city of austin
Watershed Protection

EFFECTS OF HYDROLOGY ON BIOASSESSMENT IN AUSTIN, TEXAS

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ABSTRACT

The effects of hydrology on aquatic biology of Austin area streams were evaluated using standard benthic macroinvertebrate metrics and the tools of the Indicators of Hydrologic Alteration (IHA) developed by the Nature Conservancy. Long-term stream flow data were compiled from three Austin area U.S. Geological Survey gaging stations, and the 33 IHA metrics were calculated, representing the major groups of hydrological variation including magnitude, duration, timing, rate of change, and frequency. The ability of these values and summary flow statistics to predict Rapid Biological Assessment metrics was evaluated through multiple regression after elimination of redundant independent variables and those related to seasonality not reflected in the biological data sampling design. The results indicated that both summary statistics and IHA variables were good predictors of the relative health of Austin area streams. In addition, ANOVA analysis of stream gaging data was used to determine the variation of hydrology with development conditions. In general, expected characteristics of developed watersheds such as flashiness and reduction in baseflow were illustrated by these results. Also, the hydrologic variables calculated from a relatively undeveloped Austin stream (Bear Creek) were compared to data reported from a comparable watershed in the Northeast.

The more temperate-climate perennial stream in the Northeast (similar to those used in developing the standard biological assessment methodology and metrics) was found to be significantly different in flow characteristics and hydrologic patterns from the Austin stream, and these differences were also reflected in biological metrics. In summary, this evaluation indicated that hydrological alteration from development rather than increased pollutant concentration or loading may be more responsible for biological degradation, and the ultimate separation of these sources of degradation may lead to new watershed management strategies.

INTRODUCTION

Rapid Biological Assessments (RBA’s) are used across the United States to evaluate stream health, particularly as a means to assess the effects of non-point source pollution that may not be apparent in traditional water chemistry analysis (Karr and Chu, 1999; Barbour et al., 1998; Merrit and Cummins, 1996; Resh and McElravy, 1993; Plafkin et al., 1989). Benthic macroinvertebrates, the community used most often in RBA’s, provide a sensitive measure of cumulative or low-level chronic contamination and also may reflect the physical or structural degradation of aquatic habitats that can occur in urbanized watersheds (Karr and Chu, 1999; Barbour et al., 1998; Rosenberg and Resh, 1996; Plafkin et al., 1989; Hynes, 1970). Benthic macroinvertebrate community structure data are transformed into metrics and compared to reference conditions to establish a qualitative scoring gradient (Karr and Chu, 1999; Hughes, 1994; Barbour et al., 1994) that reflects the main aspects of community structure (taxonomic richness, composition, tolerance). Assessments using these metrics and indices are often used as water quality management tools and recently as regulatory criteria in water quality monitoring programs.

Although RBA's are intended to assess the effects of point and non-point source pollution, they have not generally been used to distinguish between disturbed and undisturbed hydrologic regimes. Every effort is made during the RBA process to minimize variability in conditions outside of the changes caused by pollution sources. For example, habitat quality assessment has become an integral part of RBA's (Barbour and Stribling, 1993), in order to normalize the physical variability attributed to habitat such as substrate size, riffle development, habitat heterogeneity, and embeddedness. Seasonal and ecoregion variations are also an important consideration in most biological sampling programs. Stream hydrology, although recognized by ecologists as integral in defining ecosystem structure and function (Clausen and Biggs, 1997; Gordon, 1992; Poff and Ward, 1989; Hynes, 1970), is only superficially considered in the interpretation of RBA scores. However, the amount of variability introduced by the hydrologic regime and the unique preceding hydrologic conditions may be significant, especially in urbanized streams where impervious cover has greatly altered natural flow characteristics.

Due to the short-duration, high-intensity nature of rain patterns in Central Texas, hydrologic regimes of streams tend to be more variable and dramatic than those in more temperate regions where bioassessment protocols were developed (Figures 1 and 2). Impervious cover degrades flow regimes in urban watersheds by reducing baseflow and limiting the amount of infiltration in a watershed. This intensifies the effect in already "flashy" systems in the Austin, Texas, area, thus producing hydrologic regimes that go from destructive floods to total dewatering in very short time intervals (Figure 3). The resulting biological communities are under constant stress and adjustment. Consequently, understanding the effects of hydrology and other factors on the biological communities of streams in this region is critical to the correct interpretation of bioassessment data.

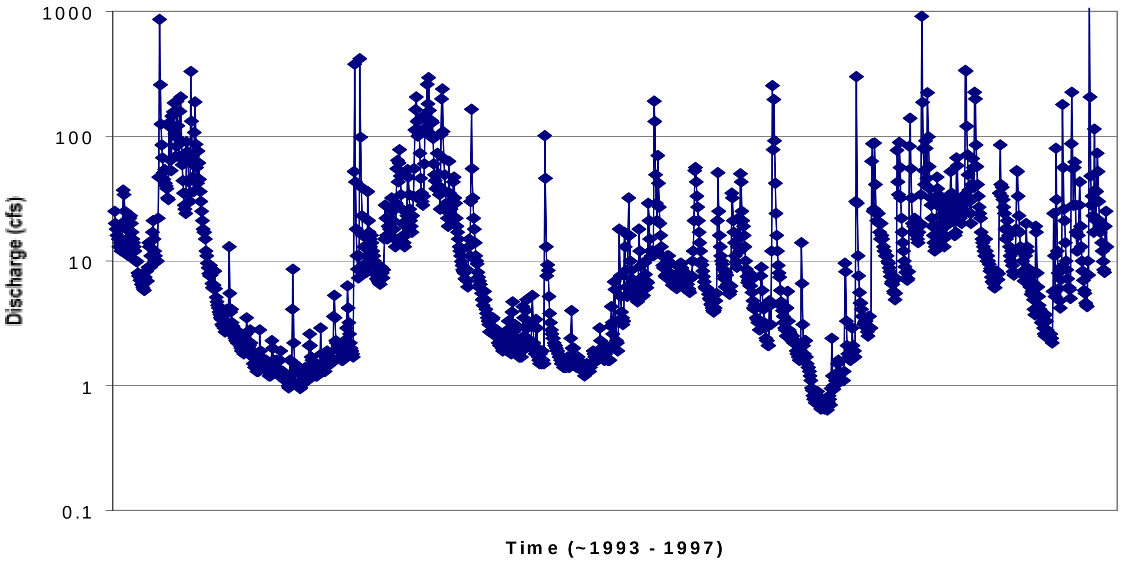

Figure 1. Hydrograph of mean daily discharge on Hague Creek, an undeveloped drainage (15 sq. mi.) in Virginia (temperate), 1993-1997.

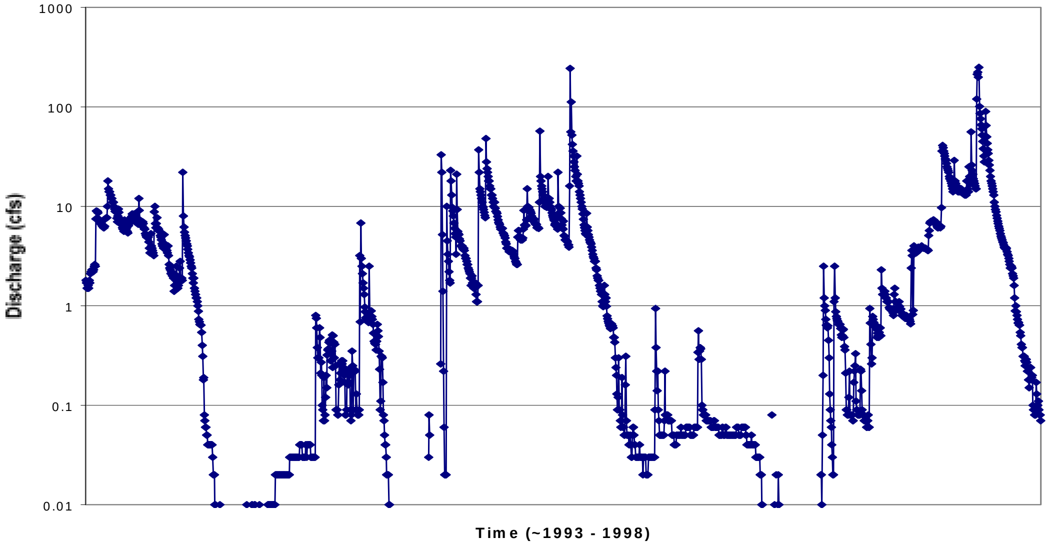

Figure 2. Hydrograph of mean daily discharge on Bear Creek, an undeveloped drainage (12.2 sq. mi.) in the Austin, Texas, area, 1993-1998.

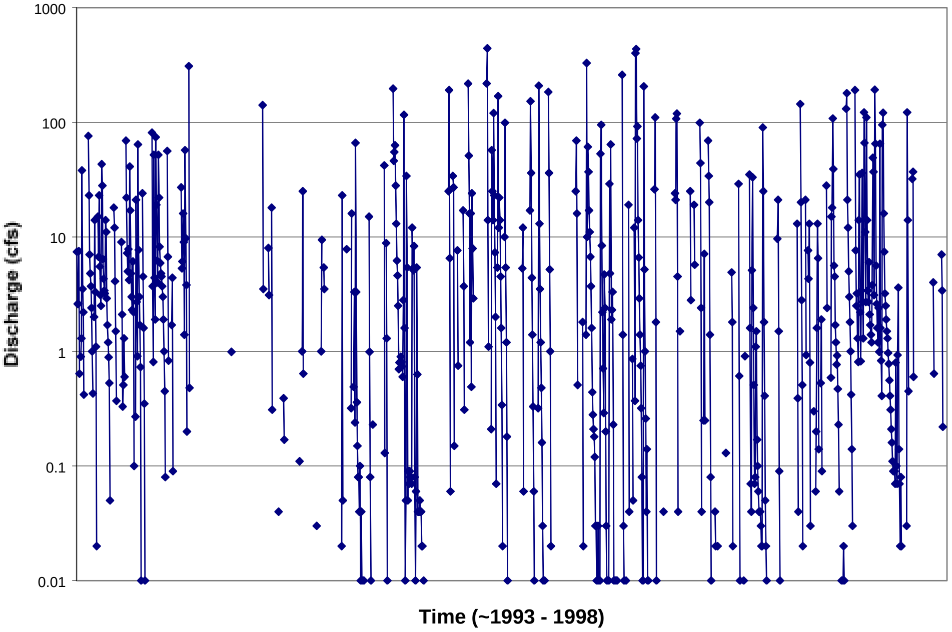

Figure 3. Hydrograph of mean daily discharge on Shoal Creek, an urban drainage (12.2 sq. mi.) in Austin, Texas, 1993-1998. Vertical lines are storms followed by no flow.

METHODS

Benthic macroinvertebrate data have been collected by City of Austin personnel in Austin streams since 1993. Standard rapid bioassessment methods (Plafkin et al., 1989) are used in the collection and processing of benthic samples. Organisms are enumerated and identified to the generic level whenever possible by City of Austin taxonomists. Data are then compiled and managed in a relational database. The data for this analysis were limited to only those watersheds that had USGS gaging stations with a daily mean flow record and only those sites that were hydrologically associated with the mainstem of the stream being gauged. These restrictions resulted in a total biological data set consisting of 333 data points at 78 sites in 11 watersheds.

The metrics used in this analysis (Table 1) were selected a priori based on representation in the basic categories of benthic macroinvertebrate community structure (taxonomic richness, composition and tolerance), regional use, and the current literature (Karr and Chu, 1999; Barbour et al, 1998; Merrit and Cummings, 1996; Resh and Jackson, 1993). Raw metric scores for each site/sample were used as the individual dependent variables in this analysis since they are the most direct measurement of community variation used in bioassessment techniques and universal reference site comparison would be inappropriate with this heterogeneous data set.

Table 1. Biological metrics used in analysis.

Metric Name		Category	Calculation
1	Total Taxa	Taxonomic Richness	# of taxa
2	Diptera Taxa	Taxonomic Richness	# of taxa in Diptera order
3	EPT Taxa	Taxonomic Richness	# of taxa in three EPT orders
4	% Dominant Taxa	Community Composition	% of largest taxa in total sample
5	% EPT Abundance	Community Composition	% of EPT organisms in total sample
6	% Chironomidae Abundance	Community Composition	% of Chironomidae family in total sample
7	EPT/EPT + Chironomid	Community Composition	Total # EPT organisms/EPT organisms plus # of Chironmidae organisms
8	Hilsenhoff Biotic Index	Community Tolerance	HBI= sum (XiTi)/n where: Xi =# of individuals in each species Ti = tolerance value of each species n= total organisms in sample

Daily mean flow measurements, taken from the 11 USGS gaging stations in the Austin area, were converted to ecologically relevant parameters as established by Poff and Ward (1989) and by Richter et al. (1996, 1997) (Table 2). These parameters correspond to five hydrological statistical “Groups” that are relevant to biological systems (magnitude, duration, timing, rate of change, and frequency) (Poff and Ward, 1989). The Indicators of Hydrological Alteration (IHA) software package (Richter et al., 1996) was used to calculate these statistics from the raw USGS daily mean flows. Correlation analysis (Statsoft,1998) was used to eliminate strongly related variables, reducing the final independent variable list into two main groups: the summary statistics (the 6 variables in group 1) and the main IHA statistics (14 variables from the other 4 groups). These multiple independent variables were used to characterize the flow regimes in local streams in an ecologically meaningful manner so that their relationship with the dependent biological variables could be evaluated.

Table 2. Hydrological parameters used to characterize flow regime. Highlighted parameters were selected using correlation analysis as the final independent variables.

Group		Type	Units
Group 1			
1	Mean annual flow	Summary	cfs
2	Annual coefficient of variation	Summary	n/a
3	Flow predictability	Summary	n/a
4	Constancy predictability	Summary	n/a
5	% of floods in 60 day period	Summary	%
6	Flood free season	Summary	# of days
Group 2			
7	Annual minima, 1-day means	Magnitude and Duration	cfs
8	Annual minima, 3-day means	Magnitude and Duration	cfs
9	Annual minima, 7-day means	Magnitude and Duration	cfs
10	Annual minima, 30-day means	Magnitude and Duration	cfs
11	Annual minima, 90-day means	Magnitude and Duration	cfs
12	Annual maxima, 1-day means	Magnitude and Duration	cfs
13	Annual maxima, 3-day means	Magnitude and Duration	cfs
14	Annual maxima, 7-day means	Magnitude and Duration	cfs
15	Annual maxima, 30-day means	Magnitude and Duration	cfs
16	Annual maxima, 90-day means	Magnitude and Duration	cfs
17	Number of zero-flow days	Magnitude and Duration	# of days
18	Baseflow (7-day minimum flow/mean for year)	Magnitude and Duration	cfs
Group 3			
19	Julian date of each annual 1-day maximum	Timing	date
20	Julian date of each annual 1-day minimum	Timing	date
Group 4			
21	Number of low pulses within each year	Frequency and Duration	#/year
22	Mean duration of low pulses within each year	Frequency and Duration	# of days
23	Number of high pulses within each year	Frequency and Duration	#/year
24	Mean duration of high pulses within each year	Frequency and Duration	cfs
25	Low Pulse Level	Frequency and Duration	cfs
26	High Pulse Level	Frequency and Duration	# of days
Group 5			
27	Rate of rise (mean positive differences between daily means)	Rate and Frequency	cfs/year
28	Rate of fall (mean negative differences between daily means)	Rate and Frequency	cfs/year
29	Number of reversals	Rate and Frequency	#/year

Graphical plots, cluster analysis, and analysis of variance were used to evaluate the ability of the hydrological parameters to visually and statistically distinguish different development levels, regional effects on hydrology, and the resolution of the measures in dividing Austin streams. Multiple linear regression was used to evaluate the relationship between the biological data (metric scores) and the hydrological characterization of the study streams (summary and IHA parameters).

RESULTS

Evaluation of the hydrologic variables

Three streams were selected from the 11 available with USGS gages that had similar geological settings and similar drainage areas but differing levels of development (Table 3). Changes in impervious cover in these watersheds during the period of record analyzed were minimal except on Bull Creek, where significant development has occurred in the last 5 years. Trend analysis, however, showed no significant changes in IHA parameters during this period.

Table 3. Watersheds selected for evaluating hydrologic variability.

Watershed	Drainage Area (square miles)	Impervious Cover (percent)	USGS Period of Record (years)
Bear Creek	12.2	<5	1979-1998
Bull Creek	22.3	14.8	1978-1998
Shoal Creek	12.2	56.2	1984-1998

Each of the 33 IHA parameters was calculated for each of these streams for each year that USGS gage data was available and compared using box and whisker plots (Statsoft, 1997). Many of these plots indicated a distinct difference between the hydrologic variability of these streams, which can generally be attributed to impervious cover (Gordon et al., 1992; USEPA, 1997). For example, the number of high pulse counts in any given flow year (discharge values above the 75th percentile of the entire period of record) was lower in the undeveloped stream than in the moderately developed stream, and both of these were much lower than the number of pulses in the highly developed stream (Figure 4). Similarly, the rise rate in these three streams was much faster in the more developed examples (Figure 5), indicating that increased impervious cover is making these streams less stable. The number of zero-flow days in any given flow year shows that groundwater influences can be an important factor in hydrologic regimes in this area (Figure 6). Although more zero-flow days were seen in the developed watershed (Shoal), the moderately developed watershed (Bull), which was more influenced by groundwater interaction, had fewer zero-flow days than did the undeveloped system.

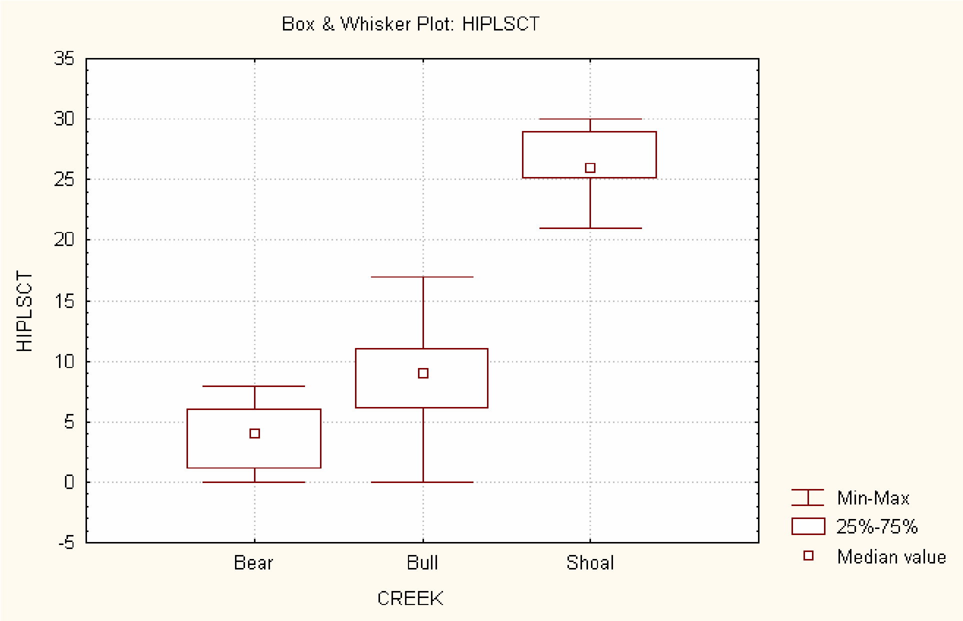

Figure 4. Number of high pulse counts in flow years during period of record.

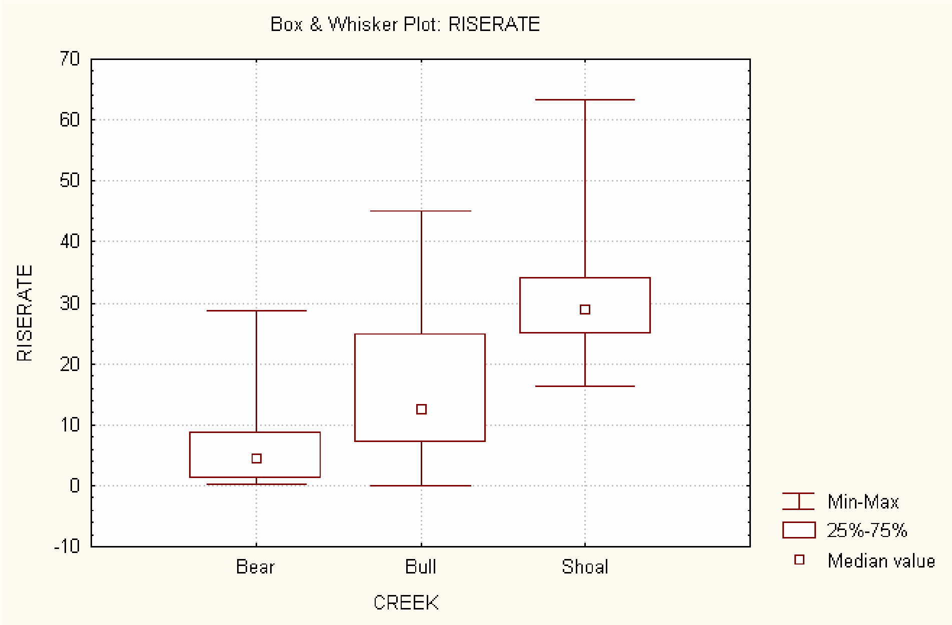

Figure 5. Median rise rate of stream discharge during period of hydrologic record.

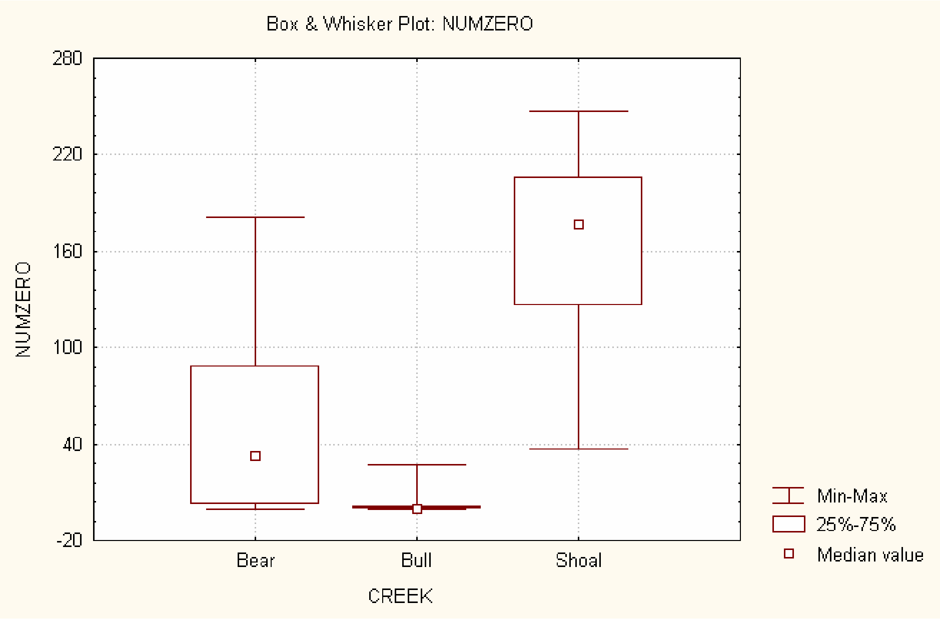

Figure 6. Number of zero-flow days during each year of period of hydrologic record.

For all 33 IHA parameters evaluated using the 3 different watershed development scenarios, 19 showed a significant difference (P = 0.05) between the 3 streams (ANOVA), indicating that impervious cover or some other aspect of development may be significantly impacting the hydrology of these streams as measured by the IHA analysis tool.

The IHA parameters were also used to compare differences between hydrologic variability in Austin and the temperate Northeast (Frederick County, Virginia). Watersheds of similar drainage area (12.2 and 15 square miles), similar development level (<5% impervious cover), and the same period of record (1979-1998) were compared based on each IHA parameter, and 26 of the 33 were significantly different (P = 0.05) between the 2 regions. This underscores the distinct differences between hydrological regimes in the Northeast, where bioassessment techniques were primarily developed, and this semi-arid region of the Southwest.

Biology vs. Hydrology

In order to evaluate the ability of the hydrologic variables to predict the variation in the biological variable (multiple regression analysis), it is important that redundancy in the independent variables be reduced. Correlation analysis was used to remove those hydrologic variables that were highly correlated (correlation coefficient > 0.75). This reduced the IHA variables from 33 to 26. Additionally, the 12 monthly means in the IHA were not used for this analysis because they pertain to specific temporal comparisons (seasonality) that are not applicable to the distribution of sampling events in this data set.

The final hydrological data set included 6 summary statistics proposed by Poff and Ward (1989), and the remaining 14 IHA variables (See Table 2). Each of these groups was regressed against a single metric data set to evaluate the relationship between the biological indicator and the characterization of hydrologic variation for each watershed

Results from each of these analyses showed a significant relationship ($p<0.0001$) between all 8 biologic metrics and some model of hydrologic variability. The summary statistics (Poff and Ward, 1989), combined with drainage area, were significantly correlated to each of the 8 metrics, explaining from 10 to 33% of the variation in the biological data (Table 4). Each metric had distinct regression models (from three to all seven variables), but based on the beta scores[1], percent of floods in a 60-day period and the annual coefficient of variation were the best independent variables in the summary statistics analysis (Figure 7).

Table 4. Results from multiple regression analysis of summary hydrologic statistics vs. each biologic metric. Table provides beta values and R2 values at the bottom for each model. NR variables are not related to the model. Highest two beta values in each model are highlighted.

	Metric 1	**Metric 2**	**Metric 3**	**Metric 4**	**Metric 5**	**Metric 6**	**Metric 7**	**Metric 8**
Model Components (Hydro-variables)	**(HBI)**	**(EPT/Chir)**	**(Taxa Richness)**	**(EPT Taxa)**	**(Diptera Taxa)**	**(Percent Dom.)**	**(Percent Chir.)**	**(Percent EPT)**
Mean Annual Flow	-0.65	0.29	-0.57	-0.45	-1.20	-0.12	-0.34	0.12
Annual Coefficient of Variation	-0.91	0.83	0.63	0.98	0.77	-0.48	-0.72	0.64
Flow Predictability	1.07	NR	0.21	-0.19	0.63	0.21	NR	NR
Constancy Predictability	-0.13	NR	-0.90	-0.38	-0.75	NR	NR	NR
% of Floods in 60 day period	0.46	-0.55	-0.92	-0.94	-0.74	0.51	0.44	-0.38
Flood Free Season	-1.72	NR	-0.69	NR	-0.86	-0.19	NR	NR
Drainage Area	0.62	NR	0.86	0.67	1.28	NR	NR	NR
Variability explained (R^2)	**0.26**	**0.33**	**0.22**	**0.28**	**0.20**	**0.10**	**0.30**	**0.18**

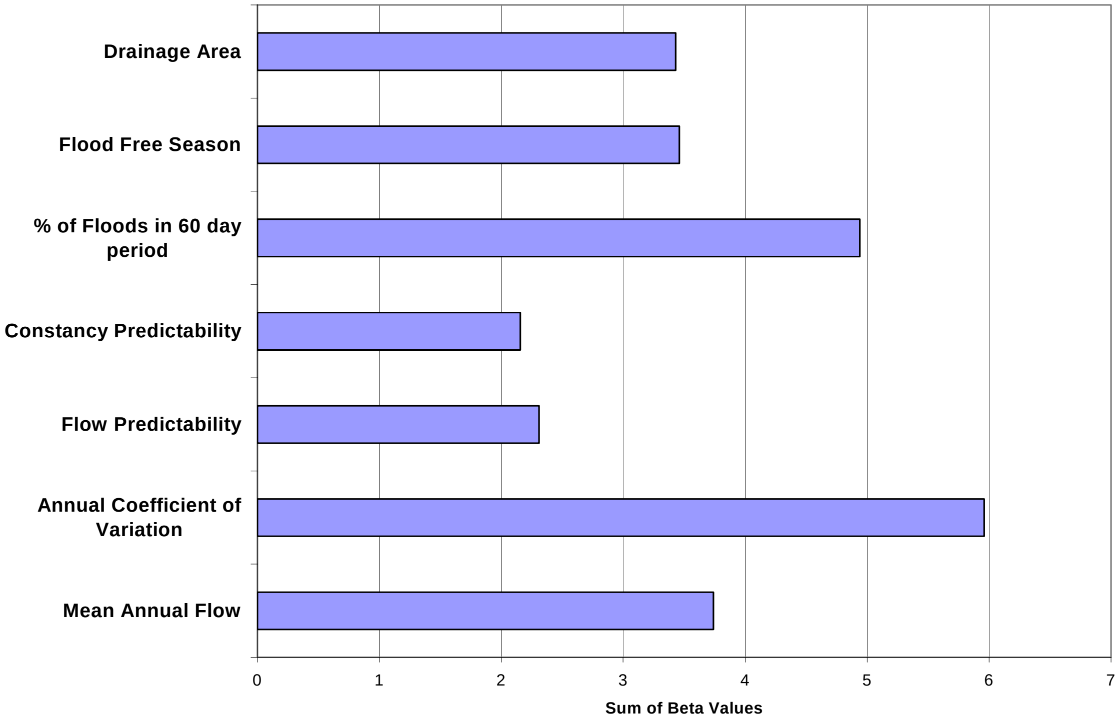

Figure 7. Sum of beta values in all models as an indicator of the strength of each independent variable in the regression of summary statistics against metric scores.

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[1] Beta scores are regression coefficients that can be used to compare the relative contribution of each independent variable in the prediction of the dependent variable.

The 14 IHA variables provided results similar to the summary statistics, but with slightly better regression models (Figure 8). There was a significant relationship ($p<0.0001$) between each of the 8 metrics and some combination of the 14 IHA variables, explaining between 10 and 38% of the variation in the biological metrics (Table 5). The beta scores in this analysis were more spread out than with the summary statistics, but the High Pulse Duration and the Date of the High Pulse were the best independent variables, explaining the most variability in the biological data (Figure 9).

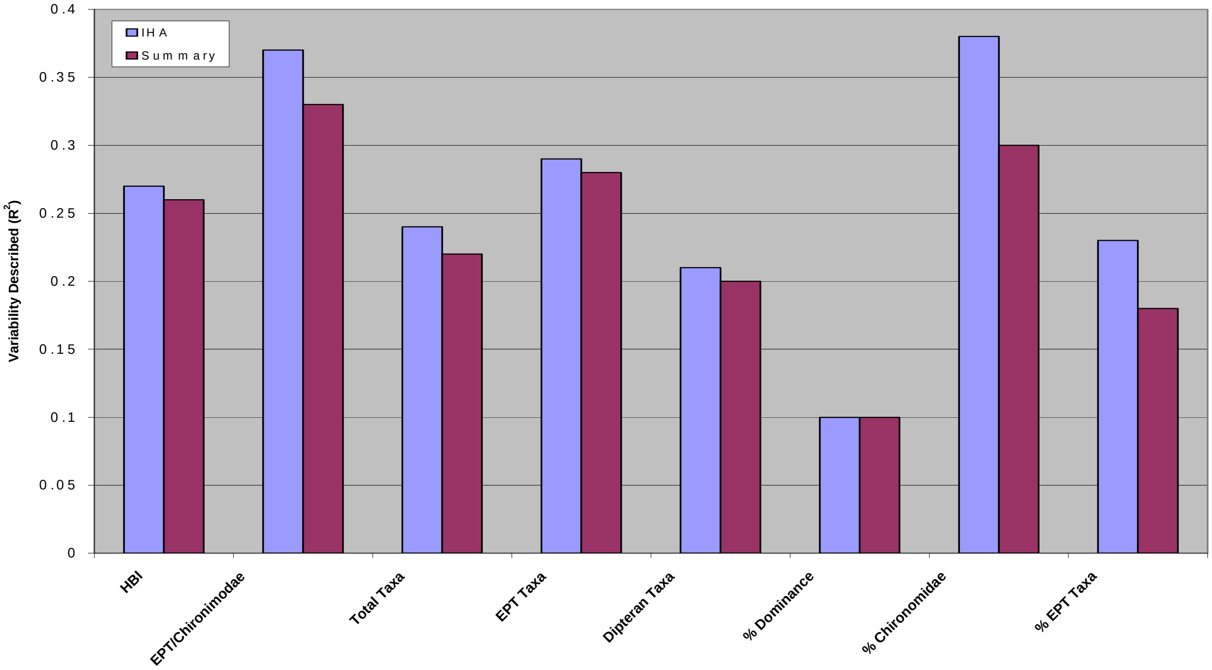

Figure 8. Comparison of R^2 values for Summary statistic models and IHA statistic models.

Table 5. Results from multiple regression analysis of IHA hydrologic statistics vs. each biological metric. Table provides Beta values and R^2 at the bottom for each model. NR variables are not related to the model. Highest two beta values in each model are highlighted.

	Metric 1	Metric 2	Metric 3	Metric 4	Metric 5	Metric 6	Metric 7	Metric 8
Model Components (Hydro-variables)	**(HBI)**	**(EPT/Chir)**	**(Taxa Richness)**	**(EPT Taxa)**	**(Diptera Taxa)**	**(Percent Dom.)**	**(Percent Chir.)**	**(Percent EPT)**
Annual min, 90-day	NR	NR	-0.84	NR	-0.62	0.09	NR	NR
Annual max, 1-day	-0.40	NR	NR	NR	NR	NR	NR	1.09
Annual max, 90-day	0.28	NR	NR	NR	-0.89	NR	0.32	-1.09
# of Zero-Flow days	NR	NR	NR	-0.40	NR	NR	0.04	0.15
Date of 1 day max	-0.18	0.07	1.10	-2.43	-1.45	0.18	0.66	-0.2
Date of 1 day min	NR	NR	0.74	-1.41	-0.77	NR	0.29	NR
# of low pulses	NR	0.38	NR	-2.32	-1.58	0.11	NR	NR
Duration of low pulses	NR	0.12	0.31	0.38	-0.18	NR	0.18	NR
# of high pulses	NR	NR	-2.10	1.83	NR	NR	NR	NR
Duration of high pulses	-0.57	0.43	-2.24	NR	-1.50	NR	NR	NR
Low pulse level	-0.63	0.41	0.93	0.02	NR	-0.31	NR	NR
High pulse level	NR	NR	NR	NR	0.85	NR	0.53	0.88
Rate of rise	NR	NR	-0.43	NR	NR	NR	NR	-0.58
Number of reversals	0.35	-0.67	NR	1.07	1.14	NR	NR	NR
Variability explained (R^2)	**0.27**	**0.37**	**0.24**	**0.29**	**0.21**	**0.10**	**0.38**	**0.23**

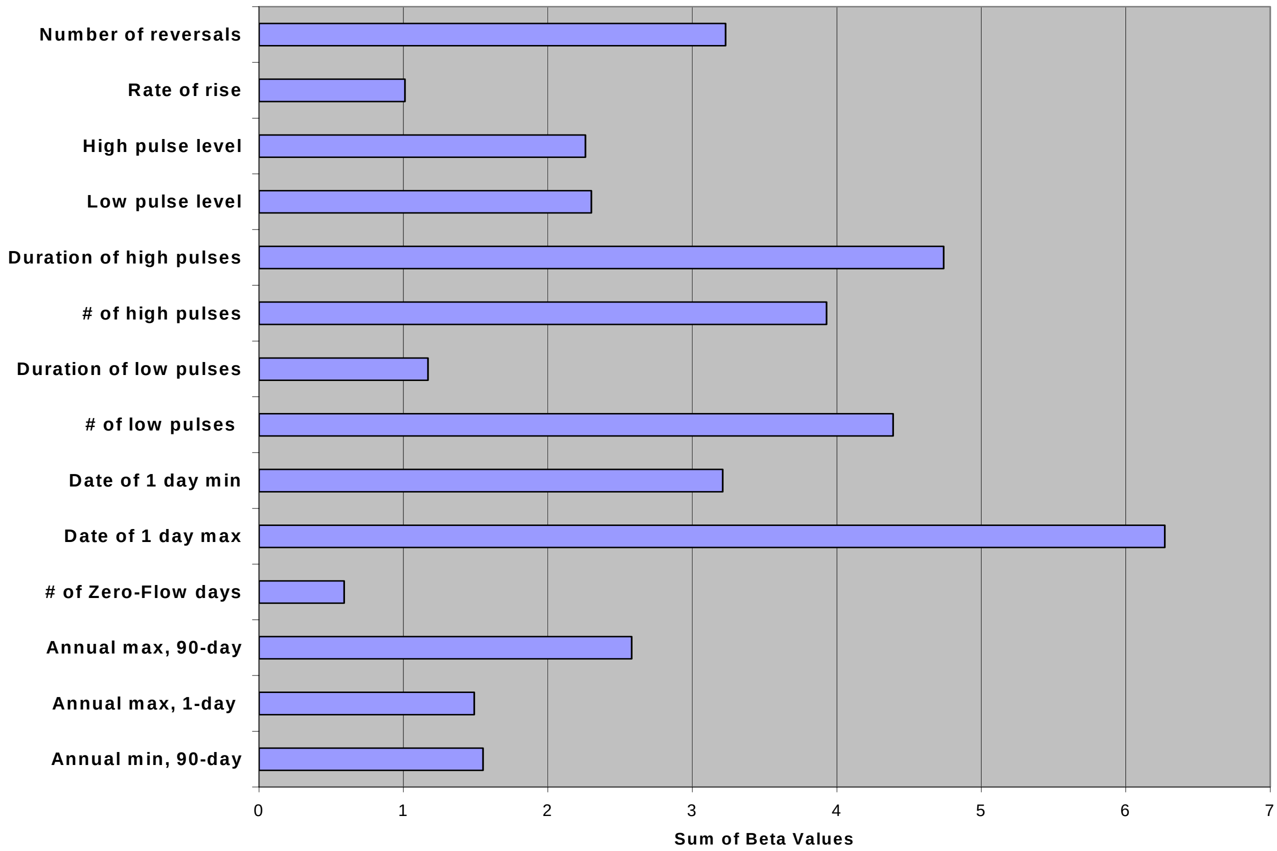

Figure 9. Sum of beta values in all models as an indicator of the strength of each independent variable in the regression of summary statistics against metric scores.

DISCUSSION

The analysis provided in this paper documents the initial investigation into how biological assessments in this area of Texas may be influenced by hydrological conditions. The summary statistics provided by Poff and Ward (1989) and the IHA statistics provided by Richter et al. (1996) are apparently effective at distinguishing hydrologic differences in watersheds in different regional climates, varying development levels, and varying geohydrological conditions. This lends support to the use of these tools in characterizing both the variability of Central Texas stream hydrology and its relationship to stream biology.

In comparing an Austin watershed (Bear Creek) to a similarly sized watershed in Virginia (Hague Creek), it is clear that there is a large difference between the hydrology of Central Texas and that of the temperate regions where bioassessment techniques were developed. The hydrological difference is not surprising, considering the large differences in climate between the regions, but it does demonstrate how these dramatic differences may influence evolutionary and biological structure and function of the benthic macroinvertebrate community. In less stable, more unpredictable environments, community structure should be regulated more by abiotic factors than by biotic interactions (Death and Winterbourn, 1994). Even in pristine systems that evolved under these conditions, the natural community is anticipated to be under a larger cycle of stress and recovery as the frequency or magnitude of disturbances increases (Death and Winterbourn, 1994). If the increased level of disturbance provided by impervious cover is added to these cycles, it is problematic to use the idea of "stabilized" community structure to measure stream health. In RBA applications in this area, the question is whether the (abiotic) chemical effect of non-point source pollution in these streams is being measured or the (abiotic) physical effect of hydrologic variability. If the biology is related to hydrologic variability, another question to be investigated would be whether the natural "background" variability is shown in the RBA or the increased variability due mainly to increasing impervious cover. Finally, the methodology to separate the natural variability from physical, and/or chemical effects on biology has yet to be developed. The focus of this analysis has been to address the first question: Can the local hydrologic regimes be characterized in an ecologically relevant way, and is this hydrology significantly correlated to the standardized measures of biological integrity that are applied universally (metrics)?

The fact that the hydrologic characterization tools in this analysis (summary and IHA statistics) separated streams based on level of development indicates that even with the naturally high level of hydrologic variability in this area, impervious cover may be significantly altering flow regimes. Ecologically relevant parameters like Rise Rate, Number of High Pulses, and Number of Zero-Flow Days all were much higher in the highly developed stream than the undeveloped stream. The significance of these differences to bioassessment methods is clear. Biological communities in developed streams are under significantly higher physical stress than are those in undeveloped streams. This, again, may be obvious, but the corollary is that *these stream communities are probably increasingly less likely to reflect non-point source chemical degradation as impervious cover goes u*p. It is likely that the physical variability in these systems is far more important than the chemical inputs.

The regression analysis in this paper is the beginning of the evaluation of the relationship between the hydrology of Austin streams and their biological communities. The fact that the hydrologic variables (summary and IHA parameters) are significantly correlated to all of the measures of community structure (metrics) indicates that this is an important part of the ecology of these streams, most likely more important in Austin than in other parts of the country. It would be beneficial to do this same analysis using hydrologic and biologic data all collected from a temperate climate to see how the different climates would compare. The amount of variation in the dependent variables that was explained by the independent variables (from 10 to 38%) indicates that although highly significant ($p<0.00001$), these models are only part of the equation. What remains to be seen is whether some measure of chemical non-point source pollution explains as much or more of the variation in these biological communities. This question will be addressed in future analyses. Historically, it has been difficult to tie City of Austin biological data to specific land use distribution or even impervious cover (COA, 1996). The results of this analysis indicate that this may have been due to the overarching influence of hydrologic variation on these assessments. If biological assessment techniques are to continue to be used in this area, a physical and more specifically a hydrologic template is needed in order to analyze and interpret community structure data in an effective and meaningful way.

One of the fundamental problems with this analysis is the inability to separate impervious cover from non-point source pollution. Often, impervious cover is used as the independent variable in analysis of biological data, assuming that an increase in impervious cover indicates an increase in concentrations of pollutant constituents associated with urbanization. However, as indicated in the above analysis, impervious cover is also highly associated with degradation of hydrologic regimes, contributing to the variability and stochasticity of these systems. Since biological data are often used as a less expensive and more effective cumulative measure of water quality than traditional water chemistry data, it is crucial that the degradation from chemical and physical/hydrological factors be isolated for these communities. Otherwise, decision-makers will likely develop and apply management practices that do not address the true source of degradation in measure. Obviously, impervious cover contributes to both chemical, physical and additively, biological degradation. In order to begin addressing these problems, particularly in urban streams, physically based ecological relationships should be isolated before moving to potentially less important and more complex chemical and biological relationships. Research into more specific hydrological indices and finer grained biological data sets will help to illuminate how accurate benthic communities can be in this area in reflecting degradation in streams due to urbanization.

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