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Evaluation of Stream Assessment Protocols for the Evaluation of Habitat in Intermittent Headwater Streams

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BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Abstract

Evaluation of Stream Assessment Protocols for the Evaluation of Habitat in Intermittent Headwater Streams

Eric J. Rasmussen

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EPA and state water resource agencies are now placing greater emphasis on monitoring and managing headwater streams. Two EPA stream protocols are available for headwater stream assessment but little effort has been made to compare these two methods or their resulting habitat quality index scores. The objectives of this effort were to 1) compare data types of the two protocols; 2) compare how the two protocols assess intermittent streams using habitat quality index (HQI) scores; and 3) compare stream characteristic emphases (geomorphology, riparia, substrate, in-stream cover for biota and hydrology) between the two protocols and their effect on overall HQI scores. This study was conducted within the Northern Glaciated Plains Ecoregion (NGP) of South Dakota. Forty reference sites were chosen using EPA's Analytical Tools Interface for Landscape Assessments (ATtILA). Twenty more sites were chosen to validate the reference sites condition. Ten of the validation sites were selected at random and the other ten were targeted sites selected through consultation with state officials. All sites were field validated using the "North Carolina Division of Water Quality's Identification Methods for the origins of Intermittent and Perennial Streams" and the "Riparian, Channel, and

Environmental Inventory for small streams in the agricultural landscape." Habitat assessments of 60 total streams occurred monthly (April-August) during the summer of 2008 following EPA's "Western Pilot Study: Field Operations Manual for Wadeable Streams" and "Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams." Headwater streams in the NGP can be summarized as low gradient ($\overline{X}$ = 0.02%) streams showing little incision ($\overline{X}$ = 0.4 m). Channel dimensions were variable (CV = 1306.1 width/depth ratio) with flat banks ($\overline{X}$ = 27.4ºC) and homogenous thalwegs ($\overline{X}_{CV}$ = 48.9 %). Substrates consisted of mostly soft/small sediments with herbaceous vegetation as the most frequently occurring in-stream cover for biota. With the exception of the Prairie Coteau Escarpment Ecoregion (46l), riparian trees were rare. Peck's protocol had 51 measurements with a mixture of ratio (n = 14), interval (n = 2), ordinal (n = 23) and nominal (n = 12) data types. Fritz's protocol had 15 measurements yielding mostly ratio (n = 10) data types, and a few interval (n = 2) and nominal data (n = 3). Substrate type was assessed differently by the two protocols. Organic substrates occurred with a frequency of 65% using Peck's protocol, while the substrate class "sand/silt/clay" occurred most frequently (89%) using Fritz's protocol. HQI scores for both protocols were compared using a sign test and a Wilcoxon Rank Sum test, revealing that they were different ($p < 0.01$). Reference HQI scores generated from Fritz metrics ($\overline{X}$ = 71%) were higher ($p < 0.01$) than Peck's HQI's ($\overline{X}$ = 63%). Riparian metrics composed 51% of Peck's measurements and 7% of Fritz's measurements but Peck's riparian HQI's scored lower ($p < 0.01$) than Fritz's riparian HQI's. Hydrologic metrics composed 36% of Fritz's protocol and 4% of Peck's protocol and still the HQI's compared favorably between the two protocols. Evaluation of stream assessments within either protocol revealed high variability in stream characteristics within the NGP ecoregion. Stream habitat scores exhibited greater similarity within level IV EPA ecoregions than between ecoregions. This supports that regionalization by level IV ecoregions may be necessary to account for regional differences in landscape features. The use of more measurements for Peck's protocol increased the ability to detect the influence of human management practices. However, some metrics were similar within Peck's protocol, leading to high redundancy. Fritz's protocol contained fewer metrics with less focus on riparian metrics, reducing the sensitivity of this protocol to human management practices. Data types also differed between and within the two protocols, complicating integration and analysis. Peck's protocol included a large number of ordinal and nominal measurements, which require training and consistency to remain unbiased. Thus, Peck's assessments were more subjective, adding another source of disparity between protocol assessments. Substrate was the only parameter measured by both protocols, but assessments differed due to the use of different substrate classes and a different cross-sectional methodology. Results of HQI differences provide evidence that the two protocols do not respond similarly to physical habitat changes. This can be attributed to the divergence in stream characteristics emphasized by the two protocols. Differences in metric emphasis reflect a focus on hydrologic permanence by the Fritz protocol and riparian metrics by the Peck protocol. Riparian condition reflect the influence of human activities more successfully based on HQI scores than hydrologic condition. This helps to explain differences seen in HQI scores and provides incentive for

the continued use of riparian metrics in stream habitat assessments. A new combined habitat metric set is proposed which places more balance between riparian and hydrologic stream characteristics.

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List of Abbreviations

ATtILA – Analytical Tools Interface for Landscape Assessments

CWA – Clean Water Act

DBH – Diameter at Breast Height

DENR – Department of Environmental and Natural Resources

DOT – Department of Transportation

EMAP – Environmental Monitoring and Assessment Program

EPA – Environmental Protection Agency

FOC – Frequency of Occurrence

GIS – Geographical Information Systems

HQI – Habitat Quality Index

LWD – Large Woody Debris

NHD+ - National Hydrography Dataset

NGP – Northern Glaciated Plains

RCC – River Continuum Concept

RCE – Riparian, Channel, and Environmental Inventory

SD – Standard Deviation

TMDL – Total Maximum Daily Loads

USDA – United States Department of Agriculture

USDI – United States Department of Interior

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1. Introduction

A. Water Quality

i. Monitoring

Monitoring of water resources increased after concerns for the nation's water quality led to the Clean Water Act (CWA) in 1972 (PL 95-217). One of the CWA's objectives was to evaluate and protect the ecological integrity of aquatic ecosystems. Ecological integrity is a combination of three components: chemical, physical, and biological (U.S. EPA 2002). The degradation of one component affects the integrity of the entire system. As a first step toward meeting the CWA's objectives, states assigned beneficial uses to all water bodies. Criteria were then developed in support of each assigned use and when combined for all uses constitute legislated water quality standards. Water quality monitoring is intended to evaluate support of assigned beneficial uses. Results of these monitoring efforts lead toward reporting requirements for each state to (1) describe the current status of all water bodies (305b Report); and (2) list water bodies failing to support assigned uses (303d List). For impaired water bodies, total maximum daily loads (TMDL), which will support beneficial uses, are estimated, and management prescriptions are written to reduce contaminant loadings below TMDL levels (U.S. EPA 1991). In this process the impaired water body goes through an assessment phase, a conservation implementation phase, and a post-implementation assessment phase.

State monitoring is valuable because water resources change in response to disturbance over time (U.S. EPA 2002). However, monitoring must incorporate more than just water chemistry to evaluate changes in ecological integrity. Human activities also influence physical habitat and biological communities (Karr 1990). Due to limited resources, it is difficult for most states to assess the three components of ecological integrity for the thousands of water bodies found in each state. Consequently states are continually trying to develop quick and efficient assessment methods that are scientifically defensible, efficient, and which cover more streams (Fritz et al. 2006; Peck et al. 2006; Peterson 1992; Plafkin et al. 1989; Rankin 1989).

ii. Status

Mankind is very dependent on flowing water for agriculture, industry, recreation, and domestic needs (Allan and Flecker 1993). A survey of the nation's wadeable streams taken in 2004-2005 revealed that only 28% of the nation's stream miles were in good condition while 42% were in poor condition (U.S. EPA 2006) (Figure 1).

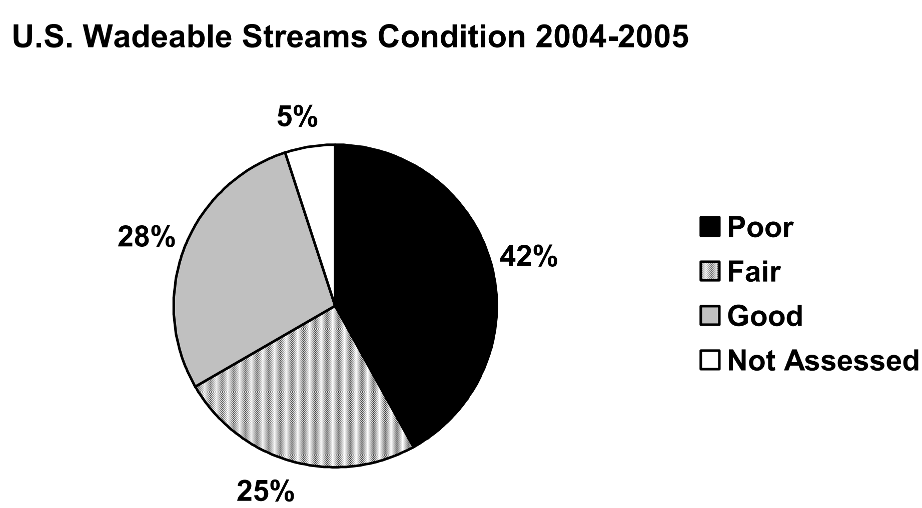

Figure 1 Wadeable stream condition across the conterminous United States (U.S. EPA 2006).

Nitrogen, phosphorous, sediment loading, and riparian disturbance were listed as the leading causes of stress to these streams (U.S. EPA 2006). After dividing the U.S. into three regions, the West was shown to have the most stream miles in good condition, the Plains and Lowlands were fair, and the Eastern Highlands had the most stream miles in poor condition (U.S. EPA 2006). The Eastern Highlands also support the greatest human population of the three regions.

Human encroachment is the ultimate cause of impairment. Humans have changed the ecology of streams (Cross et al. 1985; Rabeni 1996) through major habitat alterations including channelization, culvert installation, habitat destruction, pollution, mining, and urban/suburban sprawl (Dodds et al. 2004; Ohio EPA 2003).

Within the prairie ecoregions, streams have changed dramatically since European settlement (Matthews 1988). Most of this impact has been observed in headwaters. As early as the 1850's, journals described the effects of settlement on intermittent streams and how their change was much more apparent than that in larger rivers (Matthews 1988). This can be related to the shrinking grassland ecosystems of North America in which many intermittent streams are located (Dodds et al. 2004). These grasslands once covered an enormous expanse of land, but are now endangered because of conversion to cropland and pasture (Sampson and Knopf 1994).

South Dakota is one of many states experiencing losses of prairie to agriculture and development, resulting in impaired aquatic ecosystems. Between the years 2000 - 2007, approximately 7,904 miles of the 9,289 perennial rivers and streams in South Dakota were monitored (SD DENR 2008). Fifty one percent of the assessed stream miles were impaired (SD DENR 2008). Most of this impairment was a result of total suspended solids and fecal coliform contamination (SD DENR 2008). South Dakota also has 85,841 intermittent stream miles (SD DENR 2008), nearly 9 times the length of perennial streams. None of these intermittent streams were assessed due to the lack of baseline information and limited funding.

B. Intermittent Streams

i. Definition

The USDA and USDI (1994) define an intermittent stream as having a discernible channel which shows evidence of annual deposition or scour, but which does not carry flow year round. These streams are normally found in the headwaters, but in more arid regions, even larger streams and rivers can be intermittent. Thus, headwater stream orders can vary regionally (Strahler 1952).

ii. Hydrology

Hydrology is the main factor determining whether a stream is intermittent or perennial. Stanley and Fisher (1992) define intermittent flow has having three phases: 1) drying, in which flow relinquishes, 2) dryness, no surface water, and 3) rewetting, which can happen slowly or quickly. This general flow pattern is based on seasonal climate patterns (Matthews 1988) and has a discriminating effect on the type of habitat, invertebrates and primary producers within them (Dodds et al. 2004).

Since stream flow is the determining characteristic for intermittent streams, it is critical to the biological integrity of these systems (Poff and Ward 1989; Poff et al. 1997) (Figure 2). Differences between intermittent and perennial flow regimes allow for different processes to play greater roles on ecological condition. With intermittent flow, abiotic processes, mainly flow regime, have a greater impact on ecological condition than does perennial flow (Poff and Ward 1989). The flow regime directly and indirectly impacts important structural attributes (e.g. channel dimensions, habitat type), physicochemical attributes (e.g. dissolved oxygen, pH), and biotic communities (e.g. physiological characteristics, life history characteristics), which impact ecological condition (Dodds et al. 2004; Poff and Ward 1989; Poff et al. 1997). In perennial systems, flow is more stable to allow biotic processes (e.g. competition, predation) more control than abiotic processes (Poff and Ward 1989). In these systems, riparian areas provide nutrients, physical habitat structure provides cover, and biotic processes like nutrient cycling have a more direct effect on ecological condition than the flow regime alone. Researchers have even broken intermittent flow regimes down further to say that the dry phase plays a greater role in determining the ecological condition by its discrimination of the flora and fauna than the flooding phase (Poff and Ward 1989; Stanley and Fisher 1992). Flooding has a greater effect on biotic community processes by providing nutrients, which are less influential in intermittent streams anyway because the unstable environment limits the biotic community presence (Poff and Ward 1989).

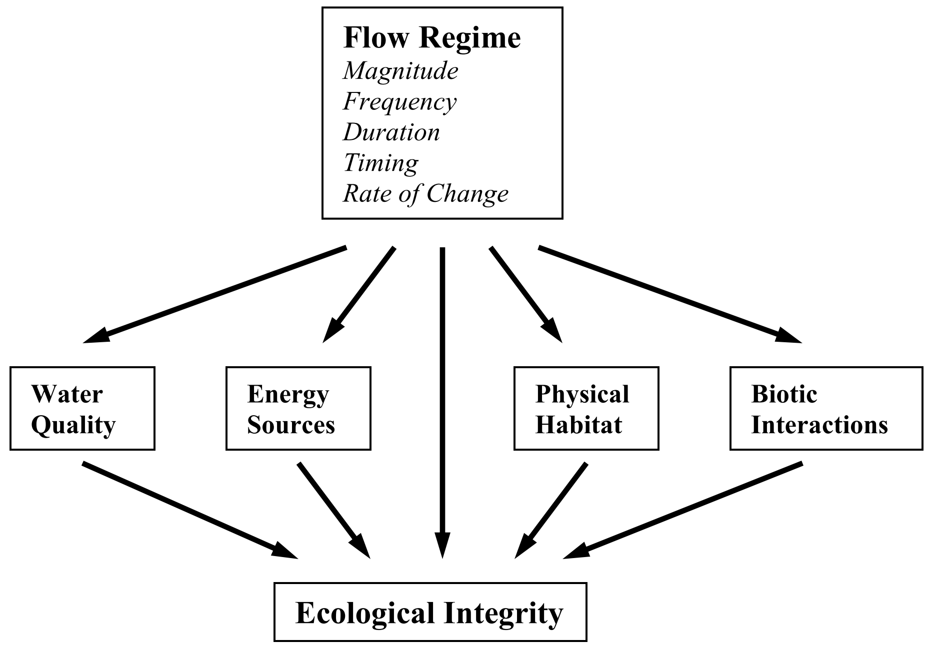

Figure 2 Diagram showing how the flow regime and its five components contribute to the ecological integrity of stream systems (Poff et al. 1997). This diagram was modeled after Karr (1991).

iii. Microbial Communities

Most prairie intermittent streams are autotrophic (Zale et al. 1989) with primary production by algal autotrophs (Dodds et al. 2004). “Algae are the trophic base of these systems” (Zale et al. 1989). “This is possible because often light isn’t restricted from reaching the stream bottom providing the energy needed for organic decomposition” (Hill and Gardner 1987; Stagliano and Whiles 2002). This differs from forested intermittent streams because of varying amounts of canopy cover and leaf litter inputs (Wiley et al. 1990).

Due to autotrophic conditions and dry periods, intermittent streams have slower decomposition rates and export than perennial streams (Zale et al. 1989). When decomposition does take place, microbial and fungal communities play a larger role in decomposition than do macroinvertebrates (Smith 1982) because they are better adapted to the harsh environment of intermittent streams.

iv. Macroinvertebrates

Macroinvertebrates are an important life form in intermittent streams and they aid in the biological functionality of these systems (Allan and Flecker 1993; Zale et al. 1989). They support the nutrient cycling of streams (Vannote et al. 1980; Zale et al. 1989) and can be used as indicators of water quality due to their vulnerability to degradation of their environment (Zale et al. 1989).

Macroinvertebrates that persist in intermittent streams are adapted to its harsh environment (Resh et al. 1988). Most macroinvertebrates found in intermittent streams reproduce quickly (Zale et al. 1989). They are generally univoltine and emerge in the spring before the drying phase (Ward 1992; Zale et al. 1989). In order to survive the variable hydrology of intermittent streams, many organisms use pools and moist areas to survive dry periods (Dodds et al. 2004; Zale et al. 1989). Diapausing in sediment during the dry periods is not an uncommon adaptation in intermittent streams (Fritz and Dodds 2002). After a flooding event, invertebrate populations recover mostly by oviposition from aerial insects (Stehr and Branson 1938).

v. Vegetation

The plant life within intermittent streams consists mostly of algae because algae are adapted to withstand the harsh environment created by intermittent flow regimes (Zale et al. 1989). Algae are autotrophic enabling them to colonize quickly after dry periods, and some species are structurally adapted to withstand scouring by flood events (Alan and Castillo 2007; Power and Stuart 1987). Aquatic submerged macrophytes are less adapted to extremes of intermittent flow regimes. Unstable sediments, turbidity, and high flows caused by floods followed by dry phases make macrophyte colonization difficult (Zale et al. 1989). However, submerged aquatic vegetation is very proficient in establishing along intermittent streams especially where pools occur (Zale et al. 1989).

vi. Importance

Intermittent streams are ecologically important because they link the surrounding terrestrial catchment to downstream water bodies (Dodds 1997; Gomi et al. 2002; Rabeni 1999). They compose the bulk of drainage basins into which all water flows from the surrounding landscape, thus having a direct effect on downstream water quality (Gomi et al. 2002). These systems provide sediment, water, nutrients, and organic matter to downstream reaches. For example, a study by Dodds and Oakes (2006) showed that land use in an entire watershed, including streams which were dry most of the year, affected the water quality downstream. This is evidence that the management of intermittent streams may have more of an effect on water quality than management of perennial streams alone.

Intermittent streams, especially those located in prairie regions, have been a long neglected aspect in the study of ecology (Ward 1992). This is troubling considering that the majority of prairie stream stretches are of intermittent flow (Dodds 1997; Dodds et al. 2004). Prairie streams show mostly intermittent flow because they occur in arid and semi-arid landscapes (Dodds et al. 2004). In contrast, woody ecosystems have a much greater runoff, which makes woody streams more perennial (Dodds et al. 2004). Overall, Dodds (1997) found that grasslands in the U.S. have about as much runoff as forests because they cover a larger land area. Yet, forested streams still receive more attention from scientists than prairie streams (Dodds 1997).

In recent years, agencies such as the Ohio EPA and the North Carolina Division of Water Quality have focused more intensively on the importance of intermittent streams. These and other agencies are researching the benefits intermittent streams provide and finding that management of them may be more effective on water quality than management of perennial streams alone. Such benefits include: sediment control, nutrient control, flood control, wildlife habitat corridors, water and food supply, support of aquatic communities, and dissipation of energy flow (Naiman and Decamps 1997; Ohio EPA 2003; Reid and Ziemer 2005). All of these benefits improve the habitat and water quality that exist downstream (Peterson et al. 2001; Dodds et al. 2004).

C. Riparian Area Influence

i. Riparian Zone

The vegetation that grows adjacent to the stream constitutes the riparian habitat. This vegetation consists mostly of colonists adapted to hydric soils (Gregory et al. 1991). Due to frequent disturbances from hydrology, these areas are greater in plant species diversity then their upslope counterparts (Gregory et al. 1991).

Gregory et al. (1991) state that, “Riparian zones are the interfaces between terrestrial and aquatic ecosystems.” The structure and function of this habitat is very important for the health and quality of the stream. Riparian habitat protects water quality, stream morphology, and provides habitat to a large variety of organisms (Ekness and Randhir 2007; Zale et al. 2005). Dodds and Oakes (2006) found that riparian cover had a great effect on water quality regulation over an entire watershed. The riparian zone is the only feature between the stream channels and all the organic and inorganic materials that are filtered down through the valleys.

ii. Nutrient and Sediment Regulation

A major function of riparian zones is as a buffer for nutrients that drain into the stream. Dissolved nutrients enter streams from terrestrial surroundings through groundwater (Gregory et al. 1991). Roots of riparian vegetation intercept these nutrients, which decreases the load entering the stream (Gregory et al. 1991). Less disturbed vegetation absorbs more nutrients (Dodds et al. 1996), whereas, cultivated land has no way of holding nutrients (Loehr 1974). Studies have shown that removal of riparian habitat in forests increased nutrient export downstream (Likens et al. 1970; Hedin et al. 1995). Vegetation not only buffers nutrients, but it also affects the sources of carbon and energy flow (Vannote et al. 1980) and the movement of dissolved ions and other particles that come from the surrounding watershed (Meybeck 1993).

Along with buffering nutrients, riparian vegetation reduces sediment input, which can otherwise have a detrimental effect on the biota within the stream (Ward 1992). This is accomplished through root networks that hold soil together, and stems that reduce erosive action of flooding waters (Abt et al. 1994). Increases in sediment can fill interstitial places in the substrate, which removes the habitat of some invertebrate species (Zale et al. 1989).

iii. Nutrient Inputs

Riparian habitat provides detritus material that serves as the food base for intermittent streams (Gregory et al. 1991; Zale et al. 2005). The quantity and composition of detritus material is regulated by the riparian zone (Gregory et al. 1991) and influences the invertebrate community structure (Cummins 1974; Cummins et al. 1989). In most prairie streams, the headwaters lack a canopy (Gray and Johnson 1988; Matthews 1988; Wiley et al. 1990) leaving grasses and shrubs as the food base. However, some prairie streams run through small gallery forests such as those in the Prairie Coteau Escarpment Ecoregion of South Dakota (Rasmussen et al. 2008). In these streams, riparian areas produce woody debris, which creates variability in stream habitat and geomorphology (Gregory et al. 1991). Woody debris, along with other riparian characteristics, also support retention of nutrients. Obstacles provided by woody debris and vegetation detain valuable nutrients that otherwise would be carried downstream before organisms can utilize them (Bilby 1981; Gregory et al. 1991). Channelization and other human induced stream modifications remove these retention devices and allow nutrient export downstream (Gregory et al. 1991).

iv. Terrestrial Wildlife

Riparian habitat is critical for wildlife because it "provides water, plant biomass, diversity of microhabitats, and migratory corridors" (Thomas et al. 1979). Corridors provide dispersal not only for wildlife but also for plants (Gregory et al. 1991). Headwaters were found to have a higher concentration of riparian habitat for most vertebrates then downstream reaches (Eckness and Randhir 2007).

v. Temperature

"Vegetation buffers temperature extremes" (Ward 1992), which has an effect on the biotic communities within the stream. This is controlled by canopy cover that can reduce or increase the amount of solar radiation entering the channel depending of canopy presence (Barton et al. 1985).

D. Protocols

Before the 1980's, states used only physical and chemical data to report surface water quality for their biennial 305b reports (Heakin et al. 2006). Though the method had good intentions, it did not provide the data needed to evaluate biotic integrity. In 1991, the U.S. Environmental Monitoring and Assessment Program (EMAP) initiated efforts to provide a standard set of protocols for collection of national scale monitoring data (Blair 2001). In 2000, EMAP-West was initiated to assess the condition and trends in aquatic ecosystems among the western states including South Dakota. EMAP-West focused primarily on wadeable streams. EMAP also developed methodology to support collection of physical, chemical, and biological data (Hughes 1993).

Through various projects during the early years of EMAP, the first sets of protocols were developed for assessing wadeable streams. The purpose of these protocols was to: "(1) Document the procedures used in the collection of field data and various types of samples for the various research studies; and (2) provide these procedures for use by other groups implementing stream monitoring programs (Lazorchak et al. 1998)."

The most recent EMAP protocol produced by EPA is the Western Pilot Study: Field Operations Manual for Wadeable Streams (Peck et al. 2006). The objective of this protocol is to efficiently assess and monitor the status, trends, and integrity of streams and rivers and thereby assist in meeting the goals of the Clean Water Act. The assessment methods described by Peck et al. (2006) were designed primarily for wadeable, perennial streams, but can be adjusted for use on headwater, intermittent streams. One section within this protocol focuses on physical habitat characterization. Physical habitat includes those attributes that influence aquatic communities within streams (Lazorchak et al. 1998). The parameters within this section were developed by Kaufmann (1993). He identified seven general physical habitat attributes important in influencing stream ecology: channel dimensions, channel gradient, channel substrate size and type, habitat complexity and cover, anthropogenic alterations, and channel-riparian interactions (Kaufmann 1993). Each measurement within these seven attributes can be directly or indirectly altered by anthropogenic activities.

In recent years, research has confirmed their importance of intermittent streams to the biological integrity and water quality of the nation's rivers and streams. With these advancements, Fritz et al. (2006) developed protocols specifically intended for use on headwater, intermittent streams. This protocol, "Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams" (Fritz et al. 2006), was designed to meet the same goals and objectives for stream assessment as that of Peck et al. (2006), but differs in design and the parameters measured. Both manuals measure water chemistry and biological communities, but they differ in the measurements for physical habitat characterization (Table 19). Peck et al. (2006) includes riparian habitat characterization whereas Fritz et al. (2006) does not. Fritz et al. (2006) includes hydrologic permanence measurements but Peck et al. (2006) does not. The metrics that aren't included within Fritz et al. (2006) but are included in Peck et al. (2001) include: riparian vegetation structure, in-stream cover for fish, algae, and aquatic macrophytes, human influences, legacy trees, and invasive alien plants. No formal comparison of habitat scores from these two protocols has been completed.

2. Research Objectives

EPA supports two sets of stream assessment protocols that can be used by managers and agencies for characterizing intermittent streams. The key differences between them are physical habitat measurements. One protocol uses riparian habitat measurements while the other uses hydrologic permanence measurements. Both riparian habitat (Gregory et al. 1991; Dodds and Oaks 2006; Naiman and Decamps 1997) and hydrologic permanence (Dodds et al. 2004; Poff and Ward 1989; Poff et al. 1997) are known to influence stream condition. The objective of this study is to investigate differences between the physical habitat characterization sections of Peck et al. (2006) and Fritz et al. (2006) by: 1) comparing data types of the two protocols; 2) comparing how the two protocols assess intermittent streams using habitat quality index (HQI) scores; and 3) comparing stream characteristic emphases between the two protocols and their effect on overall HQI scores.

3. Methods and Materials

A. Study Area

This study was conducted within the Northern Glaciated Plains (NGP) level III ecoregion of South Dakota (Figure 3). This ecoregion is characterized by its glaciated landscape of flat to gently rolling hills (Bryce et al. 1998). The NGP has many temporary and seasonal wetlands. The climate is sub-humid with precipitation ranging from approximately 406-559 mm. The natural vegetation of the region is composed of mixed tall and short grass prairie, but much of the landscape has been tilled for agriculture. Small grains, hay, and pastureland are the main land uses in the ecoregion.

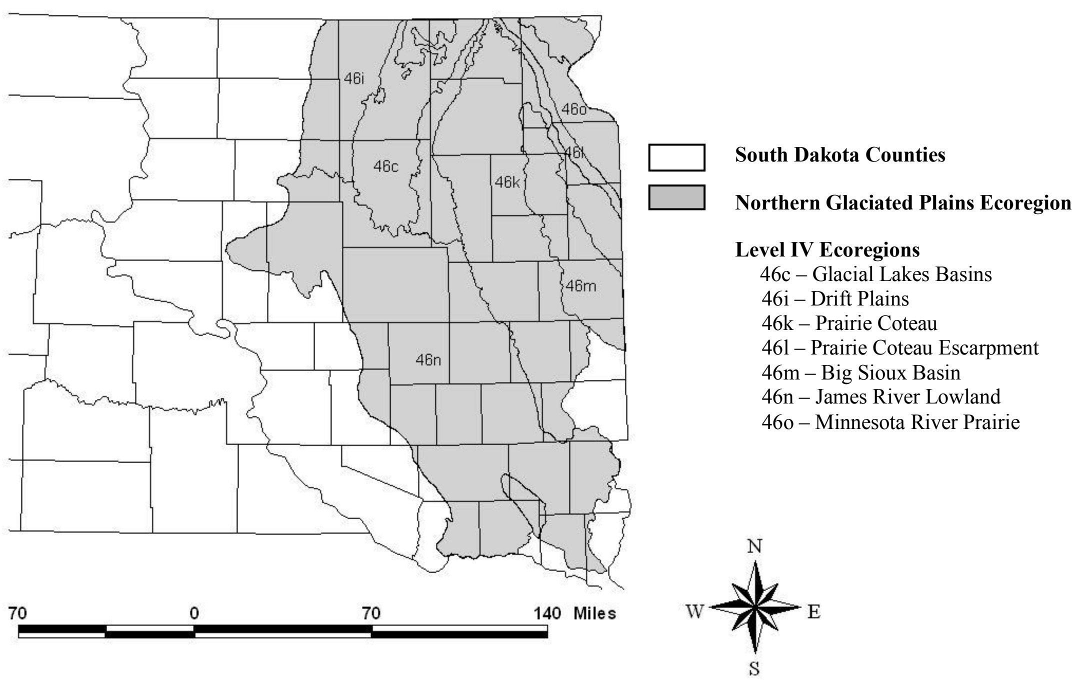

Figure 3 Study area map showing the Northern Glaciated Plains Ecoregion boundary in gray with labeled level IV ecoregion boundaries.

Within the NGP ecoregion are seven level IV ecoregions (Figure 3) that further differentiate physiography, climate and land-use (Table 1).

Table 1 Table listing the seven level IV ecoregions within the NGP and their physiographic characteristics (Bryce et al. 1998).

Level IV Ecoregion	Area (Km^2)*	Local Relief (m)*	Geography
Glacial Lakes Basins	9,283	0 – 9	Level glacial lake floors
Drift Plains	40,427	0 – 61	Flat with occasional “washboard” undulations
Prairie Coteau	13,543	15 – 46	Platform of hummocky, rolling terrain raised above surrounding drift plains
Prairie Coteau Escarpment	1,075	76 – 183	Steep escarpment with broken topography from incised perennial and intermittent streams
Big Sioux Basin	3,986	6 – 61	Rolling, erosional landscape
James River Lowland	23,898	3 – 46	Level to slightly rolling plain composed of glacial drift
Minnesota River Prairie	2,139	50 – 30	Level to gently rolling plain

*** Area and elevation measurements include portions of North Dakota in which the ecoregions fall within.**

B. Site Selection

Selection of the candidate stream reaches began with a total population of 2,849 headwater stream watersheds delineated within the National Hydrography Dataset (NHD+)(USGS 2010). Streams included in this population all met the following criteria:

- Strahler stream order = 1 based on a 1:100,000 scale NHD+ map
- Stream is located within ≤ 10 km^2 watershed
- Seasonal loss of connected surface water and progressive drying along channel during most years

- Stream is contained within a defined channel with stream bed and bank features
- Stream is not a lake outlet

EPA's Analytical Tools Interface for Landscape Assessments (ATtILA) was used to score all watersheds based upon landscape characteristics, riparian characteristics, human stressors, and physical characteristics (U.S. EPA 2001). Fifteen Geographic Information System (GIS) coverage (Table 2) along with four basic metrics were used to rank the condition of targeted intermittent streams.

Table 2 GIS coverage's and metrics used by ATtILA to develop disturbance scores.

ArcView Coverage	ATtILA Characteristic Group
National Land Cover Data 2001	Human Stressors
Ecoregion Boundaries	Landscape Characteristics
National Elevation Dataset	Physical Characteristics
2000 U.S. Census Block Dataset	Riparian Characteristics
South Dakota DOT Road Coverage	
NHD+ Flowline	
Superfund Sites	
Feedlot Point Coverage	
PRISM and NHD+ Precipitation Data	

All streams were scored 0-100 with those scoring near zero being of high quality and those scoring near 100 in the poorest condition. After the NHD+ processing and ATtILA analysis, the total number of candidate reference streams were much more than could be sampled, so a probability-based selection method was used to select at random 40 streams from the candidate reference population. These streams were taken from the 15th percentile of the high quality ATtILA scores in each of the level IV ecoregions of the Northern Glaciated Plains. These stream reaches were representative of their respective region and comprised the reference sampling sites (Figure 4).

C. Test Sites

In order to validate the reference site condition, twenty test sites were selected from the total NHD+ population discussed earlier (Figure 4). These twenty sites were selected independently of the candidate reference sites. Ten sites were selected at random, and the other ten were targeted sites selected through consultation with state officials. Water resource managers identified five targeted sites believed to be in excellent condition and five sites believed to be in poor condition. Judgments were based upon historical data and working knowledge of the study area.

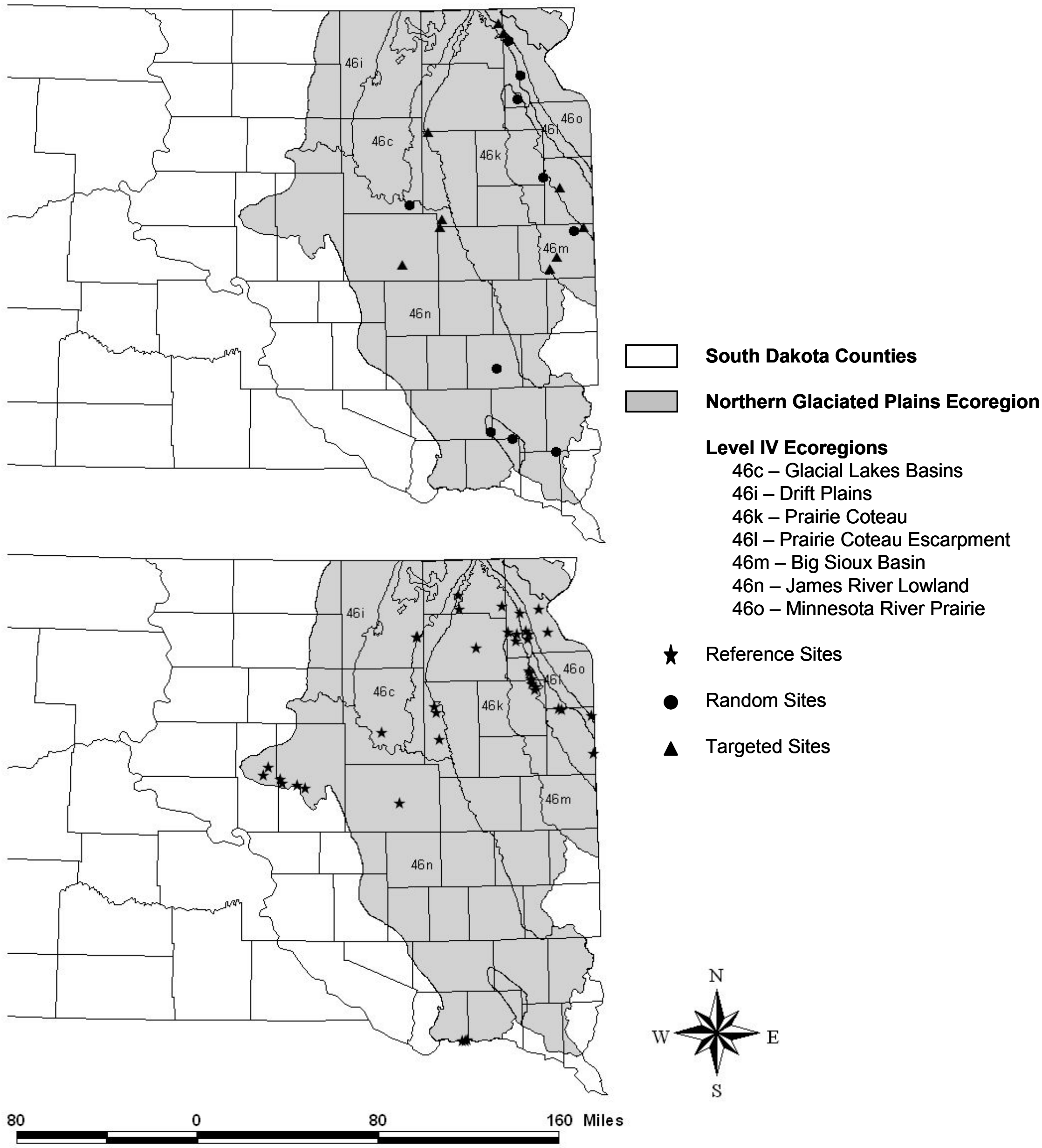

Figure 4 Study area maps showing the locations of the 60 study sites categorized by site types.

D. Field Validation

Field validation of the 60 sample sites was completed in the summer of 2007 to verify intermittency and quality of the stream. Each site was visited by a field crew for visual validation. Field crews used the North Carolina Division of Water Quality's Identification Methods for the Origins of Intermittent and Perennial streams (NC Division of Water Quality 2005) and the Riparian, Channel, and Environmental Inventory for Small Streams in the Agricultural Landscape (Petersen 1992). The intermittency identification protocol uses geomorphologic, hydrologic, and biologic stream features, which can distinguish between ephemeral, intermittent, and perennial streams (NC Division of Water Quality 2005). Each indicator was scored and compared to a weighted scale of defined criteria for intermittent flow. The RCE uses physical and biological condition of small streams to assess stream quality (Petersen 1992). Each metric is scored and totaled on a scale, then classed as excellent, very good, good, fair, or poor. Both protocols were modified to address the variable hydrologic condition in which the streams were assessed. Both protocols had biological metrics that couldn't be evaluated for those channels which were dry. Those indicators were eliminated in both protocols and index scores were recalculated. This allowed us to fairly compare flowing channels visited early with dry channels visited late in the summer. The data from these protocols were used to validate that the streams fell within the criteria for use within the study. Fifteen candidate streams were eliminated from the study using these two protocols.

E. Sampling

All 60 streams were sampled once per month from April to August 2008. Sampling protocols followed the habitat characterization sections provided by EPA's standard protocols (Fritz et al. 2006 and Peck et al. 2006). The physical attributes that were measured included: channel dimensions, channel gradient, channel substrate, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic alterations, channel-riparian interaction, and hydrologic permanence. A total of 66 habitat metrics from both protocols were evaluated monthly from each stream from April to August.

Habitat metrics were assessed along stream reach lengths of approximately 40 times average wetted width (Peck et. al 2006). Riparian measurements (i.e. vegetation structure, alien plants) were measured using visualized 10 X 10 m plots at the upstream, middle, and downstream portions of the sample reach. In-stream cover for biota (i.e. macrophyte coverage, algae coverage), hydrologic permanence (i.e. substrate moisture, depth to groundwater), and bank measurements (angle, height, undercut) were measured within the channel at the upstream, middle and downstream reach locations. Wetted widths, cross-sectional substrate, and habitat classes were measured at 11 transects distributed evenly along the reach. Large woody debris tallies, thalweg depths, and modal sediment size were measured at 21 transects spaced evenly along the sample reach. Sinuosity and slope were taken using the entire reach length.

F. Analyses

Data were summarized for each of the 60 reaches for each month sampled. There were four data types recorded: interval, ratio, ordinal, and nominal. Summaries of these data types were accomplished in two ways. The interval and ratio data were quantitative measurements allowing for calculations of within reach averages for the individual measurements at each site. The nominal and ordinal data measurements were qualitative. These measurements were summarized by calculating a within reach frequency of occurrence for each reach. The frequency of occurrence was based on the number of times a category was observed out of the total number of possible observations.

Reference habitat quality index (HQI) scores for each of the 60 sites were developed for each protocol. Two forms of HQI scoring methods were constructed to account for the type of data collected. Unlike other methods, interval and ratio data were measured in a quantitative manner rather then being placed into discrete categories given predetermined index scores (i.e. RCE, Peterson 1992; RBP, Barbour et al. 1999). In order to avoid using these discrete categories, reference habitat values of test sites were compared to reference sites.

Reference sites were sorted for each measurement by Level IV Ecoregion and by the month in which the measurement was taken. Ecoregions were assessed separately at the Level IV scale because of natural differences in physical habitat components among the Level IV regions (Rasmussen et al. 2008). Reference sites represent a distribution of possible conditions that might be expected to occur in the absence of significant human influences (Stoddard et al. 2006). Each condition or value resulting from a measurement within a reference population will show variability from both sample error and naturalness in both space and time (Stoddard et al. 2006). A distribution of reference site values for each measurement within each ecoregion was generated. This reference distribution provided the basis for scoring test sites (Frappier and Eckert 2007).

For each distribution of values, a median was calculated to represent the central-tendency of the data (Figure 5). The median value of the reference value distribution was used for test site comparison. A 95% confidence interval (CI) around the median reference value was calculated using methods as described by Conover (1980) (Figure 5). Within the 95% CI, benchmarks were set for scoring purposes. Benchmarks were created by splitting each tail of the 95% CI into thirds. The ranges of these benchmarks took into account any non-normal distributions of the data as a result of using median as the central tendency value. This helped to maintain the representativeness of the distribution. Each benchmark range was assigned a score. "Choosing a scoring system is a balance between providing as much resolution as possible while recognizing that there is limited knowledge about the relationship between a change in the indicator and environmental effects" (Ladson et al. 1999). The benchmark range closest to the median received a score of 6. The next two benchmarks in descending order received scores of 4 and 2, respectively. Any value that fell outside the 95% CI received a score of 0. By using this scoring system, resolution was provided by weighting the scores based on how far they deviated from the median reference value while maintaining the variability in condition that naturally occurs. This method also allowed for statistical significance ($\alpha = 0.05$).

Depending on the parameter being measured, it was predetermined whether the parameter would be scored with a one-tail, or two-tailed 95% CI. If a parameter was determined to have a positive biological impact through either high or low values on either side of the median value, then the measurement was treated as a two-tailed index. If a parameter was determined to have a positive biological impact through only low values or only high values, then the measurement was treated as a one-tail index and scored accordingly.

At this point, test site values were able to be compared to the reference distribution of values based on the deviation from the reference median. A score for that measurement was then assigned to the test site. This method is similar to a study that used Euclidean distance to compare reference sites to test sites (Frappier and Eckert 2007). The concept behind both methods is that as deviation from reference increases, index scores decrease (Frappier and Eckert 2007). A test value with a deviation greater than the 95% CI around the median for reference values would then fall outside of expected natural variation for reference conditions and therefore be considered degraded (Frappier and Eckert 2007).

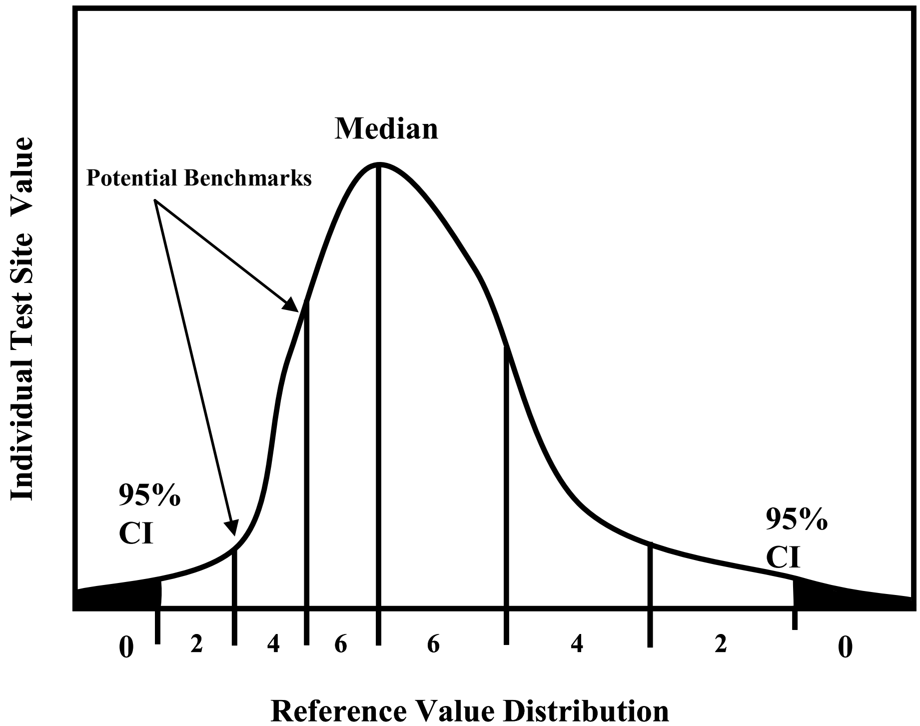

Figure 5 This is a hypothetical representation of a non-normal distribution. The median line represents the central tendency of the data. The shaded areas represent 95% confidence intervals around the median. Each vertical line represents the benchmarks and the scores which were assigned to them. Notice that the bench mark ranges vary between the two tails of the 95% CI.

Ordinal and nominal data were qualitative measurements that were placed into discrete categories in the field. A similar approach was used to score these data types. First, reference sites were sorted for each measurement by Level IV Ecoregion and by the month in which the site was visited. For each ecoregion, a frequency distribution of categorical variable occurrence was calculated for the reference sites by combining all five months of data (Figure 6). The same was done for each individual site within each ecoregion. These distributions were used to compare test sites to reference sites in order to detect degradation. The discriminatory power of the categorical variables between test sites and reference sites was measured using a Chi-square analysis (Hall et al. 2002).

Each test site response distribution was compared to the reference site distribution using a Chi-square analysis (Conover 1980). The resulting p-values from each test were used to determine the scores for each individual site. Benchmarks of alpha equal to 0.01, 0.10, and 0.50 were used for scoring purposes. These benchmarks were chosen due to the great variability of stream characteristics that can be found at the scale in which the assessments were taken. By broadening the benchmarks, more discriminatory power was gained from the test. Any Chi-square test resulting in a p-value less then 0.01 received a score of 0. Any p-value less then 0.10 but greater then 0.01 received a 2. Any p-value less then 0.50 but greater then 0.10 received a 4, and any p-value greater then 0.50 received a score of 6. By using this scoring system, resolution was provided by weighting the scores based on how close the test site distributions matched the reference site distributions. This method also allows for statistical significance at multiple alpha levels.

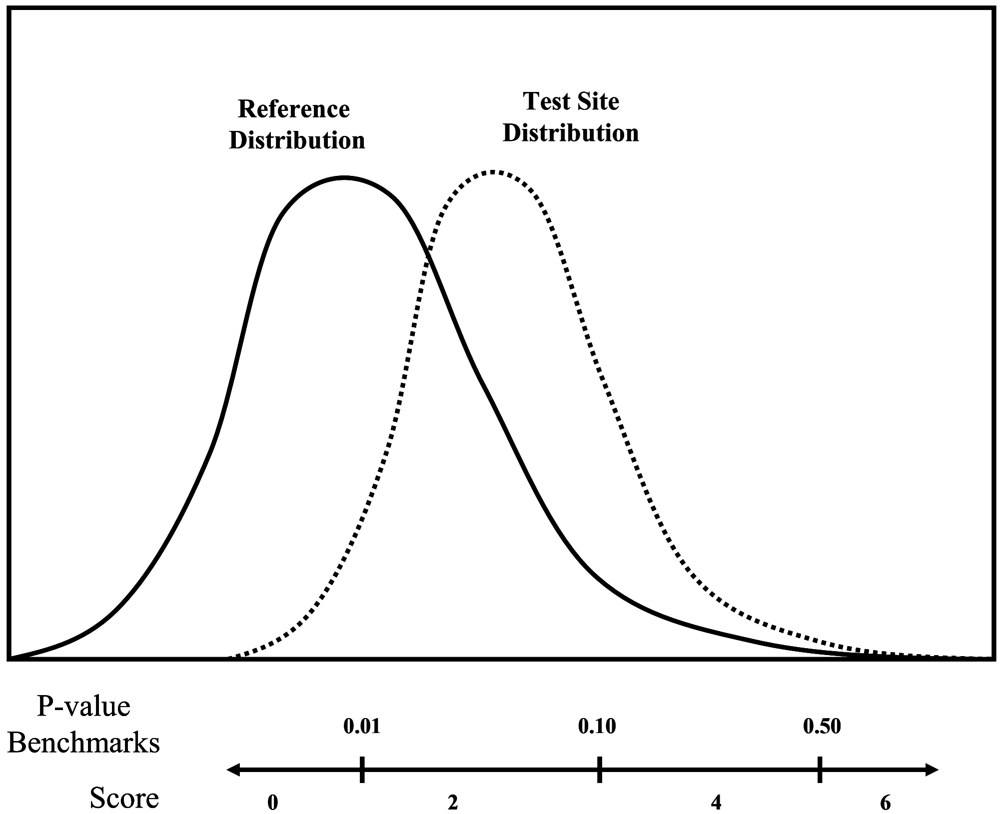

Figure 6 This is a hypothetical representation of a reference distribution and test site distribution of categorical variable occurrence. These two distributions would then be compared using a Chi-square analysis. The scale below the distributions show how the resulting p-value would be used to score the measurement.

Total HQI scores were then developed on a scale of 0-100% by summing individual metric scores from each protocol and dividing that score by the total possible score each protocol could receive. Reference streams were scored closest to 100% and impaired streams were closest to 0%. Once the final scores for each site were calculated, a Sign Test and a Wilcoxon Rank Sum Test (Analytical Software 2008) was used to compare the HQI scores between the two sets of protocols.

For the final analysis, the scores from each protocol were regressed on the scores from ATtILA, RCE, and chemical measurements (Analytical Software 2008) to test how the two protocols assessed streams on a gradient of condition.

4. Results

A. Habitat Characterization

i. Channel Geomorphology

All seven ecoregions were low in gradient (Table 3) with glides (water moving slowly, with a smooth, unbroken surface [Kaufmann 2006]) composing the dominant channel unit habitat class (Table 5). Ecoregion 46l contained the greatest variety of in-channel unit classes (Table 5). Pools were rare, occurring most frequently in Ecoregion 46i (Table 5). When pools occurred in all the ecoregions, they were shallow (Table 3) trench pools formed by unseen fluvial processes (Table 5). Ecoregion 46n contained the shallowest pools on average (Table 3; $\overline{X}$ = 16.2) while Ecoregion 46c contained the deepest (Table 3; $\overline{X}$ = 33.1). With characteristic shallow pools (Table 3) and glides (Table 3), the streams for all ecoregions contained fairly homogenous thalwegs (Table 3). Ecoregion 46c stream depths varied little (CV = 20.3 %), while those of Ecoregion 46i had the greatest depth variation (CV = 77.4 %). Bars in the channels were rare for all the ecoregions with the greatest frequency in Ecoregion 46l (FOC = 11.1%; Table 4). Streams of Ecoregions 46c and 46o contained no bars (Table 4). When bars were present in the channels they were < 1 meter in width on average (Table 3) with Ecoregion 46l having the largest average bar widths ($\overline{X}$ = 0.4 m). Backwater and side channels were also rare for all ecoregions (Table 4). Ecoregion 46o had the widest and shallowest channel dimensions on average (Bankfull width/depth $\overline{X}$ = 40.3), and Ecoregion 46i was the most uniform (Bankfull width/depth $\overline{X}$ =12.9 ; Table 3). Streams of all ecoregions showed little incision and contained flat banks with few undercuts (Tables 3 and 4).

Ecoregion 46c contained no undercuts and the flattest average bank angle ($\overline{X}$ = 10.5 º) while Ecoregion 46i had the highest frequency of undercut occurrences (20.1%) and the steepest banks ($\overline{X}$ = 42.4º; Tables 3 and 4). Stream valleys were wide with Ecoregion 46i having the narrowest valley widths ($\overline{X}$ = 43.3 m; Table 3). Despite having large valley widths, Ecoregion 46l streams had the narrowest average flood prone area ($\overline{X}$ = 8.7; Table 3). All seven ecoregions contained some sort of constraining feature within their valleys with Ecoregion 46l having the greatest portion of it's streams constrained ($\overline{X}$ = 61.4%; Table 3). Sinuosity was similar among all seven ecoregions with those of Ecoregion 46c containing the least amount of sinuosity on average despite containing the largest average valley widths ($\overline{X}$ = 1015.6 m) and largest average flood prone area ($\overline{X}$ = 185.4 m; Table 3).

Table 3 Descriptive statistics for channel geomorphology measurements from both protocols categorized by level IV ecoregion.

Parameter	Descriptive Statistics	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Slope (%)	Mean	0.00	0.03	0.02	0.03	0.02	0.03	0.02
	SD	0.00	0.02	0.03	0.01	0.02	0.02	0.03
	Variance	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	Minimum	0.00	0.01	0.01	0.01	0.00	0.00	0.00
	Median	0.00	0.03	0.01	0.04	0.02	0.02	0.00
	Maximum	0.01	0.08	0.13	0.07	0.06	0.13	0.08
Max Pool Depth (cm)	Mean	33.1	20.6	29.0	22.5	23.9	16.2	26.9
	SD	21.7	22.5	21.9	17.5	16.9	26.5	28.4
	Variance	469.3	507.8	477.5	305.9	285.0	700.9	808.6
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	36.0	15.0	24.5	24.0	24.0	7.0	22.0
	Maximum	80.0	74.0	130.0	86.0	52.0	124.0	88.0
Thalweg Depth (cm)	Mean	24.1	7.2	15.8	8.5	14.1	7.6	14.5
	SD	19.5	12.4	16.2	8.2	13.0	14.2	20.2
	Variance	381.9	154.3	260.9	66.6	169.6	201.3	407.5
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	22.0	0.0	11.0	7.5	12.0	2.0	6.0
	Maximum	80.0	74.0	130.0	86.0	52.0	124.0	88.0
Thalweg Heterogeneity (CV)	Mean	20.3	77.4	52.2	52.0	44.5	45.1	42.6
	SD	14.1	80.0	53.5	37.1	61.6	74.1	44.9
	Variance	198.7	6396.4	2863.3	1376.9	3793.6	5492.7	2018.7
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	18.9	64.8	36.7	52.4	29.7	25.8	34.1
	Maximum	46.4	226.4	268.7	177.9	317.3	458.3	135.8
Bar Width (m)	Mean	0.0	0.0	0.2	0.4	0.0	0.1	0.0
	SD	0.0	0.6	1.2	2.0	0.3	1.2	0.0
	Variance	0.0	0.4	1.5	3.9	0.1	1.3	0.0
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Maximum	0.0	10.0	13.0	20.0	6.0	30.0	0.0
Bankful Width/ Depth Ratio (m)	Mean	29.6	12.9	22.7	23.0	20.7	19.6	40.3
	SD	20.0	10.3	33.3	57.1	13.8	13.8	44.8
	Variance	400.7	105.7	1108.8	3260.0	191.7	189.9	2010.0
	Minimum	13.8	1.0	0.6	1.3	1.0	1.9	1.7
	Median	22.8	12.1	8.6	8.5	18.1	16.0	23.0
	Maximum	123.3	45.0	233.3	320.0	86.1	91.5	180.0
Incised Height (m)	Mean	0.3	0.4	0.4	0.4	0.4	0.4	0.3
	SD	0.2	0.2	0.6	0.3	0.3	0.3	0.2
	Variance	0.0	0.0	0.3	0.1	0.1	0.1	0.0
	Minimum	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.3	0.4	0.3	0.4	0.3	0.4	0.2
	Maximum	0.8	0.9	6.9	1.2	1.2	1.6	0.8

Table 3 cont.

Parameter	Descriptive Statistics	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Bank Angle (º)	Mean	11.0	42.4	34.1	39.2	19.9	18.7	24.3
	SD	7.0	48.1	36.3	33.4	27.3	28.6	40.2
	Variance	49.1	2310.1	1319.9	1117.1	744.1	815.5	1617.8
	Minimum	0.0	2.0	0.0	0.0	0.0	1.0	0.0
	Median	10.0	18.5	20.0	30.0	10.0	10.0	10.0
	Maximum	35.0	150.0	250.0	230.0	155.0	270.0	230.0
Bank Undercut (m)	Mean	0.0	0.1	0.2	0.3	0.2	0.3	0.2
	SD	0.0	0.0	0.1	0.2	0.2	0.3	0.1
	Variance	0.0	0.0	0.0	0.0	0.1	0.1	0.0
	Minimum	0.0	0.1	0.1	0.1	0.0	0.1	0.1
	Median	0.0	0.2	0.2	0.2	0.1	0.2	0.2
	Maximum	0.0	0.2	0.5	0.7	0.8	0.8	0.3
Valley Width (m)	Mean	1015.6	43.3	112.6	227.0	484.1	352.3	566.7
	SD	760.7	22.4	125.0	73211.0	573.3	518.4	311.6
	Variance	578611.0	503.6	15622.0	535978.0	328698.0	268730.0	116667.0
	Minimum	50.0	10.0	5.0	5.0	10.0	5.0	200.0
	Median	1609.3	50.0	100.0	30.0	200.0	75.0	500.0
	Maximum	1609.3	75.0	500.0	3218.7	1650.0	1609.3	1000.0
Flood Prone Area Width (m)	Mean	185.4	11.8	23.2	8.7	29.8	14.0	21.1
	SD	222.1	11.7	28.6	6.4	50.6	17.6	26.1
	Variance	29325.0	137.3	818.1	41.5	2555.8	308.7	680.3
	Minimum	7.5	0.3	0.5	2.9	0.2	0.3	2.5
	Median	16.0	8.7	12.3	6.3	12.5	8.3	10.8
	Maximum	500.0	80.0	200.0	10.0	400.0	100.0	100.0
Constraint (%)	Mean	16.7	37.5	61.4	49.9	35.4	54.4	8.3
	SD	24.4	33.0	41.1	29.8	40.7	47.9	6.5
	Variance	595.2	1087.0	1686.3	885.2	1654.7	2299.0	41.7
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	25.0	75.0	50.0	25.0	100.0	10.0
	Maximum	50.0	100.0	100.0	100.0	100.0	100.0	15.0
Sinuosity	Mean	0.0	0.2	0.2	0.2	0.1	0.1	0.1
	SD	0.0	0.1	0.2	0.1	0.2	0.1	0.2
	Variance	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	0.1	0.1	0.2	0.1	0.1	0.0
	Maximum	0.0	0.3	1.0	0.4	1.1	0.6	0.4

Table 4 Frequency of occurrence (%) for channel geomorphology structures analyzed by level IV ecorgion.

Parameter	Geomorphology Strucutures	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Presence (FOC%)	Bar	0.0	0.4	3.0	11.1	0.3	3.5	0.0
	Undercut	0.0	20.1	3.3	4.2	4.0	1.4	4.4
	Side Channel	0.0	0.4	2.9	3.6	2.2	2.9	1.2
	Backwater	0.6	0.4	1.6	7.5	5.9	0.5	0.6

Table 5 Frequency of occurrence (%) for channel unit categories and pool forming categories analyzed by level IV ecoregion.

Parameter	Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Channel Unit Code (FOC%)	Pool Plunge	0.0	0.0	0.4	0.5	0.0	0.0	2.4
	Trench Pool	4.8	18.9	9.2	7.3	9.3	9.5	6.1
	Lateral Scour Pool	0.6	0.0	0.0	1.8	0.0	0.1	0.0
	Backwater Pool	0.0	0.0	0.0	1.6	0.0	0.0	0.0
	Impoundment Pool	0.0	0.0	0.6	2.5	0.0	0.3	0.0
	Glide	87.9	25.0	71.3	52.0	65.7	46.7	51.5
	Riffle	0.0	1.5	3.5	12.3	0.3	1.5	0.6
	Dry Channel	6.7	54.5	14.9	21.8	23.9	41.9	36.4
Pool Form Code (FOC%)	No Pool	94.5	81.1	89.7	86.6	89.9	90.3	87.9
	LWD	0.0	0.0	0.0	3.9	0.0	0.0	0.0
	Rootwad	0.0	0.0	0.3	1.1	0.2	0.0	1.2
	Boulder	0.0	0.0	1.0	2.3	0.0	0.0	1.8
	Unknown	5.5	18.9	9.0	6.1	9.1	9.7	6.1

ii. Riparian Zones

With the exception of Ecoregion 46l, (FOC = 72.3%), the occurrence of canopy coverage was sparse among the level IV ecoregions (Table 7). When canopies occurred, they were dominantly deciduous (Table 7). Within these deciduous canopy layers, big trees were the dominant canopy coverage for Ecoregion 46l while small trees were the dominant canopy coverage for Ecoregions 46n and 46o (Table 7). Canopy that actually covered the stream channel was sparse with Ecoregion 46l ($\overline{X}$ = 63.0%) exhibiting the greatest stream channel coverage (Table 6). Understory layers were more frequent than canopy layers and were dominated by very heavy non-woody herbs, grasses, and forbs, and sparse to very heavy woody shrubs and saplings coverage (Table 8). Ecoregion 46l had a different understory structure with woody shrubs and saplings as the dominant vegetation cover and sparse non-woody herbs, grasses, and forbs coverage (Table 8). Ground cover was dominated by non-woody herbs, grasses and forbs (Table 9). Barren, bare dirt and duff ground cover was sparse to moderate, and streams in Ecoregion 46l had the greatest coverage (Table 9).

Table 6 Descriptive statistics analyzed by level IV ecoregion using non-standard channel canopy coverage measurements (%) with a densiometer.

Paremeter	Descriptive Statistics	Level IV Ecoregions						
		46c	46i	46k	46l	46m	46n	46o
Canopy Cover (%)	Mean	0.0	8.1	8.8	63.0	3.5	17.0	20.9
	SD	0.0	25.2	26.1	45.3	18.1	33.1	39.0
	Variance	0.0	634.8	683.6	2049.3	328.0	1095.7	1520.8
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	0.0	0.0	94.1	0.0	0.0	0.0
	Maximum	0.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 7 Frequency of occurrence (%) for canopy vegetation types and coverage categories analyzed by level IV ecoregion.

Parameter	Vegetation Type/ Coverage Categories	Level IV Ecoregions						
		46c	46i	46k	46l	46m	46n	46o
Canopy Vegetation Type (<5 m high) (FOC%)	Deciduous	0.0	0.0	8.1	72.3	0.0	15.5	24.4
	Coniferous	0.0	0.0	0.0	0.0	0.0	4.2	0.0
	Broadleaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mixed	0.0	0.0	0.0	0.0	0.0	3.9	0.0
	None	100.0	100.0	91.9	27.3	100.0	76.4	75.6
Big Tree (Trunk >0.03 m DBH) (FOC%)	Absent (0%)	100.0	100.0	93.3	39.9	100.0	89.4	85.6
	Sparse (<10%)	0.0	0.0	1.2	6.3	0.0	5.1	2.2
	Moderate (10-40%)	0.0	0.0	0.7	11.8	0.0	0.2	2.2
	Heavy (40-75%)	0.0	0.0	1.0	6.3	0.0	1.2	6.7
	Very Heavy (>75%)	0.0	0.0	3.8	35.3	0.0	4.2	3.3
Small Tree (Trunk <0.03 m DBH) (FOC%)	Absent (0%)	100.0	100.0	92.6	42.9	100.0	79.9	73.3
	Sparse (<10%)	0.0	0.0	2.9	11.3	0.0	0.5	1.1
	Moderate (10-40%)	0.0	0.0	1.7	11.3	0.0	0.0	2.2
	Heavy (40-75%)	0.0	0.0	0.7	12.2	0.0	2.3	8.9
	Very Heavy (>75%)	0.0	0.0	2.1	21.8	0.0	17.4	14.4

Table 8 Frequency of occurrence (%) for understory vegetation types and coverage categories analyzed by level IV ecoregion.

Parameter	Vegetation Type/ Coverage Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Understory Vegetation Type (0.5 to 5 m high) (FOC%)	Deciduous	11.1	39.6	21.7	80.3	1.5	8.6	33.3
	Coniferous	0.0	0.0	0.0	0.0	0.0	5.3	0.0
	Broadleaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mixed	0.0	0.0	0.0	0.0	0.0	12.0	0.0
	None	88.9	60.4	78.3	18.9	98.5	74.1	66.7
Woody Shrubs & Saplings (FOC%)	Absent (0%)	88.9	60.4	77.6	18.5	99.4	74.3	66.7
	Sparse (<10%)	0.0	5.6	8.3	4.2	0.3	6.0	3.3
	Moderate (10-40%)	0.0	9.7	4.8	12.6	0.0	4.6	8.9
	Heavy (40-75%)	2.2	24.3	3.8	16.4	0.0	7.4	16.7
	Very Heavy (>75%)	8.9	0.0	5.5	47.9	0.3	7.6	4.4
Non-Woody Herbs, Grasses, & Forbs (FOC%)	Absent (0%)	2.2	13.2	15.2	33.6	28.4	23.4	20.0
	Sparse (<10%)	2.2	0.0	2.6	22.7	5.6	5.3	4.4
	Moderate (10-40%)	6.7	2.1	6.9	12.6	4.6	2.8	4.4
	Heavy (40-75%)	0.0	31.9	8.1	12.6	3.4	8.8	20.0
	Very Heavy (>75%)	88.9	52.8	67.1	17.6	58.0	59.7	51.1

Table 9 Frequency of occurrence (%) for ground cover vegetation types and coverage categories analyzed by level IV ecoregion.

Parameter	Vegetation Type/ Coverage Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Ground Cover Vegetation Type (<0.5 m high) (FOC%)	Deciduous	11.1	41.0	22.6	81.9	0.0	6.7	28.9
	Coniferous	0.0	0.0	0.0	0.0	0.0	3.7	0.0
	Broadleaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mixed	0.0	0.0	0.0	0.0	0.0	11.1	0.0
	None	88.9	59.0	77.4	17.2	100.0	78.5	71.1
Non-woody Herbs, Grasses, & Forbs (FOC%)	Absent (0%)	0.0	0.0	1.4	0.0	0.6	0.7	0.0
	Sparse (<10%)	0.0	0.0	0.2	13.0	0.6	3.5	0.0
	Moderate (10-40%)	0.0	0.0	1.7	12.6	0.0	5.8	2.2
	Heavy (40-75%)	2.2	2.1	5.5	23.9	3.1	11.3	3.3
	Very Heavy (>75%)	97.8	97.9	91.2	50.0	95.7	78.7	94.4
Barren, Bare Dirt or Duff Ground Cover (FOC%)	Absent (0%)	93.3	97.9	87.4	29.4	96.3	69.4	95.6
	Sparse (<10%)	0.0	2.1	5.2	23.9	2.2	9.3	3.3
	Moderate (10-40%)	4.4	0.0	4.8	20.6	0.9	6.9	0.0
	Heavy (40-75%)	2.2	0.0	1.7	9.2	0.0	10.4	0.0
	Very Heavy (>75%)	0.0	0.0	1.0	16.0	0.6	3.9	1.1

Legacy trees were sparse among the ecoregions (Table 10) and varied in their average distances from the stream, with Ecoregion 46c legacy trees being located the farthest from the channel ($\overline{X}$ = 69.3 m; Table 10). Legacy trees were deciduous with high frequencies of poplar/cotton wood within Ecoregions 46c and 46k, high frequencies of willow within Ecoregion 46m and high frequencies of “other” groups in Ecoregions

46i, 46l, 46n and 46o (Table 10). Larger trees occurred in Ecoregions 46k (0.3-0.75 m DBH = 46.3%; 15-30 m height = 51.2%) and 46l (0.3-0.75 m DBH = 83.8%; 15-30 m height = 74.3%) and smaller trees occurred in Ecoregions 46i (0-0.01 m DBH = 75.9%; 5.0-15 m height = 58.6%) 46m (0.1-0.3 m DBH = 66.7%; 5.0-15 m height = 75.0%) and 46o (0.1-0.3 m DBH = 66.7%; 5-15 m height = 100%; Table 10).

Table 10 Frequency of occurrence (%) for legacy tree presence, size and type categories, and descriptive statistics for distance from wetted margin analyzed by level IV ecoregion.

		Level IV Ecoregions						
Parameter	Categories	46c	46i	46k	46l	46m	46n	46o
Legacy Tree (FOC%)	Presence	5.8	7.8	22.0	29.2	3.3	27.6	4.2
	Mean	69.3	35.0	28.8	8.6	41.7	22.5	5.8
	SD	40.8	19.5	24.9	6.2	12.3	20.0	6.8
Distance from	Variance	1660.7	378.6	622.2	37.8	151.5	401.5	46.0
Wetted Margin (m)	Minimum	50.0	0.0	0.0	2.0	25.0	0.0	0.0
	Median	50.0	50.0	25.0	7.0	50.0	20.0	2.0
	Maximum	150.0	60.0	100.0	40.0	50.0	70.0	20.0
	0-0.1	0.0	75.9	12.2	0.0	0.0	1.0	0.0
DBH (m)	0.1-0.3	28.6	24.1	35.4	16.2	66.7	33.3	66.7
(FOC%)	0.3-0.75	71.4	0.0	46.3	83.8	33.3	65.7	33.3
	0.75-2.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0
	<5	0.0	41.4	6.1	0.0	0.0	3.0	0.0
Height (m)	5.0-15	85.7	58.6	42.7	20.0	75.0	60.6	100.0
(FOC%)	15-30	14.3	0.0	51.2	74.3	25.0	36.4	0.0
	>30	0.0	0.0	0.0	5.7	0.0	0.0	0.0
	Deciduous	100.0	100.0	93.9	100.0	100.0	88.9	100.0
Type	Coniferous	0.0	0.0	0.0	0.0	0.0	11.1	0.0
(FOC%)	Broadleaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Evergreen	0.0	0.0	6.1	0.0	0.0	0.0	0.0
	Ash	0.0	0.0	0.0	11.4	0.0	26.3	0.0
	Oak	0.0	0.0	0.0	25.7	0.0	1.0	0.0
	Poplar/Cottonwood	71.4	0.0	34.1	8.6	33.3	0.0	0.0
Taxanomic Category	Willow	14.3	13.8	20.7	0.0	66.7	20.2	0.0
(FOC%)	Unknown/Other Deciduous	14.3	86.2	32.9	54.3	0.0	44.4	100.0
	Cedar/Cypress/Sequoia	0.0	0.0	0.0	0.0	0.0	8.1	0.0
	Juniper	0.0	0.0	6.1	0.0	0.0	0.0	0.0
	Snag	0.0	0.0	4.9	0.0	0.0	0.0	0.0

Among the ecoregions, riparian human influences were dominated by pasture/range/hayfields occurring mostly on the banks (Table 11). Row crops occurred most often in Ecoregions 46o and 46c at >10m from bank and the least in Ecoregion 46k (Table 11). Ecoregion 46l had the least occurrences of human disturbances while Ecoregion 46n had high occurrences (Table 11).

Table 11 Frequency of occurrence (%) for distance categories of different human influences analyzed by level IV ecoregion.

Parameters	Distance Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
	Absent	67.8	83.3	88.1	99.6	87.0	91.0	91.1
Wall/Dike/Riprap/Dam	>10 m	30.0	11.1	4.5	0.4	13.0	2.3	2.2
(FOC%)	Within 10 m	1.1	0.0	0.0	0.0	0.0	0.0	0.0
	On Bank	1.1	5.6	7.4	0.0	0.0	6.7	6.7
	Absent	100.0	97.2	95.2	100.0	96.9	94.7	100.0
Buildings	>10 m	0.0	2.8	4.8	0.0	3.1	4.9	0.0
(FOC%)	Within 10 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	On Bank	0.0	0.0	0.0	0.0	0.0	0.5	0.0
	Absent	100.0	100.0	99.5	100.0	100.0	100.0	100.0
Pavement/Cleared Lot	>10 m	0.0	0.0	0.5	0.0	0.0	0.0	0.0
(FOC%)	Within 10 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	On Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Absent	86.7	100.0	78.1	100.0	96.3	75.7	91.1
Road/Railroad	>10 m	13.3	0.0	21.9	0.0	3.7	15.5	8.9
(FOC%)	Within 10 m	0.0	0.0	0.0	0.0	0.0	6.5	0.0
	On Bank	0.0	0.0	0.0	0.0	0.0	2.3	0.0
	Absent	100.0	100.0	98.1	100.0	100.0	98.8	100.0
Pipes	>10 m	0.0	0.0	1.9	0.0	0.0	0.2	0.0
(FOC%)	Within 10 m	0.0	0.0	0.0	0.0	0.0	0.9	0.0
	On Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Absent	92.2	99.3	97.1	99.2	95.1	91.4	100.0
Landfill/Trash	>10 m	7.8	0.0	1.7	0.8	2.2	6.3	0.0
(FOC%)	Within 10 m	0.0	0.7	1.2	0.0	1.2	1.9	0.0
	On Bank	0.0	0.0	0.0	0.0	1.5	0.5	0.0
	Absent	100.0	100.0	100.0	100.0	98.8	100.0	100.0
Park/Lawn	>10 m	0.0	0.0	0.0	0.0	1.2	0.0	0.0
(FOC%)	Within 10 m	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	On Bank	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Absent	60.0	84.7	96.4	83.8	90.7	84.5	53.3
Row Crops	>10 m	34.4	11.1	3.6	3.3	8.0	5.1	30.0
(FOC%)	Within 10 m	5.6	0.0	0.0	0.0	1.2	6.7	16.7
	On Bank	0.0	4.2	0.0	12.9	0.0	3.7	0.0
	Absent	18.9	8.3	7.1	15.8	0.0	19.9	33.3
Pasture/Range/Hayfield	>10 m	3.3	16.7	0.0	0.0	0.0	0.5	0.0
(FOC%)	Within 10 m	4.4	0.0	2.9	0.0	0.0	3.2	0.0
	On Bank	73.3	75.0	90.0	84.2	100.0	76.4	66.7

Ecoregion 46l sites had the lowest alien plant occurrences while Ecoregion 46o had the most (Table 12). Ecoregion 46n had the greatest variety of alien species. Ecoregion 46o had the highest frequency of canada thistle, leafy spurge and common burdock occurrences. 46n had the greatest cheat grass occurrence and 46m had the greatest musk thistle occurrence.

Table 12 Frequency of occurrence (%) of different alien plant species analyzed by level IV ecoregion.

	Level IV Ecoregions						
Alien Plants (FOC%)	46c	46i	46k	46l	46m	46n	46o
Canada Thistle	22.2	16.7	23.3	15.0	16.0	21.3	26.7
Leafy Spurge	0.0	0.0	4.3	0.0	0.6	5.1	6.7
Common Burdock	0.0	0.0	0.0	0.0	0.0	0.9	4.4
Cheat Grass	4.4	1.4	0.0	0.0	0.0	15.3	0.0
Musk Thistle	0.0	2.8	3.8	0.0	14.8	1.9	0.0
None	73.4	79.1	68.6	85.0	68.6	44.5	37.8

iii. Stream Substrate

Soft/small sediment was present at 96-100% of the transects for all ecoregions (Table 13). Using Peck's cross-sectional substrate method, substrate class "other" was the most frequently occurring substrate followed by silt/clay/muck for all ecoregions (Table 13). Ecoregion 46l had the highest frequency of larger substrates such as boulders, cobble, coarse gravel, and fine gravel (Table 13). Using Fritz's modal sediment size method, substrate class sand, silt and clay was the most frequently occurring category for all ecoregions (Table 13). Ecoregion 46l again had higher occurrences for the larger substrates than the other ecoregions (Table 13). Ecoregion 46m had the lowest average percent embeddedness ($\overline{X} = 29\%$) and Ecoregion 46n had the highest ($\overline{X} = 74\%$) (Table 14).

Table 13 Frequency of occurrence (%) for soft/small sediment and substrate size classes analyzed by level IV ecoregion.

Parameter	Substrate Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Soft/Small Sediment (FOC%)	Presence	100.0	100.0	98.0	96.0	99.0	100.0	100.0
	Smooth Bedrock (>4000 mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Rough Bedrock (>4000 mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Boulder (250-4000 mm)	0.1	0.4	1.7	6.5	0.2	0.2	1.1
	Cobble (64-250 mm)	0.0	0.8	1.7	8.0	0.4	0.2	0.4
Substrate Cross-Sectional (FOC%)	Coarse Gravel (16-64 mm)	0.0	0.5	1.2	7.2	0.6	0.3	3.2
	Fine Gravel (2-16 mm)	0.0	0.5	2.4	8.8	0.5	1.1	0.4
	Sand (0.6-2 mm)	0.0	0.8	4.9	14.2	0.8	7.5	0.6
	Silt/Clay/Muck (<0.6 mm)	10.1	28.2	16.7	32.0	12.0	29.4	22.7
	Hardpan	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	Wood	0.0	0.1	0.4	1.4	0.0	0.2	0.0
	Other	89.8	68.6	71.0	21.6	85.6	61.1	71.6
	Bedrock/Hardpan (>512 mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Boulder (256-512 mm)	0.0	0.0	0.9	3.2	0.0	0.0	0.3
	Large cobble (128-256 mm)	0.0	0.4	1.0	1.8	0.0	0.0	0.0
	Small cobble (64-128 mm)	0.0	0.0	0.5	5.0	0.0	0.1	0.0
Modal Sediment Size (FOC%)	Large pebble (32-64 mm)	0.0	0.2	0.5	5.7	0.1	0.0	0.6
	Small pebble (16-32 mm)	0.0	0.0	1.4	6.2	0.2	0.1	1.3
	Coarse gravel (8-16 mm)	0.0	0.4	2.4	7.6	1.2	0.3	2.5
	Medium gravel (4-8 mm)	0.0	1.4	1.9	6.4	0.3	0.4	1.9
	Fine gravel (2-4 mm)	0.0	0.8	4.3	10.4	0.9	0.3	1.0
	Sand, silt, and clay (≤2 mm)	100.0	96.8	87.0	53.6	97.4	98.9	92.4

Table 14 Descriptive statistics analyzed by level IV ecoregion for estimated substrate percent embeddedness.

Parameter	Descriptive	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Embeddedness (%)	Mean	48.2	66.2	49.8	69.2	29.3	74.1	59.0
	SD	50.0	47.0	49.2	42.4	45.3	43.6	48.7
	Variance	2497.1	2210.6	2424.5	1800.2	2051.1	1901.5	2373.3
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	100.0	50.0	100.0	0.0	100.0	100.0
	Maximum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

iv. In-stream Cover and Biota

Coarse organic debris occurred at over 94% of the transects for all seven ecoregions (Table 15). Overhanging vegetation was the most frequently occurring cover class followed by brush/small woody debris (Table 15). Filamentous algae cover occurred frequently in Ecoregion 46k, but was very sparse in Ecoregion 46o. Macrophyte coverage was heavy in Ecoregion 46c but sparse in Ecoregion 46l, whereas live trees or roots were heavy in Ecoregion 46l and sparse in Ecoregion 46c (Table 15). Big woody debris was sparse for all ecoregions with the exception of Ecoregion 46l. Large woody debris counts were low among the ecoregions. Ecoregion 46l had the highest average LWD counts ($\overline{X}$ = 0.2 counts/transect) while debris was absent from Ecoregions 46i, 46m and 46o (Table 16).

Table 15 Frequency of occurrence (%) for coarse organic debris presence and in-stream cover categories analyzed by level IV ecoregion.

Parameter	Coverage Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Coarse Organic Debris (FOC%)	Presence	100.0	100.0	99.0	94.0	96.0	96.0	99.0
Filamentous Algae (FOC%)	Absent	57.8	48.6	45.2	55.8	63.6	61.6	75.6
	Sparse	26.7	22.2	19.0	29.2	19.8	19.4	2.2
	Moderate	0.0	11.1	12.4	8.3	6.2	10.2	4.4
	Heavy	0.0	11.1	8.1	5.8	7.4	4.6	8.9
	Very Heavy	15.6	6.9	14.3	0.8	3.1	4.2	8.9
Macrophyte (FOC%)	Absent	2.2	52.8	48.1	80.8	53.7	60.2	60.0
	Sparse	31.1	29.2	20.5	10.0	19.8	19.0	26.7
	Moderate	0.0	5.6	15.7	1.7	5.6	9.3	2.2
	Heavy	6.7	2.8	9.5	3.3	6.2	7.4	11.1
	Very Heavy	60.0	9.7	5.2	4.2	14.8	4.2	0.0
Big Woody Debris (>0.3 m) (FOC%)	Absent	97.8	100.0	90.5	58.3	100.0	87.5	100.0
	Sparse	2.2	0.0	3.8	26.7	0.0	9.7	0.0
	Moderate	0.0	0.0	3.8	6.7	0.0	2.8	0.0
	Heavy	0.0	0.0	0.5	6.7	0.0	0.0	0.0
	Very Heavy	0.0	0.0	0.5	1.7	0.0	0.0	0.0
Brush/Small Woody Debris (<0.3 m) (FOC%)	Absent	24.4	4.2	5.2	9.2	10.5	5.1	15.6
	Sparse	35.6	8.3	10.5	34.2	3.1	22.7	13.3
	Moderate	8.9	20.8	22.9	38.3	8.6	19.9	4.4
	Heavy	8.9	31.9	24.8	17.5	25.9	14.4	2.2
	Very Heavy	22.2	34.7	35.7	0.8	51.9	38.0	64.4
Live Trees or Roots (FOC%)	Absent	95.6	86.1	83.8	39.2	93.8	89.4	88.9
	Sparse	0.0	5.6	5.7	35.0	2.5	5.6	8.9
	Moderate	0.0	8.3	9.0	24.2	3.7	3.7	2.2
	Heavy	4.4	0.0	0.5	1.7	0.0	1.4	0.0
	Very Heavy	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Overhanging Vegetation (≤1 m of surface) (FOC%)	Absent	0.0	4.2	13.3	49.2	18.5	9.3	26.7
	Sparse	2.2	15.3	16.2	24.2	6.8	33.3	4.4
	Moderate	11.1	20.8	9.0	11.7	8.6	12.0	15.6
	Heavy	20.0	23.6	17.1	8.3	17.3	12.5	8.9
	Very Heavy	66.7	36.1	43.3	6.7	48.8	32.9	44.4

Table 16 Descriptive statistics analyzed by level IV ecoregion for LWD counts.

Parameter	Descriptive Statistics	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Large Woody Debris (≥0.1 m diameter & ≥1.5 m length)	Mean	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	SD	0.0	0.0	0.1	0.2	0.0	0.1	0.0
	Variance	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	Maximum	0.0	0.0	0.3	0.8	0.0	0.4	0.0

v. Stream Hydrology

Some sites (15%) flowed throughout the sample period. The other 85% showed some sort of drying or dry phase during the sampling season. Ecoregion 46l streams had the highest average velocity ($\overline{X}$ = 0.06 m/s) and the highest frequency of erosional habitat (Tables 17 and 18). On average, stream sites contained little water based on the small thalweg width/depth ratios (Table 17). Ecoregion 46i contained the least amount of water with an average thalweg width/depth ratio of 0.1, average depth to groundwater of 7.3 cm below ground and an average substrate moisture of 55.6% (Tables 18 and 19).

Table 17 Descriptive statistics analyzed by level IV ecoregion for hydrologic permanence measurements.

Parameter	Descriptive Statistics	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Velocity (m/s)	Mean	0.00	0.02	0.05	0.06	0.03	0.04	0.05
	SD	0.01	0.05	0.10	0.16	0.07	0.08	0.09
	Variance	0.0001	0.002	0.01	0.03	0.01	0.01	0.01
	Minimum	-0.03	-0.05	-0.05	-0.06	-0.06	-0.15	-0.02
	Median	0.00	0.00	0.00	0.01	0.00	0.01	0.00
	Maximum	0.05	0.18	0.75	2.13	0.56	0.45	0.40
Thalweg Width/Depth Ratio (cm)	Mean	0.3	0.1	0.4	0.2	0.2	0.2	0.2
	SD	0.2	0.2	2.3	0.5	0.3	0.5	0.2
	Variance	0.0	0.1	5.2	0.3	0.1	0.2	0.1
	Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Median	0.3	0.0	0.1	0.1	0.2	0.1	0.1
	Maximum	1.4	3.2	60.8	8.0	3.4	7.2	1.2
Depth to Groundwater (cm)	Mean	25.2	-7.3	12.9	9.6	12.9	1.5	3.1
	SD	25.4	38.9	20.9	6.6	21.9	33.7	40.8
	Variance	644.1	1512.2	437.1	43.8	477.8	1138.6	1664.1
	Minimum	-78.0	-87.0	-87.0	0.0	-64.0	-82.0	-86.0
	Median	24.0	6.0	11.0	9.0	14.0	4.0	9.5
	Maximum	80.0	54.0	106.0	32.0	50.0	124.0	70.0
Substrate Moisture (%)	Mean	87.2	55.6	88.3	86.3	81.0	62.7	68.7
	SD	29.0	42.2	26.5	29.8	32.0	40.1	37.7
	Variance	843.7	1782.3	699.7	889.6	1026.8	1607.2	1422.9
	Minimum	19.2	2.2	17.6	13.6	11.4	2.1	11.7
	Median	100.0	24.1	100.0	100.0	100.0	100.0	100.0
	Maximum	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 18 Frequency of occurrence (%) for habitat types analyzed by level IV ecoregion.

Parameter	Habitat Categories	Level IV Ecoregions 46c	46i	46k	46l	46m	46n	46o
Habitat Type	Erosional	0.0	5.0	21.4	33.2	18.8	24.3	14.2
	Depositional	100.0	95.0	78.6	66.8	81.2	75.7	85.8

B. Protocol Metric Comparison

An analysis of the two protocols revealed differences in their measurements (Table 19). There were 51 measurements composing the physical habitat section of Peck's protocol and only 15 measurements from Fritz. There were 44 measurements included in Peck but not in Fritz, and only 8 measurements included in Fritz that were not included in Peck. One measurement, substrate size, was measured in both protocols using different methods. This caused different results for substrate size characterizations. Peck's protocol uses a cross-sectional method (Peck et al. 2006) whereas Fritz uses a modal particle size method (Fritz et al. 2006). Each method has its own substrate size classes. Substrate size class "other" (i.e. leaves, macrophytes, filamentous algae) was the most frequently occurring class using Peck's protocol (Table 20). There was also a higher frequency of larger substrate size class occurrences using Peck's protocol. Substrate size class "sand, silt, and clay" was the most frequently occurring using Fritz's protocol.

Table 1 Table of all stream habitat measurements, their data type, and the protocol where they are used.

Measmurement	Type	Peck	Fritz	Measurement	Type	Peck	Fritz
Canopy cover	Ratio	X	X	Instream Cov. - Filamentous Algae Cover	Ordinal	X	
Sinuosity	Ratio		X	Instream Cov. - Macrophyte Cover	Ordinal	X	
Max pool depth	Ratio		X	Instream Cov. - Big Woody Debris	Ordinal	X	
Bankful Width	Ratio	X	X	Instream Cov. - Brush/Small Woody Debris	Ordinal	X	
Bankful Height	Ratio	X	X	Instream Cov. - Live Trees or Roots	Ordinal	X	
Incised Height	Ratio	X		Instream Cov. - Overhanging Vegetation	Ordinal	X	
Flood Prone Area Width	Ratio		X	Human Infl. - Wall/Dike/Riprap/Dam	Ordinal	X	
Bank Angle	Interval	X		Human Infl. - Buildings	Ordinal	X	
Bank Undercut	Ratio	X		Human Infl. - Pavement/Cleared Lot	Ordinal	X	
Large Woody Debris	Ratio	X		Human Infl. - Road/Railroad	Ordinal	X	
Velocity	Interval	X	X	Human Infl. - Pipes	Ordinal	X	
% Channel length in contact with feature	Ratio	X		Human Infl. - Landfill/Trash	Ordinal	X	
Valley Width	Ratio	X		Human Infl. - Park/Lawn	Ordinal	X	
Legacy Dist. From wetted margin	Ratio	X		Human infl. - Row Crops	Ordinal	X	
Thalweg Depth	Ratio	X	X	Human infl. - Pasture/Range/Hayfield	Ordinal	X	
Thalweg Wetted Width	Ratio	X	X	Legacy Tree DBH	Ordinal	X	
Thalweg Bar Width	Ratio	X		Legacy Tree Height	Ordinal	X	
Slope	Ratio	X	X	Legacy Tree Type	Nominal	X	
Depth to Groundwater	Interval		X	Legacy Tree Taxonomic Category	Nominal	X	
Substrate Moisture	Ratio		X	Alien Plants	Nominal	X	
% Embeddeness	Ratio	X		Soft/Small Sediment	Nominal	X	
Rip. Veg. - Canopy Vegetation Type	Nominal	X		Modal Sediment Particle Size	Nominal		X
Rip. Veg. - Big Tree Coverage	Ordinal	X		Habitat Type (E/D)	Nominal		X
Rip. Veg. - Small Tree Coverage	Ordinal	X		COD	Nominal		X
Rip. Veg. - Understory Vegetation Type	Nominal	X		Channel Unit Code	Nominal	X	
Rip. Veg. - Woody Shrubs & Saplings Coverage	Ordinal	X		Pool Form Code	Nominal	X	
Rip. Veg. - Non-woody herbs, grasses and forbs Coverage	Ordinal	X		Side Channel	Nominal	X	
Rip. Veg. - Woody Ground Cover	Ordinal	X		Back Water	Nominal	X	
Rip. Veg. - Non-woody Ground Cover	Ordinal	X		Substrate Cross-Section	Nominal	X	
Rip. Veg. - Barren, Bare Dirt or Duff Cover	Ordinal	X					

Table 19 A comparison of substrate size class characterization methods using frequency of size class occurrence for all 60 sampled streams. Cross-sectional substrate is used by Peck and modal sediment size is used by Fritz.

PECK		FRITZ	
Cross-Sectional Substrate	FOC%	Modal Sediment Size	FOC%
Boulder (250-4000 mm)	1.5	Boulder (256-512 mm)	0.7
Cobble (64-250 mm)	1.7	Large Cobble (128-256 mm)	0.5
Coarse Gravel (16-64 mm)	1.7	Small Cobble (64-128 mm)	0.8
Fine Gravel (2-16 mm)	2.2	Large Pebble (32-64 mm)	1.0
Sand (0.6-2 mm)	5.2	Small Pebble (16-32 mm)	1.3
Silt/Clay/Muck (<0.6 mm)	22.0	Coarse Gravel (8-16 mm)	2.1
Hardpan	0.0	Medium Gravel (4-8 mm)	1.7
Wood	0.3	Fine Gravel (2-4 mm)	2.8
Other	65.3	Sand, Silt, and Clay (≤2 mm)	89.0

An analysis of the two protocols also revealed differences in their data characteristics (Table 19). Peck utilizes mostly qualitative data while Fritz utilizes mostly quantitative data to assess habitat condition (Figure 7). Peck's measurements yielded various data types: ratio (n = 14), interval (n = 2), ordinal (n = 23), and nominal (n = 12). Fritz's measurements differed by yielding mostly ratio (n = 10) data types with 2 measurements using interval data and 3 using nominal data.

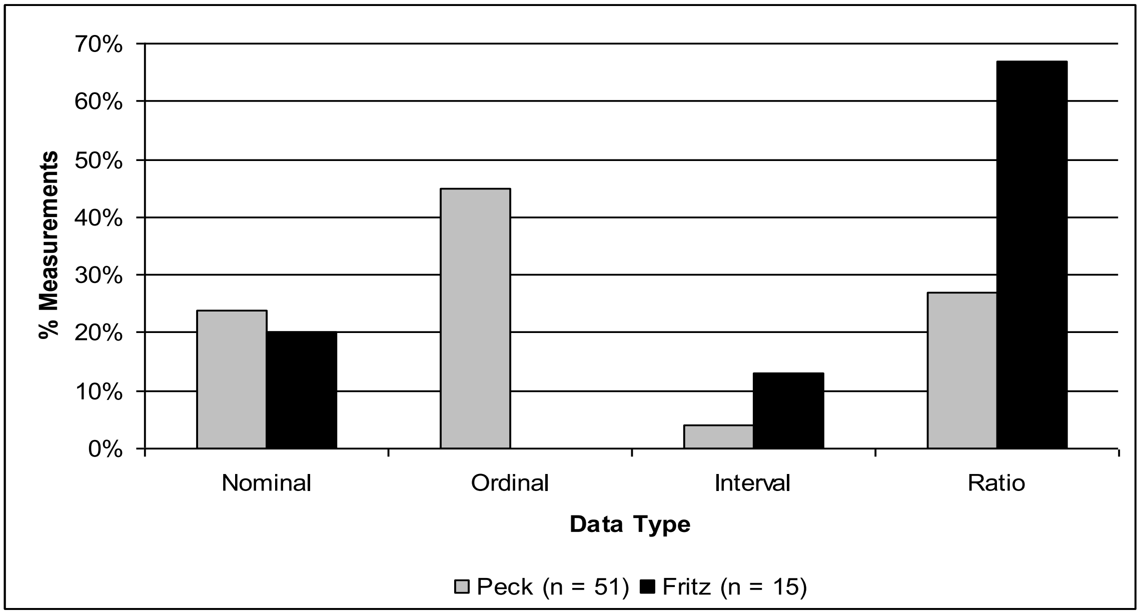

Figure 7 Bar graph showing the percent of the total measurements that fall within each data type for each protocol.

D. HQI Scores

Reference HQI scores generated from Fritz metrics ($\overline{X}$ = 71%) were consistently higher then Peck's HQI's ($\overline{X}$ = 63%)(Table 21). A sign test comparing the reference HQI scores for the two protocols yielded 34 negative differences and 6 positive differences ($p < 0.01$). A Wilcoxon Rank Sum Test supported the sign test revealing reference HQI scores were consistently higher using Fritz versus Peck ($p < 0.01$) (Figure 8).

Table 20 Summary statistics of total reference HQI scores for Peck and Fritz protocols.

Protocol	Mean	SD	Variance	Minimum	Median	Maximum
Peck (%)	63.0	10.3	105.0	42.0	65.0	81.0
Fritz (%)	71.0	10.3	106.9	51.0	69.0	93.0

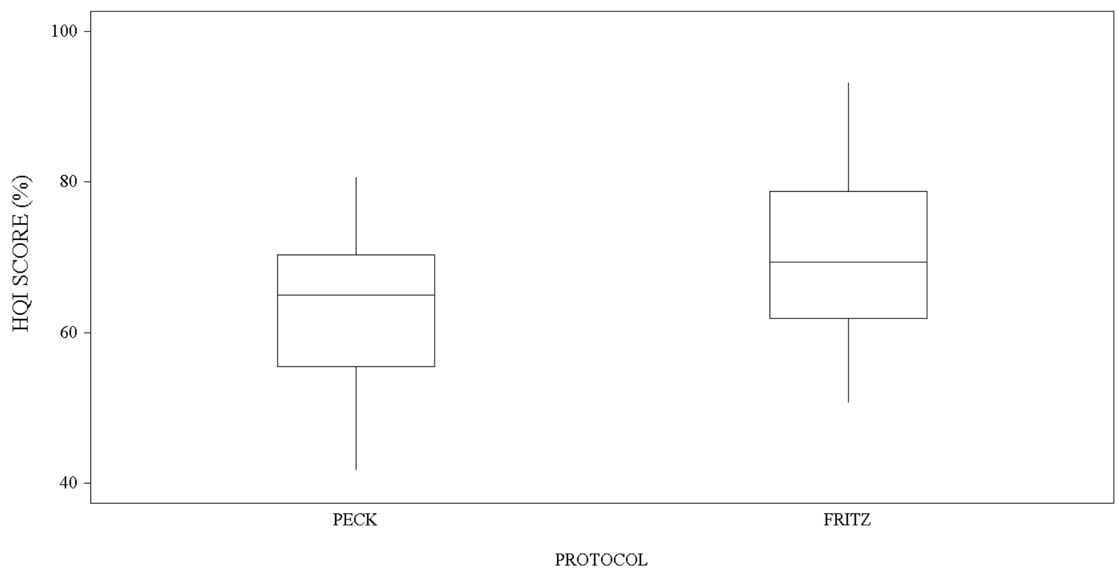

Figure 8 Box and whisker plot of total reference HQI scores for each protocol.

Peck's protocol had 12 metrics in the channel geomorphologic class which accounted for 24% of the total HQI score (Figure 9); whereas Fritz's protocol had only 6 metrics in this class accounting for 43% of the total HQI score. There were 25 metrics within the riparian-zone class which accounted for 51% of Peck's total HQI score (Figure 9), compared to only 1 metric in this class for Fritz accounting for 7% of the total HQI score. Within the substrate class, Peck's protocol had 3 metrics accounting for 6% of the total HQI score (Figure 9); whereas, Fritz's protocol had only1 metric accounting for 7% of the total HQI score. There were 7 metrics within the in-stream cover and biota class which accounted for 14% of Peck's total HQI score (Figure 9), compared to only 1 metric in this class for Fritz accounting for 7% of the total HQI score. Within the hydrologic category, Peck's protocol had only 2 metrics, accounting for 4% of the total

HQI score; whereas, Fritz's protocol had 5 metrics, accounting for 36% of the total HQI score. Specific metrics within each stream characteristic categories are listed in Table 22.

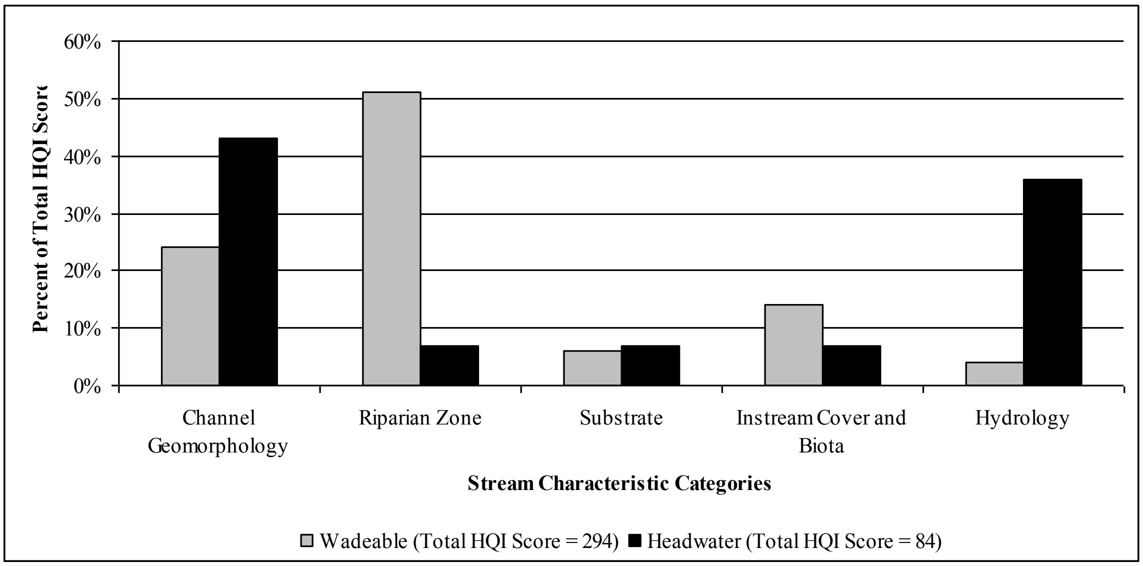

Figure 9 Bar graph showing the percent each stream characteristic category contributed to the total HQI scores for each protocol.

Channel geomorphology ($p<0.26$), in-stream cover and biota ($p<0.20$), and hydrology ($p<0.44$) categories scored no differently for reference streams between the two protocols (Figure 10). However, riparian ($p<0.01$) and substrate categories ($p <0.01$) scored significantly lower for reference streams using Peck's protocol (Figure 10). Fritz's protocol also appears to generate greater variation than Peck's protocol for substrate and in-stream cover classes.

Table 1 Classification of two habitat protocols by five classes of physical and biological characteristics. Maximum score for each index is given next to the index; maximum score for the class and its percentage of the index total score are given in parentheses. Table adopted from Stauffer and Goldstein (1997).

Channel Geomorphology	Riparian Zone	Substrate	Instream Cover and Biota	Hydrology
		Peck et al. 2006, 294		
Bankful Width/Depth Ratio	Canopy cover	Substrate Embeddedness	Large Woody Debris	Thalweg Width/Depth Ratio
Incised Height	Canopy Vegetation Type	Soft/Small Sediment	Filamentous Algae Cover	Velocity
Bank Angle	Big Tree Coverage	Substrate Cross sectional	Macrophyte Cover	
Bank Undercut	Small Tree Coverage		Big Woody Debris	
Valley Width	Understory Vegetation Type		Brush/Small Woody Debris	
% Channel length in contact with feature	Woody Shrubs & Saplings Coverage		Live Trees or Roots	
Thalweg Bar Width	Non-woody herbs, grasses and forbs Coverage		Overhanging Vegetation	
Slope	Woody Ground Cover			
Thalweg Heterogeneity(CV)	Non-woody Ground Cover			
Channel Unit Code	Barren, Bare Dirt or Duff Cover			
Pool Form Code	Wall/Dike/Riprap/Dam			
Side Channel/BackWater	Buildings			
	Pavement/Cleared Lot			
	Road/Railroad			
	Pipes			
	Landfill/Trash			
	Park/Lawn			
	Row Crops			
	Pasture/Range/Hayfield			
	Legacy Dist. From wetted margin			
	Legacy Tree DBH			
	Legacy Tree Height			
	Legacy Tree Type			
	Legacy Tree Taxonomic Category			
	Alien Plants			
(72, 24%)	(150, 51%)	(18, 6%)	(42, 14%)	(12, 4%)
		Fritz et al. 2006, 84		
	Canopy cover	Modal Sediment Particle Size	COD	Thalweg Width/Depth Ratio
Sinuosity				Habitat Type (E/D)
Bankful Width/Depth Ratio				Velocity
Flood Prone Area Width				Depth to Groundwater
Slope				Substrate Moisture
Max pool depth				
Thalweg Heterogeneity(CV)				
(36, 43%)	(6, 7%)	(6, 7%)	(6, 7%)	(30, 36%)

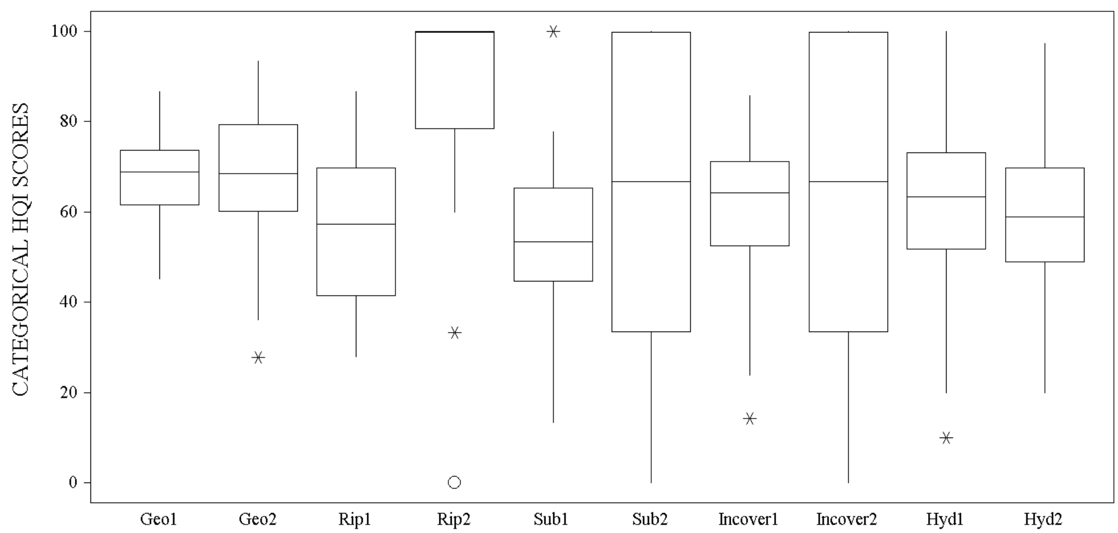

Figure 10 Box and whisker plots of total HQI scores for each stream characteristic category calculated for each protocol. Variable labels are defined as: geo = channel geomorphology, rip = riparian zone, sub = substrate, incover = in-stream cover, hyd = hydrology, 1 = Peck, and 2 = Fritz.

Targeted good, targeted bad, and randomly selected site HQI scores for both protocols were compared to ATtILA generated watershed condition scores and RCE generated reach scale condition scores (Figures 11 and 12). Peck's HQI scores decreased as watershed condition (ATtILA) decreased, however the slope is not significant ($p < 0.25$, $R^2 = 0.07$; Figure 11). Fritz's HQI scores increased slightly as watershed condition decreased; however, the slope was also not significant ($p < 0.73$, $R^2 = 0.01$; Figure 11).

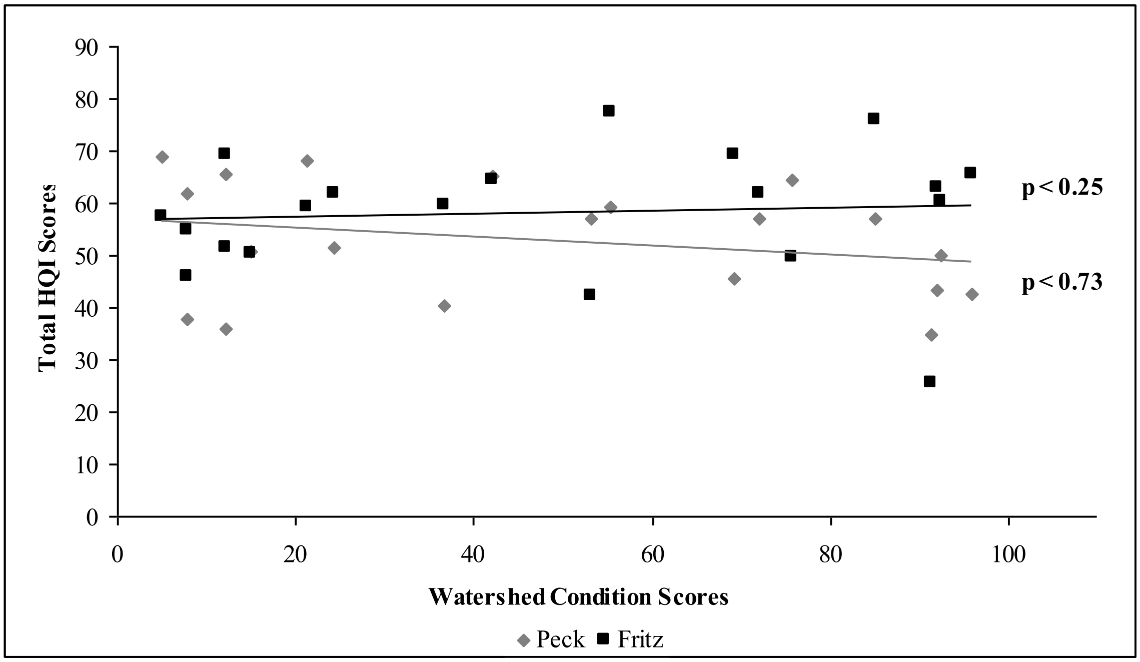

Figure 11 Scatter plot with trend line comparing targeted good, targeted bad, and randomly selected site HQI scores for each protocol over ATtILA generated watershed condition scores.

Peck's HQI scores increased as Petersen RCE scores increased, however the slope was not significant ($p < 0.12$, $R^2 = 0.13$; Figure 12). In contrast, Fritz's HQI scores decreased slightly with increasing Petersen RCE values; however, this slope was also not significant ($p < 0.59$, $R^2 = 0.02$; Figure 12).

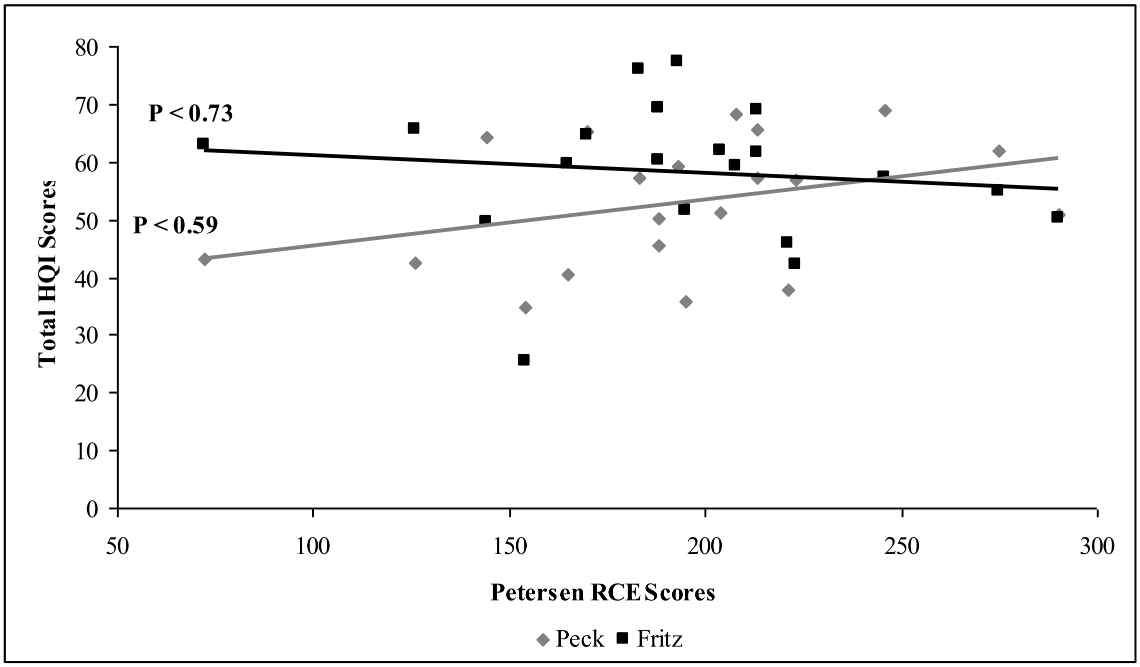

Figure 12 Scatter plot with trend line comparing targeted good, targeted bad, and randomly selected site HQI scores for each protocol over RCE generated reach scale condition scores.

Randomly selected HQI scores for Peck and Fritz were compared to the following water quality parameters using linear regression: total kjeldahl nitrogen, nitrate, ammonia, total phosphorus, fecal coliform, chloride, turbidity, dissolved oxygen, conductivity, pH, total suspended solids, total dissolved solids, and water temperature. There were no significant correlations between the two protocols' HQI scores and the water quality parameters.

Discussion

A. Level IV Ecoregion Characterization

Analysis of stream assessments revealed higher variability in stream characteristics within the NGP ecoregion. These physical differences between streams can be explained by the NGP's defining landscape characteristics (Omernik 1987; Bryce et al. 1998). When grouped by Level IV ecoregion, stream characteristics show greater similarity. Measurements did not distinguish all of the ecoregions from one another. However, measurements were able to distinguish one or two ecoregions from the group. For example, season long average depth to ground water was positive (above ground) for all ecoregions except for the Drift Plains (46i) ecoregion which averaged 7.3 cm below ground. The Prairie Coteau Escarpment (46l), in particular, seemed to be distinguished more often than the other ecoregions. This ecoregion is defined by its much steeper stream gradient (Bryce et al. 1998) causing it to have significantly different characteristics from the other ecoregions. These observations tend to support suggestions that some ecoregions are more homogeneous while others exhibit greater within-region heterogeneity (Omernik 1987; Troelstrup and Perry 1990).

Physical measurements are key components used by agencies to set stream management goals (Plafkin et. al. 1989; Rheinhardt et al. 1999; Wang et al. 1996). For example, the Prairie Coteau Escarpment (46l) is characterized as having a riparian canopy layer, whereas streams of the Prairie Coteau (46k) generally do not. Even though a riparian canopy layer is considered beneficial for a stream (Gregory et al. 1991;

Vannote et al. 1980), the lack of a canopy layer in Prairie Coteau (46k) streams does not mean they are degraded (Wiley et al. 1990). Therefore, depending on ecoregion size and variability among its defining characteristics, agencies may find it necessary to develop baseline data and management goals by level IV ecoregion. Research by Bryce and Clarke (1996) supports that regionalization at the state level (level IV) provides the scale at which streams should be characterized.

B. Metric Comparison

Peck's protocol has more habitat characterization metrics then does Fritz's, increasing the ability to detect habitat degradation. However, some metrics in Peck's protocol overlapped. For example, "large woody debris counts" and "in-stream big woody debris abundance" both measured woody organic matter. "Legacy tree" and "canopy riparian vegetation cover" both assessed the influence of large riparian trees. Streams that contained riparian areas comprised of tall grass rather than trees gave similar results for "riparian canopy cover" and "in-stream grass coverage" measurements. Such measurements risk being redundant, and can overemphasize a certain habitat characteristic and thus bias HQI scores (Stauffer and Goldstein 1997). Fritz's protocol had a smaller number of measurements in the habitat characterization section. With a smaller number of measurements, there could be degraded habitat features which are missed. This can lead to exceedingly lenient assessments causing a stream to seem less degraded than it really is.

A second observation was the presence of measurements unique to each protocol. Fritz, with only 15 measurements, contained eight that were not included in Peck's protocol. These unique measurements assessed hydrologic permanence. The unique measurements in Peck's protocol assessed mostly riparian and in-stream cover areas. These differences reveal divergence between the two protocols' indicators of degradation for the resource they were designed to assess.

Substrate was the only parameter measured by both protocols, but using different methodology. Peck measures substrate using 21 cross-sectional transects divided into five cross-sectional observation points. At each of the 105 observation points used to assess the reach, a substrate is randomly picked and sized using Table 23.

Table 21 Substrate size class coding for Peck's protocol (Kaufmann 1998).

Code	Size Class	Size Rane (mm)	Description
RS	Bedrock (Smooth)	>4000	Smooth surface rock bigger than a car
RR	Bedrock (Rough)	<4000	Rough surface rock bigger than a car
HP	Hardpan		Firm, consolidated fine substrate
BL	Boulders	>250 to 4000	Basketball to car size
CB	Cobbles	>64 to 250	Tennis ball to basket ball size
GC	Gravel (Coarse)	>16 to 64	Marble to tennis ball size
GF	Gravel (Fine)	>2 to 16	Ladybug to marble size
SA	Sand	>0.06 to 2	Smaller than ladybug size, but visible as particles - gritty between fingers
FN	Fines	<0.06	Silt Clay Muck (not gritty between fingers)
WD	Wood	Regardless of Size	Wood
OT	Other	Regardless of Size	Herbaceous material

Fritz measures substrate using modal sediment size (Fritz et al. 2006). This method employs a 0.25 m^2 frame placed at the thalweg in 31 equally spaced locations. The modal particle size (particle size with the greatest occurrence) within the frame is visually assessed and a representative particle of that modal size is picked up and classified using Table 24.

Table 22 Substrate size class coding for Fritz's protocol (Fritz et al. 2006).

Class	Size Range (mm)	Phi (Φ)
Sand, silt, and clay	≤2	≥0
Fine gravel	>2 to 4	-1 to -2
Medium Gravel	>4 to 8	-2 to -3
Coarse gravel	>8 to 16	-3 to -4
Small pebble	>16 to 32	-4 to -5
Large pebble	>32 to 64	-5 to -6
Small cobble	>64 to 128	-6 to -7
Large cobble	>128 to 256	-7 to -8
Boulder	>256 to 512	-8 to -9
Bedrock and hardpan	>512	≤-9

The two methods resulted in contrasting substrate assessments. The discrepancy between the dominant substrate size classes for our study streams are a result of differences in the size class categories used by the two methods. Fritz's protocol did not have an "other" category, so if vegetation was present in the stream bed, the substrate at the base of the vegetation was used for classification. This caused a high frequency of "sand, silt, and clay" observations. Data showing high frequencies of "sand, silt, and clay would indicate high sediment loads and stream bed aggradation, leading an observer to determine that the stream is impaired (Sennatt et al. 2006; Wood and Armitage 1997). On the other hand, Peck's protocol may determine a stream is high in herbaceous material, acting as a sediment trap, leading an observer to determine the stream is non-impaired (Abt et al. 1994).

The other discrepancy regarding substrate assessments lies in the methodology. Peck's protocol captures both the lateral and longitudinal variability that exists in streams (Sennatt et al. 2006) by taking measurements at multiple cross-sectional transects along a stream reach (Peck et al. 2006). This method may be less discriminating to larger substrates. Fritz's method fails to capture lateral variability as it only measures a particular channel unit, the thalweg, causing potential bias (Sennatt et al. 2006). The particle size with the greatest occurrence is used as the sample in Fritz's method. If a larger particle falls within the 0.25 m^2 frame, but does not occur frequently, then it is not recorded. This may cause the method to be biased towards smaller particles (Kondolf and Li 1992). Kondolf and Li (1992) found that visual estimates similar to Fritz's method tend to overemphasize the frequency of smaller particles when the deposit consists of mainly smaller particles such as fine gravel.

Both methods are similar in that they can lead to visual classification error based on experience level in which an observer incorrectly assigns a particle to the wrong size class (Faustini and Kaufmann 2007; Kondolf and Li 1992).

C. Data Comparison

The two protocols generate different data types, which complicates integration and analysis. Peck's protocol utilizes mostly qualitative data while Fritz's protocol utilizes mostly quantitative data. Measurements that give quantitative results (ratio, interval) are preferred when possible but can be very time consuming to collect in the field (Somerville and Pruitt 2004). Often these measurements are replaced by qualitative measurements (nominal and ordinal) to conserve time, but they are usually subjective. Proper training is required for both methods to reduce errors in accuracy and precision (Roper and Scarnecchia 1995).

Thirty seven of the 51 measurements that compose Peck's physical habitat assessment required some sort of cover or distance estimation. Cover and distance estimations are visually based and subjective (Somerville and Pruitt 2004). Subjective quantitative measurements included such measurements as bankfull width, height, and substrate embeddedness. All of these require formal training and experience for consistent and accurate assessment (Roper and Scarnecchia 1995; Wang et al. 1996).

The other 30 measurements within Peck's protocol yielded nominal and ordinal data. Nominal measurements, i.e. soft/small sediment, side channel, and backwater, required the observer to mark presence or absence. These measurements can result in variability among observers who may have different perceptions of parameter appearance and when to consider it present. Other nominal measurements, such as channel unit codes or pool form codes, are difficult for an observer to classify without training and experience. Ordinal measurements, such as riparian vegetation cover, require an estimate of percent cover by visually grouping vegetation layers into cover classes (i.e. <10% sparse, 10-40% moderate) (Peck et al. 2006). Other ordinal measurements, such as human influences, require the observer to estimate the distance of certain human influences from the stream and place them into one of four categories (Not present,

>10m, Within 10m, On bank). Such influences can easily be perceived differently from one observer to the next.

Fritz's protocol yielded less subjective data because the metrics involved counting or measuring habitat features directly (i.e. sinuosity, substrate moisture). Of the 15 measurements that comprose Fritz's physical habitat assessment, five required some level of judgment or estimation. Among the five included bankfull width, height and flood prone area width. Although these three measurements were quantitative (ratio), judgment was required to determine exactly where the features were located relative to the stream. The other two subjective measurements in Fritz's protocol were modal sediment size and habitat type. These two measurements were qualitative (nominal), requiring the observer to visually place parameters into specific characterization categories.

Stauffer and Goldstein (1997) found that subjectivity between three qualitative habitat indices may have explained some of the differences in their stream assessments. Certain measurements may require more training than others to reduce bias (Roper and Scarnecchia 1995) whereas other measurements can lead to differences between observers (Wang et al. 1996). Differing levels of subjectivity between the two protocols may help to explain the difference in assessments.

D. HQI Comparison

The third objective of this study was to compare HQI scores generated from the two EPA accepted stream protocols. Analysis showed that Peck's protocol scored streams consistently lower then Fritz's protocol. These results provide evidence that the two protocols do not respond to physical habitat changes similarly. Peck's protocol also appears to better discriminate habitat differences among sites.

The main cause for these differences in HQI scores is the divergence in stream characteristics emphasized by the protocols. Peck's protocol emphasizes riparian measurements while Fritz emphasizes hydrology and channel geomorphology measurements. A similar study comparing three different qualitative habitat indices also found major differences in stream scores as a result of different weights among metric classes among protocols (Stauffer and Goldstein 1997).

Differences in metric emphases between the two protocols reflect a focus on hydrologic permanence in intermittent channels. Peck's protocol generally was designed for wadeable perennial streams (Peck et al. 2006); however, it can be adjusted for intermittent, headwater streams. Perennial streams flow year round, placing greater emphasis on riparian attributes in determining stream condition (Poff and Ward 1989). Thus riparian characteristics are viewed as a critical set of driving factors influencing ecological integrity within perennial streams for aquatic organisms (Naiman and Decamps 1997; Rankin 1995). Riparian condition can directly reflect the influence of human activities, which then are included in the HQI scores. Peck's protocol tends to overemphasize riparian attributes at the expense of other stream characteristics. Riparian zone HQI scores were significantly lower for Peck than for Fritz and contributed 51% of the total scores for Peck. Stauffer and Goldstein (1997) also found that when comparing three qualitative habitat indices, overemphasized habitat features may diminish the influence of other metrics, thus causing total scores to be misleading.

Fritz’s protocol was designed for intermittent streams in which hydrologic variability may be viewed as the key factor influencing biotic communities (Fritz et al. 2006). Hydrologic variability is important because it controls the physical and chemical conditions in these streams and thus biotic communities (Boulton 2003; Dodds 2004). Any human activity that affects the hydrologic variability would be expected to negatively impact the condition of the stream (Boulton 2003) therefore lowering HQI scores. However, in this study, no lowering of total HQI scores due to hydrology or channel geomorphology was observed.

One explanation could be that there was no apparent degradation regarding these two stream characteristics. It could also mean that these measurements have difficulty exposing degradation at the spatial scale in which the measurements were taken. Hydrological regime is an important determinant of ecosystem structure and function at the catchment scale (Petts 1994). However, the measurements for this parameter were taken at a reach scale. As a result, these measurements may not reflect human influences at a larger catchment scale

A final hypothesis explaining Fritz’s higher HQI scores is underrepresentation of land use and riparian metrics. With the small size of headwater, intermittent streams, there is a close interaction between the stream and its adjacent riparia (Dodds 1997; Gomi et al. 2002). This close interaction would potentially influence the HQI scores and may not have been detected using the Fritz protocol due to the paucity of riparian metrics.

Neither protocol had a significant relationship with GIS-based watershed condition scores or RCE scores. HQI’s generated from both protocols agreed well when

ATtILA and RCE scores were in the good range, but diverged when both watershed condition and RCE scores indicated poor condition. Fritz's protocol seemed to score sites higher with decreasing watershed condition. Similar results were found when the two protocols were compared to RCE scores. The trends suggest that at the low end (i.e., in "poor" habitats) the protocols did not compare well. At the high end (i.e., "good" habitats) the protocols were comparable. Once again, as watershed condition decreased, Fritz's HQI scores increased whereas Peck's HQI scores decreased. Stauffer and Goldstein (1997) also found that between three different habitat indices, protocols compared better in good condition habitats but did not compare well in poor condition habitats. With more measurements, Peck's protocol may have the ability to detect more disturbances along a condition gradient whereas Fritz's may be lacking the necessary measurements (i.e. riparia) to detect the same disturbances.

Management Implications

Results call for a standardization of monitoring protocols for headwater stream assessments. Some guidelines should be followed in developing or modifying a protocol. First, habitat assessment procedures (i.e. sample reach designation, transect placement) need to be adjusted based on stream type (Montgomery and MacDonald 2002). Results showed that 15% of the 60 streams sampled contained perennial flow for the entire sampling season. The other 85% of the streams showed some sort of drying or dry phase during the sampling season. A standardized protocol should allow for the variability of stream flow conditions found within the Northern Glaciated Plains Ecoregion.

Existing EPA headwater assessment protocols define sample reaches as some multiple (e.g. 40x) of average wetted width (Fritz et al. 2006; Peck et al. 2006).Timing of reach designation creates variability in reach lengths under existing procedures. Average wetted widths may exceed 200 meters under high water conditions to 0 meters through seasonal drying. Oversampling or under-sampling may result from high to low ranging sample reach lengths. Average bankfull width may be used as an alternative to establish reach lengths because it is unlikely to change as streams go through seasonal flooding and drying phases.

Existing EPA headwater protocols (Fritz et al. 2006; Peck et al. 2006) evaluate channel habitat (e.g. thalweg depth, substrate size, wetted width) from multiple transect points distributed evenly along the sample reach. Peck uses 11 transects each with 10 or 15 sub-transects distributed evenly along the sample reach while Fritz uses 30 evenly distributed transects. Under existing procedures, short reach lengths result in overlapping observation areas and double-counted measurement entities. By reducing sample reach transects to 11 equally spaced transects, each with one sub-transect, oversampling will be avoided.

Finally, existing EPA headwater protocols (Peck et al. 2006) evaluate riparian habitat (e.g. riparian vegetation structure, canopy cover, human influences) using visualized 10 X 10 meter plots at eleven transects. Short reach lengths in small, intermittent channels may result in considerable overlap from one plot to the next, again leading to double-sampling of measured entities. Overlap in measurements can be avoided by reducing riparian measurements to downstream, middle and upstream plots.

Second, an ideal protocol should contain measurements that are independent and not redundant (Stauffer and Goldstein 1997). Redundancy can place greater weight (bias) on one attribute class. Greater balance in metric classes might be achieved by selectively removing metrics not applicable to a region or unable to discriminate among sites. Resulting HQI scores would then reflect equal weighting among metric classes.

Suggested modifications include the removal of “in-stream cover for biota of big woody debris” and retaining “large woody debris counts.” Soft/small sediment occurrence should be eliminated but substrate particles size class characterization across transects should be retained. Coarse organic debris (COD) occurrence could be replaced by “in-stream cover for biota of brush/small woody debris”, and habitat type designations (erosional/depositional) could be replaced by channel and pool form unit codes. A final suggestion includes the removal of legacy tree in prairie streams due to low frequencies of trees in the study region.

Stream assessment measurements should be based upon quantitative data, not qualitative judgments (Smiley et al. 2009; Stauffer and Goldstein 1997)." Variability in subjective measurements can lead to inconsistencies between observers from visit to visit. Training is necessary to help reduce these inconsistencies. When standardizing a protocol, efforts should be made to choose quantitative measurements over qualitative measurements when possible.

Suggested modifications include the replacement of both Fritz's and Peck's substrate characterization methods with a Wolman pebble count (Asmus et al. 2009). This method provides a quantitative measurement that can characterize substrate with minimal bias towards non-dominant substrates (Asmus et al. 2009). There are many variations to the Wolman pebble count, sampling location, particles selection, and sample size should be taken into consideration when choosing a modified technique (Bunte et al. 2009).

Another suggestion includes replacing visual estimation of riparian vegetation structure with a Robel pole measurement (Robel et al.1970). This method provides a quantitative measure of vegetation structure and land use impacts by taking 4 measures of visual obstruction at a standard distance (4 m) and height (1 m) (Higgins et al. 2005).

A final suggestion is to replace overhanging vegetative cover from the in-stream cover for biota measurements with a direct measure of overhanging vegetation (Platts et al. 1989). This method involves taking a direct measure of vegetation <0.5 meters above the water surface from the stream bank to the farthest point that the vegetation covers the water column.

Metrics should be scored against reference site values within level IV ecoregions. This would further stratify larger scale LIII ecoregion variability and increase the accuracy.

Table 25 provides a list of proposed stream habitat measurements that could be used to assess headwater streams. Measurements were taken from both Fritz et al. (2006) and Peck et al. (2006) protocols and include suggested measurements discussed earlier.

Table 1 Table of proposed stream habitat measurements and their data type.

Measmurement	Type	Measurement	Type
Canopy cover	Ratio	Riparian Vegetation Structure - Robel Pole	Ratio
Sinuosity	Ratio	Instream Cov. - Overhanging Vegetation Length	Ratio
Max pool depth	Ratio	Instream Cov. - Filamentous Algae Cover	Ordinal
Bankful Width	Ratio	Instream Cov. - Macrophyte Cover	Ordinal
Bankful Height	Ratio	Instream Cov. - Brush/Small Woody Debris	Ordinal
Incised Height	Ratio	Instream Cov. - Live Trees or Roots	Ordinal
Flood Prone Area Width	Ratio	Human Infl. - Wall/Dike/Riprap/Dam	Ordinal
Bank Angle	Interval	Human Infl. - Buildings	Ordinal
Bank Undercut	Ratio	Human Infl. - Pavement/Cleared Lot	Ordinal
Large Woody Debris	Ratio	Human Infl. - Road/Railroad	Ordinal
Velocity	Interval	Human Infl. - Pipes	Ordinal
% Channel length in contact with feature	Ratio	Human Infl. - Landfill/Trash	Ordinal
Thalweg Depth	Ratio	Human Infl. - Park/Lawn	Ordinal
Thalweg Wetted Width	Ratio	Human infl. - Row Crops	Ordinal
Thalweg Bar Width	Ratio	Human infl. - Pasture/Range/Hayfield	Ordinal
Slope	Ratio	Alien Plants	Nominal
Depth to Groundwater	Interval	Channel Unit Code	Nominal
Substrate Moisture	Ratio	Pool Form Code	Nominal
% Embeddeness	Ratio	Side Channel	Nominal
Wolman Pebble Count	Interval	Back Water	Nominal

Future Research

Monitoring and management efforts to address water quality issues continue to focus heavily on perennial streams, yet our understanding of stream hydrology and upstream-downstream connections suggests that headwaters play a critical role in downstream ecology and water quality. This research demonstrates the need for a standard and balanced assessment methodology for headwater streams and differences in stream habitat conditions among Level IV ecoregions of eastern South Dakota. However, results indicate the need for further collection of regional baseline data if we are to move our monitoring and management efforts into the headwaters. Contemporary environmental issues such as irrigation, drainage modification, riparian management, production of biofuels and global climate change and their effects on headwaters remain largely unknown. These issues may have important implications regarding the way we continue to monitor and assess headwaters. With so many issues yet to address, it is clear that we have only just begun to understand our headwater streams.

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