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Ecological Conditions of the Papillion Creek Watershed: Effects of Adjacent Land-Use.

Pamela D. Cox

Ecological Conditions of the Papillion Creek Watershed: Effects of Adjacent Land-Use

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Pamela D. Cox

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THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College,
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Committee

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David M. Sutherland

John Stansbury

____

____

Chairperson Thomas B. Bragg

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ABSTRACT

Ecological Conditions of the Papillion Creek Watershed: Effects of Adjacent Land-Use

Pamela D. Cox, MA

University of Nebraska, 2002

Advisor: Dr. Thomas Bragg

Stream conditions were assessed for past and present landscapes of the Papillion Creek Watershed of northwest Omaha, Nebraska based on historical records, present land-use surveys and field data collected in June 2000 using the Environmental Protection Agency's Rapid Bioassessment Protocol modified to meet the needs of this study. Less than 0.4% of the historic tallgrass prairie remains, with the present landscape mostly in agriculture (83%) or residential-commercial developments (16%). No significant differences ($P \leq 0.05$) were found between ten habitat parameters measured for each of three land-use categories, *cultivated*, *residential-commercial*, and *other*. The overall impact of increased land-use on the Papillion Creek was reflected in marginal conditions (1 = poor; 20 = optimal) for all ten habitat parameters evaluated although not all were equally as effected: *Epifaunal Substrate/Available Cover* (mean score = 8.3), *Pool Substrate Characterization* (mean score = 8.8), *Pool Variability* (mean score = 7.0), *Sediment Deposition* (mean score = 9.0), *Channel Flow* (mean score = 10.8), *Channel Alteration* (mean score = 8.3), *Channel Sinuosity* (mean score = 6.8), *Bank Stability* (mean score = 5.2), *Vegetative Protection* (mean score = 6.2), and *Riparian Vegetative*

Zone Width (mean score = 3.4). Compared to the degree of channel alteration, *Channel Sinuosity* was the habitat parameter most significantly effected ($P \leq 0.000+$). In combination, these results quantify the impact of urban expansion on stream ecosystems and support arguments for minimizing development along waterways in order to maintain the ecosystem services and habitat diversity that they provide to urban areas.

INTRODUCTION

Evidence of the influence of humans on the environment has accumulated for centuries, from both anthropological and archaeological research (Turner *et al.* 1990). The introduction of agriculture, in particular, has led to deforestation, soil erosion, and regionwide degradation of vegetative cover (Butzer 1996, Rice 1996). Nowhere has the human effect been more intense than in cities, suburbs and exurbs (Grimm 2000), with particularly adverse effects on streams and adjacent floodplains.

The United States has more than 6.5 km of rivers and streams that, along with the closely associated floodplain and upland areas, comprise biological corridors of great economic, social, cultural, and environmental value (U.S. Department of Commerce 2000). These corridors are complex ecosystems that perform a number of ecological functions including modulating stream flow, storing water, bioremediation, and providing habitat for aquatic and terrestrial biota (Maridet 1995). Stream corridors also have vegetation and soil characteristics that are distinctly different from surrounding uplands and that, consequently, support higher levels of species diversity, species densities, and biological productivity than most other landscape elements (Sotir 1998). Streams and stream-corridors change in concert with, and in response to, factors affecting the ecosystems incorporated within their watershed. Thus, land-use changes within a watershed have an impact on the physical, chemical, and biological processes occurring within streams of a watershed, with the effects eventually extending downstream (Loar 1991).

Stream systems generally function within natural ranges of flow, sediment transport, temperature, and other variables that, over time, have achieved some degree of dynamic equilibrium (U.S. Department of Commerce 2000). However, when these variables exceed their natural ranges, which may occur with urbanization, the dynamic equilibrium can be upset, often resulting in adjustments in the ecosystem that might conflict with societal interests. Flooding, for example, may change the course of a river leading to restabilization at a new dynamic equilibrium, but the time frame in which this happens can be lengthy and the result undesirable to humans.

Because stream alteration may result in adverse biological and societal effects (U.S. Army Corps of Engineers 1999), it is important to identify factors that effect such an alteration. In this study I hypothesize that alteration of land-use adjacent to streams and wetland communities is one such factor. Specifically, this study is designed to assess this hypothesis by (1) quantifying existing stream and stream-bank conditions associated with adjacent land use, and (2) contrasting past and present conditions using aerial photographs, land-survey records, and historical descriptions.

METHODS AND MATERIALS

Study Site

My study was conducted in the 103,902 ha (401mi.^{2}) Papillion Creek watershed, northwest of Omaha, Nebraska, which incorporates all or part of Douglas, Sarpy, and Washington Counties (Fig. 1). Ninety-eight percent of this watershed is privately owned with the remaining two percent owned publicly (Natural Resources Conservation Service

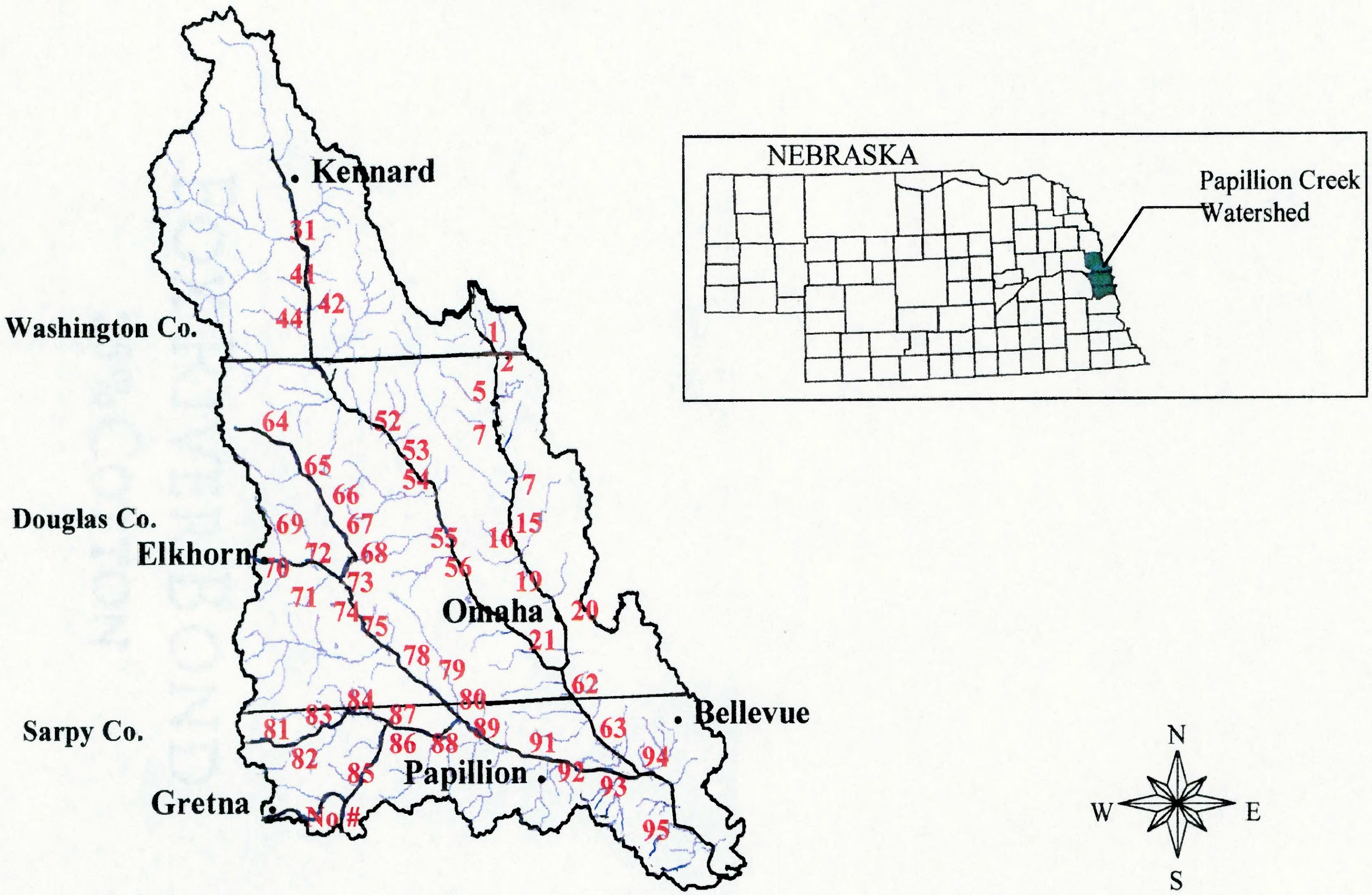


Fig. 1. Bridge-site locations and principal municipalities in the Papillion Creek Watershed of eastern Nebraska. Bridge-site numbers are not consecutive since they are a subsample of a larger study.

1995). The portions of the watershed not yet urbanized are devoted to agriculture with approximately 1,425 farms in the three-county area (U.S. Department of Agriculture 1997). The population within the three-county area totaled 587,609 in 1999 although most lived in the metropolitan Omaha area (Papio Natural Resources District 1975, U.S. Census Bureau 1999).

The Papio Creek Watershed lies in the east-central part of the Great Plains, an area noted for its climatic variability. The mean monthly air temperature ranges from a low of -5° C (23° F) in January to a high of 25° C (77° F) in July with a mean annual precipitation of 76 cm (30 in) (Papio Natural Resources District 1975). Precipitation for June 2000 (14.0 cm) was only slightly above the 127-year average (11.4 cm.) (National Oceanic and Atmospheric Administration 1999). The soils in the Papio Creek Watershed originate from three kinds of parent material: loess (silt and clay), alluvium (sand and clay), and glacial till (clay intermixed with small to large fragments of rock). These form 114 different soil types generally characterized as either alluvial or prairie soils (Papio Natural Resource District 1975). The alluvial soils occur on the floodplains of the Missouri, Platte, and Elkhorn Rivers and some of their tributaries while prairie soils occur on upland areas and in minor drainage ways.

Historically, native plant species of the upland prairie included big bluestem (*Andropogon gerardii*), little bluestem (*Andropogon scoparius*), Indian grass (*Sorghastrum nutans*), porcupine grass (*Stipa spartea*), sideoats grama (*Bouteloua curtipendula),* junegrass (*Koeleria pyramidata*) and switchgrass (*Panicum virgatum*) (Greenawalt and McKinzie 1964, Bartlett 1975). The lowland prairie was dominated by prairie cordgrass (*Spartina pectinata*) and sedges (*Carex* spp.). The principal native trees of upper slopes were bur oak (*Quercus macrocarpa*), hackberry (*Celtis occidentalis*), and black walnut (*Juglans nigra*). On the more mesic sites and on lower slopes, cottonwood (*Populus deltoides*), willow (*Salix* spp.), American elm (*Ulmus Americana*), and green ash (*Fraxinus pennsylvanica*) were the most common (Weaver 1965). Nomenclature is from Flora of the Great Plains (1986). All but approximately 400 ha (0.4% of the watershed) of native prairie vegetation has been either replaced by agriculture or urban-commercial use or degraded by woody plant encroachment (Bragg, personal communication).

Native animals of the urbanized areas are largely those that have adjusted to humans: raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitus*) and opossum (*Didelphis didelphis*). Rural areas of the watershed support a greater diversity that is more characteristic of the native fauna including prairie voles (*Microtus ochrogaster*), red fox (*Vulpes vulpes*), badger (*Taxidea taxus*), sedge wrens (*Cistothorus platensis*), red-tailed hawks (*Buteo jamaicensis*), and prairie skinks (*Eumecus* spp.). In addition, the watershed supports a wide array of invertebrates, including small populations of regal fritillary (*Speryeria idalia*), a species of butterfly found only in tallgrass prairie (Ahlering *et al.* 1999, Costello and Burk 1999). Fish inhabit some creeks but they are few in both number and diversity (Stasiak, personal communication). The most common fish belong to the Cyprinadae (minnow) family. These include the sand shiner (*Notropis stramineus*), emerald shiner (*N. blennius*) and plains minnow (*Hybognathus placitus*). Perhaps one of the most uncharacteristic fish of the minnow family to be found in the Papillion is the creek chub (*Semotilus atromaculatus*), because it is usually found in clear streams unlike that of the Papillion Creek. Other fish found in the Papillion Creek include channel catfish (*Ictalurus punctatus*), and green sunfish (*Lepomis* cyanellus) (Stasiak, personal communication).

Data Collection.

Two sources of data were used in this study: (1) past and present land-cover from public documents and (2) present land-cover from field observations.

Public Documents: Past and Present Conditions.-- A general description of the past landscape was obtained from the Washington, Douglas, and Sarpy County Soil Surveys (Greenawalt and McKinzie 1964, Bartlett 1975) and from the Papio-Missouri River Natural Resources District (PMRNRD) native vegetation map (Fig. 2) (Papio-Missouri River Natural Resources District 1999). Present land-use for the watershed also was obtained from the PMRNRD as well as from the Environmental Protection Agency's (EPA) Basins component of the ArcView GIS program (Fig. 3). Eight categories of land-cover were derived from these two sources (Table 1).

Field Observations: Present Conditions.-- Field observations were used to supplement and refine the information obtained from public documents. Procedures for field observation followed the EPA's Rapid Bioassessment Protocol (Barbour *et al.* 1999)

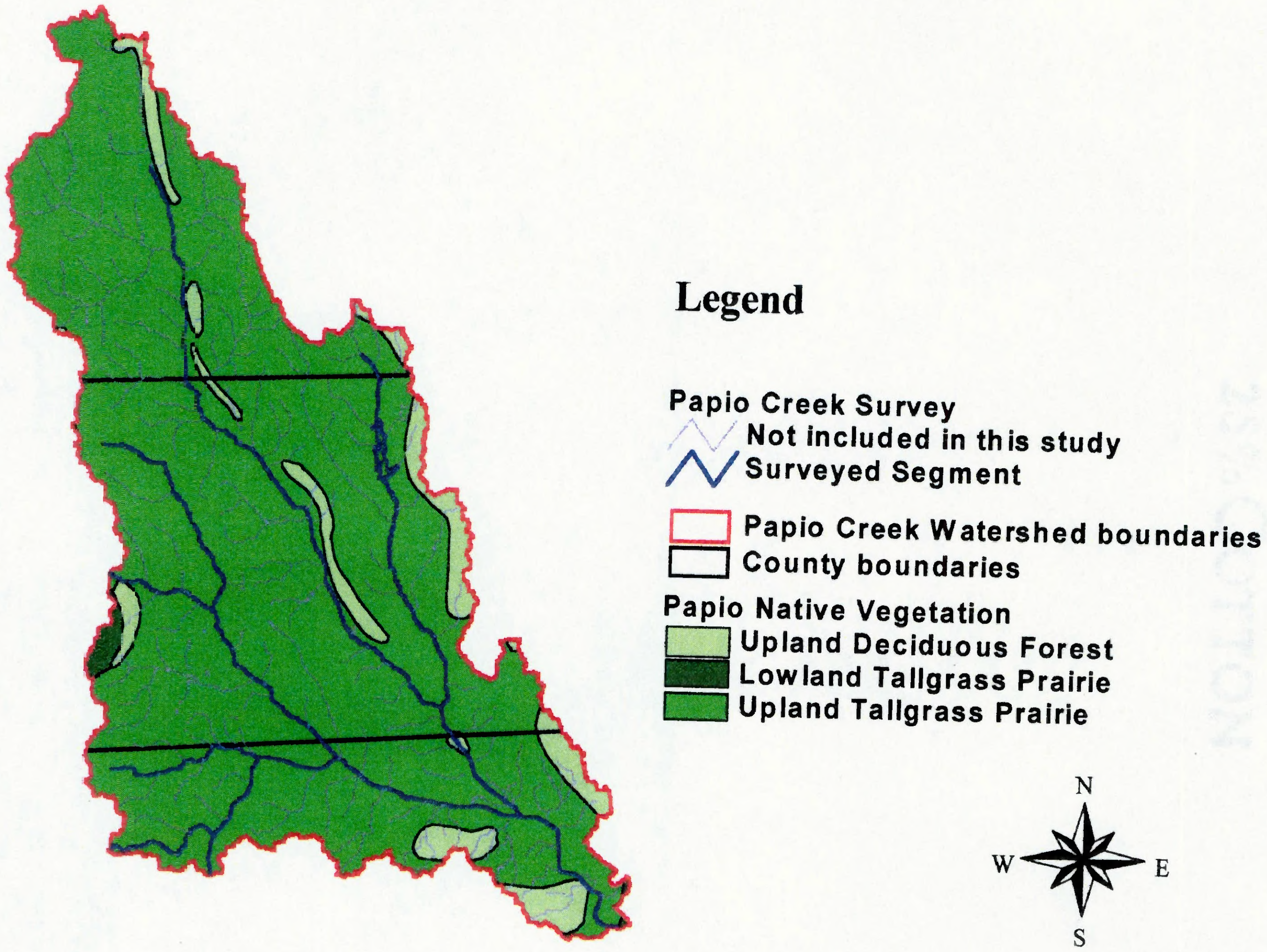


Fig. 2. Papillion (Papio) Creek watershed. Native vegetation prior to settlement by Europeans (Papio-Missouri River Natural Resources District 1999).

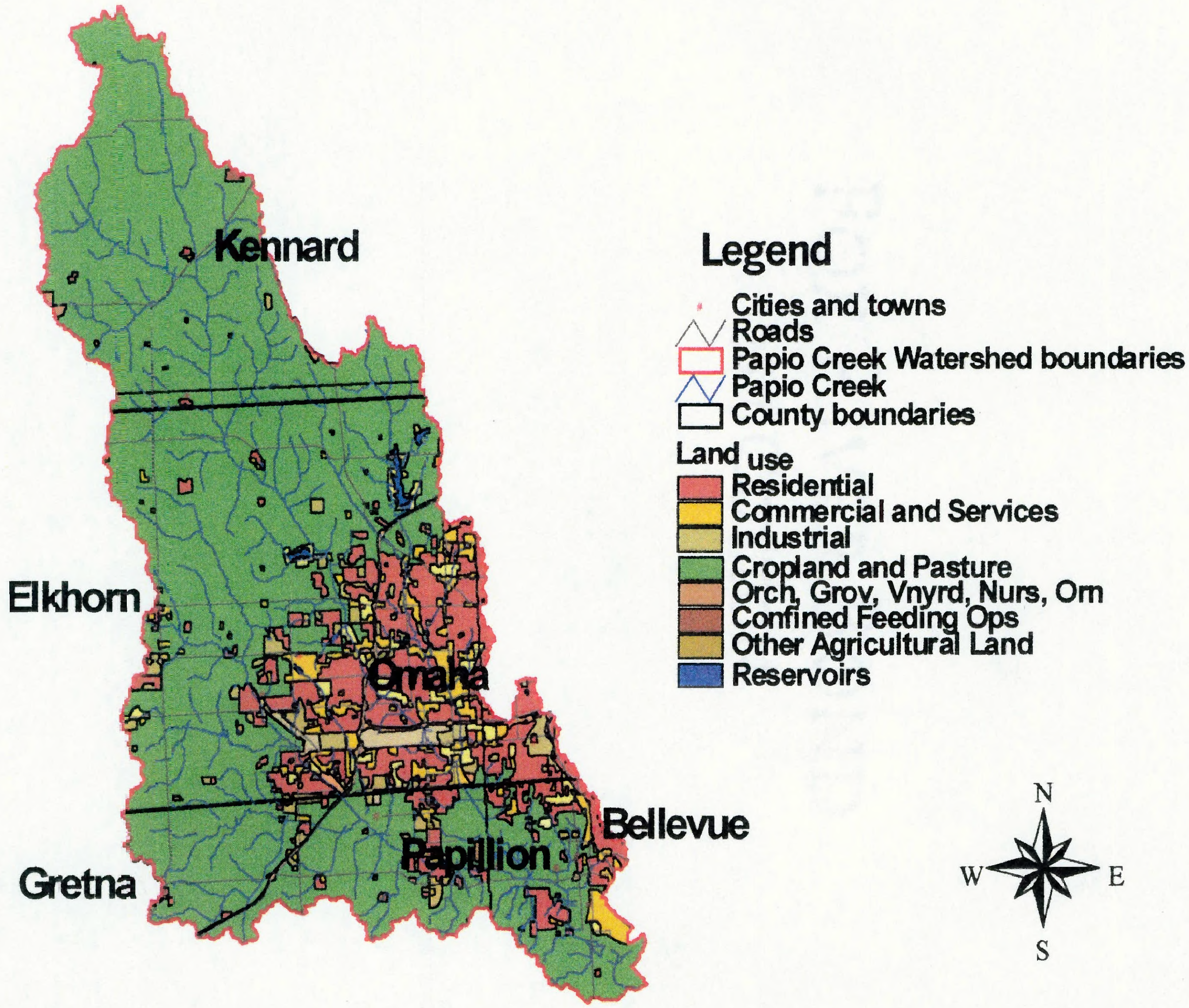


Fig. 3. Papillion (Papio) Creek watershed. Land use/Land cover in 1999 (Papio-Missouri River Natural Resources District 1999).

Table 1. Comparison between Pre-European settlement and present (1999) land-cover obtained using dot-counts from a photo-coordinate grid placed over each land-cover map. Total watershed = 103,902 ha. See text for more details and Appendix Table 6 for individual bridge-site data.

Land-Cover Categories	Year (Percent of Watershed)	
	Presettlement	1999
Native Vegetation		
Forest	13	<1*
Prairie	87	<1
Residential	0	12
Commercial and Services	0	2
Industrial	0	2
Cropland and Pasture **	0	83
Tree and Shrub Plantings***	0	<1
Confined Feeding Operations	0	<1
Other Agricultural Land	0	<1
Reservoirs	0	<1

* Personal observation.
** None of the pastures are known to be native prairie.
*** Combined Orchard, Grove, Vineyard, Nursery, and Ornamental plantings

as modified to meet the needs of this study (Appendix Fig. 1: Data sheet). This protocol involves observations made from representative bridges located throughout the area to be evaluated. For this study, 50 bridge-sites (Fig. 1, Appendix Table 1) were selected from within a larger study of 100 sites. Evaluations were conducted from 7 – 29 June 2000. At each site, information collected included general weather conditions and estimates of channel width, water depth and velocity, and associated structures (e.g. discharge pipes). Channel width was visually estimated after walking the bridge site perpendicular to the stream. Averages were recorded when widths were variable (Barbour *et al.* 1999). Water depth was visually estimated at a representative point near each bridge site. Water velocity was estimated by dropping a floating object into the stream and recording the time it took to travel an estimated distance. Two additional, more detailed, field observations also were conducted using procedures modified from EPA's Rapid Bioassessment Protocol: (1) Habitat and Biological Communities and (2) Bioassessment.

*Habitat and Biological Communities***.** Habitat and biological communities were evaluated for four locations at each bridge-site: Upstream-Right Bank, Upstream-Left Bank, Downstream-Right Bank, and Downstream-Left Bank. Upstream and Downstream locations extended 0.8 km along the stream starting at the bridge. This portion of the evaluation was further divided into *Bank-Vegetation* and *Over-Bank Land-Use/Vegetation*. Bank-vegetation was defined as that occurring from the bank-edge (i.e. where the bank-slope met the adjacent, more level land) to the water's edge (i.e. the stream-land interface). Bank vegetation was divided into four categories: trees, shrubs, grass and other. The area designated as "*Over-Bank*" was that land area extending 0.8 km upstream and downstream from the bridge and up to 0.5 km away from the bank-edge. *Over-Bank Land-Use/Vegetation* was divided into 8 categories: commercial, residential, rural (i.e. buildings, etc.), pasture, cultivated, trees, grass, and other. For *Bank-Vegetation* and *Over-bank Land-use/Vegetation* categories, the percent of total land-area in each of their respective categories was visually estimated and recorded on the EPA Rapid Bioassessment Data Sheet (Appendix Fig. 1).

Bioassessment. This portion of the *Rapid Bioassessment Protocol* consisted of evaluating ten biological and physical attributes of the landscape at each bridge site. Seven habitat parameters evaluated at each bridge site were visual estimates combining upstream and downstream conditions, including both banks; *Epifaunal Substrate-Available Cover*, *Pool Substrate Characterization*, *Pool Variability*, *Sediment Deposition*, *Channel Flow Status*, *Channel Alteration* and *Channel Sinuosity*. *Bank Stability*, *Vegetative Protection*, and *Riparian Vegetative Zone Width* were evaluated separately for upstream and downstream conditions although left-bank and right-banks were visually combined (Appendix Fig. 1).

Epifaunal Substrate-Available Cover combines upstream and downstream natural structures in the stream, such as large rocks, fallen trees, and undercut banks. A wide variety of submerged structures provide a large number of niches for a variety of macroinvertebrates and fish, thus increasing habitat diversity. For example, riffles and runs are critical for maintaining a variety and abundance of insects in most streams, serving also as spawning sites and refugia for certain species of fish (Barbour *et al.* 1999) (Appendix Table 2). As the abundance and variety of habitat structures decreases, so does diversity and the potential for population recovery following disturbance.

Pool Substrate Characterization evaluates the type and condition of bottom substrates found in pools within the stream. Firm sediment types, such as gravel, sand, and rooted aquatic plants, support a wider variety of organisms than does a pool substrate dominated by loose sediment, bedrock, or the absence of plants. In addition, a stream with a variety of substrate types, supports more types of organisms than pools with a uniform substrate (Barbour *et al.* 1999) (Appendix Table 2).

Pool Variability rates the overall mix of pool sizes and depths found in streams. A stream with many types of pools will support a wider variety of aquatic species than streams with uniform pool characteristics (Barbour *et al.* 1999) (Appendix Table 2).

Sediment Deposition measures the amount of sediment that has accumulated in pools as well as changes that have occurred along the stream bottom as a result of this deposition. This category usually measures deposition occurring from large-scale movement of sediment. High levels of sediment deposition are symptoms of an unstable and continually changing environment that becomes unsuitable for many organisms due to the filling of runs and pools (Barbour *et al.* 1999) (Appendix Table 2).

Channel Flow Status quantifies the amount of the channel that is filled with water. When water does not cover much of the streambed, the amount of suitable substrate for aquatic organisms is limited. This parameter has proven especially useful in assessing abnormal or low-flow conditions when data from other parameters are not conclusive among sites or between years (Barbour *et al.* 1999) (Appendix Table 2).

Channel Alteration is a measure of large-scale changes in the shape of the stream channel, such as those resulting from channelization or dredging. Artificial embankments, like riprap (broken rocks or concrete) and other forms of artificial bank stabilization or structures, are examples of channel alteration. Many streams in urban and agricultural areas have been deepened or diverted into channels with artificial embankments, often for the purpose of flood control or irrigation. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally occurring streams. (Barbour *et al.* 1999) (Appendix Table 2).

Channel Sinuosity is the last of the parameters evaluated by combining both upstream and downstream conditions. Sinuosity measures the degree to which a stream's channel meanders across the landscape. A high degree of sinuosity provides for diverse habitat and fauna and also better handles storm surges. For example, numerous bends help absorb energy from water surges produced by storms. They also help protect the stream from flooding and excessive erosion and provide refugia for benthic invertebrates and fish during storm events (Barbour *et al.* 1999) (Appendix Table 2).

In contrast to the previous parameters, *Bank Stability*, *Vegetative Protection* and *Riparian Vegetative Zone Width*, are separately evaluated for upstream and downstream conditions. *Bank Stability* is a measure of the amount of stream bank erosion. Eroded banks indicate sediment movement and deposition and suggest a scarcity of cover and organic input to streams (Barbour *et al.* 1999) (Appendix Table 2).

Vegetative Protection measures the protection afforded the stream bank and the adjacent riparian zone by established vegetation. For example, the root systems of plants growing on banks is particularly helpful in holding soil in place, thereby reducing the potential for erosion. In addition, this parameter measures whether or not the stream is shaded by overstory trees and shrubs. Bank-shading, in conjunction with other parameters, increases the diversity of habitats available for aquatic and riparian organisms (Barbour *et al.* 1999) (Appendix Table 2).

The *Riparian Vegetative Zone Width* measures the width of the area of natural vegetation that extends up to 18 m away from the water's edge. Characterizing the riparian zone is important since it serves, for example, as a buffer against pollutants entering a stream from runoff. The riparian zone also provides descriptive information on the zone that controls erosion, provides habitat, and effects nutrient input into streams. Degradation of these processes may be affected by adjacent land-use, including residential developments, golf courses, urban centers, and rangeland. Paths and walkways in an otherwise undisturbed riparian zone, however, do not appear to alter substantially the ecological functions of the riparian zone in which they occur (Barbour *et al.* 1999) (Appendix Table 2).

Evaluation of these ten Bioassessment habitat parameters at each bridge-site was accomplished by placing each into one of four qualitative condition categories then further placing each parameter into one of four quantitative subcategories. Categories and subcategories used were: Poor (subcategories 1-5), marginal (6-10), suboptimal (11-15) and optimal (16-20) (Appendix Fig. 1).

Analysis

A coarse quantification of pre-settlement and of present land cover was extracted from public documents by using dot-counts from a photo-coordinate grid placed over each of Figs. 2 and 3.

Current effects of land-use on streams were evaluated from field data. Analysis of field data consisted of (1) generally characterizing land-use and adjacent stream conditions, and (2) statistically testing for differences in the response of stream parameters to land-use.

Assessing Effect of Land-Use on Streams.-- Based on dot-counts from the photo-coordinate grid, *cultivated* and *residential-commercial* categories made up approximately 99% (83% and 16%, respectively) of land-use of the watershed in 1999 (Table 1), thus, these were the principal land-use categories used in assessing field data. In addition, however, I used a third category, "*other.*" This category was added since, in contrast to dot-count data, field data were detailed enough to more precisely define landscape features. This category "*other*," included the habitats "rural," "pasture," "trees," "grass," and "other" of the Field Data Sheet (Appendix Table 3, Appendix Fig. 1). A bridge-site land-use was categorized as *cultivated* (n = 17), *residential-commercial* (n = 9), or *other* (n = 24) by averaging *over-bank vegetation* percentages for upstream, downstream, left-bank, and right-bank locations (Appendix Table 3). The category for which the average value was highest, determined the site's land-use category. Mean and standard error of each habitat parameter of all bridge sites within a land-use area category were then calculated to assess the probability of differences among categories (Table 2).

Assessing Response of Habitat Parameters to Land Use.-- Since this aspect of my study focused on those areas affected by rural or urban development, I first selected only the 184 locations (46 bridge-sites each with 4 locations: left and right bank; upstream and downstream) at which >25% of the overbank land-use was categorized as being developed (i.e. cultivated or residential-commercial) (Appendix Table 3). To provide qualitative categories from which to determine stream parameters that were most affected by land-use, I next selected the single Habitat Parameter that provided the best overall characterization of all streams in the 184 locations. By comparing the descriptions of the ten habitat parameters provided in the EPA protocol (Appendix Fig. 1), *Channel Alteration* was determined subjectively to best provide this characterization. Each of the 184 locations was then placed in one of two groups based on their *Channel Alteration* score. Those with channel alteration scores from 1-7 were placed in a group identified as "*Most-Affected*" ($n = 23$) and those with scores 10-16 were placed in a second group identified as "*Least-Affected*" ($n = 23$). No locations had scores of 8 or 17-20. The two locations with scores of 9 were omitted because, as midpoint scores, they could not reasonably be placed in either group. The scores of each of the nine remaining habitat

Table 2. Mean and Standard Error (SE) of habitat parameter rankings for each of the three principal land-use categories. Rankings are from 1 (poor) to 20 (optimal); *n* = the number of bridge-sites in the land-use category. Underlined and bolded values are the highest mean ranking for each habitat parameter. See text for more details and Appendix Table 4 for individual bridge-site data.

HABITAT PARAMETER	LAND-USE CATEGORIES: Cultivated $n = 17$		Residential-Commercial $n = 9$		Other $n = 24$		*P*-Value 1-Way ANOVA
	Mean	SE	Mean	SE	Mean	SE	
Epifaunal Substrate Available Cover	8.2	1.00	**9.2**	1.5	8.0	0.73	0.724
Pool Substrate Characterization	8.3	0.67	**9.9**	0.96	8.7	0.63	0.423
Pool Variability	6.4	0.84	**8.4**	0.87	7.0	0.70	0.337
Sediment Deposition	8.6	0.86	8.6	0.71	**9.4**	0.58	0.658
Channel Flow Status	**11.0**	0.94	10.0	0.60	**11.0**	0.57	0.805
Channel Alteration	**8.5**	0.82	8.4	0.94	8.1	0.57	0.896
Channel Sinuosity	7.1	0.92	**7.3**	0.85	6.5	0.58	0.733
Bank Stability	5.1	0.46	**5.7**	0.72	5.0	0.34	0.620
Vegetative Protection	**6.5**	0.33	5.4	0.56	6.2	0.31	0.261
Riparian Vegetative Zone Width	2.9	0.44	**3.9**	0.56	3.6	0.49	0.412
Overall Mean	7.3	-	**7.7**	-	7.4	-	-

parameters in each of the groups, *Most-Affected* and *Least-Affected*, were then compared using a paired *t*-Test to determine significant differences ($P \leq 0.05$) (Zar 1999) (Table 3).

RESULTS AND DISCUSSION

Land-Cover Changes: Pre-settlement to 1999.

Not surprisingly, substantial differences were noted between pre-settlement and present-day land-use. Pre-settlement vegetation of the Papillion watershed was dominated by tallgrass prairie in the uplands and lowlands (87% of land cover) with forested areas limited to the lower region of the Big Papillion Creek (13%) (Bartlett 1975) (Fig. 2). In contrast, land-cover in 1999 was dominated by cropland and pasture (83%) followed by residential (12%), commercial and services (2%), and industry (1%) (Table 1). Native prairie and forest had all but disappeared. In June 2000, channel widths averaged 5.5 m with a water depth of 0.5 m flowing at an estimated 0.4 m/sec (Appendix Table 5). Bank vegetation was dominated by grass (52% cover) followed by "other" (31% cover), trees (17% cover), and shrubs (< 1% cover) (Appendix Table 6).

Impact of Land-Use on Stream Habitats.

Overall, this study describes a waterway substantially degraded from one subjectively considered to be natural. For example, the average value of 7.5 for all habitat parameters combined is well below the value of 20 that represents optimal conditions (Table 2, Appendix Table 4). From among the different land uses that were compared, however, some were more disruptive than others. For example, while there were no

Table 3. Mean and Standard Error (SE) of habitat parameter rankings for areas *Most-Affected* and *Least-Affected* by channel alteration. See text for details. Mean values are rankings from 1 (poor) to 20 (optimal); Significant differences (*t*-Test; $P \leq 0.05$) between *Most-Affected* and *Least-Affected* are indicated with an asterisk following the *P*-value. Sample number (*n*) = 23 bridge-sites x 4 locations at each.

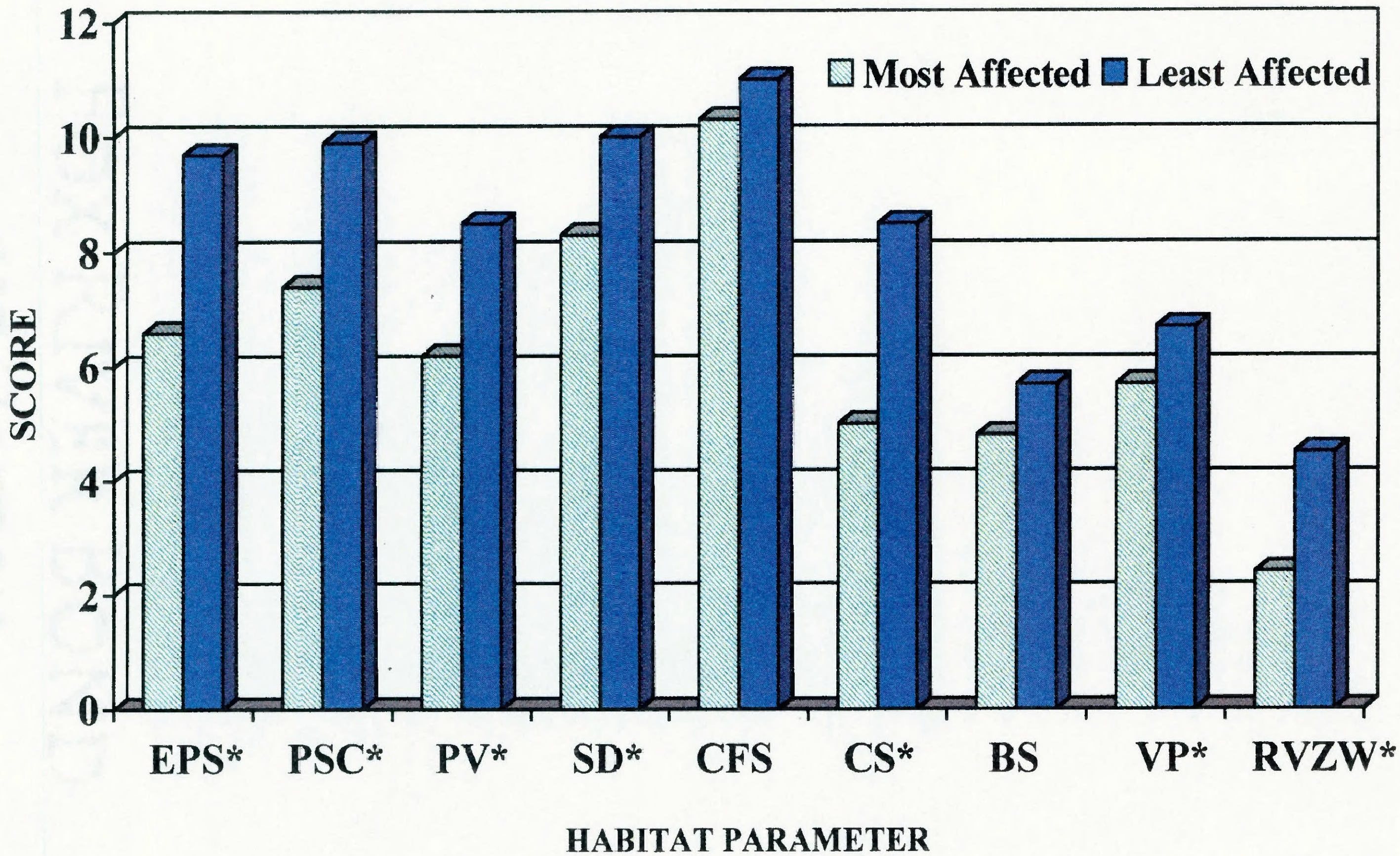
	CHANNEL ALTERATION				
HABITAT PARAMETER	Most-Affected $n = 92$		Least-Affected $n = 92$		*P*-Value
	Mean	SE	Mean	SE	
Epifaunal Substrate/Available Cover	6.6	0.72	9.7	0.81	0.008*
Pool Substrate Characterization	7.4	0.54	9.9	0.68	0.002*
Pool Variability	6.2	0.51	8.5	0.75	0.019*
Sediment Deposition	8.3	0.59	10.0	0.61	0.043*
Channel Flow Status	10.3	0.51	11.0	0.74	0.439
Channel Sinuosity	5.0	0.50	8.5	0.53	0.000+*
Bank Stability	4.8	0.35	5.7	0.35	0.155
Vegetative Protection	5.7	0.25	6.7	0.34	0.023*
Riparian Vegetative Zone Width	2.4	0.39	4.5	0.32	0.001*

significant differences among the three land-use categories, the average rankings for *residential-commercial* areas were higher (i.e. in somewhat better condition) than either *cultivated* areas or *other* categories for six of the ten habitat parameters evaluated (Table 2). Thus, residential-commercial land-use may be less disruptive to stream habitats as a whole than are other land-uses. This result is unanticipated considering that more modifications, such as removal of natural structures in and around streams, straightening of bends, and the development of urban centers, would be expected with this land-use than, for example, cultivation.

There are two exceptions to the overall observation that residential-commercial land use is less disruptive. Both *Channel Flow Status* and *Vegetative Protection* were most affected in residential-commercial areas. These results, however, are not unexpected. For example, *Vegetative Protection* within the urban area is more likely to be reduced, removed or replaced with artificial structures and embankments to ensure against bank-erosion and to maintain a high channel-flow during periods of high rainfall.

Channel Alteration and Habitat Effects.

Of the nine habitat parameters evaluated, seven were significantly more affected where cultivation and residential-commercial development most substantially altered the channel (Fig. 4, Table 3). Of these seven, the difference between mean values for *Most-Affected* and *Least-Affected* locations was greatest for *Channel Sinuosity* (Δ mean = 3.5), which also had the lowest *P*-value ($P \leq 0.000+$). Decreased channel sinuosity is not a surprising result given that channel-straightening is one of the first steps to “improve”



LEGEND:

EPS = Epifaunal Substrate
PSC = Pool Substrate Characterization
PV = Pool Variability
SD = Sediment Deposition
CFS = Channel Flow Status
CA = Channel Alteration (not listed)
CS = Channel Sinuosity
BS = Bank Stability
VP = Vegetative Protection
RVZW = Riparian Vegetative Zone Width

Fig. 4. *Most Affected* and *Least Affected* Channel Alteration groups and Habitat Parameter Conditions. Significant differences (*t*-Test, $P \leq 0.05$) between *Most Affected* and *Least Affected* are indicated by an asterisk; Scores of each habitat parameter represent habitat conditions ranking from 1 (poor) to 20 (optimal).

human use of waterways. Loss of channel sinuosity decreases the physical protection against bed-cutting and bank erosion that it affords during high-flow periods, the protection that it provides to benthic invertebrates, fish, and vegetation during flooding, and the diversity of habitats that it supports for aquatic biota throughout the year. *Epifaunal Substrate-Available Cover* was the second most affected parameter (Δ mean = 2.6). Logically, reducing channel sinuosity would reduce the variability in channel flow, which in turn, would impact the diversity of habitats available to epifaunal communities.

The parameter least affected by alteration of the channel was *Channel Flow* (Δ mean = 1.0; $P \leq 0.439$). This result is reasonable considering that channel alteration usually is designed to improve water flow which may be accommodated by removing bends in streams.

CONCLUSION

Overall, this study quantitatively supports the conventional wisdom that altering both stream channels and adjacent land adversely affects stream habitats, changes that inevitably will affect the biotic community and the ecosystem services (e.g. decomposition, waste disposal, and nutrient loading) that they provide. As a first step then, this study supports arguments that favor minimizing development along waterways, establishing broad green spaces adjacent to waterways, and maintaining stream sinuosity as means by which to incorporate physical and biological diversity in urban planning.

LITERATURE CITED*

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* See Appendix Table 7 for additional references.

Appendix

Appendix Table 1. Descriptive locations of the 50 bridge-sites evaluated in the Papillion (Papio) Creek watershed study.

Bridge-site Number	Location
	Little Papio--upper reach, main branch
1	CR 41 0.5 mile N. of CR 1
2	CR 1 between CR 41 & CR P41
	Little Papio--main
5	Pawnee Rd. between N. 96th St. (CR 40) & N. 84th St. (CR 36)
7	State St. at approx. Wenninghoff Rd.
15	Fort St. between Irvington Rd. & N. 87th Ave.
16	Maple St. between N. 88th St. & Keystone Ave.
19	Dodge St. between Beverly Dr. & S. 77th St.
20	Mercy Rd. & Aksarben Dr.
21	L St. between S. 67th St. & S. 62nd St.
	Big Papio--main
31	Hwy 30 0.3 mile E. of Kennard
41	CR 34 between CR P25 & CR P27
42	CR 36 between CR P25 & CR P27
44	CR 40 between CR P25 & CR P27
52	Bennington Rd. between N. 168th St. & N. 156th St.
53	State St. between N.144th St. & N.138th St.
54	N. 126th St. 0.2 mile N. of Military Rd.
55	Fort St. between Tranquility Park & N.120th St.
56	Old Maple Rd. between N. 120th St. & Sahler St.
62	Harrison St. & S. 60th St.
63	Cornhusker Rd. & S. 48th St.
	West Papio--North Branch
64	State St. between N.186th St. & N.168th St.
65	Ida St. between N.180th St. & N.168th St.
66	Fort St. between N.180th St. & N.168th St.
67	Maple St. at N.168th St.
68	Blondo St. between N.168th St. & N.156th St.
	West Papio--main
69	Mount Michael Rd W. of Elkhorn 0.5 mile N. of Maple St. (Hwy 64)
70	Maple St. (Hwy 64) W. of Elkhorn between Ramblewood Dr. & CR 80
71	Hwy 31 S. of Elkhorn between E. Railroad Ave. & Old Lincoln Hwy
72	N.192nd St. between Old Lincoln Hwy & W. Dodge Rd.
73	W. Dodge Rd. between S.168th St. & S.156th St.
74	Pacific St. between S.168th St. & S.156th St.
75	W. Center Rd. at approx. S.156th St.
78	S.144th St. between F St. & West Center Rd.
79	Q St. between S.144th St. & S.132nd St.
80	Harrison St. & I-80

Appendix Table 1. Descriptive locations of the 50 bridge-sites evaluated in the Papillion (Papio) Creek watershed study.

	West Papio--South, upper reach
81	S.192nd St. between Giles Rd. & Cornhusker Rd.
82	S.180th St. between Harrison St. & Giles Rd.
83	S.168th St. between Harrison St. & Giles Rd.
84	S.156th St. between Harrison St. & Giles Rd.
	West Papio--South, lower reach
No #	S.180th St. (CR 68) between Schram Rd. & Hwy 370
85	S.168th St. (CR 64) between Schram Rd. & Hwy 370
86	Hwy 370 between CR 64 & CR 60
	West Papio--South, main
87	Hwy 50 between Harrison St. & Giles Rd.
88	Giles Rd. at S.132nd St.
	West Papio--main
89	Giles Rd. between CR 46 & S. 108th St.
91	Hwy 85 between Lincoln St. & 1st St.
92	Fleetwood Dr. approx. 0.8 miles S. of Cornhusker Rd.
93	S.48th St. (CR G21) 0.8 miles N. of Hwy 370
	Big Papio--main
94	Hwy 370 between Kate Fox Rd. & S. 25th St.
95	Capehart Rd. 0.3 mile W. of Hwy 75

Appendix Table 2. Selected references for each of the ten habitat parameters evaluated. See Appendix Table 7: Bibliography for complete citations.

Habitat Parameter	Associated References
Epifaunal Substrate-Available Cover	Wesche 1985, Pearsons *et al.* 1992, Gorman 1988, Rankin 1991, Barbour and Stribling 1991, Plafkin *et al.* 1984, Platts *et al.* 1983, Osborne *et al.* 1991, Benke *et al.* 1984, Wallace *et al.* 1996, MacDonald *et al.* 1991, Reice 1980, Clements 1987, Hawkins 1982, Beechie and Sibley 1997.
Pool Substrate Characterization	Beschta and Platts 1986, EPA 1983.
Pool Variability	Beschta and Platts 1986, EPA 1983.
Sediment Deposition	MacDonald *et al.* 1991, Platts *et al.* 1983, Ball 1982, Armour *et al.* 1991, Barbour and Stribling 1991, Rosgen 1985.
Channel Flow Status	Rankin 1991, Rosgen 1985, Hupp and Simon 1986, MacDonald *et al.* 1991, Ball 1982, Hicks *et al.* 1991.
Channel Alteration	Barbour and Stribling 1991, Simon 1989a,b, Simon and Hupp 1987, Hupp and Simon 1986, Hupp 1992, Rosgen 1985, Rankin 1991, MacDonald *et al.* 1991.
Channel Sinuosity	Hupp and Simon 1991, Brussock and Brown 1991, Platts *et al.* 1983, Rankin 1991, Rosgen 1985, 1994, 1996, Osborne and Hendricks 1983, Hughes and Omernik 1983, Cushman 1985, Bain and Boltz 1989, Gislason 1985, Hawkins *et al.* 1982), Statzner *et al.* 1988.
Bank Stability	Ball 1982, MacDonald *et al.* 1991, Armour *et al.* 1991, Barbour and Stribling 1991, Hupp and Simon 1986, 1991, Simon 1989a, Hicks *et al.* 1991, Osborne *et al.* 1991, Rosgen 1994, 1996.
Vegetative Protection	Platts *et al.* 1983, Hupp and Simon 1986, 1991, Simon and Hupp 1987, Ball 1982, Osborne *et al.* 1991, Rankin 1991, Barbour and Stribling 1991, MacDonald *et al.* 1991, Armour *et al.* 1991, Myers and Swanson 1991, Bauer and Burton 1993.
Riparian Vegetative Zone Width	Barton *et al.* 1985, Naiman *et al.* 1993, Hupp 1992, Gregory *et al.* 1991, Platts *et al.* 1983, Rankin 1991, Barbour and Stribling 1991, Bauer and Burton 1993.

Appendix Table 3. Land-use by bridge-site: *Over-Bank Land-Use* data. Locations: us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.									
Bridge-Site Number	Location	Score by Habitat (% of Total Area)							
		Commercial	Residential	Rural	Pasture	Cultivated	Trees	Grass	Other
1	us - lb	0	0	0	0	85	3	12	0
	us - rb	0	0	20	0	40	10	30	0
	ds - lb	0	0	10	0	80	7	3	0
	ds - rb	0	0	0	0	85	10	5	0
Average		0.0	0.0	7.5	0.0	72.5	7.5	12.5	0.0
2	us - lb	0	0	0	0	95	0	5	0
	us - rb	5	0	5	0	80	5	5	0
	ds - lb	0	0	0	0	0	60	25	15
	ds - rb	0	0	0	0	0	60	25	15
Average		1.3	0.0	1.3	0.0	43.8	31.3	15.0	7.5
5	us - lb	0	0	0	0	0	50	35	15
	us - rb	0	0	0	0	10	45	30	15
	ds - lb	0	0	0	0	0	35	45	20
	ds - rb	0	0	0	10	0	40	35	15
Average		0.0	0.0	0.0	2.5	2.5	42.5	36.3	16.3
7	us - lb	0	0	0	0	0	35	65	0
	us - rb	0	0	0	0	0	60	20	20
	ds - lb	0	0	0	0	70	3	22	5
	ds - rb	0	0	0	0	70	3	22	5
Average		0.0	0.0	0.0	0.0	35.0	25.3	32.3	7.5
15	us - lb	5	0	0	0	30	15	5	0
	us - rb	75	0	0	0	0	15	6	4
	ds - lb	0	65	0	0	0	20	10	5
	ds - rb	25	40	0	0	0	20	10	5
Average		26.3	26.3	0.0	0.0	7.5	17.5	7.8	3.5
16	us - lb	72	0	0	0	0	20	50	3
	us - rb	72	0	0	0	0	20	5	3
	ds - lb	90	0	0	0	0	6	4	0
	ds - rb	5	70	0	0	0	15	7	3
Average		59.8	17.5	0.0	0.0	0.0	15.3	16.5	2.3
19	us - lb	0	0	0	0	0	20	80	0
	us - rb	0	0	0	0	0	20	80	0
	ds - lb	90	0	0	0	0	5	2	3
	ds - rb	90	0	0	0	0	5	2	3
Average		45.0	0.0	0.0	0.0	0.0	12.5	41.0	1.5
20	us - lb	60	0	0	0	0	10	25	5
	us - rb	25	0	0	0	0	10	25	40
	ds - lb	70	0	0	0	0	20	5	5
	ds - rb	75	0	0	0	0	10	10	5
Average		57.5	0.0	0.0	0.0	0.0	12.5	16.2	13.7
21	us - lb	60	0	0	0	0	10	25	5
	us - rb	25	0	0	0	0	10	25	40
	ds - lb	25	0	0	0	0	20	55	0
	ds - rb	75	0	0	0	0	5	20	0
Average		46.2	0	0	0	0	11.2	31.2	11.2
31	us - lb	0	0	0	0	65	15	10	15
	us - rb	0	30	0	0	0	25	30	15
	ds - lb	0	0	0	0	90	0	5	5
	ds - rb	0	0	0	0	80	10	5	5
Average		0	7.5	0	0	58.7	12.5	12.5	10

Appendix Table 3. Land-use by bridge-site: *Over-Bank Land-Use* data. Locations: us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Habitat (% of Total Area)							
		Commercial	Residential	Rural	Pasture	Cultivated	Trees	Grass	Other
41	us - lb	0	0	5	0	85	10	0	0
	us - rb	0	0	0	0	90	10	0	0
	ds - lb	0	0	0	60	30	10	0	0
	ds - rb	0	0	0	0	90	5	0	0
Average		0	0	1.2	15	73.7	8.7	0	0
42	us - lb	0	0	0	0	0	65	30	5
	us - rb	0	0	0	0	85	10	5	0
	ds - lb	0	0	0	0	85	5	10	0
	ds - rb	0	0	15	35	45	5	0	0
Average		0	0	3.7	8.7	53.7	21.2	11.2	1.2
44	us - lb	0	0	0	0	80	15	5	0
	us - rb	0	0	0	10	70	10	10	0
	ds - lb	0	0	0	0	70	10	15	5
	ds - rb	0	0	0	0	75	10	10	5
Average		0	0	0	2.5	73.7	11.2	10	2.5
52	us - lb	0	40	0	0	20	40	0	0
	us - rb	0	0	0	0	30	30	40	0
	ds - lb	0	30	0	0	40	20	10	0
	ds - rb	0	0	0	0	70	10	20	0
Average		0	17.5	0	0	40	25	17.5	0
53	us - lb	0	40	0	0	0	20	40	0
	us - rb	0	0	0	0	30	30	40	0
	ds - lb	0	0	0	0	85	10	5	0
	ds - rb	0	0	0	0	70	10	20	0
Average		0	10	0	0	47.5	17.5	26.2	0
54	us - lb	0	0	0	0	0	2	90	8
	us - rb	0	0	0	0	80	5	10	5
	ds - lb	0	0	0	0	40	0	60	0
	ds - rb	0	30	0	0	40	10	15	5
Average		0	7.5	0	0	40	4.2	43.7	4.5
55	us - lb	0	0	0	0	80	10	6	4
	us - rb	5	0	0	0	0	15	75	5
	ds - lb	40	0	0	0	50	0	5	5
	ds - rb	0	0	2	0	0	13	80	5
Average		11.2	0	0.5	0	32.5	9.5	41.5	4.7
56	us - lb	0	10	0	0	0	10	80	0
	us - rb	5	0	0	0	0	10	80	5
	ds - lb	5	15	0	0	0	25	35	20
	ds - rb	10	15	0	0	0	25	35	15
Average		5	10	0	0	0	17.5	57.5	10
62	us - lb	20	0	0	0	0	30	40	10
	us - rb	20	0	0	0	0	30	50	0
	ds - lb	10	10	0	0	0	30	25	25
	ds - rb	0	30	0	0	40	20	10	0
Average		12.5	10	0	0	10	27.5	31.2	8.75
63	us - lb	0	0	5	0	65	10	13	7
	us - rb	0	0	0	0	85	0	10	5
	ds - lb	0	0	0	0	65	10	15	10
	ds - rb	0	0	0	0	85	0	10	5
Average		0	0	1.2	0	75	5	12	6.7

Appendix Table 3. Land-use by bridge-site: *Over-Bank Land-Use* data. Locations: us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Habitat (% of Total Area)							
		Commercial	Residential	Rural	Pasture	Cultivated	Trees	Grass	Other
64	us - lb	0	0	0	0	87	3	5	5
	us - rb	0	0	0	0	95	2	3	0
	ds - lb	0	0	0	0	95	1	2	2
	ds - rb	0	0	0	0	90	3	4	3
Average		0	0	0	0	91.7	2.2	3.5	2.5
65	us - lb	0	0	0	0	85	10	5	0
	us - rb	0	0	20	25	30	15	10	0
	ds - lb	0	0	0	0	90	3	5	2
	ds - rb	0	0	0	0	90	3	5	2
Average		0	0	5	6.2	73.7	7.7	6.25	1
66	us - lb	0	0	0	0	95	1	3	1
	us - rb	0	0	0	0	95	1	3	1
	ds - lb	0	0	1	0	90	5	2	2
	ds - rb	0	0	1	0	90	5	2	2
Average		0	0	0.5	0	92.5	3	2.5	1.5
67	us - lb	0	60	0	0	0	5	30	5
	us - rb	0	0	5	0	5	75	10	5
	ds - lb	0	0	0	40	40	10	7	3
	ds - rb	0	0	40	0	0	12	40	8
Average		0	15	11.2	10	11.2	25.5	21.7	5.2
68	us - lb	0	0	0	0	0	5	5	90
	us - rb	0	15	0	0	0	5	75	5
	ds - lb	0	60	0	0	0	5	33	2
	ds - rb	0	0	0	0	50	20	25	5
Average		0	18.7	0	0	12.5	8.75	34.5	25.5
69	us - lb	0	0	0	0	90	1	7	2
	us - rb	0	0	2	0	90	4	3	1
	ds - lb	0	0	0	0	90	0	8	2
	ds - rb	0	0	10	0	75	10	5	0
Average		0	0	3	0	86.2	3.7	5.7	1.2
70	us - lb	0	0	3	0	90	3	3	1
	us - rb	0	5	3	0	80	3	6	3
	ds - lb	0	0	2	0	89	2	6	1
	ds - rb	0	0	7	0	89	1	1	2
Average		0	1.2	3.7	0	87	2.2	4	1.75
71	us - lb	60	0	0	0	0	10	10	20
	us - rb	5	60	0	0	0	10	20	5
	ds - lb	60	5	0	0	0	10	10	15
	ds - rb	40	0	0	0	0	10	20	30
Average		41.2	16.2	0	0	0	10	15	15
72	us - lb	0	0	0	0	85	10	4	1
	us - rb	0	10	10	10	10	25	30	5
	ds - lb	0	0	0	0	90	5	4	1
	ds - rb	0	20	20	0	0	10	45	5
Average		0	7.5	7.5	2.5	46.2	12.5	20.7	3
73	us - lb	0	40	0	0	0	10	35	15
	us - rb	0	8	2	0	60	15	13	2
	ds - lb	0	40	0	0	0	15	30	15
	ds - rb	0	9	1	0	70	10	7	30
Average		0	24.2	0.75	0	32.5	12.5	21.2	15.5

Appendix Table 3. Land-use by bridge-site: *Over-Bank Land-Use* data. Locations: us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Habitat (% of Total Area)							
		Commercial	Residential	Rural	Pasture	Cultivated	Trees	Grass	Other
74	us - lb	0	30	0	0	0	20	30	20
	us - rb	10	5	0	0	0	25	20	20
	ds - lb	0	10	0	0	0	30	20	40
	ds - rb	0	60	0	0	0	20	10	10
Average		2.5	25.2	0	0	0	23.7	20	22.5
75	us - lb	20	10	0	0	0	10	30	30
	us - rb	0	40	0	0	0	10	30	20
	ds - lb	20	5	0	0	0	20	40	15
	ds - rb	5	0	0	0	0	10	40	40
Average		11.2	13.7	0	0	0	12.5	35	26.2
78	us - lb	40	0	0	0	0	10	40	10
	us - rb	45	0	0	0	0	0	50	5
	ds - lb	50	0	0	0	0	1	49	10
	ds - rb	50	0	0	0	0	0	40	10
Average		46.2	0	0	0	0	2.7	44.7	8.75
79	us - lb	30	20	0	0	0	10	20	20
	us - rb	75	0	0	0	0	50	20	20
	ds - lb	80	0	0	0	0	0	10	10
	ds - rb	50	0	0	0	0	2	45	3
Average		58.7	5	0	0	0	15.5	23.7	13.2
80	us - lb	0	0	0	0	0	5	35	60
	us - rb	0	0	0	0	0	10	45	45
	ds - lb	50	0	0	0	0	0	25	25
	ds - rb	20	10	0	0	0	10	30	30
Average		17.5	2.5	0	0	0	6.2	33.7	40
81	us - lb	0	0	10	0	40	10	30	10
	us - rb	0	0	0	0	60	10	20	10
	ds - lb	0	0	5	0	80	5	5	5
	ds - rb	0	0	10	0	40	20	25	5
Average		0	0	6.25	0	55	11.2	20	7.5
82	us - lb	0	0	0	0	85	5	5	5
	us - rb	0	0	0	0	85	5	5	5
	ds - lb	20	0	0	0	40	10	10	20
	ds - rb	0	0	0	0	40	10	30	20
Average		5	0	0	0	62.5	7.5	12.5	12.5
83	us - lb	0	0	0	0	30	10	40	20
	us - rb	10	30	0	0	0	0	20	40
	ds - lb	0	75	0	0	0	5	10	10
	ds - rb	0	30	0	0	0	10	10	50
Average		2.5	33.7	0	0	7.5	6.25	20	30
84	us - lb	0	50	0	0	0	0	40	10
	us - rb	0	0	0	0	0	10	60	30
	ds - lb	0	50	0	0	0	20	20	10
	ds - rb	20	0	0	0	0	0	30	50
Average		5	25	0	0	0	7.5	37.5	25
No #	us - lb	0	0	0	0	10	20	60	10
	us - rb	0	0	65	0	0	15	15	5
	ds - lb	0	0	0	0	90	5	4	1
	ds - rb	0	0	0	0	90	5	4	1
Average		0	0	16.2	0	47.5	11.2	20.7	4.25

Appendix Table 3. Land-use by bridge-site: *Over-Bank Land-Use* data. Locations: us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Habitat (% of Total Area)							
		Commercial	Residential	Rural	Pasture	Cultivated	Trees	Grass	Other
85	us - lb	0	10	0	0	0	10	10	0
	us - rb	0	0	0	0	80	0	10	5
	ds - lb	0	0	0	0	20	10	60	10
	ds - rb	0	0	0	0	30	10	30	30
Average		0	2.5	0	0	32.5	7.5	27.5	11.2
86	us - lb	0	0	0	0	0	20	20	60
	us - rb	0	0	0	0	30	30	30	10
	ds - lb	5	10	0	0	0	30	40	15
	ds - rb	10	0	0	0	0	60	30	0
Average		3.7	2.5	0	0	7.5	35	30	21.2
87	us - lb	0	0	0	75	0	5	10	10
	us - rb	0	5	0	0	80	5	5	5
	ds - lb	90	0	0	0	0	3	2	5
	ds - rb	78	0	0	0	10	5	2	5
Average		42	1.25	0	18.7	22.5	4.5	4.7	6.2
88	us - lb	25	0	0	0	15	15	30	30
	us - rb	0	0	5	0	5	5	85	5
	ds - lb	0	0	10	0	0	10	40	40
	ds - rb	0	0	10	30	0	10	30	20
Average		6.2	0	6.2	7.5	4	10	46.2	23.7
89	us - lb	80	0	0	0	0	5	10	5
	us - rb	0	0	0	0	0	0	80	20
	ds - lb	0	0	0	0	10	15	35	40
	ds - rb	0	0	0	0	80	5	5	10
Average		20	0	0	0	22.5	5	32.5	18.7
91	us - lb	80	0	0	0	0	1	1	18
	us - rb	0	80	0	0	0	5	10	5
	ds - lb	95	0	0	0	0	0	5	0
	ds - rb	95	0	0	0	0	0	5	0
Average		67.5	20	0	0	0	1.5	5.2	5.7
92	us - lb	5	0	0	0	0	0	45	50
	us - rb	5	0	0	0	0	0	45	50
	ds - lb	0	10	0	0	0	0	45	45
	ds - rb	0	0	0	0	40	20	20	20
Average		2.5	2.5	0	0	10	5	38.7	41.2
93	us - lb	0	0	0	0	85	5	5	5
	us - rb	0	0	1	0	85	4	5	5
	ds - lb	0	0	0	0	89	1	4	6
	ds - rb	0	0	2	0	90	0	3	5
Average		0	0	0.75	0	87.2	2.5	4.2	5.2
94	us - lb	5	0	0	0	60	10	15	10
	us - rb	0	0	0	0	60	10	15	15
	ds - lb	1	0	0	0	0	2	60	37
	ds - rb	0	0	0	0	25	50	20	5
Average		1.5	0	0	0	36.2	18	27.5	16.7
95	us - lb	0	0	0	0	0	4	80	16
	us - rb	0	0	0	0	0	30	60	10
	ds - lb	0	0	0	0	0	10	60	30
	ds - rb	0	10	0	0	0	20	60	10
Average		0	2.5	0	0	0	16	65	16.5

Appendix Table 4. Bioassessment by Bridge-Site and Habitat Parameter. Where only left-bank is indicated, values are averaged for the bridge-site. Locations are defined as lb = left-bank; rb = right-bank. See Fig. 4 legend for habitat parameter definitions.

Bridge-Site Number	Location	Score by Habitat-Parameter (% of Total Area)									
		EPS	PSC	PV	SD	CFS	CA	CS	BS	VP	RVZW
1	lb	8	6	6	6	10	6	5	5	6	2
	rb	-	-	-	-	-	-	-	5	6	2
	Average	8	6	6	6	10	6	5	5	6	2
2	lb	13	12.5	8	10.5	15	10.5	5	8	9	8
	rb	-	-	-	-	-	-	-	8	9	8
	Average	13	12.5	8	10.5	15	10.5	5	8	9	8
5	lb	15	10	6	13	15	10	6	6	8	5
	rb	-	-	-	-	-	-	-	6	8	8
	Average	15	10	6	13	15	10	6	6	8	6.5
7	lb	11	9	6	8	7	12	7	6	6	4
	rb	-	-	-	-	-	-	-	6	6	4
	Average	11	9	6	8	7	12	7	6	6	4
15	lb	14	11	8	8	11	10	7	4	7	4
	rb	-	-	-	-	-	-	-	3	7	3
	Average	14	11	8	8	11	10	7	3.5	7	7
16	lb	14	11	8	8	11	10	7	4	7	4
	rb	-	-	-	-	-	-	-	3	7	3
	Average	14	11	8	8	11	10	7	3.5	7	3.5
19	lb	6	7	7	10	10	6	4	7	7	1
	rb	-	-	-	-	-	-	-	7	7	1
	Average	6	7	7	10	10	6	4	7	7	1
20	lb	7	8	7	8	9	6	5	8	6	2
	rb	-	-	-	-	-	-	-	8	6	2
	Average	7	8	7	8	9	6	5	8	6	2
21	lb	7	7	8	8	9	6	5	8	6	2
	rb	-	-	-	-	-	-	-	8	6	2
	Average	7	7	8	8	9	6	5	8	6	2
31	lb	8	6	6	6	11	5	3	4	6	2
	rb	-	-	-	-	-	-	-	4	6	1
	Average	8	6	6	6	11	5	3	4	6	1.5
41	lb	11	11	6	8	15	6	3	7	7	1
	rb	-	-	-	-	-	-	-	7	7	1
	Average	11	11	6	8	15	6	3	7	7	1
42	lb	14	1	12	13	15	6	5	6	8	1
	rb	-	-	-	-	-	-	-	6	8	1
	Average	14	1	12	13	15	6	5	6	8	1
44	lb	5	6	5	6	9	6	5	4	6	1
	rb	-	-	-	-	-	-	-	4	6	1
	Average	5	6	5	6	9	6	5	4	6	1
52	lb	10	8	6	7	13	7	7	2	7	3
	rb	-	-	-	-	-	-	-	3	6	3
	Average	10	8	6	7	13	7	7	2.5	6.5	3
53	lb	10	8	6	7	13	7	7	2	7	3
	rb	-	-	-	-	-	-	-	3	6	3
	Average	10	8	6	7	13	7	7	2.5	6.5	3
54	lb	7	8	6	8	13	7	7	3	7	1
	rb	-	-	-	-	-	-	-	3	7	1
	Average	7	8	6	8	13	7	7	3	7	1
55	lb	10	8	7	6	13	10	6	5	7	1
	rb	-	-	-	-	-	-	-	5	7	1
	Average	10	8	7	6	13	10	6	5	7	1
56	lb	8	8	6	6	13	8	6	3	8	1
	rb	-	-	-	-	-	-	-	3	8	1
	Average	8	8	6	6	13	8	6	3	8	1
62	lb	2	5	3	10	11	3	1	3	5	0
	rb	-	-	-	-	-	-	-	3	5	0
	Average	2	5	3	10	11	3	1	3	5	0
63	lb	2	5	3	1	11	3	1	3	5	0
	rb	-	-	-	-	-	-	-	3	5	0
	Average	2	5	3	1	11	3	1	3	5	0
64	lb	10	10	4	5	9	7	7	2	4	2
	rb	-	-	-	-	-	-	-	2	4	2
	Average	10	10	4	5	9	7	7	2	4	2
65	lb	2	7	2	13	17	11	6	4	8	4
	rb	-	-	-	-	-	-	-	4	8	4
	Average	2	7	2	13	17	11	6	4	8	4

Appendix Table 4. Bioassessment by Bridge-Site and Habitat Parameter. Where only left-bank is indicated, values are averaged for the bridge-site. Locations are defined as lb = left-bank; rb = right-bank. See Fig. 4 legend for habitat parameter definitions.

Bridge-Site Number	Location	Score by Habitat-Parameter (% of Total Area)									
		EPS	PSC	PV	SD	CFS	CA	CS	BS	VP	RVZW
66	lb	6	7	5	6	5	11	13	5	5	4
	rb	-	-	-	-	-	-	-	4	5	4
	Average	6	7	5	6	5	11	13	4.5	5	4
67	lb	10	14	11	10	14	13	10	7	8	6
	rb	-	-	-	-	-	-	-	7	8	6
	Average	10	14	11	10	14	13	10	7	8	6
68	lb	10	11	8	13	7	4	9	8	7	6
	rb	-	-	-	-	-	-	-	7	7	8
	Average	10	11	8	13	7	4	9	7.5	7	7
69	lb	6	6	5	8	7	12	13	8	8	2
	rb	-	-	-	-	-	-	-	-	-	-
	Average	6	6	5	8	7	12	13	8	8	2
70	lb	7	6	2	6	4	11	8	8	8	4
	rb	-	-	-	-	-	-	-	8	8	4
	Average	5	6	2	6	4	11	8	8	8	4
71	lb	5	11	9	9	9	9	8	3	3	3
	rb	-	-	-	-	-	-	-	3	3	3
	Average	5	11	9	9	9	9	8	3	3	3
72	lb	10	11	8	8	8	9	10	4	7	5
	rb	-	-	-	-	-	-	-	4	4	3
	Average	10	11	8	8	8	9	10	4	5.5	4
73	lb	11	11	10	10	10	10	10	5	6	5
	rb	-	-	-	-	-	-	-	6	6	5
	Average	11	11	10	10	10	10	10	5.5	6	5
74	lb	7	6	4	6	11	6	5	6	6	4
	rb	-	-	-	-	-	-	-	7	7	3
	Average	7	6	4	6	11	6	5	6.5	6.5	3.5
75	lb	5	5	4	8	8	10	9	4	6	4
	rb	-	-	-	-	-	-	-	4	6	4
	Average	5	5	4	8	8	10	9	4	6	4
78	lb	5	6	13	9	10	10	6	5	4	5
	rb	-	-	-	-	-	-	-	5	4	5
	Average	5	6	13	9	10	10	6	5	4	5
79	lb	7	10	10	10	8	10	8	5	6	5
	rb	-	-	-	-	-	-	-	6	6	5
	Average	7	10	10	10	8	10	8	5.5	6	5
80	lb	10	11	10	12	12	7	8	6	6	6
	rb	-	-	-	-	-	-	-	6	6	6
	Average	10	11	10	12	12	7	8	6	6	6
81	lb	8	10	15	11	13	11	11	6	8	5
	rb	-	-	-	-	-	-	-	6	8	5
	Average	8	10	15	11	13	11	11	6	8	5
82	lb	16	13	10	10	10	12	8	6	6	6
	rb	-	-	-	-	-	-	-	6	6	6
	Average	16	13	10	10	10	12	8	6	6	6
83	lb	11	11	12	11	13	10	10	5	5	5
	rb	-	-	-	-	-	-	-	5	5	5
	Average	11	11	12	11	13	10	10	5	5	5
84	lb	11	10	1	6	16	8	11	4	6	5
	rb	-	-	-	-	-	-	-	4	6	5
	Average	11	10	1	6	16	8	11	4	6	5
No#	lb	14	11	9	18	16	16	13	8	8	6
	rb	-	-	-	-	-	-	-	8	8	6
	Average	14	11	9	18	16	16	13	8	8	6
85	lb	6	16	15	16	15	11	6	2	2	2
	rb	-	-	-	-	-	-	-	2	2	2
	Average	6	16	15	16	15	11	6	2	2	2
86	lb	10	8	9	8	8	7	8	4	5	5
	rb	-	-	-	-	-	-	-	4	5	5
	Average	10	8	9	8	8	7	8	4	5	5
87	lb	15	15	11	11	12	12	10	8	8	5
	rb	-	-	-	-	-	-	-	8	8	5
	Average	15	15	11	11	12	12	10	8	8	5
88	lb	8	10	11	10	11	11	6	6	7	4
	rb	-	-	-	-	-	-	-	6	7	4
	Average	8	10	11	10	11	11	6	6	7	5

Appendix Table 4. Bioassessment by Bridge-Site and Habitat Parameter. Where only left-bank is indicated, values are averaged for the bridge-site. Locations are defined as lb = left-bank; rb = right-bank. See Fig. 4 legend for habitat parameter definitions.

Bridge-Site Number	Location	Score by Habitat-Parameter (% of Total Area)									
		EPS	PSC	PV	SD	CFS	CA	CS	BS	VP	RVZW
	Average	10	11	8	10	8	10	11	6	7	5
91	lb	3	5	3	4	8	3	3	3	4	3
	rb	-	-	-	-	-	-	-	3	4	3
	Average	3	5	3	4	8	3	3	3	4	3
92	lb	3	4	5	4	7	7	6	5	5	4
	rb	-	-	-	-	-	-	-	5	5	4
	Average	3	4	5	4	7	7	6	5	5	4
93	lb	3	5	5	5	6	6	3	5	5	3
	rb	-	-	-	-	-	-	-	5	5	3
	Average	3	5	5	5	6	6	3	5	5	3
94	lb	2	5	3	13	11	3	1	2	3	0
	rb	-	-	-	-	-	-	-	4	6	0
	Average	2	5	3	13	11	3	1	3	3	0
95	lb	2	5	3	11	11	5	1	6	3	0
	rb	-	-	-	-	-	-	-	4	6	0
	Average	2	5	3	11	11	5	1	5	4.5	0

Appendix Table 5. General information on stream and bridge-site attributes. D.S. = Discharge

Bridge-Site (ordered from upstream to downstream)	Average			
	Channel Width (m)	Water Depth (m)	Stream Velocity (m/s)	Structures
31	5.3	0.60	0.37	Culvert
41	6.9	0.76	-	D.S. Pipe
42	3.8	0.91	-	-
44	6.9	0.60	0.11	-
1	2.3	0.46	0.13	-
2	0.91	0.60	-	-
5	6.9	0.60	0.05	-
52	8.4	0.60	0.58	D.S. Pipes
64	5.3	0.38	0.46	-
53	8.4	0.76	0.43	D.S. Pipe
65	6.1	0.91	-	Erosion dike
54	6.9	0.76	0.33	Pipe
7	2.3	0.15	-	D.S. Pipes & Concrete
66	3.0	0.30	0.30	-
69	0.46	0.15	0.30	-
67	2.4	0.30	0.30	Drainage Pipe & Concrete
15	8.4	0.76	-	D.S. Pipe
55	8.4	0.60	0.64	D.S. Pipes
16	6.8	0.46	0.46	D.S. Pipes
68	3.0	0.46	0.30	Drain & Sewer Pipes
72	3.7	0.46	0.30	Drainage Pipe, Concrete/Rock
70	0.45	0.15	0.30	-
56	8.4	0.76	0.16	D.S. Pipe
73	2.1	0.60	0.30	-
19	8.3	0.46	-	-

Appendix Table 5. General information on stream and bridge-site attributes. D.S. = Discharge

Bridge-Site (ordered from upstream to downstream)	Average			
	Channel Width (m)	Water Depth (m)	Stream Velocity (m/s)	Structures
71	3.7	0.46	0.12	Concrete & Pipe
74	3.7	0.60	0.30	Drainage Pipe
20	8.3	0.76	-	-
75	3.0	0.30	1.2	-
21	6.9	0.60	5.9	D.S. Pipes
78	3.7	0.30	0.30	Drainage Pipe
79	6.1	0.30	0.30	Water pipe
62	13.7	0.60	1.7	D.S. Pipes
84	5.5	0.60	0.09	Drainage Pipes
80	4.6	0.30	0.24	-
83	1.5	0.30	-	Drainage Pipes
87	2.7	0.24	0.46	Drainage Pipe
81	1.8	0.60	-	Drainage Pipe
89	7.3	0.30	0.30	Drainage Pipes
63	4.2	0.60	-	D.S. Pipes
86	3.0	0.15	0.73	-
88	6.7	0.60	0.09	-
91	6.7	0.46	0.30	D.S. Pipe & Concrete Pipe
82	0.91	0.46	0.73	
94	13.7	0.60	-	D.S. Pipes
85	7.3	0.91	-	-
92	7.3	0.46	0.30	D.S. Pipes
93	7.3	0.46	0.30	D.S. Pipes
No. #	0.60	0.15	-	-
95	13.7	0.60	-	-
Overall Mean	5.48	0.50	0.39	-

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
1	us - lb	20	0	45	35
	us - rb	20	0	45	35
	ds - lb	20	0	45	35
	ds - rb	20	0	45	35
Average		20	0	45	35
2	us - lb	5	0	90	5
	us - rb	5	0	90	5
	ds - lb	0	0	90	10
	ds - rb	0	0	90	10
Average		2.5	0	90	7.50
5	us - lb	0	0	95	5
	us - rb	1	0	94	5
	ds - lb	0	0	95	5
	ds - rb	0	0	95	5
Average		0.25	0	94.7	5
7	us - lb	10	15	37	38
	us - rb	0	20	45	35
	ds - lb	40	0	35	25
	ds - rb	40	0	35	25
Average		22.5	8.75	38	30.7
15	us - lb	70	0	15	15
	us - rb	70	0	15	15
	ds - lb	60	0	25	15
	ds - rb	60	0	25	15
Average		65	0	20	15
16	us - lb	0	0	98	2
	us - rb	0	0	80	20
	ds - lb	0	0	99	1
	ds - rb	0	0	98	0
Average		0	0	93.7	5.75
19	us - lb	65	15	15	5
	us - rb	50	10	25	5
	ds - lb	0	0	100	0
	ds - rb	0	0	100	0
Average		28.7	6.25	60	2.5
20	us - lb	5	0	93	0
	us - rb	5	0	93	0
	ds - lb	20	3	75	0
	ds - rb	3	1	95	0
Average		8.25	1	89	0

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
21	us - lb	5	0	93	0
	us - rb	5	0	93	0
	ds - lb	0	70	30	0
	ds - rb	0	0	70	30
Average		2.5	17.5	71.5	7.5
31	us - lb	40	0	25	35
	us - rb	40	0	25	35
	ds - lb	30	0	35	35
	ds - rb	30	0	35	35
Average		35	0	30	35
41	us - lb	50	0	45	5
	us - rb	50	0	45	5
	ds - lb	50	0	45	5
	ds - rb	50	0	45	5
Average		50	0	45	5
42	us - lb	35	0	55	10
	us - rb	35	0	55	10
	ds - lb	30	0	60	10
	ds - rb	30	0	60	10
Average		32.5	0	57.5	10
44	us - lb	60	0	20	20
	us - rb	55	0	25	25
	ds - lb	60	0	30	10
	ds - rb	60	0	30	10
Average		58.7	0	26.2	16.2
52	us - lb	40	0	35	25
	us - rb	40	0	35	25
	ds - lb	50	0	20	30
	ds - rb	40	0	35	25
Average		42.5	0	31.2	26.2
53	us - lb	40	0	35	25
	us - rb	40	0	35	25
	ds - lb	50	0	30	20
	ds - rb	50	0	30	20
Average		45	0	32.5	22.5
54	us - lb	40	0	45	15
	us - rb	40	0	45	15
	ds - lb	40	0	45	15
	ds - rb	40	0	45	15
Average		40	0	45	15

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
55	us - lb	40	0	50	10
	us - rb	50	0	40	10
	ds - lb	35	0	45	20
	ds - rb	40	0	40	20
Average		41.2	0	43.7	15
56	us - lb	10	0	10	80
	us - rb	20	0	20	65
	ds - lb	40	0	50	50
	ds - rb	45	0	45	45
Average		28.7	0	31.2	60
62	us - lb	0	0	65	35
	us - rb	0	0	65	35
	ds - lb	0	0	70	70
	ds - rb	0	0	70	70
Average		0	0	67.5	52.5
63	us - lb	0	0	65	35
	us - rb	0	0	65	35
	ds - lb	0	65	35	0
	ds - rb	0	0	65	35
Average		0	16.2	57.5	26.2
64	us - lb	30	0	40	30
	us - rb	20	0	40	40
	ds - lb	2	0	13	85
	ds - rb	2	0	85	13
Average		13.2	0	44.5	42
65	us - lb	1	0	95	4
	us - rb	0	0	95	4
	ds - lb	0	0	90	10
	ds - rb	0	0	95	5
Average		0.25	0	93.7	5.75
66	us - lb	1	0	95	4
	us - rb	1	0	95	4
	ds - lb	1	0	50	49
	ds - rb	1	0	50	49
Average		1	0	72.5	26.5
67	us - lb	0	0	50	50
	us - rb	2	0	50	48
	ds - lb	0	0	90	10
	ds - rb	0	0	99	1
Average		0.5	0	72.2	27.2

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
69	us - lb	1	0	99	0
	us - rb	5	0	0	5
	ds - lb	0	0	95	5
	ds - rb	0	0	95	5
Average		1.5	0	71.7	37.5
70	us - lb	20	0	75	5
	us - rb	10	0	89	1
	ds - lb	0	0	98	2
	ds - rb	20	0	70	10
Average		12.5	0	83	4.5
71	us - lb	20	0	10	70
	us - rb	20	0	10	70
	ds - lb	30	0	10	60
	ds - rb	30	0	20	50
Average		25	0	12.5	62.5
72	us - lb	4	0	46	50
	us - rb	2	0	48	50
	ds - lb	30	0	45	25
	ds - rb	5	0	90	5
Average		10.2	0	57.2	32.5
73	us - lb	20	0	50	30
	us - rb	20	0	50	30
	ds - lb	3	0	47	50
	ds - rb	1	0	30	69
Average		11	0	44.2	44.7
74	us - lb	20	0	40	40
	us - rb	10	0	85	5
	ds - lb	20	0	50	30
	ds - rb	30	0	40	30
Average		20	0	21.5	26.2
75	us - lb	1	0	49	50
	us - rb	1	0	49	50
	ds - lb	10	0	40	50
	ds - rb	10	0	40	50
Average		5.5	0	44.5	50
78	us - lb	0	0	50	50
	us - rb	0	0	50	50
	ds - lb	20	0	20	60
	ds - rb	25	0	25	50
Average		11.2	0	23.7	77.5

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
79	us - lb	10	0	45	45
	us - rb	10	0	45	50
	ds - lb	20	0	40	40
	ds - rb	20	0	40	40
Average		15	0	42.5	43.7
80	us - lb	10	0	45	40
	us - rb	15	0	45	40
	ds - lb	15	0	50	35
	ds - rb	10	0	45	45
Average		12.5	0	46.2	40
81	us - lb	20	0	50	30
	us - rb	15	0	80	5
	ds - lb	10	0	85	5
	ds - rb	20	0	70	10
Average		16.2	0	71.2	12.5
82	us - lb	20	0	30	50
	us - rb	20	0	30	50
	ds - lb	50	0	40	55
	ds - rb	10	0	10	80
Average		25	0	27.5	58.7
83	us - lb	20	0	40	40
	us - rb	20	0	40	40
	ds - lb	20	0	20	60
	ds - rb	30	0	20	50
Average		22.5	0	30	47.5
84	us - lb	20	0	50	30
	us - rb	30	0	30	40
	ds - lb	20	0	70	10
	ds - rb	10	0	80	10
Average		20	0	57.5	22.5
No #	us - lb	0	0	50	50
	us - rb	0	0	50	50
	ds - lb	10	0	10	80
	ds - rb	10	0	10	80
Average		5	0	30	65
85	us - lb	0	0	50	50
	us - rb	0	0	50	50
	ds - lb	20	0	10	70
	ds - rb	1	0	0	98
Average		5.2	0	27.5	67

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
86	us - lb	10	0	45	45
	us - rb	10	0	45	45
	ds - lb	20	0	40	40
	ds - rb	20	0	40	40
Average		15	0	42.5	42.5
87	us - lb	20	0	40	40
	us - rb	20	0	40	40
	ds - lb	20	0	40	40
	ds - rb	20	0	40	40
Average		20	0	40	40
88	us - lb	15	0	45	40
	us - rb	15	0	45	40
	ds - lb	20	0	40	40
	ds - rb	20	0	40	40
Average		17.5	0	42.5	40
89	us - lb	20	0	40	40
	us - rb	20	0	40	40
	ds - lb	20	0	40	40
	ds - rb	10	0	50	40
Average		17.5	0	42.5	40
91	us - lb	1	0	50	49
	us - rb	1	0	49	50
	ds - lb	0	0	40	50
	ds - rb	0	0	50	50
Average		0.5	0	47.2	49.7
92	us - lb	0	0	50	50
	us - rb	0	0	50	50
	ds - lb	0	0	50	50
	ds - rb	0	0	50	50
Average		0	0	50	50
93	us - lb	0	0	50	50
	us - rb	0	0	50	50
	ds - lb	0	0	90	10
	ds - rb	0	0	90	10
Average		0	0	70	30
94	us - lb	0	0	72	30
	us - rb	0	0	65	35
	ds - lb	0	0	75	25
	ds - rb	0	0	85	15
Average		0	0	73.7	26.2

Appendix Table 6. Land-Use by bridge-site: *Bank Vegetation*. Locations are defined as us-lb = upstream left-bank; us-rb = upstream right-bank; ds-lb = downstream left-bank; ds-rb = downstream right-bank.

Bridge-Site Number	Location	Score by Bank Vegetation (% of Total Area)			
		Trees	Shrubs	Grass	Other
95	us - lb	0	0	80	20
	us - rb	0	0	80	20
	ds - lb	0	0	80	20
	ds - rb	0	0	80	20
Average		0	0	80	20

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Appendix Fig. 1. Field data sheet modified from the Field Observation Sampling Sheet of EPA's Rapid Bioassessment Protocol (Barbour *et al.* 1999).

Field Observation Sampling Sheet

Sampling Site ID: ______________________________

Sampled By: ______________________________

Date: ______________________________

Time: ______________________________

Sample Location Description:

____

____

Weather Conditions:

Temperature (°F): ____________________ **Cloud Cover (%):** ______________

Wind (circle one): Calm (0-5 mph); Light (5-15 mph); Strong (>15 mph)

Precipitation in previous 48 hours (in.): __________________

Channel:

Water width (m): _____________________ **Water depth (m):** _______________

Water velocity (m/sec): ________________

Structures (e.g. discharge pipes):

____

____

____

____

Downstream: Habitat and Biological Communities

Sampling Site ID: ______________________ **Date:** ____________________

Photo numbers and descriptions:

____

____

____

____

Bank vegetation percentages are from bank edge to water edge by 0.5 mile downstream. Overbank percentages are for the area of 1000 ft. from each stream bank by 0.5 mile downstream.

Bank Vegetation (%):

Left Bank:

Trees: ____________

Shrubs: ___________

Grass: ____________

Other: ____________

Right Bank:

Trees: ____________

Shrubs: ___________

Grass: ____________

Other: ____________

Over-Bank Land Use/Vegetation (%):

Left Bank:

Commercial: ____________

Residential: ____________

Rural: _________________

Pasture: _______________

Cultivated: _____________

Trees: _________________

Grass: _________________

Other: _________________

Right Bank:

Commercial: __________

Residential: __________

Rural: _______________

Pasture: _____________

Cultivated: ___________

Trees: _______________

Grass: _______________

Other: _______________

Upstream: Habitat and Biological Communities

Sampling Site ID: ______________________ **Date:** ____________________

Photo numbers and descriptions:

____

____

____

____

Bank vegetation percentages are from bank edge to water edge by 0.5 mile upstream. Overbank percentages are for the area of 1000 ft. from each stream bank by 0.5 mile upstream.

Bank Vegetation (%):

Left Bank:	Right Bank:
Trees: ____________	Trees: ____________
Shrubs: ___________	Shrubs: ___________
Grass: ____________	Grass: ____________
Other: ____________	Other: ____________

Over-Bank Land Use/Vegetation (%):

Left Bank:	Right Bank:
Commercial: ___________	Commercial: _________
Residential: ____________	Residential: __________
Rural: ________________	Rural: ______________
Pasture: ______________	Pasture: _____________
Cultivated: ____________	Cultivated: ___________
Trees: ________________	Trees: _______________
Grass: ________________	Grass: _______________
Other: ________________	Other: _______________

Bioassessment

Sampling Site ID: ______________ **Date:** ________________

	Condition Category			
Habitat Parameter	**Optimal**	**Suboptimal**	**Marginal**	**Poor**
Epifaunal Substrate/Available Cover	50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not newfall and not transient).	30-50% mix of stable habitat; well suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	10-30% mix of stable habitat availability less than desirable; substrate frequently disturbed or removed.	10% stable habitat, lack of habitat is obvious; substrate unstable or lacking.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Pool Substrate Characterization	Mixture of substrate materials with gravel and firm sand prevalant; root mats and submerged vegetation common.	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.	All mud or clay or sand bottom; little or no root mat; no submerged vegetation.	Hard-pan clay or bedrock; no root mat or submerged vegetation.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.	Majority of pools large-deep; very few shallow.	Shallow pools much more prevalent than deep pools.	Majority of pools small-shallow or pools absent.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Sediment Deposition	Little or no enlargement of islands or point bars and less than 20% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 80% of the bottom changing frequency; pools almost absent due to substantial sediment deposition.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mosly exposed.	Very little water in channel and mostly present as standing pools.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40-80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line.	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line.	Channel straight; waterway has been channelized for a long distance.
Score ______	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
Score (LB) ______	Left Bank 10 9	8 7 6	5 4 3	2 1 0
Score (RB) ______	Right Bank 10 9	8 7 6	5 4 3	2 1 0
Vegetative Protection (score each bank) Note: determine left or right side by facing downstream.	More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the stream bank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
Score (LB) ______	Left Bank 10 9	8 7 6	5 4 3	2 1 0
Score (RB) ______	Right Bank 10 9	8 7 6	5 4 3	2 1 0
Riparian Vegetative Zone Width (score each bank riparian zone)	Riparian zone width >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Riparian zone width 12-18 meters; human activities have impacted zone only minimally.	Riparian zone width 6-12 meters; human activities have impacted zone a great deal.	Riparian zone width <6 meters: little or no riparian vegetation due to human activities.
Score (LB) ______	Left Bank 10 9	8 7 6	5 4 3	2 1 0
Score (RB) ______	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Instructions and Terms for Field Observations:

1. **Sampling Site ID:** from same site map.

2. **Sample location description:** describe site location; e.g. south side of bridge at 60th and Dodge.

3. **Water Width:** visually estimate by walking the bridge-site perpendicular to the stream.

4. **Water Depth:** visually estimate at a representative point near bridge-site or measure with weighted line.

5. **Water Velocity:** estimate by dropping a floating object into the stream and recording the time it took to travel an estimated distance.

6. **Bank Vegetation:** identify dominant vegetation types and estimate percent cover.

7. **Over-bank land use/vegetation:** identify dominant land use types, and estimate percentages within 1000 feet of the bank.

8. **Structures:** note any structures in stream such as pipes and culverts.