CONCLUSIONS

The following conclusions have been drawn from these preliminary experimental studies. The amount of chromium adsorbed increased from lower pH to near 5.6 and then decreased rapidly with increasing pH values in the groundwater. The effects of flow rate demonstrate that velocity is a significant factor in treating to under 0.05 mg/l chromium. Comparison of three different adsorbents shows that Duolite ES-392 is the most effective adsorbent.

TABLE 2. *Liters of water treated to under 0.05 ppm chromium based on flow rate, pH and weight of adsorbent.*

F(ml.min.)	Variation pH	M(gm)	Witco 950 Liquor Treated (1)	GAC 30 Liquor Treated (1)	Duolite Es-392 Liquor Treated (1)
8.180	7.0	6	0	0	0.9816
4.076	7.0	6	0.1223	0.1223	1.4674
1.754	7.0	6	0.6341	0.8419	1.4750
4.076	4.0	6	0.4891	0.9783	2.0054
4.076	5.0	6	0.9782	1.5896	2.4456
4.076	5.6	6	1.2230	1.7608	2.7390
4.076	7.0	8	0.4891	1.5896	2.8858
4.076	7.0	10	1.1250	2.6902	4.3282

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AN ANALYSIS OF THE BENTHIC MACROINVERTEBRATE COMMUNITY OF A FLUCTUATING RIVER-RESERVOIR ZONE IN MIDDLE TENNESSEE

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ABSTRACT

Changes in the structure of a benthic macroinvertebrate community (induced by seasonal variations in reservoir stage) were studied from February - November 1981. Cluster analysis was used to study changes in benthic community structure in relation to changes in river channel morphology. Association matrices and dendrograms were construted using the Pinkham and Pearson coefficient of association. Distinctly different benthic communties were identified through cluster anlaysis and appeared to result from the alteration of micro-and macrohabitats as fluctuations in river-reservoir stage occured. In addition, cluster analysis employing the Pinkham and Pearson coefficient proved to be an effective means of providing information on the relative enviromental tolerances of the 94 taxa of benthic invertebrates identified during this study.

INTRODUCTION

Within natural lotic environments, benthic macroinvertebrate community structure varies widely. Spatial and temporal differences among communities result from natural variations in channel morphology, riparian vegetation, the type and amount of organic input to the stream, aquatic vegetation, and the natural history of benthic populations in general (Cummins et al., 1964; Cummins 1974, 1975, 1979; Hynes 1970a, 1970b). In regulated streams, however, differences in benthic community structure are usually attributed to large and frequent modifications in the morphology of the river system caused by the operation of an artificial impoundment or reservoir (Ward and Stanford 1979). In Tennessee, modifications such as these commonly result from the controlled retention and discharge from multipurpose hydroelectric impoundments. Seasonally the operation of these impoundments affects the parent river systems by altering flow rate, water level, substrate composition, water temperature, and water quality. The effects of reservoirs on stream channel morphology have been summarized by Simons (1979).

In most cases, the increased stress imparted to these systems by fluctuating environmental conditions severely depresses benthic community diversity, radically alters species abundances, and greatly changes species distribution. The purpose of this investigation was to study the effects of controlled retention on the structure of the benthic macroinvertebrate community of the Falling Water River within the headwaters zone of influence of Center Hill Reservoir in Middle Tennessee.

MATERIALS AND METHODS

The study area comprised a section of the Falling Water River, from the base of Burgess Falls to Center Hill Reservoir in White and Putnam Counties, Tennessee (Fig. 1). This section of river is approximately 1.8 kilometers in length and has been seasonally inundated each year by Center Hill Reservoir since the 1950's. Six sampling stations were established in the study area, so that all stream habitats were represented in collections.

All stations were sampled monthly (from February - November 1981) according to a stratified random sampling design. Strata were determined by flow regimes and substrate types in the low water condition. Within each stratum three random samples were collected. Sampling method varied depending upon stream depth and stratum

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type. During periods of low water, kick sampling was used (Frost et al., 1971). Other samples were obtained through the use of a standard Ekman dredge or skindiving whenever necessary. Benthic samples collected were processed in the field with a number 30 U.S. standard sieve and preserved in ten percent formalin for laboratory analysis. In addition, morphometric measurements of the stream (flow, temperature, average depth, substrate composition, dissolved oxygen, pH, and specific conductance) were taken wherever benthic samples were collected. Stream flow was calculated from direct measurements of current velocity and measurements of channel cross section. Substrate composition was obtained by graded sieve analysis. Specific conductance, pH and dissolved oxygen were determined with a DR-EL2 Hach Kit. Temperature was read directly from a maximum-minimum thermometer.

Benthic community structure was analyzed by use of cluster analysis (Boesch 1977; Sneath and Sokal 1973), which employed the Pinkham and Pearson coefficient of association (B) (Pinkham et al., 1975; Pinkham and Pearson 1976). This association coefficient compares species compositions (abundances and occurences) simultaneously and produces a more reliable analysis of ecological data than many of the more commonly used diversity indices or associaiton coefficients (e.g. Gleason's Index (Gleason, 1922), Shannon's Diversity Index (Shannon, 1948), Simpson's Index of Dominance (Simpson, 1949), Brillouin's Index (Margalef, 1956), Chutter's Biotic Index (Chutter, 1972), Jaccard's Coefficient of Community (Jaccard, 1902) and Sokal and Michner's Coefficient (Bonham-Carter, 1967) which have been summarized by Pinkham and Pearson (1976) and Brock (1977). Association Coefficients were computed by use of the following formula (Pinkham and Pearson 1976).

$$B = \frac{1}{k} \sum_{i=1}^{k} \frac{\text{Min } (X_{ia,} X_{ib})}{\text{Max } (X_{ia,} X_{ib})}$$

where: X_{ia} and X_{ib} are the number of individuals in the ith taxon for stations a and b, with the small number being divided by the larger for each species.

k, is the total number of comparisons of different taxa in the two stations.

All calculations and final dendrograms were completed with the use of a CDC Cyber 170/730 Computer and program furnished by the South Florida Water Management District.

Species data generated from all sampling methods were organized into a two dimensional matrix (sampling stations or periods were on the vertical axis and speices along the horizontal) where for the purposes of this analysis, the sampling data for all stations were pooled for each sampling period. Dendrograms were calculated for the data in two configurations achieved by transposing the original matrix about its vertical axis.

RESULTS

Variations in reservoir stage produced by winter drawdown, spring retention and summer discharge created distinct changes in the morphology of the study area. Morphometric measurements of the stream showed these changes in channel structure to be arranged successionally into a series of phases. Each phase was characterized by alterations in critical macrohabitat parameters (e.g., substrate composition, flow, depth, and temperature), which have been identified as important regulators of benthic community structure (Hynes 1970a, 1970b; Cummins et al., 1964; Cummins 1974, 1975). Structurally different phases were defined as Initial Lotic (IL), Transition-to-Lentic (TLN), Transition-to-Lotic (TLO) and Recovery Lotic (RL). Characteristic physical conditions of each phase are summarized in Table I.

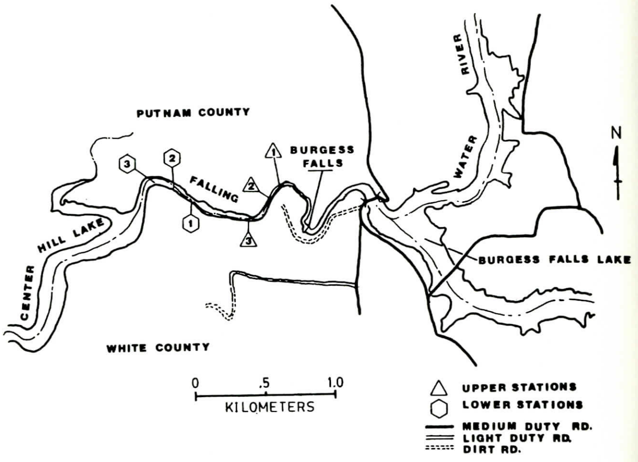

FIG. 1. *Map of the Falling Water River and study area below Burgess Falls, including headwater zone of Center Hill Lake, White & Putman Counties, Tennessee.*

Ninety-four taxa of benthic macroinvertebrates were collected and identified. The ten sampling periods were compared with the ninety-four taxa, allowing each sampling period to be compared with all the others based on species composition, which illustrates patterns of speices composition over time (Fig. 2). Four types of communities corresponding to the four structurally different phases were shown to be distinctly different, i.e., above an association coefficient of 0.5. These communities were classified according to the physical condition of the river system; therefore, communities were identified as Initial Lotic (IL), Transition-to-Lentic (TLN), Transition-to-Lotic (TLO) and Recovery Lotic (RL).

Specific variation among sampling stations for each of the various phases are presented in Fig. 2a. The degree of similarity between dendritic pairs are based on species composition (abundances and occurence). Clusters are labeled to identify specific phases. Station specific fluctuations in physical-chemical conditions resulted in spatial and temporal variations in species composition. For example the IL and RL phases had the greatest diversity of habitat. In the RL phase tolerant and intermediate taxa from previous communities caused the lower pool stations (i.e. stations 2L and 3L) to be similar to that of stations of the earlier TLO, TLN communities. For example, station September 3L is linked to stations July 1U-3U at an association value of approximately 0.90 (Fig. 2a).

Functional similarities and dissimilarities between communities were related to changes in critical macrohabitat parameters and structure of the previous benthic community. Consequently, rapid changes in stream channel morphology produced proportionate changes in benthic community structure. Large physical changes in habitat appeared to be buffered at the community level by adaptive behavioral and morphological mechanisms (Hynes, 1974a and Merritt and Cummins, 1984) exhibited by some benthic organisms collected and the persistence of refuges in the interflow zones and in the wave wash zone. In this way, community diversity was maintained during gradual changes in stream channel morphology; however, during the first transition phase in March (TLN) physical conditions changed so drastically that community composition (species abundances and occurrences) was greatly reduced in spite of buffering (i.e. behavioral and morphological) mechanisms (Fig. 2).

Association coefficients between species based upon their spatial and temporal occurrences were calculated (Fig. 3). These relationships, when compared with specific macrohabitat data for each sampling period, provide a means of determining environmental tolerances for groups and species. Based upon specific comparisons, species were classified as sensitive, intermediate, and tolerant to the physical conditions of the various communities (Fig. 3).

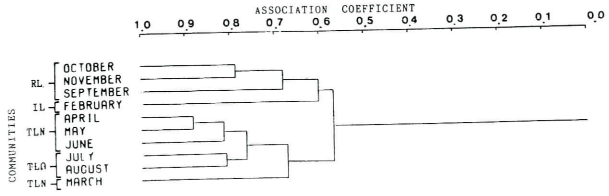

FIG. 2. *Dendrogram of sampling periods depicting communities, community designation are Recovery Lotic (RL), Initial Lotic (IL), Transition to Lentic (TLN) and Transition to Lotic (TLO) for February - November 1981*

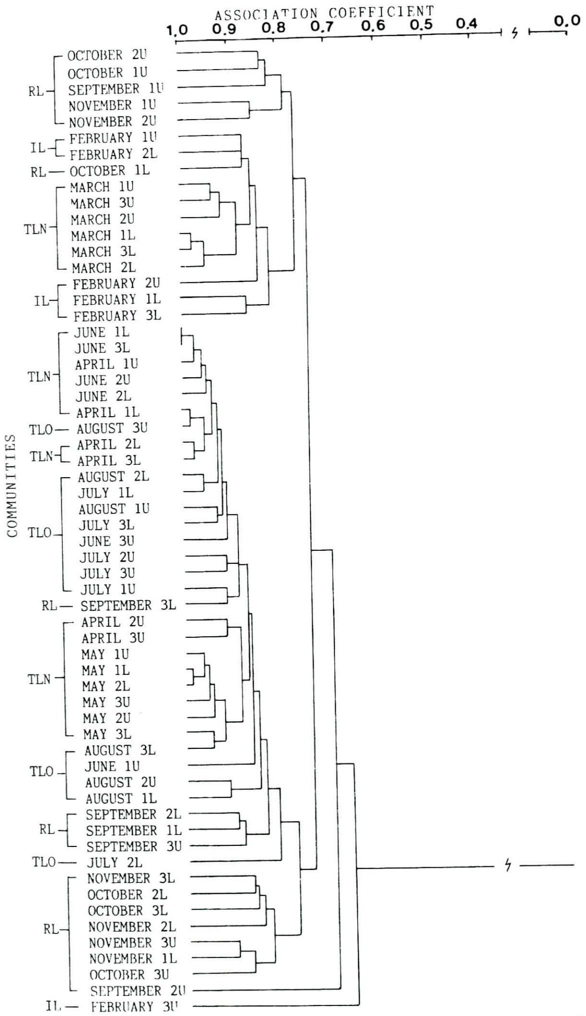

FIG. 2a. *Dendrogram of sampling stations depicting relationships based on spatial and numerical occurrences in the various communities, community designations are Initial Lotic (IL). Transition to Lentic (TLN), Transition to Lotic (TLO) and Recovery Lotic (RL) for February - November 1981*

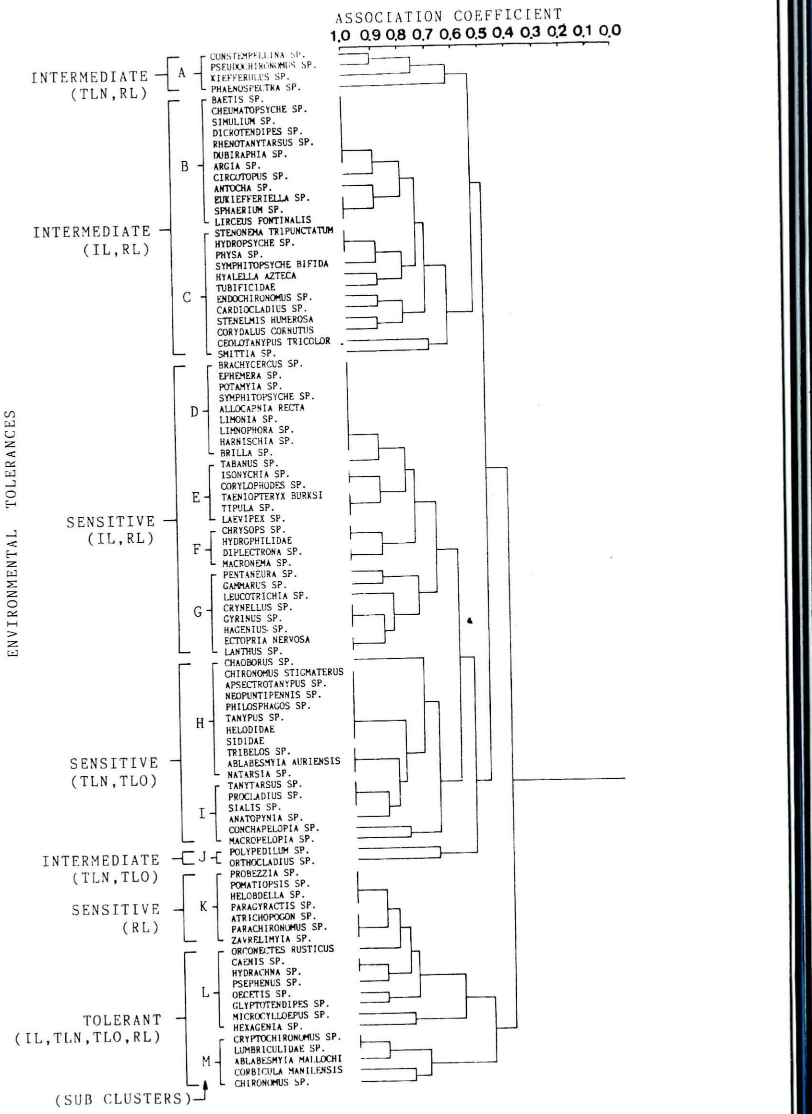

FIG. 3. *Dendrogram of environmental tolerances of taxa based upon spatial and temporal occurrences, in Initial Lotic (IL), Transition to Lotic (TLO) and Recovery Lotic (RL) communities, February-November 1981*

Environmental tolerances to critical macrohabitat parameters investigated for various groups were further defined by the association of taxa within subclusters under the previously defined major headings. Environmental limits for subclusters are provided in Table 2.

Sensitive organisms were classified as those which appeared to exist within a relatively narrow range of physical conditions (i.e. specific substrate types, flow rates and temperature regimes). Conditions suitable to sensitive taxa occurred only at the extremes of water level fluctuations. During these periods, micro-and macrohabitats were maximized as a reduction in environmental stress facilitated community development (i.e. numbers and diversity). Sensitive species of lotic communities appeared to require consistent and moderately high flow rates, coarse erosional heterogeneous substrates, and lower temperatures (Fig. 3) Some typical examples of these taxa are *Allocapnia sp., Brachycercus sp.* and *Diplectrona sp.* Sensitive species of lentic communities, on the contrary, appeared to require negligible flow, fine well-sorted depositional substrates and higher temperature regimes. Some examples of these taxa are *Tanypus sp., Philospohagos sp., Tanytarsus sp.* and *Tribelous sp.*

Intermediate species (e.g. *Polypedilum sp., Orthocladius sp., Corydalus sp., Stenonema sp.* and *Cheumatopsyche sp.*) were classified as those organisms which had a much wider range of tolerances (as attributed to their occurrence in a variety of communities). Intermediate species were not representative of any one set of environmental criteria (Fig. 3). These organisms varied between phases and communities, although typically, intermediate species were those organisms which could survive gross changes in habitat through physiologic and behavioral adaptation. Many of the organisms included under this classification were inhabitants of the initial lotic community, occupying niches in transitional runs between riffles and pools and in pools themselves.

Tolerant species (e.g. *Corbicula sp., Chironomus sp., Lumbriculidae, Caenis sp.* and *Oecetis sp.*) were classified as those organisms which had the widest range of environmental tolerances. These organisms appeared consistently in each community throughout the study. Fluctuations in channel morphology (i.e. critical macrohabitat parameters) had minimal effect upon these species and they appeared to complete their life cycles with little difficulty. Areal changes in subtrate composition appeared to have the greatest impact on these organisms by limiting their distribution during any one phase or sampling period. Typically, these taxa were inhabitats of the original transitional runs and pools present in the Initial Lotic phase. Adapted to life under transitional and lentic conditions these taxa were particularly well adapted to survive seasonal water level fluctuations.

DISCUSSION

A major problem in analyses of benthic macroinvertebrate communities of regulated streams is the inability to distinguish changes in community structure between successive sampling stations and periods. In recent investigations some researchers (Culp 1980; Gore 1977) have used analytical techniques developed from numerical classification methodologies (i.e. cluster analysis, discriminant analysis, etc.) to help solve this problem. In theory, these methods can be highly effective; however, in application many of the association coefficients used to determine community similarities have descriptive flaws. The failure to recognize these flaws could produce a misinterpretation of the data (Pinkham and Pearson 1976). In contrast, Pinkham and Pearsons' coefficient appears to account for most of the problems intrinsic to other similarity coefficients and diversity indices. However, Pinkham and Pearsons' coefficient is not an analytical panacea; Brock (1977) has determined that the coefficient is highly sensitive to rare species but not sensitive enough to variations in dominant forms. In this study, Pinkham and Pearsons' coefficient appeared to be highly effective in delimiting changes in benthic macroinvertebrate community structure. The sensitivity of the coefficient to rare species was particularly advantageous in determining differences in community composition.

All four communities appeared highly transitory in structure, moving into and out of stable states in response to fluctuations in reservoir stage. The ecological complexity of any one community was a direct function of the amount of time it existed in a stable configuration. The development of new microhabitats and the persistence of old ones (refuges), together with the effects of colonizing species from upstream (lotic) and downstream (lentic) populations, contributed to the development of each community. Periods of ecological stability, where environmental stress was reduced, occurred at the extremes of water level fluctuation. No specifically stable periods were observed during either transition phase (TLN or TLO). Community complexity during transitional phases (TLN or TLO) was directly related to the persistence of species and habitats from the previously established community and the rate of change in current micro- and macro- habitats.

Community succession (i.e. cyclic changes between phases) was strongly influenced by the rate and nature of changes in the morphology of the river. Variations in flow as a function of depth controlled the abundance and distribution of specific substrate types, an important factor in the regulaton of these benthic community structures. Changes in substrate composition, variation in flow rate, and alteration of water temperatures appear to be the major determinants in regulated stream environments. Although few studies have been conducted on headwater areas, apparently conditions modifying the habiat are consistent with those described from studies of tailwater communities (Ward and Stanford 1979). With reference to community disturbance and its subsequent restructuring within the study area, patterns of species composition appear to closely follow the ideas of resource maximization as described by the river continuum, concept (Vannote et al. 1980), which hypothesizes change in the functional groups of macrobenthos as resources are more finely partitioned over a river's course. Further studies are needed to find out if, in fact, these regulated headwater zones show a longitudinal compression in space and time which is consistent with the river continuum concept.

Analysis of species tolerance to ecological variations in river channel morphology was only partially successful. While information on environmental requirements for assemblages of organisms was provided, measurements of microhabitat parameters in the data set were not detailed enough to provide any species specific information. Nevertheless, specific environmental requirements have only been compiled on a few orders of stream benthos; therefore, any information generated in this regard is important.

TABLE 1. *Primary descriptive physical conditions of the study area, for Initial Lotic (IL), Transition to Lentic (TLN), Transition to Lotic (TLO), and Recovery Lotic (RL) phases, February - November 1981*

(Communities)	IL	TLN			TLO			RL		
PARAMETER (Months)	F	M	A	M	J	J	A	S	O	N
Flow (m^3/s) $\bar{X}$ Range	2.09 2.59-1.56	3.19 5.46-1.78	*	*	0.30 1.05-<0.30	2.61 9.35- <0.30	3.24 11.7- <0.30	0.30 0.793-0.42	1.86 2.43-1.42	0.83 1.55-0.61
Velocity (m/s)	0.66 0.76-0.36	0.49 0.73-0.26	**	**	0.02 0.05-<0.10	0.15 0.55- <0.10	0.21 0.67-<0.10	0.16 0.42-0.17	0.27 0.50-0.10	0.45 0.51-0.30
Temperature (^0C)	4.0 4.6 -3.7	9.0 ***	20.7 21.0-20.0	17.8 20.0-15.0	20.5 21.0-20.0	26.2 27.0-25.0	28.0 ***	18.5 20.0-17.0	15.3 16.0-15.0	8.0 ***
Depth (m)	0.65 1.01-0.35	0.84 1.01-0.46	3.68 5.50-2.50	3.43 4.50-1.80	2.87 4.00-1.50	2.78 4.50-1.20	2.53 3.80-1.30	0.66 1.20-0.21	0.79 1.10-0.33	0.19 0.31-0.12
Dissolved Oxygen (mg/1)	4.50 3.00-6.00	4.17 5.00-4.00	4.00 ***	4.00 ***	4.00 ***	3.5 4.00-3.00	4.00 ***	4.25 4.50-4.00	4.50 5.00-4.00	4.33 5.00-3.00
pH (Std. Units)	7.40 7.6 -7.3	7.43 7.5 -7.3	7.47 7.5 -7.3	7.58 7.6 -7.5	7.58 7.6 -7.5	7.50 ***	7.50 ***	7.50 ***	7.30 7.4 -7.2	7.25 7.3 -7.2
Specific Cond. (mhos/cm)	127.5 140.0-120.0	113.3 116.0-112.0	207.0 210.0-201.0	203.7 210.0-200.0	202.0 210.0-200.0	193.3 210.0-180.0	184.5 206.0-170.0	235.0 300.0-180.0	288.3 325.0-200.0	287.7 300.0-250.0
<u>Relative Substrate Comp. (%)</u>										
Silt (< -.0625mm) $\bar{X}$ Range	7.2 8.0-2.0	18.4 38.0-2.0	31.5 41.0-21.0	32.8 40.0-18.0	33.8 38.0-8.0	30.5 34.0-16.0	26.6 32.0-8.0	18.8 28.0-8.0	15.2 18.0-2.0	10.2 11.0-2.0
Sand (.625-.50mm)	17.5 25.0-5.0	16.6 22.0-4.0	26.5 30.0-24.0	30.5 32.0-22.0	27.6 30.0-10.0	28.8 30.0-14.0	25.6 28.0-12.0	23.6 28.0-10.0	19.6 20.0-12.0	28.1 38.0-10.0
Gravel (.50-4.0mm)	28.3 35.0-12.0	24.8 30.0-1.0	19.3 20.0- 1.0	25.2 32.0- 0.0	24.3 28.0- 1.0	20.6 25.0- 1.0	19.2 22.0-10.0	25.3 26.0-12.0	26.2 28.0-14.0	26.4 30.0-12.0
Cobbles (4.0-256.mm)	29.1 30.0-10.0	27.3 30.0-2.0	18.6 18.0- 0.0	9.8 10.0- 0.0	11.2 12.0- 0.0	16.2 18.0- 0.0	18.4 20.0- 1.0	18.2 28.0-10.0	24.0 25.0- 4.0	18.0 20.0-10.0
Boulders (256.- > mm)	8.0 11.0- 2.0	4.3 10.0-0.0	4.1 10.0- 0.0	3.9 11.0- 0.0	3.1 8.0- 0.0	3.9 10.0- 1.0	4.0 10.0- 1.0	6.1 10.0- 1.0	6.4 10.0- 1.0	8.1 11.0- 1.0
Bedrock	10.1 12.0- 5.0	8.6 12.0-0.0	0.0 ***	0.0 ***	0.0 ***	0.0 ***	6.2 8.0- 0.0	8.0 11.0- 0.0	8.6 11.0- 0.0	9.2 22.0- 0.0

* - values below measuring capability (<$0.30m^3/s$)
** - values below measuring capability (<0.10m/s)
*** - range equal to mean

TABLE 2. *Environmental tolerances of taxa based upon spatial and temporal occurrences as determined from Cluster Analysis, depicted in dendrogram (Fig. 3) relative to the physical condition of study area, February - November 1981*

	SUB CLUSTERS												
Parameter	A	B	C	D	E	F	G	H	I	J	K	L	M
Temperature (^{0}C)	21.0–9.0	20.0–4.0	28.0–4.0	4.0–3.7	8.0–4.0	9.0–4.0	20.0–17.0	27.0–20.0	28.0–20.0	28.0–4.0	16.0–8.0	28.0–8.0	28.0–3.7
Velocity (m/s)	0.63– 0.10	0.762– 0.10	0.762– 0.10	0.76–0.36	0.76–0.30	0.76–0.26	0.42– 0.17	0.55– 0.10	0.67– 0.10	0.76– 0.10	0.51–0.10	0.67– 0.10	0.76– 0.10
Flow (m^3/s)	2.64– 0.30	4.02 - 0.30	11.7 - 0.30	2.59–1.56	2.59–0.61	5.46–1.56	0.79– 0.42	9.35– 0.30	11.7 - 0.30	11.7 - 0.30	2.43–0.61	11.7 - 0.30	11.7 - 0.30
Depth (m)	2.30– 0.94	1.01 - 0.12	4.5 - 0.12	1.01–0.35	1.01–0.12	1.01–0.35	1.20– 0.21	4.5 - 1.2	4.5 - 1.3	5.5 - 0.21	1.10–0.12	4.5 - 0.12	5.5 - 0.12
Dissolved Oxygen (mg/1)	5.0 - 4.0	6.0 - 3.0	6.0 - 3.0	6.0 -5.0	6.0 -3.0	6.0 -3.0	5.0 - 4.0	4.0 - 3.0	4.0 - 3.0	6.0 - 3.0	5.0 -3.0	5.0 - 3.0	6.0 - 3.0
pH (Std. Units)	7.6 - 7.3	7.6 - 7.2	7.6 - 7.2	7.6 -7.3	7.2 -7.2	7.6 -7.3	7.5 - 7.2	7.6 - 7.5	7.6 - 7.5	7.6 - 7.3	7.4 -7.2	7.6 - 7.2	7.6 - 7.2
Specific Cond. (MHOS/cm)	210 - 112	300 - 140	325 - 120	140 -120	300 -120	140 -112	300 - 180	210 - 180	210 - 170	210 - 112	325 -200	325 - 170	325 - 112
Habitat (Substrate)	Depositional; flood interflow zones; well sorted silts, sands and gravels.	Erosional; riffle areas; poorly sorted sands, gravel cobbles and boulders; some bedrock.	Transitional; riffle-runs, pools; well sorted sands, gravels and cobbles some boulders.	Erosional; riffle areas; poorly sorted sands, gravels, cobbles and boulders; some bedrock.	Transitional; riffle-runs, pools; well sorted sands, gravels and cobbles.	Erosional; riffle areas; poorly sorted sands, gravels, cobbles and boulders; some bedrock.	Transitional; riffle-runs, pools, well sorted, sands, gravels, and cobbles.	Depositional; flood interflow zones; well sorted silts, sands and gravels.	Depositional; flood interflow zones; well sorted silts, sands and gravels; some cobbles.	Transitional-Depositional; riffle-runs, pools-flood interflow zones; Diverse well sorted silts, sands, gravels, and cobbles.	Transitional; riffle-runs, pools; well sorted sands, gravels, and cobbles; some bedrock.	Transitional-Depositional; riffle-runs, pools-flood interflow zones; Diverse well sorted silts, sands, gravels, and cobbles; some boulders and bedrock.	Erosional-Transitional-Depositional; riffle areas; riffle-runs, pools-flood interflow zones; Diverse well sorted and poorly sorted silts, sands, gravels, and cobbles; some boulders and bedrock.

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