Assessing Geomorphic and Habitat Metrics for Functional Lift from Urban Stream Restoration in the East Tennessee Ridge and Valley Province

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DEDICATION

To my friends, family, and peers who have provided a wealth of support and inspiration.

To my biggest support and inspiration, Chloe, thanks for always believing in me

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ABSTRACT

Urban watersheds experience a variety of ecosystem stressors including hydromodification and impaired water quality. Impacts of hydromodification include rapid geomorphic adjustment to the channel and degraded habitat which potentially can harm benthic macroinvertebrate and fish communities. Stream restoration is occasionally implemented to mitigate damage to habitats that support these communities, but often the ecological component is ignored, or design criteria is improperly implemented. Because geomorphic attributes often define habitat structure, they are a necessary component to stream condition and restoration design. However due to watershed-scale stressors impacting urban streams, ecological recovery from geomorphic-habitat restoration practices remains mixed, and the potential for functional lift not well quantified. The following research explores the degree to which functional lift is possible in restored urban streams by comparing three classifications of streams: urban impaired (UI), urban restored (UR), and ecoregion reference (ERR) sites. Because compensatory mitigation is required by the U.S. Clean Water Act for aquatic resource loss and functional lift to be quantified, this research also assess the utility of the Tennessee Stream Quantification Tool (TNSQT) from urban stream restoration by using the tool to estimate existing condition scores (ECS) among UI, UR, and ERR sites. The study assessed multiple geomorphic, channel stability, riparian corridor, and mesohabitat characteristics using many field-based metrics measurements (e.g., channel longitudinal profile, pool-riffle-bar structure, etc.); utilized existing assessment indicator tools including the Rapid Geomorphic Assessment (RGA), a modified EMAP procedure, and the Rapid Bioassessment Protocol (RBP); and applied the TNSQT. All data were assessed to quantify the departure of impaired and restored streams from the reference streams. The RGA and RBP index scores were significantly different among the three stream condition types. The RGA and RBP index scores were governed by individual metrics related to bank stability/erosion, channel incision, riparian vegetation, and sediment deposition and embeddedness. The scoring provided by the current version of the TNSQT failed to reflect any improvement between stream condition types. The findings of this portion of the study indicate that a combination of the RGA and RBP may conditionally be a better indicator of functional lift from urban stream restorations than the TNSQT.

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CHAPTER ONE

Introduction and Literature Review

INTRODUCTION

The effects of urbanization on stream ecosystems are complex and diverse. Hydromodification is a direct consequence of anthropogenic impacts on the watershed (Booth et al. 2004, Khaleghi 2017, Konrad and Booth 2005, Walsh et al. 2005) and approximately 46% of American rivers and streams are considered impaired with respect to biology (EPA 2009). A primary stressor-source for urban streams is the increase in peak flows and longer duration high flows from watershed impervious cover. Impervious cover typically comes in the forms of pavement and roads, compaction of soils, and land cleared of woody vegetation. Another contributor to hydromodification in urban streams is ineffective stormwater management and infrastructure (Burns et al. 2012, DeGasperi et al. 2009, May and Horner 2002). Increased imperviousness and ineffective stormwater infrastructure can potentially increase peak flows and runoff volumes entering streams.

Increased runoff often translates to a change in flow regime and an increase in pollutant transport. More extreme flow events relate to increased flooding, changes in sediment transport processes, and increased bank erosion and failure (Booth 1990, Meyer et al. 2005, Neller 1989, Palmer and Bernhardt 2006, Paul and Meyer 2001, Walsh et al. 2005). Hydromodification from urbanization also leads to larger cross-sectional areas (McBride and Booth 2005) and decreases in large woody debris (LWD) (Finkenbine et al. 2000). Rapid channel adjustment process affecting the physical structure results in impacts to stream physical habitat, including the embeddedness of fine soil particles instream (Wolman and Schick 1967) and deterioration of pool-riffle sequencing (Schwartz et al. 2015, Bledsoe and Watson 2001). These impacts change in water quantity and quality also negatively affect lotic biological communities (Booth et al. 2004, Grimm et al. 2005, Horner et al. 1996, Walsh et al. 2005).

To mitigate the effects of urbanization on surface waters, restoration efforts have increased in project numbers, and reach-scale design techniques have advanced (Bernhardt et al. 2005, Shields et al. 2003). Stream restorations have seen a shift in focus from solely geomorphic stabilization to more projects that incorporate ecological criteria into the design practice (Palmer and Bernhardt 2006). A continuing problem, however, is that habitat degradation from urbanization is associated with the loss of hydrologic connectivity and altered sediment transport processes that are a key function of watershed-scale processes (Konrad and Booth 2005). To this end, many problems facing stream restoration projects are that designs as described by Rosgen

(1996) focus solely on only reach-scale geomorphic metrics (Shields et al. 2003, Simon et al. 2007). Successful restoration is defined by its objectives, and typically enhancing ecological conditions are generally noted by practitioners (Alexander and Allan 2007, Bain et al. 2014, Nilsson et al. 2014, Pander and Geist 2013, Ryder and Miller 2005). Though an ecological objective may be stated, projects with a primary goal to reduce flooding, for example, may not consider finer-scale instream habitat rehabilitation (Rabeni and Jacobsen 1993, Tuttle and Wenberg 1996, Palmer et al. 2005, Kondolf et al. 2006). In addition, projects may only consider a single objective such as geomorphic stability in urban streams and assume biota will return. The "build it and they will come" assumption does not hold true if ecological principles are not incorporated into the design process (Palmer and Bernhardt 2006). Therefore, ecological objectives will likely not be achieved if they are not part of the restoration design process (Schwartz 2016).

The effectiveness of urban stream restoration projects needs more detailed investigation, primarily in the area of pre-design assessment to improve what are sustainable practices in urban watersheds subjected to hydromodification (Walsh et al. 2005). Alexander and Allen (2007), for instance, found that a small majority (53%) of projects monitored were successful, but this was largely based on reach stability and not on ecological lift, where only 11% of streams were deemed successful based on "a specific ecological indicator" (Bain et al. 2014, Selvakumar et al. 2010). Nilsson et al. (2015) found that only one of five studies produced any improvement in fish populations, and their study was restricted to brown trout only. Jungwirth et al. (1995) found that mesohabitat sequencing improvement was positively related to an increase in fish taxa richness, but Alexander and Allen (2007) found that adding riffles and flow deflectors did not improve general fish abundance. Bain et al. (2014) suggested that improvement was observed in tolerant-species only after the removal of barriers for fish passage in different parts of the Nine Mile Run project. It is possible that the variety of outcomes is due to the praxis used in design, single versus multi-species focus, and the inherent complexity of processes and interactions affecting ecosystems (Ryder and Miller 2005). Schwartz and Herricks (2007) found in a Chicago stream restoration project focused on pool-riffle habitat enhancements that fish biodiversity increased significantly but the newly recruited species were those considered tolerant of poor water quality. A consensus can be made though, in the fact that not nearly enough pre- or post-restoration monitoring is being conducted (Alexander and Allen 2007, Bain et al. 2014, Bernhardt et al. 2005, Nilsson et al. 2014). Only a few studies have been published that have focused on the combination of geomorphology, habitat, and biological integrity (Moerke et al. 2004, Schwartz and Herricks 2007, Schwartz et al. 2015).

To improve the likelihood of ecological success from urban stream restoration projects, the following must be incorporated into the assessment and design process by understanding the following: 1) ecological recovery is limited in urban streams because they cannot be returned to a pristine state, 2) watershed-scale hydrology and sediment transport processes are continuingly changing over time and space, thus hydraulic geometry concepts based on geomorphic equilibrium are not valid; and regional curve data are also not valid; 3) reach-scale modification to the riparian area, channel, and associated physical habitat cannot solve stressors caused by watershed-scale alterations, such as water quality impairment, and 4) habitat elements must designed that are sustainable, multidimensional with flow stage, and specially relate to a community of biota and their fundamental life history needs (Cluer and Thorne 2013, Palmer and Bernhardt 2006, Pander and Geist 2013, Paul and Meyer 2001, Ryder and Miller 2005, Schwartz et al. 2015, Schwartz 2016, Simon et al. 2007, Walsh et al.2005).

In general, with project design, it is first necessary to understand the ecological limits of restoration projects, and whether their net outcome justifies their implementation (Booth et al. 2004, Cluer and Thorne 2013, Palmer et al. 2005, Walsh et al. 2005). It is always a possibility that an improper understanding of a system leads to not only failure of the restoration structurally due to channel instability, but also increased stress to lotic communities, (Alexander and Allen 2007, Bain et al. 2014). A proper and well-rounded understanding of the urban stream system is only possible via a comprehensive of watershed processes impacting a project site.

River modification in the United States began in the 1960's primarily addressing flood control and need for water supply and was conducted by hydraulic engineers (Lave 2002). However, in the 1990s Rosgen (1996) began promoting a reference reach approach using hydraulic geometry (regional curve) methods primarily for ecologists and biologists. The regulatory community (i.e., federal and state agencies) adopted his approach, and its use has significantly grown over the years (Bernhardt et al. 2005).

Compensatory mitigation requirements have also fueled the significant increase in project numbers (Harman 2012). Concern over the reference reach, or analog approach being uniformly applied in all watersheds has concerned some in the professional community because watersheds vary in their basic hydrology, geology and sediment sources, land use patterns, and ecology (Shields et al. 2003, Simon et al. 2007). As noted above, urbanizing system need to be assessed with a different tool box because of hydromodification. To address the needs mentioned above, it is necessary to question the effectiveness of the current state of stream restoration practice in urban streams. A good beginning question is what constitutes a healthy urban stream? This question reiterates the need for confluence between many disciplines including: ecology, hydrology, biology, hydraulics, chemistry, and sociology (Bernhardt et al. 2005, Niezgoda et al. 2014, Palmer et al. 2003, Walsh et al. 2005). Are the habitat and geomorphic metrics used for assessment representative of successful stream restorations? It is the hope of this study that a dominant set of habitat and geomorphic metrics will serve holistically to advance the approach to assess functional lift. Finally, why are certain metrics excluded from current mitigation tools, and is that exclusion justified?

Acknowledging the restoration of urban streams is different from streams that are not impacted by hydromodification. The potential recovery of both geomorphic and ecological attributes needs to be better understood. As noted above, pre- and post-restoration monitoring, and analysis are rarely conducted and published for the practice as a whole (Bash and Ryan 2002). Nonetheless, there is a need to quantify the functional lift from restoration for compensatory mitigation and the determination of mitigation credits from projects (Harman 2012). The stream quantification tool has been adopted by a few states, including Tennessee (TDEC 2018). However, this tool is based on a reference reach approach for restoration and potentially fails to identify the altered watershed process in urbanized areas. There is a critical need to investigate what geomorphic, habitat, and ecological parameters best characterize the functional lift from urban stream restoration.

It is the primary objective of this study to better comprehend the role of geomorphic and habitat structure within urban streams and how they may be used to assess functional lift in urban restored stream sites. Channel and unit measurements can point to the physical quality of habitat and channel stability with respect to geomorphology. More specifically, the goal is to study geomorphology in regard to channel characteristics and stability as it relates to habitat maintenance processes and to understand the limits of ecological recovery in urban streams. A secondary objective was to investigate the Tennessee Stream Quantification Tool (TNSQT) and whether the metrics used reflect functional lift from urban stream restoration projects.

<u>LITERATURE REVIEW</u>

Current State

Urban streams at present are under an immense amount of stress, caused primarily by anthropogenic hydromodification and channel alteration (Booth and Jackson 1997, Schwartz et al. 2015, Walsh et al. 2005). Approximately one-third of rivers in the United States are at some level of impairment (EPA 2009). The effects of urbanization are not a simple and uniform set of stressors, where Walsh et al. (2005) has termed these effects as the "urban stream syndrome". Hydromodification due to an increase in urban land use and cover degrades the physical, chemical, and biological states of fluvial systems.

Urbanization within catchments has direct consequences to the geomorphology of rivers and streams. A major player in geomorphic changes in urban streams is modification to runoff hydrographs from increases in impervious cover resulting in greater stormflow magnitude and duration (Jennings and Jarnagin 2002, Konrad and Booth 2005). Increases in peak stream flows can also be caused by direct and rapid conveyance to streams via stormwater infrastructure (Beechie et al. 2010, FISRWG 2001, Jennings and Jarnagin 2002, Konrad and Booth 2005, Schwartz et al. 2015). Because of the increased, changes in the hydrological budget can also include diminishing aquifer recharge and evaporation (Akbarpour and Niksokhan 2018, Konrad and Booth 2005). Increased stream flow contributes to channel erosion via greater shear stresses at the bed and bank, where geomorphologic changes include channel incision and widening, and potentially bank mass failures. The intentional removal or alteration of floodplains and vegetated riparian zones only exacerbates the potential harm from increased flow and sediment transport rates (Booth and Jackson 1997). Depending on the location in the catchment and its land cover patterns upstream, hydromodification may increase the sediment supply causing bed aggradation, deposition of fines and embeddedness, and other alterations that destabilize channels and degrade habitat.

Hydromodification has severe impacts with regard to water quality and pollutant loading in urban streams (Charbonneau and Kondolf 1993, Johnson et al. 2015). Associated with increased runoff and riparian loss, as well as new point-sources from urban development, pollutants consist of nutrients (nitrogen and phosphorus), contaminants, and sediment (increased turbidity and total suspended solids), and bacterial pathogens (fecal coliforms and *E.coli*) and reduced dissolved oxygen (Walsh et al. 2005). Usually most pollutants are co-associated because of a common stressor, for example, hydromodification often brings with it increased sediment transport and phosphorous which is known to bind to soil particles.

Urbanization-caused hydromodification can affect aquatic biota, ecosystem structure and function, and biotic integrity (Booth and Jackson 1997, Yoder et al. 1999). The degradation of aquatic communities is primarily caused by the geomorphic and water quality changes described above. Aquatic communities are vulnerable to a variety of stressors including loss of habitat structural diversity that serves multiple ecological functions such as spawning, feeding, rearing, etc., increased temperature, modified nutrient dynamics, and altered flow regimes such as increased flood peaks and lower baseflows (Lynch et al. 2019, Zeiger and Hubbart 2019, Zhang et al. 2019). Habitat degradation may occur for a variety of reasons including fragmentation and loss of structure and function (Casatti et al. 2006, Collier et al. 2019, Violin et al. 2011). Channel morphology provides the physical structure for habitat at multiple spatial scales from the largest unit, the watershed to smaller scales including from the reach to the mesohabitat (pool-riffle) and bed sediment features (Frissell et al. 1986, Frothingham et al. 2002). Rapid geomorphic adjustment from urbanization most commonly effects habitat structure at the reach and lower spatial scales. It is then no surprise that extinction rates for aquatic communities are much higher than the rates of terrestrial species (Bernhardt et al. 2015). In assessing the quality of habitat in urban streams, it is important to take a holistic view of all fluvial habitat scales and processes modified by hydromodification (Bain et al. 2014, Leps et al. 2016, Ryder and Miller 2005).

Geomorphology, Habitat, and Channel Stability

A valuable way to assess stream ecosystems is to examine the structure and process-based function occurring at different spatial scales, as noted above from Frissell et al. (1986), and the temporal scales for habitat maintenance. In order to maintain biological stasis and channel stability, fluvial systems are governed by geomorphic and habitat mechanisms such as the scouring of biofilm on cobble, energy dissipation/distribution, and sediment transport (Beechie et al. 2010, Ryder and Miller 2005, Schwartz et al. 2015). The scale of these processes can extend from the catchment to the particle (Knighton 1998, Sear 1994). Examining instream processes based on the scale they operate within is a good way to understand them, and this is how they will be broken done in the paragraphs to come, starting with the watershed scale.

Watersheds are topographic features defined by their drainage divides and outlet (Knighton 1998). Headwaters exist near upper watershed boundaries and this area contributes approximately 95% of the runoff water into drainage networks (Knighton 1998). The transport of water and sediment towards the catchment's outlet is responsible for the creation of channel morphology (both channel type and drainage patterns and networks). Slope varies greatly between higher and lower elevation streams, and streams at lower elevations tend to have lower gradients (Montgomery and MacDonald 2002). The location of the stream within the catchment can also influence how instream processes influence channel formation and geomorphology (Lane and Richards 1997). Montgomery and MacDonald (2002) notes that "…headwater channels are often subject to disturbance by debris flows and high flows confined by valley walls, whereas lower-gradient alluvial channels tend to be subject to channel migration and avulsion…". Additionally, the type of valley occupied by the watershed will affect stream shape. For example, colluvial channels (typically located at higher elevations) tend to be straighter and narrower than alluvial channels (Rosgen 1996).

A very significant amount of sediment, organic matter, and potentially pollutants are supplied by the water transported from catchments. (FISRWG 2001, Knighton 1998). Sediment transport at the watershed scale comes largely from surface erosional processes, creep, and landslides (Beechie et al. 2010, Nelson and Booth 2002). As sediment erodes it deposits at various downstream points of the watershed. Some effects of increased sediment include channel-widening, braiding, and aggradation (Booth and Fischenich 2015). Wolman (1967) notes that excessive sediment transport throughout urban watersheds leads to the creation of sand bars and banks of sand overlaying previous gravel beds. Additionally, Wolman (1967) makes the point that, in urban watersheds, the increase in runoff and sediment transport, "…should contribute to an increase in channel erosion and to an increase in channel width". Simon and Hupp (1986) created a channel evolution model that was largely informed by the fluvial transport of sediment. Channel adjustment processes from a disturbance in flow, sediment, and geometry were described systemically in the channel evolution model including bank widening, change in cross-section geometry, incision and general degradation of the channel through mass wasting (Simon and Hupp 1986).

The complexity of previously mentioned processes increases at the reach-scale as separate reaches typically feature unique geomorphology (Montgomery 1999). There exist multiple theoretical concepts to view reach-scale habitat processes, but two particularly informative concepts are the River Continuum Concept (RCC) and Patch Dynamics Concept (PDC). The RCC was proposed in Vannote et al. (1980) and implies a utilitarian albeit non-exact equilibrium lotic corridor for aquatic life whose "…community structure and function adjust to changes in certain geomorphic, physical, and biotic variables such as streamflow, channel morphology, detritus loading…". One particular idea is the energy gradient process commuting downstream, i.e., energy that is unused or only partially processed is transmitted to downstream communities for use. Incorporating both temporal dynamics and spatial scales, PDC posits the idea that stream ecosystems are comprised of a mosaic of "patches", often with distinct disturbances, colonizations, reactions, and upkeep processes (Montgomery 1999, Townsend 1989).

Geomorphic processes within the reach-scale related to pool-riffle sequences and their maintenance is of critical importance to stream ecosystems because so many lotic organisms have evolved to exploit the natural resources of mesohabitat units (Schwartz and Herricks 2008). Mesohabitat classification at the pool-riffle geomorphic scale serves to characterize habitat diversity. Geomorphic processes are linked to mesohabitat maintenance, and habitat structures are maintained by the variations in flow stages and sediment transport (Almeida and Rodriquez 2011, Lane and Richards 1997). Lane and Richards (1997) also noted the circular interplay involved by stating, "As channel morphology evolves, so the channel's sediment transporting capacity evolves". Generally, pool spacing in unimpacted streams occur on an average frequency of five to seven channel widths (Gregory et al. 1994, Leopold et al. 1964). Gregory et al. (1994) found additionally that altered channels had values lower than this average range and that downstream changes in channel width do not affect the pool-riffle sequence. Calderon and An (2016) showed that tolerant guilds tended to dominate reaches that were composed mostly of pools, and that intolerant species preferred riffle-controlled sequences.

Another important feature of the reach-scale corridor is the riparian zone (Gregory et al. 1991). Although not located directly in the stream channel, the riparian zone has an impact on in-channel geomorphology and habitat. LWD provides hydraulic resistance reducing flow capacity and stream power, minimizes channel widening, and generally provides for geomorphic stability and diversity (Booth and Fischenich 2015, Hupp 1999, Montgomery and Buffington 1997). Alternatively, the introduction of LWD may increase bank scour, force mesohabitat unit change, and decrease flood conveyance, primarily through flow alteration and manipulation (Abbe and Montgomery 1996, Booth et al. 1997, Hupp 1999).

Vegetative canopy cover provided by the riparian zone is also important (Barbour et al. 1999). Temperature regulation and providing leaf litter are two benefits supplied to sufficient canopy cover (Allan and Castillo, Hawkins et al. 1982). Vannote et al. (1980) notes that where there is a canopy opening, the variance in stream temperatures will be greater due to greater solar input during the day. Canopy cover over streams also inhibits the growth of some aquatic plants such as periphytons and algae which means that benthic macroinvertebrate and fish communities require watershed and riparian input for sustenance in forested headwater reaches (FISRWG 2001). With respect to habitat, riparian-zone canopy cover is essential for diversifying habitat availability for a variety of animal communities not only where full cover exists, but also in more open downstream extents (Beechie et al. 2010, FISRWG 2001, Vannote et al. 1980).

Functional Lift in Urban Stream Restoration

Stream ecological function may be defined in many ways. Jax and Setala (2005) gives four definitions for ecological function including functions: as roles, services, and process; and the function(ing) of a system. For the purposes of this study, function is best viewed as a set of physical, chemical, and biological processes and services (Harman et al. 2012). Functional lift then can be considered the improvement of these processes and services, at least partially, to a pre-disturbance state. In assessing functional lift, it is vital to consider the multifaceted elements of these processes and services. In order to assess the success of stream restoration efforts, Beechie et al. (2010) suggests assessment methods are needed to quantify the potential increased function of the entire stream system.

While it is necessary to reestablish mesohabitat structure and geomorphic channel stability through stream restoration projects, it is also important to pay attention to hydrologic, hydraulic, and ecological relationships during design of channel and habitat structures (Pander and Geist 2013, Schwartz et al. 2015). One such example, harkening back to Walsh's USS, Bain et al. (2014) notes, "If urbanization imparts a syndrome…discharge is one of the fundamental vital signs to monitor during recovery, particularly as assumed benefits of restoration often depend on channel stability and therefore depend on reductions in storm flow". Often increased flows from urbanization caused degradation of habitat and geomorphology so simply reconstructing these physical structures is likely to be inefficient. Therefore, it may be the goal of the restoration designer to increase the flow capacity in the channel, reduce discharge rates with upland stormwater controls, or dissipate power through greater hydraulic resistance on the channel boundaries. Hydrologically, reduction in flow may be difficult to manipulate or assess for lift because watershed hydrologic factors may lie outside of the designer's ability. Floodplain reconnection and rehabilitation of the riparian zone have been considered as ways to dampen the effects of hydromodification, but with mixed results (Bain et al. 2014, Larsen et al. 2017, Parker 2019). For instance, Bain et al. (2014) found, in the streams surveyed, that floodplain reconnection did not contribute to nutrient abatement, while Larsen et al. (2017) actually increased nutrient loading (phosphorus), albeit temporarily. Success in restoration projects, it seems, is bound to the innate complexity of stream ecosystems and may not be achieved by focusing on single geomorphic and/or habitat metrics (Alexander and Allan 2007, Bain et al. 2014).

The stream functions pyramid provided by Harman et al. (2012) Includes the physiochemical category . The TNSQT physiochemical portion focuses on four metrics: *E. coli* numbers, percent nutrient tolerant macroinvertebrates as a surrogate for nutrients, and nitrate-nitrite and total phosphorus concentrations. Little focused documentation on *E. coli* reduction caused by stream restoration projects exists, although Fisher (2019) noted a reduction in concentrations between the same UI and UR streams used in a concurrent study. There also appears to be varying project outcomes for the reduction of *E.* coli numbers from green engineering and infrastructure (Chandrasena et al. 2016, Page et al. 2015).

With respect to nutrient tolerant macroinvertebrates, there exists some decrease based on restoration projects. Although typically phrased as in an increase in %EPT (the percentage of more intolerant taxa within the orders Ephemeroptera, Plecoptera, and Trichoptera), there are several examples of a decrease in tolerant taxa (Bain et al. 2014, Fisher 2019, Schwartz et al. 2015). Decrease, in this case, is potentially a sign of improvement as it would theoretically mean the increase in intolerant species. Additionally, it should be noted that with respect to intolerant macroinvertebrate recruitment water quality improvements and nutrient abatement is very important (Schwartz and Herricks 2007, Sundermann et al. 2011).

The level of nitrogen and phosphorous in-channel is directly related to the growth of aquatic vegetation (especially algae) through eutrophication and, in excess, many species of aquatic flora and fauna cannot thrive or survive (Palmer et al. 2014). For example, Palmer et al.

(2014) shows that the reduction of nitrogen exports was largely dependent on storm size (and thus discharge and runoff levels) and the retention ability of the stream. Meanwhile, Line (2015) showed no significant improvement in the restored stream with respect to nitrogen or phosphorus. This variety of results continued throughout the literature (Johnson et al. 2015, Lammers and Bledsoe 2017, McMillan and Noe 2017). Based on the above information it is clear that the analysis of nutrient change in restored streams is a difficult.

A major factor used to quantify functional lift from urban stream restoration projects is the improvement of biological communities. This should include not only biodiversity and the inclusion of intolerant species, but general species health. To this extent there exists a wide variety of responses to restorations in the literature, and it may be more useful to discuss what factors increased biological recruitment. Martens et al. (2019) attached moderate improvement to the reinstatement of riparian zones and LWD. Finally, although not directly tied to a restoration, Matthews and Styron (1981) note that even position (headwaters vs downstream) in the reach may make a difference in species tolerance. Bain et al. (2014) saw some large improvements in both numbers and weights for fish, which was attributed to the removal of obstructions to passage, but relatively small increases in macroinvertebrate populations. Likewise, Sundermann et al. (2011) saw no significant improvement for invertebrates, which the study attributed to poor water quality and habitat availability.

With the variety of results on every level of a lift assessment, it may worthwhile to conceptualize the potential causations. One such driver may be the potential limits of mitigation and ecological improvement (Beechie et al. 2010, Booth and Jackson 1997, Palmer and Bernhard 2006). Some limiting factors, such as watershed processes and aspects of urbanization may be hard or not worthwhile to upend based on factors considered by shareholders. It would also be of use to inspect not only how, but to what extent pre- and post-restoration monitoring occurs. For instance, a recurring theme to the outcome of restoration projects is temporal variance and how often functional lift may not be assessable until long after the time spans used currently for monitoring (Beechie et al. 2010, Leps et al. 2016, Nilsson et al. 2015). Pre-restoration monitoring should also be considered a necessity, and pre-design guiding questions should be established (Beechie et al. 2010, Nilsson et al. 2015)

CHAPTER TWO

Methodology

METHODOLOGY

Study Sites

Twelve stream reaches were chosen to be representative of the Tennessee "Ridge and Valley" ecoregion 67 and four each were chosen from three different condition classifications: urban impaired (UI), urban restored (UR), and ecoregion reference (ERR). The UI study sites include Beaver Creek, Baker Creek, Third Creek, Friar Branch. The UR sites include Beaver Creek, Williams Creek, Third Creek, and Friar Branch. The ERR sites include Indian Creek, Big War Creek, Mill Creek, and Dry Creek (Figure 2.1).

Study Design

As stated by the study objectives in the Introduction, physical measurements of streams among the three condition classifications were completed, including: channel geomorphology, stream habitat, and riparian vegetation. In addition to physical measurements, biological surveys were completed for the same set of streams by Fisher (2019). Though this study focuses on physical conditions, both the physical and biological studies were conducted to better understand the recovery potential from stream restoration projects in urban streams. The key tools included geomorphic structure measurements (channel longitudinal profile, cross-sections, pool-riffle-bar structure, substrate) channel stability measurements using the Rapid Geomorphic Assessment (RGA), mesohabitat structure surveys, and riparian corridor and channel habitat surveys using a modified EMAP procedure and the Rapid Bioassessment Protocol (RBP). The Tennessee stream quantification tool (TNSQT) was used as well to meet a secondary project objective to test whether it can be used to differentiate stream condition among a gradient from undisturbed to disturbed from urban hydromodification, and how the TNSQT scores functional lift from urban stream restoration projects. These study sites range in percent urban land cover from 5.625 to 62.375 %; in drainage area size from 1.66 to 24.61 sq. mi. (Table 2.1).

The modified EMAP procedures included several measurements categories including geomorphology, mesohabitat, and riparian vegetation (Kaufmann et al. 1999). The TNSQT also requires similar measurements for geomorphology and riparian vegetation (TDEC 2019). Field surveys/measurements will be described by elements of physical structure and overlap of field measurement protocols will be noted. The biological survey data from Fisher (2019) was used for this assessment of the TNSQT.

Geomorphic Structure and Stability Measurements

The RGA is an assessment tool for channel stability applying the channel evolution model (Simon 1992) which contains nine questions scored zero to four (four being the least ideal situation). The RGA is a reach-based assessment and observed reach lengths were determined by multiplying the bankfull channel width by 15 per Kaufmann et al. (1999). Primary bed material is first and most straightforward, meaning to capture what the majority of the bed is made of, with stationary materials (bedrock, boulder, etc.) scoring lower than easily-transported material such as silt clay. Bed/bank protection is a measurement of artificial implementations. Degree of incision monitors how much of the reach is vertically and laterally incised and relates to ER discussed earlier. With respect to this method some clarification may be needed. The metric is measured by measuring 'normal' water depth and dividing it by the bank height.

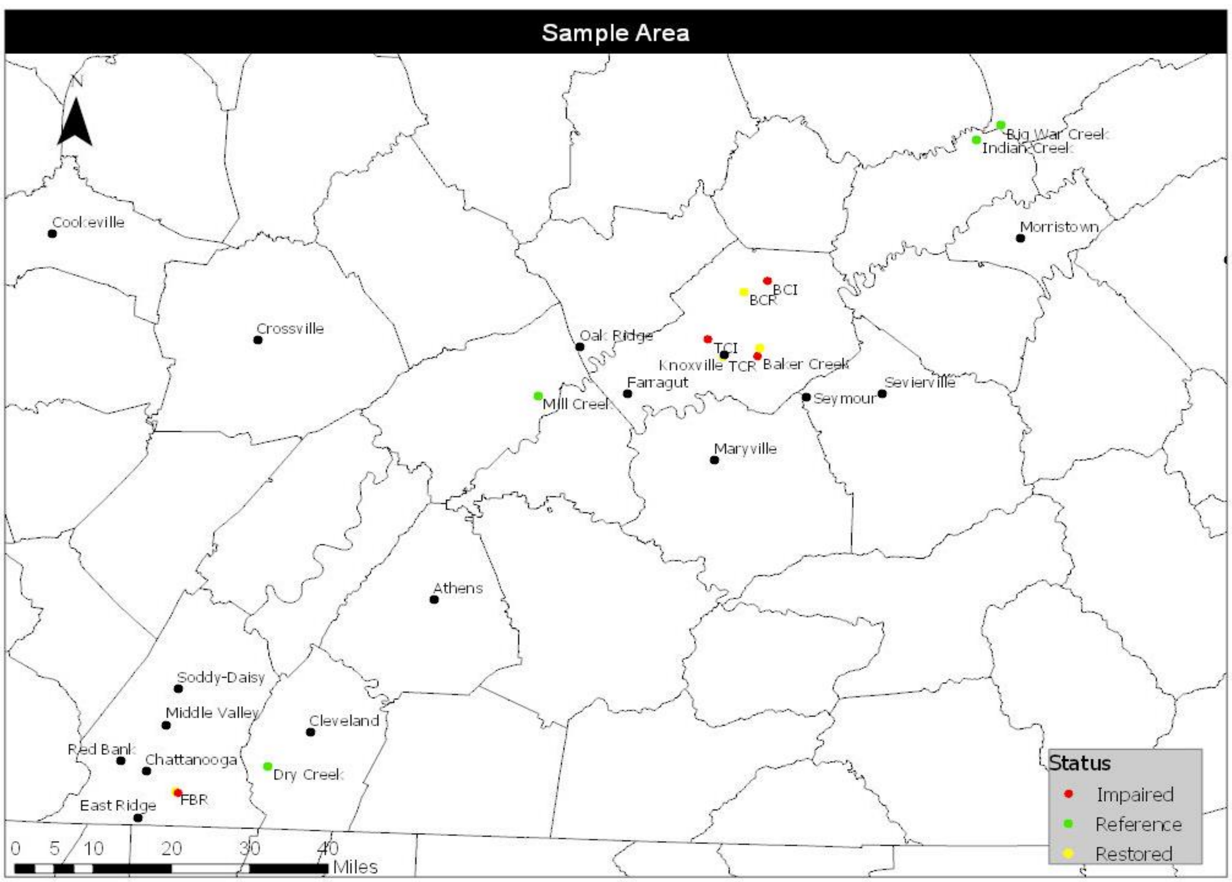

Figure 2.1. Site Locations Separated by Stream Condition Type. (Fisher 2019)

In this way, lower water depths (in some instances caused by incision) will technically have a lower percentage value for degree of incision, while less classically-defined incised fluvial systems will have higher ratios because their channel is deeper. Degree of constriction is the fourth measurement and measures the difference in bank width at the upstream extent with that of the downstream outlet.

Assessments five through eight of the RGA are evaluations of the left and right bank separately. Streambank erosion is first and gives a tertiary option. Each bank can have no or fluvial erosion, or mass wasting. Mass wasting is considered a geotechnical failure and much rarer than fluvial erosion. Streambank instability is simply the percentage of that bank that is eroding over the whole reach. Established riparian woody vegetation is a measurement of what portion of each bank is protected by thick, woody rooted vegetation. The occurrence of bank accretion is the percentage of each bank that experiences fluvial deposition. The final assessment is the stage of channel evolution (Figure 2.2.) which follows procedures in Simon and Hupp (1986). A summation of the parameters and their respective collection methods can be found in Table 2.2.

Morphological Surveys

The Environmental Monitoring and Assessment Program (EMAP) was created by the U.S. Environmental Protection Agency (EPA) to streamline measuring physical attributes of streams deemed influential to stream ecology (Kaufmann and Robison 1998). As defined in Kaufmann et al. (1999), the EMAP focuses on seven general physical parameters: channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic alterations, and channel-riparian interaction. For use in tandem with the TNSQT, a modified EMAP was conducted. The modified procedure, separated into three sheets, is detailed in Table 2.3.

Vital to many of the aforementioned assessments and the TNSQT was conducting a full-reach survey, including representative cross-sections. To circumvent any possible issues with technology an automatic level was used. An initial back sight was set at a hydraulic grade point when possible, which ended up being possible in all the observed reaches. The initial back sight served as a reference elevation, set to 100 ft. To simplify data entry, turning points were used only when necessary. Longitudinal surveys were completed to at least a length of 15 times the bankfull channel width located at the hydraulic control used. To get planform views, a survey compass was used to discern field sinuosity of the reach.

Cross-sectional information was vital to retrieving many measurements for the TNSQT. Specifically, data for pools and riffles is required, and measured for the modified EMAP protocols. The standard in the TNSQT utilized was obtaining cross-sections for at least three riffles and two pools per reach. In some cases, more cross-sections were made. If more pools and riffles existed than were needed, cross-sections were documented at the ones that showcased the most characteristic features. Finally, the downstream hydraulic grade control was noted, when available, and this was unique to this study. The downstream hydraulic grade control can help to mitigate erosion and potentially harsher changes like head cuts upstream (Bledsoe et al. 2016).

Bank Erosion Hazard Index (BEHI)

The Bank Erosion Hazard Index (BEHI) is a measure of potential bank erosion. Of specific importance is the identification of bankfull indicators (Rosgen 1996). Bankfull width, height, and depth were measured using a survey tape and stadia rod. Next, floodprone area width was inspected by examining the near-bank ground expanse at twice the bankfull depth. The rest of the BEHI assessment involves visual inspection of bank-specific features. Bank materials and stratification are inspected to document soil types present and their prevalence. Root bank depth, density, and surface protection were assessed to catalogue to what extent the bank site was protected by natural materials and structures. Finally, the bank angle was estimated. At each stream examined, a minimum of three BEHI sites were included, although most sites contained more. The bottom portion of the assessment form contains the only metrics that factor into the BEHI score (Appendix A). Each of these metrics was then scored based on a scheme presented in Table 1 of Rosgen (2001). Scores were then averaged to make a final site score.

Characterization of Bed Sediment

To understand bed material, a Wolman pebble count was conducted. Wolman pebble counts consist of measuring the width of the b-axis for 100 bed sediment pieces. Pebble counts were conducted using a stadia rod, except one field day when an SI-based ruler was used. All measurements this day were converted into tenths of inches to conform to other measurements. From the Wolman count, it was possible to find a D_{50} as well as a distribution and p-value (Potyondy and Bunte 2002, Wolman 1954).

Table 2.1. Study sites for urban impaired, urban restored, and ecoregion reference classifications, and data for watershed urban and forested % land covers, drainage area, channel slope of surveyed reach, and the 2-yr frequency discharge (Q_2).

Site	Classification	Urban Land Cover (%)	Forested Land Cover (%)	Drainage Area (sq. mi.)	Channel Slope (ft/ft)	Q_2 (cfs)*
Baker	UI	87	10	1.90	0.003	245
Beaver	UI	65	5	8.94	0.003	374
Friar	UI	60	10	3.10	0.002	500
Third	UI	82.5	7.5	3.03	0.014	231
Beaver	UR	75	15	15.17	0.004	1150
Friar	UR	65	10	5.36	0.004	511
Third	UR	75	20	11.60	0.001	736
Williams	UR	15	35	1.93	0.001	165
Big War	ERR	5	50	25.41	0.008	1150
Dry	ERR	7.5	85	3.55	0.0036	346
Indian	ERR	5	80	15.10	0.001	853
Mill	ERR	5	75	0.63	0.0072	238

* Q2 obtained from USGS StreamStats.

Table 2.2. Rapid Geomorphic Assessment Parameter and Collection Methods (USDA 2005)[1]

Parameter	Variable Description	Collection Method
Primary Bed Material	Reach-scale assessment of the constitutive sediment type	Visual inspection throughout the reach
Bed/Bank Protection	Inspection for the presence of artificial protection measures (concrete, rip-rap, etc.)	Visual inspection
Degree of Incision	Percentage of reach experiencing a low bed-to-bankfull elevation ratio caused by downcutting and changes in sediment transport and supply	Comparison of bank versus bankfull height based on measurements made with a stadia rod
Degree of Constriction	The extent to which bankfull width decreases from upstream to downstream	Inspection of width measurements taken in the longitudinal survey as well as acknowledgment of constrictive structures such as bridge abutments
Stream Bank Erosion*	Chronicles the primary type of erosion present	Visual inspection for distinctive erosional types
Stream Bank Instability*	Percentage of bank erosion. If >50% should be considered mass wasting	Visual inspection coupled with measurements made in the BEHI assessment
Established Riparian Woody-Vegetative Cover*	Representation of vegetation growth on the bank; grasses and other impermanent vegetation are not considered	A reach-scale visual survey of percent coverage
Occurrence of Bank Accretion*	The portion of banks that have experienced fluvial deposition	Visual inspection in the change of deposition on banks

[1] Denotes parameter is measured separately for each bank

Table 2.2. Continued

Parameter	Variable Description	Collection Method
Stage of Channel Evolution	Phase in channel-adjustment based on several systematic processes (sediment transport, cuts in the bedform, etc.)	Analysis based off of previous eight questions as well as acknowledgment of other systematic processes

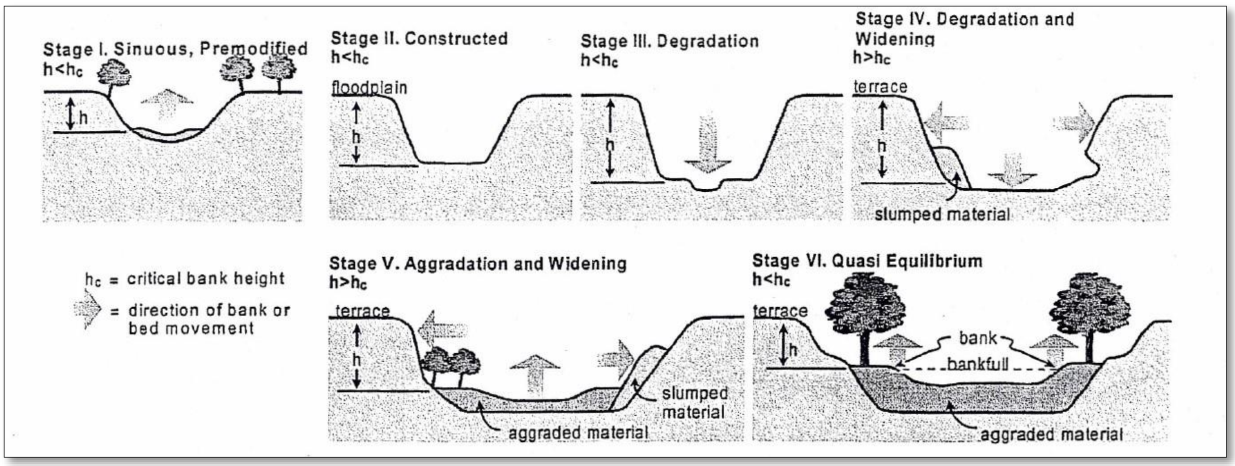

Figure 2.2. Channel Evolution Model Used in the RGA (Simon and Hupp 1986)

Table 2.3. Modified EMAP Habitat Survey (Kaufmann et al. 1999)

Parameter	Sheet Location	Variable Description	Collection Method
Unit No./Channel Unit ID#	1,2,3	Working upstream, designating changes in unit type (i.e., P1 = Pool 1; I3 = Riffle 3)	As part of the longitudinal survey, changes in mesohabitat were visually noted and then recorded
Pool-Type Code	1	A way to better describe the geomorphology of pools present	Decided based on the prescribed definition and visual inspections
Pool-Form Code	1	Used to describe the origin and maintenance of pools (i.e., F = Fluvial, B = Bedrock)	Visual inspection for characteristic/dominant feature
Side-Channel	1	Acknowledgment of divergent channel	Simple visual inspection of presence or absence
Channel Unit Length	1	Measurement of individual unit lengths	Determined by measurements taken along the thalweg with an automatic level, stadia rod, and surveying tape
Channel Unit and Bar Widths	1	Measurement of the bank to bank width of a channel unit	Bank-to-Bank measure with survey tape, preferably multiple time creating an average
Channel Unit Maximum Depth	1	Measurement of lowest elevation in channel unit	Using a stadia rod, measure/record the deepest point for each channel unit
Fish Cover Elements	1	Representation of various structures in place that facilitate habitation	Visual inspection of abundance translated into a percent of total unit area
Bed Substrate	2	Assesses the constitutive geology of each unit	A visual inspection into percentages (should sum to 100%)
Canopy Cover	2	Represents that amount of vegetative cover	Use of a convex spherical densiometer in a minimum of four channel units

Table 2.3. Continued

Parameter	Sheet Location	Variable Description	Collection Method
Riparian Vegetation	2	Constitutive survey of the canopy, understory, and ground for various sizes of vegetation, as well as density	Simple count/visual inspection of both banks
Human Influence	2	Noting any anthropogenic impacts or objects present in the channel or w/in 10 m of the channel	Visual inspection
Large Woody Debris	3	Pieces of wood in the channel and above channel are counted and put in a size range	Pieces are measured using survey tape and put in the appropriate category

Riparian and Stream Habitat Surveys

Riparian habitat measurements were a feature of the modified EMAP protocols. It included an estimate of the amount of woody-vegetation present in three vertical zones on both banks. The first zone was the canopy, considered to be anything greater than five meters from the ground. The understory consisted of anything in the 0.5-5 m. range, and ground cover included anything less than 0.5 meters. Another aspect of the riparian survey included an assessment of human influence on the riparian buffer zone, namely in the constriction of buffer width, or the distance of legacy trees to the wetted margin. Legacy trees are old-growth trees that have not been removed by natural or anthropic means.

Mesohabitat Surveys

Channel units were visually determined in the field with positions recorded in sequence with the longitudinal profile survey conducted. This method is also described in the modified EMAP protocols (Kaufmann et al. 1999). Channel units were classified by mesohabitat type, primarily riffles, runs, and pools. Riffles were characterized as areas of shallow flow, often moving faster than flow in runs or pools. Pools were defined as deeper areas of sediment deposition.

Typically, the flow of pools is much calmer and slower. Runs were characterized as having a medium, uniform flow and depth. Distinguishing between the three was done by visual inspection coupled with an understanding of fluvial geomorphologic processes. Each of these mesohabitat classifications has its importance for aquatic ecosystems and were discussed in greater detail in the literature review.

Large Woody Debris

Large Woody Debris (LWD) has a myriad of cataloged benefits in stream ecosystems (Finkenbine et al. 2000). To this end, they are included in many aspects of this study including the TNSQT, RBP, and general habitat analysis. Their primary origin methodically lies in the modified EMAP protocols. To be counted, a piece must be at least one meter in length, and either be located in-channel or acting as a bridge above bankfull. Per the modified EMAP protocols, pieces were separated into groups as follows: 1-2 m in length; 2-5 m; >5 m.

Rapid Bioassessment Protocol

The RBP is a qualitative assessment of both the presence and quality of available riparian and stream habitat (Barbour et al. 1999, TDEC 2018). Comprised of ten metrics scoring from zero to 20 (20 being the highest "optimal" score), the RBP begins with epifaunal substrate cover which is a simple measurement of the availability and diversity of habitat such as logs and cobble for fish to utilize. Embeddedness, the second measure, is the percentage of bed material that is surrounded by fine sediment. Third, is velocity/depth regimes present, which optimally includes four regimes: slow-deep, slow-shallow, fast-deep, and fast-shallow. Each regime represents a different functionality for fish and macroinvertebrate communities. The presence and increase in islands and point bars are measured by the metric “sediment deposition”, and how much water is present in-channel for the reach is measured by “channel flow status”.

Channel alteration is the RBP’s sixth measurement and is meant to represent whether or not the channel has been anthropogenically changed with respect to channelization, dredging, etc. The seventh metric is the frequency of riffles, or more generally, the diversity of mesohabitat. Parameters eight through ten are split into left and right bank measurements with bank stability being the first measurement. Bank stability in the RBP, like with the RGA, is simply looking at the percentage of the reach that is experiencing (or is likely to experience) fluvial erosion or mass wasting. Vegetative protection is an assessment of the plants available that directly provide bank support (similar to the seventh metric in the RGA). Finally, the RBP looks at the width of the riparian zone and to what degree the riparian zone is affected by anthropogenic activities. Table 2.4. summarizes the individual RBP parameters and their collection methods.

Tennessee Stream Quantification Tool (TNSQT)

Per the *TN SQT Data Collection and Analysis Manual*, there are preliminary steps to data collection. Parameters measured in the TNSQT based on the stream pyramid include five categories (Harman 2012). They are hydrology, hydraulics, geomorphology, physiochemistry, and biology.

To represent hydrology the watershed land use runoff score was found using StreamStats. The watershed land use runoff score is used by the TNSQT in a fashion similar to curve numbers in the Rational Method and is intended to represent land-use in the watershed. The watershed for each stream was delineated based on the downstream extent of the reach. Then land use percentages were calculated based on use types set forth in the TNSQT manuals, and include forested, open, low residential, high residential, and other urban land uses (impervious cover, gravel, etc.). TNSQT prescribed a correction coefficient (see Figure 2.3) to each of these types that was multiplied with the contributing land area to adjust the type’s effect on permeability

Table 2.4. RBP Summary (Barbour et al. 1999)[2]

Parameter	Variable Description	Collection Method
Epifaunal Substrate/Available Cover	Assesses the availability/diversity of natural structures in-stream that provide refugia, feeding, spawning and nursery sites for aquatic microfauna	Visual inspection of the presence/quality cover including snags, submerged logs, undercut banks, cobble, and other stable habitat structures
Embeddedness	A measure of the degree to which gravel, cobble, and boulders are enveloped by silt, sand, and mud	Visual inspection translated into percent coverage ranges
Velocity/Depth Regime	Inspects the presence of four regimes: slow-deep, slow-shallow, fast-deep, fast-shallow; more regimes present translates to a more stable aquatic environment	Visual inspection coupled with channel unit information from the longitudinal study
Sediment Deposition	A measure of accumulation of sediment in pools in addition to the formation and enlargement of islands and point bars	Visual inspection especially looking for changes between site visits
Channel Flow Status	A representation of how much of the channel is filled with water. When the substrate is not covered with water, habitat is diminished.	A measure of flow depth versus bank height
Channel Alteration	Assessing whether the stream channel has been artificially straightened, deepened, or diverted	Visual inspection for concrete, riprap, rootwads, etc.
Frequency of Riffles (or bends)	A measure of pool-riffle sequencing and subsequently diversity of habitat	The longitudinal survey conducted includes channel units which can be used to figure out percentages
Bank Stability*	Representation of current and potential bank erosion	Visual inspection coupled with BEHI assessment
Vegetative Protection*	Representation of stream bank and near-stream vegetative diversity and density	Visual inspection

[2] *Denotes parameter is measured separately for each bank

Table 2.4. Continued

Parameter	Variable Description	Collection Method
Riparian Vegetative Zone*	Evaluates the width of vegetation from edge-of-bank; tangentially represents human impedance	A mixture of visual inspection, pacing, and measuring with survey tape

Land-Use	Coefficient
Forest and native range	1.0
Low density residential (> 1-acre lots)	0.3
Open space (pasture, lawns, parks, golf courses, cemeteries)	0.2
High density residential (< 1-acre lots)	0.1
Impervious cover	0
Gravel	0
Industrial, commercial and business	0
Newly graded areas (bare soil, no vegetation or pavement)	0

Figure 2.3. TNSQT Watershed Land Use Runoff Score Correction Coefficients (TDEC 2018)

and runoff for the drainage area. The corrected numbers were summed and then divided by the total drainage area to get a runoff score.

The hydraulics category was represented by the bank-height ratio (BHR) and entrenchment ratio. BHR is simply top of bank height divided by bankfull height. The entrenchment ratio is the flood-prone width divided by the surface bankfull discharge width (Southerland 2004). To ascertain the bank heights and channel widths, a stadia rod and survey flagging tape was used. Floodprone width was determined by first by doubling the bankfull depth at the thalweg and raising the stadia rod to that height. The potential flood-prone channel width was then measured at this height. If it was empirically obvious that the ratio was going to be 2.2 or greater (high lateral floodplain connectivity) it was recorded as such versus obtaining an actual measurement. An ER above 2.2 represents a channel connected to its floodplains (Rosgen 1996).

Within the TNSQT, geomorphologic metrics constitute a majority. This section, therefore, ended up directing most of our geomorphologic assessment. First, large woody debris (LWD) were counted. LWD is considered to be any piece of in-channel wood that has a minimum diameter of 10 cm and a minimum length of one meter (Harman et al. 2017). Plots 100 m^2 in land area were made to survey diameter at breast height (DBH), tree density, and native shrub and herbaceous cover. Additionally, the riparian buffer width was measured. All of the geomorphic parameters measured are summarized in Table 2.5.

Bedform diversity was also a vital part of geomorphologic measurements. Included in the measurements were the pool spacing ratio, the pool depth ratio, and the percent riffle, all of which all feature as mesohabitat metrics as well. The pool spacing ratio is simply a longitudinal measurement from the deepest part of one pool to the next. Pool depth ratio is a way to measure pool quality via flow depth versus bank height. A longitudinal profile also gives percent riffle which showcases a diversity of geomorphology and mesohabitat. It is important to note that the only classifications for bedform are pool and riffle although other forms exist (such as runs) in other schools of thought. Sinuosity was measured primarily through field surveys and estimates were supplemented by maps provided by Google Earth, StreamStats, and the Soil Survey provided by USDA. StreamStats is an application provided by the U.S. Geological Survey (USGS). Finally, the physiochemical and biological data required by the TNSQT was provided by Fisher (2019) who evaluated indices of biotic integrity and functional traits analysis among the three stream condition classifications (UI, UR, and ERR).

As previously mentioned, to assess bank erosion potential at the sites, the BEHI was used. BEHI catalogs bank stability via such metrics as root depth, density, and bank angle. A primary method for achieving the parameters required by the BEHI was to measure relative heights and widths with a stadia rod and surveying tape. Other measurements, such as root density, were visually inspected and reported as the percent of streambank that is protected by plant roots. All metrics were then scored based on the provided scale and put into a hazard index based on their likeliness to erode.

The scoring of the TNSQT involves combining the aforementioned metrics into larger functional categories as follows: Hydrology, Hydraulics, Geomorphology, Physiochemical, and Biology. All component field values are given a weighted index value based on literature cited by the TNSQT's creators. Index values are then averaged for a functional category to get its parameter score. Parameter scores are then averaged to obtain category scores. Category scores range from zero to one. These category scores are given qualitative indicators of not functioning (0.00-0.29), function at risk (0.30-0.69), and functioning (0.70-1.00). All categorical scoring is finally averaged to arrive at an Existing Condition Score (ECS). The same qualitative values are applied to the ECS. The ECS is eventually used by the TNSQT to measure potential functional improvement of a restoration project. (TDEC 2018)

Statistical Analysis

To better understand patterns among and between the data collected it was necessary to perform several statistical tests. All tests were run in either SPSS (version 25) or PCORD (version 7). The first step for each data set was to obtain basic descriptive statistics. The descriptive statistics calculated included mean, standard deviation, minimum and maximum values, standard error of the mean, kurtosis, and skewness. Although skewness and kurtosis values gave some indication of normality, normality tests were also run for all data sets to decide whether parametric or non-parametric tests would be used.

It was decided that it would be useful to evaluate the variance among the three stream types, but Analysis of Variance (ANOVA) tests could not be used because a portion of the data obtained had non-normal distributions. Therefore, the Kruskal-Wallis H test was chosen as there is no assumption tied to normality. Note that if medians were being compared (an option inherent

Table 2.5. Geomorphic Parameters Measured for the TNSQT (TDEC 2018)

Parameter	Variable Description	Collection Method
Rosgen Stream Class	Method for integrating in-stream morphologic features to add consistency to hydrologic/hydraulic study	Based on the following in-field measurements: - Entrenchment Ratio - Stream Pattern - Slope - Cross-sectional Shape
Site Entrenchment Ratio	The extent of vertical containment of stream	At multiple cross-sections, bankfull width/flood prone width was recorded using a survey tape
Sinuosity	Ratio describing channel deviation between two points and a straight line	Combination of a longitudinal field study and map data
Channel Slope	Change in elevation over stream length	Longitudinal field survey
Width-to-Depth Ratio	The ratio of bankfull surface width to mean depth of the bankfull channel	Measured width with survey tape at bankfull; measured mean depth by plotting cross-sections, finding their area, and then dividing the deepest point recorded by that area
Active Channel Width	Channel formed by prevailing stream discharges; more attenuated than bankfull width	Survey tape measured width perpendicular to flow to the edge of permanent vegetation
Longitudinal Profile	Characterization of slopes and depths within a stream over a determined linear distance	Automatic level and stadia rod were used to find incremental but representative elevations
Rapid Geomorphic Assessment	Multi-variate appraisal of channel stability and channel evolution	A mixture of reach-scale visual inspection and data from cross-sectional surveys
Stream Power	Rate of in-channel energy dissipation over a downstream distance	Discharge rates (Q_2) found via StreamStats; downstream length based on longitudinal survey
BEHI	Multi-variate assessment of streambank erosion potential	Bankfull widths taken with survey tape; depths/heights taken using a stadia rod; all other metrics taken via visual inspection

Table 2.5. Continued

Parameter	Variable Description	Collection Method
Pool Spacing Ratio	Used to assess geomorphologic diversity; space between the deepest point in one pool to the next	Data extrapolated from longitudinal and cross-sectional surveys
Pool Depth Ratio	A measure of pool quality with respect to depth (i.e. deeper pools receiving a higher value)	Data extrapolated from longitudinal and cross-sectional surveys
Percent Riffle	The portion of reach that is occupied by riffle structures; a measure of geomorphologic diversity	Channel units were a feature of the longitudinal survey
D_{50}/Pebble count	Gives a representation of bed cover	A Wolman Pebble Count was used

in the test), the assumption of homoscedasticity would need to be satisfied. The null hypothesis of the Kruskal-Wallis test is that the rank means of the variables are the same. Rank means are converted means balanced with respect to the rest of the data. The significance value used was the asymptotic significance while the significance level was set to $\alpha = 0.05$. (McDonald 2014)

Principal Component Analysis (PCA) is an exploratory data ordination method accounting for variance and clustering similar classes (stream condition type) by attributes (the measured and/or computed stream site metrics). One aim of the PCA is to reduce multivariate covariance testing down to as few axes as possible (i.e., the components that are describing the most variance in the data set). Before conducting the test, it was necessary to perform data reduction and transformation. It should be noted that PCA in of itself can be considered a form of data reduction, but it performs better if the data initially has more independent variables than dependent variables. This was not always easy to create since most of the data sets included nine or more variables. Initial data reduction was achieved by using both skewness and kurtosis values, as well as correlation and covariance values. If a variable showed high correlation (or no significant difference) among all groups, it was removed. Likewise, if a variable had small values for skewness or kurtosis ($\leq \pm 1$) it was excluded from the PCA. The remaining variables were transformed using either a log (x) or log (x+1) transformation. The necessity of the transformation was to minimize the skewness and kurtosis of the remaining data.

Eigenvalues and eigenvectors are the main outputs of the PCA. In the PCA there is an axis for every dependent variable, albeit a single axis' variance may not be wholly explained by one single variable. The first set of eigenvalues defines the magnitude of variance explained by each axis. Due to the nature of the test, axis one has the highest value, with each following axis accounting for less and less of the data set's variance. For this study, any axis that represented less than five percent of the total variance was not included. The eigenvectors given portray the relative Euclidean distance to each axis of each variable. For instance, if variable "A" has the largest eigenvector value for axis one, it likely represents the most variance attributed to that axis.

CHAPTER THREE

Results and Discussion

RESULTS

This study applied descriptive univariate, multivariate analysis, and ordination statistical approaches to assess relationships among channel geomorphic and habitat parameters, and stream condition classes. The condition classes reflect the degree to which functional lift occurs among urban restored (UR) sites bounded by urban impaired sites (UI) with no restoration and ecologically healthy streams defined as the ecoregion reference (ERR) sites. Most of these parameters were directly tied to the TNSQT as inputs, but many served as surrogate measures to various channel features and morphological conditions providing a more comprehensive examination of stream condition. The first step was to compile descriptive statistics for the parameters measured from the field survey efforts, followed by testing for statistical differences among the stream types (UI, UR, and ERR) for the site parameters, and ordination to examine what parameters best characterize the three stream condition types.

Descriptive Statistics

Geomorphic and habitat parameters measured from the field efforts were summarized by the three stream classes: UI, UR, and ERR sites. Descriptive statistics for each reside in Tables 3.1.-3.38 consisting of a stream condition class: mean, standard deviation, 95% confidence interval and a range minimum to maximum.

Rapid Geomorphic Assessment

The mean scores (a range of 0-36) for the RGA decreased along a hydromodification disturbance gradient from UI to UR, to the ERR sites as undisturbed morphologically and ecologically healthy are shown in Table 3.1. The scale for the scoring of the RGA is as follows: < 11 – Stable; 11-19 – Conditionally Stable; 20+ - Unstable. The means for UI, UR, and ERR sites were 22.4, 14.0, and 8.8, respectively, following a geomorphic stability gradient from unstable to conditional stable, to stable. Standard deviations increased along the stream class gradient from UI, UR, and ERR sites (Table 3.1). The 95% confidence interval was smallest for UI sites (3.918) while the confidence intervals for UR and ERR were larger computed as 10.2714 and 11.6818, respectively. Finally, the confidence intervals for maximum and minimum scores within a type increases, smallest for UI sites (21.25 to 23.50) and largest for ERR sites (4.25 to 13.00).

The next set of descriptive data is for each individual metric within the RGA (which score individually as 0-4). Table 3.2. is a summary table, but since there are several metrics a visual representation was needed for the means as shown in Figures 3.3.-3.10, illustrating the means for each metric per stream condition types (UI, UR, and ERR).

Primary bed material scores zero to four in the following order: bedrock, boulder/cobble, gravel, sand, and silt-clay, representing the most stable material bedrock to the most erodible material (i.e., silt-clay). One UI stream, Friar Branch (x_i = 2.00), scored as having a bed primarily composed of gravel, while the other three sites were more dominated by fines (2.75, 3.00, and 3.00). Three of the four UR sites had scores in the neighborhood of gravel (1.75, 2.00, and 2.25) but the mean (μ = 2.50) was skewed by Beaver Creek's largely silt-clay bed (x_i = 4.00). Scores for ERR streams were proximal to boulder/cobble (0.75, 1.00, and 1.25) with a score for Mill Creek at 2.00, or gravel-dominated. The standard deviation was smallest for UI (σ = 0.47) sites but similar to ERR sites (σ = 0.54). UR sites had the highest values for the deviation at σ = 1.02. The minimum and maximum value range was widest for UR streams (1.75 to 4.00) and smallest for UI streams (2.00 to 3.00). Values for primary bed material are visually represented in Figure 3.2.

Bed/bank protection, based on artificial protection, was scored a little differently than the other metrics. A reach with protection on both banks received a score of three, one bank a score of two, and no protection a score of one. The way the metric was set up, a score of zero or four

Table 3.1. Descriptive Statistics for Rapid Geomorphic Assessment (RGA) Scores (Range 0-36) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (Range of 0-36)	Standard Deviation	95% Confidence Interval for Mean		Minimum (Range of 0-36)	Maximum (Range of 0-36)
				Lower Bound	Upper Bound		
Urban Impaired	4	22.44	1.23	20.48	24.40	21.25	23.50
Urban Restored	4	14.00	3.23	8.86	19.14	10.75	17.25
Ecoregion Reference	4	8.81	3.67	2.97	14.65	4.25	13.00

is not possible. Three of the four UR streams had scores indicating that at least one bed was artificially protected (2.00 for all three). Two ERR streams had averaged scores indicating single-bank protection (2.00), while only one UI stream (Third Creek) had a score of 2.00 signaling the presence of bank protection. ERR sites had the largest value for standard deviation ($\sigma = 0.47$) whereas UR had the lowest ($\sigma = 0.25$). The minimum and maximum values range was narrowest for UR sites (1.5 to 2.00) and the same for UI and ERR sites (1.00 to 2.00). The scores for bed/bank protection are visually depicted in Figure 3.3.

Degree of incision was evaluated in percentage ranges (0-10, 11-25, 26-50, 51-75, 76-100%) with lower percentages of incision receiving higher scores. At first glance, this may seem counterintuitive, but a more in-depth explanation can be found in the RGA section of the methods of this paper. For ease of relating the results, degree of incision will be discussed as the depth-of-flow to bank-height ratio. UR streams had 75% of the scores indicating flow-to-bank height ratios of greater than 0.5 (0.00, 0.50, and 1.00), while the restored portion of Beaver Creek had the lowest flow-to-bank height ratio ($x_i = 1.50$). ERR sites had higher scores (and therefore lower flow to bank height ratios), with only two sites, Big War and Mill Creek, indicating ratios greater than 50%. UI sites had the lowest ratios, ultimately indicating the greatest degree of incision, with no ratio above 0.25. ERR sites had the highest value for standard deviation ($\sigma = 1.493$) and UI the lowest ($\sigma = 0.250$). ERR sites also had the widest minimum and maximum value ranges from zero to 3.5. The degree of incision values for each reach is mirrored in Figure 3.4.

Degree of constriction was scored inversely of the degree of incision (higher percentages of incision get higher scores). Generally, UI reaches experienced the most constriction (all four values at 0.50) but even their values tracked low (~10% constriction for the observed reach). There was little to no constriction in UR streams except for Williams Creek ($x_i = 1.50$). ERR sites had no score above 0.00 (0-10% channel constriction). There existed zero deviation for UI and ERR sites. UR sites had a value of 0.75 for standard deviation. Minimum and maximum value ranges were widest for UR sites (0 to 1.50). There was no range for UI and ERR sites as scores remained constant for both groups. The values for degree of constriction recorded are represented in Figure 3.5.

Parameters for streambank erosion start a series of metrics measured for each bank, splitting the scores (each bank can have a maximum score of two). A score of zero was equivalent to no reach-length erosion, a score of 1 indicates the presence of fluvial erosion, and a score of two indicates mass wasting or geotechnical failure of the left and/or right bank. Although a combined score of 2.00 could indicate mass wasting on one bank, it would indicate no erosion on the other, which is unlikely. The presence of mass wasting is not considered until the summation is closer to a value of 3.00. With respect to UR sites, three of the sites had scores less than 2.00 indicating some fluvial erosion but usually dominated by a single bank. The restored portion of Beaver Creek is the only UR site that had a value of two, indicating fluvial erosion on both banks. Indian Creek had the highest value for ERR sites ($x_i = 1.25$), Dry and Mill Creek both had values of 1.00, and Big War Creek had a score of 0.25 representing minimal bank erosion. The impaired portion of Friar Branch had a score of 3.50, and mass wasting had occurred. The other three UI sites had values greater than or equal to 2.00 (2.75, 2.50, and 2.00) indicating fluvial erosion was occurring on each bank. The standard deviation value was lowest for ERR streams ($\sigma = 0.515$) and highest for UR sites ($\sigma = 0.736$). The width for minimum and maximum values was highest for UR streams (0.25 to 2.00) and narrowest for ERR streams (0.25 to 1.50). Figure 3.6 portrays the summed values for each stream type.

Streambank instability was scored as a percentage of each bank failing. The percentage ranges are the same as with the degree of incision and constriction. As a higher percentage of the banks are considered failing reach-length, the score increases. Two of the UR sites' scores indicate 0-10% bank instability, while the other streams (Beaver and Williams) indicate 11-25% instability for at least one bank. Williams Creek had the highest mean of the UR stream sites at 0.75. ERR sites faired similarly to UR streams although no ERR stream scored as high as Williams Creek. UI sites all had scores over 2.00 indicating much higher levels of instability. The standard deviation was largest for UR sites at a value of 0.38, followed by ERR ($\sigma = 0.29$) and UI ($\sigma = 0.13$) sites. The range for minimum and maximum values was largest for UR sites (0.00 to 0.75) and smallest for UI streams (2.25 to 2.50). Bank instability scores are shown in Figure 3.7.

The established riparian woody-vegetative cover parameter was intended to represent the amount of permanent vegetation present on the stream bank and continues the practice of assessing and scoring each bank individually. As the percentage of riparian vegetation increases, the score lowers. ERR stream sites had the lowest mean ($\mu = 0.590$) with two streams, Big War and Indian, having approximately 75% of the banks covered. Dry Creek had the least cover scoring in the 11-25% grouping. UR streams had less coverage, but still had three streams with around 25% coverage (0.50, 1.25, 1.5) with Williams featuring the least coverage (x_i = 3.75). No UI site had a value under 2.50, indicating minimal coverage. UR sites had the largest value for standard deviation (σ = 1.40), and UI streams had the smallest value at 0.43. The range for minimum and maximum values was widest for UR sites (0.50 to 3.75) and narrowest for UI sites (2.50 to 3.50). The scores tied to coverage can be seen in Figure 3.8.

The final left-to-right bank assessment for the RGA was the occurrence of bank accretion. The percentages for this parameter represent the amount of each bank that features fluvial deposition of sediment. The lowest mean value belongs to ERR streams (μ = 2.19) indicating that higher accretion occurring at the sites, Dry Creek being the exception with a score of 3.50. Accretion was lowest in UR streams with no site having a score of less than 3.50. The standard deviation was smallest for UR sites (σ = 0.24) and highest for ERR sites (σ = 1.07). ERR streams had the widest range for minimum and maximum values (1.00 to3.50) and the range was narrowest for UR streams (3.5 to 4.0). Figure 3.9 depicts the scores for stream types in relation to bank accretion.

The stage of channel evolution was the final metric evaluated for the RGA. Figure 3.1 shows the scoring distribution for this metric, and Figure 2.2 gives a visual representation of the stages of channel evolution. The field sheet can be found in Appendix A. UR sites all had average scores of 1.50 indicating being somewhere between a stage two and three stream class. All ERR sites scored as stage one streams (0.00) except for Indian Creek (x_i = 0.75) which was classified between a stage one and two. All scores for UI sites indicate stages between three and four (2.00, 2.25, 4.00, 4.00). The UR value for standard deviation was zero while UI streams had a value of 1.08. The range of minimum and maximum values was highest for UI sites (2.00 to 4.00), and UR streams had no range as all recorded values were 1.50. The stage of channel evolution scores are shown in Figure 3.10.

<u>Rapid Bioassessment Protocol</u>

The mean scores for the RBP, presented in Table 3.3., increase along a habitat disturbance gradient from poor quality UI (μ =135.13) to UR (μ = 158.50) and to the high quality ERR sites (μ = 179.75). A score of 160 or above is considered ‘optimal’ quality while a score between 110 and 159 is considered suboptimal quality (TDEC 2018). All UI stream sites have scores placin

Table 3.2. Descriptive Statistics for Individual Metrics Used in the RGA (# out of 4) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type		Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurrence of Bank Accretion	Stage of Channel Evolution
Urban Impaired	Mean	2.69	1.50	3.13	0.50	2.69	2.44	2.94	3.50	3.06
	N	4	4	4	4	4	4	4	4	4
	Std. Deviation	0.47	0.41	0.25	0.00	0.63	0.13	0.43	0.35	1.09
	Minimum	2.00	1.00	3.00	0.50	2.00	2.25	2.50	3.00	2.00
	Maximum	3.00	2.00	3.50	0.50	3.50	2.50	3.50	3.75	4.00
Urban Restored	Mean	2.50	1.88	0.75	0.38	1.25	0.31	1.75	3.69	1.50
	N	4	4	4	4	4	4	4	4	4
	Std. Deviation	1.02	0.25	0.65	0.75	0.74	0.38	1.40	0.24	0.00
	Minimum	1.75	1.50	0.00	0.00	0.25	0.00	0.50	3.50	1.50
	Maximum	4.00	2.00	1.50	1.50	2.00	0.75	3.75	4.00	1.50

Table 3.2. Continued

Stream Condition Type		Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody Vegetative Cover	Occurrence of Bank Accretion	Stage of Channel Evolution
Ecoregion Reference	Mean	1.25	1.69	1.63	0.00	0.94	0.25	0.69	2.10	0.19
	N	4	4	4	4	4	4	4	4	4
	Std. Deviation	0.54	0.47	1.49	0.00	0.52	0.29	0.59	1.07	0.38
	Minimum	0.75	1.00	0.00	0.00	0.25	0.00	0.25	1.00	0.00
	Maximum	2.00	2.00	3.50	0.00	1.50	0.50	1.50	3.50	0.75

Stage of channel evolution					
I	II	III	IV	V	VI
0	1	2	4	3	1.5

Figure 3.1. Stages of Channel Evolution Used in Assessment #9 of the RGA (Simon and Hupp 1986)

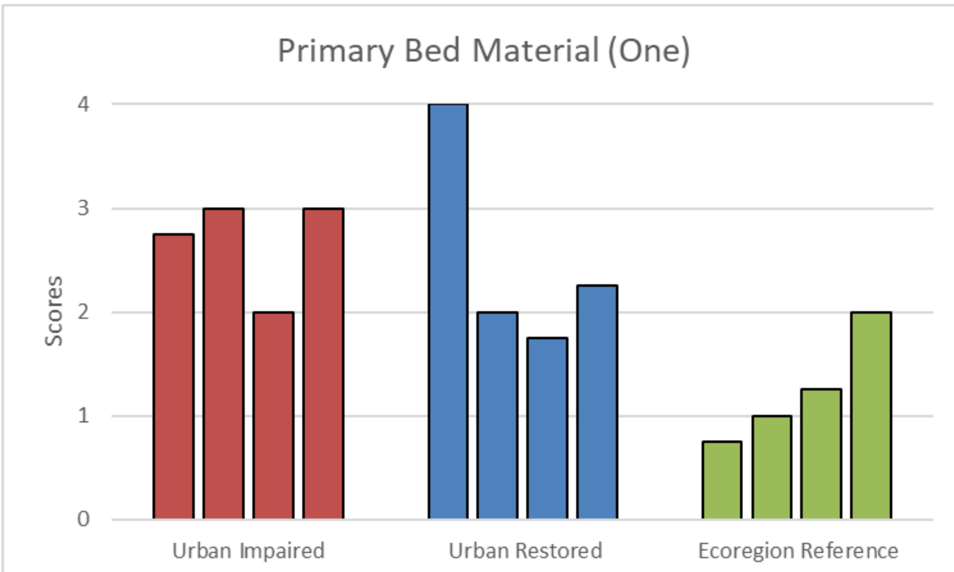

Figure 3.2. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Primary Bed Material (Assessment One of the RGA).

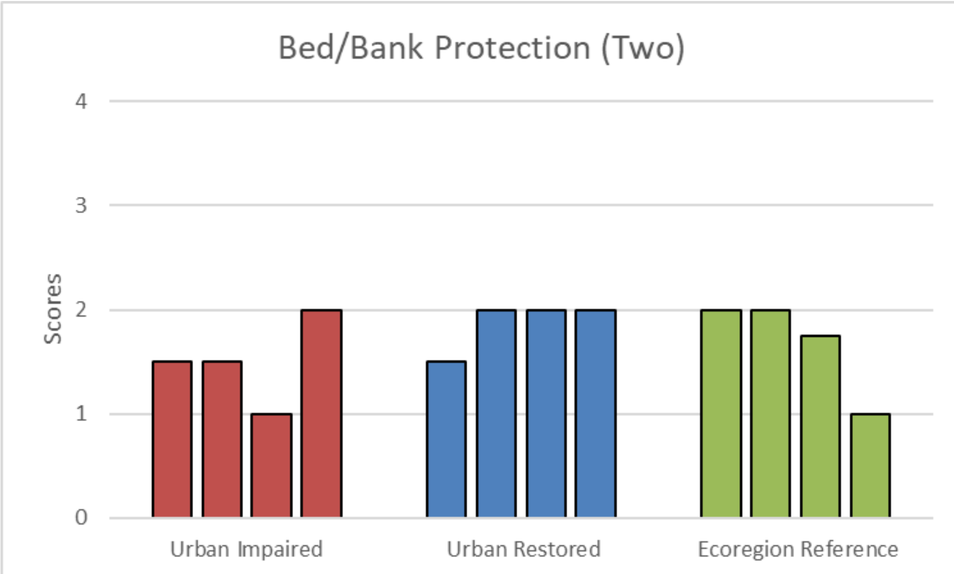

Figure 3.3. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Bed/Bank Protection (Assessment Two of the RGA).

Figure 3.4. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for the Degree of Incision (Assessment Three of the RGA).

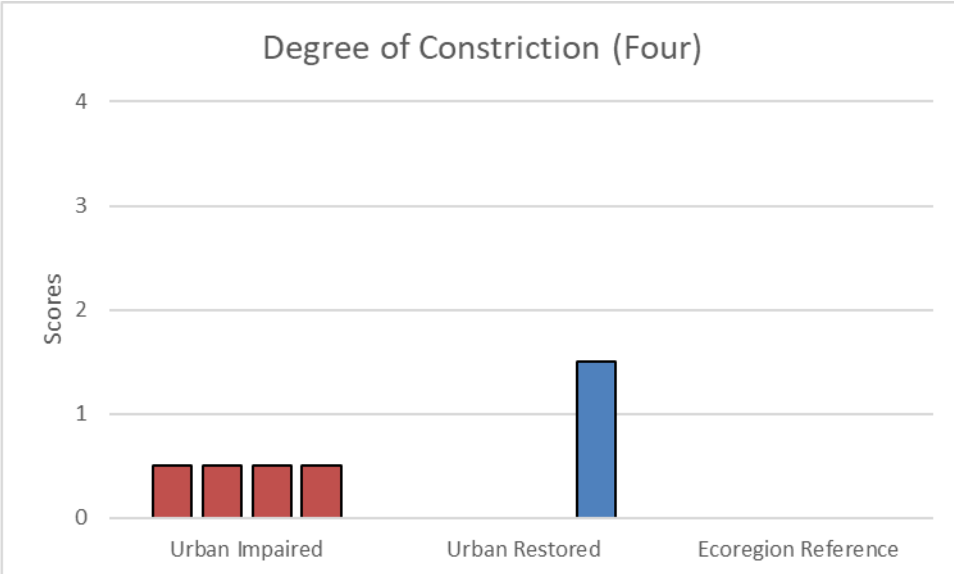

Figure 3.5. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for the Degree of Constriction (Assessment Four of the RGA).

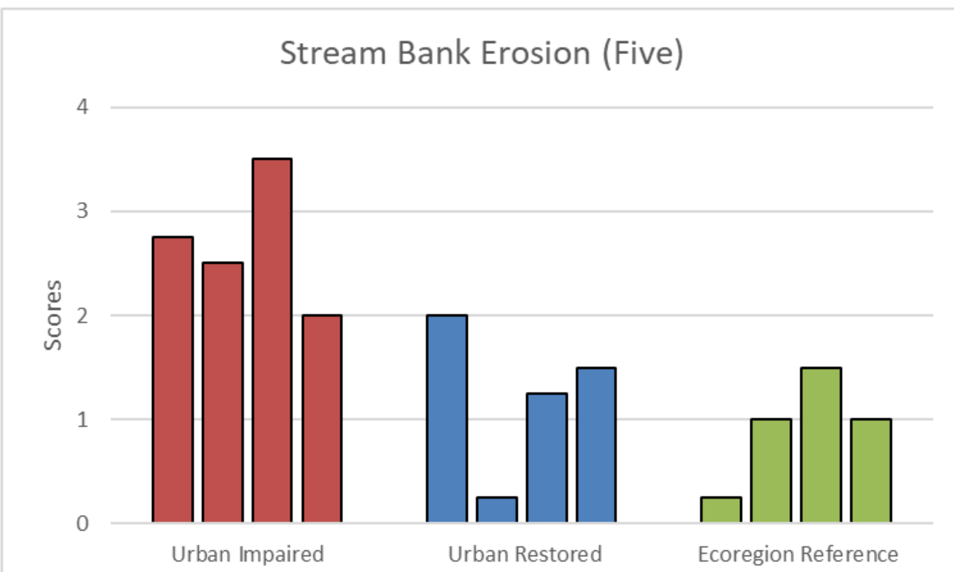

Figure 3.6. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Stream Bank Erosion (Assessment Five of the RGA).

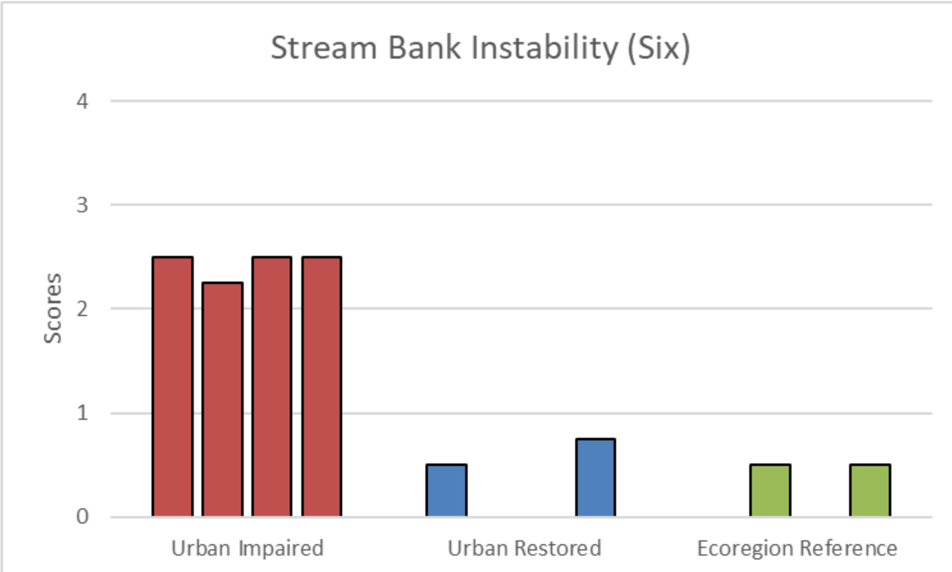

Figure 3.7. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Stream Bank Stability (Assessment Six of the RGA).

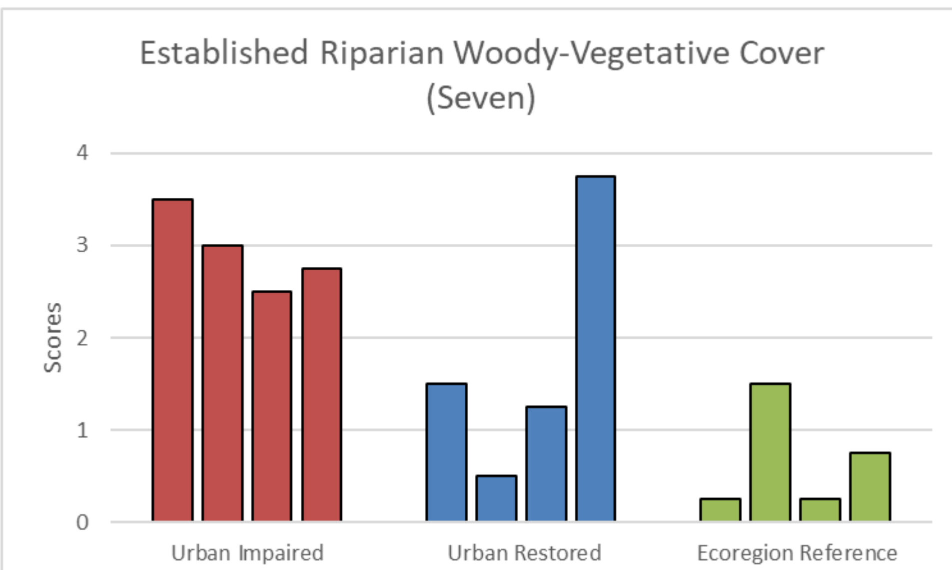

Figure 3.8. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Established Woody-Vegetative Cover (Assessment Seven of the RGA).

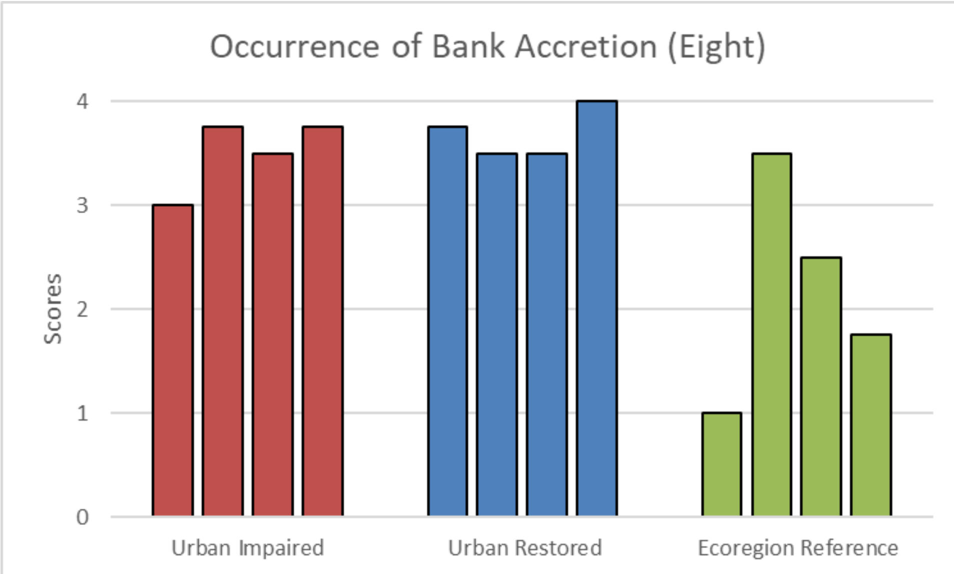

Figure 3.9. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for the Occurrence of Bank Accretion (Assessment Eight of the RGA).

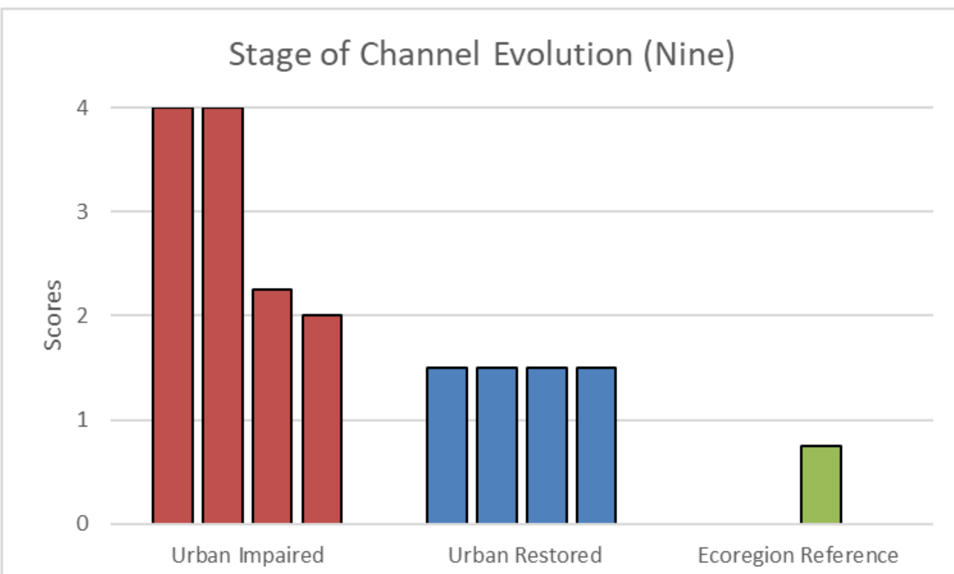

Figure 3.10. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for the Stage of Channel Evolution (Assessment Nine of the RGA).

them in the suboptimal classification. The restored portions of Friar Branch (x_i = 166.50) and Third Creek (x_i =178.00) scored optimally while Beaver and Williams Creek scored suboptimally, 152.00 and 137.50 respectively. All ERR sites performed optimally with Big War having the highest score of 193.00. The standard deviation was highest for UR sites (σ = 17.58) and smallest for UI sites (σ = 4.21). UR sites also had the largest range for the minimum and maximum value (137.50 to 178.00) while UI had the smallest (131.00 to 141.00).

The first RBP parameter measured was the epifaunal substrate/available cover. This metric was intended to represent the percentage and diversity of habitat structure (LWD, substrate material, etc.). As with all RBP metrics, the closer the score is to 20, the more ideal or optimal the in-channel circumstance. All four ERR sites scored optimally. Excluding Williams Creek suboptimal score of 13.00, all UR streams scored optimally (19.00, 19.00, and 18.00). The unrestored portion of Friar Branch was the only UI site to perform optimally (x_i = 16.00) while the other UI sites scored suboptimal (15.00, 15.00, and 13.00). The standard deviation value was highest for UR streams (σ = 2.87) and lowest for ERR sites (σ = 1.11). The range was widest for UR minimum and maximum values (13.00 to19.00) and narrowest for ERR sites (17.50 to 20.00). A depiction of scores can be found in Figure 3.11.

Embeddedness is a measure of what percentage of bed substrate is enveloped by fine-grained soils. Three of the four UR sites performed optimally (16.00,17.00, and 18.00) indicating no or little new formation. Third Creek was the only site that scored suboptimally (x_i = 14.50). ERR sites followed the same trend with three sites performing optimally (20.00, 20.00, and 17.50) and one stream, Mill Creek, scoring suboptimal (x_i = 15.00). The impacted portion of the Friar Branch was the only UI site to score optimally (x_i = 17.50), while Baker scored suboptimal (x_i = 12.00), and both the impaired portions of Beaver and Third Creek scored marginally (9.00 for both). UI stream sites had the highest standard deviation at 4.01 and UR streams had the lowest standard deviation at 1.49. The widest range for minimum and maximum values occurred at UI sites as well (from 9.00 to 17.50) and narrowest for UR streams (from 14.50 to 18.00). Figure 3.12 represents the scores, categorized by stream type. The parameter "Velocity/Depth Regime" indicates the presence of four velocity/depth regimes: slow-deep, slow-shallow, fast-deep, fast-shallow. An optimum score ($\geq$16) indicates all four regimes are present within the reach. Three of the four UR sites performed optimally (16.50, 17.50, and 18.00) while the restored portion of Beaver Creek scored in the marginal condition category (x_i = 10.50). All ERR

Table 3.3. Descriptive Statistics for Rapid Bioassessment Protocol (RBP) Scores (Range of 0-200) for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (Range of 0-200)	Standard Deviation	95% Confidence Interval for Mean		Minimum (Range of 0-200)	Maximum (Range of 0-200)
				Lower Bound	Upper Bound		
Urban Impaired	4	135.13	4.21	128.43	141.83	131.00	141.00
Urban Restored	4	158.50	17.58	130.52	186.48	137.50	178.00
Ecoregion Reference	4	179.75	10.02	163.80	195.70	171.50	193.00

(20.00, 17.50, 20.00, and 20.00) and UI (16.50, 20.00, 17.50, and 17.50) sites scored in the optimal category. UR sites had the highest value for standard deviation ($\sigma = 3.47$) while ERR streams had the smallest value ($\sigma = 1.25$). The minimum and maximum range was widest for UR sites (10.50 to 18.00) and narrowest for ERR sites (17.50 to 20.00). Figure 3.13 visually illustrates these results.

For the RBP, the metric sediment deposition represents the change in point and/or mid-channel bar formation. Three-quarters of the UR sites performed optimally (19.50, 18.00, and 17.00) while only the restored portion Friar Branch scored suboptimal ($x_i = 15.50$). Excluding Mill Creek ($x_i = 15.00$) all ERR sites (19.00, 20.00, and 18.00) scored optimally with respect to the presence of increased deposition. With respect to UI sites, Friar Branch scored optimally ($x_i = 17.50$), Baker and Third Creek scored suboptimal (13.50 and 13.00 respectively), and Beaver Creek scored marginally ($x_i = 10.00$). The standard deviation value was highest for UI sites ($\sigma = 3.08$) and lowest for UR streams at 1.68. UR and ERR streams had the narrowest range for minimum and maximum values at a width of four. The values for sediment deposition are shown in Figure 3.14.

Channel flow status is a parameter that represents the normal water elevation in-stream relative to bank height. All UR streams performed optimally (17.50, 18.50, and 19.50) except for Williams Creek ($x_i = 13.50$). All ERR streams scored in the optimal range (18.50, 16.50, 17.00, and 18.00). Three of the UI streams performed suboptimal (13.50, 11.00, and 11.50) while Baker Creek scored marginally (x_i = 8.50). ERR streams had the lowest value for standard deviation (σ = 0.913) while UR sites had the largest value (σ = 2.630). The width for maximum and minimum values is widest for UR streams (13.50 to 19.50) and smallest for ERR streams (16.50 to 18.50). Figure 3.15 illustrates the scoring regime for channel flow status.

The habitat parameter channel alteration indicates whether channelization, dredging, or another form of artificial change has occurred within the stream reach. With respect to UR sites, Beaver and Williams Creek scored suboptimal (15.00 and 12.50) while Friar Branch and Third Creek scored optimally (16.50 and 20.00). Excluding Dry Creek (x_i = 14.50) which was categorized as being in suboptimal condition, all ERR scored optimally (19.50, 20.00, and 20.00). Three of the four UI sites scored optimally (19.50, 17.00, and 18.00) while the impacted portion of Friar Branch scored suboptimal (x_i = 12.50). UR sites had the highest standard deviation at 3.14 and ERR had the lowest at 2.68. The width of the range for minimum and maximum values was smallest for ERR sites (14.50 to 20.00) and widest for UR sites (12.50 to 20.00). A visual representation of the scores, separated by stream type, can be observed in Figure 3.16.

The frequency of riffles (or bends) parameter scoring is based on a ratio of the distance riffle to riffle divided by stream width. Optimal scoring typically indicates a ratio of less than 7:1. Suboptimal scoring represents a ratio between 7 and 15. For UR streams, Friar Branch (x_i = 18.00) and Williams Creek (x_i = 17.00) scored optimally, while Beaver (x_i = 13.50) and Third Creek (x_i = 15.50) performed suboptimal. All ERR sites scored in the optimal range (20.00, 19.50, 19.50, and 19.00). The standard deviation was highest between UR sites (σ = 1.96) and lowest for ERR sites (σ = 0.41). Additionally, the width for minimum and maximum values was widest for UR streams (13.50 to 18.00) and narrowest for ERR streams (19.00 to 20.00). Figure 3.17 shows the scores for the frequency of riffle and bend mesohabitat.

Bank stability is the first of three parameters that were measured for each bank and was visually scored on the percentage of erosional processes occurring per bank. Friar Branch and Third Creek both scored optimally at 18.00, as did Beaver Creek at 16.00, but Williams Creek scored suboptimal (x_i = 15.00). Three of the UI streams performed suboptimally (11.00, 11.00, and 11.50) indicating that 5-30% of the bank features erosion, and the impacted portion of Friar Branch scored marginally (x_i = 9.50). All ERR streams scored optimally with respect to bank stability (18.50, 17.00, 17.00, and 18.50). UR streams had the highest standard deviation at 1.50 while the standard deviation values for UI and ERR streams were the same ($\sigma = 0.87$). The minimum and maximum value range was widest for UR streams (15.00 to 18.00) and smallest for ERR sites (17.00 to 18.50). A representation of the scores for bank stability can be found in Figure 3.18.

Vegetative protection is scored on the percentage of bank and adjacent riparian area that is covered with native vegetation. It, like bank stability and riparian vegetative zone width, was scored for each bank. Williams Creek ($x_i = 9.50$) scored marginally, Beaver Creek scored suboptimal ($x_i = 15.50$) and the remaining two UR streams, Friar Branch and Third Creek, performed optimally (16.00 and 17.50). ERR sites all scored optimally (19.00, 16.00, 18.00, and 17.00). Three of the four UI sites scored suboptimal (15.00, 15.00, and 13.00) while the impacted portion of Friar Branch scored in the marginal condition category ($x_i = 8.50$). ERR had the lowest value for the standard deviation ($\sigma = 1.29$). UR sites had the highest value for standard deviation at 3.52. Additionally, minimum and maximum values had the widest range for UR streams (9.50 to 17.50) and narrowest for ERR streams (16.00 To 19.00). Figure 3.19 shows the scores for each stream type for vegetative protection.

The intention of measuring the riparian vegetative zone width is assessing the effect of human activities on the riparian zone. The UR streams Beaver and Williams scored marginally (7.50 and 6.00), Friar Branch score suboptimal ($x_i = 12.50$), and Third Creek scored optimally ($x_i = 18.50$). Big War scored optimally ($x_i = 18.50$), but all other ERR scored suboptimal (13.00, 15.50, and 11.50). With respect to UI sites, Baker Creek scored suboptimal ($x_i = 11.50$) while the remaining sites scored marginally (9.00, 6.00, and 7.50). UR streams had the highest value for standard deviation ($\sigma = 5.65$). Widths for minimum and maximum values were greatest for UR streams (6.00 to 18.50) and the smallest for UI sites (6.00 to 11.50). The scores recorded for the riparian vegetative zone width are shown in Figure 3.20.

<u>Tennessee Stream Quantification Tool Metrics</u>

Descriptive statistics for the TNSQT are provided in three ways. First, each individual metric recorded is presented. There are two caveats as follows: individual metrics listed under the physiochemical and biological categories are not included, as they are covered more in-depth in Fisher (2019) and will be summarized in the Discussion section. Riparian data is represented under the results of the modified EMAP protocols. The second presentation of the TNSQT data

Table 3.4. Descriptive Statistics for Epifaunal Substrate/Available Cover for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	14.75	1.26	13.00	16.00
Urban Restored	4	17.25	2.87	13.00	19.00
Ecoregion Reference	4	18.88	1.11	17.50	20.00

Table 3.5. Descriptive Statistics for Embeddedness for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	11.88	4.01	13.00	16.00
Urban Restored	4	16.38	1.49	14.50	18.00
Ecoregion Reference	4	18.13	2.39	15.00	20.00

Table 3.6. Descriptive Statistics for Velocity/Depth Regime for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	17.88	1.49	9.00	17.50
Urban Restored	4	15.63	3.47	10.50	18.00
Ecoregion Reference	4	19.38	1.25	17.50	20.00

Table 3.7. Descriptive Statistics for Sediment Deposition for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	13.50	3.08	10.00	17.50
Urban Restored	4	17.50	2.63	13.50	19.50
Ecoregion Reference	4	18.00	2.16	15.00	20.00

Table 3.8. Descriptive Statistics for Channel flow status for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	10.75	1.55	8.50	12.00
Urban Restored	4	17.25	2.63	13.50	19.50
Ecoregion Reference	4	17.50	0.91	16.50	18.50

Table 3.9. Descriptive Statistics for Channel Alteration for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	16.75	3.01	12.50	19.50
Urban Restored	4	16.00	3.14	12.50	20.00
Ecoregion Reference	4	18.50	2.68	14.50	20.00

Table 3.10. Descriptive Statistics for Frequency of Riffles (or bends) for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	17.50	0.91	16.50	18.50
Urban Restored	4	16.00	1.96	13.50	18.00
Ecoregion Reference	4	19.50	0.41	19.00	20.00

Table 3.11. Descriptive Statistics for Bank Stability for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	10.75	0.87	9.50	11.50
Urban Restored	4	16.75	1.50	15.00	18.00
Ecoregion Reference	4	17.75	0.87	17.00	18.50

Table 3.12. Descriptive Statistics for Vegetative Protection for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	12.88	3.07	8.50	15.00
Urban Restored	4	14.63	3.52	9.50	17.50
Ecoregion Reference	4	17.50	1.29	16.00	19.00

Table 3.13. Descriptive Statistics for Riparian Vegetative Zone Width for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# out of 20)	Standard Deviation	Minimum (# out of 20)	Maximum (# out of 20)
Urban Impaired	4	8.50	2.35	6.00	11.50
Urban Restored	4	11.13	5.65	6.00	18.50
Ecoregion Reference	4	14.63	3.07	11.50	18.50

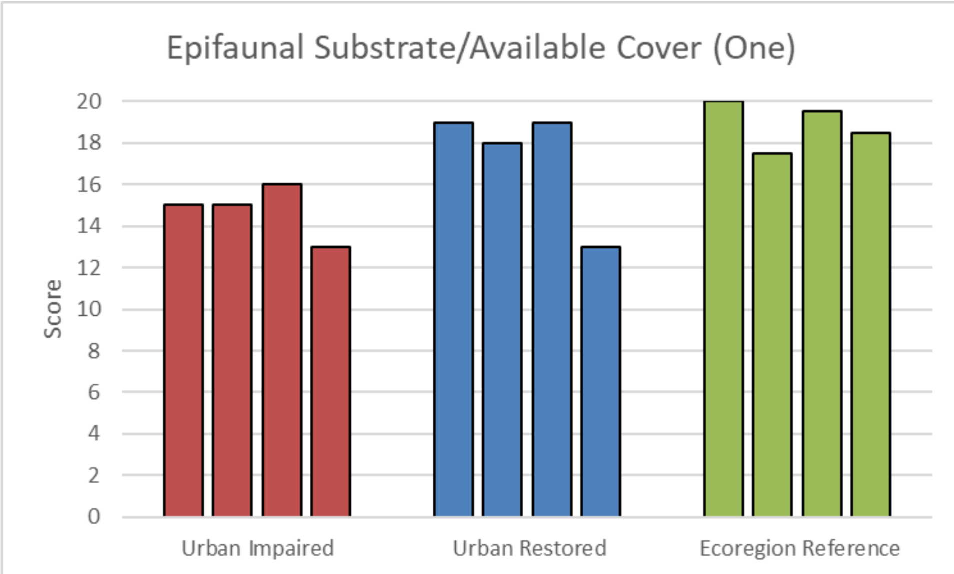

Figure 3.11. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Epifaunal Substrate/Available Cover (Assessment One of the RBP).

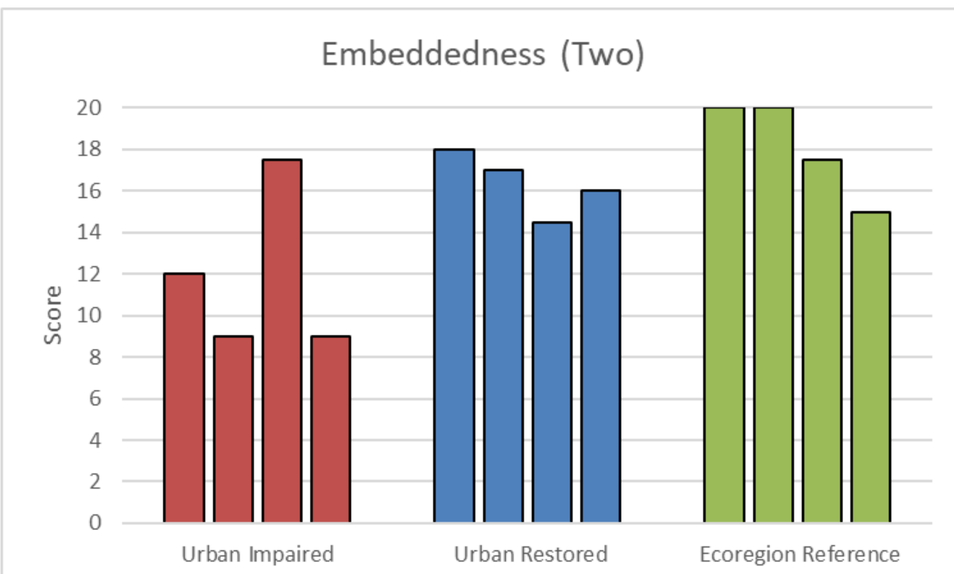

Figure 3.12. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Embeddedness (Assessment Two of the RBP).

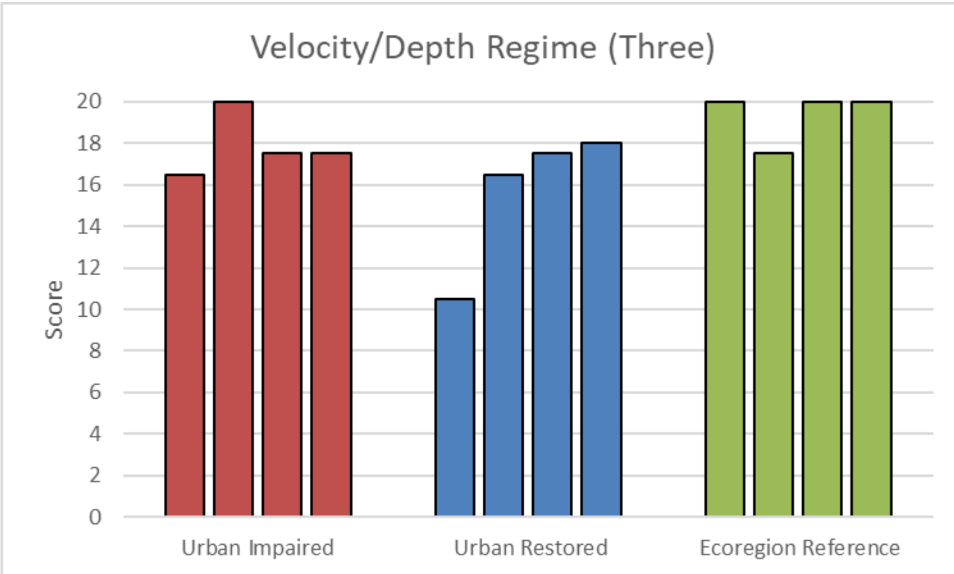

Figure 3.13. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Velocity/Depth Regime (Assessment Three of the RBP).

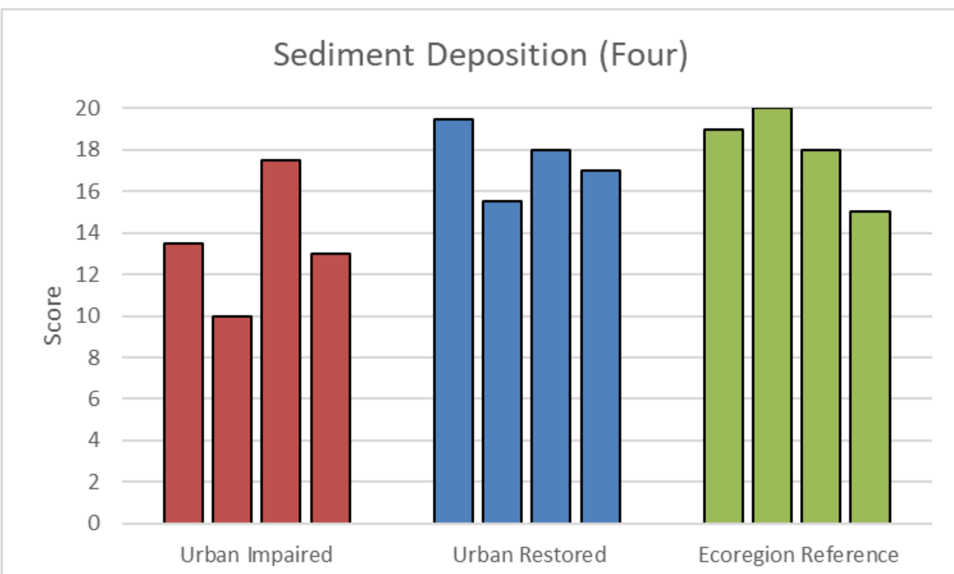

Figure 3.14. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Sediment Deposition (Assessment Four of the RBP).

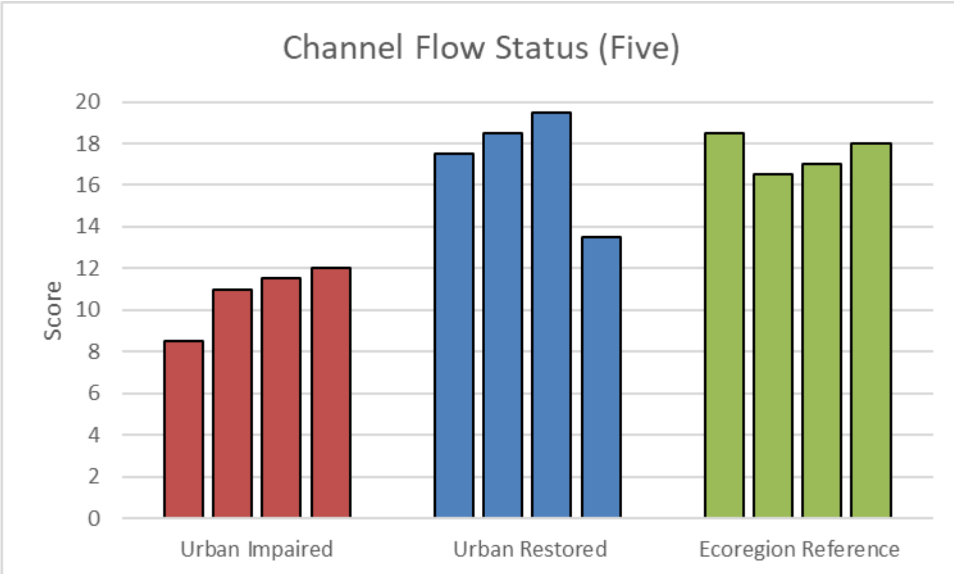

Figure 3.15. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Channel Flow Status (Assessment Five of the RBP).

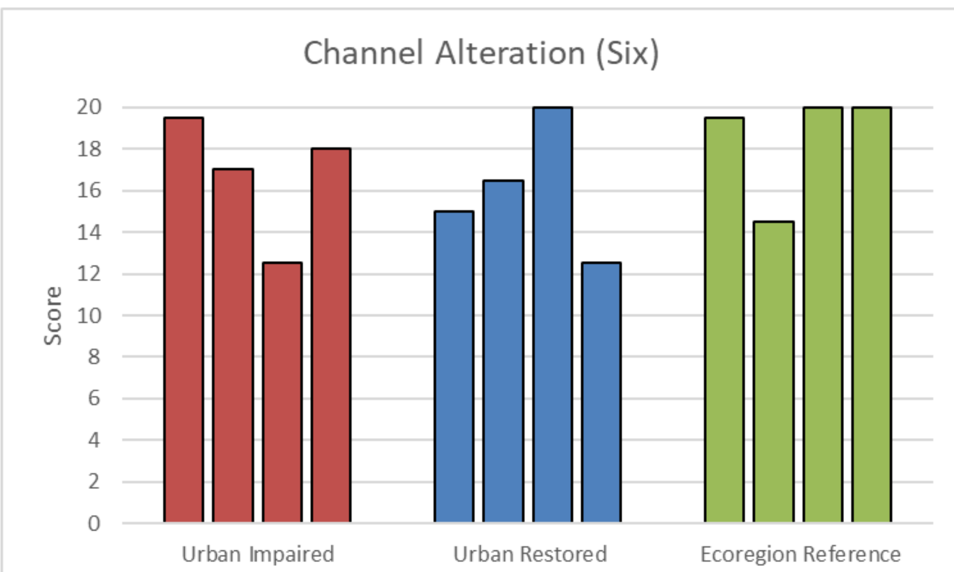

Figure 3.16. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Channel Alteration (Assessment Six of the RBP).

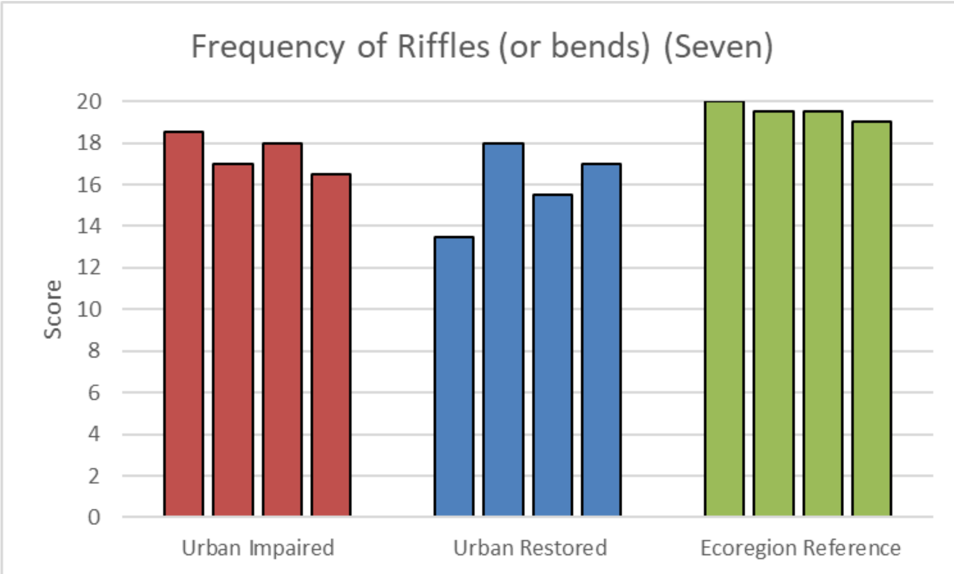

Figure 3.17. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for the Frequency of Riffles (or bends) (Assessment Seven of the RBP).

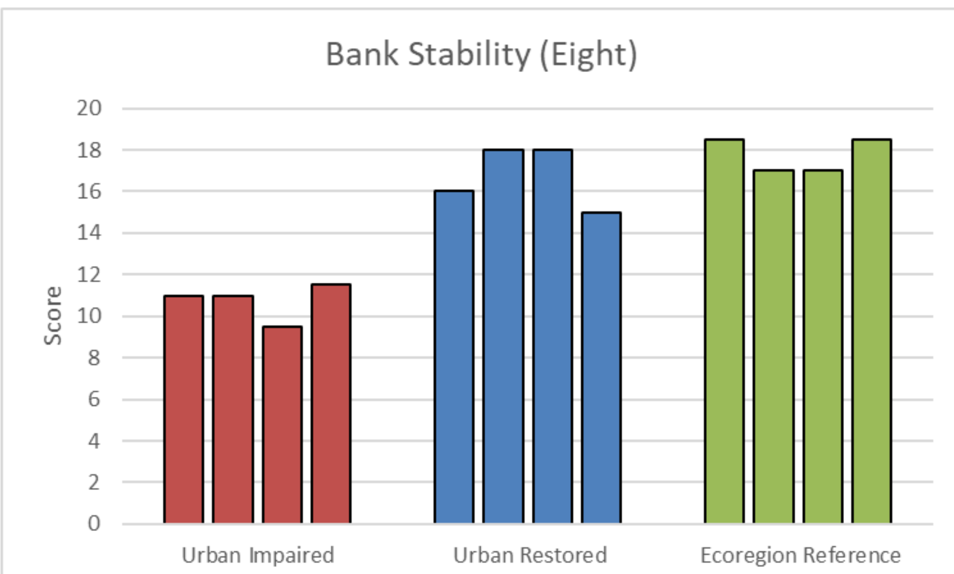

Figure 3.18. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Bank Stability (Assessment Eight of the RBP).

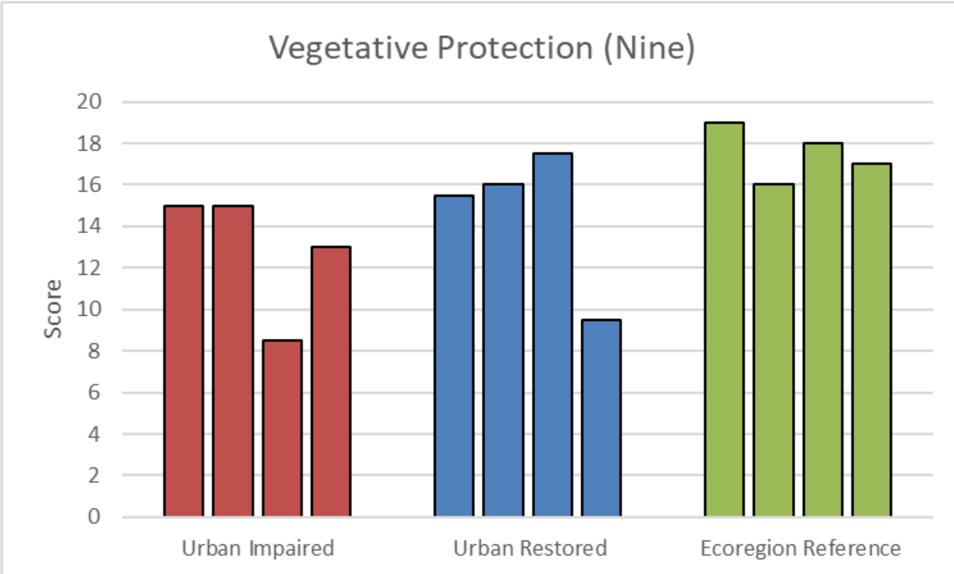

Figure 3.19. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Vegetative Protection (Assessment Nine of the RBP).

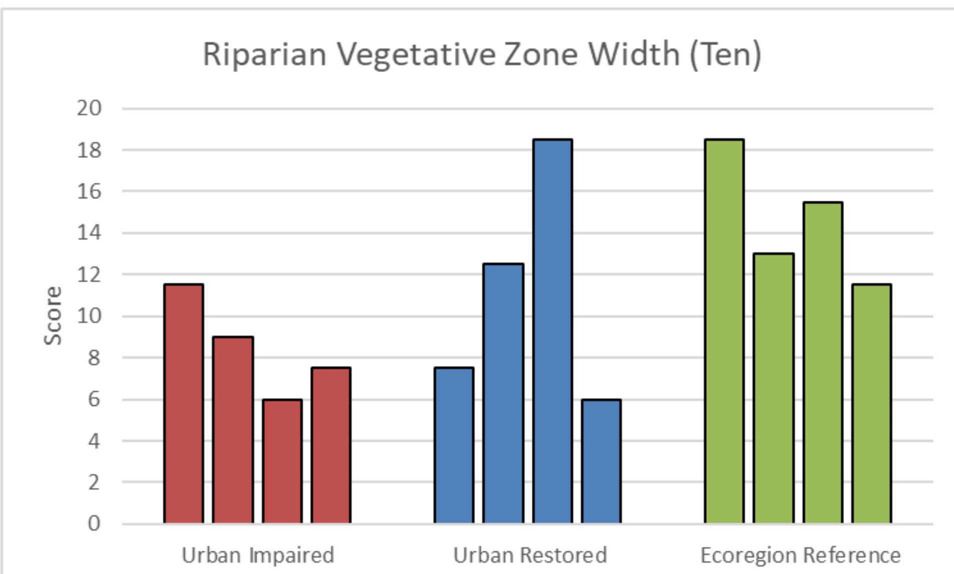

Figure 3.20. Score Representation for Urban Impaired, Urban Restored, and Ecoregion Reference Sites for Riparian Vegetative Zone Width (Assessment Ten of the RBP).

is in the form of the rollup up score. Finally, the results for the existing condition score (ECS)are provided, which constitutes the rolled-up score from the five functional categories. The scoring scale for all TNSQT data, unless otherwise noted, is as follows: not function (0.00 – 0.29), functioning-at-risk (0.30 – 0.69), and functioning (0.70 – 1.00).

The watershed land use runoff score (Table 3.14) is meant to characterize potential impacts from land use disturbances, such as hydromodification, agricultural erosion, and other impacts within a stream's catchment. The calculation is explained in the methodology but, essentially, the closer the ratio is to 1.00, the more unimpacted and forested the land is. With respect to UR streams, Beaver Creek and Friar Branch scored as non-functioning (0.24 for both), and Third and Williams Creek scored as functioning-at-risk (0.30 and 0.48). Excluding the impaired portion of Beaver Creek (x_i = 0.59) all UI stream sites scored in the non-functioning classification. All ERR streams, except Big War (x_i = 0.61), scored as functioning (0.84, 0.84, and 0.81). ERR and UR sites had the same and lowest standard deviation (σ = 0.11) while UI had a standard deviation of 0.19. The range for minimum and maximum values is largest for UI streams (0.18 to 0.59) and smallest for ERR sites (0.61 to 0.84)

The entrenchment ratio represents a stream's connection to the floodplain, and it is the flood-prone width divided by the bankfull width of the channel. Entrenchment ratios are also

Table 3.14. Descriptive Statistics for Watershed Land Use Runoff Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (Range of 0.00-1.00)	Standard Deviation	95% Confidence Interval for Mean		Minimum (Range of 0.00-1.00)	Maximum (Range of 0.00-1.00)
				Lower Bound	Upper Bound		
Urban Impaired	4	0.31	0.19	0.01	0.61	0.18	0.59
Urban Restored	4	0.32	0.11	0.13	0.50	0.24	0.48
Ecoregion Reference	4	0.78	0.11	0.60	0.95	0.61	0.84

Table 3.15. Descriptive Statistics for Entrenchment Ratio (ft/ft) Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	2.30	0.21	1.98	2.63	2.20	2.61
Urban Restored	4	2.20	0.00	2.20	2.20	2.20	2.20
Ecoregion Reference	4	2.00	0.25	1.60	2.39	1.71	2.20

integral to defining stream type per Rosgen (1994, 1996). Almost all streams across stream condition types had entrenchment ratios greater than or equal to 2.20 signaling a low entrenchment and good connectivity to the floodplain. The exceptions were the ERR streams Big War (x_i = 1.71) and Dry Creek (x_i = 1.87). As seen in Table 3.15, all UR values were equal to 2.20 there was no standard deviation. ERR stream sites had the largest standard deviation at 0.25. There was no minimum and maximum range for UR and ERR had the widest range (1.71 to 2.20).

The possible score ranges for the BEHI assessment are as follows: Very Low Adjective Hazard – 5-9.5; Low Adjective Hazard – 10-19.5; Moderate Adjective Hazard – 20-29.5; High Adjective Hazard – 30-39.5; Very High Adjective Hazard – 40-45; Extreme Adjective Hazard – 46-50. Williams Creek is the only UR stream site that scored in the moderate adjective hazard category (x_i = 23.00) while the remainder scored in the low adjective hazard category (15.00, 15.00, and 18.00). All UI sites scored as being subject to moderate adjective hazard (22.00, 29.00, and 24.00) except for Baker Creek (x_i = 16.00). Indian Creek scored in the high adjective hazard category (x_i = 31.00) while the other three ERR sites scored in the moderated category (23.00, 20.00, and 27.00). Per Table 3.16, UR sites had the smallest standard deviation (σ = 3.80) and UI sites had the largest at 5.70. Similarly, UR had the narrowest range of minimum and maximum values (15.00 to 23.00) while UI sites had the largest (16.00 to 29.00).

Table 3.16. Descriptive Statistics for Bank Erosion Hazard Index (BEHI) Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (Range of 0-45)	Standard Deviation	95% Confidence Interval for Mean		Minimum (Range of 0-45)	Maximum (Range of 0-45)
				Lower Bound	Upper Bound		
Urban Impaired	12	22.81	5.70	13.74	31.87	16.00	29.00
Urban Restored	12	17.67	3.80	11.62	23.72	15.00	23.00
Ecoregion Reference	12	25.13	4.64	17.75	32.52	20.00	31.00

Percent streambank erosion is, as the name indicates, the amount of bank erosion in linear feet divided by the reach length (*100). The scoring range with respect to the general TNSQT scoring of functioning, functioning-at-risk, and not functioning is as follows: 0.00-9.00, 9.10 – 25.9, and 26.00 - > 40.00%. The impaired portion of Friar Branch scored in the not-functioning category (x_i = 36.00) while the remainder of the UR streams scored functioning-at-risk (12.00, 12.00, and 9.00). The impaired portion of Third Creek scored as functioning-at-risk (x_i = 12.00) while the three other UI streams scored as not-functioning (37.00, 26.00, and 30.00). All ERR streams scored as not functioning (36.00, 36.00, and 55.00) except Indian Creek (x_i = 14.00). The smallest standard deviation belonged to UI sites (σ = 10.53) while the largest belonged to ERR stream sites (σ = 16.76), as seen in Table 3.17. The width for the range of minimum and maximum values was similar for UR and ERR sites (40.00 versus 41.00) but was lowest for UI stream sites (12.00 to 37.00).

The TNSQT uses a calculated p-value to represent prevailing bed material, but using the median, D_{50}, seemed like a clearer representation to evaluate, and a visual representation of the associated descriptive statistics can be found in Table 3.18. A USGS spreadsheet tool is suggested for the computation (Potyondy and Bundy 2002). The UR sites Beaver and Williams Creek had D_{50} scores indicating a bed of pebble gravel (0.16 and 0.30) while Friar Branch and Third Creek had scores in the granule gravel classification. With respect to UI sites, Beaver

Creek was comprised primarily of very coarse sand (x_i = 0.06) while the other three streams were in the granule gravel classification (0.12, 0.08, and 0.10). Three of the ERR had D_{50} values in the granule gravel category (0.14, 0.09, and 0.11) while Dry Creek had a value in the pebble gravel class (x_i = 0.19). Concerning standard deviations, UI sites had the smallest value (σ = 0.03) while UR had the greatest (σ = 0.09). Likewise, the range for minimum and maximum values widest for UR stream sites (0.09 to 0.30) and narrowest for UI stream sites (0.06 to 0.12).

The measure of (LWD) was simply a count of eligible in-channel pieces as defined in the methodology. The TNSQT scores 0-3 pieces as non-functioning, 4-8 pieces as functioning-at-risk, and greater than or equal to nine as functioning for streams in Tennessee Ecoregion 67. For this metric, all streams scored as functioning, although Williams Creek (x_i = 10.00) and the impaired version of Third Creek were closer to the functioning-at-risk category (x_i = 12.00). Between condition types, the mean was lowest for UI stream sites (μ = 20.75), increasing in UR stream sites (μ = 31.75) towards reference site conditions (μ = 41.75). The standard deviation (Table 3.19) was the highest UR sites (σ = 20.27) and smallest for UI sites (σ = 6.34). UR stream sites had the largest range of values (10.00 to 50.00) and UI the smallest (12.00 to 27.00).

Sinuosity was scored based on valley type. The streams surveyed were located in unconfined alluvial valleys. The TNSQT scores as follows: not-functioning - <1.20 | >1.50; functioning-at-risk – 1.41 to 1.50; functioning – 1.20-1.40. With this scoring, Baker Creek (x_i = 1.20) was the only functioning reach. The mean score was highest for UI sites (μ = 1.22), with UR and UI sites having the same mean (μ = 1.05). UR sites had the lowest standard deviation (σ = 0.06), while UI sites had the highest (σ = 0.22). As seen in Table 3.20, the range of values was largest for UI streams (1.04 to 1.53) and the smallest for UR streams (1.00 to 1.13).

Like sinuosity, the slope is used to help identify the Rosgen (1996) stream type in the TNSQT. Unlike sinuosity, channel slope does not factor into the overall scoring of the TNSQT. Because of this, there is no set of functioning score criteria for it. Per Table 3.21, UR streams had the lowest mean (μ = 0.26%) followed by ERR streams (μ = 0.50%) and then UI streams (μ = 0.55%). The mean for UI streams was skewed heavily by the impaired portion of Third Creek which had a slope of 1.4%. The standard deviation was highest for UI streams (σ = 0.57) and lowest for UR streams (σ = 0.19). UI streams had the widest range for minimum and maximum values (0.20 to 1.40) while UR streams had the smallest (0.10 to 0.44).

Table 3.17. Descriptive Statistics for Percent Stream Bank Erosion (%) Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (%)	Standard Deviation	95% Confidence Interval for Mean		Minimum (%)	Maximum (%)
				Lower Bound	Upper Bound		
Urban Impaired	4	26.25	10.53	9.49	43.00	12.00	37.00
Urban Restored	4	17.25	12.58	-2.77	37.27	10.00	50.00
Ecoregion Reference	4	35.25	16.76	8.58	61.92	14.00	55.00

Table 3.18. Descriptive Statistics for Bed Particle Size (D_{50}) (in) at Riffles for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (in)	Standard Deviation	95% Confidence Interval for Mean		Minimum (in)	Maximum (in)
				Lower Bound	Upper Bound		
Urban Impaired	4	0.09	0.03	0.05	0.13	0.06	0.12
Urban Restored	4	0.17	0.09	0.02	0.32	0.09	0.30
Ecoregion Reference	4	0.13	0.04	0.06	0.20	0.09	0.19

Table 3.19. Descriptive Statistics for Large Woody Debris (LWD) (# of Pieces/Reach) In-Channel for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (# of Pieces/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (# of Pieces/Reach)	Maximum (# of Pieces/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	20.75	6.34	10.65	30.66	12.00	27.00
Urban Restored	4	31.75	20.27	-0.51	64.01	10.00	50.00
Ecoregion Reference	4	41.75	13.48	21.31	41.52	22.00	52.00

The width-to-depth ratio is a measure used to define the potential degree of incision and is used a s a key parameter in the Rosgen (1996) stream classification system. A score of 12.00 separates Rosgen stream types "A", "G", and "E" streams from "B", "C", and "F" types. All UR streams, except Friar Branch (x_i = 15.20), had values below twelve (7.00, 10.13, and 9.44) All UI sites had values under 12.00 (9.40, 11.20, 6.47, 7.53). Dry Creek was the only ERR stream site with a WDR lower than 12.00 at 10.70. The standard deviation was the largest for ERR sites at 19.57 and lowest for UI sites (σ = 2.09). The range for minimum and maximum values (see Table 3.22) was largest for ERR sites (10.70 to 51.97) and smallest for UI sites (6.47 to 11.20).

Stream power is a representation of the amount of available energy within a designated stream channel length based on flow (a specified discharge) and slope relative to the channel length. The flow chosen to the stream power calculations was the two-year return frequency discharges, which in fluvial geomorphology is considered the channel forming flow (Knighton 1998). The mean of UI streams was the lowest (μ = 39.32 W/ft^2), increasing in UR streams (μ = 48.70 W/ft^2) towards ERR stream sites (μ = 83.99 W/ft^2). This trend continues between UI, UR, and ERR streams with standard deviation values of 29.75, 50.93, and 102.76 respectively. The widths of the confidence interval were smallest for UI streams (-8.02 to 86.66) and largest for ERR sites (-79.52 to 247.50). UI stream sites had the narrowest range for minimum and maximum values (18.98 to 83.50 W/ft^2) while ERR sites had the widest (22.02 to 237.52 W/ft^2)

(Table 3.23). The higher variance may be due to the fact that each site is unique in its stream power from the drainage area size (a surrogate for flow) and slope.

The pool-spacing ratio is the distance from the deepest point of one pool to another divided by bankfull width. The scoring scheme associated with the TNSQT is as follows: not functioning - ≤ 1.00-1.8 | ≥ 6.20; functioning-at-risk – 1.90-2.90 | 5.10-6.10; functioning – 3.00-5.00. With respect to UR sites, Friar Branch and Williams Creek were considered functioning (4.60 and 3.50), Third Creek was considered functioning-at-risk (x_i = 5.10), and Beaver Creek was considered not functioning (x_i =18.50). The impaired portion of Third Creek was considered functioning (x_i = 4.60) while all other UI stream sites were functioning-at-risk (2.00, 5.60, and 5.80). Regarding ERR stream sites, Big War and Mill Creek scored as functioning (3.50 and 3.00) while Dry Creek scored as functioning-at-risk (x_i = 2.80) and Indian Creek scored as not functioning (x_i = 1.60). The standard deviation, per Table 3.24, was smallest for ERR sites (σ = 0.81) and largest for UR sites (σ = 7.93). The range of values is widest for UR sites (3.50 to 18.50) and the smallest for ERR sites (1.60 to 3.50).

Like the PSR, the pool-depth ratio (PDR) is a measure of bedform diversity. The PDR is calculated by dividing the maximum bankfull pool depth by the mean bankfull riffle depth. The scoring regime related to the TNSQT is as follows: not functioning - ≤ 1.00 – 1.42; functioning-at-risk – 1.43 – 1.99; functioning - ≥ 2.00. Functioning UR streams included Beaver (x_i = 2.10) and Williams (x_i =2.80) Creek, while both Friar Branch and Third Creek scored as not functioning (1.20 and 0.70). UI site Friar Branch scored as functioning (x_i =2.00) while Beaver Creek scored as functioning-at-risk (x_i =1.90), and Beaver and Third Creek scored as non-functioning (0.30 and 1.40). Big War was the only ERR site to score as functioning (x_i =2.00), while Mill Creek scored as functioning-at-risk (x_i = 1.70) and both Dry and Indian Creek scored as not functioning (1.00 and 0.70). The standard deviation (see Table 3.25) was highest for UR sites (σ = 0.93) and lowest for ERR stream sites (σ = 0.60). The range of values was widest for UR sites (0.70 to 2.80) and narrowest for ERR sites (0.70 to 2.00).

The percent length of riffles per total surveyed length represents channel characteristics for bedform morphology and mesohabitat diversity. Similar to the scoring for PSR, the scoring scheme for percent riffle is as follows: not functioning - ≤ 20.00 – 27.00% | ≥ 83.00 %; functioning-at-risk – 28.00 – 37.00% | 73.00 – 82.00%; functioning – 38.00 – 72.00%.

Table 3.20. Descriptive Statistics for Reach Sinuosity (ft/ft) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	1.22	0.22	0.86	1.57	1.04	1.53
Urban Restored	4	1.05	0.06	0.95	1.14	1.00	1.13
Ecoregion Reference	4	1.05	0.07	0.94	1.15	1.00	1.14

Table 3.21. Descriptive Statistics for Reach Slope (%) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (%)	Standard Deviation	95% Confidence Interval for Mean		Minimum (%)	Maximum (%)
				Lower Bound	Upper Bound		
Urban Impaired	4	0.55	0.57	-0.35	1.45	0.20	1.40
Urban Restored	4	0.26	0.19	-0.04	0.56	0.10	0.44
Ecoregion Reference	4	0.50	0.33	-0.02	1.01	0.10	0.80

Table 3.22. Descriptive Statistics for Width-to-Depth Ratio (ft/ft) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	8.65	2.09	5.33	11.97	6.47	11.20
Urban Restored	4	10.44	3.44	4.96	15.92	7.00	15.20
Ecoregion Reference	4	23.39	19.57	-7.74	54.53	10.70	51.97

Table 3.23. Descriptive Statistics for Stream Power (W/ft^2) based on Q_2 (CFS) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (W/ft^2)	Standard Deviation	95% Confidence Interval for Mean		Minimum (W/ft^2)	Maximum (W/ft^2)
				Lower Bound	Upper Bound		
Urban Impaired	4	39.32	29.75	-8.02	86.66	18.98	83.50
Urban Restored	4	48.70	50.93	-32.35	129.74	4.26	118.76
Ecoregion Reference	4	83.99	102.76	-79.52	247.50	22.02	237.52

Table 3.24. Descriptive Statistics for Pool-Spacing Ratio (PSR)(ft/ft) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	4.50	1.75	1.72	7.28	2.00	5.80
Urban Restored	4	8.10	7.93	-3.34	19.19	3.50	18.50
Ecoregion Reference	4	2.73	0.81	1.44	4.01	1.60	3.50

Table 3.25. Descriptive Statistics for Pool-Depth Ratio (PDR) (ft/ft) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	1.40	0.78	0.16	2.64	0.30	2.00
Urban Restored	4	1.70	0.93	0.21	3.19	0.70	2.80
Ecoregion Reference	4	1.35	0.60	0.39	2.31	0.70	2.00

The only UR site to not score as functioning (45.00, 56.00, and 52.00%) was Friar Branch (x_i = 31.00%). For UI sites, Baker and Third Creek scored as functioning (63.00 and 45.00%) while Beaver Creek and Friar Branch scored as functioning-at-risk (29.00 and 37.00%). Regarding ERR stream sites, Big War and Dry Creek scored as functioning (69.00 and 61.00%) while Indian Creek scored as functioning-at-risk (x_i = 76.00%) and Mill Creek scored as not functioning (x_i =87%). The largest standard deviation value was held by UI streams (σ = 14.55) and the lowest by UR sites (σ = 10.98). Per Table 3.26, the range of values was smallest for UR streams (31.00 to 56.00%) and largest for UI sites (29.00 to 63.00%).

The bank height ratio is an indication of bank susceptibility to mass failure and relates to floodplain connectivity. It is calculated by dividing the bank height for the lowest bank by the maximum bankfull riffle depth. Scoring for the BHR is as follows: not functioning - ≥ 1.52; functioning-at-risk – 1.21-1.51; functioning - ≤ 1.20. Three of the four UR stream sites scored as functioning (1.20, 1.20, and 1.10) while Williams Creek scored functioning – at – risk (x_i = 1.40). Likewise, three of the four UI streams scored as functioning (all 1.00) while the impaired portion of Third Creek scored as functioning-at-risk (x_i = 1.30). All ERR sites scored as functioning (1.20, 0.90, 0.60, and 1.20). As seen in Table 3.27, the standard deviation was highest for ERR sites (σ = 0.29) and lowest for UR sites (σ = 0.13). The range of values was widest for ERR stream sites (0.60 to 1.20) and the same width for UR and UI sites (0.30).

In addition to the individual metrics scored for the TNSQT, the TNSQT uses the individual metric scores to roll-up into a category score based on hydrology, hydraulics, geomorphology, physiochemical, and biology. PCA analysis was utilized to assess these category scores to assess their relative contribution to computing the total existing condition score (ECS). Also, using the TNSQT rollup scores was one way to examine general relationships between geomorphic and habitat data, as most of those metrics were involved in the assessment. The first functional category is hydrology. The restored portions of Beaver Creek and Friar Branch scored as not functioning (0.25 for both), while Third and Williams Creek scored as functioning-at-risk (0.32 and 0.51). The impaired portion of Beaver Creek scored as functioning-at-risk (x_i = 0.62) while the other three UI stream sites scored as not functioning (0.19, 0.26, and 0.24). All ERR streams, except Big War (x_i = 0.64) scored as functioning (0.92, 0.88, and 0.85). The standard deviation was lowest for UR sites (0.122) and highest for UI sites

(0.197). The range of minimum and maximum scores was widest for UI streams (0.19 to 0.62) and narrowest for UR streams (0.25 to 0.51).

Hydraulics is the next category in the TNSQT rollup scoring and is intended to represent floodplain connectivity. Three of the four UR sites scored as functioning (0.70, 0.70, 0.84), while the restored portion of Williams Creek scored as functioning-at-risk (x_i = 0.43). Three of the four UI stream sites scored as functioning (all 1.00), but the impaired portion of Third Creek scored as functioning-at-risk (x_i = 0.56). All ERR sites scored as functioning (0.70, 1.00, 1.00, 0.70). The standard deviation was highest for UI sites (σ = 0.22) and the same value for UR and ERR sites (σ = 0.17). The minimum and maximum values range was largest for UI streams (0.56 to 1.00) and smallest for ERR sites (0.70 to 1.00).

The geomorphology category has the largest number within the TNSQT functional categories, having 22 function-based metrics. With respect to UR sites, all four sites performed as functioning-at-risk (0.60, 0.54, 0.61, and 0.64). The impaired portion of Beaver Creek scored as functioning (x_i = 0.71), and the other three sites performed as functioning-at-risk (0.49, 0.49, and 0.61). All ERR sites scored as functioning-at-risk (0.62, 0.50, 0.57, and 0.57). The value for the standard deviation was smallest for UR streams (σ = 0.04) and largest for UI stream sites (σ = 0.11). UI sites had the widest range for minimum and maximum values (0.49 to 0.71) while UR streams had the smallest (0.54 to 0.64).

Table 3.26. Descriptive Statistics for Percent Riffle (PERRIFF) (%) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (%)	Standard Deviation	95% Confidence Interval for Mean		Minimum (%)	Maximum (%)
				Lower Bound	Upper Bound		
Urban Impaired	4	43.50	14.55	20.35	66.65	29.00	63.00
Urban Restored	4	46.00	10.98	28.52	63.48	31.00	56.00
Ecoregion Reference	4	73.25	11.03	55.70	90.80	61.00	87.00

Table 3.27. Descriptive Statistics for Bank Height Ratio (BHR) (ft/ft) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft/ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft/ft)	Maximum (ft/ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	1.08	0.15		1.31	1.00	1.30
Urban Restored	4	1.23	0.13	1.02	1.43	1.10	1.40
Ecoregion Reference	4	0.98	0.29		1.43	0.60	1.20

Physiochemical metrics comprise the fourth functional category of the TNSQT tool. A more thorough analysis of the data collected for the physiochemical and biological TNSQT requirements of this study can be found in Fisher (2019). All UR stream sites scored as functioning (0.92, 0.70, 0.75, and 0.87). Three of the four UI scored as functioning as well (0.92, 0.76, and 0.73) while the impaired portion of Baker Creek scored as functioning-at-risk (x_i = 0.49). All ERR sites scored as functioning (0.96, 0.80, 0.81, and 0.98). UI sites had the largest value for the standard deviation (σ = 0.18) while UR and ERR had the same value (σ = 0.10). The minimum and maximum values range was narrowest for ERR streams (0.80 to 0.98) and widest for UI sites (0.42 to 0.92).

The final functional category for the TNSQT is biology. Again, a more thorough inspection of these metrics and an expanded ecological analysis on species functional traits can be found in Fisher (2019). Regarding UR streams, Beaver Creek was the only creek to score as functioning (x_i = 0.73) while Friar Branch scored as functioning-at-risk (x_i = 0.63), and Third and Williams Creek scored as not-functioning (0.27 and 0.26). The impaired portions of Beaver Creek and Friar Branch scored as functioning-at-risk (0.45 and 0.39) while Baker and Third Creek scored as not functioning (0.15 and 0.18). Big War and Mill Creek scored as functioning (0.71 and 0.72) but the other ERR stream sites scored as functioning-at-risk (0.65 and 0.55). UR sites had the largest value for standard deviation (σ = 0.24) while ERR stream sites had the lowest (σ = 0.08). UR streams also had the widest range for minimum and maximum values (0.26 to 0.73) and ERR the narrowest (0.55 to 0.72).

The TNSQT generates the ECS that represents a cumulative measure of the TNSQT rollup scoring. It is the functional condition, whereas functional lift is the difference between the proposed condition score (PCS) using the same spreadsheet tool with metrics derived from the proposed restoration design and the ECS. . The difference between the PCS and ECS is the basis for estimating mitigation credits and potential lift or stream improvement. All UR sites scored as functioning-at-risk (0.64, 0.56, 0.56, and 0.54). The impaired portion of Beaver Creek scored as functioning (x_i = 0.70), but otherwise, the remaining UI sites scored as functioning-at-risk (0.51, 0.58, and 0.46). All ERR sites scored as functioning (0.73, 0.77, 0.76, and 0.76). The mean ECS score was highest for ERR sites (σ = 0.76) followed by UR streams (σ = 0.58) and then UI sites (σ = 0.56). The ERR standard deviation value (σ = 0.02) was lowest followed by UR streams (σ = 0.04) and then UI sites (σ = 0.10). The range for minimum and maximum values was largest for UI streams (0.46 to 0.70) and smallest for ERR stream sites (0.73 to 0.77).

<u>Modified EMAP Protocols</u>

Not all of the metrics represented in the Modified EMAP Protocols, that data was collected for, are represented here, primarily because they are featured in other sections. Many of the metrics of the protocols deal with mesohabitat diversity. The first mesohabitat parameter measured was the pool unit width which was simply the average of several width measurements taken along each pool unit. As seen in Table 3.30, pool unit width means increased from UI sites (μ = 13.38 ft.) to UR sites (μ = 17.61 ft.) with ERR streams have the largest mean for pool unit widths (μ = 26.52 ft.) The standard deviation was smallest for UR streams (σ = 4.37) and largest for ERR sites (σ = 13.14). The range of values was largest for ERR streams (13.00 to 43.33 ft.) and smallest for UR sites (13.14 to 23.50 ft.)

The average pool depth (Table 3.31) was the product of multiple depth measurements for each pool unit. UR stream sites had the highest mean for pool depth (μ = 1.54 ft.) followed by ERR streams (μ = 1.10 ft.) and UI streams (μ = 1.05 ft.). The standard deviations for all three stream condition types were similar decreasing from UI sites (σ = 0.51) to UR sites (σ = 0.50) and finally to ERR sites (σ = 0.49). The widest range of values was found in UR streams (0.88 to 2.10 ft.) and the smallest for ERR streams (0.60 to 1.73 ft.).

Similar with the pool units, riffles were measured for their unit width based on any average. The means (see Table 3.32) for riffle unit width increased from UI streams (μ = 11.83 ft.) to UR streams (μ = 14.00 ft.) and ERR sites (μ = 25.28 ft.) with the highest value. The largest standard deviation value was found in ERR streams (σ = 12.91) while UR streams had the smallest value (σ = 2.84). The range of riffle unit widths was widest for ERR streams (9.80 to 40.00 ft.) and smallest for UR streams (11.40 to 17.67 ft.).

Riffle depths were, on average, highest for ERR sites (μ = 0.56 ft.) followed by UR streams (μ = 0.46 ft.). Per Table 3.33, UI sites had the smallest mean (μ = 0.34 ft.). The standard deviation was largest for ERR streams (σ = 0.32) and the smallest for UI streams (σ = 0.09). Similarly, the range of depth values for the ERR sites was widest (0.29 to 1.00 ft.) and UI sites had the narrowest range of values (0.25 to 0.45 ft.).

The maximum pool depth is intended, like most of the modified EMAP protocol metrics, to give a better indication of the state and availability of mesohabitat variety in-channel. As seen in Table 3.34, the mean depth was shallowest for ERR sites (μ = 2.05 ft.) followed by UI sites (μ = 2.65 ft.). UR streams, on average, had the deepest pools (μ = 3.06 ft.). The standard deviation was largest among UI stream sites (σ = 1.83) while UR sites had the smallest standard deviation (σ = 0.94). The range of maximum depth values was largest for UI sites (1.20 to 5.10 ft.) and smallest for UR stream sites (1.82 to 4.00 ft.).

The average riffle depth is another representation of marking the diversity of habitat. It, like average pool depth, is the mean of several depth measurements taken at each riffle unit.

The max riffle depth measurement is intended to give an idea of the general variety and availability of riffle mesohabitat structure in-channel. The mean depth value was largest for UR sites (μ = 0.98 ft.) followed by ERR sites (μ = 0.91 ft.). Maximum riffle depths were, on average shallowest for UI stream sites (μ = 0.59 ft.). Per Table 3.35, the range of maximum depth values was largest for ERR sites (0.35 to 1.50 ft.) and the smallest for UI streams (0.45 to 0.80 ft.).

The next mesohabitat parameter measured was aquatic vegetation. This was simply a count of macrophytes and filamentous algae located in-channel for each channel unit. Vegetation provides cover and nutrients for some aquatic organisms. As seen in Table 3.36, all stream condition types had a mean of six vegetation classes per reach, largely due to a couple of sites in the UR and ERR site types having no or little vegetation. The standard deviation is largest for ERR sites (σ = 8.04), decreasing UR sites (σ = 6.48). UI sites had the smallest standard deviation at a value of 2.16. The range of values was largest for ERR sites (0.00 to 17.00) followed by UR sites (0.00 to 13.00), while UI sites had the smallest range (4.00 to 9.00).

Categorized as "big" wood in the modified EMAP protocols, pieces of woody debris greater than 0.3m were measured next, and the general descriptive statistics for that measurement are shown in Table 3.37. The unit of measurement is the number of pieces in-channel per reach. These pieces provide refuge and habitat diversity, as well as flow alteration. UR streams had the highest mean value (μ = 15.50) which was similar to ERR streams (μ = 15.00). UI sites had the lowest mean (μ = 11.00). The standard deviation was highest among UR streams (σ = 5.74) and smallest among UI sites (σ = 4.69). The range of values was smallest for UI stream sites (6.00 to 17.00) and the largest for ERR sites (9.00 to 22.00).

The presence of "small" woody debris was measured next. Both of these debris' measurements are different from LWD measurements, although some of the "big" debris measured may be also considered LWD. The unit of measurement is the number of pieces in-channel per reach. UR sites had the largest mean value (μ = 19.50) followed by ERR sites (μ = 16.75). Per Table 3.38, UI sites had the smallest mean among the three groups (μ = 14.00). The standard deviation among was largest among UI sites (σ = 6.22) and smallest among UR sites (σ = 3.11). The range of values was widest for UI streams (9.00 to 23.00) and the narrowest for UR streams (16.00 to 23.00).

Overhanging vegetation is just one measurement of cover and may serve a variety of habitat functions from shielding fish from predation to providing in-channel structure for reproduction and general refugia needs. The unit is the number of pieces per reach. As seen in Table 3.39, UR sites had the highest mean for overhanging vegetation (μ = 29.25) followed by UI sites (μ = 18.00), albeit the ERR mean was close (μ = 17.75). The standard deviation was smallest among UI sites (σ = 4.90) and largest for UR sites (σ = 6.29). The range of values was largest for UR sites (22.00 to 35.00) and smallest for UI sites (12.00 to 22.00).

The presence of undercut banks was measured next for the modified EMAP protocols. Undercut banks act as fish cover and are measured as the number of individual, unique areas available for the reach. Per Table 3.40, the mean value was highest for UR sites (μ = 18.25) while UI and ERR sites had the same mean value (μ = 15.75). The standard deviation was highest for ERR**.**

Table 3.28. Descriptive Statistics for the TNSQT Rollup Scoring for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type		Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Urban Impaired	Mean	0.33	0.89	0.58	0.73	0.29
	N	4	4	4	4	4
	Std. Deviation	0.20	0.22	0.11	0.18	0.15
	Minimum	0.19	0.56	0.49	0.49	0.15
	Maximum	0.62	1.00	0.71	0.92	0.45
Urban Restored	Mean	0.33	0.67	0.60	0.81	0.47
	N	4	4	4	4	4
	Std. Deviation	0.12	0.17	0.04	0.10	0.24
	Minimum	0.25	0.43	0.54	0.70	0.26
	Maximum	0.51	0.84	0.64	0.92	0.73
Ecoregion Reference	Mean	0.82	0.85	0.57	0.89	0.66
	N	4	4	4	4	4
	Std. Deviation	0.13	0.17	0.05	0.10	0.08
	Minimum	0.64	0.70	0.50	0.80	0.55
	Maximum	0.92	1.00	0.62	0.98	0.72

Table 3.29. Descriptive Statistics for the TNSQT Existing Condition Scores (ECS) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type				Statistic
ECS	UI	Mean		0.56
		95% Confidence Interval for Mean	Lower Bound	0.40
			Upper Bound	0.73
		Std. Deviation		0.10
		Minimum		0.46
		Maximum		0.70
	UR	Mean		0.58
		95% Confidence Interval for Mean	Lower Bound	0.50
			Upper Bound	0.65
		Std. Deviation		0.04
		Minimum		0.54
		Maximum		0.64
	ERR	Mean		0.76
		95% Confidence Interval for Mean	Lower Bound	0.73
			Upper Bound	0.78
		Std. Deviation		0.02
		Minimum		0.73
		Maximum		0.77

sites (σ = 8.26) and the smallest among UI sites (σ = 2.99). The range of values was largest for ERR stream sites (6.00 to 24.00) and smallest for UR sites (12.00 to 19.00).

Boulders provide fish coverage as well as act as flow-altering mechanisms to enhance hydraulic diversity. Boulders were identified by being 250 to 4000 mm (Kaufmann 1999). The unit of measurement was the number of boulders present in-channel per reach. The mean was highest for ERR sites (μ = 12.75) followed by UI sites (μ = 10.50) (Table 3.41). UR sites had the smallest mean (μ = 10.00). The standard deviation was smallest among UI sites (σ = 5.92) and largest for UR stream sites (σ = 9.49). The range of values was widest for UR sites (3.00 to 24.00) and smallest for UI sites (4.00 to 16.00).

The presence of artificial structures in-or-near channel is an indicator of human influence but is also a resource available for fish cover. It is also the last measurement of sheet one of the modified EMAP protocol, measured as the number of pieces available for the entire reach. The mean was highest for UR sites (μ = 5.75) followed by UI sites (μ = 3.50). As seen in Table 3.33, ERR stream sites had the lowest mean value at 2.25. The standard deviation was largest among UR sites (σ = 4.50) and smallest for UI sites (σ = 3.11). The range of values was the same for UI and ERR sites (0.00 to 7.00) and largest for UR sites (0.00 to 11.00).

Measuring the percent bedrock is the first measurement on sheet two of the modified EMAP protocols. The actual measurement was a simple count but describing it as a percentage

<u>Table 3.30. Descriptive Statistics for Pool Unit Widths (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.</u>

Stream Condition Type	N	Mean (ft.)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft.)	Maximum (ft.)
				Lower Bound	Upper Bound		
Urban Impaired	4	13.38	5.55	4.54	22.21	8.50	20.75
Urban Restored	4	17.61	4.37	10.66	24.56	13.14	23.50
Ecoregion Reference	4	26.52	13.14	5.60	47.44	13.00	43.33

Table 3.31. Descriptive Statistics for Average Pool Depth (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft.)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft.)	Maximum (ft.)
				Lower Bound	Upper Bound		
Urban Impaired	4	1.05	0.51	0.23	1.87	0.56	1.75
Urban Restored	4	1.54	0.50	0.73	2.34	0.88	2.10
Ecoregion Reference	4	1.10	0.49	0.32	1.88	0.60	1.73

Table 3.32. Descriptive Statistics for Riffle Unit Width (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft)	Maximum (ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	11.83	4.95	3.95	19.70	9.25	19.25
Urban Restored	4	14.00	2.84	9.48	18.51	11.40	17.67
Ecoregion Reference	4	25.28	12.91	4.74	45.83	9.80	40.00

of the total reach allows it to describe mesohabitat and geomorphic diversity. Bedrock was considered as any substrate greater than 4000mm and acts as a mesohabitat forming agent. UI sites had the highest mean at 12.86% followed by ERR sites at 12.05%. UR stream sites had the smallest percentage of bedrock at 6.46%. As seen in Table 3.43, the standard deviation was largest among UI sites ($\sigma = 14.59$) and the smallest among UR streams ($\sigma = 5.60$). The range was largest for ERR streams (0.00-27.78%) and smallest for UR streams (0.00 to 13.67%). Measuring percent boulder continues the investigation of bedform and mesohabitat diversity based on the percentage of substrate present in reach. Boulders are 250-4000 mm in size and alter or form mesohabitat structure. The mean value (shown in Table 3.44) was highest in ERR sites ($\mu = 14.69\%$) followed by UI sites ($\mu = 11.39\%$). The smallest mean value for percent boulder was found in UR streams ($\mu = 6.83\%$). The standard deviation was smallest among UR stream sites ($\sigma = 4.73$) and largest for ERR sites ($\sigma = 13.56$). The range of values was largest for ERR sites (0.71 to 32.22%) and smallest for UI sites (2.00 to 11.67%).

Cobble was measured as substrate 64 – 250 mm in size. The mean percentage of the cobble substrate was highest for ERR sites ($\mu = 27.03\%$) followed by UR sites ($\mu = 21.81\%$). UI sites had the smallest mean percentage ($\mu = 13.96\%$). Per Table 3.45, the standard deviation was smallest for UI sites ($\sigma = 7.30$) and largest for UR sites ($\sigma = 9.52$). The range of percentages is smallest for UI sites (7.14 to 24.30%) and largest for UR sites (11.50 to 32.50%).

Per the modified EMAP protocol, gravel is categorized as substrate from two to 64 mm. Gravel provides spawning fish and the development of invertebrates. Shown in Table 3.46, the mean percentage was the highest UI sites ($\mu = 36.78\%$) and the smallest ERR sites ($\mu = 27.04\%$). UR sites had a mean of 33.81%. The standard deviation was lowest for UI sites ($\sigma = 7.96$) and highest for UR sites ($\sigma = 14.50$). The range of percentages was widest for UR sites (22.17 to 52.50%) and narrowest for UI sites (28.57 to 46.67%).

The percentage of silt-clay substrate present was the final modified EMAP protocol to be measured. Per Table 3.47, the largest mean percentage is among UR streams ($\mu = 31.10$ %) and smallest in ERR sites ($\mu = 19.20\%$). The mean percentage for silt-clay in UI streams in 25.27%. The standard deviation is lowest among ERR sites ($\sigma = 8.35$) and highest among UR sites ($\sigma = 9.08$). The range of percentages is smallest for ERR sites (10.56 to 29.29%) and largest for UI sites (15.63 to 36.67%).

Table 3.33. Descriptive Statistics for Average Riffle Depth (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft.)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft.)	Maximum (ft.)
				Lower Bound	Upper Bound		
Urban Impaired	4	0.34	0.09	0.19	0.48	0.25	0.45
Urban Restored	4	0.46	0.12	0.27	0.65	0.33	0.62
Ecoregion Reference	4	0.56	0.32	0.06	1.06	0.29	1.00

Table 3.34. Descriptive Statistics for Maximum Pool Depth (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (ft)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft)	Maximum (ft)
				Lower Bound	Upper Bound		
Urban Impaired	4	2.65	1.83	-0.26	5.56	1.20	5.10
Urban Restored	4	3.06	0.94	1.56	4.55	1.82	4.00
Ecoregion Reference	4	2.05	1.05	0.37	3.73	0.95	3.00

Table 3.35. Descriptive Statistics for Maximum Riffle Depth (ft.) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province

Stream Condition Type	N	Mean (ft.)	Standard Deviation	95% Confidence Interval for Mean		Minimum (ft.)	Maximum (ft.)
				Lower Bound	Upper Bound		
Urban Impaired	4	0.59	0.15	0.34	0.83	0.45	0.80
Urban Restored	4	0.98	0.43	0.29	1.66	0.45	1.35
Ecoregion Reference	4	0.91	0.47	0.17	1.66	0.35	1.50

Table 3.36. Descriptive Statistics for Aquatic Vegetation (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	6.00	2.16	2.56	9.44	4.00	9.00
Urban Restored	4	6.00	6.48	-4.31	16.31	0.00	13.00
Ecoregion Reference	4	6.00	8.04	-6.80	18.80	0.00	17.00

Table 3.37. Descriptive Statistics for Wood > 0.3m (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	11.00	4.69	3.54	18.46	6.00	17.00
Urban Restored	4	15.50	5.74	6.36	24.64	12.00	24.00
Ecoregion Reference	4	15.00	5.35	6.48	23.52	9.00	22.00

Table 3.38. Descriptive Statistics for Wood < 0.3 m (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	14.00	6.22	4.11	23.89	9.00	23.00
Urban Restored	4	19.50	3.11	14.55	24.44	16.00	23.00
Ecoregion Reference	4	16.75	3.86	10.60	22.90	11.00	19.00

Table 3.39. Descriptive Statistics for Overhanging Vegetation (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	18.00	4.90	10.20	25.80	12.00	22.00
Urban Restored	4	29.25	6.29	19.24	39.26	22.00	35.00
Ecoregion Reference	4	17.75	5.56	8.90	26.60	14.00	26.00

Table 3.40. Descriptive Statistics for Undercut Banks (#/ Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	15.75	2.99	11.00	20.50	12.00	19.00
Urban Restored	4	18.25	5.91	8.85	27.65	10.00	24.00
Ecoregion Reference	4	15.75	8.26	2.60	28.90	6.00	24.00

Table 3.41. Descriptive Statistics for Number of Boulders (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	10.50	5.92	1.09	19.91	4.00	16.00
Urban Restored	4	10.00	9.49	-5.10	25.10	3.00	24.00
Ecoregion Reference	4	12.75	8.66	-1.02	26.52	1.00	21.00

Table 3.42. Descriptive Statistics for Number of Artificial Structures (#/Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (#/Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (#/Reach)	Maximum (#/Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	3.50	3.11	-1.45	8.45	0.00	7.00
Urban Restored	4	5.75	4.50	-1.41	12.91	0.00	11.00
Ecoregion Reference	4	2.25	3.20	-2.84	7.34	0.00	7.00

Table 3.43. Descriptive Statistics for Percent Bedrock (% of Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (% of Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (% of Reach)	Maximum (% of Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	12.86	14.59	-10.36	36.07	0.00	26.63
Urban Restored	4	6.46	5.60	-2.45	15.37	0.00	13.67
Ecoregion Reference	4	12.05	14.04	-10.29	34.39	0.00	27.78

Table 3.44. Descriptive Statistics for Percent Boulder (% of Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (% of Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (% of Reach)	Maximum (% of Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	11.39	6.64	0.83	21.96	4.17	18.20
Urban Restored	4	6.83	4.73	-0.69	14.35	2.00	11.67
Ecoregion Reference	4	14.69	13.56	-6.88	36.26	0.71	32.22

Table 3.45. Descriptive Statistics for Percent Cobble (% of Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (% of Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (% or Reach)	Maximum (% of Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	13.96	7.30	2.34	25.58	7.14	24.30
Urban Restored	4	21.81	9.52	6.67	36.95	11.50	32.50
Ecoregion Reference	4	27.03	7.68	14.81	39.24	17.78	35.71

Normality Tests

In order to decide what statistical analysis to conduct to examine differences in metrics, scores, etc., among the stream condition classes (UI, UR, and ERR sites), it was necessary to check all data for normality, in which the Shapiro-Wilk test was performed. The level of significance (p-value) for all tests was 0.05, or 95% confidence. Additionally, kurtosis and skewness were assessed. Kurtosis can be thought of as representing the magnitude of the peak, or alternatively, how much of the data is in the distribution's tails. Skewness is a way to represent which direction and to what magnitude data lies outside of a normal distribution. Tables 3.2.1 through 3.2.8 display the results from those tests.

Of the 14 individual TNSQT metrics measured, six were normally distributed. The BEHI data was normal with a positive skew and a negative kurtosis (p = 0.60, 0.19, -0.98). The D_{50} data was non-normally distributed and had relatively-high positive skew and kurtosis values (p = 0.02, 1.85, 4.09). The data for LWD was normally distributed with a positive skew and negative kurtosis (p = 0.05, 0.14, -1.85). All skewness and kurtosis values for these metrics were positive and had some of the highest values among the data (see Table 3.48). Pool-depth ratio data had a normal distribution, a slight positive skew (the lowest among the parameters), and a negative kurtosis (p = 0.88, 0.03, -0.60). The distribution of percent riffle (PERRIFF) was normal with a positive skew and negative kurtosis (p = 0.94, 0.27, -0.64). Finally, the data collected for bank height ratios (BHR) was normally distributed, had a negative skew and a positive kurtosis (p = 0.30, -0.99, 1.66).

The ECS data for all stream types was normally distributed. UI sites had the largest Shapiro-Wilk value (p = 0.78) with a positive skew of 0.819 and a relatively small kurtosis of 0.03. Per Table 3.49, the lowest Shapiro- Wilk value belonged to UR streams (p = 0.10) which had a positive skew of 1.72 and a kurtosis value of 3.27. Finally, ERR sites had a Shapiro-Wilk value of p = 0.20 with a negative skew (-1.54) and a kurtosis value of 2.89.

Of the five functional categories in the TNSQT, three had normally distributed data sets (see Table 3.50). The Shapiro-Wilk value (making its distribution non-normal) for the hydrology category was p = 0.40 and the data set had a slightly positive skewness (0.47) and a negative kurtosis (-1.55). The hydraulics category was the only other non-normally distributed data set with a Shapiro-Wilk value of 0.04 a negative skew of -0.44 and a kurtosis value of -0.95.

The geomorphology category was normally distributed (p = 0.53) with a positive skew (0.23) and a negative kurtosis value (-0.18). The Shapiro-Wilk value for the physiochemical category was p = 0.33, making the category's data set normally distributed. The physiochemical category had a negative skew of -0.95 and a positive kurtosis value of 1.40. Finally, the biology function-based category was normally distributed (p = 0.14) with a small negative skew (-0.25) and negative kurtosis (-1.65).

Per Table 3.51, the RGA data was normal with slight negative skew and a negative (excess) kurtosis (p = 0.49, -0.08, -1.20).

There are nine individual parameters involved with the RGA. Five of those nine were normally distributed. Primary bed material was the first of these and has a positive skew and negative kurtosis (p= =0.85, 0.38, -0.24). The data distribution for bed/bank protection did not exhibit a normal distribution (p = 0.01) and had negative skewness and kurtosis values (-0.92, -0.44). The degree of incision data was normally distributed and has a negative skew and kurtosis (p = 0.12, -0.09, -1.68). The degree of constriction results featured a non-normal distribution, and positive skew, and a positive (and relatively high) kurtosis (p = 0.00, 1.95, 4.37). The distribution for stream bank erosion data was found to be normally distributed with a positive skew and a negative kurtosis (p = 0.84, 0.35, -0.26). Streambank instability data collected had a non-normal distribution with a positive skew and a negative kurtosis (0.00, 0.64, -1.62). A normal distribution was found in the established riparian woody-vegetative cover which also had a positive skew and negative kurtosis (p = 0.26, 0.25, -1.46). The data for the occurrence of bank accretion had a non-normal distribution, negative skew, and positive kurtosis (p = 0.01, -1.52, 1.52). Finally, the stage of channel evolution was normally distributed with a positive skew and a negative kurtosis (p = 0.08, 0.69, -0.07). These results are summarized in Table 3.52.

Shown in Table 3.54, of the 10 parameters associated with the RBP, eight were normally distributed. Epifaunal substrate/available cover showed a normal distribution with negative skew and kurtosis values (p = 0.17, -0.52, -1.16). The distribution for embeddedness data was also normally distributed with negative skew and kurtosis values (p = 0.16, -0.73, -0.43). The data for velocity/depth regime was the first non-normal distribution for RBP data and had a negative skew but positive kurtosis value (p = 0.00, -1.87, 4.89). Sediment deposition data had a normal distribution, a negative skew, and a positive kurtosis value (p = 0.43, -0.82, 0.09). Channel flow also featured a normal distribution but had a negative skew and a negative kurtosis value (p = 0.14, -0.57, -1.17). The distribution for channel alteration was normally distributed and had negative skew and kurtosis values (p = 0.06, -0.53, -1.22). The distribution of data for the frequency of riffles was normally distributed and had a negative skew but positive a kurtosis value (p = 0.43, -0.92, 0.71). Bank stability data had a non-normal distribution, a negative skew, and a negative kurtosis value (p = 0.03, -0.60, -1.46). Vegetative protection data was normally distributed, featured a negative skew, and a positive kurtosis value (0.11, -1.09, 0.53). Finally, the distribution of data for riparian vegetation was normally distributed, had a positive skew, and a negative kurtosis (p = 0.27, 0.42, -0.95).

Of the 18 metrics measured in the modified EMAP protocols and shown in Table 3.55, 15 were normally distributed. Pool unit width had a normal distribution with a Shapiro-Wilk significance of 0.07 as well as skewness of 1.54 and a kurtosis of 2.78. Average pool depth was also normally distributed (p = 0.43) with a relatively low positive skew (0.25) and a negative kurtosis (-1.28). Riffle unit width is non-normally distributed (p = 0.01) with a skewness of 1.54 and a kurtosis of 1.97. Average riffle depth is also non-normally distributed (p = 0.01) with a skewness of 1.91 and relatively large kurtosis value (4.41). The data for maximum pool depth is normally distributed (p = 0.34). The skewness and kurtosis values for maximum pool depth are 0.43 and -0.47 respectively. Maximum riffle depth data is also normally distributed (p = 0.22) with a positive skew (0.58) and negative kurtosis (-0.90). The Shapiro-Wilk significance for aquatic vegetation, p = 0.31, indicated the data set is normally distributed. The skewness value for aquatic vegetation is 0.64 and the kurtosis is negative at -0.29).

Per Table 3.53, distribution for the RBP data was normal, and the data was skewed positive with a negative kurtosis (p = 0.17, 0.15, -1.62).

Continuing with mesohabitat data, the data set for woody debris greater than 0.3 m was normally distributed (p = 0.49) with positive skewness and kurtosis values (0.69 and 0.24). A Shapiro-Wilk significance level of p = 0.35 indicated that the data for woody debris less than 0.3m was also normally distributed. The data set had negative skewness and kurtosis values at -0.31 and -1.16 respectively. The undercut bank's data set was normally distributed (p = 0.66) with negative skewness (-0.42) and kurtosis (-0.67). The Shapiro-Wilk significance (p = 0.52) indicated that the data set for the number of boulders was normally distributed with a positive skewness (0.35) and negative kurtosis (-1.13). The number of artificial structures data set also had a positive skewness (0.53), negative kurtosis (-0.73), and featured a normal distribution (p = 0.10).

The last portion of data of the Modified EMAP protocols examined was substrate composition percentages. The percent bedrock data was non-normally distributed (p = 0.02) with a positive skewness (0.55) and negative kurtosis (-1.58). The Shapiro-Wilk significance for

Table 3.46. Descriptive Statistics for Percent Cobble (% of Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (% of Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (% of Reach)	Maximum (% of Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	36.78	7.96	24.11	49.45	28.57	46.67
Urban Restored	4	33.81	14.50	10.74	56.88	22.17	52.50
Ecoregion Reference	4	27.04	12.07	7.83	46.24	11.67	38.69

Table 3.47. Descriptive Statistics for Percent of Silt-Clay (% of Reach) for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type	N	Mean (% of Reach)	Standard Deviation	95% Confidence Interval for Mean		Minimum (% of Reach)	Maximum (% of Reach)
				Lower Bound	Upper Bound		
Urban Impaired	4	25.27	8.65	11.51	39.04	15.63	36.67
Urban Restored	4	31.10	9.08	16.65	45.54	20.00	40.83
Ecoregion Reference	4	19.20	8.35	5.92	32.49	10.56	29.29

Table 3.48. Normality, Skewness, and Kurtosis Values for Individual TNSQT Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Runoff	N	0.03	0.45	-1.61
Entrenchment	N	0.00	-0.36	2.73
BEHI	Y	0.60	0.19	-0.98
Percent Stream Bank Erosion	Y	0.10	0.44	-0.57
D_{50}	N	0.02	1.85	4.09
LWD	Y	0.05	0.14	-1.85
SIN	N	0.00	2.42	6.67
SLOPE	N	0.02	1.68	3.09
WDR	N	0.00	2.96	9.29
POWER	N	0.00	2.27	5.51
PSR	N	0.00	2.93	9.42
PDR	Y	0.88	0.03	-0.60
Percent Riffle	Y	0.94	0.27	-0.64
BHR	Y	0.29	-0.99	1.66

Table 3.49. Normality, Skewness, and Kurtosis Values for TNSQT ECS Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Urban Impaired	Y	0.78	0.82	0.03
Urban Restored	Y	0.10	1.72	3.27
Ecoregion Reference	Y	0.20	-1.54	2.89

Table 3.50. Normality, Skewness, and Kurtosis Values for TNSQT Rollup Scoring for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Hydrology	N	0.04	0.47	-1.55
Hydraulics	N	0.04	-0.44	-0.95
Geomorphology	Y	0.53	0.23	-0.18
Physiochemical	Y	0.33	-0.95	1.40
Biology	Y	0.14	-0.25	-1.65

Table 3.51. Normality, Skewness, and Kurtosis Values for Whole RGA Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
RGA	Y	0.49	-0.08	-1.20

Table 3.52. Normality, Skewness, and Kurtosis Values for Individual RGA Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Primary Bed Material	Y	0.85	0.38	-0.24
Bed/Bank Protection	N	0.01	-0.92	-0.44
Degree of Incision	Y	0.12	-0.09	-1.68
Degree of Constriction	N	0.00	1.95	4.37
Stream Bank Erosion	Y	0.84	0.35	-0.26
Stream Bank Instability	N	0.00	0.64	-1.62
Established Riparian Woody-Vegetative Cover	Y	0.26	0.25	-1.46
Occurrence of Bank Accretion	N	0.01	-1.52	1.52
Stage of Channel Evolution	Y	0.08	0.69	-0.07

Table 3.53. Normality, Skewness, and Kurtosis Values of Whole RBP Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
RBP	Y	0.17	0.15	-1.62

Table 3.54. Normality, Skewness, and Kurtosis Values for Individual RBP Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Epifaunal Substrate/Available Cover	Y	0.165	-0.524	-1.164
Embeddedness	Y	0.163	-0.734	-0.428
Velocity/Depth Regime	N	0.004	-1.865	4.89
Sediment Deposition	Y	0.426	-0.822	0.093
Channel Flow	Y	0.137	-0.565	-1.171
Channel Alteration	Y	0.063	-0.526	-1.222
Frequency of Riffles	Y	0.426	-0.92	0.71
Bank Stability	N	0.031	-0.597	-1.463
Vegetative Protection	Y	0.108	-1.086	0.53
Riparian Vegetation	Y	0.265	0.416	-0.947

percent boulder was $p = 0.19$ which indicated a normal distribution for the data set. Both the skewness and kurtosis values were over one and positive for percent boulder data, 1.20 and 1.74 respectively. The percent cobble data was normally distributed ($p = 0.61$) with a relatively small positive skewness (0.12) and a negative kurtosis (-1.31). The percent gravel data was also normally distributed with a high significance of $p = 0.99$. The skewness and kurtosis values for percent gravel data were both negative and small, -0.04 and -0.25 respectively. Finally, the percent silt-clay data set was normally distributed ($p = 0.93$) with a positive skewness (0.15) and negative kurtosis (-0.81).

Statistical Analysis of Variance (ANOVA)

The initial instinct for variance analysis was to perform a one-way multivariate analysis of variance (MANOVA); however, after finding that a varying amount of the data did not have a normal distribution it was decided another test was needed since the one-way univariate analysis of variance (ANOVA) tests are not valid with non-normal data sets. It was required that a non-parametric test was used, and the Kruskal-Wallis H test was used. The null hypothesis for the Kruskal-Wallis H (KW) test is that all rank means are the same for all stream types. The alternative hypothesis is that, for at least one type, the rank mean is significantly different. The significance level used for this test was 0.05 ($\alpha = 0.05$).

For all data sets the first step was to determine whether there were statistically significant differences among the three stream types (UI, UR, and ERR sites). The KW test creates rank means for each subcategory, an "H" value, and the gives the asymptotic significance. This process was then completed to compare two stream types (UI vs UR, UR vs ERR, etc.) in what acts like a post-hoc test. To validate the results of the pairwise comparisons, several Mann Whitney U tests were run. All results were the same. Important output of the results lies in Appendix B, while Tables 3.56-3.63 hold those results discovered to be significant.

Tennessee Stream Quantification Tool Metrics

A Kruskal-Wallis test was conducted to inspect for differences among all three stream types for the aggregated geomorphic and habitat data present in the TNSQT. There existed a significant difference between the groups with respect to the watershed land use runoff score ($p = 0.02$) and percent riffle ($p = 0.03$). The KW test was then used to compare two stream types to each other. Seen in Table 3.56, between UI and UR sites there was no statistically significant difference between any of the metrics. The significant differences between UR and ERR streams included PERRIFF (0.02), PSR (0.03), and watershed land use runoff score (0.02). Between UI and ERR sites watershed land use runoff score (0.02) and percent riffle (0.04) presented the only differences.

A KW test was conducted for all stream types with respect to their respective TNSQT Rollup scoring (Table 3.57). Among all three stream types, hydrology appeared to be the only factor of difference ($p = 0.02$). Between UI and UR sites there was no significant difference in rank means. For UR and ERR streams, the only difference was in hydrology scores ($p = 0.02$). The KW test performed to display differences between UI and ERR showed that differences arose in hydrology and biology scores, both with an asymptotic significance of 0.02.

The final Kruskal-Wallis test performed for TNSQT data collected was for the existing condition scores (ECS) data set (Table 3.58). A more thorough explanation of the ECS score can be found in the methodology. Between all stream condition types, there was a significant difference in the scores ($p = 0.01$). The scores between UI and UR stream sites showed no difference. There was a significance between the ECS scores for UR and ERR streams ($p = 0.03$). Finally, there was also a notable difference between UI and ERR sites ($p = 0.03$).

Rapid Geomorphic Assessment

First, a KW test was run for the whole RGA scores. Between all types, there existed a significant difference (p = 0.01). Per Table 3.59, total RGA scores also differed significantly for UI and UR streams (p = 0.02). UR and ERR types had no difference between their mean scores. Finally, there was a difference between the total RGA scores for UI and ERR streams (p = 0.02).

Conducting a KW test for all stream types showcased the differences between all site types, namely: primary bed material (p = 0.05), degree of constriction (p=0.05), stream bank erosion (p = 0.02), stream bank instability (p = 0.02) and stage of channel evolution (p = 0.01). Between UI and UR sites there existed a significant difference between the degree of incision (p = 0.02), stream bank erosion (p = 0.03), stream bank instability (p = 0.02), and stage of channel evolution (p = 0.01). Per Table 3.60, the stage of channel evolution and occurrence of bank accretion were the only significant differences between UR and ERR streams, p = 0.04 and 0.01 respectively. Significant differences in rank means among UI and ERR streams included primary bank material (p = 0.03), degree of constriction (0.01), stream bank erosion (0.02), stream bank instability (0.02), established riparian wood-vegetative cover (0.02) and stage of channel evolution (0.02).

Rapid Bioassessment Protocols

Before looking at the individual parameters within the RBP a KW test was undertaken for the whole scores (Table 3.61). Between all site types compared there existed a statistically significant difference in whole RBP scores (p = 0.02). UI sites had a significant difference in scores between UR and ERR sites, 0.04 and 0.02 respectively. There existed no difference between the scores of UR and ERR sites.

When looking at the results for the KW test performed for the RBP on all site types, channel flow status, frequency of riffles (or bends), bank stability, and vegetative protection all displayed significance. Respective asymptotic significances were as follows: 0.11, 0.00, 0.00, and 0.02. When the KW test was conducted for UI and UR differences for channel flow status and bank stability were found, with p-values equal to 0.02 for both. Per Table 3.62, the only difference that existed between UR and ERR sites was the frequency of riffles (or bends) with an asymptotic significance of 0.02. The final KW test performed for the RBP data showed differences between UI and ERR sites with respect to epifaunal substrate/available cover (p = 0.02), sediment deposition (p = 0.04) channel flow status (p = 0.02), frequency of riffles (or bends) ($p = 0.02$), bank stability ($p = 0.02$), vegetative protection ($p = 0.02$), and riparian vegetative zone width ($p = 0.03$).

With respect to mesohabitat metrics, there existed no significant difference between all stream condition types (Table 3.63). There was, however, a difference between UI and UR sites, namely overhanging vegetation ($p = 0.04$). No difference existed in the mesohabitat data between UR and ERR sites. Finally, between UI and ERR stream sites differences were found between riffle unit width ($p = 0.04$) and percent cobble ($p = 0.04$) values.

Principal Components Analysis (PCA)

To better understand the relationships among measured metrics with respect to the stream condition type a principal components analysis (PCA) was used. Before these tests could be conducted, however, it was necessary to perform some data reduction. Initially, correlations were inspected for all the data in hopes of reducing redundant relationships. This tactic ended up being ineffective as it eliminated factors that explained a large amount of variance, and it still did not optimize data set sizes. To correct these issues, looking at the kurtosis and skewness values for the data was used as a process to weed out potentially insignificant data. Any parameter that had a skewness or kurtosis value greater than or equal to ± 1.00 was kept in the analysis. Full results for the PCA tests conducted can be found in Appendix B, but eigenvalues, eigenvectors, and percentages of variance explained by the chosen axes can be found in Tables 3.64-3.73. If an axis did not explain at least four percent of variation it was not used for analysis. Additionally, ordination plots are shown as Figures 3.21-3.25.

<u>Individual Tennessee Stream Quantification Tool Metrics</u>

Upon completing the PCA for the geomorphic and habitat data represented in the TNSQT, it was found that 95% of the variance in the data set could be attributed to the first four axes. Furthermore, nearly 74% of that variance was to be found on the first two axes (axis one = 47.57%, axis two = 26.07%). Stream power (POWER) was responsible for most of the variance of axis one ($\mathbf{v} = -0.90$, $r = -0.98$). Axis two was primarily controlled by the PSR ($\mathbf{v} = 0.58$, $r = 0.75$) and PDR ($\mathbf{v} = 0.56$, $r = 0.74$) scores. Less significantly, axis three was dominated by WDR scores ($\mathbf{v} = -0.55$).

Results for the PCA performed for the TNSQT roll-up data showed that almost 98% of the total variance lies within the first three axes. Axis one accounted for essentially 69% of the total variance, primarily due to hydrology ($\mathbf{v} = 0.71$, $r = 0.89$) scores between the stream types.

Biology rollup scores was the primary factor of axis two (**v** = 0.72, r = 0.49). The remaining categories made up the variance accounted for by axis three and had eigenvectors as follows: hydraulics = 0.94, geomorphology = -0.14, and physiochemical = -0.30.

<u>Rapid Geomorphic Assessment</u>

The first three axes constituted almost 97% of the variance among stream types per the performed PCA for the RGA data set. Of that that percentage, 89.39% was found on the first two axes (axis one = 66.44%, axis two = 23.04%). The variance held on axis one was accounted for by stream bank instability (**v** = -0.62, r = -0.96) and established riparian woody-vegetative cover (**v** = -0.52, r = 0.87). For axis two the majority of the variance was held by degree of incision (**v** = -0.77, r = -0.67) and degree of constriction (**v** = 0.44, r = 0.72). Occurrence of bank accretion (**v** = 0.77) and bed/bank protection (**v** = 0.29) had their largest eigenvectors on axis three.

<u>Rapid Bioassessment Protocols</u>

Per the PCA conducted for the RBP data set axes one through three contained 92% of the variance for the three stream types. Axis one (55.51%) and two (25.57%) accounted for 81% of this cumulative variance. Riparian vegetative zone width (**v** = 0.61, r = 0.89) and vegetative protection (**v** = 0.40, r = 0.79) were the dominant factors for axis one. The variance accounted for by axis two was attributed to embeddedness (**v** = -0.59, r = -0.68) and sediment deposition (**v** = -0.49, r = -0.72). Velocity/depth regime and frequency of riffle (or bends) were associated most with axis three having eigenvectors of 0.68 and 0.53 respectively.

<u>EMAP Modified Protocol Mesohabitat Data</u>

Almost 93% of the variance in the mesohabitat data presented was accounted for by the first three axes in the PCA conducted on the data set. Axis one accounted for approximately 64% of this variance and was dominated by percent bedrock (**v =** -0.83, r = -0.95). Axis two explained almost 20% of the total variance and was constituted mostly of percent boulder (**v** = 0.62, r = 0.66). Axis three which explained an additional 9% of the variation in the data set was dominated by pool unit width (**v** = -0.66).

<u>DISCUSSION</u>

The primary objective of this study was to better understand the degree in which stream restoration can improve, or lift the functional condition based on geomorphic and habitat attributes. Additionally, it was of interest to evaluate the potential limit of ecological recovery

Table 3.55. Normality, Skewness, and Kurtosis Values for Individual Modified EMAP Protocol Parameters for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

	Normal?	Shapiro-Wilk	Skewness	Kurtosis
Pool Unit Width	Y	0.07	1.54	2.78
Average Pool Depth	Y	0.43	0.25	-1.28
Riffle Unit Width	N	0.01	1.54	1.97
Average Riffle Depth	N	0.01	1.91	4.41
Maximum Pool Depth	Y	0.34	0.43	-0.47
Maximum Riffle Depth	Y	0.22	0.58	-0.90
Aquatic Vegetation	Y	0.31	0.64	-0.29
Wood > 0.3 m	Y	0.49	0.69	0.24
Wood < 0.3 m	Y	0.35	-0.31	-1.16
Overhanging Vegetation	Y	0.24	0.61	-0.58
Undercut Banks	Y	0.66	-0.42	-0.67
Number of Boulders	Y	0.52	0.35	-1.13
Number of Artificial Structures	Y	0.10	0.53	-0.73
Percent Bedrock	N	0.02	0.55	-1.58
Percent Boulder	Y	0.19	1.20	1.74
Percent Cobble	Y	0.61	0.12	-1.31
Percent Gravel	Y	0.99	-0.04	-0.25
Percent Silt-Clay	Y	0.93	0.15	-0.81

Table 3.56. Kruskal-Wallis H Test Summary for Individual TNSQT Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	Watershed Land Use Runoff Score and Percent Riffle (PERRIFF)	0.02, 0.04
UI & UR	-	-
UR & ERR	Watershed Land Use Runoff Score, Pool-Spacing Ratio (PSR) and Percent Riffle (PERRIFF)	0.02, 0.03, 0.02
UI & ERR	Watershed Land Use Runoff Score, PERRIFF	0.20, 0.04

Table 3.57. Kruskal-Wallis H Test Summary for TNSQT Rollup Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	Hydrology	0.02
UI & UR	-	-
UR & ERR	Hydrology	0.02
UI & ERR	Hydrology & Biology	0.02

Table 3.58. Kruskal-Wallis H Test Summary for TNSQT ECS Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Exact Significance Values
All	ECS	0.01
UI & UR	-	-
UR & ERR	ECS	0.03
UI & ERR	ECS	0.03

Table 3.59. Kruskal-Wallis H Test Summary for Whole RGA Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	RGA	0.01
UI & UR	RGA	0.02
UR & ERR	-	-
UI & ERR	RGA	0.02

Table 3.60. Kruskal-Wallis H Test Summary for Individual RGA Parameters for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	primary bed material, degree of constriction, stream bank erosion, stream bank instability, and stage of channel evolution	0.05, 0.05, 0.02, 0.02, 0.01
UI & UR	degree of incision, stream bank erosion, stream bank instability, and stage of channel evolution	0.02, 0.03, 0.02, 0.01
UR & ERR	occurrence of bank accretion and Stage of channel evolution	0.04, 0.01
UI & ERR	primary bed material, degree of constriction, stream bank erosion, stream bank instability, established riparian wood-vegetative cover and stage of channel evolution	0.03, 0.01, 0.02, 0.02, 0.02, 0.02

Table 3.61. Kruskal Wallis H Test Summary for Whole RBP Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameter Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	RBP	0.02
UI & UR	RBP	0.04
UR & ERR	-	-
UI & ERR	RBP	0.02

Table 3.62. Kruskal-Wallis H Test Summary for Individual RBP Parameters for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Condition Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	channel flow status, frequency of riffles (or bends), bank stability, and vegetative protection	0.02, 0.02,0.02, 0.03
UI & UR	Channel flow status and bank stability	0.02, 0.02
UR & ERR	Frequency of riffles (or bends)	0.02
UI & ERR	Epifaunal substrate/available cover, sediment deposition, channel flow status, frequency of riffles (or bends), bank stability, vegetative protection, and riparian vegetative zone width	0.02, 0.04, 0.02, 0.02, 0.02, 0.02, 0.03

Table 3.63. Kruskal-Wallis H Test Summary for EMAP Modified Protocol Parameters for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Stream Type Comparison	Parameters Causing Significant Difference Among Groups	Respective Asymptotic Significance Values
All	-	-
UI & UR	Overhanging Vegetation	0.038
UR & ERR	-	-
UI & ERR	Riffle Unit Width, Percent Cobble	0.04, 0.04

Table 3.64. Axis Variance for Individual TNSQT Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Axis	Eigenvalue	% of Variance	Cum. % of Variance
1	0.24	47.57	47.57
2	0.13	26.07	73.64
3	0.07	13.13	86.77

Table 3.65. Variable Eigenvectors for Individual TNSQT Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Variable	Eigenvector (by Axis)		
	1	2	3
BEHI	0.04	-0.03	**-0.22**
LWD	-0.21	-0.36	**0.44**
Sinuosity	0.02	**0.04**	-0.03
WDR	-0.21	-0.41	**-0.55**
POWER	**-0.90**	0.10	0.01
PSR	-0.27	**0.58**	0.42
PDR	-0.16	**0.56**	-0.53
BHR	-0.03	**0.18**	-0.08

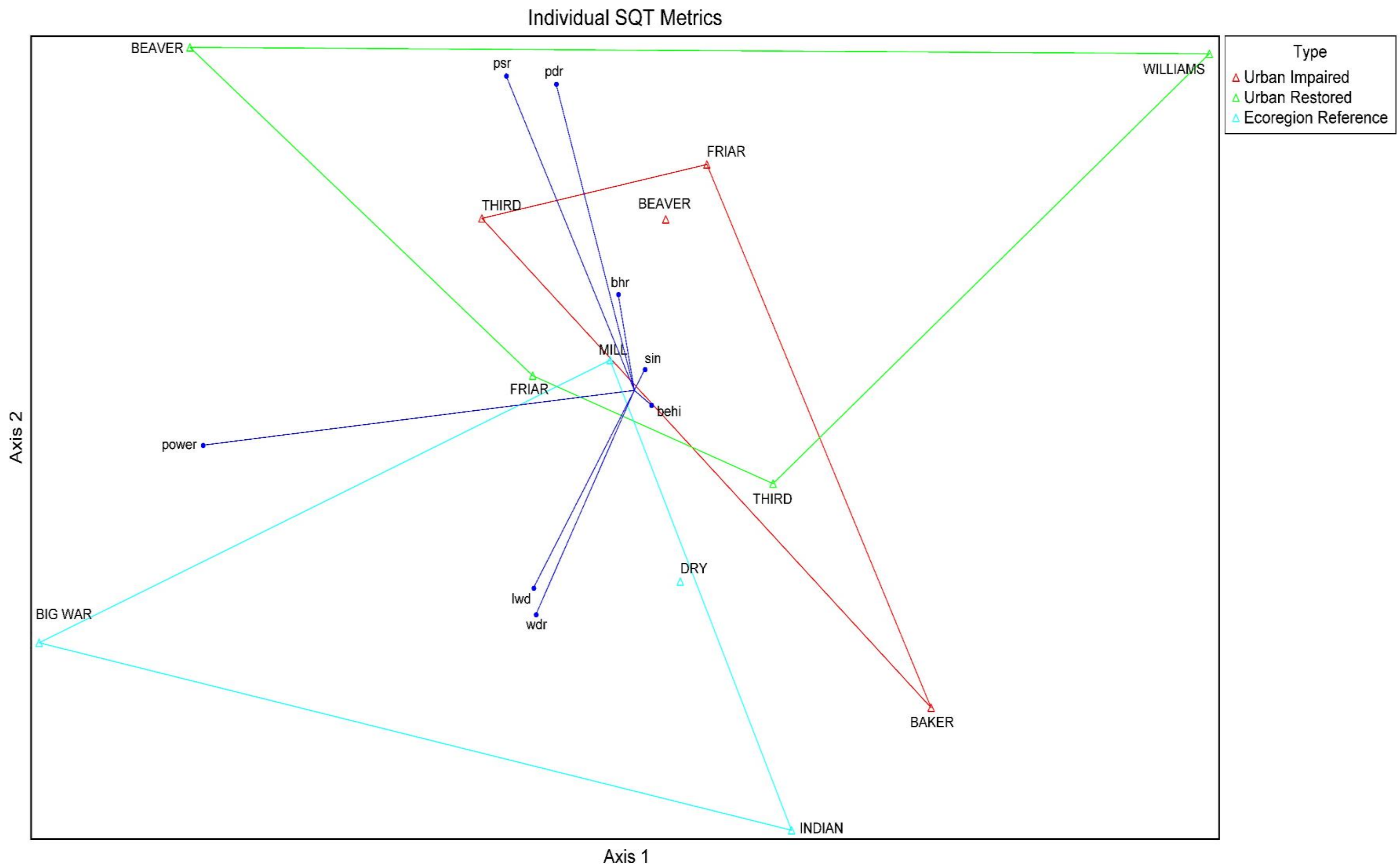

Figure 3.21. Ordination Plot for Individual TNSQT Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Table 3.66. Axis Variance for TNSQT Rollup Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Axis	Eigenvalue	% of Variance	Cum. % of Variance
1	0.10	68.77	68.77
2	0.03	18.87	87.63
3	0.02	10.32	97.95

Table 3.67. Variable Eigenvectors for TNSQT Rollup Scores for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Variable	Eigenvector (by Axis)		
	1	2	3
Hydrology	**0.71**	-0.69	0.02
Hydraulics	0.05	0.04	**0.94**
Geomorphology	-0.08	-0.06	**-0.14**
Physiochemical	0.20	0.03	**-0.30**
Biology	0.67	**0.72**	-0.03

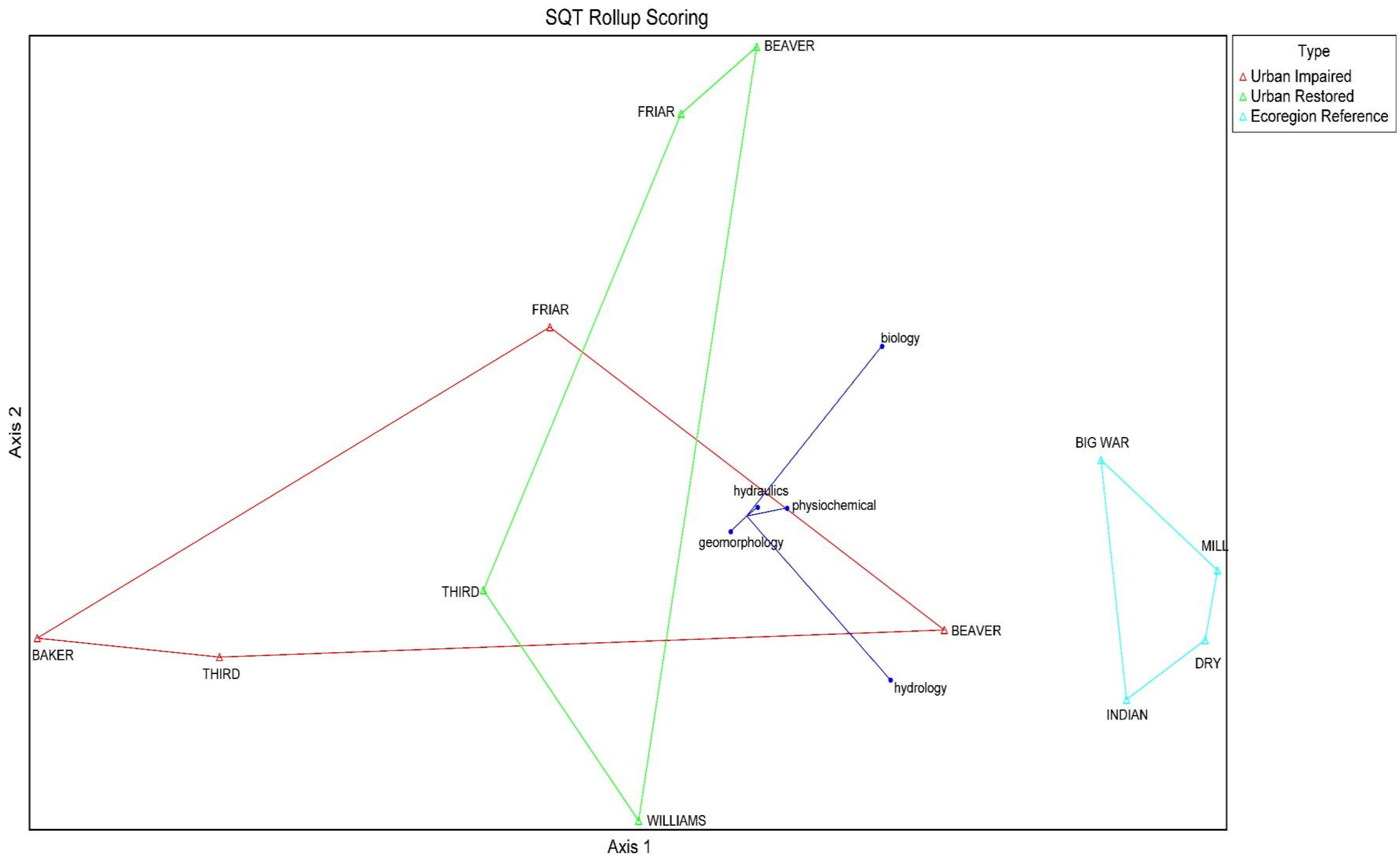

Figure 3.22. Ordination Plot for Rollup TNSQT Scoring for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province

Table 3.68. Axis Variance for Individual RGA Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Axis	Eigenvalue	% of Variance	Cum. % of Variance
1	0.13	66.35	66.35
2	0.04	23.04	89.39
3	0.01	7.22	96.61

Table 3.69. Variable Eigenvectors for Individual RGA Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Variable	Eigenvector (by Axis)		
	1	2	3
Bed/Bank Protection (Two)	0.06	0.08	**0.29**
Degree of Incision (Three)	-0.50	**-0.77**	0.16
Degree of Constriction (Four)	-0.22	**0.44**	-0.03
Stream Bank Instability (Six)	**-0.62**	0.07	-0.51
Established riparian woody-vegetative cover (Seven)	**-0.52**	0.45	0.20
Occurrence of Bank Accretion (Eight)	-0.20	0.07	**0.77**

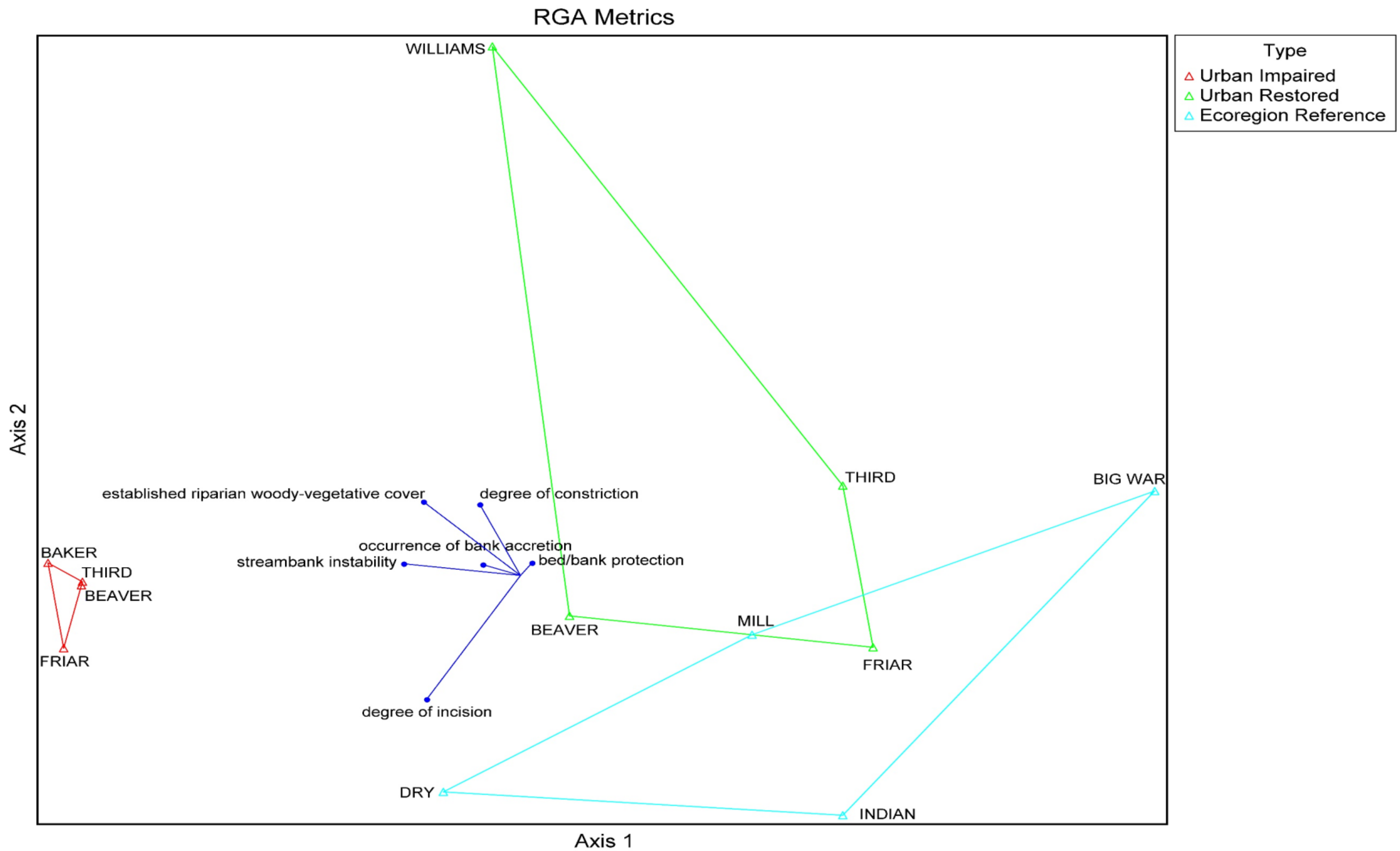

Figure 3.23. Ordination Plot for the Individual RGA Data Set for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province

Table 3.70. Axis Variance for Individual RBP Metrics for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Axis	Eigenvalue	% of Variance	Cum. % of Variance
1	41.68	55.51	55.51
2	19.20	25.57	81.08
3	7.97	10.62	91.70

Table 3.71. Variable Eigenvectors for Individual RBP Metrics for Urban Impaired, Urban Restored and Ecoregion Stream Sites in the East Tennessee Ridge and Valley Province.

Variable	Eigenvector (by Axis)		
	1	2	3
Embeddedness (Two)	0.39	**-0.59**	0.31
Velocity/Depth Regime (Three)	0.07	0.37	**0.68**
Sediment Deposition (Four)	0.30	**-0.49**	0.03
Frequency of Riffles (or bends) (Seven)	0.11	0.11	**0.53**
Bank Stability (Eight)	0.46	-0.06	-0.19
Vegetative Protection (Nine)	**0.40**	0.32	-0.36
Riparian Vegetative Zone Width (Ten)	**0.61**	0.40	-0.01

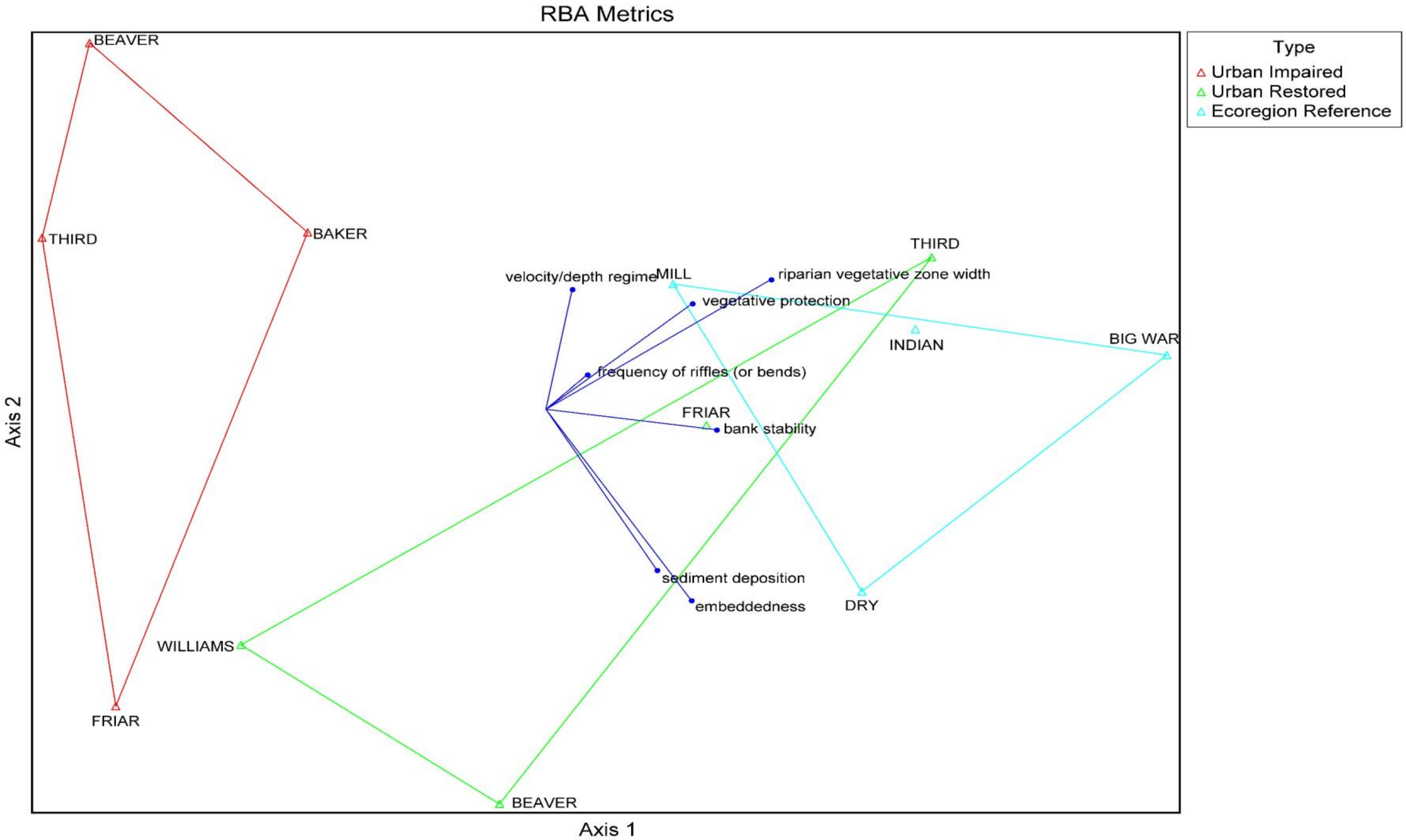

Figure 3.24. Ordination Plot for Individual Metrics RBP Data Set for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Table 3.72. Axis Variance for Modified EMAP Protocols Data for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Axis	Eigenvalue	% of Variance	Cum. % of Variance
1	0.51	64.16	64.16
2	0.16	19.76	83.92
3	0.07	8.98	92.90

Table 3.73. Variable Eigenvectors for Modified EMAP Protocols Data for Urban Impaired, Urban Restored, and Ecoregion Reference Stream Sites in the East Tennessee Ridge and Valley Province.

Variable	Eigenvector (by Axis)		
	1	2	3
Pool Unit Width	-0.07	0.03	**-0.66**
Average Pool Depth	0.02	-0.05	**-0.20**
Riffle Unit Width	-0.13	0.13	**-0.62**
Average Riffle Depth	-0.03	-0.01	**-0.11**
Wood < 0.3 m	-0.06	**0.15**	-0.06
Number of Boulders	-0.36	**0.51**	0.14
Percent Bedrock	**-0.83**	-0.50	-0.00
Percent Boulder	-0.37	**0.62**	0.16
Percent Cobble	0.10	**0.27**	-0.26

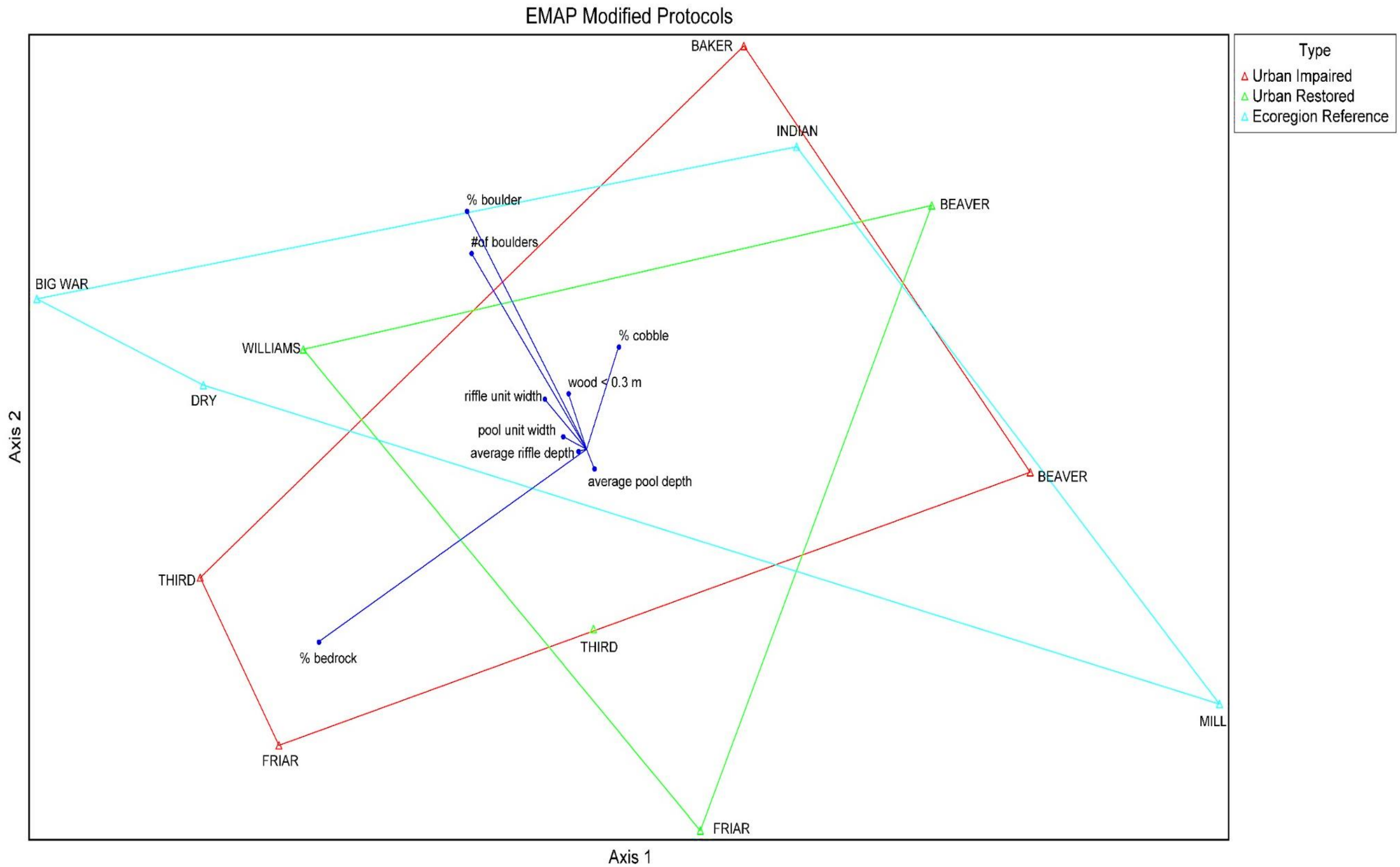

Figure 3.25. Ordination Plot for Individual Metrics of the Modified EMAP Protocol Data for Urban Impaired, Urban Restored, and Ecoregion Reference Sites in the East Tennessee Ridge and Valley Province

from restoration in urban streams. A secondary objective was to investigate whether TNSQT existing condition scores reflect stream degradation observed in urban streams, and what increased range in scores occur from restoration practices in urban streams. The fundamental hypothesis of this research was to identify what measures of geomorphic, habitat, riparian vegetation, and biota improve through restoration practices in urban streams, and which measures remain unchanged. Founded in this hypothesis is the understanding that urban streams cannot be restored to a pre-developed watershed and pristine channel condition, but rather incremental improvements should be observed (Schwartz and Herricks 2007, Wade et al. 2002).

Rapid Geomorphic Assessment

It is first necessary to approach the RGA as a single unit. As an assessment, it is intended to be a comprehensive qualitative summary of the status of reach-scale geomorphic conditions (USDA 2005). There was a significant improvement between UR and UI sites, placing all UR streams in the conditionally stable category, and the scores indicate that there was improvement towards geomorphic function and structures found in ecoregion reference streams. It should be noted that the RGA is an in-field rapid assessment, and some subjectivity among surveys occurs in all field rapid assessment methods (Habberfield et al. 2014, Booth and Jackson 1997, Beechie et al. 2010).

Looking at the individual metrics of the RGA was also insightful. Significant differences between UI and UR streams included the degree of incision, stream bank instability, and stage of channel evolution (Table 3.60). Per the results of the KW test, UR streams saw a significant decline in a suite of interrelated attributes including channel incision, stream bank instability, and bank erosion from the high levels found in UI streams. These decreases suggest that structural stability can be achieved from restoration projects though still impacted by hydromodification affects (Harman et al. 2012, USDA 2005, Rosgen 1997). The only significant differences between UR and ERR sites were the stage of channel evolution and the occurrence of bank accretion, but as previously mentioned, the difference in the stage of channel evolution is largely theoretical, as no ERR has never been disturbed.

The stage of channel evolution improved significantly for all UR streams to a place between the constructed stage and the degrading stage (stages two and three) whereas all UI sites were between the degradation stage and threshold stage (stages three and four) (Simon and Hupp 1986). On an ideological level all ERR streams were in a “pre-modified” stage, and the argument could be made that comparing urban streams of any class to those largely unaffected by hydromodification would be a poor comparison. This is just one example of the potential problems that arise when using reference streams as analogs for stream restoration design (Bledsoe et al. 2016). ERR streams scoring optimally with respect to geomorphic stability represents that stable end point among a disturbance, or stability gradient.

Bank accretion was significantly higher in UR streams than levels at ERR sites likely because these streams were in a geomorphic recovery stage with sufficient sediment supply. This also suggests that aggradation is an outcome of the geomorphic improvement towards a stable equilibrium found in the reference sites (Hupp and Simon 1991, Rosgen 1997). If this is the case though, it does beg the question of why the UR sites were not characterized as stage five streams. Stage five, the aggradation stage, is when the most aggradation occurs as a stream moves towards stability (Simon and Hupp 1986). One possibility is that the streams were disturbed by urban hydromodification do not represent a stage of evolution as linearly described Simon and Hupp (1986). The stream evolution model proposed in Cluer and Thorne (2013) may better reflect the dynamics in urban streams impacted by hydromodification where they describe sediment supply-reach transport dynamics as possible feed-back loops at different stages.

The ordination plot produced by the PCA of the individual RGA metrics helps to visualize the improvement in geomorphology between UI and UR streams. The principal components of axis one (therefore the variables that explained the largest portion of the variance in the data set) were stream bank instability and established riparian woody-vegetative cover. This means that as data moves from left to right along axis one, bank instability is decreasing, and vegetative cover is increasing. The separation in the domain convex exteriors helps show that, with respect to the variance described by axis one, UI streams varied greatly. Combining results from the KW test and the PCA it can be said that, per the individual RGA metrics, there is some significant geomorphologic improvement between UI and UR sites, towards reference conditions. The RGA remains a valuable tool for portraying geomorphologic conditions in fluvial systems.

Rapid Bioassessment Protocols

As with the RGA, it is first important to look at the RBP per the whole assessment score. Generally, scores improved between UI and UR sites, but UR scores were relatively separated from ERR scores. Only two of the four UR sites scored optimally (>160). All UI sites scored in the suboptimal range (110-159) and all ERR sites scored optimally (Barbour et al. 1999). Performing a KW test showed that no difference existed between UR and UI nor UR and ERR sites. There was, however, a distinction in RBP scores between ERR and UI sites. Fisher (2019) did, however, note biotic improvement in the UR streams surveyed. A potential problem is that the RBP total score does not necessarily recognize root causes of impairment (Winger et al. 2005). Therefore, examining the RBP individual metrics contains more valuable information on how to improve the habitat-based functional lift for urban streams. Potential suggestions to improve the assessment for evaluating functional lift from stream restoration are discussed later in this section.

While there existed no substantial difference in the overall RBP scores between UR and the other stream types, there are differences in the individual metrics. Between UI and UR sites the first difference was found in channel flow status. All but one UR site (Williams Creek) scored optimally, improving from the marginal (6-10) and suboptimal (11-15) results for UI sites. Bank stability scores for UR improved similarly. These improvements overlap with geomorphic adjustment seen in the RGA between the two stream types. The only difference between UR and ERR is in the frequency of riffles (or bends). Only half of the UR sites scored optimally and most of the UI actually performed better with respect to this metric. This may be attributed to a variety of urban-centric stressors that influence pool-riffle sequencing including increased shear stress, sediment loads, and runoff. Alternatively, it may be attributed to difficult to control geomorphic features such as slope and sinuosity.

The PCA conducted on the RBP data set showed that the riparian vegetative zone width explained the most variance between groups. Other important factors with respect to axis one included the metrics bank stability and vegetative protection. UR sites Friar Branch and Third Creek performed like ERR sites, while Williams and Beaver Creek performed more like UI sites with respect to axis one components. The condition of riparian vegetative width, while important, is likely bound to urban land-use restrictions, like the issue observed with the TNSQT runoff score. For example, the restored portion of Williams Creek surveyed runs through the middle of a public golf course and is therefore tree-sparse in the riparian corridor. The restored portion of Beaver Creek, while performing better, exhibits a similar habitat condition.

Embeddedness and sediment deposition dominated the variance described by axis two. Overall, UR streams performed better than UI streams with respect to both parameters. More explicitly, UR streams were featured less embeddedness and sediment deposition. The restored portion of Third Creek was the exception to this trend, having UI-level sediment deposition and embeddedness. These metrics of difference are ones that, to some extent, can be and likely were changed by designers for the potential ecological and structural improvement involving the substratum (Barbour et al. 1999, Winger et al. 2005).

Tennessee Stream Quantification Tool Data

In the course of filling out the TNSQT spreadsheet it was necessary to collect geomorphic and habitat data in addition to the data collected for the RGA and RBP. The tables in the TNSQT portion of the results highlight the increase or decrease in mean scores for each parameter between the three classes. There were many cases where UR sites had means closer to those of the ERR streams, possibly indicating geomorphic and habitat improvement from restoration. However, as the following discussion details, few of those improvements were significant.

The KW statistical test for the TNSQT data set was not particularly illuminating and few significant differences were observed. This finding makes sense because many of the variables, including channel slope and sinuosity, cannot be changed substantially in urban streams by the restoration designer. There were no significant differences in UR and UI sites. The differences between ERR sites and the other two condition types (watershed land use runoff score, PSR, and percent riffle) were expected as the hydromodification associated with urbanization and the increase in effective imperviousness often directly effects pool-riffle sequencing (Chin and Gregory 2005, Gregory et al. 1992, Meyer et al. 2005, Walsh et al. 2005).

Per the PCA completed for the general data set, stream power accounts for the most variance. This may not be as important as it may seem because stream power is not a response variable from disturbance and is dominantly based on the reach slope set by the catchment geology. Slope appears to dominate over the channel discharge and does not reflect a stream condition type. The bulk of the variance accounted for by axis two (26% of the total variance) is from the PSR. While the restored portions of Third Creek and Friar Branch had PSR values closer to ERR sites both Williams Creek and the restored portion of Beaver Creek performed like UI sites.

As with the RBP and RGA, the TNSQT scores were first evaluated as a whole via the ECS. There was no significant difference between UR and UI scores with respect to ECS, while both differ from ERR streams. The significance (or lack thereof) is likely affected by several factors embedded in the tool itself. One of the measurement methods (and the one used by this study) for the hydrology category is the watershed land use runoff score. As stated before, this method acts similarly to the “C” value in the Rational formula or the curve number used for the NRCS’ TR-55 method. Using the land-use runoff score to represent reach hydrology may not be problematic in and of itself but giving it such a scoring power (1/6 of the ECS) is. The problem with empowering it so is that it is a factor that the restoration designer has little-to-no control over and may severely limit functional lift and ecological recovery. A design otherwise considered successful may suffer from urban land use percentages and changes.

Another issue with the TNSQT and its progression towards the ECS is the number of measurement methods within the geomorphology section. Little objection exists in the inclusion of so many parameters, as the in-stream processes associated with geomorphology are often complex. The issue at hand is that with so many factors in one functional category, each metric’s value is marginalized. Within the category, it is possible that 21 metrics would have the same weight as hydrology’s metric. This seems an oversimplification of the role that geomorphology plays in stream processes. It is possible if alterations were made to these problems, the relationships between the three types may have changed. These are just two issues observed with the TNSQT to estimate functional condition.

Between the different functional categories, there was no difference between UI and UR streams. Both urban stream types feature separations between their values for hydrology and the values found for ERR sites. This is altogether unsurprising as no ERR sites existed in urban or suburban-dominated landscapes, and the means for UI and UR streams were almost the same. There was a difference between UI and ERR streams with respect to biology. Half of the UI streams could be considered functioning-at-risk while the other half would be considered not-functioning. Likewise, half of the ERR streams are considered functioning-at-risk with respect to biology, but the other sites are considered to be functioning. Fisher (2019) further details the marginal improvement in biology in urban stream restoration projects.

Mesohabitat Data

The Kruskal-Wallis test showed no difference between UR and ERR sites for mesohabitat metrics measured by the modified EMAP protocols. This indicates that with respect to their substrate composition, cross-sections of channel units, and available vegetation there is little difference between stream types (UI, UR, and ERR sites.   Differences between UI and UR streams included only the amount of overhanging vegetation, where UR streams contained significantly more overhanging vegetation. This is a positive result as overhanging vegetation provides fish cover, debris for various in-channel processes, and temperature regulation (Kaufmann 1999, Booth and Jackson 1997, Vannote et al. 1980, FISRWG 2001).

According the PCA conducted for mesohabitat data, the primary sources of variance were the percent bedrock and boulder that were compositional in the channel's substrate. As the ordination plot shows though, the variance is so high that no discernable pattern emerges. With respect to percent bedrock and cobble, it appears that the UR streams have the least variance which is likely due to the intentional alteration often a part of restoration projects towards the goal of habitat improvement (Buffagni et al. 2019, Taylor et al. 2019).

Suggestions

This study was a preliminary study and more research needs to be conducted on the efficacy of using the various geomorphic and habitat metrics to quantify functional condition, and possible functional lift.   Some metrics within the RGA and RBP were significantly difference among the three stream types (UI, UR, and ERR) and others were not. The metrics that were significantly different are good candidates for use in a tool to quantify functional condition. All the metrics that were not provide little value to a functional condition score (i.e., ECS) and possible "dilute" the power of the useful metrics.

Collecting data from a larger set of streams within each of the three stream condition types would have provided greater statistical power to this study's findings.   Greater insight would increase with a larger number of stream sites.   Also, to the degree possible it is recommended that the site selection be more random. Many statistical tests require this as an assumption however this issue occurs in must stream studies because of the linear nature of a drainage network and so many streams have been impacted at one time or another.

While this research was being conducted, the TNSQT made slight adjustments to its present form. In the process, certain measurement methods changed in the way they were to be taken, such as the method for measuring riparian vegetation. Now that the version in use is possibly more static, it may be of use to include metrics that were not covered (% armoring and erosion rate to name two).

Conclusion

Changes in stream geomorphology and habitat processes are just two ways of many that hydromodification has impacted urban streams (Walsh et al. 2005, Konrad and Booth 2005, Bernhardt et al. 2015). This study was an attempt at quantifying those changes and assessing the potential for improvement in UR streams toward reference conditions. To that end, 12 streams in TN Ecoregion 67 (Ridge and Valley) categorized as urban impaired (UI), urban restored (UR), and ecoregion reference (ERR) sites were assessed using the following tools: the rapid geomorphic assessment (RGA), the rapid bioassessment protocol (RBP), the modified EMAP protocols, and the Tennessee Stream Quantification Tool (TNSQT). Some important findings of this study include:

(i) There existed no significant or useful distinction between UR and ERR streams per the RGA scores and the individual geomorphic parameters covered within the RGA. In both comparisons, RGA scores for UI streams were observed to be significantly less than UR and ERR streams. It can, therefore, be said that the RGA may represent the improvement of geomorphology for urban stream restoration projects, trending towards reference conditions.

(ii) Regarding the RBP scores, UR sites showed no difference to overall UI or ERR scores. There were, however, several individual metrics, namely channel flow status and bank stability, that differed significantly between UI and UR sites, whereas only the frequency of riffles (or bends) differed between UR and ERR sites.

(iii) With respect to mesohabitat data found in the modified EMAP protocols, the only metric between UI and UR sites that was significantly difference was the amount of overhanging vegetation. Additionally, while mesohabitat metrics did not differ between UR and ERR sites, the metrics differing between UI and ERR sites was minimal (riffle unit width and percent cobble) potentially indicating high levels of variance in the data. These findings were further reaffirmed by the PCA.

(iv) Significant differences with respect to individual TNSQT metrics were related to pool-riffle sequencing and separated UI and UR streams from ERR streams which had much higher performing mesohabitat units. There was no difference between UI and UR sites per the KW test performed for the TNSQT metrics.

(v) With respect to the TNSQT, no significant difference was seen in the ECS between UI and UR sites, but both were different from ERR sites. The hydrology metric was responsible for the differences observed among the means, which may be problematic as the functional condition metric.

Overall, this study identified what metrics and methods that could be used to better estimate functional condition within urban streams, and the potential lift from restoration. With further analysis, suggestions for improving the TNSQT metric when used in an urban settling can be advanced. Coupled with the work by Fisher (2019) who studied the biology from the same sites in this study, it is evidence that incremental improvements to urban streams are possible with geomorphology, habitat, and biology. It is also evident that improvements to a pristine condition are not possible, however as noted by the Beaver Creek (UR) site that biological integrity can be enhanced to remove the stream from being 303d listed for impairment.

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APPENDICES

APPENDIX A

Fieldwork Forms

CHANNEL-STABILITY RANKING SCHEME

River________________________ Site Identifier___________________________________

Date _____________ Time_______ Crew _______________ Samples Taken________________________

Pictures (circle) U/S D/S X-section Slope_________ Pattern: Meandering / Straight / Braided

1. Primary bed material							
	Bedrock	Boulder/Cobble		Gravel	Sand	Silt Clay	
	0	1		2	3	4	____
2. Bed/bank protection							
	Yes	No	(with)	1 bank protected	2 banks		
	0	1		2	3		____
3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
	4	3	2	1	0		____
4. Degree of constriction (Relative decrease in top-bank width from up to downstream)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
	0	1	2	3	4		____
5. Stream bank erosion (Each bank)							
	None	Fluvial	Mass wasting (failures)				
Left	0	1	2				____
Right	0	1	2				____
6. Stream bank instability (Percent of each bank failing)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	0	0.5	1	1.5	2		____
Right	0	0.5	1	1.5	2		____
7. Established riparian woody-vegetative cover (Each bank)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	2	1.5	1	0.5	0		____
Right	2	1.5	1	0.5	0		____
8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)							
	0-10%	11-25%	26-50%	51-75%	76-100%		
Left	2	1.5	1	0.5	0		____
Right	2	1.5	1	0.5	0		____
9. Stage of channel evolution							
	I	II	III	IV	V	VI	
	0	1	2	4	3	1.5	____

Figure 1 – Channel stability ranking scheme used to conduct rapid geomorphic assessments (RGAs). The channel stability index is the sum of the values obtained for the nine criterion.

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS (FRONT)

STREAM NAME	LOCATION	
STATION #________ RIVERMILE________	STREAM CLASS	
LAT ____________ LONG ____________	RIVER BASIN	
STORET #	AGENCY	
INVESTIGATORS		
FORM COMPLETED BY	DATE ______ TIME ______ AM PM	REASON FOR SURVEY

Parameters to be evaluated in sampling reach

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
1. Epifaunal Substrate/ Available Cover	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity/Depth Regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is < 0.3 m/s, deep is > 0.5 m.)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS (BACK)

Parameters to be evaluated broader than sampling reach

Habitat Parameter	Condition Category: Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score ________

BEHI Field Data Sheet

Bank Erosion Hazard Index (Rosgen 1996)

River/Stream ______________________ Date ______________

Reach Location (Lat/Long) ______________________ Personnel: ______________

Basic Site Information:

BANK SITE	Bankfull Height	Bankfull Width	Bankfull Depth	Floodprone Area Width	Bank Materials	Bank Stratification
1						
2						
3						
4						
5						
6						
7						
8						

Site BEHI:

BANK SITE	Bank Height/ Bankfull Ht	Root Depth/ Bank Ht.	Root Bank Density	Bank Angle (degrees)	Surface Protection %	TOTAL SCORE
1						
2						
3						
4						
5						
6						
7						
8						

EXISTING CONDITION ASSESSMENT					Roll Up Scoring				
Functional Category	Function-Based Parameters	Measurement Method	Field Value	Index Value	Parameter	Category	Category	ECS	ECS
Hydrology	Catchment Hydrology	Watershed Land Use Runoff Score							
	Reach Runoff	Stormwater Infiltration							
Hydraulics	Floodplain Connectivity	Bank Height Ratio							
		Entrenchment Ratio							
Geomorphology	Large Woody Debris	Large Woody Debris Index							
		# Pieces							
	Lateral Migration	Erosion Rate (ft/yr)							
		Dominant BEHI/NBS							
		Percent Streambank Erosion (%)							
		Percent Armoring (%)							
	Riparian Vegetation	Left - Average Diameter at Breast Height (DBH; in)							
		Right - Average DBH (in)							
		Left - Buffer Width (feet)							
		Right - Buffer Width (feet)							
		Left - Tree Density (#/acre)							
		Right - Tree Density (#/acre)							
		Left - Native Herbaceous Cover (%)							
		Right - Native Herbaceous Cover (%)							
		Left - Native Shrub Cover (%)							
		Right - Native Shrub Cover (%)							
	Bed Material Characterization	Size Class Pebble Count Analyzer (p-value)							
	Bed Form Diversity	Pool Spacing Ratio							
		Pool Depth Ratio							
		Percent Riffle (%)							
		Aggradation Ratio							
	Plan Form	Sinuosity							
Physicochemical	Bacteria	E. Coli (Cfu/100 mL)							
	Organic Enrichment	Percent Nutrient Tolerant Macroinvertebrates (%)							
	Nitrogen	Nitrate-Nitrite (mg/L)							
	Phosphorus	Total Phosphorus (mg/L)							
Biology	Macroinvertebrates	Tennessee Macroinvertebrate Index							
		Percent Clingers (%)							
		Percent EPT - Cheumatopsyche (%)							
		Percent Oligochaeta and Chironomidae (%)							
	Fish	Native Fish Score Index							
		Catch per Unit Effort Score							

APPENDIX B

Raw Statistical Analysis Data

Full Results of the Mann-Whitney U Test for TNSQT Roll-Up Scoring

Mann-Whitney Test

Ranks

	Type	N	Mean Rank	Sum of Ranks
Hydrology	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Hydraulics	Urban Impaired	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Geomorphology	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
Physiochemical	Urban Impaired	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		
Biology	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		

Test Statistics[a]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Mann-Whitney U	.000	7.000	7.000	2.000	.000
Wilcoxon W	10.000	17.000	17.000	12.000	10.000
Z	-2.309	-.333	-.292	-1.732	-2.309
Asymp. Sig. (2-tailed)	.021	.739	.770	.083	.021
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.886[b]	.886[b]	.114[b]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Hydrology	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
Hydraulics	Urban Impaired	4	5.75	23.00
	Urban Restored	4	3.25	13.00
	Total	8		
Geomorphology	Urban Impaired	4	4.13	16.50
	Urban Restored	4	4.88	19.50
	Total	8		
Physiochemical	Urban Impaired	4	4.13	16.50
	Urban Restored	4	4.88	19.50
	Total	8		
Biology	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		

Test Statistics[a]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Mann-Whitney U	6.000	3.000	6.500	6.500	4.000
Wilcoxon W	16.000	13.000	16.500	16.500	14.000
Z	-.581	-1.488	-.438	-.436	-1.155
Asymp. Sig. (2-tailed)	.561	.137	.661	.663	.248
Exact Sig. [2*(1-tailed Sig.)]	.686[b]	.200[b]	.686[b]	.686[b]	.343[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Hydrology	Urban Restored	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Hydraulics	Urban Restored	4	3.50	14.00
	Ecoregion Reference	4	5.50	22.00
	Total	8		
Geomorphology	Urban Restored	4	5.25	21.00
	Ecoregion Reference	4	3.75	15.00
	Total	8		
Physiochemical	Urban Restored	4	3.50	14.00
	Ecoregion Reference	4	5.50	22.00
	Total	8		
Biology	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		

Test Statistics[a]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Mann-Whitney U	.000	4.000	5.000	4.000	5.000
Wilcoxon W	10.000	14.000	15.000	14.000	15.000
Z	-2.323	-1.239	-.871	-1.155	-.866
Asymp. Sig. (2-tailed)	.020	.215	.384	.248	.386
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.343[b]	.486[b]	.343[b]	.486[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Hydrology	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Hydraulics	Urban Impaired	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Geomorphology	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
Physiochemical	Urban Impaired	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		
Biology	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		

Test Statistics[a]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Mann-Whitney U	.000	7.000	7.000	2.000	.000
Wilcoxon W	10.000	17.000	17.000	12.000	10.000
Z	-2.309	-.333	-.292	-1.732	-2.309
Asymp. Sig. (2-tailed)	.021	.739	.770	.083	.021
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.886[b]	.886[b]	.114[b]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Full Results of the Kruskal-Wallis H Test for TNSQT Roll-Up Scoring

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
Hydrology	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Ecoregion Reference	4	10.50
	Total	12	
Hydraulics	Urban Impaired	4	8.00
	Urban Restored	4	4.25
	Ecoregion Reference	4	7.25
	Total	12	
Geomorphology	Urban Impaired	4	5.88
	Urban Restored	4	7.63
	Ecoregion Reference	4	6.00
	Total	12	
Physiochemical	Urban Impaired	4	4.63
	Urban Restored	4	5.88
	Ecoregion Reference	4	9.00
	Total	12	
Biology	Urban Impaired	4	3.50
	Urban Restored	4	6.75
	Ecoregion Reference	4	9.25
	Total	12	

Test Statistics[a,b]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Kruskal-Wallis H	7.565	2.707	.593	3.136	5.115
df	2	2	2	2	2
Asymp. Sig.	.023	.258	.744	.208	.077
Exact Sig.	.009	.254	.770	.222	.074
Point Probability	.002	.010	.010	.005	.011

a. Kruskal Wallis Test

b. Grouping Variable: Type

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
Hydrology	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
Hydraulics	Urban Impaired	4	5.75
	Urban Restored	4	3.25
	Total	8	
Geomorphology	Urban Impaired	4	4.13
	Urban Restored	4	4.88
	Total	8	
Physiochemical	Urban Impaired	4	4.13
	Urban Restored	4	4.88
	Total	8	
Biology	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	

Test Statistics[a,b]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Kruskal-Wallis H	.337	2.215	.192	.190	1.333
df	1	1	1	1	1
Asymp. Sig.	.561	.137	.661	.663	.248
Exact Sig.	.629	.114	.743	.771	.343
Point Probability	.114	.029	.171	.171	.143

a. Kruskal Wallis Test

b. Grouping Variable: Type

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
Hydrology	Urban Restored	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
Hydraulics	Urban Restored	4	3.50
	Ecoregion Reference	4	5.50
	Total	8	
Geomorphology	Urban Restored	4	5.25
	Ecoregion Reference	4	3.75
	Total	8	
Physiochemical	Urban Restored	4	3.50
	Ecoregion Reference	4	5.50
	Total	8	
Biology	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	

Test Statistics[a,b]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Kruskal-Wallis H	5.398	1.534	.759	1.333	.750
df	1	1	1	1	1
Asymp. Sig.	.020	.215	.384	.248	.386
Exact Sig.	.029	.314	.457	.343	.486
Point Probability	.029	.200	.086	.143	.143

a. Kruskal Wallis Test

b. Grouping Variable: Type

Ranks

	Type	N	Mean Rank
Hydrology	Urban Impaired	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
Hydraulics	Urban Impaired	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
Geomorphology	Urban Impaired	4	4.25
	Ecoregion Reference	4	4.75
	Total	8	
Physiochemical	Urban Impaired	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	
Biology	Urban Impaired	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	

Test Statistics[a,b]

	Hydrology	Hydraulics	Geomorphology	Physiochemical	Biology
Kruskal-Wallis H	5.333	.111	.085	3.000	5.333
df	1	1	1	1	1
Asymp. Sig.	.021	.739	.770	.083	.021
Exact Sig.	.029	1.000	.857	.114	.029
Point Probability	.029	.286	.143	.057	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

Full Results of the PCA for TNSQT Roll-Up Scoring

****************** PRINCIPAL COMPONENTS ANALYSIS ******************

PC-ORD, 7.08

19 Nov 2019, 19:41:44

Project file: C:\Users\jmelt\Desktop\Thesis\Stats\RBA\RBA PCA.7prj

Main matrix: C:\Users\jmelt\Desktop\Thesis\Stats\TNSQT Rollup\PCORD\TNSQTRollup (Tranmain).mjm

sites in variables space

Randomization test requested. 999 runs.

4455 = Seed for random number generator.

Cross-products matrix is VARIANCE-COVARIANCE centered by variables

VARIANCE EXTRACTED, FIRST 5 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	0.102	68.767	68.767	0.068
2	0.028	18.867	87.634	0.038
3	0.015	10.318	97.951	0.023
4	0.002	1.408	99.360	0.013
5	0.001	0.640	100.000	0.006

Sum of eigenvalues: 0.14894

FIRST 5 EIGENVECTORS, scaled to unit length.

These can be used as coordinates in a distance-based biplot,

where the distances among objects approximate their Euclidean

distances.

	Eigenvector				
variables	1	2	3	4	5
hydrology	0.7112	-0.6928	0.0221	-0.0970	0.0663
hydraulics	0.0538	0.0399	0.9440	0.1199	-0.3002
geomorpholog	-0.0792	-0.0644	-0.1429	-0.6560	-0.7341
physiochemic	0.1967	0.0349	-0.2952	0.7129	-0.6039
biology	0.6681	0.7163	-0.0296	-0.1941	0.0443

FIRST 5 EIGENVECTORS, each scaled to its standard deviation.

These are sometimes called V vectors and, when applied to

PCA of a correlation matrix, are the same as the correlation

coefficient between scores for rows in the main matrix and the

column variables.

	Eigenvector				
variables	1	2	3	4	5
hydrology	0.2276	-0.1161	0.0027	-0.0044	0.0020
hydraulics	0.0172	0.0067	0.1170	0.0055	-0.0093
geomorpholog	-0.0254	-0.0108	-0.0177	-0.0300	-0.0227
physiochemic	0.0629	0.0058	-0.0366	0.0327	-0.0186

biology	0.2138	0.1201	-0.0037	-0.0089	0.0014

COORDINATES (SCORES) OF sites

	Axis (Component)				
sites	1	2	3	4	5
1 BEAVER	0.0082	0.3315	-0.0764	0.0029	-0.0422
2 FRIAR	-0.0543	0.2845	-0.0329	-0.0393	0.0603
3 THIRD	-0.2179	-0.0526	0.0387	0.0179	-0.0296
4 WILLIAMS	-0.0895	-0.2152	-0.2528	-0.0012	0.0161
5 BAKER	-0.5870	-0.0863	0.1579	-0.0766	-0.0154
6 BEAVER	0.1636	-0.0804	0.0974	0.0817	-0.0072
7 FRIAR	-0.1626	0.1336	0.1154	0.0712	0.0151
8 THIRD	-0.4362	-0.0996	-0.1216	0.0347	0.0142
9 BIG WAR	0.2930	0.0398	-0.0745	-0.0305	-0.0372
10 DRY	0.3796	-0.0874	0.1131	-0.0150	0.0414
11 INDIAN	0.3139	-0.1295	0.1051	-0.0325	-0.0081
12 MILL	0.3893	-0.0385	-0.0694	-0.0133	-0.0074

0.17 = inflation factor for biplot scores

BEGINNING RANDOMIZATIONS

RANDOMIZATION RESULTS

999 = N = number of randomizations

Axis	Eigenvalue from real data	Eigenvalues from randomizations: Minimum	Average	Maximum	p *	n
1	0.10242	0.65679E-01	0.80898E-01	0.12111	0.047000	46
2	0.28100E-01	0.11571E-01	0.49620E-01	0.66820E-01	0.960000	959
3	0.15367E-01	0.40303E-02	0.12194E-01	0.19463E-01	0.063000	62
4	0.20974E-02	0.12236E-02	0.47885E-02	0.75220E-02	0.988000	987
5	0.95377E-03	0.22098E-03	0.14395E-02	0.24684E-02	0.830000	829

* p-value for an axis is (n+1)/(N+1), where n is the number of randomizations with an eigenvalue for that axis that is equal to or larger than the observed eigenvalue for that axis. N is the total number of randomizations.

Full Results of Mann-Whitney U Test for the Individual TNSQT Metrics

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
RGA	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		
RBA	Urban Impaired	4	2.75	11.00
	Urban Restored	4	6.25	25.00
	Total	8		
Runoff	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
Entrenchment	Urban Impaired	4	5.00	20.00
	Urban Restored	4	4.00	16.00
	Total	8		
BEHI	Urban Impaired	4	5.75	23.00
	Urban Restored	4	3.25	13.00
	Total	8		
PerSBEro	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
D50	Urban Impaired	4	3.13	12.50
	Urban Restored	4	5.88	23.50
	Total	8		
LWD	Urban Impaired	4	4.25	17.00
	Urban Restored	4	4.75	19.00
	Total	8		
SIN	Urban Impaired	4	5.75	23.00
	Urban Restored	4	3.25	13.00
	Total	8		
SLOPE	Urban Impaired	4	5.00	20.00
	Urban Restored	4	4.00	16.00
	Total	8		
WDR	Urban Impaired	4	3.75	15.00
	Urban Restored	4	5.25	21.00
	Total	8		

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
POWER	Urban Impaired	4	4.50	18.00
	Urban Restored	4	4.50	18.00
	Total	8		
PSR	Urban Impaired	4	4.38	17.50
	Urban Restored	4	4.63	18.50
	Total	8		
PDR	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
PERRIFF	Urban Impaired	4	4.13	16.50
	Urban Restored	4	4.88	19.50
	Total	8		
BHR	Urban Impaired	4	3.25	13.00
	Urban Restored	4	5.75	23.00
	Total	8		

Test Statistics[a]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro
Mann-Whitney U	.000	1.000	6.000	6.000	3.000	4.000
Wilcoxon W	10.000	11.000	16.000	16.000	13.000	14.000
Z	-2.323	-2.021	-.581	-1.000	-1.443	-1.183
Asymp. Sig. (2-tailed)	.020	.043	.561	.317	.149	.237
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.057[b]	.686[b]	.686[b]	.200[b]	.343[b]

Test Statistics[a]

	D50	LWD	SIN	SLOPE	WDR	POWER
Mann-Whitney U	2.500	7.000	3.000	6.000	5.000	8.000
Wilcoxon W	12.500	17.000	13.000	16.000	15.000	18.000
Z	-1.597	-.289	-1.452	-.584	-.866	.000
Asymp. Sig. (2-tailed)	.110	.773	.146	.559	.386	1.000
Exact Sig. [2*(1-tailed Sig.)]	.114[b]	.886[b]	.200[b]	.686[b]	.486[b]	1.000[b]

Test Statistics[a]

	PSR	PDR	PERRIFF	BHR
Mann-Whitney U	7.500	6.000	6.500	3.000
Wilcoxon W	17.500	16.000	16.500	13.000
Z	-.145	-.577	-.436	-1.488
Asymp. Sig. (2-tailed)	.885	.564	.663	.137
Exact Sig. [2*(1-tailed Sig.)]	.886[b]	.686[b]	.686[b]	.200[b]

a. Grouping Variable: Stream Type

b. Not corrected for ties.

```
 NPAR TESTS
  /M-W= RGA RBA Runoff Entrenchment BEHI PerSBEro D50 LWD SIN SLOPE WDR POWER
PSR PDR PERRIFF BHR
    BY Type(2 3)
  /MISSING ANALYSIS.
```

NPar Tests

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
RGA	Urban Restored	4	6.00	24.00
	Ecoregion Reference	4	3.00	12.00
	Total	8		
RBA	Urban Restored	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		
Runoff	Urban Restored	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Entrenchment	Urban Restored	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		
BEHI	Urban Restored	4	2.88	11.50
	Ecoregion Reference	4	6.13	24.50
	Total	8		
PerSBEro	Urban Restored	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		
D50	Urban Restored	4	4.88	19.50
	Ecoregion Reference	4	4.13	16.50
	Total	8		
LWD	Urban Restored	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
SIN	Urban Restored	4	4.38	17.50
	Ecoregion Reference	4	4.63	18.50
	Total	8		
SLOPE	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
WDR	Urban Restored	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
POWER	Urban Restored	4	4.00	16.00
	Ecoregion Reference	4	5.00	20.00
	Total	8		
PSR	Urban Restored	4	6.38	25.50
	Ecoregion Reference	4	2.63	10.50
	Total	8		
PDR	Urban Restored	4	5.13	20.50
	Ecoregion Reference	4	3.88	15.50
	Total	8		
PERRIFF	Urban Restored	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
BHR	Urban Restored	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		

Test Statistics[a]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro
Mann-Whitney U	2.000	2.000	.000	4.000	1.500	2.000
Wilcoxon W	12.000	12.000	10.000	14.000	11.500	12.000
Z	-1.732	-1.732	-2.337	-1.512	-1.888	-1.786
Asymp. Sig. (2-tailed)	.083	.083	.019	.131	.059	.074
Exact Sig. [2*(1-tailed Sig.)]	.114[b]	.114[b]	.029[b]	.343[b]	.057[b]	.114[b]

Test Statistics[a]

	D50	LWD	SIN	SLOPE	WDR	POWER
Mann-Whitney U	6.500	5.500	7.500	5.000	2.000	6.000
Wilcoxon W	16.500	15.500	17.500	15.000	12.000	16.000
Z	-.436	-.726	-.155	-.887	-1.732	-.577
Asymp. Sig. (2-tailed)	.663	.468	.877	.375	.083	.564
Exact Sig. [2*(1-tailed Sig.)]	.686[b]	.486[b]	.886[b]	.486[b]	.114[b]	.686[b]

Test Statistics[a]

	PSR	PDR	PERRIFF	BHR
Mann-Whitney U	.500	5.500	.000	4.000
Wilcoxon W	10.500	15.500	10.000	14.000
Z	-2.178	-.726	-2.309	-1.230
Asymp. Sig. (2-tailed)	.029	.468	.021	.219
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.486[b]	.029[b]	.343[b]

a. Grouping Variable: Stream Type

b. Not corrected for ties.

```
 USE ALL.
COMPUTE filter_$=(Type = 1 | Type = 3).
VARIABLE LABELS filter_$ 'Type = 1 | Type = 3 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
NPAR TESTS
  /M-W= RGA RBA Runoff Entrenchment BEHI PerSBEro D50 LWD SIN SLOPE WDR POWER
PSR PDR PERRIFF BHR
    BY Type(1 3)
  /MISSING ANALYSIS.
```

NPar Tests

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
RGA	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
RBA	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Runoff	Urban Impaired	4	2.50	10.00
	Ecoregion Reference	4	6.50	26.00
	Total	8		
Entrenchment	Urban Impaired	4	5.75	23.00
	Ecoregion Reference	4	3.25	13.00
	Total	8		
BEHI	Urban Impaired	4	4.00	16.00
	Ecoregion Reference	4	5.00	20.00
	Total	8		
PerSBEro	Urban Impaired	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
D50	Urban Impaired	4	3.25	13.00
	Ecoregion Reference	4	5.75	23.00
	Total	8		
LWD	Urban Impaired	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		
SIN	Urban Impaired	4	5.75	23.00
	Ecoregion Reference	4	3.25	13.00
	Total	8		
SLOPE	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
WDR	Urban Impaired	4	3.00	12.00
	Ecoregion Reference	4	6.00	24.00
	Total	8		

Ranks

	Stream Type	N	Mean Rank	Sum of Ranks
POWER	Urban Impaired	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
PSR	Urban Impaired	4	5.75	23.00
	Ecoregion Reference	4	3.25	13.00
	Total	8		
PDR	Urban Impaired	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		
PERRIFF	Urban Impaired	4	2.75	11.00
	Ecoregion Reference	4	6.25	25.00
	Total	8		
BHR	Urban Impaired	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		

Test Statistics[a]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro
Mann-Whitney U	.000	.000	.000	3.000	6.000	5.000
Wilcoxon W	10.000	10.000	10.000	13.000	16.000	15.000
Z	-2.323	-2.309	-2.323	-1.654	-.577	-.871
Asymp. Sig. (2-tailed)	.020	.021	.020	.098	.564	.384
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.029[b]	.200[b]	.686[b]	.486[b]

Test Statistics[a]

	D50	LWD	SIN	SLOPE	WDR	POWER
Mann-Whitney U	3.000	2.000	3.000	7.000	2.000	5.000
Wilcoxon W	13.000	12.000	13.000	17.000	12.000	15.000
Z	-1.443	-1.732	-1.452	-.290	-1.732	-.866
Asymp. Sig. (2-tailed)	.149	.083	.146	.772	.083	.386
Exact Sig. [2*(1-tailed Sig.)]	.200[b]	.114[b]	.200[b]	.886[b]	.114[b]	.486[b]

Test Statistics[a]

	PSR	PDR	PERRIFF	BHR
Mann-Whitney U	3.000	7.500	1.000	6.000
Wilcoxon W	13.000	17.500	11.000	16.000
Z	-1.443	-.145	-2.021	-.595
Asymp. Sig. (2-tailed)	.149	.885	.043	.552
Exact Sig. [2*(1-tailed Sig.)]	.200[b]	.886[b]	.057[b]	.686[b]

a. Grouping Variable: Stream Type

b. Not corrected for ties.

Full Results of Kruskal-Wallis H Test for the Individual TNSQT Metrics

Kruskal-Wallis Test

Ranks

	Stream Type	N	Mean Rank
RGA	Urban Impaired	4	10.50
	Urban Restored	4	6.00
	Ecoregion Reference	4	3.00
	Total	12	
RBA	Urban Impaired	4	2.75
	Urban Restored	4	6.75
	Ecoregion Reference	4	10.00
	Total	12	
Runoff	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Ecoregion Reference	4	10.50
	Total	12	
Entrenchment	Urban Impaired	4	8.25
	Urban Restored	4	7.00
	Ecoregion Reference	4	4.25
	Total	12	
BEHI	Urban Impaired	4	7.25
	Urban Restored	4	3.63
	Ecoregion Reference	4	8.63
	Total	12	
PerSBEro	Urban Impaired	4	6.75
	Urban Restored	4	4.00
	Ecoregion Reference	4	8.75
	Total	12	
D50	Urban Impaired	4	3.88
	Urban Restored	4	8.25
	Ecoregion Reference	4	7.38
	Total	12	
LWD	Urban Impaired	4	4.75
	Urban Restored	4	6.13
	Ecoregion Reference	4	8.63
	Total	12	

	Stream Type	N	Mean Rank
SIN	Urban Impaired	4	9.00
	Urban Restored	4	5.13
	Ecoregion Reference	4	5.38
	Total	12	
SLOPE	Urban Impaired	4	6.75
	Urban Restored	4	5.25
	Ecoregion Reference	4	7.50
	Total	12	
WDR	Urban Impaired	4	4.25
	Urban Restored	4	5.75
	Ecoregion Reference	4	9.50
	Total	12	
POWER	Urban Impaired	4	5.75
	Urban Restored	4	6.00
	Ecoregion Reference	4	7.75
	Total	12	
PSR	Urban Impaired	4	7.63
	Urban Restored	4	8.50
	Ecoregion Reference	4	3.38
	Total	12	
PDR	Urban Impaired	4	6.13
	Urban Restored	4	7.63
	Ecoregion Reference	4	5.75
	Total	12	
PERRIFF	Urban Impaired	4	4.38
	Urban Restored	4	4.88
	Ecoregion Reference	4	10.25
	Total	12	
BHR	Urban Impaired	4	5.75
	Urban Restored	4	8.75
	Ecoregion Reference	4	5.00
	Total	12	

Test Statistics[a,b]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro	D50
Kruskal-Wallis H	8.800	8.115	7.592	4.440	4.120	3.601	3.321
df	2	2	2	2	2	2	2
Asymp. Sig.	.012	.017	.022	.109	.127	.165	.190

Test Statistics[a,b]

	LWD	SIN	SLOPE	WDR	POWER	PSR	PDR
Kruskal-Wallis H	2.383	3.010	.822	4.500	.731	4.658	.610
df	2	2	2	2	2	2	2
Asymp. Sig.	.304	.222	.663	.105	.694	.097	.737

Test Statistics[a,b]

	PERRIFF	BHR
Kruskal-Wallis H	6.552	2.548
df	2	2
Asymp. Sig.	.038	.280

a. Kruskal Wallis Test

b. Grouping Variable: Stream Type

	Stream Type	N	Mean Rank
RGA	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	
RBA	Urban Impaired	4	2.75
	Urban Restored	4	6.25
	Total	8	
Runoff	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
Entrenchment	Urban Impaired	4	5.00
	Urban Restored	4	4.00
	Total	8	
BEHI	Urban Impaired	4	5.75
	Urban Restored	4	3.25
	Total	8	
PerSBEro	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
D50	Urban Impaired	4	3.13
	Urban Restored	4	5.88
	Total	8	
LWD	Urban Impaired	4	4.25
	Urban Restored	4	4.75
	Total	8	
SIN	Urban Impaired	4	5.75
	Urban Restored	4	3.25
	Total	8	
SLOPE	Urban Impaired	4	5.00
	Urban Restored	4	4.00
	Total	8	
WDR	Urban Impaired	4	3.75
	Urban Restored	4	5.25
	Total	8	

	Stream Type	N	Mean Rank
POWER	Urban Impaired	4	4.50
	Urban Restored	4	4.50
	Total	8	
PSR	Urban Impaired	4	4.38
	Urban Restored	4	4.63
	Total	8	
PDR	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
PERRIFF	Urban Impaired	4	4.13
	Urban Restored	4	4.88
	Total	8	
BHR	Urban Impaired	4	3.25
	Urban Restored	4	5.75
	Total	8	

Test Statistics[a,b]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro	D50
Kruskal-Wallis H	5.398	4.083	.337	1.000	2.083	1.400	2.551
df	1	1	1	1	1	1	1
Asymp. Sig.	.020	.043	.561	.317	.149	.237	.110

Test Statistics[a,b]

	LWD	SIN	SLOPE	WDR	POWER	PSR	PDR
Kruskal-Wallis H	.083	2.108	.341	.750	.000	.021	.333
df	1	1	1	1	1	1	1
Asymp. Sig.	.773	.146	.559	.386	1.000	.885	.564

Test Statistics[a,b]

	PERRIFF	BHR
Kruskal-Wallis H	.190	2.215
df	1	1
Asymp. Sig.	.663	.137

a. Kruskal Wallis Test

b. Grouping Variable: Stream Type

	Stream Type	N	Mean Rank
RGA	Urban Restored	4	6.00
	Ecoregion Reference	4	3.00
	Total	8	
RBA	Urban Restored	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	
Runoff	Urban Restored	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
Entrenchment	Urban Restored	4	5.50
	Ecoregion Reference	4	3.50
	Total	8	
BEHI	Urban Restored	4	2.88
	Ecoregion Reference	4	6.13
	Total	8	
PerSBEro	Urban Restored	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	
D50	Urban Restored	4	4.88
	Ecoregion Reference	4	4.13
	Total	8	
LWD	Urban Restored	4	3.88
	Ecoregion Reference	4	5.13
	Total	8	
SIN	Urban Restored	4	4.38
	Ecoregion Reference	4	4.63
	Total	8	
SLOPE	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
WDR	Urban Restored	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	

	Stream Type	N	Mean Rank
POWER	Urban Restored	4	4.00
	Ecoregion Reference	4	5.00
	Total	8	
PSR	Urban Restored	4	6.38
	Ecoregion Reference	4	2.63
	Total	8	
PDR	Urban Restored	4	5.13
	Ecoregion Reference	4	3.88
	Total	8	
PERRIFF	Urban Restored	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
BHR	Urban Restored	4	5.50
	Ecoregion Reference	4	3.50
	Total	8	

Test Statistics[a,b]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro	D50
Kruskal-Wallis H	3.000	3.000	5.463	2.286	3.563	3.190	.190
df	1	1	1	1	1	1	1
Asymp. Sig.	.083	.083	.019	.131	.059	.074	.663

Test Statistics[a,b]

	LWD	SIN	SLOPE	WDR	POWER	PSR	PDR
Kruskal-Wallis H	.527	.024	.788	3.000	.333	4.744	.527
df	1	1	1	1	1	1	1
Asymp. Sig.	.468	.877	.375	.083	.564	.029	.468

Test Statistics[a,b]

	PERRIFF	BHR
Kruskal-Wallis H	5.333	1.514
df	1	1
Asymp. Sig.	.021	.219

a. Kruskal Wallis Test

b. Grouping Variable: Stream Type

	Stream Type	N	Mean Rank
RGA	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
RBA	Urban Impaired	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
Runoff	Urban Impaired	4	2.50
	Ecoregion Reference	4	6.50
	Total	8	
Entrenchment	Urban Impaired	4	5.75
	Ecoregion Reference	4	3.25
	Total	8	
BEHI	Urban Impaired	4	4.00
	Ecoregion Reference	4	5.00
	Total	8	
PerSBEro	Urban Impaired	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	

	Stream Type	N	Mean Rank
D50	Urban Impaired	4	3.25
	Ecoregion Reference	4	5.75
	Total	8	
LWD	Urban Impaired	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	
SIN	Urban Impaired	4	5.75
	Ecoregion Reference	4	3.25
	Total	8	
SLOPE	Urban Impaired	4	4.25
	Ecoregion Reference	4	4.75
	Total	8	
WDR	Urban Impaired	4	3.00
	Ecoregion Reference	4	6.00
	Total	8	
POWER	Urban Impaired	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
PSR	Urban Impaired	4	5.75
	Ecoregion Reference	4	3.25
	Total	8	
PDR	Urban Impaired	4	4.63
	Ecoregion Reference	4	4.38
	Total	8	
PERRIFF	Urban Impaired	4	2.75
	Ecoregion Reference	4	6.25
	Total	8	
BHR	Urban Impaired	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	

Test Statistics[a,b]

	RGA	RBA	Runoff	Entrenchment	BEHI	PerSBEro	D50
Kruskal-Wallis H	5.398	5.333	5.398	2.734	.333	.759	2.083
df	1	1	1	1	1	1	1
Asymp. Sig.	.020	.021	.020	.098	.564	.384	.149

Test Statistics[a,b]

	LWD	SIN	SLOPE	WDR	POWER	PSR	PDR
Kruskal-Wallis H	3.000	2.108	.084	3.000	.750	2.083	.021
df	1	1	1	1	1	1	1
Asymp. Sig.	.083	.146	.772	.083	.386	.149	.885

Test Statistics[a,b]

	PERRIFF	BHR
Kruskal-Wallis H	4.083	.354
df	1	1
Asymp. Sig.	.043	.552

a. Kruskal Wallis Test

b. Grouping Variable: Stream Type

Full Results of the PCA for the Individual TNSQT Metrics

****************** PRINCIPAL COMPONENTS ANALYSIS ******************

Cross-products matrix is VARIANCE-COVARIANCE centered by variables

VARIANCE EXTRACTED, FIRST 8 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	0.237	47.574	47.574	0.169
2	0.130	26.066	73.640	0.107
3	0.065	13.129	86.769	0.076
4	0.042	8.405	95.175	0.055
5	0.017	3.362	98.537	0.040
6	0.004	0.772	99.309	0.027
7	0.002	0.395	99.704	0.017
8	0.001	0.296	100.000	0.008

Sum of eigenvalues: 0.49851

FIRST 6 EIGENVECTORS, scaled to unit length.

These can be used as coordinates in a distance-based biplot,

where the distances among objects approximate their Euclidean

distances.

variables	Eigenvector 1	2	3	4	5	6
behi	0.0360	-0.0264	-0.2229	0.1314	-0.6011	-0.3102

lwd	-0.2112	-0.3641	0.4359	0.7149	-0.1274	0.2361
sin	0.0220	0.0382	-0.0292	-0.0263	0.0238	-0.5411
wdr	-0.2061	-0.4126	-0.5452	0.2740	0.5695	-0.2293
power	-0.9009	-0.1014	-0.0116	-0.3610	-0.2069	0.0212
psr	-0.2676	0.5789	0.4170	0.2047	0.3608	-0.3699
pdr	-0.1634	0.5644	-0.5308	0.4448	-0.1948	0.2131
bhr	-0.0343	0.1764	-0.0800	-0.1606	0.2943	0.5657

FIRST 6 EIGENVECTORS, each scaled to its standard deviation.
These are sometimes called V vectors and, when applied to
PCA of a correlation matrix, are the same as the correlation
coefficient between scores for rows in the main matrix and the
column variables.

	Eigenvector					
variables	1	2	3	4	5	6
behi	0.0175	-0.0095	-0.0570	0.0269	-0.0778	-0.0192
lwd	-0.1028	-0.1312	0.1115	0.1463	-0.0165	0.0146
sin	0.0107	0.0138	-0.0075	-0.0054	0.0031	-0.0336
wdr	-0.1004	-0.1487	-0.1395	0.0561	0.0737	-0.0142
power	-0.4387	-0.0366	-0.0030	-0.0739	-0.0268	0.0013
psr	-0.1303	0.2087	0.1067	0.0419	0.0467	-0.0229
pdr	-0.0796	0.2034	-0.1358	0.0910	-0.0252	0.0132
bhr	-0.0167	0.0636	-0.0205	-0.0329	0.0381	0.0351

COORDINATES (SCORES) OF sample

sample	Axis (Component) 1	2	3	4	5	6
1 BEAVER	-0.6984	0.4748	0.4185	0.1327	0.0427	0.0010
2 FRIAR	-0.1601	0.0209	-0.0656	-0.1702	0.1815	0.0105
3 THIRD	0.2176	-0.1293	0.3471	0.1636	0.1225	0.0283
4 WILLIAMS	0.9033	0.4664	-0.3548	0.1201	0.1202	0.0429
5 BAKER	0.4661	-0.4391	0.2559	-0.3353	0.0925	-0.0223
6 BEAVER	0.0498	0.2369	-0.0778	0.0545	0.0274	-0.1397
7 FRIAR	0.1144	0.3132	0.0724	0.1180	-0.1863	-0.0188
8 THIRD	-0.2391	0.2384	-0.0729	-0.4178	-0.1331	-0.0010
9 BIG WAR	-0.9352	-0.3496	-0.4103	0.1062	0.1056	0.0125
10 DRY	0.0727	-0.2643	0.1092	0.1005	-0.1040	0.1076
11 INDIAN	0.2468	-0.6096	-0.0508	0.2049	-0.1236	-0.0708
12 MILL	-0.0380	0.0412	-0.1708	-0.0771	-0.1454	0.0496

0.75 = inflation factor for biplot scores

Full Results of the Mann-Whitney U Test for Individual RGA Metrics

Mann-Whitney Test

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	6.38	25.50
	Ecoregion Reference	4	2.63	10.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
Degree of Incision	Urban Impaired	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Degree of Constriction	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	.500	5.500	3.500	.000
Wilcoxon W	10.500	15.500	13.500	10.000
Z	-2.191	-.749	-1.340	-2.646
Asymp. Sig. (2-tailed)	.028	.454	.180	.008
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.486[b]	.200[b]	.029[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.000	.000	.000	1.500
Wilcoxon W	10.000	10.000	10.000	11.500
Z	-2.323	-2.397	-2.323	-1.899
Asymp. Sig. (2-tailed)	.020	.017	.020	.058
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.029[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.381
Asymp. Sig. (2-tailed)	.017
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	5.13	20.50
	Urban Restored	4	3.88	15.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.38	13.50
	Urban Restored	4	5.63	22.50
	Total	8		
Degree of Incision	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		
Degree of Constriction	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.38	25.50
	Urban Restored	4	2.63	10.50
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	5.500	3.500	.000	4.000
Wilcoxon W	15.500	13.500	10.000	14.000
Z	-.730	-1.423	-2.366	-1.265
Asymp. Sig. (2-tailed)	.465	.155	.018	.206
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.200[b]	.029[b]	.343[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.500	.000	4.000	6.000
Wilcoxon W	10.500	10.000	14.000	16.000
Z	-2.178	-2.381	-1.155	-.607
Asymp. Sig. (2-tailed)	.029	.017	.248	.544
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.343[b]	.686[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.477
Asymp. Sig. (2-tailed)	.013
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Restored	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Bed/Bank Protection	Urban Restored	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
Degree of Incision	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
Degree of Constriction	Urban Restored	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
Stream Bank Erosion	Urban Restored	4	5.25	21.00
	Ecoregion Reference	4	3.75	15.00
	Total	8		
Stream Bank Instability	Urban Restored	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Restored	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Occurence of Bank Accreation	Urban Restored	4	6.25	25.00
	Ecoregion Reference	4	2.75	11.00
	Total	8		
Stage of Channel Evolution	Urban Restored	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	1.500	6.000	5.000	6.000
Wilcoxon W	11.500	16.000	15.000	16.000
Z	-1.888	-.661	-.877	-1.000
Asymp. Sig. (2-tailed)	.059	.508	.381	.317
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.686[b]	.486[b]	.686[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	5.000	7.000	3.500	1.000
Wilcoxon W	15.000	17.000	13.500	11.000
Z	-.882	-.316	-1.315	-2.071
Asymp. Sig. (2-tailed)	.378	.752	.189	.038
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.886[b]	.200[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.530
Asymp. Sig. (2-tailed)	.011
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Mann-Whitney Test

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	6.38	25.50
	Ecoregion Reference	4	2.63	10.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
Degree of Incision	Urban Impaired	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Degree of Constriction	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	.500	5.500	3.500	.000
Wilcoxon W	10.500	15.500	13.500	10.000
Z	-2.191	-.749	-1.340	-2.646
Asymp. Sig. (2-tailed)	.028	.454	.180	.008
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.486[b]	.200[b]	.029[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.000	.000	.000	1.500
Wilcoxon W	10.000	10.000	10.000	11.500
Z	-2.323	-2.397	-2.323	-1.899
Asymp. Sig. (2-tailed)	.020	.017	.020	.058
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.029[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.381
Asymp. Sig. (2-tailed)	.017
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Full Results of the Kruskal-Wallis H Test for the Individual TNSQT Metrics

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	9.00
	Urban Restored	4	7.50
	Ecoregion Reference	4	3.00
	Total	12	
Bed/Bank Protection	Urban Impaired	4	4.75
	Urban Restored	4	8.13
	Ecoregion Reference	4	6.63
	Total	12	
Degree of Incision	Urban Impaired	4	9.63
	Urban Restored	4	3.75
	Ecoregion Reference	4	6.13
	Total	12	
Degree of Constriction	Urban Impaired	4	9.50
	Urban Restored	4	6.00
	Ecoregion Reference	4	4.00
	Total	12	
Stream Bank Erosion	Urban Impaired	4	10.38
	Urban Restored	4	5.38
	Ecoregion Reference	4	3.75
	Total	12	
Stream Bank Instability	Urban Impaired	4	10.50
	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	12	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	9.50
	Urban Restored	4	6.63
	Ecoregion Reference	4	3.38
	Total	12	
Occurence of Bank Accreation	Urban Impaired	4	7.63
	Urban Restored	4	8.75

Ranks

	Type	N	Mean Rank
	Ecoregion Reference	4	3.13
	Total	12	
Stage of Channel Evolution	Urban Impaired	4	10.50
	Urban Restored	4	6.50
	Ecoregion Reference	4	2.50
	Total	12	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	6.107	2.046	5.510	6.200	7.441
df	2	2	2	2	2
Asymp. Sig.	.047	.360	.064	.045	.024
Exact Sig.	.031	.403	.052	.030	.013
Point Probability	.001	.062	.001	.006	.002

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	7.922	5.820	5.733	10.391
df	2	2	2	2
Asymp. Sig.	.019	.054	.057	.006
Exact Sig.	.012	.042	.041	.000
Point Probability	.003	.001	.006	.000

a. Kruskal Wallis Test

b. Grouping Variable: Type

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	5.13
	Urban Restored	4	3.88
	Total	8	
Bed/Bank Protection	Urban Impaired	4	3.38
	Urban Restored	4	5.63
	Total	8	
Degree of Incision	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	
Degree of Constriction	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
Stream Bank Erosion	Urban Impaired	4	6.38
	Urban Restored	4	2.63
	Total	8	
Stream Bank Instability	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
Occurence of Bank Accreation	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
Stage of Channel Evolution	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	.534	2.025	5.600	1.600	4.744
df	1	1	1	1	1
Asymp. Sig.	.465	.155	.018	.206	.029
Exact Sig.	.571	.371	.029	.143	.057
Point Probability	.114	.343	.029	.029	.057

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	5.671	1.333	.368	6.137
df	1	1	1	1
Asymp. Sig.	.017	.248	.544	.013
Exact Sig.	.029	.343	.714	.029
Point Probability	.029	.143	.257	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

```
NPAR TESTS
 /K-W=One Two Three Four Five Six Seven Eight Nine BY Type(2 3)
 /MISSING ANALYSIS
 /METHOD=EXACT TIMER(5).
```

NPar Tests

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Restored	4	6.13
	Ecoregion Reference	4	2.88
	Total	8	
Bed/Bank Protection	Urban Restored	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	
Degree of Incision	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
Degree of Constriction	Urban Restored	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	
Stream Bank Erosion	Urban Restored	4	5.25
	Ecoregion Reference	4	3.75
	Total	8	
Stream Bank Instability	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Restored	4	5.63
	Ecoregion Reference	4	3.38
	Total	8	
Occurence of Bank Accreation	Urban Restored	4	6.25
	Ecoregion Reference	4	2.75
	Total	8	
Stage of Channel Evolution	Urban Restored	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	3.563	.438	.768	1.000	.778
df	1	1	1	1	1
Asymp. Sig.	.059	.508	.381	.317	.378
Exact Sig.	.086	.714	.457	1.000	.486
Point Probability	.057	.286	.114	1.000	.114

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	.100	1.729	4.288	6.400
df	1	1	1	1
Asymp. Sig.	.752	.189	.038	.011
Exact Sig.	1.000	.257	.086	.029
Point Probability	.514	.114	.086	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

```
USE ALL.
COMPUTE filter_$=(Type = 1 | Type = 3).
VARIABLE LABELS filter_$ 'Type = 1 | Type = 3 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
NPAR TESTS
  /K-W=One Two Three Four Five Six Seven Eight Nine BY Type(1 3)
  /MISSING ANALYSIS
  /METHOD=EXACT TIMER(5).
```

NPar Tests

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	6.38
	Ecoregion Reference	4	2.63
	Total	8	
Bed/Bank Protection	Urban Impaired	4	3.88
	Ecoregion Reference	4	5.13
	Total	8	
Degree of Incision	Urban Impaired	4	5.63
	Ecoregion Reference	4	3.38
	Total	8	
Degree of Constriction	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Stream Bank Erosion	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Stream Bank Instability	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Occurence of Bank Accreation	Urban Impaired	4	6.13
	Ecoregion Reference	4	2.88
	Total	8	
Stage of Channel Evolution	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	4.802	.561	1.794	7.000	5.398
df	1	1	1	1	1
Asymp. Sig.	.028	.454	.180	.008	.020
Exact Sig.	.057	.571	.229	.029	.029
Point Probability	.057	.171	.057	.029	.029

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	5.744	5.398	3.607	5.671
df	1	1	1	1
Asymp. Sig.	.017	.020	.058	.017
Exact Sig.	.029	.029	.086	.029
Point Probability	.029	.029	.057	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

Full Results of the PCA for Individual RGA Metrics

****************** PRINCIPAL COMPONENTS ANALYSIS ******************

PC-ORD, 7.08

19 Nov 2019, 20:15:49

Project file: C:\Users\jmelt\Desktop\Thesis\Stats\RBA\RBA PCA.7prj

Main matrix: C:\Users\jmelt\Desktop\Thesis\Stats\RGA\PCORD\RGA (redux).mjm

sites in variables space

Randomization test requested. 999 runs.

4961 = Seed for random number generator.

Cross-products matrix is VARIANCE-COVARIANCE centered by variables

VARIANCE EXTRACTED, FIRST 6 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	0.128	66.348	66.348	0.079
2	0.044	23.041	89.390	0.047
3	0.014	7.223	96.613	0.031
4	0.003	1.569	98.182	0.020
5	0.002	1.224	99.406	0.012
6	0.001	0.594	100.000	0.005

Sum of eigenvalues: 0.19283

FIRST 6 EIGENVECTORS, scaled to unit length.
These can be used as coordinates in a distance-based biplot, where the distances among objects approximate their Euclidean distances.

	Eigenvector					
variables	1	2	3	4	5	6
bed/bank pro	0.0634	0.0775	0.2881	0.8302	-0.4273	-0.1875
degreein	-0.5011	-0.7656	0.1587	0.1789	0.1066	0.3069
degreecon	-0.2187	0.4377	-0.0258	0.4146	0.7231	0.2553
streambank i	-0.6237	0.0705	-0.5082	0.0489	-0.0715	-0.5834
established	-0.5169	0.4545	0.2048	-0.2097	-0.4694	0.4690
occurren	-0.2022	0.0692	0.7688	-0.2460	0.2402	-0.4951

FIRST 6 EIGENVECTORS, each scaled to its standard deviation.
These are sometimes called V vectors and, when applied to PCA of a correlation matrix, are the same as the correlation coefficient between scores for rows in the main matrix and the column variables.

	Eigenvector					
variables	1	2	3	4	5	6
bed/bank pro	0.0227	0.0163	0.0340	0.0457	-0.0208	-0.0063

degreein	-0.1793	-0.1614	0.0187	0.0098	0.0052	0.0104
degreecon	-0.0782	0.0923	-0.0030	0.0228	0.0351	0.0086
streambank i	-0.2231	0.0149	-0.0600	0.0027	-0.0035	-0.0197
established	-0.1849	0.0958	0.0242	-0.0115	-0.0228	0.0159
occurren	-0.0723	0.0146	0.0907	-0.0135	0.0117	-0.0168

COORDINATES (SCORES) OF sites

	Axis (Component)					
sites	1	2	3	4	5	6
1 BEAVER	0.0462	-0.0438	0.0853	-0.0812	-0.0308	-0.0174
2 FRIAR	0.3290	-0.0784	0.1187	0.0109	0.0361	-0.0516
3 THIRD	0.3006	0.0973	0.1349	-0.0484	-0.0599	-0.0074
4 WILLIAMS	-0.0267	0.5741	0.0748	0.0177	0.0504	0.0279
5 BAKER	-0.4410	0.0138	-0.0790	0.0111	-0.0458	0.0322
6 BEAVER	-0.4095	-0.0066	-0.0157	0.0019	-0.0015	-0.0099
7 FRIAR	-0.4267	-0.0790	-0.0818	-0.0499	0.0646	-0.0104
8 THIRD	-0.4101	-0.0109	-0.0150	0.0751	-0.0245	-0.0567
9 BIG WAR	0.5920	0.0917	-0.2160	0.0603	-0.0434	-0.0068
10 DRY	-0.0720	-0.2347	0.1305	0.0360	-0.0431	0.0578
11 INDIAN	0.3014	-0.2596	0.0356	0.0545	0.0820	0.0264
12 MILL	0.2167	-0.0640	-0.1722	-0.0881	0.0160	0.0159

0.18 = inflation factor for biplot scores

BEGINNING RANDOMIZATIONS

RANDOMIZATION RESULTS

999 = N = number of randomizations

Axis	Eigenvalue from real data	Eigenvalues from randomizations: Minimum	Average	Maximum	p *	n
1	0.12794	0.60033E-01	0.83194E-01	0.11927	0.001000	0
2	0.44430E-01	0.29263E-01	0.54836E-01	0.77426E-01	0.912000	911
3	0.13928E-01	0.12635E-01	0.32090E-01	0.51776E-01	0.999000	998
4	0.30257E-02	0.47738E-02	0.13772E-01	0.23507E-01	1.000000	999
5	0.23606E-02	0.18177E-02	0.68873E-02	0.13618E-01	0.992000	991
6	0.11451E-02	0.69657E-04	0.20452E-02	0.42979E-02	0.827000	826

----

* p-value for an axis is (n+1)/(N+1), where n is the number of randomizations with an eigenvalue for that axis that is equal to or larger than the observed eigenvalue for that axis. N is the total number of randomizations.

Full Results of the Mann-Whitney U Test for Individual RBP Metrics

Mann-Whitney Test

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	6.38	25.50
	Ecoregion Reference	4	2.63	10.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
Degree of Incision	Urban Impaired	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Degree of Constriction	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	.500	5.500	3.500	.000
Wilcoxon W	10.500	15.500	13.500	10.000
Z	-2.191	-.749	-1.340	-2.646
Asymp. Sig. (2-tailed)	.028	.454	.180	.008
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.486[b]	.200[b]	.029[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.000	.000	.000	1.500
Wilcoxon W	10.000	10.000	10.000	11.500
Z	-2.323	-2.397	-2.323	-1.899
Asymp. Sig. (2-tailed)	.020	.017	.020	.058
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.029[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.381
Asymp. Sig. (2-tailed)	.017
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	5.13	20.50
	Urban Restored	4	3.88	15.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.38	13.50
	Urban Restored	4	5.63	22.50
	Total	8		
Degree of Incision	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		
Degree of Constriction	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.38	25.50
	Urban Restored	4	2.63	10.50
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Urban Restored	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	5.500	3.500	.000	4.000
Wilcoxon W	15.500	13.500	10.000	14.000
Z	-.730	-1.423	-2.366	-1.265
Asymp. Sig. (2-tailed)	.465	.155	.018	.206
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.200[b]	.029[b]	.343[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.500	.000	4.000	6.000
Wilcoxon W	10.500	10.000	14.000	16.000
Z	-2.178	-2.381	-1.155	-.607
Asymp. Sig. (2-tailed)	.029	.017	.248	.544
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.343[b]	.686[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.477
Asymp. Sig. (2-tailed)	.013
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Restored	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Bed/Bank Protection	Urban Restored	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
Degree of Incision	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
Degree of Constriction	Urban Restored	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
Stream Bank Erosion	Urban Restored	4	5.25	21.00
	Ecoregion Reference	4	3.75	15.00
	Total	8		
Stream Bank Instability	Urban Restored	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Restored	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Occurence of Bank Accreation	Urban Restored	4	6.25	25.00
	Ecoregion Reference	4	2.75	11.00
	Total	8		
Stage of Channel Evolution	Urban Restored	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	1.500	6.000	5.000	6.000
Wilcoxon W	11.500	16.000	15.000	16.000
Z	-1.888	-.661	-.877	-1.000
Asymp. Sig. (2-tailed)	.059	.508	.381	.317
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.686[b]	.486[b]	.686[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	5.000	7.000	3.500	1.000
Wilcoxon W	15.000	17.000	13.500	11.000
Z	-.882	-.316	-1.315	-2.071
Asymp. Sig. (2-tailed)	.378	.752	.189	.038
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.886[b]	.200[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.530
Asymp. Sig. (2-tailed)	.011
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Mann-Whitney Test

Ranks

	Type	N	Mean Rank	Sum of Ranks
Primary Bed Material	Urban Impaired	4	6.38	25.50
	Ecoregion Reference	4	2.63	10.50
	Total	8		
Bed/Bank Protection	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
Degree of Incision	Urban Impaired	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
Degree of Constriction	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Erosion	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Stream Bank Instability	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		
Occurence of Bank Accreation	Urban Impaired	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
Stage of Channel Evolution	Urban Impaired	4	6.50	26.00
	Ecoregion Reference	4	2.50	10.00
	Total	8		

Test Statistics[a]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction
Mann-Whitney U	.500	5.500	3.500	.000
Wilcoxon W	10.500	15.500	13.500	10.000
Z	-2.191	-.749	-1.340	-2.646
Asymp. Sig. (2-tailed)	.028	.454	.180	.008
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.486[b]	.200[b]	.029[b]

Test Statistics[a]

	Stream Bank Erosion	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation
Mann-Whitney U	.000	.000	.000	1.500
Wilcoxon W	10.000	10.000	10.000	11.500
Z	-2.323	-2.397	-2.323	-1.899
Asymp. Sig. (2-tailed)	.020	.017	.020	.058
Exact Sig. [2*(1-tailed Sig.)]	.029[b]	.029[b]	.029[b]	.057[b]

Test Statistics[a]

	Stage of Channel Evolution
Mann-Whitney U	.000
Wilcoxon W	10.000
Z	-2.381
Asymp. Sig. (2-tailed)	.017
Exact Sig. [2*(1-tailed Sig.)]	.029[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Full Results of Kruskal-Wallis H Test for Individual RBP Metrics

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	9.00
	Urban Restored	4	7.50
	Ecoregion Reference	4	3.00
	Total	12	
Bed/Bank Protection	Urban Impaired	4	4.75
	Urban Restored	4	8.13
	Ecoregion Reference	4	6.63
	Total	12	
Degree of Incision	Urban Impaired	4	9.63
	Urban Restored	4	3.75
	Ecoregion Reference	4	6.13
	Total	12	
Degree of Constriction	Urban Impaired	4	9.50
	Urban Restored	4	6.00
	Ecoregion Reference	4	4.00
	Total	12	
Stream Bank Erosion	Urban Impaired	4	10.38
	Urban Restored	4	5.38
	Ecoregion Reference	4	3.75
	Total	12	
Stream Bank Instability	Urban Impaired	4	10.50
	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	12	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	9.50
	Urban Restored	4	6.63
	Ecoregion Reference	4	3.38
	Total	12	
Occurence of Bank Accreation	Urban Impaired	4	7.63
	Urban Restored	4	8.75

Ranks

	Type	N	Mean Rank
	Ecoregion Reference	4	3.13
	Total	12	
Stage of Channel Evolution	Urban Impaired	4	10.50
	Urban Restored	4	6.50
	Ecoregion Reference	4	2.50
	Total	12	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	6.107	2.046	5.510	6.200	7.441
df	2	2	2	2	2
Asymp. Sig.	.047	.360	.064	.045	.024
Exact Sig.	.031	.403	.052	.030	.013
Point Probability	.001	.062	.001	.006	.002

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	7.922	5.820	5.733	10.391
df	2	2	2	2
Asymp. Sig.	.019	.054	.057	.006
Exact Sig.	.012	.042	.041	.000
Point Probability	.003	.001	.006	.000

a. Kruskal Wallis Test

b. Grouping Variable: Type

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	5.13
	Urban Restored	4	3.88
	Total	8	
Bed/Bank Protection	Urban Impaired	4	3.38
	Urban Restored	4	5.63
	Total	8	
Degree of Incision	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	
Degree of Constriction	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
Stream Bank Erosion	Urban Impaired	4	6.38
	Urban Restored	4	2.63
	Total	8	
Stream Bank Instability	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
Occurence of Bank Accreation	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
Stage of Channel Evolution	Urban Impaired	4	6.50
	Urban Restored	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	.534	2.025	5.600	1.600	4.744
df	1	1	1	1	1
Asymp. Sig.	.465	.155	.018	.206	.029
Exact Sig.	.571	.371	.029	.143	.057
Point Probability	.114	.343	.029	.029	.057

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	5.671	1.333	.368	6.137
df	1	1	1	1
Asymp. Sig.	.017	.248	.544	.013
Exact Sig.	.029	.343	.714	.029
Point Probability	.029	.143	.257	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

```
NPAR TESTS
 /K-W=One Two Three Four Five Six Seven Eight Nine BY Type(2 3)
 /MISSING ANALYSIS
 /METHOD=EXACT TIMER(5).
```

NPar Tests

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Restored	4	6.13
	Ecoregion Reference	4	2.88
	Total	8	
Bed/Bank Protection	Urban Restored	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	
Degree of Incision	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
Degree of Constriction	Urban Restored	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	
Stream Bank Erosion	Urban Restored	4	5.25
	Ecoregion Reference	4	3.75
	Total	8	
Stream Bank Instability	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Restored	4	5.63
	Ecoregion Reference	4	3.38
	Total	8	
Occurence of Bank Accreation	Urban Restored	4	6.25
	Ecoregion Reference	4	2.75
	Total	8	
Stage of Channel Evolution	Urban Restored	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	3.563	.438	.768	1.000	.778
df	1	1	1	1	1
Asymp. Sig.	.059	.508	.381	.317	.378
Exact Sig.	.086	.714	.457	1.000	.486
Point Probability	.057	.286	.114	1.000	.114

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	.100	1.729	4.288	6.400
df	1	1	1	1
Asymp. Sig.	.752	.189	.038	.011
Exact Sig.	1.000	.257	.086	.029
Point Probability	.514	.114	.086	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

```
USE ALL.
COMPUTE filter_$=(Type = 1 | Type = 3).
VARIABLE LABELS filter_$ 'Type = 1 | Type = 3 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
NPAR TESTS
  /K-W=One Two Three Four Five Six Seven Eight Nine BY Type(1 3)
  /MISSING ANALYSIS
  /METHOD=EXACT TIMER(5).
```

NPar Tests

Ranks

	Type	N	Mean Rank
Primary Bed Material	Urban Impaired	4	6.38
	Ecoregion Reference	4	2.63
	Total	8	
Bed/Bank Protection	Urban Impaired	4	3.88
	Ecoregion Reference	4	5.13
	Total	8	
Degree of Incision	Urban Impaired	4	5.63
	Ecoregion Reference	4	3.38
	Total	8	
Degree of Constriction	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Stream Bank Erosion	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Stream Bank Instability	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Established Riparian Woody-Vegetative Cover	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	
Occurence of Bank Accreation	Urban Impaired	4	6.13
	Ecoregion Reference	4	2.88
	Total	8	
Stage of Channel Evolution	Urban Impaired	4	6.50
	Ecoregion Reference	4	2.50
	Total	8	

Test Statistics[a,b]

	Primary Bed Material	Bed/Bank Protection	Degree of Incision	Degree of Constriction	Stream Bank Erosion
Kruskal-Wallis H	4.802	.561	1.794	7.000	5.398
df	1	1	1	1	1
Asymp. Sig.	.028	.454	.180	.008	.020
Exact Sig.	.057	.571	.229	.029	.029
Point Probability	.057	.171	.057	.029	.029

Test Statistics[a,b]

	Stream Bank Instability	Established Riparian Woody-Vegetative Cover	Occurence of Bank Accreation	Stage of Channel Evolution
Kruskal-Wallis H	5.744	5.398	3.607	5.671
df	1	1	1	1
Asymp. Sig.	.017	.020	.058	.017
Exact Sig.	.029	.029	.086	.029
Point Probability	.029	.029	.057	.029

a. Kruskal Wallis Test

b. Grouping Variable: Type

Full Results of the PCA for the Individual RBP Metrics

****************** PRINCIPAL COMPONENTS ANALYSIS ******************

PC-ORD, 7.08

19 Nov 2019, 20:05:59

Project file: C:\Users\jmelt\Desktop\Thesis\Stats\RBA\RBA PCA.7prj

Main matrix: C:\Users\jmelt\Desktop\Thesis\Stats\RBA\PCORD\RBA PCA (redux).mjm

sites in variables space

Randomization test requested. 999 runs.

5908 = Seed for random number generator.

Cross-products matrix is VARIANCE-COVARIANCE centered by variables

VARIANCE EXTRACTED, FIRST 7 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	41.682	55.511	55.511	27.813
2	19.198	25.568	81.079	17.086
3	7.973	10.618	91.697	11.723
4	3.481	4.636	96.333	8.147
5	1.882	2.507	98.840	5.466
6	0.537	0.716	99.556	3.320
7	0.334	0.444	100.000	1.532

Sum of eigenvalues: 75.087

FIRST 6 EIGENVECTORS, scaled to unit length.

These can be used as coordinates in a distance-based biplot, where the distances among objects approximate their Euclidean distances.

	Eigenvector					
variables	1	2	3	4	5	6
embeddedness	0.3935	-0.5861	0.3091	-0.0275	0.3193	-0.1922
velocity/dep	0.0699	0.3673	0.6767	0.2454	-0.2642	0.4302
sediment dep	0.3004	-0.4929	0.0318	-0.2552	-0.2933	0.5785
frequency of	0.1117	0.1071	0.5295	0.0290	0.4684	-0.2240
bank stabili	0.4595	-0.0633	-0.1937	0.7780	-0.2654	-0.2021
vegetative p	0.3952	0.3243	-0.3570	0.0573	0.5990	0.4899
riparian veg	0.6086	0.3975	-0.0124	-0.5144	-0.3059	-0.3351

FIRST 6 EIGENVECTORS, each scaled to its standard deviation.

These are sometimes called V vectors and, when applied to PCA of a correlation matrix, are the same as the correlation coefficient between scores for rows in the main matrix and the column variables.

Eigenvector						
variables	1	2	3	4	5	6
embeddedness	2.5402	-2.5679	0.8729	-0.0514	0.4380	-0.1409
velocity/dep	0.4513	1.6095	1.9108	0.4578	-0.3625	0.3154
sediment dep	1.9391	-2.1596	0.0898	-0.4760	-0.4023	0.4240
frequency of	0.7213	0.4694	1.4951	0.0541	0.6427	-0.1642
bank stabili	2.9663	-0.2774	-0.5470	1.4515	-0.3641	-0.1481
vegetative p	2.5514	1.4210	-1.0079	0.1069	0.8217	0.3591
riparian veg	3.9289	1.7417	-0.0351	-0.9597	-0.4197	-0.2456

COORDINATES (SCORES) OF sites

	Axis (Component)					
sites	1	2	3	4	5	6
1 BEAVER	-0.7771	-7.5667	-6.4487	0.0093	1.0682	0.5836
2 FRIAR	2.7094	-0.3000	-1.0702	1.6730	0.6835	-1.7996
3 THIRD	6.5114	2.9039	-3.0206	-1.7233	-3.2203	-0.1588
4 WILLIAMS	-5.1431	-4.5113	2.1363	2.2938	-2.0490	-0.2701
5 BAKER	-4.0227	3.3910	-0.6893	-2.6533	1.4725	-0.8478
6 BEAVER	-7.6985	7.0054	-0.1227	0.4236	0.6784	0.3837
7 FRIAR	-7.2482	-5.6895	4.2295	-2.3049	-0.2556	-0.0866
8 THIRD	-8.5016	3.2783	-1.3481	0.0761	-0.6467	0.5773
9 BIG WAR	10.4757	1.0430	2.1537	-0.9112	0.4556	0.0643
10 DRY	5.3237	-3.4861	1.6589	-0.3041	0.8725	0.3558

11 INDIAN	6.2259	1.5256	1.7692	-0.2828	0.4334	0.8969
12 MILL	2.1451	2.4065	0.7522	3.7040	0.5075	0.3013

6.25 = inflation factor for biplot scores

BEGINNING RANDOMIZATIONS

RANDOMIZATION RESULTS

999 = N = number of randomizations

	Eigenvalue from	Eigenvalues from randomizations				
Axis	real data	Minimum	Average	Maximum	p *	n
1	41.682	21.121	27.870	41.072	0.001000	0
2	19.198	11.334	18.358	27.536	0.364000	363
3	7.9728	6.2169	12.373	19.016	0.992000	991
4	3.4810	3.6072	8.1162	12.607	1.000000	999
5	1.8821	1.7966	4.8334	8.8050	0.998000	997
6	0.53727	0.67520	2.5401	5.8617	1.000000	999
7	0.33372	0.67841E-01	0.99576	2.7392	0.922000	921

* p-value for an axis is (n+1)/(N+1), where n is the number of randomizations with an eigenvalue for that axis that is equal to or larger than the observed eigenvalue for that axis. N is the total number of randomizations.

Full Results of the Mann-Whitney U Test for the Modified EMAP Protocol Data

Ranks

	Type	N	Mean Rank	Sum of Ranks
PoolUnitWidth	Urban Impaired	4	3.25	13.00
	Ecoregion Reference	4	5.75	23.00
	Total	8		
PoolAVGDepth	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
RiffUnitWidth	Urban Impaired	4	2.75	11.00
	Ecoregion Reference	4	6.25	25.00
	Total	8		
RiffAVGDepth	Urban Impaired	4	3.25	13.00
	Ecoregion Reference	4	5.75	23.00
	Total	8		
RiffMaxDepth	Urban Impaired	4	3.50	14.00
	Ecoregion Reference	4	5.50	22.00
	Total	8		
PoolMaxDepth	Urban Impaired	4	4.88	19.50
	Ecoregion Reference	4	4.13	16.50
	Total	8		
AquaticVeg	Urban Impaired	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Wood > 0.3 m	Urban Impaired	4	3.63	14.50
	Ecoregion Reference	4	5.38	21.50
	Total	8		
Wood < 0.3m	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
OverhangVeg	Urban Impaired	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		
UCutBanks	Urban Impaired	4	4.38	17.50
	Ecoregion Reference	4	4.63	18.50
	Total	8		

Ranks

	Type	N	Mean Rank	Sum of Ranks
Boulders	Urban Impaired	4	4.00	16.00
	Ecoregion Reference	4	5.00	20.00
	Total	8		
ArtStruct	Urban Impaired	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
PerBed	Urban Impaired	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		
PerBould	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
PerCobb	Urban Impaired	4	2.75	11.00
	Ecoregion Reference	4	6.25	25.00
	Total	8		
PerGrav	Urban Impaired	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		
PerSiltClay	Urban Impaired	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		

Test Statistics[a]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth
Mann-Whitney U	3.000	7.000	1.000	3.000
Wilcoxon W	13.000	17.000	11.000	13.000
Z	-1.443	-.289	-2.021	-1.443
Asymp. Sig. (2-tailed)	.149	.773	.043	.149
Exact Sig. [2*(1-tailed Sig.)]	.200[b]	.886[b]	.057[b]	.200[b]

Test Statistics[a]

	RiffMaxDepth	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m
Mann-Whitney U	4.000	6.500	7.000	4.500	5.500
Wilcoxon W	14.000	16.500	17.000	14.500	15.500
Z	-1.162	-.436	-.290	-1.016	-.730
Asymp. Sig. (2-tailed)	.245	.663	.772	.309	.465
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.686[b]	.886[b]	.343[b]	.486[b]

Test Statistics[a]

	OverhangVeg	UCutBanks	Boulders	ArtStruct	PerBed	PerBould
Mann-Whitney U	7.500	7.500	6.000	6.000	7.500	7.000
Wilcoxon W	17.500	17.500	16.000	16.000	17.500	17.000
Z	-.146	-.145	-.577	-.588	-.145	-.289
Asymp. Sig. (2-tailed)	.884	.885	.564	.557	.885	.773
Exact Sig. [2*(1-tailed Sig.)]	.886[b]	.886[b]	.686[b]	.686[b]	.886[b]	.886[b]

Test Statistics[a]

	PerCobb	PerGrav	PerSiltClay
Mann-Whitney U	1.000	4.000	4.000
Wilcoxon W	11.000	14.000	14.000
Z	-2.021	-1.155	-1.155
Asymp. Sig. (2-tailed)	.043	.248	.248
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.343[b]	.343[b]

a. Grouping Variable: Type

b. Not corrected for ties.

```
NPAR TESTS
  /M-W= PoolUnitWidth PoolAVGDepth RiffUnitWidth RiffAVGDepth RiffMaxDepth Poo
lMaxDepth AquaticVeg
    Woodgt Woodlt OverhangVeg UCutBanks Boulders ArtStruct PerBed PerBould Per
Cobb PerGrav PerSiltClay
    BY Type(1 2)
```

Ranks

	Type	N	Mean Rank	Sum of Ranks
PoolUnitWidth	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
PoolAVGDepth	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
RiffUnitWidth	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
RiffAVGDepth	Urban Impaired	4	3.38	13.50
	Urban Restored	4	5.63	22.50
	Total	8		
RiffMaxDepth	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
PoolMaxDepth	Urban Impaired	4	4.00	16.00
	Urban Restored	4	5.00	20.00
	Total	8		
AquaticVeg	Urban Impaired	4	4.50	18.00
	Urban Restored	4	4.50	18.00
	Total	8		
Wood > 0.3 m	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
Wood < 0.3m	Urban Impaired	4	3.38	13.50
	Urban Restored	4	5.63	22.50
	Total	8		
OverhangVeg	Urban Impaired	4	2.75	11.00
	Urban Restored	4	6.25	25.00
	Total	8		
UCutBanks	Urban Impaired	4	3.63	14.50
	Urban Restored	4	5.38	21.50
	Total	8		

Ranks

	Type	N	Mean Rank	Sum of Ranks
Boulders	Urban Impaired	4	4.88	19.50
	Urban Restored	4	4.13	16.50
	Total	8		
ArtStruct	Urban Impaired	4	3.88	15.50
	Urban Restored	4	5.13	20.50
	Total	8		
PerBed	Urban Impaired	4	4.88	19.50
	Urban Restored	4	4.13	16.50
	Total	8		
PerBould	Urban Impaired	4	5.50	22.00
	Urban Restored	4	3.50	14.00
	Total	8		
PerCobb	Urban Impaired	4	3.50	14.00
	Urban Restored	4	5.50	22.00
	Total	8		
PerGrav	Urban Impaired	4	5.00	20.00
	Urban Restored	4	4.00	16.00
	Total	8		
PerSiltClay	Urban Impaired	4	3.75	15.00
	Urban Restored	4	5.25	21.00
	Total	8		

Test Statistics[a]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth
Mann-Whitney U	4.000	4.000	4.000	3.500
Wilcoxon W	14.000	14.000	14.000	13.500
Z	-1.155	-1.155	-1.155	-1.307
Asymp. Sig. (2-tailed)	.248	.248	.248	.191
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.343[b]	.343[b]	.200[b]

Test Statistics[a]

	RiffMaxDepth	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m
Mann-Whitney U	4.000	6.000	8.000	4.000	3.500
Wilcoxon W	14.000	16.000	18.000	14.000	13.500
Z	-1.169	-.577	.000	-1.183	-1.307
Asymp. Sig. (2-tailed)	.243	.564	1.000	.237	.191
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.686[b]	1.000[b]	.343[b]	.200[b]

Test Statistics[a]

	OverhangVeg	UCutBanks	Boulders	ArtStruct	PerBed	PerBould
Mann-Whitney U	1.000	4.500	6.500	5.500	6.500	4.000
Wilcoxon W	11.000	14.500	16.500	15.500	16.500	14.000
Z	-2.071	-1.016	-.436	-.730	-.436	-1.155
Asymp. Sig. (2-tailed)	.038	.309	.663	.465	.663	.248
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.343[b]	.686[b]	.486[b]	.686[b]	.343[b]

Test Statistics[a]

	PerCobb	PerGrav	PerSiltClay
Mann-Whitney U	4.000	6.000	5.000
Wilcoxon W	14.000	16.000	15.000
Z	-1.155	-.577	-.866
Asymp. Sig. (2-tailed)	.248	.564	.386
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.686[b]	.486[b]

a. Grouping Variable: Type

b. Not corrected for ties.

```
 NPAR TESTS
  /M-W= PoolUnitWidth PoolAVGDepth RiffUnitWidth RiffAVGDepth RiffMaxDepth Poo
lMaxDepth AquaticVeg
    Woodgt Woodlt OverhangVeg UCutBanks Boulders ArtStruct PerBed PerBould Per
Cobb PerGrav PerSiltClay
    BY Type(2 3)
```

Ranks

	Type	N	Mean Rank	Sum of Ranks
PoolUnitWidth	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
PoolAVGDepth	Urban Restored	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		
RiffUnitWidth	Urban Restored	4	3.50	14.00
	Ecoregion Reference	4	5.50	22.00
	Total	8		
RiffAVGDepth	Urban Restored	4	4.50	18.00
	Ecoregion Reference	4	4.50	18.00
	Total	8		
RiffMaxDepth	Urban Restored	4	4.50	18.00
	Ecoregion Reference	4	4.50	18.00
	Total	8		
PoolMaxDepth	Urban Restored	4	5.63	22.50
	Ecoregion Reference	4	3.38	13.50
	Total	8		
AquaticVeg	Urban Restored	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Wood > 0.3 m	Urban Restored	4	4.38	17.50
	Ecoregion Reference	4	4.63	18.50
	Total	8		
Wood < 0.3m	Urban Restored	4	5.13	20.50
	Ecoregion Reference	4	3.88	15.50
	Total	8		
OverhangVeg	Urban Restored	4	6.13	24.50
	Ecoregion Reference	4	2.88	11.50
	Total	8		
UCutBanks	Urban Restored	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		

Ranks

	Type	N	Mean Rank	Sum of Ranks
Boulders	Urban Restored	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
ArtStruct	Urban Restored	4	5.13	20.50
	Ecoregion Reference	4	3.88	15.50
	Total	8		
PerBed	Urban Restored	4	4.13	16.50
	Ecoregion Reference	4	4.88	19.50
	Total	8		
PerBould	Urban Restored	4	4.00	16.00
	Ecoregion Reference	4	5.00	20.00
	Total	8		
PerCobb	Urban Restored	4	3.75	15.00
	Ecoregion Reference	4	5.25	21.00
	Total	8		
PerGrav	Urban Restored	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
PerSiltClay	Urban Restored	4	5.75	23.00
	Ecoregion Reference	4	3.25	13.00
	Total	8		

Test Statistics[a]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth
Mann-Whitney U	5.000	4.000	4.000	8.000
Wilcoxon W	15.000	14.000	14.000	18.000
Z	-.866	-1.155	-1.155	.000
Asymp. Sig. (2-tailed)	.386	.248	.248	1.000
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.343[b]	.343[b]	1.000[b]

Test Statistics[a]

	RiffMaxDepth	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m
Mann-Whitney U	8.000	3.500	7.000	7.500	5.500
Wilcoxon W	18.000	13.500	17.000	17.500	15.500
Z	.000	-1.307	-.296	-.146	-.730
Asymp. Sig. (2-tailed)	1.000	.191	.767	.884	.465
Exact Sig. [2*(1-tailed Sig.)]	1.000[b]	.200[b]	.886[b]	.886[b]	.486[b]

Test Statistics[a]

	OverhangVeg	UCutBanks	Boulders	ArtStruct	PerBed	PerBould
Mann-Whitney U	1.500	7.500	7.000	5.500	6.500	6.000
Wilcoxon W	11.500	17.500	17.000	15.500	16.500	16.000
Z	-1.888	-.145	-.289	-.735	-.436	-.577
Asymp. Sig. (2-tailed)	.059	.885	.773	.462	.663	.564
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.886[b]	.886[b]	.486[b]	.686[b]	.686[b]

Test Statistics[a]

	PerCobb	PerGrav	PerSiltClay
Mann-Whitney U	5.000	7.000	3.000
Wilcoxon W	15.000	17.000	13.000
Z	-.866	-.289	-1.443
Asymp. Sig. (2-tailed)	.386	.773	.149
Exact Sig. [2*(1-tailed Sig.)]	.486[b]	.886[b]	.200[b]

a. Grouping Variable: Type

b. Not corrected for ties.

Ranks

	Type	N	Mean Rank	Sum of Ranks
PoolUnitWidth	Urban Impaired	4	3.25	13.00
	Ecoregion Reference	4	5.75	23.00
	Total	8		
PoolAVGDepth	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
RiffUnitWidth	Urban Impaired	4	2.75	11.00
	Ecoregion Reference	4	6.25	25.00
	Total	8		
RiffAVGDepth	Urban Impaired	4	3.25	13.00
	Ecoregion Reference	4	5.75	23.00
	Total	8		
RiffMaxDepth	Urban Impaired	4	3.50	14.00
	Ecoregion Reference	4	5.50	22.00
	Total	8		
PoolMaxDepth	Urban Impaired	4	4.88	19.50
	Ecoregion Reference	4	4.13	16.50
	Total	8		
AquaticVeg	Urban Impaired	4	4.75	19.00
	Ecoregion Reference	4	4.25	17.00
	Total	8		
Wood > 0.3 m	Urban Impaired	4	3.63	14.50
	Ecoregion Reference	4	5.38	21.50
	Total	8		

Ranks

	Type	N	Mean Rank	Sum of Ranks
Wood < 0.3m	Urban Impaired	4	3.88	15.50
	Ecoregion Reference	4	5.13	20.50
	Total	8		
OverhangVeg	Urban Impaired	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		
UCutBanks	Urban Impaired	4	4.38	17.50
	Ecoregion Reference	4	4.63	18.50
	Total	8		
Boulders	Urban Impaired	4	4.00	16.00
	Ecoregion Reference	4	5.00	20.00
	Total	8		
ArtStruct	Urban Impaired	4	5.00	20.00
	Ecoregion Reference	4	4.00	16.00
	Total	8		
PerBed	Urban Impaired	4	4.63	18.50
	Ecoregion Reference	4	4.38	17.50
	Total	8		
PerBould	Urban Impaired	4	4.25	17.00
	Ecoregion Reference	4	4.75	19.00
	Total	8		
PerCobb	Urban Impaired	4	2.75	11.00
	Ecoregion Reference	4	6.25	25.00
	Total	8		
PerGrav	Urban Impaired	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		
PerSiltClay	Urban Impaired	4	5.50	22.00
	Ecoregion Reference	4	3.50	14.00
	Total	8		

Test Statistics[a]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth
Mann-Whitney U	3.000	7.000	1.000	3.000
Wilcoxon W	13.000	17.000	11.000	13.000
Z	-1.443	-.289	-2.021	-1.443
Asymp. Sig. (2-tailed)	.149	.773	.043	.149
Exact Sig. [2*(1-tailed Sig.)]	.200[b]	.886[b]	.057[b]	.200[b]

Test Statistics[a]

	RiffMaxDepth	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m
Mann-Whitney U	4.000	6.500	7.000	4.500	5.500
Wilcoxon W	14.000	16.500	17.000	14.500	15.500
Z	-1.162	-.436	-.290	-1.016	-.730
Asymp. Sig. (2-tailed)	.245	.663	.772	.309	.465
Exact Sig. [2*(1-tailed Sig.)]	.343[b]	.686[b]	.886[b]	.343[b]	.486[b]

Test Statistics[a]

	OverhangVeg	UCutBanks	Boulders	ArtStruct	PerBed	PerBould
Mann-Whitney U	7.500	7.500	6.000	6.000	7.500	7.000
Wilcoxon W	17.500	17.500	16.000	16.000	17.500	17.000
Z	-.146	-.145	-.577	-.588	-.145	-.289
Asymp. Sig. (2-tailed)	.884	.885	.564	.557	.885	.773
Exact Sig. [2*(1-tailed Sig.)]	.886[b]	.886[b]	.686[b]	.686[b]	.886[b]	.886[b]

Test Statistics[a]

	PerCobb	PerGrav	PerSiltClay
Mann-Whitney U	1.000	4.000	4.000
Wilcoxon W	11.000	14.000	14.000
Z	-2.021	-1.155	-1.155
Asymp. Sig. (2-tailed)	.043	.248	.248
Exact Sig. [2*(1-tailed Sig.)]	.057[b]	.343[b]	.343[b]

Full Results of the Kruskal-Wallis H Test for the Modified EMAP Protocols

Ranks

	Type	N	Mean Rank
PoolUnitWidth	Urban Impaired	4	4.25
	Urban Restored	4	6.75
	Ecoregion Reference	4	8.50
	Total	12	
PoolAVGDepth	Urban Impaired	4	5.25
	Urban Restored	4	8.50
	Ecoregion Reference	4	5.75
	Total	12	
RiffUnitWidth	Urban Impaired	4	3.75
	Urban Restored	4	6.50
	Ecoregion Reference	4	9.25
	Total	12	
RiffAVGDepth	Urban Impaired	4	4.13
	Urban Restored	4	7.63
	Ecoregion Reference	4	7.75
	Total	12	
RiffMaxDepth	Urban Impaired	4	4.50
	Urban Restored	4	7.50
	Ecoregion Reference	4	7.50
	Total	12	
PoolMaxDepth	Urban Impaired	4	6.38
	Urban Restored	4	8.13
	Ecoregion Reference	4	5.00
	Total	12	
AquaticVeg	Urban Impaired	4	6.75
	Urban Restored	4	6.75
	Ecoregion Reference	4	6.00
	Total	12	
Wood > 0.3 m	Urban Impaired	4	4.63
	Urban Restored	4	7.38
	Ecoregion Reference	4	7.50
	Total	12	
Wood < 0.3m	Urban Impaired	4	4.75
	Urban Restored	4	8.25

Ranks

	Type	N	Mean Rank
	Ecoregion Reference	4	6.50
	Total	12	
OverhangVeg	Urban Impaired	4	4.88
	Urban Restored	4	9.88
	Ecoregion Reference	4	4.75
	Total	12	
UCutBanks	Urban Impaired	4	5.50
	Urban Restored	4	7.50
	Ecoregion Reference	4	6.50
	Total	12	
Boulders	Urban Impaired	4	6.38
	Urban Restored	4	5.88
	Ecoregion Reference	4	7.25
	Total	12	
ArtStruct	Urban Impaired	4	6.38
	Urban Restored	4	7.75
	Ecoregion Reference	4	5.38
	Total	12	
PerBed	Urban Impaired	4	7.00
	Urban Restored	4	5.75
	Ecoregion Reference	4	6.75
	Total	12	
PerBould	Urban Impaired	4	7.25
	Urban Restored	4	5.00
	Ecoregion Reference	4	7.25
	Total	12	
PerCobb	Urban Impaired	4	3.75
	Urban Restored	4	6.75
	Ecoregion Reference	4	9.00
	Total	12	
PerGrav	Urban Impaired	4	8.00
	Urban Restored	4	6.25
	Ecoregion Reference	4	5.25
	Total	12	

Ranks

	Type	N	Mean Rank
PerSiltClay	Urban Impaired	4	6.75
	Urban Restored	4	8.50
	Ecoregion Reference	4	4.25
	Total	12	

Test Statistics[a,b]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth	RiffMaxDepth
Kruskal-Wallis H	2.808	1.885	4.654	2.615	1.866
df	2	2	2	2	2
Asymp. Sig.	.246	.390	.098	.271	.393
Exact Sig.	.277	.436	.097	.294	.421
Point Probability	.017	.039	.003	.004	.003

Test Statistics[a,b]

	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m	OverhangVeg
Kruskal-Wallis H	1.520	.117	1.660	1.911	5.372
df	2	2	2	2	2
Asymp. Sig.	.468	.943	.436	.385	.068
Exact Sig.	.503	.965	.486	.411	.066
Point Probability	.012	.026	.013	.012	.005

Test Statistics[a,b]

	UCutBanks	Boulders	ArtStruct	PerBed	PerBould	PerCobb	PerGrav
Kruskal-Wallis H	.622	.299	.897	.273	1.038	4.269	1.192
df	2	2	2	2	2	2	2
Asymp. Sig.	.733	.861	.639	.872	.595	.118	.551
Exact Sig.	.767	.879	.685	.915	.648	.122	.592
Point Probability	.038	.012	.028	.054	.018	.008	.034

Test Statistics[a,b]

	PerSiltClay
Kruskal-Wallis H	2.808
df	2
Asymp. Sig.	.246
Exact Sig.	.277
Point Probability	.017

a. Kruskal Wallis Test

b. Grouping Variable: Type

```
 NPAR TESTS
  /K-W=PoolUnitWidth PoolAVGDepth RiffUnitWidth RiffAVGDepth RiffMaxDepth Pool
MaxDepth AquaticVeg
    Woodgt Woodlt OverhangVeg UCutBanks Boulders ArtStruct PerBed PerBould Per
Cobb PerGrav PerSiltClay
    BY Type(1 2)
  /MISSING ANALYSIS
  /METHOD=EXACT TIMER(5).
```

NPar Tests

Ranks

	Type	N	Mean Rank
PoolUnitWidth	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
PoolAVGDepth	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
RiffUnitWidth	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
RiffAVGDepth	Urban Impaired	4	3.38
	Urban Restored	4	5.63
	Total	8	
RiffMaxDepth	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
PoolMaxDepth	Urban Impaired	4	4.00
	Urban Restored	4	5.00
	Total	8	
AquaticVeg	Urban Impaired	4	4.50
	Urban Restored	4	4.50
	Total	8	
Wood > 0.3 m	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
Wood < 0.3m	Urban Impaired	4	3.38
	Urban Restored	4	5.63
	Total	8	
OverhangVeg	Urban Impaired	4	2.75
	Urban Restored	4	6.25
	Total	8	
UCutBanks	Urban Impaired	4	3.63
	Urban Restored	4	5.38
	Total	8	

Ranks

	Type	N	Mean Rank
Boulders	Urban Impaired	4	4.88
	Urban Restored	4	4.13
	Total	8	
ArtStruct	Urban Impaired	4	3.88
	Urban Restored	4	5.13
	Total	8	
PerBed	Urban Impaired	4	4.88
	Urban Restored	4	4.13
	Total	8	
PerBould	Urban Impaired	4	5.50
	Urban Restored	4	3.50
	Total	8	
PerCobb	Urban Impaired	4	3.50
	Urban Restored	4	5.50
	Total	8	
PerGrav	Urban Impaired	4	5.00
	Urban Restored	4	4.00
	Total	8	
PerSiltClay	Urban Impaired	4	3.75
	Urban Restored	4	5.25
	Total	8	

Test Statistics[a,b]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth	RiffMaxDepth
Kruskal-Wallis H	1.333	1.333	1.333	1.708	1.366
df	1	1	1	1	1
Asymp. Sig.	.248	.248	.248	.191	.243
Exact Sig.	.343	.343	.343	.229	.371
Point Probability	.143	.143	.143	.057	.200

Test Statistics[a,b]

	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m	OverhangVeg
Kruskal-Wallis H	.333	.000	1.400	1.708	4.288
df	1	1	1	1	1
Asymp. Sig.	.564	1.000	.237	.191	.038
Exact Sig.	.686	1.000	.314	.229	.086
Point Probability	.200	.114	.114	.057	.086

Test Statistics[a,b]

	UCutBanks	Boulders	ArtStruct	PerBed	PerBould	PerCobb	PerGrav
Kruskal-Wallis H	1.033	.190	.534	.190	1.333	1.333	.333
df	1	1	1	1	1	1	1
Asymp. Sig.	.309	.663	.465	.663	.248	.248	.564
Exact Sig.	.371	.743	.571	.771	.343	.343	.686
Point Probability	.057	.114	.171	.171	.143	.143	.200

Test Statistics[a,b]

	PerSiltClay
Kruskal-Wallis H	.750
df	1
Asymp. Sig.	.386
Exact Sig.	.486
Point Probability	.143

a. Kruskal Wallis Test

b. Grouping Variable: Type

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
PoolUnitWidth	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
PoolAVGDepth	Urban Restored	4	5.50
	Ecoregion Reference	4	3.50
	Total	8	
RiffUnitWidth	Urban Restored	4	3.50
	Ecoregion Reference	4	5.50
	Total	8	
RiffAVGDepth	Urban Restored	4	4.50
	Ecoregion Reference	4	4.50
	Total	8	
RiffMaxDepth	Urban Restored	4	4.50
	Ecoregion Reference	4	4.50
	Total	8	
PoolMaxDepth	Urban Restored	4	5.63
	Ecoregion Reference	4	3.38
	Total	8	
AquaticVeg	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
Wood > 0.3 m	Urban Restored	4	4.38
	Ecoregion Reference	4	4.63
	Total	8	
Wood < 0.3m	Urban Restored	4	5.13
	Ecoregion Reference	4	3.88
	Total	8	
OverhangVeg	Urban Restored	4	6.13
	Ecoregion Reference	4	2.88
	Total	8	
UCutBanks	Urban Restored	4	4.63
	Ecoregion Reference	4	4.38
	Total	8	

Ranks

	Type	N	Mean Rank
Boulders	Urban Restored	4	4.25
	Ecoregion Reference	4	4.75
	Total	8	
ArtStruct	Urban Restored	4	5.13
	Ecoregion Reference	4	3.88
	Total	8	
PerBed	Urban Restored	4	4.13
	Ecoregion Reference	4	4.88
	Total	8	
PerBould	Urban Restored	4	4.00
	Ecoregion Reference	4	5.00
	Total	8	
PerCobb	Urban Restored	4	3.75
	Ecoregion Reference	4	5.25
	Total	8	
PerGrav	Urban Restored	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
PerSiltClay	Urban Restored	4	5.75
	Ecoregion Reference	4	3.25
	Total	8	

Test Statistics[a,b]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth	RiffMaxDepth
Kruskal-Wallis H	.750	1.333	1.333	.000	.000
df	1	1	1	1	1
Asymp. Sig.	.386	.248	.248	1.000	1.000
Exact Sig.	.486	.343	.343	1.000	1.000
Point Probability	.143	.143	.143	.114	.086

Test Statistics[a,b]

	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m	OverhangVeg
Kruskal-Wallis H	1.708	.088	.021	.534	3.563
df	1	1	1	1	1
Asymp. Sig.	.191	.767	.884	.465	.059
Exact Sig.	.229	.914	.971	.543	.086
Point Probability	.057	.257	.171	.114	.057

Test Statistics[a,b]

	UCutBanks	Boulders	ArtStruct	PerBed	PerBould	PerCobb	PerGrav
Kruskal-Wallis H	.021	.083	.540	.190	.333	.750	.083
df	1	1	1	1	1	1	1
Asymp. Sig.	.885	.773	.462	.663	.564	.386	.773
Exact Sig.	.971	.886	.514	.771	.686	.486	.886
Point Probability	.171	.200	.114	.171	.200	.143	.200

Test Statistics[a,b]

	PerSiltClay
Kruskal-Wallis H	2.083
df	1
Asymp. Sig.	.149
Exact Sig.	.200
Point Probability	.086

a. Kruskal Wallis Test

b. Grouping Variable: Type

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
PoolUnitWidth	Urban Impaired	4	3.25
	Ecoregion Reference	4	5.75
	Total	8	
PoolAVGDepth	Urban Impaired	4	4.25
	Ecoregion Reference	4	4.75
	Total	8	
RiffUnitWidth	Urban Impaired	4	2.75
	Ecoregion Reference	4	6.25
	Total	8	
RiffAVGDepth	Urban Impaired	4	3.25
	Ecoregion Reference	4	5.75
	Total	8	
RiffMaxDepth	Urban Impaired	4	3.50
	Ecoregion Reference	4	5.50
	Total	8	
PoolMaxDepth	Urban Impaired	4	4.88
	Ecoregion Reference	4	4.13
	Total	8	
AquaticVeg	Urban Impaired	4	4.75
	Ecoregion Reference	4	4.25
	Total	8	
Wood > 0.3 m	Urban Impaired	4	3.63
	Ecoregion Reference	4	5.38
	Total	8	
Wood < 0.3m	Urban Impaired	4	3.88
	Ecoregion Reference	4	5.13
	Total	8	
OverhangVeg	Urban Impaired	4	4.63
	Ecoregion Reference	4	4.38
	Total	8	

Ranks

	Type	N	Mean Rank
UCutBanks	Urban Impaired	4	4.38
	Ecoregion Reference	4	4.63
	Total	8	
Boulders	Urban Impaired	4	4.00
	Ecoregion Reference	4	5.00
	Total	8	
ArtStruct	Urban Impaired	4	5.00
	Ecoregion Reference	4	4.00
	Total	8	
PerBed	Urban Impaired	4	4.63
	Ecoregion Reference	4	4.38
	Total	8	
PerBould	Urban Impaired	4	4.25
	Ecoregion Reference	4	4.75
	Total	8	
PerCobb	Urban Impaired	4	2.75
	Ecoregion Reference	4	6.25
	Total	8	
PerGrav	Urban Impaired	4	5.50
	Ecoregion Reference	4	3.50
	Total	8	
PerSiltClay	Urban Impaired	4	5.50
	Ecoregion Reference	4	3.50
	Total	8	

Test Statistics[a,b]

	PoolUnitWidth	PoolAVGDepth	RiffUnitWidth	RiffAVGDepth	RiffMaxDepth
Kruskal-Wallis H	2.083	.083	4.083	2.083	1.349
df	1	1	1	1	1
Asymp. Sig.	.149	.773	.043	.149	.245
Exact Sig.	.200	.886	.057	.200	.286
Point Probability	.086	.200	.029	.086	.057

Test Statistics[a,b]

	PoolMaxDepth	AquaticVeg	Wood > 0.3 m	Wood < 0.3m	OverhangVeg
Kruskal-Wallis H	.190	.084	1.033	.534	.021
df	1	1	1	1	1
Asymp. Sig.	.663	.772	.309	.465	.884
Exact Sig.	.743	.800	.400	.571	.971
Point Probability	.114	.029	.114	.114	.171

Test Statistics[a,b]

	UCutBanks	Boulders	ArtStruct	PerBed	PerBould	PerCobb	PerGrav
Kruskal-Wallis H	.021	.333	.346	.021	.083	4.083	1.333
df	1	1	1	1	1	1	1
Asymp. Sig.	.885	.564	.557	.885	.773	.043	.248
Exact Sig.	.943	.686	.686	.971	.886	.057	.343
Point Probability	.114	.200	.229	.171	.200	.029	.143

Test Statistics[a,b]

	PerSiltClay
Kruskal-Wallis H	1.333
df	1
Asymp. Sig.	.248
Exact Sig.	.343
Point Probability	.143

a. Kruskal Wallis Test

b. Grouping Variable: Type

Full Results of the PCA for the Modified EMAP Protocols

****************** PRINCIPAL COMPONENTS ANALYSIS ******************

PC-ORD, 7.08

19 Nov 2019, 19:08:18

Project file: C:\Users\jmelt\Desktop\Thesis\Stats\RBA\RBA PCA.7prj

Main matrix: C:\Users\jmelt\Desktop\Thesis\Stats\Mesohabitat\Emap redux.mjm

sites in variables space

Randomization test requested. 999 runs.

1806 = Seed for random number generator.

Cross-products matrix is VARIANCE-COVARIANCE centered by variables

VARIANCE EXTRACTED, FIRST 9 AXES

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	0.505	64.162	64.162	0.247
2	0.156	19.757	83.919	0.160
3	0.071	8.979	92.897	0.116
4	0.033	4.164	97.061	0.087
5	0.012	1.574	98.636	0.065
6	0.005	0.661	99.297	0.048
7	0.004	0.494	99.791	0.033

8	0.001	0.152	99.942	0.021
9	0.000	0.058	100.000	0.010

Sum of eigenvalues: 0.78735

FIRST 6 EIGENVECTORS, scaled to unit length.

These can be used as coordinates in a distance-based biplot,

where the distances among objects approximate their Euclidean

distances.

	Eigenvector					
variables	1	2	3	4	5	6
plunwid	-0.0742	0.0331	-0.6637	0.1744	0.0986	-0.0176
avgpldep	0.0237	-0.0501	-0.2048	0.2832	0.3584	-0.0047
rifunwid	-0.1296	0.1317	-0.6245	0.1254	-0.1241	-0.1117
avgrifdep	-0.0252	-0.0053	-0.1105	0.0147	-0.0387	0.1897
wdlt	-0.0566	0.1451	-0.0561	-0.3245	0.6668	0.6036
#of boulders	-0.3597	0.5073	0.1411	-0.1402	0.3898	-0.6293
% bedrock	-0.8333	-0.4987	-0.0046	-0.1939	-0.0815	0.0525
% boulder	-0.3737	0.6176	0.1566	0.3514	-0.3401	0.4330
% cobble	0.0993	0.2655	-0.2602	-0.7664	-0.3551	0.0244

FIRST 6 EIGENVECTORS, each scaled to its standard deviation.

These are sometimes called V vectors and, when applied to

PCA of a correlation matrix, are the same as the correlation coefficient between scores for rows in the main matrix and the column variables.

variables	Eigenvector 1	2	3	4	5	6
plunwid	-0.0527	0.0131	-0.1765	0.0316	0.0110	-0.0013
avgpldep	0.0168	-0.0198	-0.0545	0.0513	0.0399	-0.0003
rifunwid	-0.0921	0.0519	-0.1660	0.0227	-0.0138	-0.0081
avgrifdep	-0.0179	-0.0021	-0.0294	0.0027	-0.0043	0.0137
wdlt	-0.0402	0.0572	-0.0149	-0.0588	0.0742	0.0436
#of boulders	-0.2556	0.2001	0.0375	-0.0254	0.0434	-0.0454
% bedrock	-0.5923	-0.1967	-0.0012	-0.0351	-0.0091	0.0038
% boulder	-0.2656	0.2436	0.0416	0.0636	-0.0379	0.0312
% cobble	0.0706	0.1047	-0.0692	-0.1388	-0.0395	0.0018

COORDINATES (SCORES) OF sites

sites	Axis (Component) 1	2	3	4	5	6
1 BEAVER	0.6493	0.3818	-0.0258	0.1018	-0.0478	0.0909
2 FRIAR	0.2133	-0.5978	-0.0244	-0.0102	0.1885	0.1068
3 THIRD	0.0128	-0.2807	-0.2024	-0.0113	0.1639	-0.0410
4 WILLIAMS	-0.5321	0.1568	0.1593	-0.3585	0.0708	-0.0672

5 BAKER	0.2958	0.6312	0.3678	-0.0440	0.0424	0.0667
6 BEAVER	0.8343	-0.0360	0.1367	0.2952	-0.0101	-0.0978
7 FRIAR	-0.5793	-0.4638	-0.0626	0.0814	-0.1266	-0.0355
8 THIRD	-0.7259	-0.2015	0.5085	0.1629	-0.0134	-0.0206
9 BIG WAR	-1.0335	0.2355	-0.4012	0.1544	-0.0404	0.0735
10 DRY	-0.7202	0.1008	-0.0332	-0.1498	-0.1131	0.0018
11 INDIAN	0.3946	0.4733	-0.3567	0.0081	0.0603	-0.0992
12 MILL	1.1908	-0.3995	-0.0659	-0.2300	-0.1746	0.0215

0.60 = inflation factor for biplot scores

BEGINNING RANDOMIZATIONS

RANDOMIZATION RESULTS

999 = N = number of randomizations

Axis	Eigenvalue from real data	Eigenvalues from randomizations: Minimum	Average	Maximum	p *	n
1	0.50518	0.39246	0.43514	0.52618	0.016000	15
2	0.15555	0.10133	0.15974	0.24820	0.542000	541
3	0.70693E-01	0.46453E-01	0.94102E-01	0.14977	0.862000	861
4	0.32783E-01	0.20344E-01	0.45709E-01	0.75327E-01	0.946000	945
5	0.12396E-01	0.99140E-02	0.27678E-01	0.46794E-01	0.992000	991
6	0.52072E-02	0.50512E-02	0.15000E-01	0.31040E-01	0.998000	997
7	0.38873E-02	0.99802E-03	0.68082E-02	0.16333E-01	0.900000	899
8	0.11943E-02	0.14824E-03	0.25781E-02	0.89701E-02	0.900000	899

9	0.45451E-03	0.44913E-05	0.58852E-03	0.21914E-02	0.547000	546

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* p-value for an axis is (n+1)/(N+1), where n is the number of randomizations with an eigenvalue for that axis that is equal to or larger than the observed eigenvalue for that axis. N is the total number of randomizations.

VITA

Jeremy Melton is a current resident and native of Knoxville, TN. His first Bachelors of Science degree was obtained at Middle Tennessee State University in Music Business. Jeremy received an additional Bachelor of Science degree from the University of Tennessee – Knoxville in Civil Engineering, concentrating in Water Resources and Geotechnical Engineering. He is currently finishing up his Master of Science degree in Environmental Engineering, concentrating in Water Resources Engineering. His academic areas of interest include green infrastructure and stream restoration.