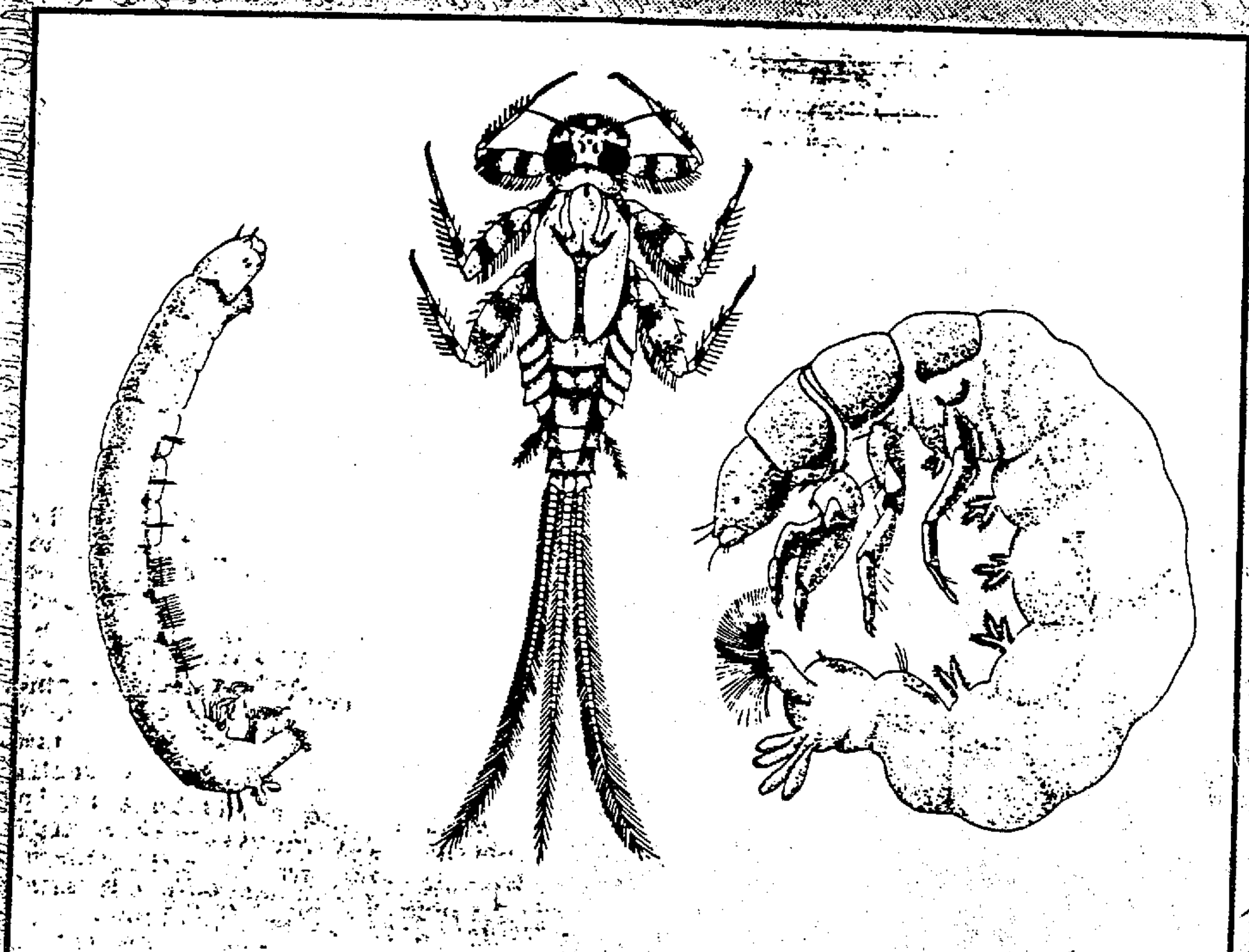
Rapid Bioassessments of Lotic Macroinvertebrate Communities: Biocriteria Development



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RAPID BIOASSESSMENTS

OF

LOTIC MACROINVERTEBRATE COMMUNITIES:

Biocriteria Development

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TABLE OF CONTENTS

LIST OF TABLES

PREFACE

"Are the invertebrates important?" he inquired. I was rather taken aback and briefly hesitated to determine if his question had been asked in jest. The man I speak of was well-educated and had years of experience in the design of wastewater treatment facilities. Our conversation dealt with the effects of chlorine on aquatic invertebrate communities. Upon seeing that he was serious when he posed the thought-provoking question, I realized our objectives for pollution control differed. The focus of his expertise stopped where mine started - at the end of the drainpipe.

This is a prime example of interdisciplinary barriers encountered in the realm of water resource management. The phenomenon, coined as "technological transfer," was an issue discussed at the 1987 EPA-sponsored National Workshop on Instream Biological Criteria. Biotechnology has made tremendous advances in recent years but the lag in tech transfer has prevented the application of these advances. An enhancement of communication among the various disciplines involved in water resource management is necessary to overcome this problem. The solution lies not only in awareness that the problem exists, but in professional assertiveness to bring about the mutual exchange of knowledge. It is the objective of this publication to make information available as a contribution to "technological transfer."

INTRODUCTION

Traditionally, the examination of resident biota has been recognized as perhaps the most straightforward method of assessing water quality since conditions must be favorable for a balanced biological community to exist and perpetuate. Biosurveys are an important method of identifying impairment of aquatic life and can easily be used in conjunction with other biological and chemical monitoring tools in the design of biocriteria. However, from the regulatory standpoint, biological monitoring has had its share of shortcomings. For statewide monitoring programs, the classical intensive quantitative evaluations of biotic communities have been, in many cases, too labor-intensive, time-consuming and expensive. Often, the usefulness of the data has been limited since only aquatic ecologists could understand it.

The increased emphasis on the receiving stream and water quality-based limits created a need for the development of abbreviated methods of generating useful biological data. In the early 1980's, aquatic biologists produced rapid bioassessment techniques and provided information on the concept at the 1986, 1987 and 1988 annual meetings of the North American Benthological Society. Further development of these techniques has continued by numerous state agencies and at the federal level with EPA providing technical guidance (Plafkin et al. 1987). The realization that rapid bioassessments can overcome previously ineffective applications of biological methods is gaining acceptance in the water quality management community. Impact assessment information can now be readily obtained in a cost-effective manner. Rapid bioassessments are useful for screening and as a good starting point when an integration of methods is appropriate.

The primary objective of this report is to convey information pertaining to the validity and reproducibility of a rapid bioassessment technique initiated by the Biomonitoring Section of the Arkansas Department of Pollution Control and Ecology (ADPCE) in 1986. A pilot study was conducted whereby comparisons were made between the complete laboratory analysis of a five-minute riffle samples and field processed 100-organism rapid bioassessments. Investigator subjectivity was tested through a sampling regime of replicate samples collected at: 1) the same riffle by the same individual, 2) the same riffle by two different individuals, 3) two successive riffles in a minimally stressed stream by the same individual and 4) two successive riffles in a minimally stressed stream by two different individuals. Examples of the data generated from these methods are included in this report. A scoring system, using biometrics, was designed to include qualitative and semi-quantitatively measures of the aquatic macroinvertebrate community to develop biocriteria for determining aquatic life use status. The biometric scoring criteria were structured from data generated by the replicate samples which revealed variations between any two samples taken at the same site.

Various levels of uncertainty have been encountered in the application of numeric criteria due to the complexity of aquatic ecosystems. In some scenarios the so-called "safe number" may not adequately protect aquatic life, while in others, unnecessary regulatory requirements prevail. This does not imply that numeric criteria have no place as a management tool, but their application may be enhanced when supplemented with narrative biological criteria developed from biosurveys of ambient fauna. There is no better way to determine the aquatic life use status of a stream than to examine its inhabitants.

PART I: RAPID BIOASSESSMENT PROCEDURES

Criteria for Site and Habitat Selection

At the Arkansas Department of Pollution Control and Ecology, biomonitoring stations are chosen on a priority basis and are primarily at streams possessing high resource values and/or potential for water quality problems. A priority list is developed to aid in the selection of monitoring stations. The list is formulated from available information such as discharge monitoring reports, knowledge of potential sources of pollutants and awareness of land uses in different regions of the state.

Since the 1970's, Arkansas' biomonitoring program has involved the analysis of macroinvertebrate samples to investigate point source pollution, nonpoint source pollution and water quality trends. The environmental effects of point source pollution on aquatic life can be accurately measured by taking samples above and below discharge points. Although the current emphasis in Arkansas' rapid bioassessment program is on point sources, nonpoint sources can also be monitored by these methods. In some situations, however, an upstream unimpacted station is either inaccessible or nonexistent and it becomes necessary to collect samples from a neighboring reference stream. Trend analyses, whether point or nonpoint source, can be determined with a minimum of time and expense, by rapid bioassessments conducted over a period of years. Attainment of water quality goals can be determined when assessments are performed "before" and "after" implementation of pollution control measures.

To compare changes in community structure and function resulting from a pollutant source, the paired station approach should be employed whenever possible. Selection of samples sites should be made so habitat differences between upstream/downstream sites are minimal. Variables which exert the greatest effect on the invertebrate community include flow, velocity, substrate, temperature, riparian vegetation and dissolved substances (Cummins 1975; USEPA 1983; ADPCE 1987b). Station locations should be where water quality, not habitat, is the potential limiting factor (Plafkin et al. 1987).

Selection of habitat type should be based on the specific need of the biosurvey. Riffles have the reputation for being the most productive and diverse habitat type which supports the most sensitive organisms. It should not be assumed, however, that rapid bioassessments are limited to the riffle habitat. Pool samples may be useful since pools often serve as settling basins for toxicants bound to suspended particles. There is also evidence pools may be a better indicator than riffles for identifying impacts caused by siltation (McDaniel 1988). Lenat (1988) reports that communities other than those found in riffles can aid as water quality indicators. Pool samples from wadable lowland streams where riffles are nonexistent have proven to be a valuable assessment tool for ADPCE ecologists.

Rapid bioassessments can be performed on a single habitat basis (pool or riffle) for impact identification or on a multi-habitat basis (pools and riffles) where more specific information is needed. Successive samples collected downstream from a pollutant source can be used to determine the downstream extent of an impact.

Ecoregions

The significance of ecoregions has received much attention in recent years. Arkansas is among the states that have identified and conducted extensive research on the least-disturbed streams within its ecoregions (ADPCE 1987a, 1987b). Due to the overlap of taxa among some of the ecoregions in Arkansas, differences in macroinvertebrate communities were more easily observed on the basis of hydrology (upland versus lowland), habitat (riffle versus pool), watershed size and seasonality. Even though this taxonomic overlap exists, it does not occur with all taxonomic groups or all ecoregions. There are, in fact, organisms that are characteristic of specific ecoregions in Arkansas. Use of the ecoregion approach is recommended since the degree of overlap may vary from one geographical region to another. The use of paired stations actually is an application of the ecoregion approach. Sample sites that bracket a pollutant source not only compare communities within the same ecoregion but examine site-specific changes in water quality as well. Reference streams used in lieu of an upstream station, should be within the same ecoregion and of similar watershed size to make a valid comparison of biota.

Seasonality

Throughout the annual cycle, changes in seasonal periodicity such as temperature, precipitation and photoperiod have a strong influence on community structure and function. The life cycles and activities of many aquatic organisms are programmed by seasonal changes in the physical environment (Cummins 1987). Thus, community periodicity is a function of seasonal periodicity. It has been determined for Arkansas streams , as watershed size decreases, the seasonal variations in community structure become more pronounced (ADPCE 1987b).

Sampling efforts should be carried out during stable periods of base flow and temperature. At these times, organisms are larger and impacts are easier to detect. This avoids sampling during periods when macroinvertebrate communities are primarily composed of eggs and early instars (Cummins 1987).

In Arkansas, optimum sampling periods that correspond to stable flows are generally from July through September in the summer and from February through March in the late winter. Plafkin (et al. 1987) has outlined optimum sampling periods for various climatic regions.

Habitat Evaluation / Visual Observations

A description of the physical habitat is a necessary prerequisite for comparing upstream/downstream communities. This aids in verification of whether significant differences between the communities are attributed to habitat or to water quality. Methods similar to those of Platts (et al. 1983) were used in the Arkansas pilot study. An example of the habitat evaluation field sheet is contained in Appendix A. Portions of the habitat evaluation sheet do not require on-site measures and can be completed with the use of maps, aerial photos, discharge permit information or discharge monitoring reports. Prior knowledge of land uses, potential pollutants, gradient, ecoregion and watershed size can facilitate the consistency of sampling efforts and the selection of sample sites. All on-site measures and visual observations are recorded in the field to identify obvious changes that occur downstream from the pollutant source. Often this information is helpful in determining generic cause.

Sampling Procedures

A minimum of two people are required to execute the methods described in this publication. Three individuals per team, however, will expedite completion of the procedures. The team leader should be an experienced aquatic biologist who is knowledgable about the taxonomy and ecology of macroinvertebrate communities of the region. This is especially important since professional judgement is used in the various stages of the biological assessment. Individuals involved in the collection and analysis of macroinvertebrate samples must first be able to demonstrate an acceptable level of proficiency. This includes taxonomic expertise and the ability to provide reproducible data. The other individual(s) can serve as support personnel for operating instruments and recording data.

The rapid bioassessment is initiated with one individual, the "collector," collecting the macroinvertebrates while another individual, the "recorder," records habitat data. In Arkansas, macroinvertebrates are collected with a Wildco indestructible A-frame net (Turtox design 73-412) with a 800 micron X 900 micron multifilament polyester bag. Sampling is executed in a consistent manner with the same individual collecting at all stations for each pollutant source monitored. If available, a third individual can operate instruments to measure flow, dissolved oxygen, temperature, pH and conductivity. If the third individual is not available these parameters are measured by the recorder.

The most efficient use of time involves collecting at the upstream site prior to the downstream site. The data is analyzed and the impairment status is determined at the downstream site where a decision is made concerning additional sampling for further biological or chemical analysis. The type of additional sampling is decided on a case by case basis and is done where significant impacts are identified. If the downstream sample is collected prior to the upstream sample, much time is wasted transporting personnel and sampling gear back to the downstream site when collection of additional samples is necessary.

Riffles are sampled for five minutes and pools are sampled for three minutes. An LCD wrist watch, used in the stop watch mode, is activated only when the actual sampling is in progress. It is deactivated during periodic interruptions such as removal of large pieces of debris from the net or movement to another subhabitat within the sample area. Subhabitats are sampled in equal time allotments. For example, an equal amount of time is spent sampling a riffle at the tail, head, midstream and edges. This helps eliminate a potential source of error caused by the non-random distribution of organisms.

At riffles, sampling begins at the tail or downstream end and proceeds upstream using the method commonly known as "kick sampling." The net rim is placed against the stream bottom with the handle held at arms length and downstream from the collector. The substrate is agitated by kicking, allowing the current to carry organisms into the net. As this is done, the collector wades back and forth across the stream channel until arriving at the head of the riffle.

At pools, substrate agitation is accomplished by the collector with a "digging" or "shoveling" movement. The net rim is repeatedly swept slightly above the substrate surface to agitate the substrate by currents created from the movement of the net. Bottom-dwelling organisms that become suspended in the water are subsequently captured. As collecting is in progress, the collector slowly moves along the stream bank spending equal time at all wadable habitat types within the pool.

For larger non-wadable waterbodies, rock baskets or other types of artificial substrate samplers can be used and subsampled in the field (Hilsenhoff 1982). Care should be exercised to assure consistent placement of all samplers used to monitor any given pollutant source.

After completion of collecting, the contents of the net are rinsed, deposited in a 14" X 9" X 2" white enamel pan and covered with water. Organisms clinging to the net are removed with forceps and placed in the pan. The larger pieces of debris, rocks, leaves or other extraneous material are visually examined and discarded after attached organisms are removed and added to the remainder of the sample.

As a 100-organism subsample is removed from the contents of the pan, the collector verbalizes the identification of each organism. The recorder writes this information on the field data sheet (Appendix B) and keeps tally of the number of organisms subsampled with a counter. The collector must exercise care to randomly pick the 100-organism subsample, keeping in mind that the objective is to remove a representative subsample of the invertebrate community. This can be facilitated by frequently swirling the contents of the pan to maintain a homogeneous mixture of organisms and expose those that may become concealed in the extraneous debris. For samples containing large amounts of leaf litter or algal mats, only a handful at a time should be placed in the pan. The entire mass should be examined, however, for removal of the 100 organisms. Random selection of organisms is accomplished by the collector inspecting the contents of the pan, performing a visual scan back and forth from top to bottom. When an organism is sighted, it should be removed, and identified. An attempt to recover as many species as possible should be avoided. It is not the intent of this procedure to perform a complete taxonomic inventory, but to remove the organisms in relative abundances as they occur in the complete sample. The collector should avoid passing up taxa that are repeatedly sighted. The "I've picked enough of those. What else can I find?" approach is inappropriate for picking the 100-organism subsample. The collector should be cognizant of larger, less motile organisms which are easier to see and remove, and may bias the subsample. It is recommended that prior to extensive use of this technique, a series of replicate samples be collected to confirm that prescribed procedures are being followed. If properly done, results are repeatable as shown in the next section.

Some investigators suggest subsampling by the use of a numbered grid marked on the bottom of the pan. All organisms are removed from squares within the grid selected by a random numbers table until the desired subsample size is obtained (Hilsenhoff 1987; Plafkin et al. 1987; Vermont ANR 1987). The use of a grid was not the preferred method in the Arkansas study. It is probably better for subsampling preserved samples in the laboratory but more difficult to apply with living motile organisms subsampled in the field. Field picking and identifications, as practiced in Arkansas, give the advantage of an on-site determination of impairment status which forms the basis for the decision of whether or not additional sampling is necessary. Although Hilsenhoff (1982) found differences do exist between field picked and laboratory-picked samples, it was not enough to alter the final evaluation of the biotic status.

A pilot study in North Carolina compared 100-organism versus 300-organism subsamples (Plafkin et al. 1987). It was determined that 100 organisms are adequate for making a good evaluation even at the family level. The additional information obtained from a 300-organism sample did not justify the necessary expenditure of time and resources. A 100-organism sample has also proven adequate in numerous other studies for impact detection (Hilsenhoff 1982, 1987; Nuzzo 1986; Plafkin et al. 1987; Bode 1988). Other methodologies for rapid bioassessment field procedures have been developed by Hilsenhoff (1977, 1982, 1987, 1988), Shelor and Ayers (1984), Cummins and Wilzbach (1985), Nuzzo (1986), Vermont ANR (1987), Lenat (1988) and Bode (1988).

Rather than selecting any one taxonomic level, field identifications are made to the lowest possible level. At relatively unimpacted sites in Arkansas, experienced biologists can identify 85-90% of the organisms to generic level in the field without the aid of a microscope. Even greater precision is possible when a hand lens is used. Problems are encountered for generic level field identifications at sites that exhibit imbalanced communities with large numbers of chironomids. Since the Arkansas rapid bioassessment protocol incorporates relative abundance, generic level identifications of chironomids are not necessary for making a field assessment of biotic quality. However, the 100-organism subsamples are preserved with 70% ethanol and archived for possible microscopic analysis. This is done because it has been reported generic level identification of chironomids can be helpful in determining specific cause at severely impacted streams (Mount et al. 1986; Ferrington 1987; Lenat 1988).

Examples of Rapid Bioassessment Data

The example in Table 1 demonstrates the reproducibility of the rapid bioassessment. The macroinvertebrate communities listed were collected from a minimally stressed site by two biologists at two different riffles of similar substrate composition. The biologists had spent a considerable amount of time following prescribed collecting, picking and identification procedures.

Throughout the discussion of examples and biometrics, in this report, "station A" refers to upstream sample site or "above" the pollutant source while "station B" denotes the downstream sample point or "below" the pollutant source.

Table 1. - Replicate rapid bioassessments from the Cossatot River

	Primary Sample	Replicate Sample
Substrate Composition	5% bedrock 10% small boulders 30% cobble 45% gravel 10% sand	10% bedrock 15% small boulders 40% cobble 30% gravel 5% sand
Number of taxa	14	13
Ephemeropteran taxa	4	3
Trichopteran taxa	2	2
Plecopteran taxa	1	1
Coleopteran taxa	1	1
Chironomid taxa	0	0
% Ephemeropterans	45	48
% Trichopterans	34	27
% Plecopterans	7	12
% Coleopterans	2	1
% Chironomids	0	0

Community Dominants*

Primary	%	Replicate	%
Cheumatopsyche	27%	*Isonychia*	33%
Isonychia	22%	*Cheumatopsyche*	19%
Stenonema	14%	*Stenonema*	13%
Neoperla	7%	*Neoperla*	12%
Baetis	7%	*Chimarra*	8%

*Although not included as a dominant in the primary sample, *Chimarra* sp. had a relative abundance of 6%.

Functional Groups

	Primary Sample	Replicate Sample
% Scrapers	16	15
% Shredders	3	0
% Collectors	67	65
% Predators	14	20

The 100-organism subsampling procedure has received criticism as allegedly being too subjective. No doubt, there are individual variations in picking methods, but there is little risk of subjectively overpicking mayflies from a sample composed of 90% chironomids. Regardless of individual subjectivity, there would be little chance of picking any organisms other than chironomids. As shown in the Arkansas study, conflicting impairment status determinations did not result from variations in the subsampling. If proper quality control is followed, it is not probable that a stream will be classified as "Minimally Impaired" by one individual and "Excessively Impaired" by another. The development of the Arkansas biometric scoring criteria from replicate samples was designed to account for individual variations in performing the bioassessment. Several studies report individual variations in kick net samples are not significant if standardized methods are followed (Egglishaw 1964; Pollard 1981; Lenat 1988).

In July of 1988, Region VI EPA personnel accompanied Arkansas Department of Pollution Control and Ecology ecologists on rapid bioassessment field trips. An ADPCE ecologist collected a macroinvertebrate sample from Prairie Creek near Russellville, Arkansas. As the ecologist picked and identified a 100-organism subsample, an EPA employee moved out of hearing range and collected a sample in the same vicinity. The EPA employee had no prior experience with rapid bioassessment techniques and was not familiar with the taxonomy of the aquatic invertebrates collected. A 50-organism subsample was picked by the EPA employee and identified by the ADPCE ecologist. The results show striking similarities in the community composition even though the optimum level of quality control had not been followed (Table 2).

Table 2. - Comparison of replicate rapid bioassessment samples collected at Prairie Creek

ADPCE ecologist (100-organism subsample)		EPA employee (50-organism subsample)	
Corixidae	41%	Corixidae	52%
Caenis	24%	*Caenis*	21%
Chironomidae	14%	Chironomidae	11%
Physa	5%	*Physa*	10%
Berosus	1%	*Berosus*	4%
		Uvarus	2%
Ischnura	4%		
Baetis	3%		
Tropisternus	2%		
Libellula	1%		
Tipula	1%		
Lumbriculidae	1%		
Gerris	1%		
Derralus	1%		

Realistically, when a point source is monitored, one individual collects samples from similar habitat types at two different sites (upstream/downstream). The example in Table 3 was designed to simulate the "worst case" scenario where the upstream habitat does not closely resemble the downstream habitat. Sample sites were selected at three riffles near a POTW at Harrison, Arkansas. Two of the samples were collected at an upstream (A1) and downstream (B) pair of stations with very similar substrate composition. An additional upstream site (A2), with substrate composition unlike sites A1 and B was intentionally selected to investigate the influence of habitat. Results in Table 3 show substrate composition does play an important role in determining community composition. However, the downstream impact was evident, regardless of which upstream sample was used for comparison. The change in dominants and the decline in ephemeropterans and trichopterans below the discharge was detected by both upstream samples.

As discussed in other sections of this report, a quantitative approach for benthic bioassessments is not necessary for detecting an impact. It not only requires numerous man-hours of laboratory work, but also precludes an in-the-field impact determination. In such cases, a return trip to an impacted site is necessary to collect additional samples for chemical or biological analyses. Table 4 compares data from the rapid bioassessment to a more intensive quantitative method. Three sites were sampled on Osage Creek near the sewage treatment plant at Berryville, Arkansas. At each site, riffles were sampled for five minutes and 100-organism rapid bioassessments were performed in the field. The 100 organisms and the remainder of each sample were preserved and analyzed in the laboratory for the quantitative workup.

A comparison of data from the two methods revealed numerous similarities. The slight increase in taxa, percent trichopterans and percent chironomids at the downstream site, as determined by numerous hours in the laboratory, was detected in the field by the rapid bioassessment. The slight decline in the relative abundance of ephemeropterans and the replacement of Ephoron sp. by chironomids as a dominant was determined in both field and laboratory analyses. The functional characteristics of the community shown by the rapid bioassessment is representative of percentages generated by the more laborious approach. These similarities demonstrate that a determination of water quality by rapid bioassessment can be made in much less time, even where moderate impacts occur. For rapid bioassessments in Arkansas, two to five man-hours per pair of stations were required from initiation of sampling to calculation of the Mean Biometric Score. Completion of bioassessments with quantitative five minute riffle samples, picked and identified in the lab, required approximately 30 to 120 man-hours per pair of stations.

Table 3. - Rapid bioassessments above and below POTW discharge into Crooked Creek at Harrison, Arkansas

	Station A2	Station A1	Station B
	Replicate Upstream Sample	Primary Upstream Sample	Downstream Sample
Substrate Composition	10% bedrock 20% sm. boulders 55% cobble 10% gravel 5% sand	10% cobble 75% gravel 15% sand	5% bedrock 5% cobble 80% gravel 10% sand
No. of taxa	14	16	18
Ephemeropteran taxa	4	5	4
Trichopteran taxa	2	2	1
Coleopteran taxa	2	3	5
% Ephemeropterans	45	56	29
% Trichopterans	32	21	2
% Coleopteran	2	9	18
% Chironomids	1	0	2
% Annelids	1	1	10
Functional Groups			
% Scrapers	21	27	14
% Shredders	7	5	25
% Collectors	62	61	50
% Predators	12	7	12

% Community Dominants

Station A2	%	Station A1	%	Station B	%
Cheumatopsyche	24	*Stenonema*	25	Cambarinae	16
Isonychia	23	*Cheumatopsyche*	20	*Caenis*	14
Stenonema	19	*Tricorythodes*	14	*Asellus*	9
Chimarra	9	*Baetis*	10	Lumbriculidae	9
Corydalus	9	*Isonychia*	6	*Stenonema*	9

Table 4. - Comparison of quantitative bioassessments and rapid bioassessments conducted at Osage Creek

	Quantitative Bioassessment			Rapid Bioassessment		
Station	A1	A2	B	A1	A2	B
No. of taxa	30	35	35	12	17	16
% Ephemeropterans	71	63	51	66	54	43
% Trichopterans	21	26	32	20	24	32
% Chironomids	3	3	11	1	1	7
% Scrapers	30	27	27	27	17	19
% Shredders	<1	1	<1	4	6	0
% Collectors	68	67	71	64	69	72
% Predators	2	3	1.5	5	7	9

Community Dominants

Quantitative Bioassessment*

A1		A2		B	
Stenonema	27%	Stenonema	24%	Cheumatopsyche	29%
Cheumatopsyche	20%	Cheumatopsyche	24%	Stenonema	26%
Isonychia	15%	Isonychia	19%	Baetis	16%
Ephoron	11%	Ephoron	8%	Isonychia	7%
Baetis	9%	Baetis	7%	Polypedilum	7%

Rapid Bioassessment

A1		A2		B	
Stenonema	24%	Isonychia	20%	Cheumatopsyche	18%
Ephoron	20%	Ephoron	16%	Stenonema	16%
Cheumatopsyche	19%	Cheumatopsyche	13%	Isonychia	15%
Isonychia	18%	Stenonema	13%	Chimarra	14%
Cambarinae	4%	Chimarra	9%	Chironomidae	7%

*Stenonema spp. was identified to species level in the laboratory for the quantitative bioassesssment but was grouped at the generic level to compare to rapid bioassessment data.

Data Analysis and Interpretation

Biometric Scoring System

Aquatic life use impairment in Arkansas streams is determined by the Biometric Scoring System. This is a modification of the Community Condition Index (ADPCE 1982) and the Benthic Community Criteria System (ADPCE 1984) previously used in Arkansas water quality monitoring reports. The general format of these systems is to obtain an average of the sum of scores assigned to various characteristics (metrics) of the benthic community. The calculated value is then categorized by a set of aquatic life use status criteria. Similar applications have been reported by Hilsenhoff (1982), Nuzzo (1986), Ohio EPA (1987), (Plafkin et al. 1987),Lenat (1988) and Bode (1988). In the Biometric Scoring System, each biometric is assigned a score based on criteria that define the relative change between communities upstream and downstream from a pollutant source. Scores are recorded in the field, on the biometric score sheet (Appendix C). The scoring criteria were developed from mean and range metric values obtained from replicate sample comparisons at minimally impacted sites. This provides the ability to differentiate variations among samples that are normal occurrences from those that are impacted related. The Mean Biometric Score, which indicates the degree of impairment, can be used to rank monitoring stations in terms of water quality. Biometric scores and the corresponding aquatic life use status are shown in Table 5. Narrative criteria for aquatic life use status are contained in Appendix D.

Table 5. - Biometric scores, mean biometric scores and corresponding aquatic life use status

Biometric Scores

4 - No impairment to biointegrity indicated by scoring criteria of this biometric

3 - Minimal impairment to biointegrity indicated by scoring criteria of this biometric

2 - Substantial impairment to biointegrity indicated by scoring criteria of this biometric

1 - Excessive impairment to biointegrity indicated by scoring criteria of this biometric

Mean Biometric Score	Aquatic Life Use Status
3.5 - 4.0	No Impairment
2.6 - 3.4	Minimal Impairment
1.6 - 2.5	Substantial Impairment
1.0 - 1.5	Excessive Impairment

A combination of semi-quantitative and qualitative measures are utilized in the seven biometrics. Data from the Arkansas pilot study indicate qualitative measures (presence/absence) and semi-quantitative measures (relative abundances) are more cost effective and reproducible than quantitative measures (standing crop or density). Frequently, replicate samples closely resembled one another in terms of relative abundances of organisms but differed considerably in absolute abundance (Table 7). This indicates a much greater effort, in terms of time and expense, is probably necessary to obtain an accurate quantitative measure. Similar findings, when comparing quantitative and qualitative methods, have been documented by Needham and Usinger (1956) and Lenat (1988).

The combined examination of semi-quantitative/qualitative measures becomes an important part of the scoring system. As pollutant stress is increasingly exerted on the environment, there is a progressive change in the biota beginning with a reduction in the relative abundances of the more sensitive organisms, continuing to the point of absence. Consequently, a "Minimal" to "Substantial Impairment" is usually indicated by low semi-quantitative metric scores as relative abundances change. "Excessive Impairments" usually exhibit low scores in both semi-quantitative and qualitative metrics as the removal of species triggers low qualitative metric scores. The biometrics used in the Arkansas rapid bioassessment protocol are listed in Table 6. They employ measures of diversity, indicator organisms and community function.

Table 6. - Biometrics used for Arkansas rapid bioassessments

Community Diversity Approach	
Biometric (1)	Dominants In Common (DIC)
Biometric (2)	Common Taxa Index (CTI)
Biometric (3)	Quantitative Similarity Index (QSI)
Biometric (4)	Taxa Richness
Indicator Organism Approach	
Biometric (5)	Indicator Assemblage Index (IAI)
Biometric (6)	Missing Taxa
Functional Group Approach	
Biometric (7)	Functional Group Per Cent Similarity (FGPS)

The concept of community diversity is a classical measure of biotic stability. Biometrics 1-4 compare taxonomic structure at paired sites to detect changes in composition associated with pollutants.

Indicator organisms have been employed in a variety of ways for biological assessments by Rabeni and Gibbs (1977), Simpson and Bode (1980), Learner (et al. 1983) and Plafkin (et al. 1987). Numerous investigators have devised biotic indices which utilize tolerance values in conjunction with relative abundances (Chandler 1970; Chutter 1972; Winget and Mangum 1979; Jones et al. 1981; Hilsenhoff 1977, 1982). Plafkin (et al. 1987) recommends that due to regional differences in organisms responses to the various types of pollutants, the states should adopt their own biotic index rather than relying on one based on criteria from another region. In the biometric scoring system, Biometrics 5 and 6 were used in lieu of a biotic index with tolerance values. Although specifically designed for Arkansas streams, their application in other regions may be possible.

Valuable knowledge can be obtained by examining macroinvertebrate community function since energy circuits of streams are driven by excess production available by export from other systems (Cummins 1974). As expressed by Lotspeich (1980), the dynamics of aquatic ecosystems are essentially "an integration of the upstream drainage" Therefore, ecological events in the watershed (whether point or nonpoint) affect energy flow in the aquatic ecosystem. Several functional roles concerning the processing and metabolism of allochthonous particulate have been identified on the basis of feeding strategies (Cummins 1973, 1974; Platts et al. 1983; Merritt and Cummins 1984; Cummins and Wilzbach 1985). The functional groups are separated into shredders, collectors, scrapers and predators. Changes in the abundance of the functional groups can indicate changes in trophic structure which reflect the ecosystem's food base. This can be measured as demonstrated by Biometric 7.

Community Diversity Approach

Biometric (1) Dominants In Common

An examination of community dominants can provide insight to community structure because dominants specialize on the prevailing environmental complex of the aquatic ecosystem. Benthic studies have shown that tolerant species are present in nearly all streams, but are dominants only in polluted systems (Nuzzo 1986; Lenat 1988; Bode 1988). Metrics used in rapid bioassessment techniques developed in Massachusetts (Nuzzo 1986) and New York (Bode 1988) employ an examination of community dominants.

A comparison of the community dominants at paired stations, can be used to identify changes in community structure relative to a pollutant source. Biometric 1, developed for biosurveys in Arkansas, determines the Dominants-In-Common or DIC (ADPCE 1987c). The DIC is defined as the number of dominants common to both the upstream and downstream communities, regardless of their order of abundance. For this metric, the dominants are the five most abundant taxa each of which usually have a relative abundance that is greater seven percent. The DIC is a semi-quantitative measure since it deals with the most abundant organisms and has the qualitative feature of making a taxonomic comparison of dominants. Replicate rapid bioassessments in Arkansas have exhibited DIC values that range from 3-5 and average 3.93. This information has been utilized to design the criteria shown below. Penrose (1988) reports the DIC works well as an indicator of biological status when applied to North Carolina streams.

Scoring Criteria for Biometric (1) Dominants In Common (DIC)

Score	Criteria
4.0 - No Impairment	- DIC values range from 4-5
3.0 - Minimal Impairment	- DIC value = 3; 2 of the dominants at station A may be present at station B but have become non-dominants.
2.0 - Substantial Impairment	- DIC value = 2; 3 of the dominants at station A have been dramatically reduced at station B and/or one or more of the dominants at station A may be absent at station B.
1.0 - Excessive Impairment	- DIC values range from 0-1; more than one dominant at station A is absent at station B OR fewer than 5 taxa are present at station B.

Biometric (2) Common Taxa Index (CTI)

Comparisons of upstream/downstream invertebrate communities have been done in Arkansas using the Common Taxa Index (CTI) (ADPCE 1986,1987c). This metric is strictly qualitative as it deals only with the presence or absence of taxa and disregards relative abundance. It is expressed as follows:

$$CTI = TIC/max\ (Ta,Tb)$$

where:

TIC = taxa in common or the number of taxa that are present at both stations A and B

Ta = total number of taxa collected at station A

Tb = total number of taxa collected at station B

max(Ta,Tb) = the maximum possible value at station A or B in terms of the number of taxa

Values range from 0-1.0 and decrease as environmental stress increases. CTI values averaged 0.74 for rapid bioassessment replicates. Values >0.50 are typical of situations where the station with the most taxa has more than half of those taxa in common with the station possessing the fewest taxa. This is characteristic of areas exhibiting "No" to "Minimal Impairment." Conversely, values <0.50 typify "Substantial" to "Excessive Impairment." In these cases, less than one half of the taxa at the richest community are common to those in the community with fewer taxa. Occasionally, all of the taxa found at the site with the lower taxa richness are present at the site with the higher taxa richness. The latter ,however, may have numerous additional taxa not found at the former. The CTI takes this into account when viewing taxonomic similarities of the communities. The CTI has been used to assess water quality in North Carolina streams (Penrose 1988).

Scoring Criteria for Biometric (2) Common Taxa Index

Score		Criteria
4.0 - No Impairment	-	CTI > 0.70
3.0 - Minimal Impairment	-	CTI = 0.50-0.70
2.0 - Substantial Impairment	-	CTI = 0.30-0.49
1.0 - Excessive Impairment	-	CTI < 0.29

Biometric (3) Quantitative Similarity Index

A useful method of comparing the composition of two communities is the Quantitative Similarity Index (QSI), or percent similarity (Whittaker 1952; Bray and Curtis 1957). The equation not only taxonomically compares two communities in terms of presence or absence (qualitative), but also takes relative abundance (semi-quantitative) into account. The index is expressed as:

$$S_{ab} = \sum \min(pia, pib)$$

where:

S = QSI

pia = the relative abundance of species i at station A

pib = the relative abundance of species i at station B

min(pia,pib) = the minimum possible value of species i at station A or B in terms of relative abundance

Values for this index range from 0-100, with identical communities having a value of 100 and totally different communities having a value of 0. An average of 75.0 and a range from 60.0 to 85.0 was obtained with replicate bioassessments in Arkansas. These values were used to design the following scoring criteria. In general, values less than 65.0 indicate environmental stress whereas values greater than 65.0 occur as expected variations.

Scoring Criteria for Biometric (3) Quantitative Similarity Index

Score	Criteria
4.0 - No Impairment	- QSI > 65
3.0 - Minimal Impairment	- QSI = 56-65
2.0 - Substantial Impairment	- QSI = 45-55
1.0 - Excessive Impairment	- QSI < 45

The index has received criticism in a hypothetical example illustrated by Pinkham and Pearson (1976) as shown below.

Number of individuals of species	A	B	C	D	E
Station A	40	20	10	10	10
Station B	20	10	5	5	5

The example was devised with each species at station A being twice as abundant as those at station B. Their relative abundances are the same, therefore a QSI using relative abundances equals 100. This indicates the communities are identical when ,in reality, they differ significantly with respect to absolute abundance or standing crop. The validity of the QSI has been questioned on this basis.

The Arkansas rapid bioassessment study frequently demonstrated populations from replicate quantitative samples actually do differ significantly in terms of standing crop, but exhibit very similar relative abundances (Table 7). Perhaps the nonrandom distribution of macroinvertebrates has a greater influence on absolute abundance than it does on relative abundance. This suggests the Pinkham and Pearson (1976) example may be more "real world" than hypothetical. As discussed in the narrative portion of the "Data Analysis and Interpretation" section, quantitative measures are often more difficult to reproduce than qualitative ones. The example in Table 7 shows actual data from replicates collected by the same individual at successive riffles in a minimally stressed stream. Although the two samples differed significantly in terms of absolute abundance, the relative abundance of organisms were similar. The QSI, DIC and CTI values also indicate similarities.

Table 7. - Replicate quantitative samples from Crooked Creek

	Primary Sample	Replicate Sample
Total number of organisms	1,872	516
Number of taxa	28	23
% Ephemeropterans	67	72
% Trichopterans	16	11
% Chironomids	3	2
% other taxocenes	14	15

QSI = 77.2

DIC = 5

CTI = 0.68

Biometric (4) Taxa Richness

Taxa richness is commonly used as a measure of community status (Platts et al. 1983; Plafkin et al. 1987). In this publication, the term "taxa" refers to the lowest possible level of identification. Rather than selecting one taxonomic level, all organisms were identified to the lowest possible taxon.

In Arkansas streams, a 10% natural variation of taxa richness occurs between replicate samples. The percent change from upstream to downstream is used in Biometric 4 to mathematically express the effect of pollutant stress. This biological parameter is a quantitative measure, addressing only taxa richness without considering which taxa are present.

Scoring Criteria for Biometric (4) Taxa Richness

Score	Criteria
4.0 - No Impairment	- Taxa richness exhibits a change of 10% or less from station A to station B
3.0 - Minimal Impairment	- Taxa richness exhibits a change of 11-30% from station A to station B
2.0 - Substantial Impairment	- Taxa richness exhibits a change of 31-45% from station A to station B
1.0 - Excessive Impairment	- Taxa richness exhibits a change of > 45% from station A to station B

Biometric (5) Indicator Assemblage Index

Biometric 5 incorporates both qualitative and semi-quantitative elements by integrating pollution tolerance with the relative abundance of selected taxonomic groups or "taxocenes". The groups ephemeroptera, plecoptera, trichoptera, chironomidae and annelida were selected as indicator groups. Although sensitivities to various pollutants vary within these groups, it is well-documented that ephemeropterans, plecopterans and trichopterans (EPT) are relatively sensitive to pollutants (Andrews and Minshall 1979; Plafkin et al. 1987), while chironomids and annelids (CA) have been shown to be relatively tolerant to pollutants (Minshall and Andrews 1973; ADPCE 1986; Plafkin et al. 1987). There are exceptions, however, where intolerant species of chironomids inhabit pristine streams, or a relatively tolerant species of ephemeropteran exists below the discharge of poorly treated sewage. Regardless , indicator assemblages can be used as ecological indicators when relative abundance is taken into consideration. For example, a riffle sample composed of 90% chironomids indicates an imbalance and is not likely to be primarily composed of sensitive taxa. It is not necessary in this case to know what types of chironomids are present to make a determination of degree of impact. Similarly, the species of mayfly in the sewage discharge is probably not a community dominant. Applications of indicator assemblages have been described by Plafkin (et al. 1987) and Resh (1988) where ratios of EPT and chironomid abundances are used to indicate biotic condition. For analyzing rapid bioassessment data in Arkansas, the phylum annelida was included since a dramatic increase in the relative abundance of leeches or aquatic earthworms is often associated with pollutant stress.

The Indicator Assemblage Index (IAI) is expressed as follows:

$$IAI = 0.50\ (\%EPTb/\%EPTa + \%CAa/\%CAb)$$

where:

- IAI = Indicator Assemblage Index
- 0.50 = constant
- %EPTb = total relative abundances of ephemeropterans, plecopterans, and trichopterans at station B (downstream)
- %EPTa = total relative abundances of ephemeropterans, plecopterans, and trichopterans at station A (upstream)
- %CAa = total relative abundances of chironomids and annelids at station A (upstream)
- %CAb = total relative abundances of chironomids and annelids at station B (downstream)

The objective of the index is to measure the change in the relative abundance of tolerant and intolerant organisms associated with a pollutant source. Values range from 0 to >1.0 and are inversely proportional to the degree of environmental stress. An IAI value that approaches 1.0 indicates little change in community balance has taken place (Table 8). An examination of the variables in the equation, clarifies the application of this metric. The %EPTb/%EPTa provides a measure of the change in the abundance of sensitive organisms while %CAa/%CAb indicates a change in the abundance of tolerant organisms. A reduction of either component contributes to a reduction of the IAI (Table 9).

Table 8. - Example of IAI value from stations exhibiting similar biotic quality

	Upstream Station (A)	Downstream Station (B)
%EPT	48	45
%CA	5	7

%EPTb/%EPTa = 45/48
= 0.94

%CAa/%CAb = 5/7
= 0.71

IAI = 0.50 (%EPTb/%EPTa + %CAa/%CAb)
= 0.50 (45/48 + 5/7)
= 0.50 (0.94 + 0.71)
= 0.50 (1.65)
= 0.83

Table 9 illustrates a situation where the community has been significantly impacted. The %EPTb/%EPTa is calculated as: 42/68 = 0.62 which means the %EPT below the discharge is 62% of the %EPT at the upstream station. The %CAa/%CAb indicates an increase in pollution tolerant organisms. Both sets of variables, in this example, indicate environmental stress.

Table 9. - Example of IAI value from stations exhibiting dissimilar biotic quality

	Upstream Station (A)	Downstream Station (B)
%EPT	68	42
%CA	7	39

%EPTb/%EPTa = 42/68
= 0.62

%CAa/%CAb = 7/39
= 0.18

IAI = 0.5 (%EPTb/%EPTa + %CAa/%CAb)
= 0.5 (0.62 + 0.18)
= 0.5 (0.80)
= 0.40

A closer examination is recommended when IAI is greater than 1.0 or when any variable in the equation equals zero. The latter was found to occur in certain Arkansas ecoregions that have few organisms from the EPT groups. Although an improvement in water quality is implied when IAI >1.0, a potential misinterpretation of data may result when relying only on the index value. As shown in Table 10, an actual improvement in water quality is generally characterized by both an increase in %EPT and a decrease in %CA. Conversely, a toxic impact is occasionally identified when IAI >1.0 and a reduction in %CA is observed without an increase in %EPT. This was found to occur in some Arkansas streams particularly where moderate upstream organic input exists. In these situations, the upstream sites exhibited above average numbers of chironomids but a significant decline in chironomids was observed at the downstream site. This decline is to the degree to cause IAI to be greater than 1.0 and is often the result of toxic effects on the chironomids or their food source. The toxic impact example (Table 10) is assigned a biometric score of 1.0 due to the decline in %EPT and the %CAb/%CAa being less than 50%.

Other clues for confirmation of toxic impacts should include the use of professional judgement. An examination of scores from other metrics or an observation of situations where less than 100 organisms are collected at the downstream station, when no problem in picking 100 organisms was experienced at the upstream station can be useful for identifying toxic dischargers.

Table 10. - Example for interpreting water quality improvement and toxic impacts from IAI values

	WATER QUALITY IMPROVEMENT		TOXIC IMPACT	
	Upstream	Downstream	Upstream	Downstream
%EPT	16	49	11	3
%CA	38	9	21	3
	IAI = 3.64		IAI = 3.64	

Replicate rapid bioassessments in Arkansas showed natural variations in the relative abundance of any given taxocene may vary by as much as 20%. This information was utilized in designing the IAI scoring criteria.

Scoring Criteria for Biometric (5) Indicator Assemblage Index

Score	Criteria
4.0 - No Impairment	IAI > 0.80
3.0 - Minimal Impairment	IAI = 0.65 - 0.80 OR when IAI > 1.0 and CAb is 65 - 80% of CAa
2.0 - Substantial Impairment	IAI = 0.50 - 0.64 OR when IAI > 1.0 and CAb is 50 - 64% of CAa
1.0 - Excessive Impairment	IAI = < 0.50 OR when IAI > 1.0 and CAb is < 50% of CAa

Biometric (6) Missing Genera

It is accepted among aquatic ecologists that a decline in the number of taxa from the orders ephemeroptera, plecoptera and trichoptera is associated with environmental stress (Plafkin et al. 1987). Biometric 6 examines the EPT genera that are present above but absent below a suspected impact source. It combines a quantitative measure of richness and a qualititative measure of intolerant groups on a presence/absence basis and is not a measure of relative abundance as is Biometric 5. Replicate benthic samples from Arkansas streams have a natural variation of plus or minus one genus for any one of the EPT orders. Any difference in richness beyond these values appears to be the result of pollution. This metric is similar to the EPT index used by Bode (1988) in New York State and Lenat (1988) in North Carolina. Rather than using predetermined numeric criteria, as the EPT index, it measures the relative change in EPT richness above and below a pollutant source.

Care should be used in the correct application of this biometric for predicting variations among replicate samples. Arkansas biosurvey data showed that it is not unusual for a non-dominant genus, with a relative abundance of 4% or less in one sample, to be completely absent in a replicate sample. For example, if a given ephemeropteran genus makes up 3% of the sample at the upstream site and is not collected at the downstream station, it should not be considered to be absent due to a change in water quality. This information suggests the importance of rare or uncommon taxa may have been overemphasized. To avoid inaccurate interpretations, the scoring criteria excludes taxa with relative abundances of 4% or less.

Scoring Criteria for Biometric (6) Missing Genera

Score	Criteria
4.0 - No Impairment	- when any one of the EPT orders has no more than one missing genus
3.0 - Minimal Impairment	- when any one of the EPT orders has two missing genera
2.0 - Substantial Impairment	- when two of the EPT orders have two missing genera
1.0 - Excessive Impairment	- when two or more of the EPT orders have more than two missing genera

Biometric (7) Functional Group Percent Similarity (FGPS)

The change in an aquatic community's function, relative to an impact source, can be examined by applying the QSI equation (Biometric 3) to the relative abundances of functional groups. Replicate samples generated a mean FGPS value of 91.6 and a range of 78.0-98.0. Any significant deviation from these values indicates interference with the energy flow mechanisms of the aquatic ecosystem.

Scoring Criteria for Biometric (7) Functional Group Percent Similarity (FGPS)

Score	Criteria
4.0 - No Impairment	- FGPS > 85
3.0 - Minimal Impairment	- FGPS = 75-85
2.0 - Substantial Impairment	- FGPS = 65-74
1.0 - Excessive Impairment	- FGPS < 65

82%

Generic Cause

For streams classified by the biometric scoring system as "Substantially" or "Excessively Impaired", a potential generic cause is established. This involves an examination of biometric scores, habitat assessment data and background information such as effluent characteristics, treatment processes, discharge monitoring reports, reported fish kills and land uses. Generic causes are delineated as organic, toxic or physical alteration, any of which may result from point or nonpoint source pollution. It is possible for more than one type of generic cause to be responsible for an impact.

An individual examination of biometrics 5, 6, and 7 is especially helpful in determining the potential generic cause. Further confirmation of suspected generic cause can be accomplished by additional investigative actions such as aqueous or sediment toxicity tests.

Organic

Organic impacts are generally associated with municipal sewage, food processing or animal wastes. Fats, proteins, carbohydrates, detergents, oils, and sewage are among the organic pollutants responsible for high BOD/low DO conditions that are harmful to aquatic organisms. Any of the following changes may be observed when conducting the habitat evaluation: 1) an increase in attached or suspended algae, 2) a visible increase in suspended solids or turbidity, 3) an increase in substrate embeddedness or presence of organic sludge deposits, 4) water color may be green or gray 5) low dissolved oxygen.

The community structure and function is altered as conditions become more advantageous for organisms capable of withstanding low dissolved oxygen concentrations. Organic pollutants can also affect periphyton quality causing diatom populations to decline allowing filamentous algae to become more abundant. The macroinvertebrate community's response is often a shift from scraper to collector abundance. In Arkansas streams, an increase in filtering collectors has been observed where suspended solids are a problem. A rise in gathering collectors was found to indicate excessive attached filamentous algae and organic fine particulates. The Arkansas rapid bioassessment study indicated that an increase in collector abundance from 25-50 % is common for "Substantial Impairment" whereas an increase > 50% is associated with an "Excessive Impairment". Plafkin (et al. 1987) report similar changes in community structure and function due to organic pollutants.

Toxic

Toxic pollutants are generally related to the use or synthesis of chemical compounds that have a direct effect (acute or chronic) on the survival and growth of biota. Toxics essentially interfere with the biochemical processes necessary for completion of the life cycle. Toxics include inorganic compounds such as acids, alkalies, salts of heavy metals, phosphates and soluble salts of sulfates, chlorides and nitrates. Among the organic toxicants are pesticides, solvents and petroleum based compounds. Visually, there may or may not be a change in water color or turbidity. In Arkansas, it has been noted that in many instances where toxicity from chlorine, metals or excessive ph occurs, no appreciable change in water color is observed. Other characteristics commonly associated with toxicity include abnormal substrate residues or a reduction in algal growth, aquatic vegetation, or riparian vegetation.

Occasionally, toxic impacts cause a reduction of intolerant organisms and organisms known to be tolerant of organic loading. This may vary depending on the specific toxicant, the severity of the impact and the ecoregion. *Cricotopus* sp., for instance, has been shown to be relatively tolerant of metals (Ferrington 1987; Ohio EPA 1987). Chironomids as a whole, however, are often sensitive to toxic agents.

Since many toxicants have an affinity for particulate in the aquatic ecosystems, the detritus-based macroinvertebrate community may be susceptible when the toxicant is biologically available. Some of the effects of toxic agents on community function have been described by Cummins (1987) and Plafkin (et al. 1987). Shredders may be adversely affected either by direct exposure or by a reduction of the microorganisms on which they feed that inhabit the coarse particulate. A comparison of shredders versus non-shredders above and below a pollutant source can indicate a change in community function. Similarly, filtering collectors may be sensitive to toxicants in suspended particulate. Research indicates that the bioavailability of a toxicant is often increased when in suspension (McFarland 1987) creating unfavorable conditions for filter feeders.

Physical Alteration

This type of generic cause results from disturbance of the physical habitat. It can be an aquatic habitat alteration which actually occurs within the waterbody, such as channelization, dredging, damming, gravel mining, or thermal discharge, or it can be the result of riparian habitat alterations which occur in the watershed from agriculture, silviculture, urbanization or mining. Among the physical products of these alterations are siltation, sedimentation, atypical nutrient loads, unnatural temperature or flow regimes, interference with elements of the hydrologic cycle and actual removal or covering of the physical habitat. The biological consequences become evident when the physical habitat is destroyed and the requirements for sustaining certain populations are no longer met. This, in turn, has an adverse effect on organisms that are dependent on these populations. Consequently, significant changes in community composition occur.

PART II: DEVELOPMENT AND APPLICATION OF BIOCRITERIA FROM RAPID BIOASSESSMENT DATA

Among the objectives of the Water Quality Act of 1987, are the "restoration and maintenance of the biological integrity of the nations waters". The first step in accomplishing this goal, is to find the appropriate tools to measure biological integrity. EPA has recommended an acceleration in the development and application of promising biological monitoring techniques to characterize aquatic systems and identify water quality problems (U.S. EPA 1987a). Consequently, technological advances have made it more feasible to use biological methods in the regulatory process. The expensive labor-intensive methods of the past are no longer necessary for examining ambient biological conditions.

The successful application of these methods requires the effective use of biological data. Hence, EPA is taking an active role in the development of biological criteria based on bioassessment methods as required by the Water Quality Act of 1987. The "National Workshop on Instream Biological Monitoring and Criteria" was sponsored by EPA to exchange information with and make recommendations to the States for designing programs specific to their needs (U.S. EPA 1988a). The States are encouraged to incorporate biological data into regulatory permitting programs and have the legal authority to develop water quality-based regulatory measures for the protection of aquatic life uses (U.S. EPA 1984, 1987a).

EPA's policy statement on control of toxic pollutants provides the general narrative criteria of "no toxic materials in toxic amounts." A problem in enforcement comes when attempting to define "in toxic amounts" without the convenience of numeric criteria. As a solution, it was recommended at the 1987 National Instream Biological Criteria Workshop that numerical instream biocriteria be implemented to " translate narrative criteria for protecting aquatic life uses into more quantifiable measures of attainment." This was the primary focus in the design of Arkansas' Biometric Scoring System. The mean biometric score is a collective expression of the metric scores and provides a measure of site specific biological integrity that is translated in terms of aquatic life use status (Appendix D). It has become more accepted that site specific measures of macroinvertebrate community health are as valid, if not more, than a broadly applied numeric value. As stated in the Instream Biological Report (USEPA 1988a), "site specific biosurvey data should be considered the optimum means to assess attainment of designated aquatic life uses." The same general approach used to develop biological criteria in Arkansas can be applied in other states based on their specific needs, ecological systems and water quality problems.

Selection of Metrics/Scoring Criteria Development

Although multimetric biosurveys have potential for broad application, individual biometrics or scoring criteria may require some modification from one geographic region to another. In designing the Biometric Scoring System in Arkansas, a balanced set of metrics was selected to qualitatively and semi-quantitatively assess the effects of pollutants on various elements of the macroinvertebrate community. The appropriate combination of metrics and scoring criteria can be determined through a regime of replicate samples at minimally stressed and impacted streams in each ecoregion. This approach has given Arkansas biologists the ability to differentiate natural variations in community structure from impact related variations. The relative sensitivity of numerous biometrics for measuring community responses to various pollutant types has been documented by Plafkin (et al. 1987) and Resh (1988)

Arkansas Biocriteria

Rapid bioassessments in Arkansas are currently used in a decision matrix for impact identification which triggers further investigative action (Table 11). Its use as a permit limit or water quality standard, to date, is in the proposal stage although in addition to federal guidelines, Arkansas has the legal authority to implement this practice. The Arkansas Water Quality Standards "provide for protection and propagation of fish, shellfish and other forms of aquatic life" via protection of fisheries use (ADPCE 1988). The proposed inclusion of supplemental macroinvertebrate biocriteria, as a water quality standard, would enhance the protection of fisheries uses. As legislative rationale, the Arkansas Water Pollution Control Act (ADPCE 1965) states: "it shall be unlawful for any person to cause pollution of any waters of the state." It further defines pollution as including "alterations of biological properties .... that are detrimental to legitimate beneficial uses or other aquatic life." The Act gives the Arkansas Department of Pollution Control and Ecology the "powers to conduct investigations, research surveys and studies and gather data and information necessary or desirable in the administration or enforcement of pollution laws". The Arkansas rapid bioassessment and aquatic life use criteria provide a measure of "alterations of biological properties." Table 12 exemplifies the proposed application of biological criteria developed from rapid bioassessment data.

Table 11. - Decision matrix for application of rapid bioassessments

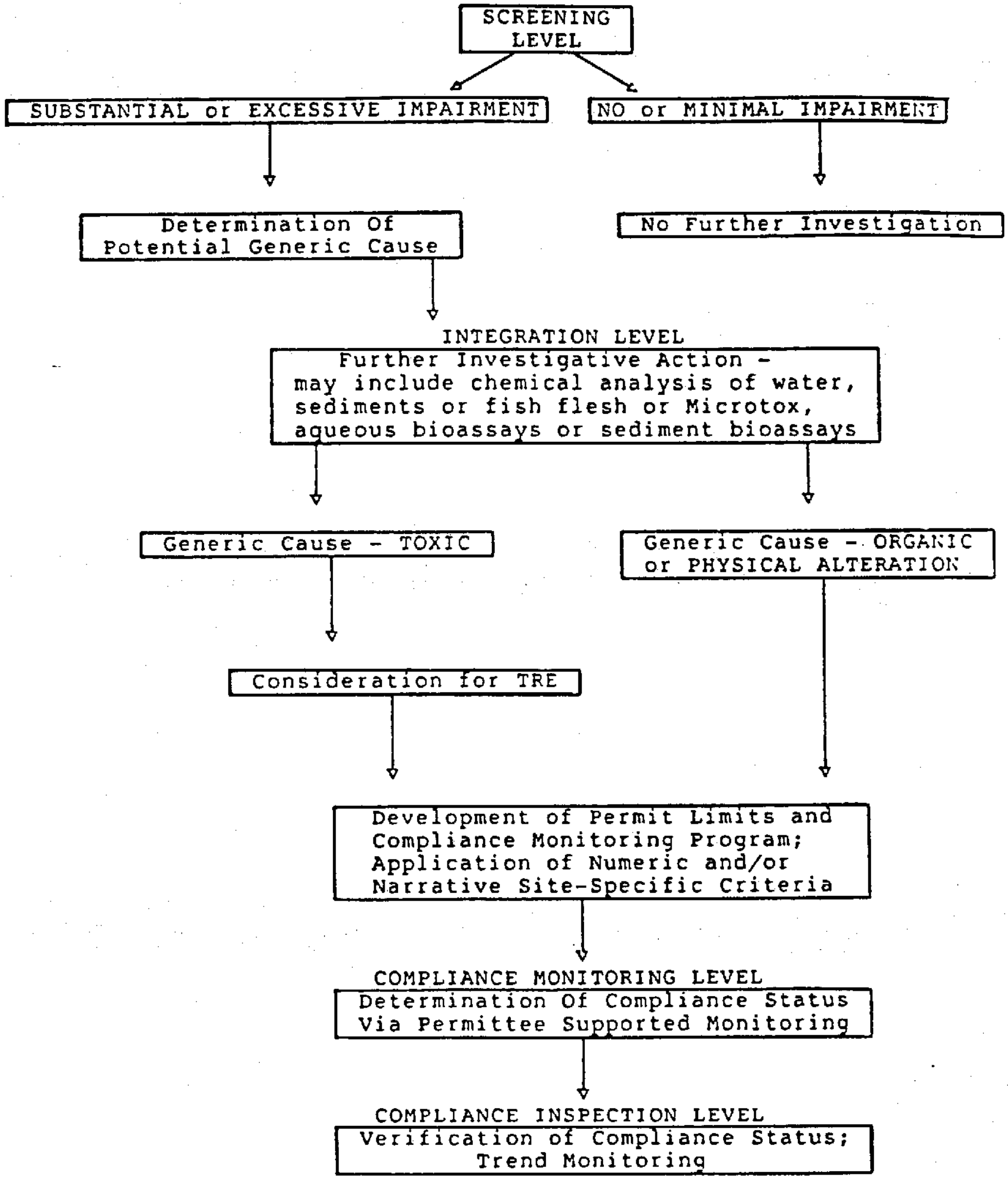

Table 12. - Application of biological criteria for aquatic life use status of Arkansas streams

Biocriteria Classification	Aquatic Life Use Status	Compliance Status	Increased Monitoring Recommended	Enforcement Action
NO IMPAIRMENT	Full Support	Compliant	No	Not Required
MINIMAL IMPAIRMENT	Full Support	Compliant	No	Not Required
SUBSTANTIAL IMPAIRMENT	Partial or Marginal Support	Potential Non-Compliant	Yes	Under Consideration
EXCESSIVE IMPAIRMENT	Non-Support	Non-Compliant	Yes	Required

Screening Level

Rapid bioassessments at paired stations that bracket a pollutant source can be used as a screening tool for impact identification. As shown in Table 11, the initial rapid bioassessment screen may result in the application of other biological and chemical methods. After completion of screening, an on-site decision can be made for subsequent action. In situations where "No Impairment" or "Minimal Impairment" classifications are obtained, field efforts are discontinued until further information indicates a problem exists. Streams classified as "Substantially"or "Excessively Impaired" trigger additional investigative steps which employ an integration of methods. As discussed in Part I, generic cause and professional judgement become vital factors for determining "if" and "how" higher levels of investigation are implemented.

Integration Level

Streams exhibiting significant impacts can be ranked on the basis of their mean biometric score. The ranking can serve as a priority list for taking subsequent action which may include additional monitoring and/or a permit review. The integration of biological and chemical methods is utilized to obtain more information about the impact and to develop the appropriate pollution control measures. EPA supports the integration strategy because previous programs that relied on chemical or biological methods alone have often proven ineffective. It has become more evident that biological and chemical methods, when used in combination, produce a better understanding of the environmental effects of pollutants thus more efficient regulatory controls (Nemetz and Drechsler 1980; Lenat 1988; U.S.EPA 1988b).

The Arkansas Department of Pollution Control and Ecology conducts rapid bioassessments primarily at industrial and municipal point sources. Selection of the appropriate supplemental monitoring tools is done on a case by case basis. When an impact is identified, sediment and/or fish flesh samples may be collected and preserved for chemical analysis. An aliquant of the sediment is placed in a separate container to be used in a sediment toxicity testing program currently being developed for Arkansas. Sediment bioassays have potential as a companion method to rapid bioassessments since macroinvertebrates actually inhabit the substrate. Research has shown sediment bioassays frequently discover toxic impacts that go undetected by effluent or water column bioassays (Westerman 1987). This may result from inconsistent effluent characteristics or from water insoluble toxicants that have an affinity for sediments. Since sediments often play an important role in the bioavailability of contaminants (Francis et al.1984; McFarland and Clark 1986), their use as a testing medium can help reduce the uncertainty of predicting in-stream biological responses (Van Hassel and Gaulke 1986). Sediment bioassays have been successfully used to develop site-specific criteria when integrated with other field and laboratory methods (Chapman 1986; Swartz et al. 1985; Van Hassel and Gaulke 1986). Methodologies for acute, chronic and bioconcentration sediment bioassays have been developed by Nebeker (et al. 1984) and NFCRC (1988). Rather than replacing aqueous bioassays with sediment bioassays, ADPCE will use both methods. The whole effluent aqueous tests examine wastewater treatment efficiency at the point of discharge and the sediment bioassay reflects the effects of the wastewater after introduction into the receiving stream.

In situations where data from several methods do not appear to be congruent, regulatory decisions are based on the preponderant data. If any of the methods used, consistently indicate a water quality problem, subsequent actions may include a permit review and revision, compliance monitoring program revisions or consideration for a Toxics Reduction Evaluation.

To determine the extent of the impact, often requires a more intensive examinination of the macroinvertebrate community. This means "more intensive" in terms of the number of samples collected, and may be preferred over "more intensive" in terms of the level of effort per sample. Similar biosurvey designs have indicated that data from several variously impacted sites are more useful than separate intensive studies of only one or two sites (Hall et al. 1978). Successive rapid bioassessments below a pollutant source can trace its effects by identifying the extent of the impact zone and the beginning of the recovery zone. Supplemental samples for chemical analysis taken at the successive biosurvey sample locations will give a better understanding of cause and effect relationships between pollutants and aquatic biota. Guidance is available for site selection of stations, number of stations required to determine the impact zone (Cairns and Dickson 1971) and use of upstream/downstream reference sites (Hughes et al. 1983).

Compliance Sampling Inspection Level

ADPCE routinely conducts Compliance Sampling Inspections (CSI) at permitted discharges. Effluent samples are collected for *Daphnia* sp. and Microtox toxicity tests and analyses of permit parameters. CSI data is used to confirm a suspected toxics problem identified by screening, verify the validity of compliance monitoring data or monitor "before" and "after" effects of pollution control measures. When a CSI identifies a toxic discharge that has no available rapid bioassessment data, the facility is included on a "candidates for rapid bioassessment" list. Similarly, when rapid bioassessments indicate a toxicity problem at a facility that has not had a recent CSI, the permittee is included on a "candidates for CSI" list. This strategy provides complementary biosurvey, bioassay and chemical data.

Compliance Monitoring Level

The Water Quality Act of 1987 gives EPA and NPDES delegated States the authority to "require NPDES permit applicants to provide chemical, toxicity and instream biological data necessary to assure compliance with standards." Permit limitations and compliance monitoring programs can be designed as site-specific. The compliance monitoring and reporting requirements, at the discretion of the State regulatory agency, may include a combination of biological and chemical methods or an appropriate indicator parameter. Rapid bioassessments can be used in establishing permit limits and for demonstrating compliance status or aquatic life use support status. An acceptable quality assurance plan should be required for permittee or consultant supported monitoring.

CONCLUSIONS

Although it may not be a panacea for biotechnology, the rapid bioassessment alleviates many of the problems encountered in biological monitoring. It is an accurate, cost-effective tool that integrates well with other methods. It has not been feasible in Arkansas' statewide monitoring program, to apply an integration strategy which includes intensive quantitative biosurveys. The tremendous time lag in obtaining usable biosurvey data resulted in addressing todays questions with yesterdays answers. With the transition to rapid bioassessments, biologists return from the field with data, not large containers of samples to be processed. Rather than concentrating all efforts on one method, more time is now available to generate and analyze data from several methods. This allows prompt reporting and prompt decision-making. Multi-metric scoring systems have the potential to cross interdisciplinary barriers in the water quality management realm. When incorporated into biological criteria, they provide technical information to biologists and interpretations of aquatic life status to non-biologists.

Although EPA and state regulatory agencies have long recognized the importance of assessing in-stream biota, massive pendulum swings in the application of biological data in environmental policy have taken place. The current emphasis on water quality-based controls, creates a new opportunity for the development and application of biological methods. To maintain this inertia, biologists must face the tech transfer challenge by providing understandable interpretations of the effects of pollutants on the environment.

The successful management of any system first requires an understanding of that system. For those involved in water quality management it should include the understanding - "Yes, the invertebrates are important!"

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APPENDIX A

HABITAT EVALUATION SHEET

Pollutant Source City of Mountain View NPDES Permit # AR0020117

Receiving Stream Hughes Creek Habitat Sampled Riffle

Potential Pollutants Sewage

Date 870805 Collector SBS Recorder REM

Ecoregion Ozark Highlands Watershed Size < 10 sq. mi

Gradient 18.1'/mi.

(Riffle/Pool)	AB	BL
Width	4-6'	6-8'
Length	15'	40'
Depth	0.5-1.0'	0.5-1.0
Velocity		
Flow		
Temp.		
D.O.		
pH		
Conduct.		

Land Uses(%)

Urban	20	Agriculture	50
Other		Silviculture	30

SUBSTRATE COMPOSITION (%)

Inorganic

	AB	BL
Bedrock		
Lg.Boulders (>24.0")	5	5
Sm.Boulders (12.1-24.0")	45	40
Cobble (3.0-12.0")	35	40
Gravel (0.20-2.9")	10	10
Sand (.0625-0.19")	5	5
Silt (<.0625")		
% Embeddedness	5	75

Organic

	AB	BL
Emergent Vegetation	15	10
Submerged Vegetation		
Brush/Logs/Roots	10	10
Leaf Litter	20	25
Fine Detritus	10	20
Periphyton		
Algal Mats		

RIPARIAN AREA (%)

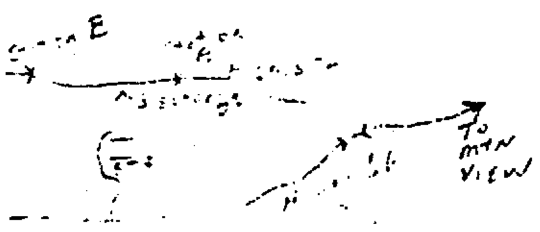
(Vegetation)	AB	BL
Trees	60	60
Shrubs	30	30
Grasses and Forbs	10	10
Rock Outcroppings		
Bare Ground		
Altered		
% Canopy	100	100

(Bank Stability)	AB	BL
Stable	✓	✓
Moderate		
Unstable		

(Predominant Forest Type)

Coniferous		Upland	✓
Deciduous	✓	Lowland	
Mixed Con./Dec.			

Schematic of Sample Sites and Proximity to Pollutant Source
(Visual Observations & Comments Recorded on Back)



Extensive black sludge bank at Station B. Gray-black material becomes suspended when disturbing substrate.
Black residue on rocks.

APPENDIX B

RAPID BIOASSESSMENT FIELD SHEET

NPDES permit # AR0025117

Pollutant Source City of Mtn View Date 870805

ABOVE Station # WHI 11A BELOW Station # WHI 11B

Cnt.	Taxa	Tally	Cnt.	Taxa	Tally
3	Combinae	///			
5	Rhagovelia	~~////~~			
26	Stenonema	/ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~			
5	Isonychia	~~////~~			
2	Baetis	//			
1	Choroterpes	/			
	Neoperla	/			
30	Chimarra	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~			
9	Cheumatopsyche	//// ~~////~~			
1	Tabanidae	/			
3	Chironomidae	///	73	Chironomidae	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ /// ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~
1	Hydrophilidae - adult	/			
1	Stenelmis - adult	/	2	Stenelmis - adult	//
1	Asellus	/			
	Sialis	/			
4	Corydalus	////	5	Corydalus	~~////~~
6	Psephenus - larvae	~~////~~ /			
100			1	Ancyronyx - adult	/
			15	Physa	~~////~~ ~~////~~ ~~////~~
			1	Argia	/
			1	Helichus	/
			1	Tipulidae	/
			1	Caenis	/
			100		

APPENDIX C

BIOMETRIC SCORE SHEET

Station *Hughes Creek near Mtn. View STP* NPDES Permit #*AR0022 17*

Habitat Sampled *Riffle* Date *870805*

	Biometric Score
Biometric (1) - Dominants-In-Common	*1*

DIC = *0*

Dominants Above	Dominants Below
1. *Chimarra 30%*	1. *Chironomidae 72%*
2. *Stenonema 20%*	2. *Physa 15%*
3. *Cheumatopsyche 9%*	3. *Hydrobiidae 5%*
4. *Psephenus 6%*	4. *Stenelmis adult 2%*
5. *Isonychia/Hydroptila 5%*	5. *others 1% each*

	Biometric Score
Biometric (2) - Common Taxa Index	*1*

CTI = *0.18*

3/17 = 0.18

	Biometric Score
Biometric (3) - Quanitative Similarity Index	*1*

QSI = *8*

	Biometric Score
Biometric (4) - Taxa Richness	*1*

of Taxa Above = *17*

of Taxa Below = *9*

% difference = *47% decline*

	Biometric Score
Biometric (5) - Indicator Assemblage Index	*1*

	%EPT	%CA
Above	*74*	*3*
Below	*1*	*73*

0.5(1/74 + 3/73) = 0.09

IAI = *0.09*

	Biometric Score
Biometric (6) Missing Taxa	*2*

Comments *Stenonema, Isonychia, Chimarra, Cheumatopsyche - abundant upstream but absent downstream*

	Biometric Score
Biometric (7) - Functional Group Percent Similarity	*3*

	Above	Below
% Shredders	*4*	*1*
% Scrapers	*34*	*18*
% Collectors	*49*	*74*
% Predators	*13*	*7*

FG % Similarity = *75*

MEAN BIOMETRIC SCORE = *1.43*

AQUATIC LIFE USE STATUS *Excessive Impairment*

POTENTIAL GENERIC CAUSE *Organic*

APPENDIX D

BIOLOGICAL CRITERIA FOR AQUATIC LIFE USE STATUS OF ARKANSAS STREAMS

Mean Biometric Score	Aquatic Life Use Status
3.5-4.0	No Impairment

No change is observed in the structure and function of the macroinvertebrate community below the potential pollutant source. The expected taxa are present in balanced proportions characteristic of the watershed size and ecoregion. All biological parameters measured indicate maintenance of biological integrity and full support of aquatic life uses. Where applicable, an in-compliance status is assigned to permitted dischargers. No enforcement action or increase in monitoring is necessary at this time.

2.6-3.4 — Minimal Impairment

Minor changes in the structure and function of the macroinvertebrate community are observed below the pollutant source. Although a slight reduction in the abundance of pollution sensitive organisms was detected, all biological parameters measured indicate maintenance of biological integrity and full support of aquatic life uses. Where applicable, an in-compliance status is assigned to permitted dischargers. No enforcement action or increase in monitoring is necessary at this time.

1.6-2.5 — Substantial Impairment

Significant changes in the structure and function of the macroinvertebrate community are observed below the pollutant source. A major reduction in the abundance and taxa richness of pollution sensitive organisms is detected. The majority of the biological parameters measured indicate the biological integrity is threatened and aquatic life uses are marginally or partially supported. Where applicable, a potential non-compliance status is assigned to permitted dischargers. Additional monitoring should be conducted to determine the level of risk to aquatic life. Enforcement action should be considered.

1.0-1.5 — Excessive Impairment

A dramatic change in the structure and function of the macroinvertebrate community is observed below the pollutant source. Extirpation of key species that are integral constituents of the ecosystem has taken place. Only tolerant organisms are present OR conditions are not suitable to support any life forms. All biological parameters measured indicate an unacceptable level of change of the biological integrity and non-support of aquatic life uses. Where applicable, a non-compliant status is assigned to permitted dischargers. Additional monitoring should be conducted. Enforcement action should be taken.