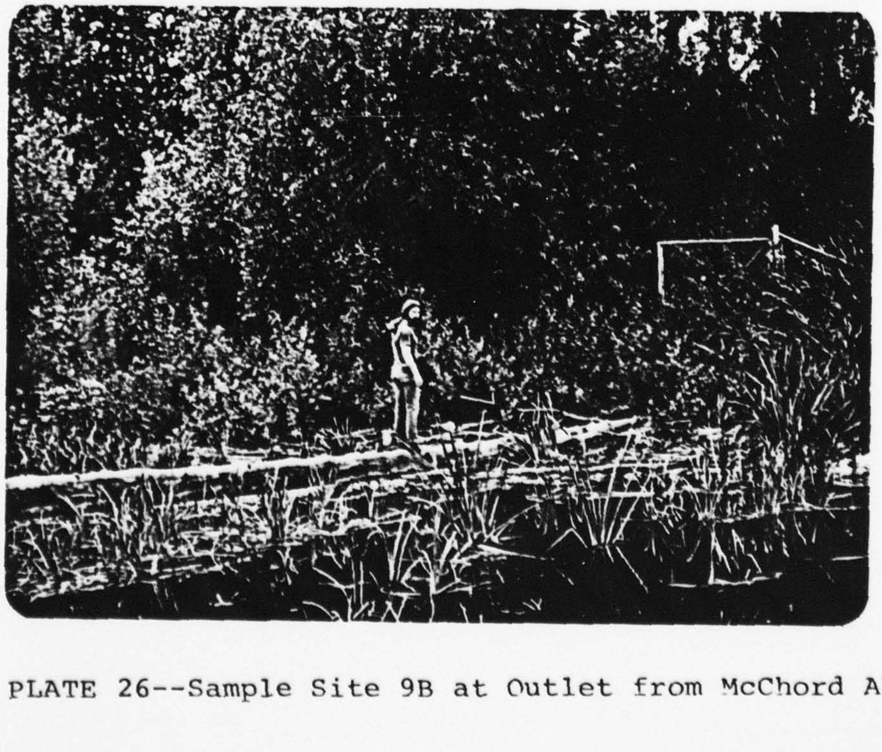

PLATE 26--Sample Site 9B at Outlet from McChord AFB.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An evaluation of the ecological parameter pertinent to developing a water quality assessment model was completed. The final report from this project describes the nature and complexities of biotic communities and current primitive status of knowledge at the community-ecosystem level. Difficulties of applying mathematical modeling techniques to biological systems was illustrated. The importance of time-series studies for the development, interpretation, implementation and verification of water quality assessment models was highlighted by an ecological study of Clover Creek, McChord Air Force Base, Washington. A general

20. input-output compartmental model was developed as well as a proposed biotic sampling/analytical program for Clover Creek. The report includes significant bibliographies on modeling of biotic communities, structure and dynamics of biotic communities in stream ecosystems, and general contemporary theories and concepts in community ecology.