# Effects of hydrologic variability on biological assessments in streams in Austin, TX

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**ABSTRACT:**

*Rapid Biological Assessments (RBA's) are used across the United States to evaluate the condition of stream health, particularly as a means to assess the effects of non-point source pollution that are not apparent in traditional water chemistry analyses. The City of Austin, Texas has been using RBA's in urban and non-urban streams for the last six years in an effort to expand and improve its environmental monitoring programs. Central Texas weather, which is characterized by flashy spates and long dry periods, is distinct from the temperate climates where the RBA's were developed. In addition to naturally dramatic hydrological cycles, urbanization and its high levels of impervious cover further exaggerate stream flow patterns, producing greater runoff volumes, higher peak flows and less baseflow. Documentation of recent and/or long-term hydrologic variability is not a common practice in the municipal, state or national agencies that conduct RBA's. Our hypothesis is that hydrologic variability in this region will have a significant relationship to benthic macroinvertebrate community structure (as expressed by an index of univariate metrics).*

*Hydrologic parameters were calculated using historical USGS flow data for study streams and compared to available City of Austin biological data. Results show that hydrologic regimes in Austin have a significant relationship to benthic community metrics. Hydrologic variability is an important structural mechanism in this region and should be utilized as a template in interpreting biological assessments using RBA metrics.*

## 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 & 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 which 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), normalizing the physical variability attributed to habitat, such as substrate size, riffle development, habitat heterogeneity, and embeddedness. Seasonal and ecoregion variation 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.

The biological response to hydrologic disturbance has been well documented in studies of relatively pristine systems (Clausen and Biggs, 1997; Dole-Olivier et al., 1997; Quinn and Hickey, 1994; Poff and Ward, 1989), as has the biological, physical and chemical response of streams to urbanization (Gordon et al., 1992; Baker, 1977; Poff et al., 1997; Britton et al., 1993; USEPA, 1997; Lenat and Crawford, 1994; Tikkanen et al., 1994; Pratt et al., 1981). However, the effects of hydrologic variability and antecedent hydrologic conditions on biological assessments used in monitoring programs are not well known.

Urban streams in Austin, Texas present the typical hydrological problems encountered in densely developed areas all over the world. Impervious cover reduces baseflow by limiting the amount of infiltration in a watershed. Flow volumes and velocities in streams generally increase during storms due to the higher quantity of water that runs off impervious cover and into the stream channel. This creates a very unstable system that goes from destructive floods to total de-watering in very short time intervals (Fig. 1). The resulting biological communities are under constant stress and adjustment. 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 in more temperate regions, where bioassessment protocols were developed (Fig. 2,3). Consequently, understanding the effects of hydrology and other factors on the biological communities of urban streams in this region is critical to the correct interpretation of bioassessment data.

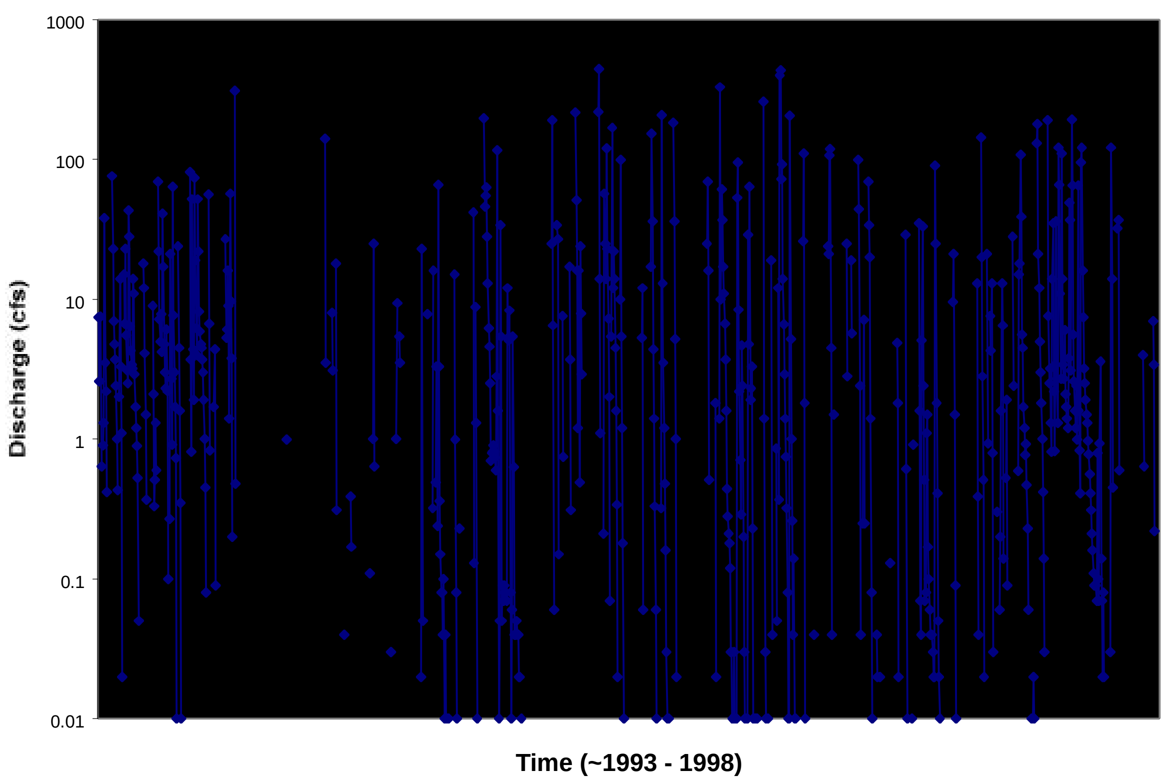


Figure 1. Hydrograph of mean daily discharge on Shoal Creek from 1993 - 1998, an urban drainage (12.2 sq. mi.) in Austin, TX. Vertical lines are storms followed by no flow.

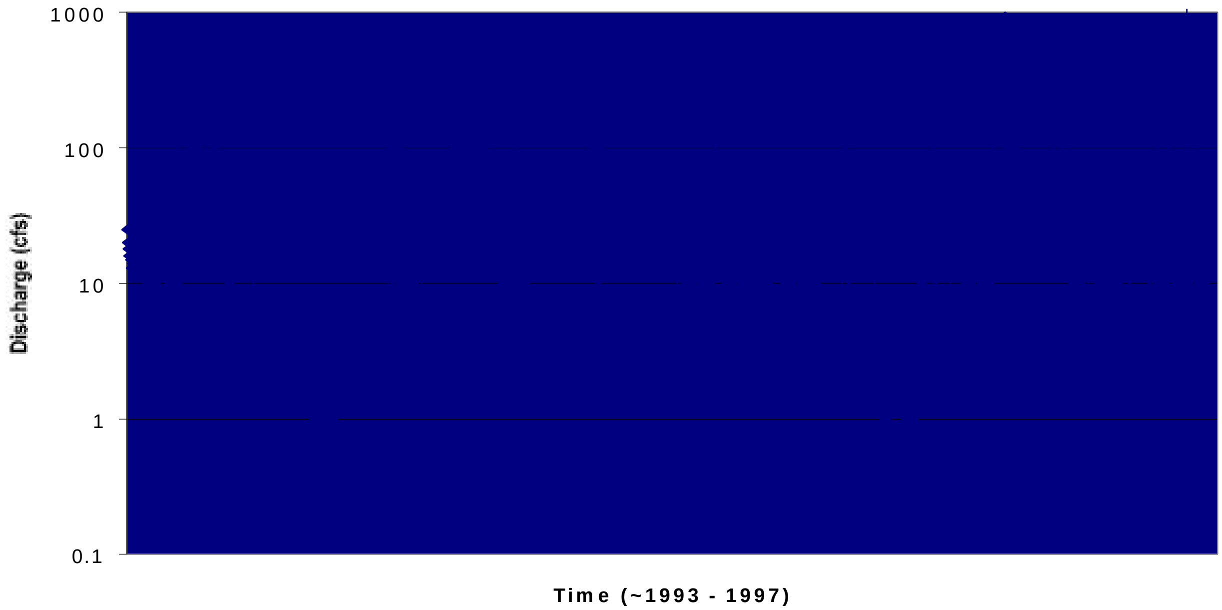


Figure 2. Hydrograph of mean daily discharge on Hague Creek from 1993 - 1997, an undeveloped drainage (15 sq. mi.) in Virginia (Temperate).

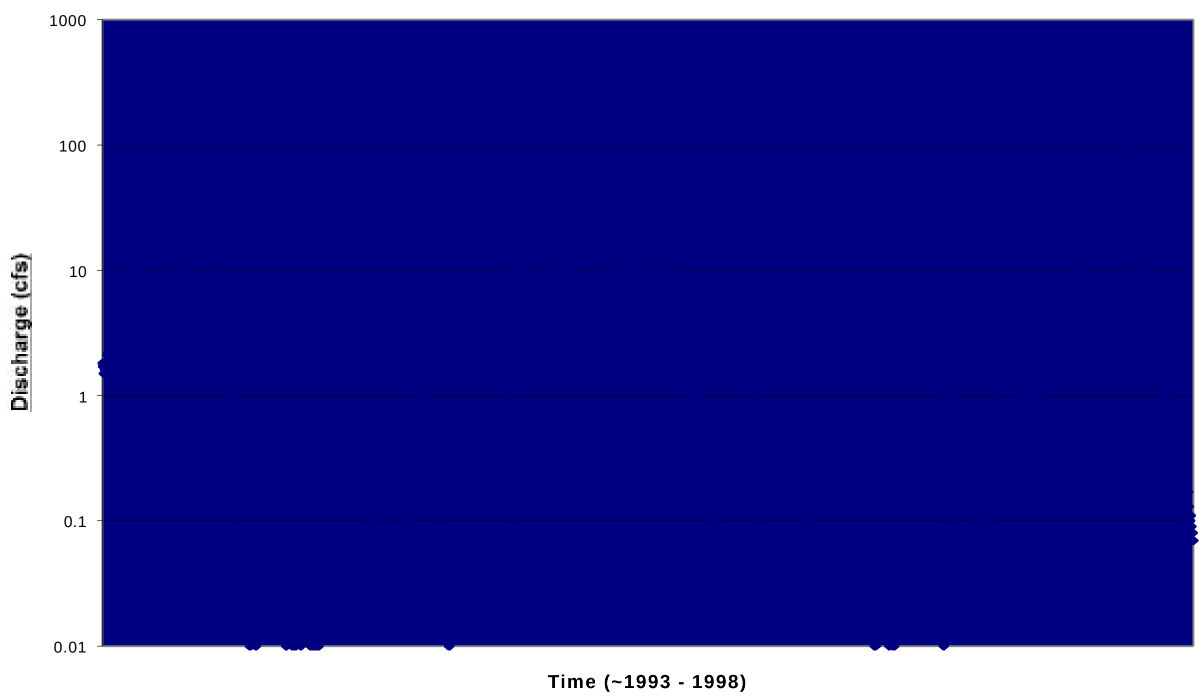


Figure 3. Hydrograph of mean daily discharge on Bear Creek from 1993 - 1998, an undeveloped drainage (12.2 sq. mi.) in the Austin, Tx area.

The City of Austin, Texas has been using RBA's in area streams for the last six years in an effort to expand and improve its environmental monitoring programs. Biological surveys of streams are completed every three years in most of the urbanized watersheds within the City's jurisdiction. Documentation of hydrologic character is not a common practice for any municipal, state or national agency that conducts RBA's because long-term hydrology data is generally available only at select USGS gaging stations and is rarely collected prior to an RBA analysis. This paper hypothesizes that general hydrologic stream character will have a significant relationship to the benthic macroinvertebrate community (as expressed by univariate metrics).

**METHODS:**

City of Austin benthic macroinvertebrate data has been collected in area streams from 1993 - 1999. Standard rapid bioassessment methods (EPA, 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 and then compiled and managed in a relational database. The data for this analysis was limited to only those watersheds which had USGS gaging stations with a daily mean flow record and only those sites which 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. There was some variation in methods used for the collection and processing of the benthic organisms. However, transformation of the community structure data into univariate metrics and the large number of data points in this analysis should make potential sampling bias negligible (Poff and Ward, 1989, Poff and Allan, 1995).

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. Proposed biological metrics.

| | **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 orgs/EPT orgs plus # of Chironmidae orgs |
| 8 | Hilsenhoff Biotic Index | Community Tolerance | HBI=sum (XiTi)/n where: Xi=# of indiv. In each species, Ti=tolerance value of each species, n=total organims in sample |
| 9 | # of Tolerant Taxa | Community Tolerance | # of taxa with tolerance value >6 |
| 10 | % Tolerant Abundance | Community Tolerance | % of organisms in sample with tolerance value >6 |

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 was used to eliminate strongly related variables, reducing the final independent variable list into two main groups, the summary statistics (6 variables in group 1) and the main IHA statistics (14 variables from the remaining groups). These parameters are used to characterize the flow regimes in local streams in an ecologically meaningful manner so that their relationship with the biological variables can be evaluated. The hydrology variables were used as multiple independent variables in these analyses.

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

| | **Group 1** | **Type** | **Units** |
|---|---|---|---|
| 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 | # 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 | # days |
| 18 | Baseflow (7-day minimum flow/mean for year) | Magnitude and Duration | cfs |
| | **Group 3** | | |
| 19 | Julian date of each annual 1 day maximim | 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 | # 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 | # days |
| 25 | The low pulse level | Frequency and Duration | cfs |
| 26 | The high pulse level | Frequency and Duration | cfs |
| | **Group 5** | | |
| 27 | Rate of rise (mean of positive differences between daily means) | Rate and Frequency | cfs/year |
| 28 | Rate of fall (mean of negative differences between daily means) | Rate and Frequency | cfs/year |
| 29 | Number of reversals | Rate and Frequency | #/year |

Graphical, cluster and analysis of variance were used to evaluate the efficacy of the hydrological parameters in distinguishing between 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 hydrology variables:**

The effectiveness of the selected hydrological parameters at distinguishing between Austin area streams was tested using graphical plots and analysis of variance. Three streams were selected from the 11 with USGS gages which 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 development has occurred in the last five years. Trend analysis, however, showed no significant changes in IHA parameters during this period.

Table 3. Selected watersheds for evaluating hydrological variability.

| Watershed | Drainage Area | Impervious Cover | USGS Period of Record |
|---|---|---|---|
| | (Square Miles) | (percent) | (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 were 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. For example, the number of high pulse counts in any given flow year (discharge values above the 75$^{th}$ percentile of the entire period of record) was lower in the undeveloped stream than the moderately developed and both of these were much lower than the number of pulses in the highly developed stream (Fig. 4). Similarly, the rise rate in these three streams was much faster in the more developed examples (Fig. 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 (Fig. 6). Although we did see more zero flow days in the developed watershed (Shoal), the moderately developed watershed (Bull), with it's greater groundwater influenced geology , had much fewer zero flow days than the undeveloped system.

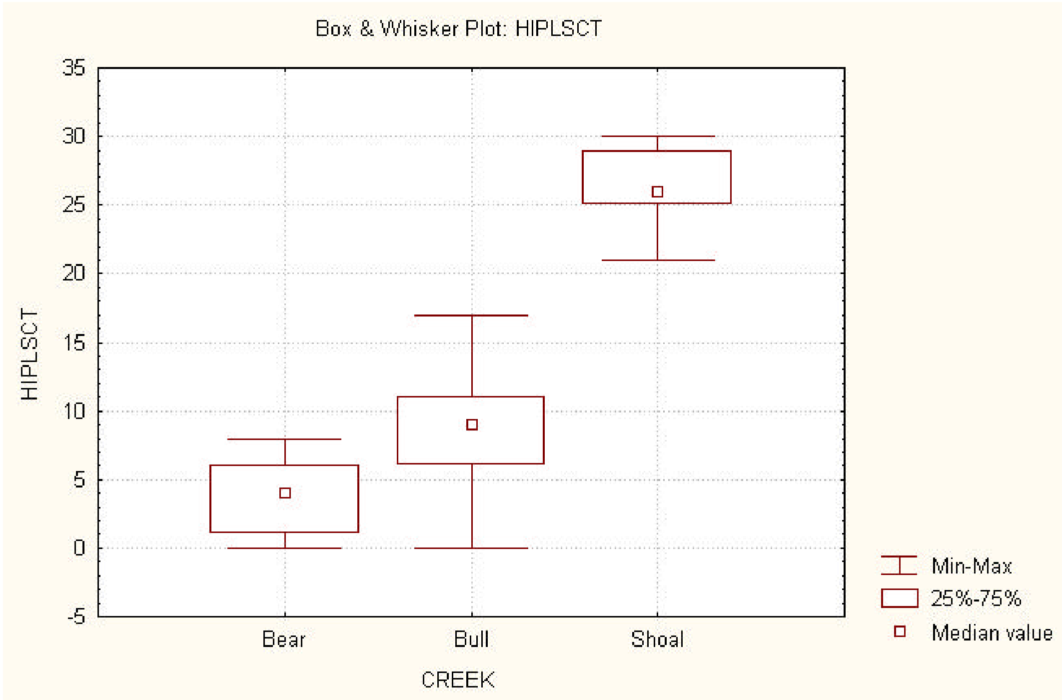


Figure 4. Number of high pulse counts in flow years during period of record.


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

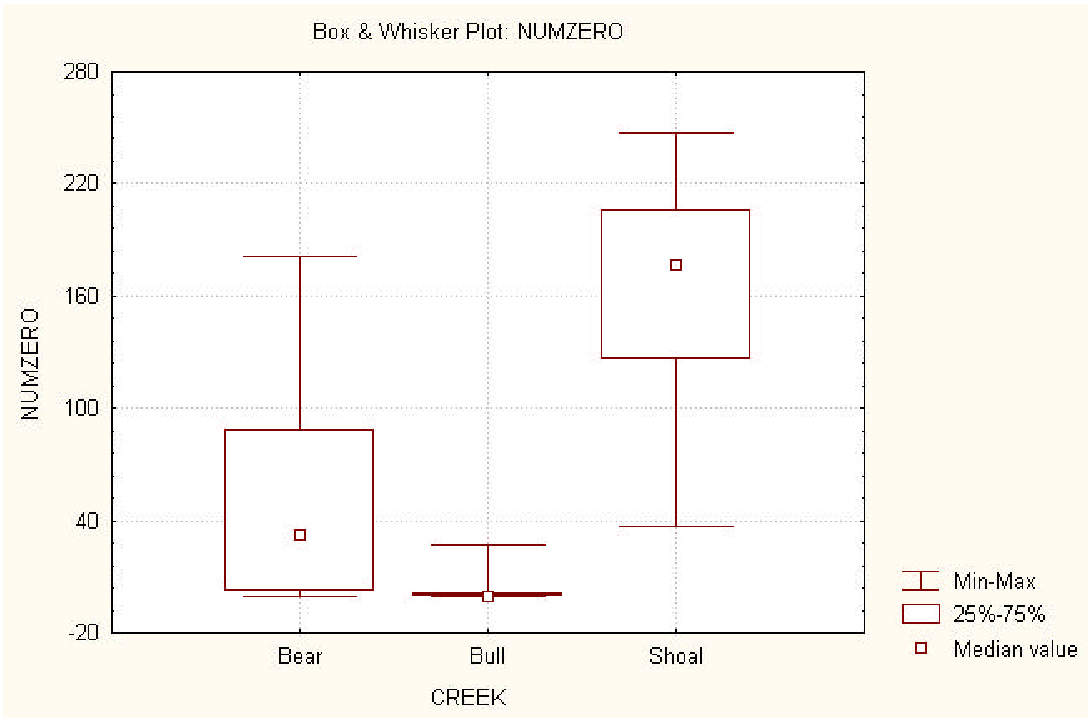

Figure 6. Number of zero flow days during each year of period of hydrologic record.

For all 33 IHA parameters evaluated using the three different watershed development scenarios, 19 showed a significant difference (P=0.05) between the three streams (ANOVA), indicating that impervious cover or some other aspect of development is 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 out of the 33 were significantly different (P=0.05) between the two 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.

Cluster analysis (Statsoft, 1997) was also used to evaluate the effectiveness of the IHA parameters at distinguishing between streams in the Austin area. 11 USGS gaged streams in the Austin area were analyzed using the five main ecological grouping variables within the IHA: Magnitude, Duration, Timing, Rate of Change and Frequency (Poff and Ward, 1989). Each of the 33 IHA variables pertain to one of these ecological groupings, which was then used to cluster the 11 watersheds in question. The results showed that each one of these five basic measures of hydrologic variability cluster the streams differently. There was some crossover, pertaining most likely to drainage area and impervious cover, but in general, each cluster analysis produced different results. This indicates that each of these five statistical groups, and the IHA parameters in general, are measuring distinct ecological variables that, in turn, should contribute to a more robust analysis.

**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 is reduced. Correlation analysis was used to remove those hydrologic variables which 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 since 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 hydrological variation for each watershed.

Results from each of these analyses showed a significant relationship ($p<0.0001$) between all 8 biological 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 10-33% of the variation in the biological data. Each metric had distinct regression models (from three to all seven variables), but based on the beta scores[1], <u>% of floods in a 60-day period</u> and the <u>annual coefficient of variation</u> were the best independent variables in the summary statistics analysis (Table 4).

Table 4. Results from multiple regression analysis of summary hydrologic statistics vs. each biological metric. Table provides Beta values and $R^2$ values at the bottom for each model. NR variables are not related to the model. Highest two beta values in each model are highlighted.

| Model Components (Hydro-variables) | Metric 1 (HBI) | Metric 2 (EPT/Chir) | Metric 3 (Taxa Richness) | Metric 4 (EPT Taxa) | Metric 5 (Diptera Taxa) | Metric 6 (Percent Dom.) | Metric 7 (Percent Chir.) | Metric 8 (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** |

The 14 IHA variables provided similar results to the summary statistics, but with slightly better regression models (higher $R^2$). There was a significant relationship ($p<0.0001$) between each of the eight metrics and some combination of the 14 IHA variables, explaining between 10 and 38% of the variation in the biological metrics. The beta scores in this analysis were more spread out than with the summary statistics, but the <u>High Pulse Duration</u> and the <u>Date of the High Pulse</u> were the best independent variables (Table 5).

[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.

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 | | | -0.84 | | -0.62 | 0.09 | | |
| Annual max, 1-day | -0.40 | | | | | | | 1.09 |
| Annual max, 90-day | 0.28 | | | | -0.89 | | 0.32 | -1.09 |
| # of Zero-Flow days | | | | -0.40 | | | 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 | | | 0.74 | -1.41 | -0.77 | | 0.29 | |
| # of low pulses | | 0.38 | | -2.32 | -1.58 | 0.11 | | |
| Duration of low pulses | | 0.12 | 0.31 | 0.38 | -0.18 | | 0.18 | |
| # of high pulses | | | -2.10 | 1.83 | | | | |
| Duration of high pulses | -0.57 | 0.43 | -2.24 | | -1.50 | | | |
| Low pulse level | -0.63 | 0.41 | 0.93 | 0.02 | | -0.31 | | |
| High pulse level | | | | | 0.85 | | 0.53 | 0.88 |
| Rate of rise | | | -0.43 | | | | | -0.58 |
| Number of reversals | 0.35 | -0.67 | | 1.07 | 1.14 | | | |
| **Variability explained ($R^{2)}$** | **0.27** | **0.37** | **0.24** | **0.29** | **0.21** | **0.10** | **0.38** | **0.23** |

**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 similar sized watershed in Virginia (Hague Creek) it is clear that there is a large difference between the hydrology in Central Texas and that of the temperate regions where bioassessment techniques were developed. This 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, is the natural "background" variability shown in the RBA or is the increased variability due mainly to increasing impervious cover? How are these components to be seperated? The focus of this analysis has been to address the first question: Can the local hydrology 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 hydrological 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 is still 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 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 up. 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 in Austin streams and their biological communities. The fact that the hydrologic variables (summary and IHA parameters) were 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 than in other parts of the country. It would be interesting to do this same analysis using hydrological and biological 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 10-38%) 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 we are going to continue to use biological assessment techniques in this area, a physical and specifically, a hydrological 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 we have seen here, impervious cover is also highly associated with degradation of hydrologic regimes, contributing to the variability and stochasticity of these systems. Since biological data is often used as a cheaper more effective measure of water quality than traditional water chemistry data, it is crucial that we are able to distinguish between chemical and physical degradation using these communities. Otherwise, decision-makers won't be able to effectively develop or apply management practices. Obviously, impervious cover contributes to both chemical, physical and additively, biological degradation. In order to begin addressing these problems, particularly in urban streams, we should be trying to isolate physically based ecological relationships before we move 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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