Walnut Creek Update Report

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Abstract

One of the few large perennial streams in the Austin area, Walnut Creek was monitored intensely from 1996-2008, including chemical, physical and biological measures. This report provides a cursory overview of general water quality status of the watershed, looking at spatial changes from headwaters in Northwest Austin to it's confluence with the Colorado River downstream of Longhorn Dam, as well as temporal changes that have occurred since the watershed was designated as part of the "desired development zone". Although there are some areas of concern, and there is quite a bit of future development pressure, water quality measures generally indicate that the catchment is in fairly good health, and appears to have improved slightly during the study period.

Introduction

Walnut Creek is approximately 23 miles in length and has a drainage area of 56.5 square miles. The stream flows from north-south, crossing from the Central Texas Plateau ecoregion on the western side of Austin to the Blacklands Prairie on the eastern side of Austin and finally draining into the Colorado River downstream of Longhorn Dam. The upper portion of the watershed, to the Northwest, is heavily developed with commercial and residential land uses and recharges the Northern Edwards Aquifer in its headwaters. It is characterized by Edwards limestone outcropping and bedrock, springs, bluffs and rimrock, as well as typical hill country vegetative cover and steep canyons. The lower part of the watershed transitions into deeper soils, large hardwood bottomlands, rolling hills and a relatively deep, incised channel with a robust and diverse riparian zone. This section is less developed, but is classified under City of Austin regulations as being in the Desired Development Zone (DDZ) and is expected to see intensive growth over the next 20 years.

One of the four large, perennial streams in Austin, along with Barton, Onion, and Bull creeks, Walnut has been monitored extensively for the past 12 years by Environmental Resource Management (ERM) staff. During this time we have made over 350 site visits, collecting 274 water chemistry samples, 84 biological samples (bugs and diatoms) and 12 habitat assessments, for an average of about 5 visits per year to each of the 5 study sites in the watershed. This report is a cursory review of the entire Walnut Creek data set, from 1996 to 2008, including biological, chemical and physical constituents over both spatial and temporal scales in an effort to summarize current status and trends.

Methods

Site selection and watershed characteristics

Site selection is based on drainage area, hydrological influences (tributaries, recharge areas), land use patterns and accessibility. Data in this report reflects four mainstem reaches of Walnut Creek, including the intervening drainage areas upstream of each of the mainstem sites (WLN sites) and one reach on the major tributary, Wells Branch (WLS site). Generally speaking, there are three sites in the upper section of the watershed, representing the Central Texas Plateau ecoregion, and 2 sites in the lower section of the watershed, representing the transition to the Blackland Prairie ecoregion (Figure 1). Although we have sporadically collected data at other locations in the watershed, these are the sites with the most robust and longest period of record and are the focus of this report.

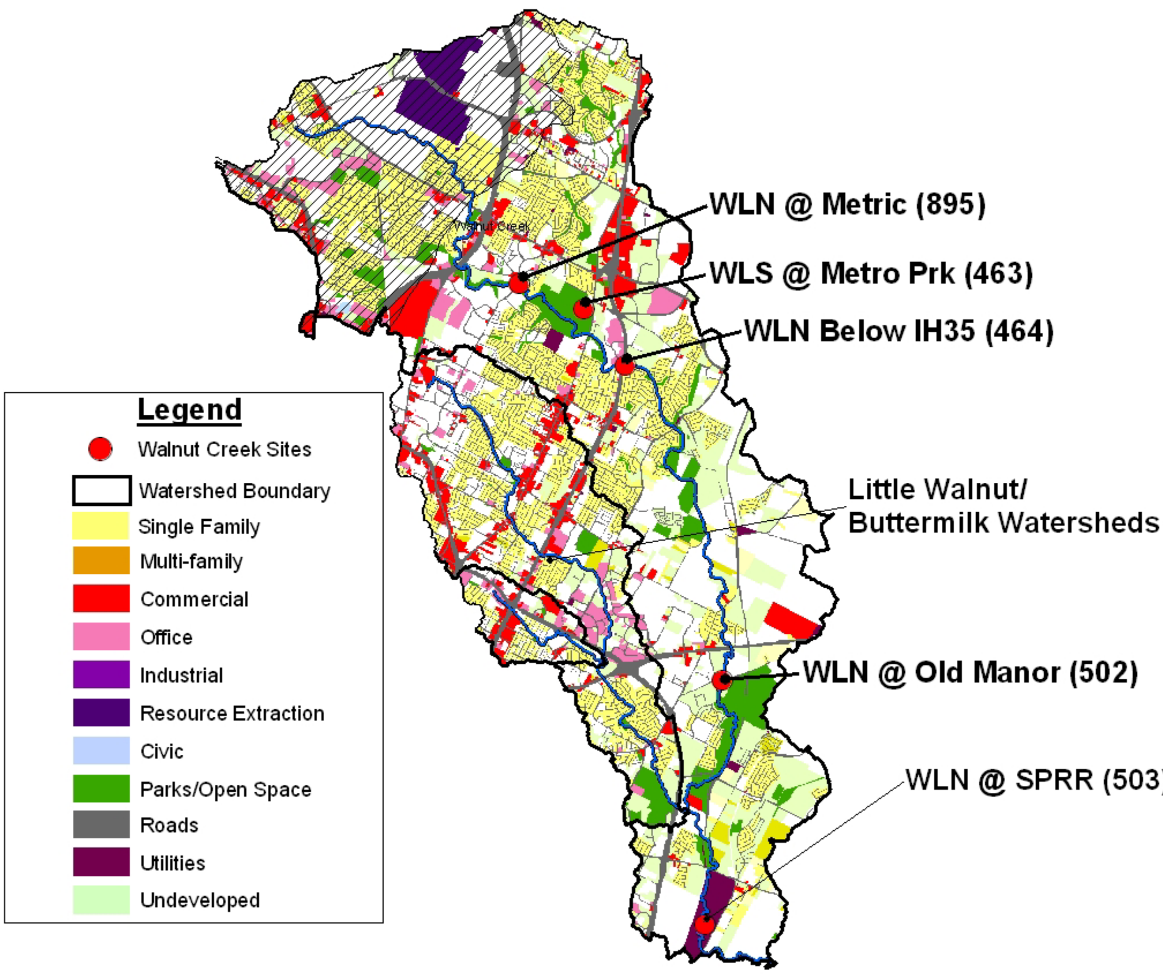
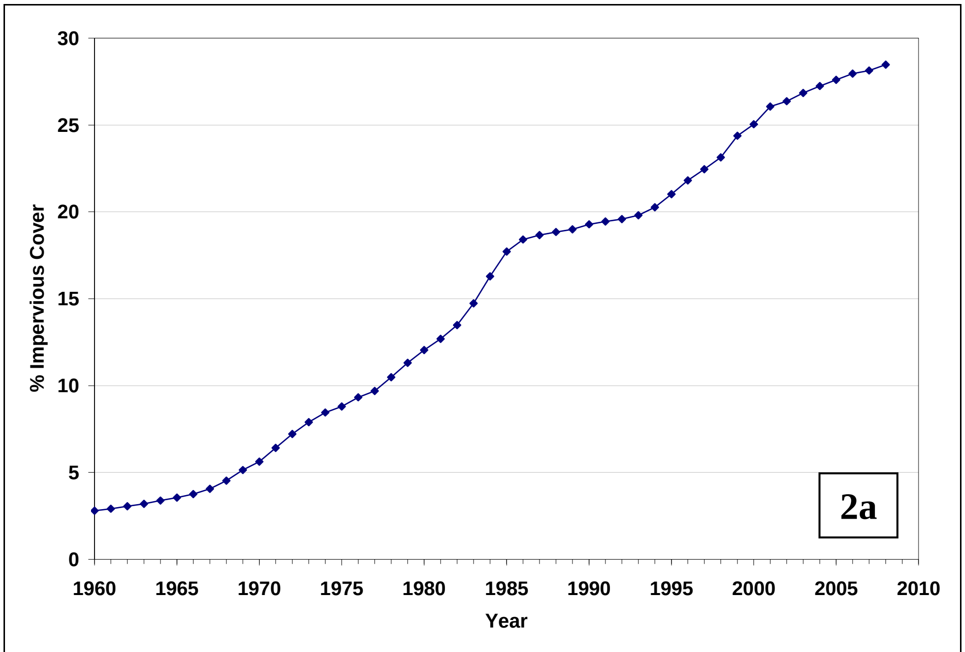


Figure 1. Walnut Creek watershed land use (2006) and 5 study sites assessed in this report. The Little Walnut Creek and Buttermilk watersheds are also shown for reference purposes. The Northern Edwards Aquifer recharge zone is shown in cross-hatch.

Walnut Creek at Metric Boulevard (WLN@Metric) is at the downstream end of the densest residential development in the watershed but has relatively perennial flow due to ground water inputs down-gradient from the Northern Edwards recharge zone (cross-hatch). Total impervious cover in this upper reach, calculated from 2006 land use estimates, is 32%. The Wells Branch tributary of Walnut (WLS @ Metro Park) drains older residential and commercial development along I35 and is typical of Central Texas Plateau geology and ecology, with abundant limestone and clear water. Total impervious cover at this site is 38%. Walnut at U.S. Interstate 35 (WLN@I35) is just downstream from a large metropolitan park and is essentially the dividing line between the Central Texas Plateau and Blackland Prairie ecoregions and has a reach impervious cover of 33%. The next site, traveling downstream, Walnut at Old Manor Road (WLN@Old Manor) represents the least developed stretch of the watershed as land use shifts from residential to rural/agricultural with large sections of undeveloped land. Impervious cover in this reach is the lowest, at 14%. The farthest downstream site, Walnut at Sewage Plant Rail Road (WLN@SPRR) is approximately 1.5 miles from Walnut's confluence with the Colorado River, but is the last accessible location. It represents the accumulation of the entire watershed drainage area, including the large and heavily urbanized Little Walnut tributary. Impervious cover in this lower, relatively undeveloped reach is only 16%, while cumulative watershed impervious cover at this mouth site is 26%

Land use in the watershed (Fig. 1) is currently dominated by single family residential (22 %), followed by transportation (17%), undeveloped land (13%), agricultural and industrial (both 11%), and a mix of multifamily, commercial, parkland, civic and office (all <7%). Urban development generally occurred first in the northern or upper section of the watershed as Austin growth moved North in the 1960's, culminating in a total watershed impervious cover of 28.5% in 2008 (Fig 2a). Development has generally been more dense and grown faster in the northern part of the watershed (WLN@Metric, WLS@Metro Park and WLN@I35), increasing from approximately 20% to 35% impervious cover during our study period, versus the lower part of the watershed (WLN@Old Manor, WLN@SPRR) which went from about 10 to 15% impervious cover over the same period(Fig. 2b).



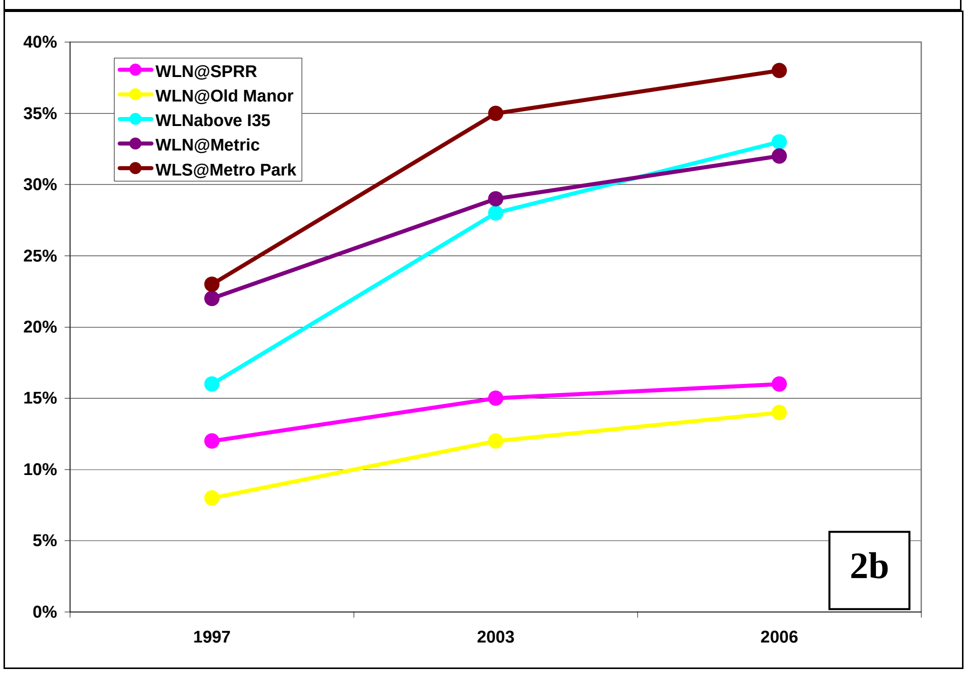


Figure 2. Impervious cover changes in the Walnut watershed from 1960-2008 (2a, from Herrington, 2010) and at each Walnut study reach during our study period (2b).

Since about 1986, when the Comprehensive Watershed Ordinance was adopted, environmental protection became more rigorous and regulated, with a proliferation of water quality controls for new commercial and residential development (Fig 3), resulting in 45% of the development in the Walnut watershed being treated by some kind of control structure by 2008 (about 9,000 acres of development treated).

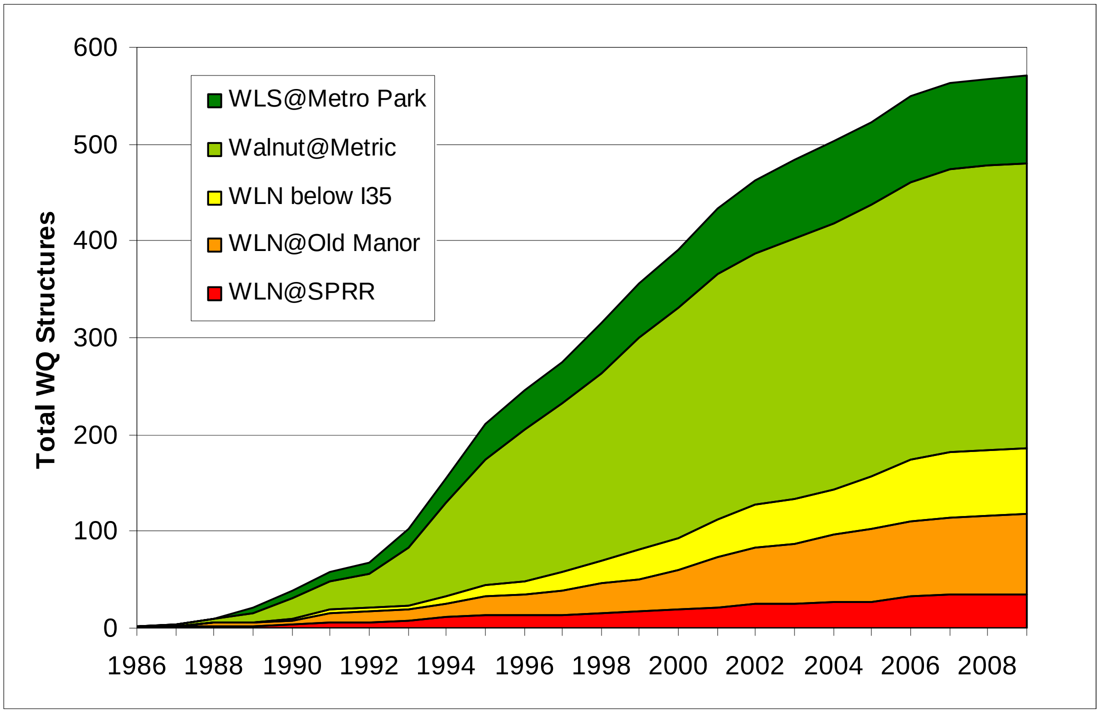


Figure 3. Increase in number of water quality structures (sand filters, ponds) installed in each of the study reaches on Walnut Creek since 1986, when regulations began requiring stormwater treatment.

Water Chemistry Monitoring

Water chemistry via instream grab samples was collected according to standard procedures (WRE SOP 2008) approximately 3 times per year at all sites. All lab parameters (Table 1) were analyzed by the Walnut Creek Analytical Lab Services through 2005 and then the Lower Colorado River Authority Environmental Lab from 2005 to the present. Both labs were EPA/NELAC certified. In addition to site samples, replicates, splits and blank samples were collected to assess both field and lab accuracy and precision. Although quality assurance data will not be presented or assessed in this report, all data included in this analysis complied with City of Austin quality assurance objectives (WRE SOP section 3.4) and generally followed the States (TCEQ) guidance on Quality Assurance Project Plans (QAPPs). Field parameters were measured at all site visits using a multi-probe (Hydrolab Datasonde) and included dissolved oxygen (mg/l), temperature(ºC), Conductivity (µS/cm), and pH (standard units).

Table 1. Laboratory and field constituents sampled during periodic water chemistry surveys at five Walnut Creek sites.

Laboratory Analysis	**Field Measurements**
Nitrate + Nitrite (mg/l)	Flow (cfs)
Ammonia (mg/l)	Temp (ºC)
Orthophosphorus (mg/l)	pH (St. Units)
Total Suspended Solids (mg/l)	Conductivity (uS/cm)
E. Coli Bacteria (mpn/100ml)	Dissolved Oxygen (mg/l)

Biological Monitoring

Standard rapid bioassessment methods, Level III (WRE SOP 2010 section 5.3, Barbour et al. 1999) were followed in the collection and processing of benthic macroinvertebrate community samples with the following exceptions:

- All organisms were sorted and preserved in the field, as opposed to the laboratory.

- Samples were generally sorted in their entirety, as opposed to sub-sampling to a fixed-count.
- High abundance samples (>1000 organisms) were subsampled using a Caton subsampler.
- Surber samplers (0.1 m^2, 500um mesh net) were used instead of $1m^2$ kick nets.

Three replicate surbers were collected from each riffle, composited and sorted in the field. Organisms from each sample were enumerated and identified to the lowest practicable taxonomic unit, usually genus, by City of Austin taxonomists using the keys of Merritt and Cummins (2008), Wiggins (1996), Epler (1996), Thorp and Covich (1991), Pennak (1989) and Berner & Pescador (1988). The following groups were not identified to genus: Chironomidae, Ostrocoda, Hydracarina, Hirudinea, and Oligochaeta.

Diatoms are single celled algae that have been shown to be an excellent indicator of environmental health due to their predictable response to a variety of anthropogenic stressors. Routine diatom collections are sampled from periphyton from rocks (epilithon) in the same study riffle that benthic macroinvertebrates are collected using standard field procedures (WRE SOP 2010 section 5.4). Generally, three rocks are collected from the study riffle, scraped clean of periphyton using a stainless steel bristle brush, composited and preserved with formalin. Collected periphyton samples are processed and diatoms were enumerated and identified to the species level by B. Winsborough. All benthic macroinvertebrate and diatom counts were tabulated and used to calculate uni-variate metrics (WRE SOP 2010 Section 9.7, 9.8) to assess spatial and temporal patterns.

Habitat Monitoring

Physical characterization of the stream sites, including riffle, reach and instream cover assessment was completed three times, in 2005, 2006 and 2007, using a modified version of the EMAP habitat assessment method (WRE SOP 2008). In addition, during each benthic macroinvertebrate survey, the EPA RBP visual Habitat Quality Index sheet was used to generally inventory habit quality (Barbour et al. 1999). Both of these data sets are used to compare overall habitat quality and spatial differences among sites in the interpretation of the biological data.

Analysis

Most analysis in this report focuses on the four mainstem Walnut Creek sites (excluding the Wells Branch Tributary), due to the longer and more comprehensive data sets at these sites. If clear spatial differences or temporal trends were noted at this site, they are reported in the appropriate sections.

The most recent City of Austin's Environmental Integrity Index (EII) score was calculated for each watershed in Austin. The EII score is a combination of a water quality, sediment, contact recreation, non-contact recreation, physical integrity, aquatic life, algae cover, benthic macroinvertebrate, diatom, and fish scores. Watersheds are not sampled for EII every year. Thus years that the scores were calculated for ranged from 2006 to 2008 depending on the watershed. Scores were ranked, compared between watersheds, and placed in categories. EII scores range from 0 to 100 and are grouped in the following categories:

0-12.5 = Very Bad	12.6-25 = Bad	25.1-37.5 = Poor	37.6-50 = Marginal
50.1-62.5 = Fair	62.6-75 = Good	75.1-87.5 = Very Good	87.6-100 = Excellent

The most recent overall watershed EII score was graphed for all watersheds. The EII sediment score for Walnut Creek was plotted over time.

Spatial analysis was performed on water quality data, benthic macroinvertebrate metrics, and diatom metrics from samples collected beginning in 1996 to 2008 on Walnut Creek. Water quality parameters included nutrients, *E. coli*, and field measurements. Benthic macroinvertebrate metrics included number of taxa, number of diptera taxa, number of ephemeroptera taxa, number of ept taxa, number of intolerant taxa, percent dominance (top 3 taxa), hilsenhoff biotic index, percent of total as chironomidae, percent of total as elmidae, percent of total as ept, percent of total as collector/gatherer, percent of total as predator, percent of total as filterers, percent of total as grazers, ratio of intolerant to tolerant organisms, percent of total as tolerant organisms, and TCEQ qualitative aquatic life use score. Diatom metrics included number of taxa, pollution tolerance index, cymbella richness, percent motile taxa, and percent similarity to a reference condition.

The distribution of water quality, benthic macroinvertebrate, and diatom data was checked for normality by the Shapiro-Wilk test in SAS. Analysis of Variance was carried out on the parameters with a normal distribution while a Kruskal-Wallis test was performed on the non-normally distributed parameters to examine whether or not a difference existed between sites for a given parameter. To examine which sites were significantly different for each parameter a Tukey-HSD multiple comparison test was performed on parameters where a significant difference existed according to an ANOVA. The minimum p-value multiple comparison test was performed on parameters where a significant difference existed according to a Kruskal-Wallis test. All alpha levels were set to 0.05 for this analysis.

The water quality, benthic macroinvertebrate, and diatom data was analyzed for temporal trends from 1996 to 2008. The same parameters that were analyzed in the spatial analysis were analyzed for temporal trends. Parameter data that was normally distributed was analyzed using least-squares regression with the PROC REG procedure in SAS, while data that was non-normal was ranked first and then analyzed using general linear regression using the PROC GLM procedure in SAS. Water quality data that contained values below detection level were analyzed using Cox's proportional hazards regression in SAS using the PROC PHREG procedure. Alpha levels were set to 0.1 for temporal analysis. Only significant trends were presented in this report.

Intensive habitat surveys included 5 transects at each site that measured bank stability, vegetative protection, channel alteration, flow within the channel, embeddedness, epifaunal substrate, frequency of riffles, riparian zone width, sediment deposition, and the number of velocity/depth categories. Habitat data was compiled and placed into a matrix to calculate the Habitat Quality Index (HQI) for each site. A Kruskal-Wallis test was used to examine the difference between sites in HQI score. The minimum p-value multiple comparison test was used to determine which sites had significantly different HQI scores.

Results

General

The Walnut Creek watershed scored in the 78th percentile when compared to all other Austin-area watersheds in our most recent Environmental Integrity Index (EII) survey. With an overall score of 72 out of 100, it fell below 10 other watersheds (Figure 4). In four EII surveys over the past 12 years, Walnut has consistently scored in the "Good" category range (62.5-75), the highest score being 76 in 2000 and the lowest being 67 in 1996. These scores are a robust measure of overall environmental health, incorporating aquatic biology, water chemistry, sediment chemistry, habitat, and contact/non-contact recreation measures (COA-EII Methods, 1998).

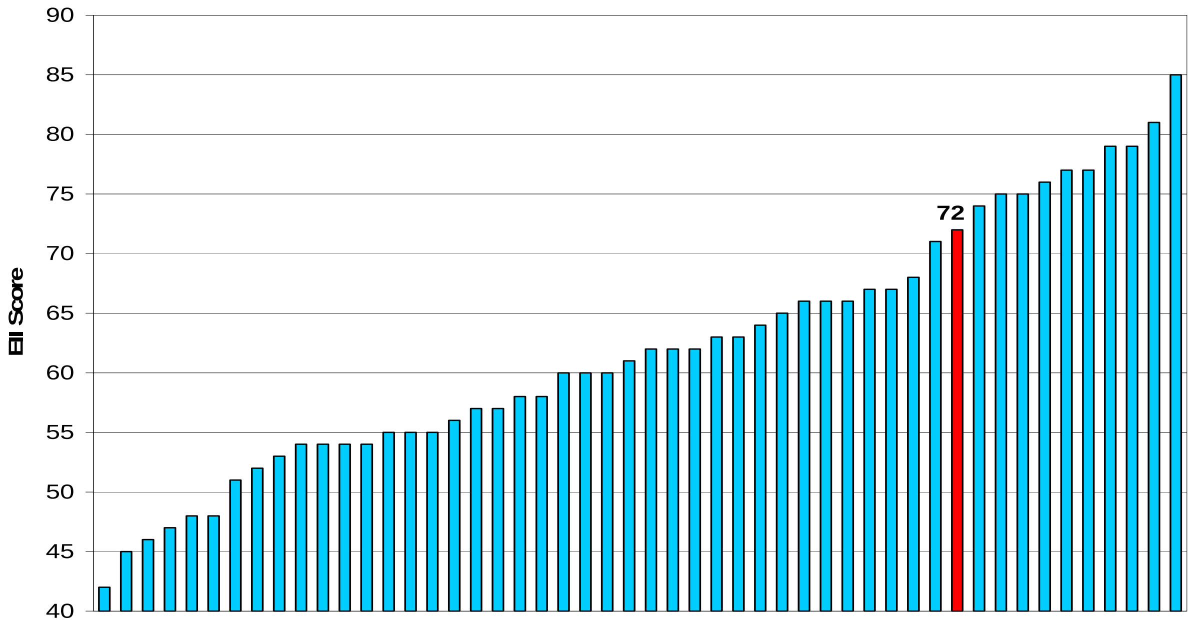


Figure 4. Overall EII scores from most recent surveys for all 50 monitored watersheds, with Walnut Creek score indicated in red.

The EII sediment score is a more specific, but also robust measure of watershed health that combines a wide range of chemical constituents (24) that accumulate from the entire watershed drainage area. Walnut sediment scores have remained in at least the "Very Good" category during all four EII surveys, with the 2000 data scoring in the "Excellent" category (Figure 5). . These scores reflect the long term accumulation of pollutants that cling to sediments (metals, polycyclic aromatic hydrocarbons and herbicides/pesticides) that can be significant stressors to aquatic life and tend to increase with increasing levels of urbanization.

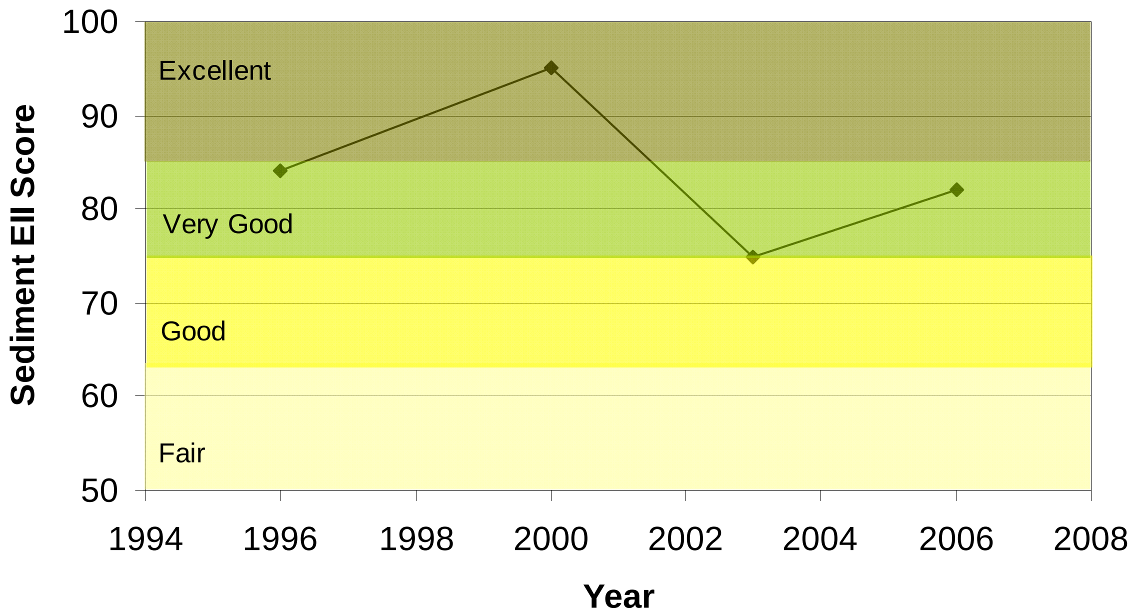


Figure 5. Sediment EII score for the Walnut Creek watershed for the four survey years, 1996, 2000, 2003 and 2006.

Water Chemistry

Spatial

The 12 year water chemistry data set shows very little significant difference among the four mainstem study sites (not including the Wells Branch tributary). Most parameters showed no difference among sites, but there were some general spatial patterns that emerged (Figure 6). As would be expected, flow increased from upstream to downstream (A), going from a mean of about 3 cfs at the upstream site (Metric Blvd) to a mean of 9 cfs at the downstream site (SP Railroad). The SP Railroad site was the only one with a significantly higher mean among the other sites. Conductivity was similar among sites, but the upstream site was elevated, although only significantly higher than the I35 and SP Railroad sites (B). E. coli bacteria, an indicator of contact recreation risk was much higher at the upstream Metric Blvd site than all other sites (C) and Total Suspended Solids, an indicator of erosion and fine sediment degradation, was significantly higher at the downstream SP Railroad site (D).

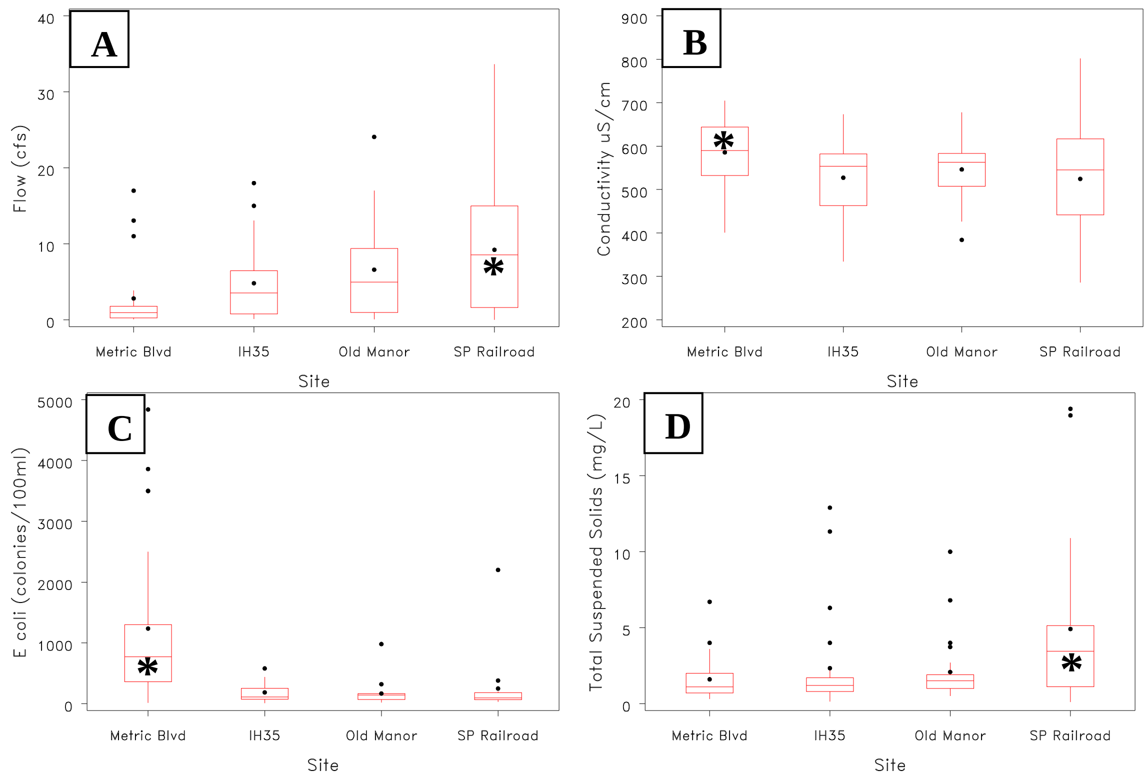


Figure 6. Examples of spatial patterns in Flow (A), Conductivity (B), E. Coli bacteria (C) and Total Suspended Solids (D) at four mainstem Walnut Study sites from upstream to downstream (left to right). An asterisk (*) indicates a site that is significantly different from the other sites.

Temporal

There were significant temporal trends in the water chemistry data among the Walnut study sites that indicate potentially important changes in the watershed. Conductivity (Figure 7) and Nitrate (Figure 8) had significant decreasing trends over time at multiple sites. In addition to these two parameters, there were also noted improvements in water chemistry measures at individual sites for orthophosphorus and phosphorus. In all, out of 11 chemistry measures, 4 showed a significant improvement over time at more than one site (Conductivity, Nitrate, Orthophosphorus and Phosphorus), 2 showed degradation over time at only one site (pH and Turbidity), and 5 showed no significant trends at any sites (Ammonia, Dissolved Oxygen, E.coli, Total Suspended Solids and Temperature). No water chemistry variables showed significant negative trends.

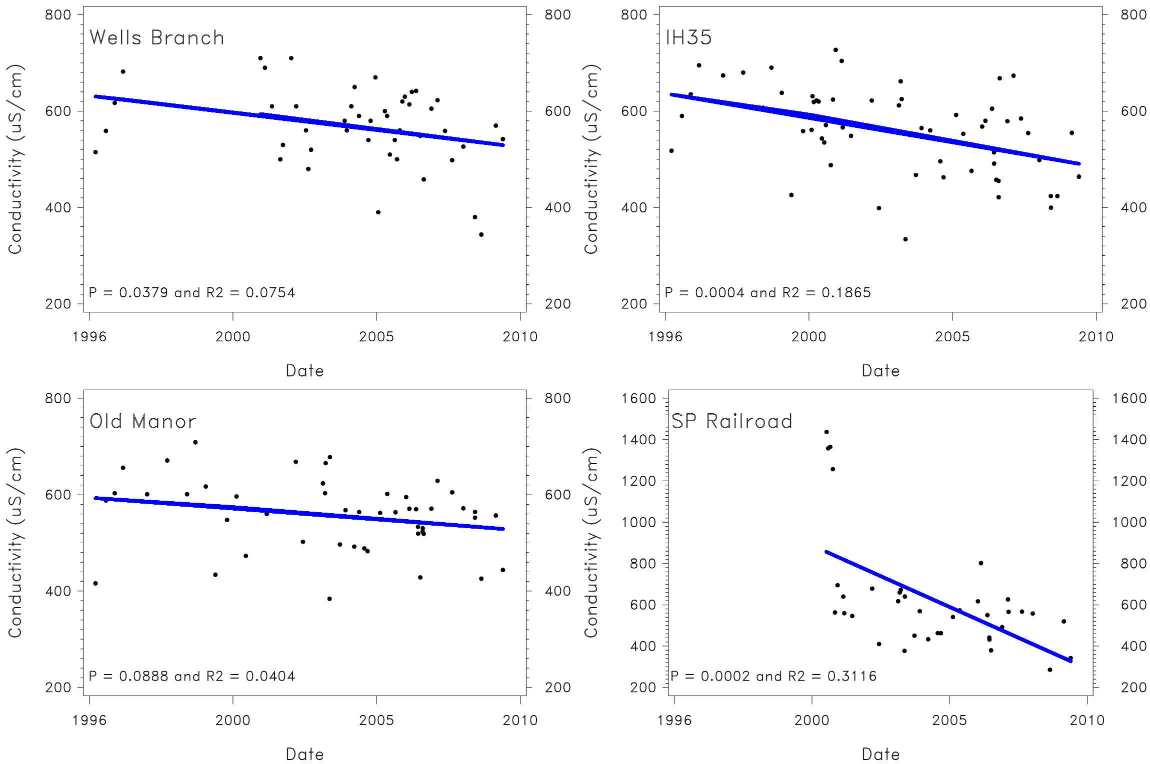


Figure 7. Examples of significant temporal patterns in conductivity at four Walnut Study sites. Alpha-level (p-value) and R^2 value are noted on each graph.

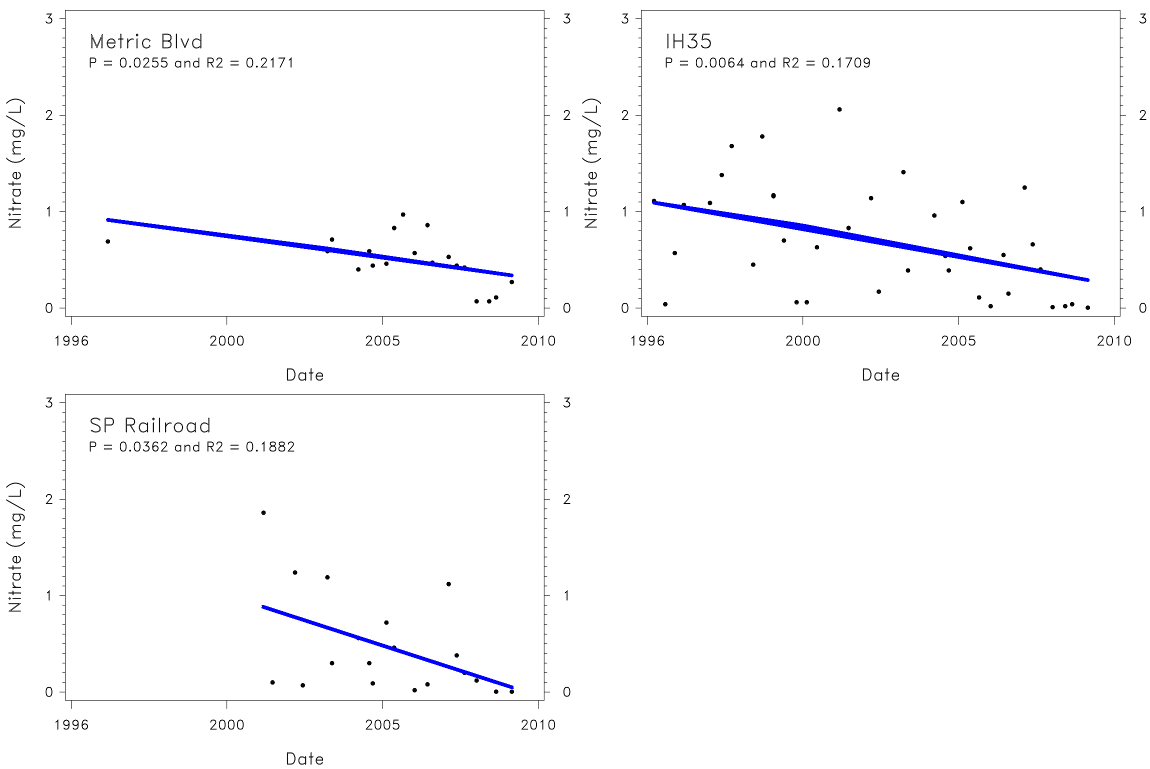


Figure 8. Examples of significant temporal patterns in Nitrate-N at three Walnut Study sites. Alpha-level (p-value) and R^2 value are noted on each graph.

Biology

Spatial
In general, similar to the water chemistry variables, the biological data did not strongly distinguish among study sites. The most notable spatial pattern on mainstem Walnut (not including the Wells Branch Trib), from an upstream to downstream direction, was degradation at the most upstream site and most downstream site compared to higher community health at the two midstream sites (Figure 9). The Hilsenhoff Biotic index measures sensitivity of the benthic macroinvertebrate community to organic enrichment, resulting in a score from 1-10, where 1 is an intolerant, low nutrient community (good) and 10 is an enriched, tolerant community (bad). In this analysis, the upstream site (Metric Blvd) had a significantly higher/worse mean score than any of the other sites (7A) while the downstream site (SP Railroad) appears to have a higher mean than the two mid-stream sites, but the difference was not significant. The ratio of Tolerant to Intolerant Organisms showed a similar pattern, where Metric and SP Railroad bridge were not different from each other, but the two midstream sites (IH35 and Old Manor) had better mean scores than the other sites (7B), indicating a higher portion of intolerant or sensitive benthic macroinvertebrates. One taxa, the riffle beetle family Elmidae, showed this same pattern very distinctly, with the upstream and downstream sites having significantly lower abundances of this organism than the two midstream sites (7C). This taxa is not known to be particularly sensitive, but does have narrow habitat tolerances which may be driven by hydrology. Only one diatom community metric, the Pollution Tolerance Index, showed significant differences among study sites (7D). This index is similar to the Hilsenhoff Biotic Index, compositing tolerance values for the entire diatom taxa list and indicating a more nutrient enriched, degraded community at the downstream site, SP Railroad.

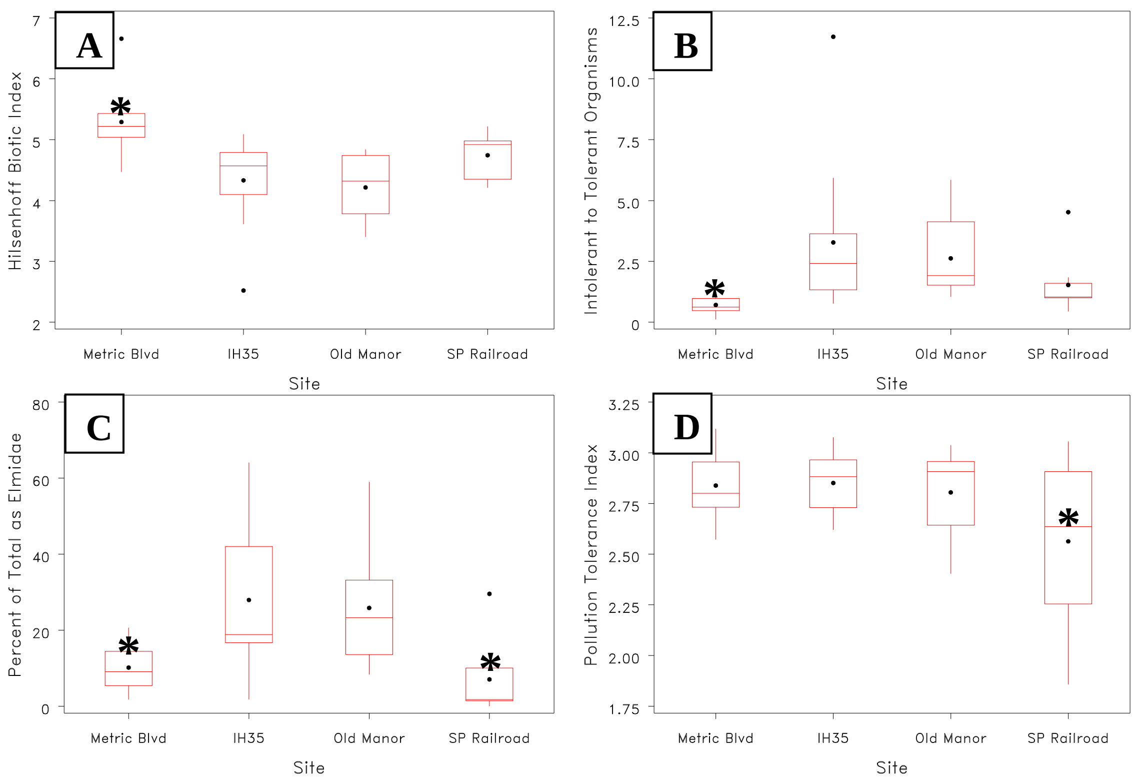


Figure 9. Examples of spatial patterns in biological metrics in the benthic macroinvertebrate (A, B, C) and diatom community (D) measures at four mainstem Walnut Study sites from upstream to downstream (left to right). An asterisk (*) indicates a site that is significantly different from the other sites.

Temporal

Out of the 22 biological measures evaluated at the four mainstem study sites, (17 benthic macroinvertebrate and 5 diatom metrics), 8 were significant (6 benthic macroinvertebrate measures, 2 diatom measures), all showing improvements over time for at least one study site. In general, there was a mix of different measures with significant trends at different sites from either the benthic macroinvertebrate community or the diatom community. However, some were relatively consistent watershed wide. The Hilsenhoff Biotic Index showed significant improvement over the study period at three of the four mainstem sites, starting at I35 and including all downstream sites (Figure 10). Other measures that are important, and showed significant improvement over time, but were not consistent among sites were: Number of Taxa at Metric Blvd, Percent Dominance (3 taxa) at Wells Branch, Number of Intolerant Taxa at I35 and the diatom Pollution Tolerance Index and the diatom Percent Motile both at I35.

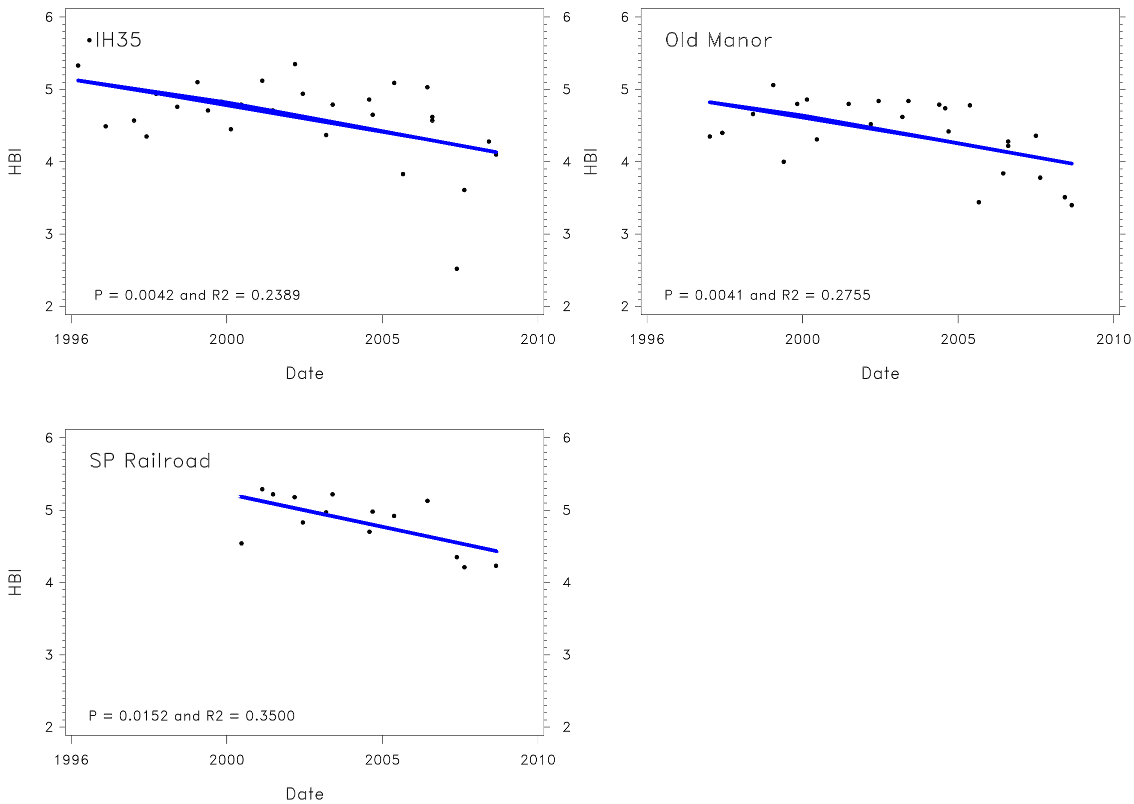


Figure 10. Examples of significant temporal patterns in the Hilsenhoff Biotic Index, all increasing in community health over time, at three Walnut Study sites. Alpha-level (p-value) and R^2 value are noted on each graph.

Habitat

Spatial

The visually-based Habitat Quality Index (Barbour et al. 1999) was used during biological surveys to assess general habitat quality, including in-channel, bank and riparian measures. The general pattern of habitat quality on Walnut creek was a decrease from upstream to downstream, with the Wells Branch Tributary (WLS@Metro Park) having the highest scoring reach followed by the most upstream Walnut site (WLN@Metric) and then decreasing at the downstream sites (Fig. 11). However, the only significant difference among these sites was that the two downstream sites (WLN@Old Manor, WLN@SPRR) scored lower than the three upstream sites. In general, they all fell within the sub-optimal range in the EPA scoring system.

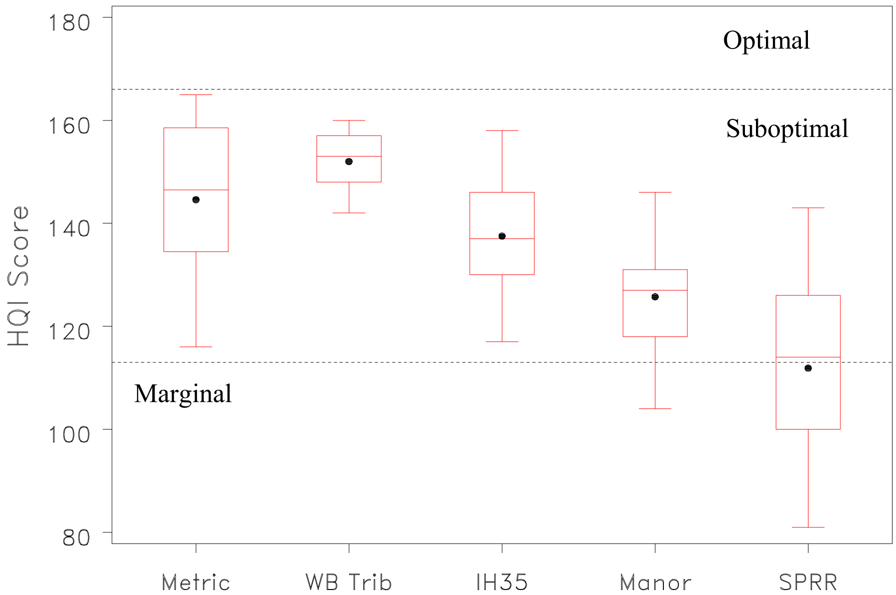


Figure 11. Distribution of HQI scores among 5 Walnut creek study sites, collected between 1996 and 2008. Box plots show mean (dot), Median (center line), quartiles (box) and range (whiskers) of all data for each site. Manor and SPRR sites are significantly different from Metric, WBTrib and IH35.

In addition to the HQI, quantitative habitat surveys were conducted three times in 2005-2008 to understand spatial variation among study sites and for interpretation of biological data. In general, habitat physical measures were predictably different from upstream headwater conditions at Walnut @ Metric to larger channel conditions toward the mouth, at Walnut@SPRR. Canopy coverage was high upstream (86% at Walnut @ Metric) and got progressively lower as drainage area increased (16% at Walnut @ SPRR). Bed substrate size, as measured using a 100 point pebble count, generally decreased from upstream to downstream, with small cobble (65-128mm)) dominating at the upstream sites (Walnut @ Metric, Walnut @ I35), coarse gravel (33-45mm) dominant at the midstream site (Walnut @ Old Manor) and finally sand (<2mm) dominant at the mouth site (Walnut @ SPRR). Instream cover, including woody debris, roots, undercut banks and aquatic vegetation, was highest at the upstream site (Walnut @ Metric) with about 30% total cover, while all the downstream sites had about 20% cover of aquatic habitat. Reach length at the study sites was established based on bankfull width (20 x Bankfull width) and increased predictably from upstream to downstream, going from 385 ft at Walnut @ Metric up to 1200 ft at Walnut @ SPRR . Stream habitat type was fairly consistent among study sites, with all sites having 2-3 each of riffle, run and pool habitats per site reach with the exception of the most downstream site, Walnut @ SPRR, which had 5 riffles, 3 runs and 4 pools in the study reach.

Discussion

Walnut Creek sites showed only minimal differences among them for our study variables. Water chemistry along Walnut Creek does not change very much, apart from higher E. coli bacteria levels at the most upstream site. Other physico-chemical differences can be accounted for by drainage area and the geologic changes that occur as Walnut goes from the Central Texas Plateau ecoregion and the Northern Edwards Aquifer recharge zone into the Blacklands Prairie ecoregion. Examples of this are increases in flow volume, increases in total suspended solids, and decreases in substrate particle sizes from upstream to downstream. Within the biological data, there is evidence that the headwaters and the mouth site are in worse shape than the middle two sites. This corresponds with density of development in the upper portion of the watershed, and the negative influence of heavily urbanized Little Walnut Creek, that enters Walnut mainstem above the mouth site. The two middle sites, particularly Old Manor, benefit from large riparian areas that are relatively intact and park and preserve land that is undeveloped, thus providing some area for "recovery". This is an interesting pattern to note and worth keeping track of as development continues over the next 10 years.

Over our study period, we have documented some small but interesting trends. Water chemistry is not degrading over time at any sites, and for several measures, including conductivity, nitrates and phosphorus, we have observed significant improvement, or decreases in concentrations, at multiple sites during our study period. A similar pattern was observed in the biological measures, which in general, are a more robust measure of overall stream health. None of the indexed benthic macroinvertebrate or diatom metrics showed significant degradation over time, and several showed improvement over time at various sites. The Hilsenhoff Biotic Index, which is a measure of tolerance of the benthic macroinvertebrate community to organic enrichment, showed significant improvement at three sites.

These patterns of increased stream health over time are the opposite of what would be expected, considering the increased development and impervious cover that have occurred in this watershed during our study period (Fig 2). There are a couple possible explanations for this, but no clear answer. Walnut Creek was developed fairly intensely during the 70's and 80's (Fig 2a), and from analysis of flow and impervious cover, there was apparently a threshold hydrologic response (degradation) to that development that shows up between 13-18% impervious cover, which occurred between 1981-1986 (Herrington, 2010). It is possible that enough time has passed that the Walnut watershed is "relaxing" into this new hydrologic regime, adjusting it's channel size and sediment distribution, and starting to recover from the more extreme stress that occurred approximately 30 years ago.

The other possible explanation, which corresponds to the above hydrologic threshold, but is not directly related, has to do with the development conditions that have been in place during our study period. As noted (Fig 3), more rigorous structural controls were implemented in Austin starting just before this study began, in the early 90's. These controls are intended to remove solid and dissolved pollutants and in some cases, detain and "shave" peak flows. Austin has been on the forefront of development of stormwater controls, and it is possible that they have, in fact, mitigated the negative effects of development in the watershed to some extent. This would be impressive if the watershed showed no degradation over this period, but the fact that it shows improvement suggests that there is something else going on, probably related to legacy stressors as discussed above.

The water quality patterns in the Walnut Creek watershed, as presented here, appear to be a complex mix of spatial and temporal factors that include the quantity and quality of development that occurred long before this study started, the stormwater and construction related best management practices that have evolved over the past 30 years, and the ecological resilience of the watershed (geologically, hydrologically, and biologically). Considering the increased development pressure that this catchment will see over the next 30 years, it is important to continue to mitigate any and all ecological stressors and protect and preserve as much open space as is feasible to maintain the currently positive trend we appear to be observing.

Recommendations

- Continue to monitor all four mainstem and the major tributary (Wells Branch) sites using the Environmental Integrity Index, on a biannual basis to evaluate long term trends and keep track of locally important spatial variation.
- Perform a special study to identify and remove the source of E. coli bacteria to the upstream site (WLN@Metric).
- Perform comprehensive riparian integrity study using the Index of Riparian Integrity to evaluate apparent recovery phenomenon at mid-watershed sites (WLN@I35 and WLN@Old Manor).

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