ASSESSMENT OF URBAN STREAMS IN FAIRMOUNT PARK, PHILADELPHIA, PA

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ABSTRACT: A variety of methods exist for the rapid assessment of stream reaches. They vary widely in the type of data collected, the complexity of the methods, and the conclusions that can be drawn from the results. Relying on a variety of these methods as a basis, the we developed a method to assess streams based on geomorphic, habitat and riparian features. Over 60 km of streams including 426 stream reaches were assessed during a 2 month field effort. Analysis of the data produced an overall Stream Quality Index (SQI) used to classify streams into four major categories: severely impaired, impaired, moderately impaired, and slightly or non-impaired. The SQI rating was used in conjunction with other natural resource inventory data to aid in restoration planning and overall management of the Fairmount Park System, Philadephia, PA.

INTRODUCTION

As a watershed urbanizes, the supply of water and sediment to stream channels changes dramatically (Leopold,). Peak discharges and total runoff increase as water quickly runs off paved surfaces (Schueler, 1994). Because less water infiltrates in to the ground, less water reaches the stream through the groundwater, reducing the amount of water during low flow periods (DNREC et al., 1997; Finkenbine, et al., 2000). Stream channels in urbanized areas respond to these changes in several ways. Reduced sediment supply and increased storm discharges promote erosion, increasing the width and depth of the stream (Hammer, 1972; Schueler, 1994; Sovern and Washington, 1997, Pizzuto et al., 2000). As the stream incises, or cuts deeper into the valley, the flood plain becomes progressively more isolated, the water table is lowered, and floodwaters are less able to interact with the streamside (riparian) forest ecosystem. Scour also causes reduced development of pool/riffle topography that provides important habitat features for aquatic organisms (Pizzuto et al., 2000). These changes often lead to stream instability which is characterized by abrupt, episodic, and progressive changes in the location, geometry, gradient, or pattern of a river/stream (Schueler, 1994). Unstable channels can destroy property, damage structures, reduce water quality, diminish aquatic (and terrestrial) habitat, and degrade aesthetic quality (Booth and Jackson, 1997).

In this paper we provide an overview of an urban stream assessment methodology developed for the Fairmount Park system in Philadelphia, PA. Stream reaches were characterized according to channel morphology, in-stream habitat, and riparian zone condition. Based on these measures, a Stream Quality Index (SQI) was developed that reflects the extent of urban impacts on individual stream reaches. The SQI is being used to target stream restoration and protection activities within the park. The desired end result of this effort is a system of streams and natural areas within the park that exhibits characteristics typical of less urbanized areas, and that provides healthy/diverse habitat for aquatic and terrestrial biota (Academy of Natural Sciences, 1999).

STUDY AREA

The Fairmount Park system (Figure 1) was created in 1855 to protect and buffer the City of Philadelphia's water supplies. It is the largest municipal park in the U.S. (36 km^2) and is comprised mostly of six stream valleys, containing more than 95 km of streams. In 1996, the William Penn Foundation awarded the Fairmount Park Commission a $26.6 million grant over five years to aid in the restoration and protection of the park (Goldenberg, 1999). A team of researchers headed by The Academy of Natural Sciences of Philadelphia have conducted an inventory and assessment of park natural resources, including: streams; fish; aquatic and terrestrial insects; birds; amphibians; reptiles; and vegetation communities. All data were organized in a geographic information system (GIS) to aid in determining disturbance levels within the park as well as identify areas for both stream and vegetation restoration and protection projects.

All streams assessed in this project exist in the Piedmont Province of southeastern Pennsylvania. The study reaches were all located within the Fairmount Park boundaries in Philadelphia, PA. Reference reaches were located in rural agricultural watersheds just outside Philadelphia (Pizzuto, et al., 2000). The watersheds for all the major streams within the park extended beyond both the park and city boundaries.

METHODS

The stream assessment protocol was designed to test hypotheses about what is occurring in the urban stream channels of the park as compared to rural stream channels and to help guide restoration. To accomplish these goals, a watershed level characterization and two levels of stream assessments (screening and detailed) were completed. The screening-level assessment was specifically developed to provide cursory data that could be collected for the entire length of streams within the park. These screening-level data allowed us to evaluate the condition and rank all stream lengths within the park. This was a valuable tool for prioritizing restoration activities and for educating the public. In addition, the screening-level assessment was used to identify areas or stream reaches to be included in the detailed stream surveys. The detailed assessment involved taking quantitative measures of channel morphology and sediment characteristics for 20 stream reaches in Fairmount Park. The results of the detailed surveys were used to compare the Fairmount Park channels to 16 rural reference stream reaches in southeastern PA.

Watershed Level Characterization and Mapping

The watersheds of the streams within the park were characterized by extending beyond the park boundaries to develop watershed-scale maps showing the watershed boundaries, streams, Fairmount Park boundaries, and county boundaries for each of the major streams (Schuylkill River, Wissahickon Creek, Cobbs Creek, Tacony Creek, Pennypack Creek, and Poquessing Creek). Land use percentages were calculated for each watershed using the Landsat Thematic Mapper satellite imagery from 1991, 1992, and 1993 compiled and classified by the Multi-Resolution Land Characteristics Interagency Consortium (Vogelmann et al., 1998). Understanding the watershed context of these streams was essential for assessment and restoration planning.

Screening Level Assessment

We developed a screening-level assessment to allow for rapid collection of data for all streams within the park. Over 60 km of streams including 426 reaches were sampled during the early spring of 1998. This time period was chosen as it is the best season to collect macroinvertebrates (reference) and the absence of foliage increased the ability to obtain accurate locations with the global positioning system (GPS). Reach length varied with the width of the stream and only every fifth reach along a stream was characterized unless there was an obvious change in condition or characteristics. The reach length characterized was approximately 20 times the bed width. The field team used a Trimble Pro-XR (Trimble Navigation Limited, Sunnyvale, CA) GPS unit with differential correction to accurately locate all the stream reaches for inclusion in the GIS database. The data collected during the screening level was used to classify the tributary streams into unique geomorphic types as well as identify the level of impact due to various disturbances. In particular, the condition of distinct stream reaches in terms of geomorphic condition, aquatic habitat, and riparian zone condition was assessed.

Geomorphic condition. The geomorphic classifications were based on the channel-reach morphology characteristics as described by Montgomery and Buffington (1997). Field surveys included observations of: dominant sediment size; floodplain type; bed morphology; type and presence of bars; channel form; and channel cross sectional area scaled by drainage basin area (Figure 2). Comparisons between the classification data (collected during the screening level assessment) and measured data (collected during the detailed level assessment) were first done to verify that trends indicated by the classification measures were actually reflected in the measured data. Statistically, all classification variables appeared to be reliable. The raw differences in the frequency distributions of classification data for these two sets of sites can be seen in Figure 3.

Second, a cumulative index, PCRUDS (Patrick Center Regional Urbanization Delimiter for Streams), was developed by combining and weighting the observations in the five classification variables. PCRUDS is scaled so values range from 0 to 1, with 0 reflecting large urbanization effects, and 1 reflecting no urbanization effects (Tables 1 and 2). Next, the numerical values were summed and normalized to a value of 1 by dividing by the maximum value of 4.5. These numerical values were assigned to the variables within the 5 categories based on differences seen in the detailed assessment observations for the sites in Fairmount Park and the reference sites in Chester County. Each reach was scored based on this system. The final PCRUDS number is equal to the final score multiplied by 100.

Habitat. The habitat assessment was approached from two perspectives, the physical condition of the habitat and the condition or health of benthic communities (functional habitat). For physical habitat, we used a modified version of the Environmental Protection Agency's (EPA) Rapid Bioassessment

Protocols (RBP) for Habitat Assessment (Barbour et al. 1997). The habitat function is based on the health of the benthic communities as a coarse measure of ecosystem function. We examined the biota attached to rocks, logs, and leaf packs. The rationale for assessing both physical habitat and the health of the aquatic community is that if the habitat appears near-optimal, but the function appears severely degraded, there may be other influences impairing the development of a "healthy" biota. This is important information from a restoration point of view, because habitat restoration may not improve the function of streams with very poor water quality. Both "physical habitat" and "habitat function" assessments described 8 characteristics. We summed the scores for each characteristic to provide ranking criteria. To expedite the assessment we only used the four broad physical habitat categories that Barbour (1997) proposes. However, we added a few categories to fit purposes of this study. For example, one characteristic described was "physical structures". For this characteristic, "Complex" is considered the optimal condition. However we added a category "Complex, Manmade" to the "physical structure" rating criteria and gave it a rank The rationale is that although fish might find the cover provided by shopping carts as suitable as the cover provided by a tree's roots, human debris represents a degradation of the stream. Thus we gave the "Complex, Manmade" a score intermediate to "optimal" and "sub-optimal" (Figure 4). The sum of the scores was used to rank and describe the physical condition of stream habitat.

Typically, the scores of such an assessment would be contrasted against the scores of a "typical" reference stream. However, since all our streams are within the city of Philadelphia, a suitable reference was not available. Thus, we arbitrarily ranked the streams into 4, equally sized rating categories: severely-impaired, impaired, moderately impaired, and slightly /non-impaired. Thus very low scores represent degraded systems which probably suffer both habitat and water quality degradation.

Riparian condition. The riparian zones, or streamside corridors, were assessed based on three characteristics: 1) vegetation type and condition; 2) width of vegetated corridor; and 3) level of human disturbance (Figure 5). Within each category, the riparian zone was ranked as optimal, suboptimal, marginal or poor and given an associated score. For vegetation type and condition, > 90% coverage with native, diverse vegetation was considered optimal and < 50% coverage was considered poor. The riparian assessments were also modeled after the Rapid Bioassessment Protocol for Use in Streams and Rivers (Barbour, et al., 1997).

Detailed Level Assessment

The detailed level assessment, or surveying, involved specific measures of channel morphology and sediment characteristics. The results of the detailed surveys were used to compare the highly urbanized forested stream channels of Fairmount Park to forested reference streams in less-impacted rural areas. Twenty channels in Fairmount Park were compared to 16 channels in undeveloped, rural areas of southeastern Pennsylvania. This comparison provided us with valuable information concerning the relative health and stability of the streams and helped provide goals for restoration. The detailed assessment also provided data for a paired watershed study (Pizzuto et al., 2000).

Reach lengths of from 100 to 200 meters long were surveyed using a laser level to develop a longitudinal profile and several cross sectional profiles. For the longitudinal profile, water surface and channel bottom elevations were recorded at important features such as top of pool, deep point of pool, and top of riffle along the entire reach. Typically, five cross sections were surveyed within the study reach, equally spaced along the length of the reach. The survey team chose one cross section per reach as a permanent site to allow for future surveys to assess channel change over time. Finally, the team sampled the stream substrate particle size distribution using a modification of the Wolman (1954) method (Pizzuto et al., 2000). Similar data were previously collected for rural streams in southeastern Pennsylvania by the Patrick Center of The Academy of Natural Sciences as part of a separate research study.

RESULTS

Watershed Level Characterization and Mapping

Summary information for the watershed characterization is shown in Table 3. Only two of the six parks (Cobbs and Tacony) have the majority of their watershed within the Philadelphia city boundaries. Therefore, four of the six main tributaries (Schuylkill River, Wissahickon Creek, Pennypack Creek, Poquessing Creek) are controlled largely by watershed conditions outside the park and city boundaries. As a result, assessment efforts were concentrated on smaller tributaries whose contributing watersheds existed within the park boundaries.

Screening Level Assessment

The Stream Quality Index was developed by scaling each of the scores obtained for stream geomorphology, aquatic habitat, and riparian condition to values ranging from 0 to 100. The three scaled scores were summed, resulting in a final Stream Quality Index ranging from 0 to 300 for each stream reach. The final SQI scores were grouped into four categories representing impairment caused by urbanization: severely impaired (0 to 75); impaired (76 to 150); moderately impaired (151 to 225); and slightly or non-impaired (226 to 300). Figure 6 shows the number of reaches in each impairment class for the individual SQI components as well as the total score for all the assessed reaches in the Fairmount Park system. The data indicate that 56% of the streams within the Fairmount Park system show moderate impacts due to urbanization. Only 2% show no impacts.

The three components of the SQI were also tested for correlation. Our original hypothesis was that there may be some relationships between geomorphology, habitat and riparian condition. All correlations are statistically insignificant at the α = 0.05 level. The scatter plots for each pairing are shown in Figure 7.

Detailed Level Assessment

To quantify the changes in Fairmount Park stream channels, we compared 19 channels in Fairmount Park with 16 channels in undeveloped, rural areas of southeastern Pennsylvania. The results are dramatic (Figure 8), the urbanized Fairmount Park channels are, on average, 110% wider and 80% deeper than rural channels. Bank angles of Fairmount Park channels are steeper, suggesting increased erosion and incision caused by urbanization. Only 20% of the channels of Fairmount Park have active flood plains, while 60% of the rural channels have active flood plains. 64% of the rural channels have well-developed pool/riffle topography, while only 44% of the Fairmount Park channels have well-developed pool/riffle topography. Pools in rural channels are 130% deeper than pools in Fairmount Park channels. As a result of these changes in morphology, we estimate that urbanized Fairmount Park channels can transmit an order of magnitude more water and 2 orders of magnitude more sediment at flood stage than corresponding rural channels of southeastern Pennsylvania.

As reported by Pizzuto et al. (2000), bankfull (the level of the flood plain lying along each bank) depth, reach-averaged bed slope, and median grain size are similar for these urban and rural watersheds. The urban channels are wider and have larger cross-sectional areas than corresponding rural channels. The urban channels have lower pool depths and sinuosities than rural channels. Estimated Manning's *n* values are significantly lower in urban channels than rural channels, indicating that urban channels respond to increased peak discharges by reducing resistance. Dimensionless bankfull discharges, computed using the Manning equation and scaled by drainage basin area and the acceleration of gravity, are significantly higher in urban channels than rural channels. Histograms of bed sediment size distributions in urban channels lack a secondary mode in the size range 2-64 mm characteristic of rural channels, indicating that these sizes tend to be selectively removed from urban channels. However, bankfull Shields stresses (which provide an estimate of the ability of stream flows to erode channel sediments) in urban and rural channels exceed typical threshold values at most sites, indicating significant bedload transport at bankfull stage.

These data clearly suggest that Fairmount Park channels have been strongly influenced by urban stormwater runoff. The data quantify these changes and provide useful, goals for restoration and mitigation. Restoration or enhancement of Philadelphia's streams requires an understanding of the changes in fluvial morphologic variables as well as the causal factors. The results of this study serve as an important empirical basis for restoration or rehabilitation.

DISCUSSION

The final impairment classification based on the SQI is meant to provide an overall picture and basis for comparison of the condition of streams within the Fairmount Park system. To make this comparison visually, stream quality maps were generated for the 6 assessed parks within Fairmount Park system from the overall SQI scores. For example, Figure 9 shows the maps generated for Tacony Creek Park. Most of the segments of the stream were either moderately impaired or impaired with one reach of the stream severely impaired. The maps were used in conjunction with the terrestrial habitat quality assessments (vegetation and faunal inventories) to identify areas of special interest for restoration or protection.

The next step in this project will be to further assess the relationships between geomorphology, habitat and riparian zone. Preliminary statistical analysis shows very little correlation between the indices. While we expected to see some correlation among the three parameters, there are many reasons this may not have occurred. For example, the riparian zone adjacent to most of the stream reaches is fairly well developed even though the reaches are in highly urbanized watersheds. The results we obtained indicate that the geomorphology is more strongly affected by the upstream watershed than by the local riparian condition. Similarly, habitat may be affected by factors outside the existing geomorphology and riparian zone. While there were a number of physical factors contributing to the overall habitat score, organisms sensitive to water quality were also counted and collected. Therefore, the habitat quality score could be reflecting water quality, which was not measured, in addition to physical habitat availability.

In addition, a number of issues surfaced during the field data collection. First, although the majority of the riparian zones within Fairmount Park are forested, there were a number of assessed stream reaches with grassed banks. It has been shown that the type of riparian cover, grassed or forested, effects many channel characteristics such as width (Davis-Colley, 1997; Hession et al., 2000; Trimble, 1997). In this study only forested reference reaches were used. Future research should include grassed reference reaches to remove possible sources of error from comparing rural forested reaches and grassed urban reaches. Second, bankfull height was measured as one of the geomorphology parameters during the streamwalk This is an important parameter in assessing the effects to the channel from urbanization as bankfull discharge is considered to be the channel forming and shaping flow (Leopold, 1994). However, bankfull discharge can be difficult to measure accurately (Johnson and Heil, 1996), especially in urban streams. Improved methods for the determination of bankfull height could aid in increasing the accuracy of the stream assessment.

Despite these complications, the Stream Quality Index for Fairmount Park has provided a useful measure of urbanization effects for planning and restoration efforts. The stream quality maps quickly convey the status of the stream reaches for each park and within the GIS system were easily combined with other natural resource inventory data (vegetation classification, faunal surveys, etc.). Together, this information formed the basis for master planning for the Fairmount Park system.

CONCLUSION

The desired end result of this effort is a park system of streams and natural areas that exhibits characteristics typical of less urbanized areas, and that provides healthy/diverse habitat for aquatic and terrestrial biota. The first step in this process was to conduct a park-wide natural resource inventory. The second step was to use this data to make recommendations for specific restoration and protection projects. A wide variety of restoration and protection options were considered including: protection and enhancement of high quality stream and vegetation sites; exotic control; removal of trash; bank and riparian zone stabilization and regrading; dam modification or removal; daylighting of streams; improvement/maintenance of current structures; and building of infiltration structures or berms.

Scientists of The Academy of Natural Sciences and the Fairmount Park Commission, with input from citizens groups and other stakeholders, have prioritized restoration activities and created final high priority lists for all seven major parks within the Fairmount Park system based on the natural resource inventory and stream assessments. Implementation has begun for Cobbs Creek Park and Tacony Creek Park. For these two parks, recommendations included a total of 98 sites covering about 1 sq. km of park land. Implementation for the remaining parks will take place over next few years.

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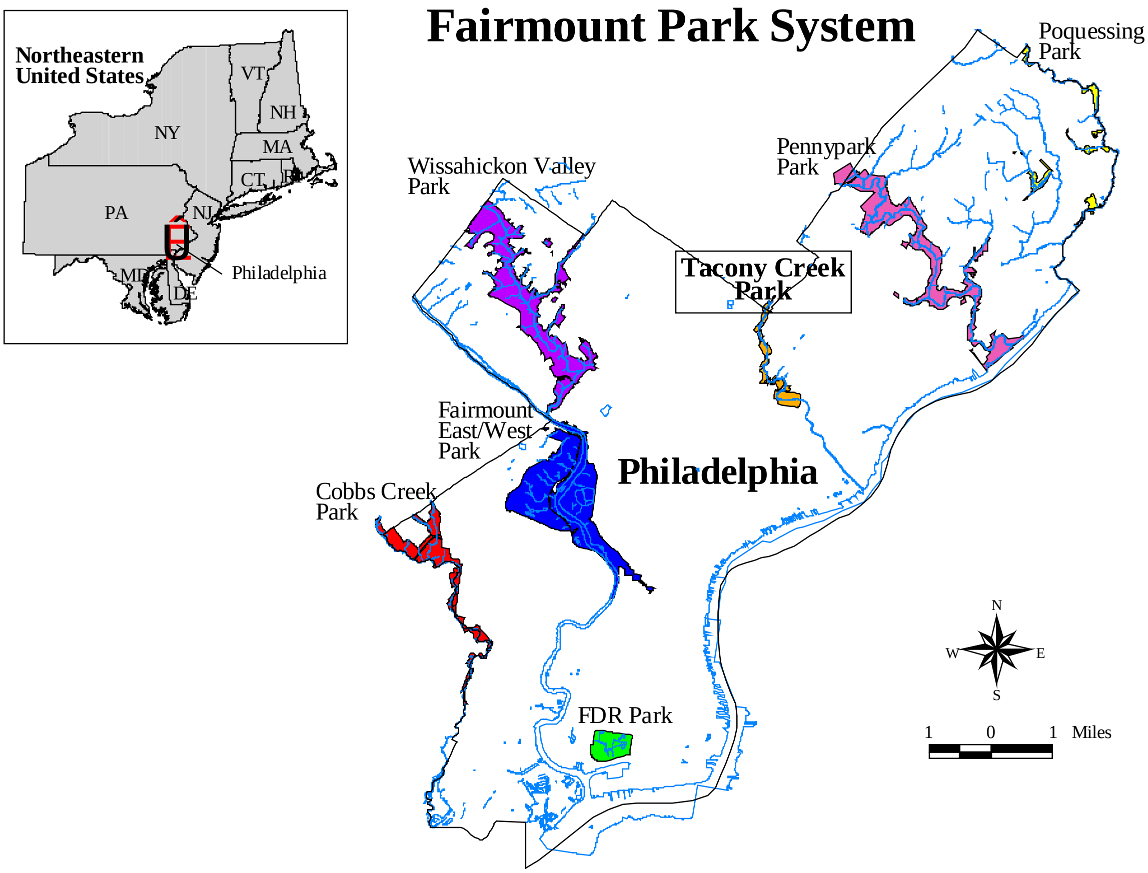

Figure 1. Fairmount Park System, Philadelphia, PA.

Streamwalk Field Notes

Trib name: ______________________ Date: __________ Picture #: ______________

Park name: __________ ID: __________ Time: __________ GPS file: ______________

Geomorphology

Bed sediment

Size: sand (<2mm) Bedrock in channel: Y/N

cobble (>64mm) Areal exposure of fines: __________ % sand/mud in bed

boulder (>256mm)

Bed morphology: cascade; step/pool; plane bed (cobble, boulder); pool/riffle; plane bed (sand)

Bed sediment storage features: alternate bars; mid-channel bars; point bars; none

Channel planform: meanders; sinuous/straight; braided; anastomosed

Floodplain classification: active; inactive(incised); anthropogenic(fill); unsure; none (colluvial/bedrock)

Width of bed: __________ Width at top of banks: __________ Height to top of banks: __________

Notes:

Figure 2. Screening level assessment field data sheet for geomorphic classification.

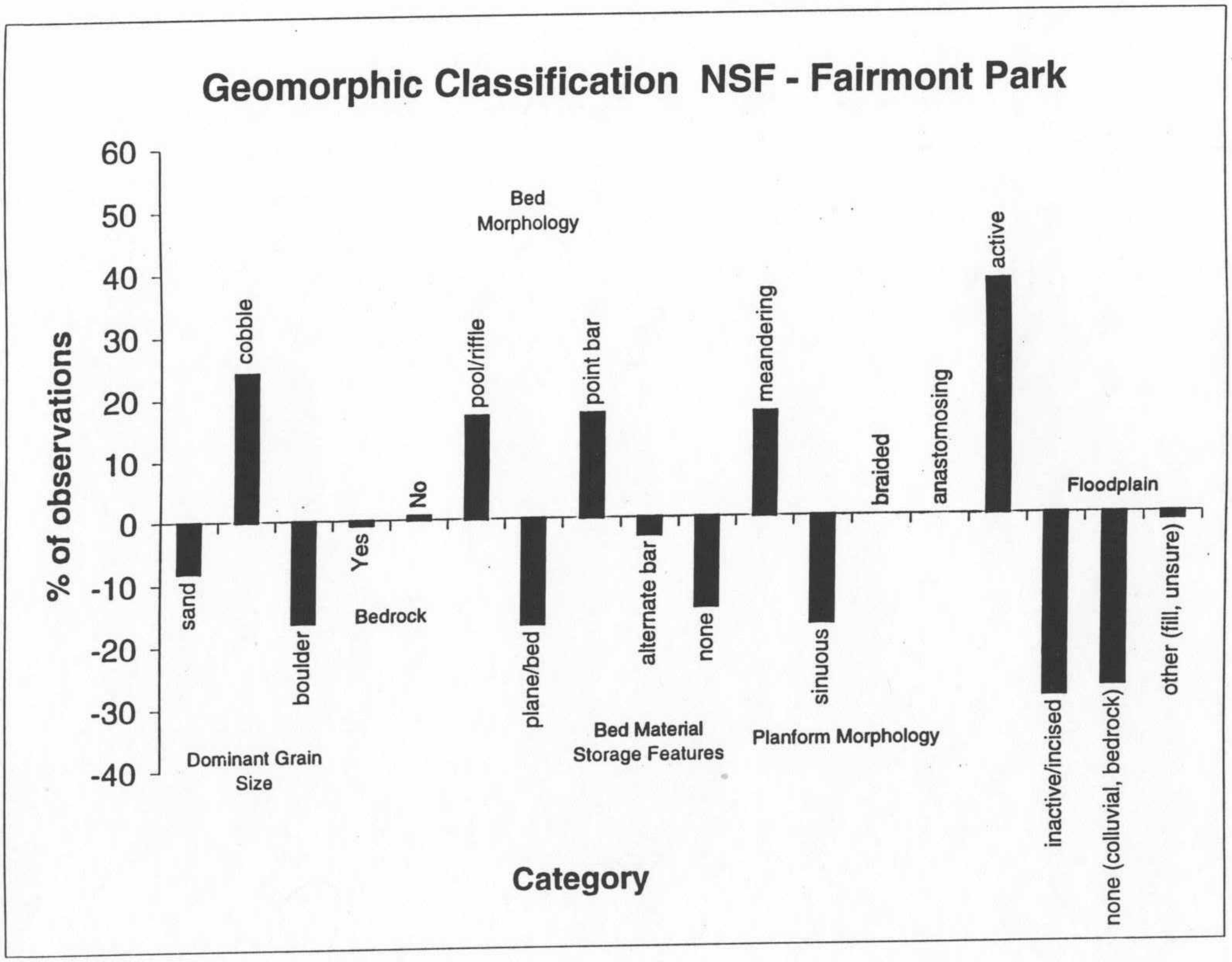

Figure 3. Raw differences in frequency distribution of classification data for Fairmount Park sites (urban) and reference sites (rural).

Table 1. Numerical values assigned to different categories in computing the PCRUDS index.

CLASSIFICATION	CATEGORY	NUMERICAL VALUE
Bed morphology	Pool/riffle	1
	Plane/bed	0
Planform morphology	Meandering	0.5
	Sinuous/Straight	0.0
Bed Material Storage Features	Point Bars	1
	Alternate Bars	1
	None	0
Flood plain	Active	1
	Inactive/incised	0.5
	Anthropogenic/fill	0
	None	1

Table 2. Numerical values and frequencies for different ranges of the dimensionless bankfull channel area (The dimensionless measure of channel size is obtained by dividing the estimated channel area by the drainage basin area).

Range of Channel Area (m^2)/ Drainage Area (mi^2)	**Numerical Value**	**# of Reference Sites In class**	**# Fairmount Park Sites In class**
0-5	1	14	2
5-10	0.8	1	6
10-20	0.5	1	5
20-50	0.3	0	5
50-100	0.1	0	2
> 100	0	0	2

	SCORE						
Physical Habitat Criteria	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Embeddedness	75-100%		50-75%		25-50%		0-25%
Channel Flow Status	very little water		25-75%		75-100%		100%
Riffles	none	other	runs only	slow		fast	complex
Riffle Quality	none	poor	marginal		suboptimal		optimal
Physical Structures (fish)	none/other	poor		moderate		complex manmade	complex
Bank Stability	poor		marginal		suboptimal		optimal
Dominant Riffle Substrata	none	gravel/ other/ snags		pebble		boulder	cobble
Portion of riffle dominated by sand/gravel	75-100%		50-75%		25-50%		0-25%

	Scores of Criteria						
Habitat Function Criteria	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Coarse Woody Debris [Amount]	None	some/few		moderate			abundant
Coarse Woody Debris [Habitat]	green	chironomids		hydropsychids		EPT	many
	no bugs	other					
	no bugs/silt						
Course Particulate Organic Material [Amount]	none		few		moderate		abundant
Course Particulate Organic Material [Processing]	no break	some break		moderate			high processing
Course Particulate Organic Material [Habitat]	no bugs	chironomids	other	tipulids	predators	EPT	many
Cobble - habitat	no bugs	chironomids	other	hydropsychids		EPT	many
Primary production - green algae	choke	filamentous	some filamentous				none patchy
Primary prodution - diatoms	none			uniform			patchy
Additional Notes:	If moss was present, the total habitat function score was increased by 1. If blue green algae were present and "patchy" the total habitat function score was decreased by 2, if "moderate" the score was decreased by 3, if "complete" the score was decreased by 5, and if "choke" the score was decreased by 7.						

Figure 4. Screening level assessment scoring data sheet for physical and functional habitat.

Streamwalk Field Notes

Trib name: ______________________ Date: __________ Picture #: __________

Park name: __________ ID: __________ Time: __________ GPS file: __________

Riparian Zone

Bank vegetation:	optimal	>90%, native, diverse
	suboptimal	70-90%, native, one class of plants missing
	marginal	50-70%, disrupted
	poor	<50%, disrupted

Streamside vegetation type: conifer; deciduous; small trees/shrubs; grasses

Width of riparian vegetation:

	LB	RB
>18m (60ft)		
12-18m (40-60ft)		
6-12m (20-40ft)		
<6m (20ft)		

Exotics present: ______________________

Disturbance level:	optimal	no human impacts
	suboptimal	minimal impacts
	marginal	large impacts
	poor	little-no riparian vegetation due to human impact

Observed: sewage lines; debris dams; trash; stormwater discharge; CSOs; sewage leakage; structures (dams, bridges, trails, buildings)

Notes:

Figure 5. Screening level assessment field data sheet for riparian classification.

Table 3. Summary of watershed characteristics for the 6 main Fairmount Park watersheds.

Park Name	Watershed Name	Watershed Size	Area in City	Area in Park	Watershed Land Cover (%)				
		(mi^2)	(%)	(%)	Urban	Grass	Forest	Agriculture	Other
East/West	Schuylkill River	1848	2	0	10%	0%	48%	39%	3%
Wissahickon	Wissahickon Creek	64	17	5	47%	4%	40%	12%	1%
Pennypack	Pennypack Creek	56	32	5	68%	6%	28%	3%	1%
Cobbs	Cobbs Creek	22	60	6	84%	7%	15%	0%	1%
Tacony	Tacony Creek	35	61	1	84%	5%	15%	0%	2%
Poquessing	Poquessing Creek	22	25	2	69%	2%	19%	10%	2%

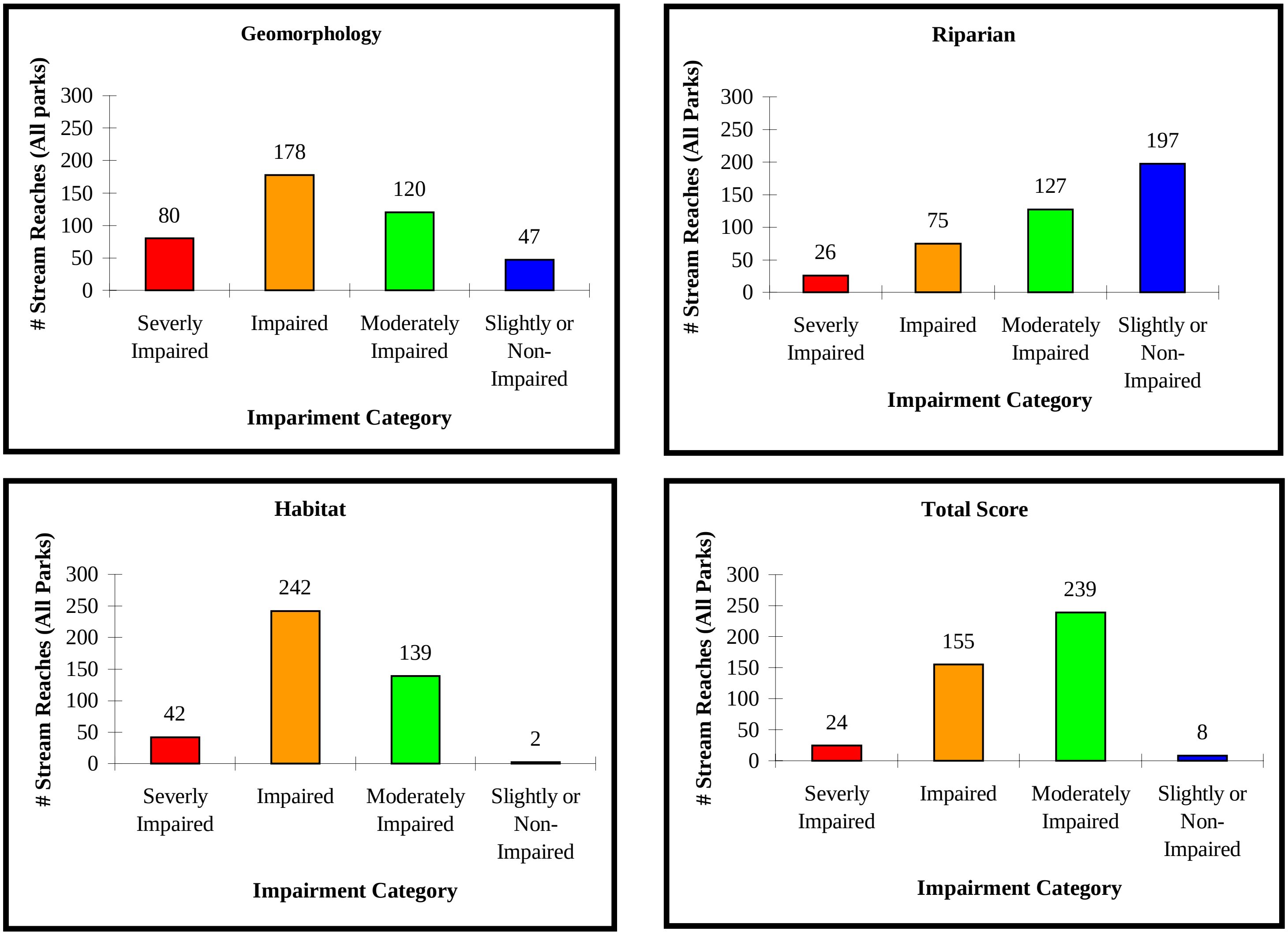

Figure 6. Number of stream reaches in each impairment category for each element of the Stream Quality Index as well as the total SQI for all the assessed stream reachs in the Fairmount Park system.

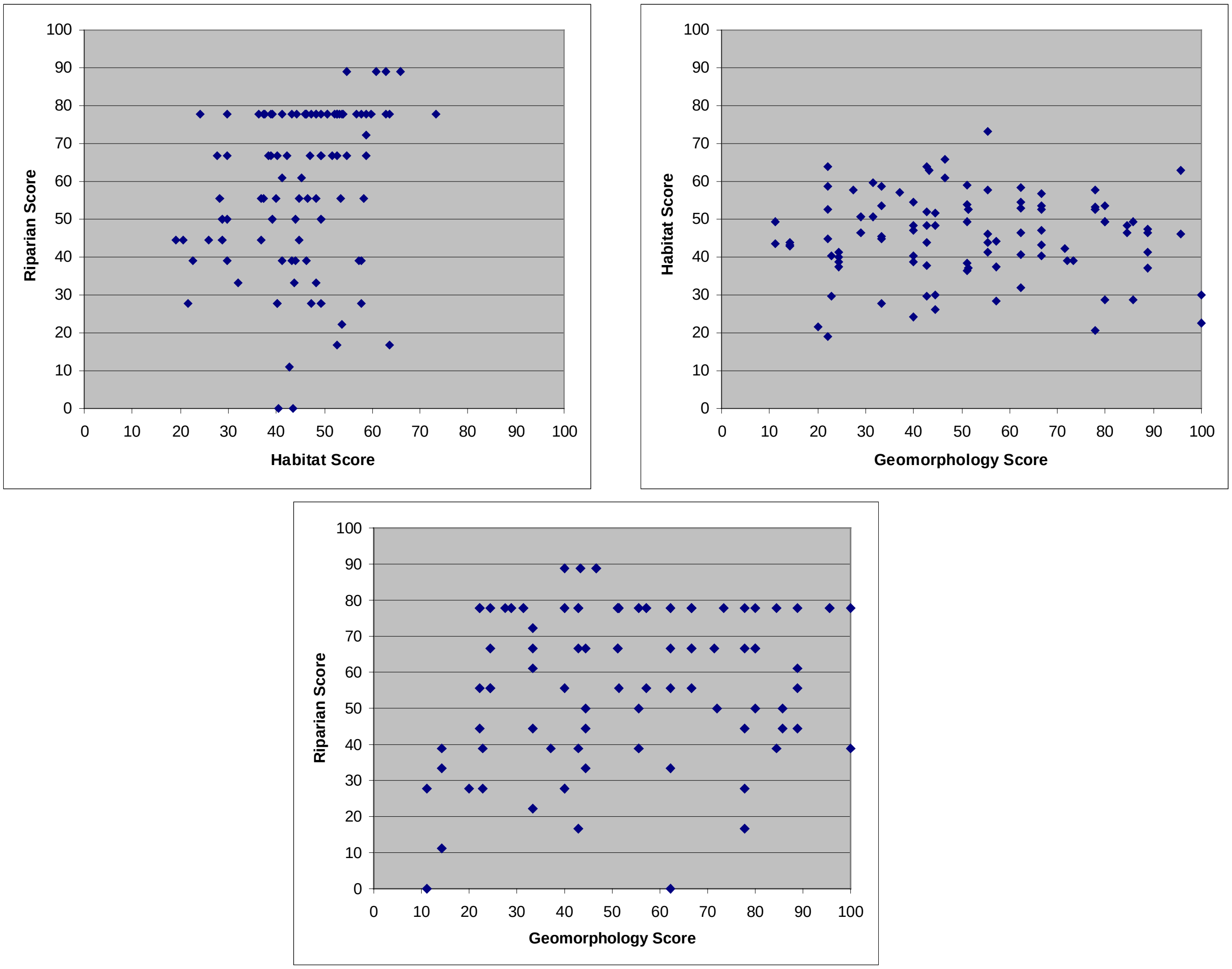

Figure 7. XY scatter plots for three assessment parameters: geomorphology, habitat, and riparian condition.
Plots show no evidence of correlation between the factors.

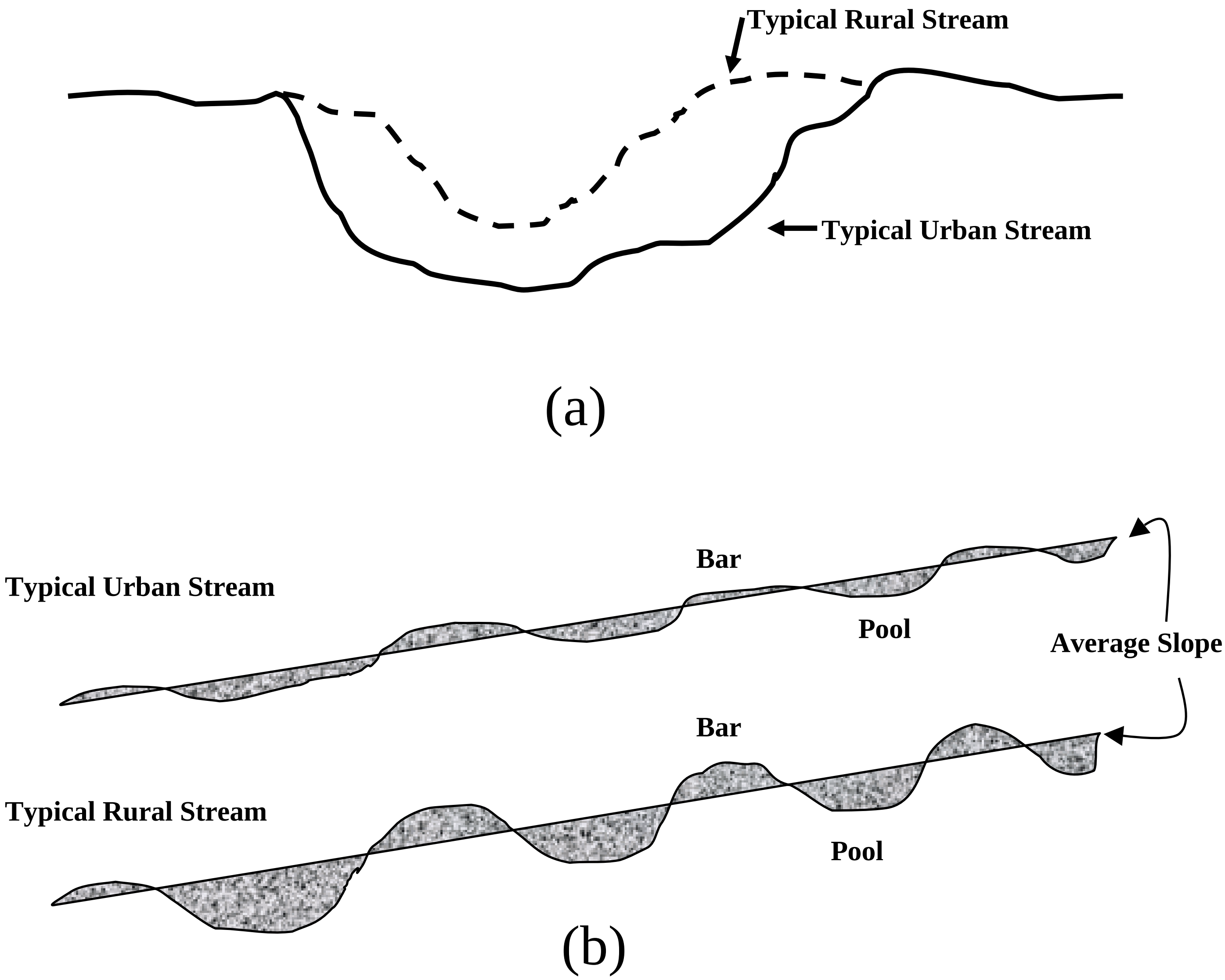

Figure 8. Differences found between typical urban and rural streams for: a) cross sectional profile and b) pool depths.

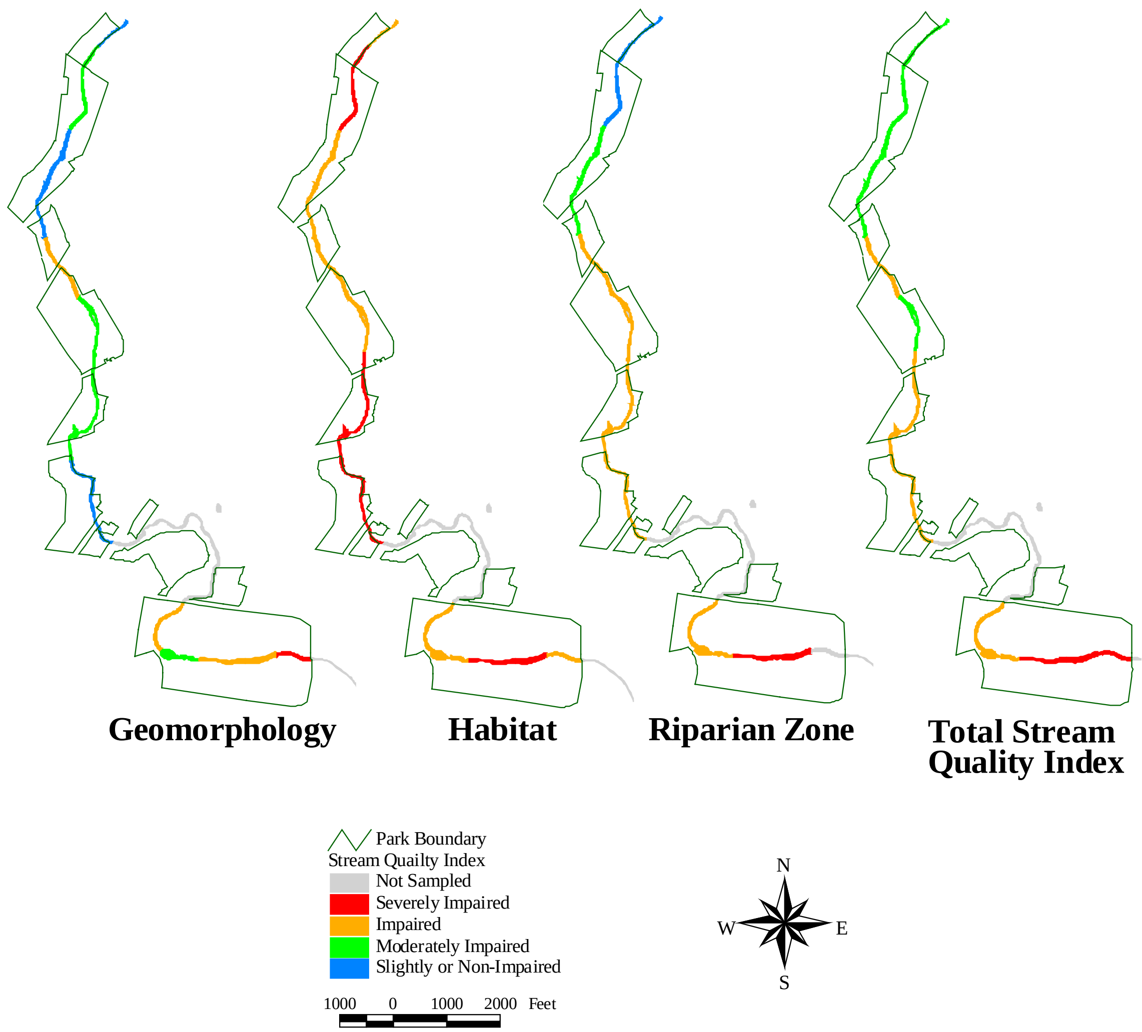

Figure 9. Stream reach classifications for Tacony Creek Park for geomorphology, habitat and riparian zone as well as the total Stream Quality Index.