WESTERN GREAT PLAINS RIPARIAN WOODLAND AND SHRUBLAND ECOLOGICAL SYSTEM

ECOLOGICAL INTEGRITY ASSESSMENT

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Prepared by: Karin Decker

Colorado Natural Heritage Program
Colorado State University
254 General Services Building
Fort Collins, CO 80523

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A. INTRODUCTION

A.1 Classification Summary

CES303.956 Western Great Plains Riparian Woodland and Shrubland

Classifiers:

Landcover class:	Mixed Upland and Wetland
Spatial Scale & Pattern:	Linear
Classification Confidence:	Strong
Required Classifiers:	Natural/Seminatural, Vegetated (> 10% vascular cover), Upland
Diagnostic Classifiers:	Woody-Herbaceous Riverine / Alluvial Very Short Disturbance Interval Flood Scouring Riparian Mosaic
Non-Diagnostic Classifiers:	Lowland Lowland Forest and Woodland (Treed) Shrubland (Shrub-dominated) Alluvial fan Arroyo Floodplain Fluvial Toeslope/Valley Bottom Temperate Temperate Xeric Broad-Leaved Deciduous Tree Broad-Leaved Deciduous Shrub Evergreen Sclerophyllous Shrub Graminoid Intermittent Flooding Short (<5 yrs) Flooding Interval

U.S. Distribution: CO, MT, NM, TXpotentially occurs, WY
Global Range: Riparian areas of medium and small rivers and streams throughout the Western Great Plains. It is likely most common in the Central Shortgrass Prairie and Northern Great Plains Steppe, but extends west into the Wyoming Basins.
Primary Biogeographic Division: 303 – Western Great Plains
TNC Ecoregions:

10	Wyoming Basins	Predicted or probable
26	Northern Great Plains Steppe	Confident or certain
27	Central Shortgrass Prairie	Confident or certain

28 Southern Shortgrass Prairie Predicted or probable

Concept summary: This system is found in the riparian areas of medium and small rivers and streams throughout the Western Great Plains. It is likely most common in the Shortgrass Prairie and Northern Great Plains Steppe but extends west and as far as the Rio Grande in New Mexico and into the Wyoming Basins in the north. It is found on alluvial soils in highly variable landscape settings, from deep cut ravines to wide, braided streambeds. Hydrologically, these sites tended to be more flashy with less developed floodplain than on larger rivers, and may dry down completely for some portion of the year.

Dominant vegetation shares much with generally drier portions of larger floodplain systems downstream, but overall abundance of vegetation is generally lower. Communities within this system range from riparian forests and shrublands to gravel/sand flats. Dominant species include *Populus deltoides, Salix* spp., *Artemisia cana* ssp. *cana*, *Pascopyrum smithii, Panicum virgatum, Panicum obutsum, Sporobolus cryptandrus*, and *Schizachyrium scoparium.* These areas are often subjected to heavy grazing and/or agriculture and can be heavily degraded. *Tamarix* spp., *Elaeagnus angustifolia*, and less desirable grasses and forbs can invade degraded examples up through central Colorado. Groundwater depletion and lack of fire have resulted in additional species changes.

Component Associations

ALLIANCE/Association name	Element code	G rank
ARTEMISIA CANA TEMPORARILY FLOODED SHRUBLAND ALLIANCE (A.843)		
Artemisia cana / Pascopyrum smithii Shrubland	CEGL001072	G4
ANDROPOGON GERARDII - (SORGHASTRUM NUTANS) HERBACEOUS ALLIANCE		
Andropogon gerardii - Sorghastrum nutans Western Great Plains Herbaceous Vegetation	CEGL001464	G2
CAREX NEBRASCENSIS SEASONALLY FLOODED HERBACEOUS ALLIANCE (A.1417)		
Carex nebrascensis Herbaceous Vegetation	CEGL001813	G4
CAREX PELLITA SEASONALLY FLOODED HERBACEOUS ALLIANCE (A.1414)		
Carex pellita Herbaceous Vegetation	CEGL001809	G3
COBBLE/GRAVEL SHORE SPARSELY VEGETATED ALLIANCE (A.1850)		
Riverine Gravel Flats Great Plains Sparse Vegetation	CEGL005223	GNR
ELAEAGNUS ANGUSTIFOLIA SEMI-NATURAL WOODLAND ALLIANCE (A.3566)		
Elaeagnus angustifolia Semi-natural Woodland	CEGL005269	GNA
ELEOCHARIS PALUSTRIS SEASONALLY FLOODED HERBACEOUS ALLIANCE		
Eleocharis palustris Herbaceous Vegetation	CEGL001833	G5
MUHLENBERGIA ASPERIFOLIA INTERMITTENTLY FLOODED HERBACEOUS ALLIANCE (A.1334)		
Muhlenbergia asperifolia Herbaceous Vegetation	CEGL001779	GU
POPULUS DELTOIDES TEMPORARILY FLOODED FOREST ALLIANCE (A.290)		
Populus deltoides / Muhlenbergia asperifolia Forest	CEGL000678	G3
POPULUS DELTOIDES TEMPORARILY FLOODED WOODLAND ALLIANCE (A.636)		
Populus deltoides - (Salix amygdaloides) / Salix (exigua, interior) Woodland	CEGL000659	G3G4
Populus deltoides - (Salix nigra) / Spartina pectinata - Carex spp. Woodland	CEGL002017	G1
Populus deltoides (ssp. wislizeni, ssp. monilifera) / Salix exigua Woodland	CEGL002685	G3
Populus deltoides / Carex pellita Woodland	CEGL002649	G2
Populus deltoides / Panicum virgatum - Schizachyrium scoparium Woodland	CEGL001454	G2
Populus deltoides (ssp. wislizeni, ssp. monilifera) / Sporobolus airoides Woodland	CEGL005977	G3
Populus deltoides / Symphoricarpos occidentalis Woodland	CEGL000660	G2G3
Populus deltoides / Sporobolus airoides Woodland	CCNHPXXX16	G2Q
Populus deltoides / Sporobolus cryptandrus Woodland	CCNHPXXX18	G1G2Q

Populus deltoides / Pascopyrum smithii – Panicum obtusum Woodland	CCNHPXXX19	G1G2Q
PRUNUS VIRGINIANA SHRUBLAND ALLIANCE (A.919)		
Prunus virginiana - (Prunus americana) Shrubland	CEGL001108	G4Q
SALIX (EXIGUA, INTERIOR) TEMPORARILY FLOODED SHRUBLAND ALLIANCE (A.947)		
Salix exigua / Mesic Graminoids Shrubland	CEGL001203	G5
Salix exigua / Barren Shrubland	CEGL001200	G5
SCHOENOPLECTUS ACUTUS - (SCHOENOPLECTUS TABERNAEMONTANI) SEMIPERMANENTLY FLOODED HERBACEOUS ALLIANCE (A.1443)		
Scirpus acutus - Scirpus tabernaemontani Herbaceous Vegetation		
SCHOENOPLECTUS PUNGENS SEMIPERMANENTLY FLOODED HERBACEOUS ALLIANCE (A.1433)		
Schoenoplectus pungens Herbaceous Vegetation	CEGL001587	G3G4
SPARTINA PECTINATA TEMPORARILY FLOODED HERBACEOUS ALLIANCE (A.1347)		
Spartina pectinata Western Herbaceous Vegetation	CEGL001476	G3?
SPOROBOLUS AIROIDES HERBACEOUS ALLIANCE (A.1267)		
Sporobolus airoides Southern Plains Herbaceous Vegetation	CEGL001685	G3Q
SYMPHORICARPOS OCCIDENTALIS TEMPORARILY FLOODED SHRUBLAND ALLIANCE (A.961)		
Symphoricarpos occidentalis Shrubland	CEGL001131	G4G5
TYPHA (ANGUSTIFOLIA, LATIFOLIA) - (SCHOENOPLECTUS SPP.) SEMIPERMANENTLY FLOODED HERBACEOUS ALLIANCE (A.1436)		
Typha (latifolia, angustifolia) Western Herbaceous Vegetation	CEGL002010	G5

A.2 Ecological System Description

A.2.1 Environment

The Western Great Plains landscape is characterized by relatively low topographic relief. Landscape features range from the tablelands and high hills of the northern high plains, to the sandhills, low hills, and plains of the central high plains, and the flat to irregular plains of the southern high plains (Covich et al. 1997). Due to low rainfall, high evaporation, frequent natural fires, and grazing by migratory bison herds, the terrestrial vegetation throughout the region has historically been dominated by grasslands which are dissected by many streams of small to moderate size as well as large rivers fed by snowmelt runoff from the Rocky Mountains (Covich 1997).

Streams of the western Great Plains include both major rivers and perennial to intermittent or ephemeral streams that flow only during part of the year (Matthews 1988). The floodplain communities of the larger perennial rivers such as the Platte and Arkansas, which receive significant snowmelt runoff from the adjacent Rocky Mountains, are included in the Western Great Plains Floodplain ecological system. The vast majority of streams included in the Western Great Plains Riparian and Woodland ecological system have their headwaters on the plains, and are driven primarily by local precipitation and groundwater inflow. While most prairie streams follow this pattern, at the western edge of the Great Plains, the lower reaches of streams that originate in the mountains may extend for some distance out onto the plains, where they share characteristics with the prairie streams. In most years, the peak flow for these streams is associated with the spring runoff, but in some years flash flooding from thunderstorms provides the highest flow (Friedman et al. 1996). These piedmont tributary streams are transitional between the Rocky Mountain Lower Montane-Foothill Riparian Woodland

and Shrubland system, and the Western Great Plains Riparian woodland and shrubland system.

Streamflows are highly variable in Western Great Plains streams. It is not known how much flows have changed since settlement, but a certain amount of intra- and inter-annual variation appears to be normal (Matthews 1988). Nearly all prairie steams are susceptible to lack of water during some years if not annually. Although most streams receive groundwater inflow, recharge to groundwater is low due to limited precipitation, and water loss to evapotranspiration can be significant. The minimal to moderate groundwater inflow and the large loss of both groundwater and surface water to evapotranspiration resulted in many high plains streams having little to no flow under pre-settlement, natural conditions, except during spring floods (Covich et al. 1997). Since settlement, trees are no longer suppressed by fires, variation in water flow is regulated by dams and diversions, agricultural activities have increased siltation rates and introduced both non-native species and chemical changes, and native grazers have been largely replaced by domestic cattle.

Climate

The western Great Plains has a continental climate with both east-west and north-south gradients. Over the central plains, precipitation decreases from east to west, while temperatures and day-lengths increase from north to south. Mean summer rainfall decreases very sharply westward from the 100th meridian, especially in the summer months (Borchert 1950). Mean annual precipitation decreases from 40-60 in. east of the Mississippi River to about 10 in. in the western part of the central shortgrass Prairie, with an abrupt increase to around 18-23 inches in the narrow strip just east of the Rocky Mountains (Hansen et al. 1978). Although the number of wet days is essentially the same from west to east at a given latitude, the amount of precipitation from any single storm event is generally higher toward the east (Borchert 1950).

Precipitation on the Western Great Plains generally originates from the Gulf of Mexico. In spring and summer months, warm moist air from the Gulf extends further north, while in fall and winter, cold Arctic air from the polar region dominates. When these contrasting air masses meet, severe weather and precipitation often result. Conditions can change rapidly as air masses shift . Along the western edge of the plains, the Rocky Mountains create a rain shadow and a zone of increasing precipitation in the foothill and piedmont areas. Flooding is typically due to local, intense spring or summer thunderstorms that can deliver the equivalent of an average year's precipitation during a few hours (Friedman and Lee 2002). Periodic severe drought is also a common phenomenon in the Western Great Plains (Borchert 1950, Stockton and Meko 1983, Covitch et al. 1997).

Geology

Thick deposits of sedimentary bedrock contain the Great Plains aquifer system that underlies most of Nebraska, about one-half of Kansas, the eastern one-third of Colorado, and small parts of New Mexico, Oklahoma, Texas, South Dakota, and Wyoming (USGS 1997). The sedimentary bedrock of the plains is covered by alluvial deposits of varying thickness. Differences in substrate affect the turbidity of a stream.

Hydrology

Streams of the Western Great Plains generally exhibit seasonality of flow, and most are water-limited for at least part of the year. There is considerable variation in flow patterns between areas in the north and west where flows are more tied to snowmelt and depth of montane snowpack, and areas to the south and east that are dominated by local rainfall (Matthews 1988). The wet-dry cycle of central and southern prairie streams is driven by heavy rains in the spring and early summer, and rapid evapotranspiration after midsummer that causes desiccation. Deficits of precipitation relative to evaporation range from about 10-60 inches and are greater in the south (Covich et al. 1997). Late summer rains are often absorbed by dry prairie soils before reaching a stream bed (Matthews 1988). Most plains streams are dominated by local rainfall events that typically produce low-volume, short-duration flows. Rare storm events can produce peak instantaneous discharges in these streams that approach the highest discharges ever recorded on the major rivers (Friedman and Lee 2002). Even ephemeral streams provide an important hydrological function as focal points for groundwater recharge (Covich et al. 1997).

A.2.2 Vegetation & Ecosystem

Western Great Plains Riparian Woodland and Shrubland occurrences may include riparian forests or woodlands, as well as shrublands, tallgrass or mixedgrass wet meadows, herbaceous wetlands, and gravel/sand flats. Vegetation may be a mosaic of communities that are not always tree or shrub dominated. Stream-side vegetation in this region is primarily deciduous, even in the foothills of the Rocky Mountains (Brown and Matthews 1995).

Riparian forest and woodland communities of this system are often dominated by plains cottonwood (*Populus deltoides* ssp. *monilifera*), but may include the hybrid *Populus* x *acuminata* and *Salix amygdaloides.* Other deciduous trees such as *Acer negundo, Fraxinus pennsylvanica* and may contribute to the canopy. The non-native species *Salix fragilis, Tamarix* spp., and *Elaeagnus angustifolia* are increasingly present in these communities. Willow species may form a conspicuous layer with cottonwood saplings near the stream channel, or may form the overstory layer. The understory composition and structure are variable. A shrub layer may be present, with species such as *Salix* spp., *Symphoricarpos occidentalis, Artemisia cana, Ericameria nauseosa, Prunus virginiana,* and *Celtis reticulata* predominating.

The herbaceous stratum is variable. Subirrigated area may support tallgrass meadows dominated by *Andropogon gerardii*, *Sorghastrum nutans,* or *Spartina pectinata*. Other graminoids include *Carex emoryi, Carex pellita (= Carex lanuginosa), Schizachyrium scoparium, Pascopyrum smithii, Hesperostipa spartea, Sporobolus heterolepis*, *Panicum virgatum,* and *Sporobolus cryptandrus. Toxicodendron rydbergii, Equisetum arvense* and *Glycyrrhiza lepidota* are common understory forbs. These sites are prone to invasion by exotic grasses and forbs, the most widely established being *Agrostis stolonifera, Bromus tectorum, Cirsium arvense, Bassia scoparia (= Kochia scoparia), Melilotus* spp., *Taraxacum officinale, and Tragopogon dubius*. Plant associations of the North American

Arid West Emergent Marsh ecological system may occurr along or adjacent to portions of this system.

Biogeochemistry

Although riparian zones are a relatively minor component of the Western Great Plains landscape, they are extremely important as linkages between terrestrial and aquatic ecosystems. The natural channeling effect of landscape drainage brings water, air masses, dissolved and particulate matter, and living organisms together in these areas, where they can be filtered, regulated, and modified by the riparian system (Gregory et al. 1991). Riparian zones mediate the transfer of nutrients from adjacent upland systems to the aquatic system. These areas support enhanced levels of microbial activity due to high soil moisture levels and a relative abundance of organic matter. Nutrients in soil solution may be greatly reduced by riparian vegetation before passing into the aquatic system. The structure and abundance of riparian vegetation also affects the retention of nutrients in the aquatic system.

Productivity

Variation in ecosystem productivity is related primarily to light, temperature, and rainfall. Although plains riparian areas share the same levels of solar incidence, precipitation, and seasonal temperature patterns as adjacent upland areas, water availability is generally higher in the riparian zone, allowing primary productivity to be higher as well. In addition, natural drainage patterns tend to bring additional nutrient input to these areas. Brown and Matthews (1995) report that where gallery forests exist, annual litter fall is comparable to that of the eastern U.S. deciduous forests. Litter contributions are considerably less where arid conditions limit the growth of flood-plain forests. Even so, litter fall in these woodlands is substantially greater than in adjacent grasslands, even tallgrass. Streamside vegetation can limit productivity in the aquatic system by shading, but limitation from drying and nutrient availability is also likely in unshaded aquatic systems (Brown and Matthews 1995).

Animals

Riparian woodlands can be important vertebrate habitat in an otherwise treeless landscape, although many riparian species are forest-edge generalists that have expanded into the plains since settlement (Friedman et al. 1997). Native amphibians and reptiles (e.g., leopard frogs, spadefoot toads), and native prairie fishes are indicators of a healthy riparian shrubland and woodland system. Although not restricted to the riparian, the threatened Preble's Meadow Jumping Mouse (*Zapus hudsonius preblei*) is often found in these habitats in the Colorado Front Range.

A.2.3 Dynamics

Fluvial processes play a key role in the dynamics of Western Great Plains streams. The nature of these processes is often indicated by channel morphology. Meandering channels generally have a shallow gradient, low flow variability, and sediment loads dominated by silt and finer particles, while braided channels are characterized by a steep gradient, high flow variability, and a sediment load dominated by sand and coarser particles (Osterkamp 1978).

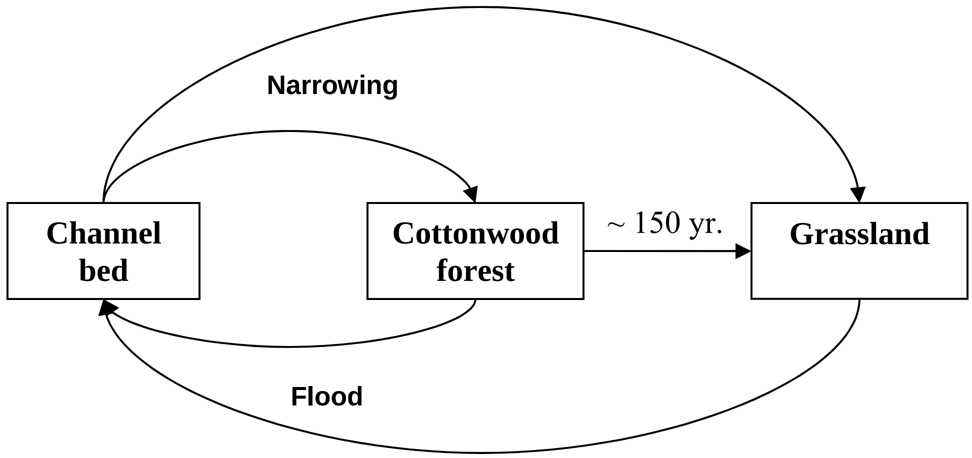
Friedman et al (1996) and Scott et al. (1996) discuss three fluvial process that are important for Great Plains streams—channel narrowing, meandering, and flood deposition (Table 1). Various combinations of these three factors may be acting at any particular site, depending on geologic and climate factors, including flow variability, sediment load, and gradient. Channel narrowing results when the stream abandons a portion of the former channel bed or when flow ceases in a channel. Narrowing happens when a period low flow prevents the reworking of the entire channel bed, and allows vegetation to establish. Newly established vegetation reduces erosion and promotes the deposition of fine sediment. On meandering streams, cutbanks on the outside bends gradually erode and the sediments are deposited downstream as point bars on the insides of bends. Vegetation is able to establish on these newly created moist surfaces. Flood deposition can produce bare, moist surfaces for tree establishment that are above the normal channel bed, and protected from normal flow-related disturbance.

Table 1. Characteriztics of fluvial processes for Great Plains Streams

Geomorphic process	**Flow**	**Landform**	**Cottonwood community patterns**
Channel narrowing	One to several years of flow below level which is necessary to rework channel bed	Channel bed	• Spatial patterns variable but often with long axis parallel to direction of flow • Usually not even-aged stands • Establishment surface at relatively low elevation of former channel bed
Meandering	Frequent moderate flows	Point bars	• Moderate number of even-aged stands, arranged in narrow arcuate bands • Strong left-bank, right-bank asymmetry in distribution corresponding to meander pattern • Establishment surface of mature trees often well below current ground surface and near channel bed elevation
Flood deposition	Infrequent high flows	Flood deposits	• Linear stands • Small number of even-aged stands • Establishment coincident with floods • Establishment surface of mature trees near current ground surface and well above channel bed elevation

(adapted from Scott et al. 1996)

Friedman et al. (1997) present a transition model where prairie bottomlands cycle between riparian forest and flowing channel bed. Flooding removes some established forest, but also permits establishment of new trees. Cottonwood reproduction is primarily in the former channel bed during the narrowing period between major floods. In the absence of fluvial disturbance, a lack of reproduction within mature stands of cottonwood should result in succession to grassland after about 150-200 years. Long-term heavy grazing by domestic livestock could slow the rate of channel narrowing by reducing vegetation density (Friedman and Lee 2002).



Adapted from Friedman et al. (1997)

Additional factors affecting the dynamics of this system include drought, grazing, and fire. Riparian vegetation is affected by climatic drought that reduces soil moisture in the unsaturated zone and decreases streamflows, which reduces recharge and lowers the alluvial water table (Friedman et al. 1997). The elimination of beavers from most of the plains watersheds probably decreased water storage and increased variability in plains streams, although some of these changes were later reversed by dam construction (Friedman et al. 1997). The replacement of native grazers, especially bison, with fenced cattle has changed the regeneration patterns of cottonwood, as has the reduction in fire frequency since settlement.

A.2.4 Landscape

Riparian communities are often similar to small patch communities, but usually occur as linear strips that include a mosaic of different landforms, plant communities, and environments (Gregory et al. 1991). Similar to small patch communities, linear communities occur in very specific conditions, and the aggregate of all linear communities covers, or historically covered, only a small percentage of the natural vegetation of the ecoregion. These communities also tend to support a specific and restricted set of associated flora and fauna. Linear communities differ from small patch communities in that both local-scale processes and large-scale processes, such as riverine flow regimes, strongly influence community structure and function (Anderson et al. 1999).

The relationship of riparian systems to both upland areas and downstream systems underscores the importance of connectivity in evaluating landscape context. In addition, the diversity, abundance, and spatial distribution of riparian patch types affect the flow and movement of water and nutrients as well as seed dispersal and animal movement (Wiens 2002).

Riparian systems link terrestrial and aquatic ecosystems, acting as ecotones between upland and wetland abiotic factors, ecological processes, and plant communities (Gregory et al. 1991). The quality and quantity of ground and surface water input into riparian areas is almost entirely determined by the condition of the surrounding landscape, hence their integrity is partly determined by processes operating in the surrounding landscape, especially in the local watershed. Different types of land use can alter surface runoff and recharge of local aquifers, and introduce excess nutrients, pollutants, or sediments.

A.2.5 Size

Western Great Plains riparian woodlands and shrublands are usually composed of a mosaic of different plant associations, often including small patches of herbaceous vegetation. The size of an occurrence will naturally depend on the topography, soils, and hydrological processes of the area. Many prairie streams are short and intermittently wet, and would not naturally form extensive riparian corridors. Other, larger streams would naturally encompass a range of variation in hydrology, soil texture, and geomorphology. Larger occurrences are more likely contain sufficient internal variability to capture characteristic biophysical gradients and retain natural geomorphic and hydrologic disturbance. They are buffered from edge effects and small hydrology alterations.

Very large examples of many of these communities are probably naturally rare in the Central Shortgrass Prairie ecoregion. Furthermore, occurrence size criteria may not be as critical for linear communities as it is for matrix-forming communities (Anderson et al. 1999). Because of the high edge to area ratio of linear systems, landscape context is of particular importance. If a riparian area has not been reduced in size by human impacts or is surrounded by natural landscape that has not been affected by human disturbances, then size is less important to the assessment of ecological integrity. If, however, human disturbances have decreased the size of the riparian corridor, or if the surrounding landscape is impacted and has the potential to affect the site, bigger occurrences are able to buffer against these impacts better than smaller sized occurrences due to the fact they generally possess a higher diversity of abiotic and biotic processes allowing them to recover and remain more resilient. Under such circumstances, size may be more important in assessing ecological integrity.

A.3 Ecological Integrity

A.3.1 Threats

Hydrological Alteration

Western Great Plains riparian systems have been substantially impacted by the development of both groundwater and surface water for irrigation. Alteration of natural hydrological processes by dams, diversions, ditches, roads, etc., and abiotic resource consumption through groundwater pumping have considerably altered the presettlement condition of the Western Great Plains. The vast majority of hydrological alteration in the Great Plains is due to agricultural needs, except in highly developed areas along the mountain front where other uses are overtaking agricultural use. Heavy use of the Ogallala-High Plains aquifer has lowered the water table such that many formerly flowing streams are now dry for much of the year (Dodds 1997). Watersheds that are not influenced by agricultural irrigation or urbanization are often maintained for cattle grazing, which can also result in hydrologic changes (Dodds 1997).

Dams, reservoirs, diversions, ditches and other human land uses alter the natural flow regime of a stream, and can disrupt the ecological integrity of the riparian system. Physical changes resulting from altered flow regimes include downstream erosion and channelization, reduced change in channel morphology, reduced base and/or peak flows, lower water tables in floodplains, and reduced sediment deposition in the floodplain (Poff et al. 1997).

An unaltered hydrologic regime is crucial to maintaining the diversity and viability of the riparian area. Vegetation responds hydrologic changes by shifting from wetland and riparian dependent species to more mesic and xeric species typical of adjacent uplands and/or encroaching into the stream channel. When periodic flooding is eliminated by water management, riparian areas may become dominated by late-seral communities due to the inability of pioneer species (e.g., cottonwood and willow) to regenerate. Flood control many also decrease the abundance and spatial distribution of various patch types, and greatly reduce the spatial complexity of riparian and wetland habitat. Activities that lower the water table, such as groundwater pumping or gravel mining, can cause mortality in riparian forest (Friedman et al 1997, Frieman and Lee 2002).

Climate change

The streams of the Western Great Plains are highly dynamic and responsive to extreme climatic fluctuations (Covich et al. 1997). Although naturally subjected to episodes of drought and flooding, these streams could also be affected by long-term climate change. The difficulty of distinguishing climatic effects from the multitude of changes induced by the hydrologic alterations discussed above makes it difficult to make robust predictions about the potential effects of climate change on this system. Rapid changes of the spatial and temporal distributions of rainfall and temperature have been documented during the Holocene. Past changes altered the distribution of aquatic plants and animals, water levels and salinities (Covich et al. 1997), and it is likely that similar effects would be seen under the predicted scenario of increased warming and decreased precipitation. Native prairie fishes, in particular, which are already living in some of the warmest free-flowing waters known, may be vulnerable to extinction under predicted warming scenarios (Matthews and Zimmerman 1990).

Habitat conversion and fragmentation

Land use within the riparian area as well as in adjacent and upland areas can fragment the landscape and reduce connectivity between riparian patches and between riparian and upland areas. This fragmentation can adversely affect the movement of surface/ groundwater, nutrients, and dispersal of plants and animals. Roads, bridges, and development can also fragment both riparian and upland areas. Intensive grazing and recreation can also create barriers to ecological processes. Many prairie streams are further endangered because remaining prairie fragments are not large enough to include a significant, functional watershed (Dodds et al. 2004).

Nutrient enrichment

Pollution from agricultural runoff can introduce excess nutrients into riparian areas. Increased nutrients can alter species composition by allowing aggressive, invasive species to displace native species. Nutrient cycles may also be disrupted by water management that eliminates normal flooding cycles and prevents deposition of organic material from floodwaters.

Invasive species

Non-native plants or animals can have wide-ranging impacts. Non-native plants can increase dramatically under the right conditions and essentially dominate a previously natural area. This can lead to detrimental effects on animals (particularly invertebrates) that depend on native plant species for forage, cover, or propagation. Tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*) are two aggressive non-native shrubs which can drastically alter ecological processes in these plains riparian areas. Common and widely established non-native forb species in Western Great Plains riparian zones include *Agrostis stolonifera, Bromus tectorum, Cirsium arvense, Bassia scoparia (= Kochia scoparia), Melilotus* spp., *Taraxacum officinale, and Tragopogon dubius*.

A.3.2 Justification of Metrics

Landscape Context: Land use within the contributing watershed and riparian corridor has important effects on the connectivity and sustainability of many ecological processes critical to this system.

Biotic condition: Species composition and diversity, presence of conservative plants, regeneration, and invasion of exotics are important measures of biological integrity.

Abiotic Condition: Hydrological integrity is the most important variable to measure, however land use within the wetland can have detrimental impacts on other important abiotic processes such as nutrient cycling, bank stability, and floodplain interaction.

Size: Absolute size is important for consideration of conservation values as well as ecosystem resilience. Absolute size relative to potential size provides information regarding historical loss or degradation of occurrence size.

A.3.3 Ecological Integrity Metrics

A synopsis of the ecological metrics and ratings is presented in Table 1. The three tiers refer to levels of intensity of sampling required to document a metric. Tier 1 metrics are able to be assessed using remote sensing imagery, such as satellite or aerial photos. Tier 2 typically require some kind of ground sampling, but may require only qualitative or semi-quantitative data. Tier 3 metrics typically require a more intensive plot sampling or other intensive sampling approach. A given measure could be assessed at multiple tiers, although some measures can not be assessed at Tier 1 (i.e., they require a ground visit). The focus for this System is primarily on a Tier 2 approach.

Core and Supplementary Metrics

The Scorecard (see Tables 1 & 2) contains two types of metrics: Core and Supplementary. Separating the metrics into these two categories allows the user to adjust the Scorecard to available resources, such as time and funding, as well as providing a mechanism to tailor the Scorecard to specific information needs of the user.

Core metrics are shaded gray in Tables 2 & 3 and represent the minimal metrics that should be applied to assess ecological integrity. Sometimes, a Tier 3 Core metric might be used to replace Tier 2 Core Metrics. For example, if a Vegetation Index of Biotic Integrity is used, then it would not be necessary to use similar Tier 2 Core metrics such as Percentage of Native Graminoids, Percentage of Native Plants, etc.

Supplementary metrics are those which should be applied if available resources allow a more in depth assessment or if these metrics add desired information to the assessment. Supplementary metrics are those which are not shaded in Tables 2 & 3

Table 2. Overall Set of Metrics for the Western Great Plains Riparian Woodland and Shrubland system.

Tier: 1 = Remote Sensing, 2 = Rapid, 3 =Intensive. Shading indicates core metrics.

Category	Essential Ecological Attribute	Indicators / Metrics	Tier
LANDSCAPE CONTEXT	Landscape Composition	Adjacent land use	1
		Buffer width	1
		Percentage of unfragmented landscape within 1km	1
		Riparian corridor continuity	1, 2
BIOTIC CONDITION	Community Composition	Percent cover of native plant species	2
		Floristic quality index	3
		Saplings/seedlings of native woody species	2, 3
		Presence and abundance of invasive exotic spp.	2, 3
	Patch Diversity	Patch structure - variety	2
		Patch structure - interspersion	2
ABIOTIC CONDITION	Energy/Material Flow	Land use within the riparian area	2
		Sediment loading index	1
	Hydrological Regime	Upstream surface water retention	1
		Upstream/onsite water diversions	1
		Floodplain interaction	2
		Surface water runoff index	1
		Index of Hydrological Alteration NOTE: this metric should be used in lieu of B.3.3, B.3.4, B.3.5 and B.3.6 when data are available.	3
		Bank stability	2
	Chemical/physical processes	Litter cover	2
		Nutrient/pollutant Loading Index	1
		Nitrogen Enrichment (C:N)	3
		Phosphorous Enrichment (C:P)	3
		Soil Organic Matter Decomposition	2
		Soil Organic Carbon	3
		Soil Bulk Density	3
SIZE	Absolute size	Absolute size	1
	Relative size	Relative size	1

Table 3. Metrics and Rating Criteria for the Western Great Plains Riparian Woodland and Shrubland System.

Tier: 1 = Remote Sensing, 2 = Rapid, 3 =Intensive. (Alpha-numeric codes in parentheses is reference to the metric ID and corresponds to the section in which the metric is described). Confidence column indicates that reasonable logic and/or data support the index. Shading indicates core metrics.

Category	**Essential Ecological Attributes**	**Indicators/ Metics**	**Tier**	**Metric Ranking Criteria**			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
LANDSCAPE CONTEXT	Landscape Compostion	Adjacent land use (B.1.1)	1	Average land use score = 1.0 – 0.95	Average land use score = 0.80 – 0.95	Average land use score = 0.40 – 0.80	Average land use score = <0.40
		Buffer width (B.1.2)	1	Wide > 100m	Medium 50 – 100m	Narrow 25 – 50m	Very narrow < 25m
	Landscape Pattern	Percentage of unfragmented landscape within 1 km. (B.1.3)	1	Embedded in 90-100% unfragmented, roadless natural landscape; internal landscape; internal fragmentation absent	Embedded in 60-90% unfragmented natural landscape; internal fragmentation minimal	Embedded in 20-60%% unfragmented natural landscape; Internal fragmentation moderate	Embedded in < 20% unfragmented natural landscape. Internal fragmentation high
		Riparian corridor continuity (B.1.4)	1	< 5% of riparian reach with gaps / breaks due to cultural alteration	> 5 - 20% of riparian reach with gaps / breaks due to cultural alteration	>20 - 50% of riparian reach with gaps / breaks due to cultural alteration	> 50% of riparian reach with gaps / breaks due to cultural alteration
BIOTIC CONDITION	Community composition	Percent cover of native plant species (B.2.1)	2	100% cover of native plant specis	85-100%	50-85%	<50%
		Floristic quality index (Mean C) (B.2.2)	3	>4.5	3.5-4.5	3.0-3.5	<3.0
		Presence and abundance of invasive species (B.2.3)	2	System altering invasive species (e.g., *Tamarix ramosissima, Elaeagnus angustifolia*) are either not present or occupy less than 1 percent of the	System altering invasive species (e.g., *Tamarix ramosissima, Elaeagnus angustifolia*) occupy less than 5 percent of the occurrence	Exotic invasives (e.g., *Tamarix ramosissima, Elaeagnus angustifolia*) may be widespread but potentially manageable with restoration of most	Invasive exotic species, such as *Tamarix* spp., or *Elaeagnus angustifolia* may be dominant over significant portions of area, with little

Category	Essential Ecological Attributes	Indicators/ Metics	Tier	Metric Ranking Criteria			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
				occurrence		natural processes.	potential for control.
		Saplings/seedlings of native woody species (B.2.4)	2	Saplings/seedlings of native woody species (cottonwood/willow) present in expected amount; Obvious regeneration.	Saplings/seedlings of native woody species (cottonwood/willow) present but less than expected; Some seedling/saplings present.	Saplings/seedlings of native woody species (cottonwood/willow) present but in low abundance; Little regeneration by native species.	No reproduciton of native woody species
	Community Extent	Patch structure – variety (B.2.5)	2	> 75-100% of possible patch types are present in the occurrence	> 50-75% of possible patch types are present in the occurrence	25-50% of possible patch types are present in the occurrence	< 25% of possible patch types are present in the occurrence
		Patch structure – interspersion (B.2.6)	2	Horizontal structure consists of a very complex array of nested and/or interspersed, irregular biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a moderately complex array of nested or interspersed biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a simple array of nested or interspersed biotic/abiotic patches.	Horizontal structure consists of one dominant patch type and thus has relatively no interspersion
ABIOTIC CONDITION	Energy/ Material Flow	Land use within the riparian area (B.3.1)		Average land use score = 1.0 – 0.95	Average land use score = 0.80 – 0.95	Average land use score = 0.40 – 0.80	Average land use score = <0.40
		Sediment loading index (B.3.2)		Average score = 0.9 – 1.0	Average score = 0.8 – 0.89	Average score = 0.7 – 0.79	Average score = <0.7
	Hydrological Regime	Upstream water retention (B.3.3)	1	<5% of drainage basin drains to surface water storage facilities	5-20% of drainage basin drains to surface water storage facilities	20-50% of drainage basin drains to surface water storage facilities	>50% of drainage basin drains to surface water storage facilities
		Upstream/onsite water diversions	1	No upstream or onsite water	Few diversions present upstream of	Many diversions present upstream of	Water diversions are very numerous

Category	**Essential Ecological Attributes**	**Indicators/ Metics**	**Tier**	**Metric Ranking Criteria**			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
		(B.3.4)		diversions present	the riparian area relative to contributing watershed size. Onsite diversions, if present, do not appear to have only minor impact on local hydrology.	the riparian area relative to contributing watershed size. Onsite diversions, if present, appear to have a major impact on local hydrology.	upstream of the riparian area relative to contributing watershed size. Onsite diversions, if present, have drastically altered local hydrology.
		Floodplain interaction (geomorphic modifications to stream channel affecting interaction between stream and floodplain) (B.3.5)		Floodplain interaction is within natural range of variability. There are no geomorphic modifications (incised channel, dikes, levees, riprap, bridges, road beds, etc.) made to contemporary floodplain.	Floodplain interaction is disrupted due to the presence of a few geomorphic modifications. Up to 20% of streambanks are affected.	Floodplain interaction is highly disrupted due to multiple geomorphic modifications. Between 20 – 50% of streambanks are affected.	Complete geomorphic modification along river channel. The channel occurs in a steep, incised gulley due to anthropogenic impacts. More than 50% of streambanks are affected.
		Surface water runoff index (B.3.6)		Average score = 0.9 – 1.0	Average land use score = 0.80 – 0.95	Average land use score = 0.40 – 0.80	Average land use score = <0.40
		Index of hydrological alteration (B.3.7)	3	No significant change from Reference Hydrographs	Slight change from Reference Hydrographs	Moderate change from Reference Hydrographs	Large change from Reference Hydrographs
		Bank stability (B.3.8)	2	Banks stable; evidence of erosion of bank failure absent or minimal; little potential for future problems. < 5% of bank affected. Streambanks	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion. Streambanks have	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods. Streambanks have	Unstable; many eroded areas; "raw" AREAS frequent along straight sections and bends; obvious bank sloughing; 60-

Category	**Essential Ecological Attributes**	**Indicators/ Metics**	**Tier**	**Metric Ranking Criteria**			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
				dominated (> 90% cover) by Stabilizing Plant Species (OBL & FACW)	75-90% cover of Stabilizing Plant Species (OBL & FACW)	60-75% cover of Stabilizing Plant Species (OBL & FACW)	100% of bank has erosional scars. Streambanks have < 60% cover of Stabilizing Plant Species (OBL & FACW)
	Chemical/ Physical processes	Litter cover (B.3.9)	2	Litter cover 75-125% of Reference Standard (Litter > 50% cover)	Litter cover 25-75% of Reference Standard (Litter 10-50% cover)	Litter cover 0-25% of Reference Standard (Litter cover present but sparse < 10%)	No litter present.
		Nutrient/pollutant Loading Index (B.3.10)	1	Average score = 0.9 – 1.0	Average score = 0.8 – 0.89	Average score = 0.7 – 0.79	Average score = <0.7
		Nitrogen Enrichment (C:N) (B.3.11)	3	Leaf tissue C:N is equivalent to natural range of variability	Leaf tissue C:N is slightly less and outside of natural range of variability	Leaf tissue C:N is significantly lower than natural range of variability	Leaf tissue C:N is significantly lower than natural range of variability
		Phosphorous Enrichment (C:P) (B.3.12)	3	Leaf tissue C:P is equivalent to natural range of variability	Leaf tissue C:P is slightly less and outside of natural range of variability	Leaf tissue C:P is significantly lower than natural range of variability	Leaf tissue C:P is significantly lower than natural range of variability
		Soil Organic Matter Decomposition (B.3.13)	2	Mature Cottonwoodareas: OMDF > 2.25; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF > 0.8	Mature Cottonwood areas: OMDF 1.1 - 2.25; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF 0.4 - 0.8	Mature Cottonwood areas: OMDF 0.5 - 1.1; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF 0.2 - 0.4	Mature Cottonwood areas: OMDF < 0.5; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF < 0.2
		Soil Organic Carbon (B.2.14)	3	Soil C is equivalent to natural range of variability	Soil C is nearly equivalent to natural range of variability	Soil C is significantly lower than natural range of variability	Soil C is significantly lower than natural range of

Category	**Essential Ecological Attributes**	**Indicators/ Metics**	**Tier**	**Metric Ranking Criteria**			
				Excellent (A)	Good (B)	Fair (C)	Poor (D)
							variability
		Soil Bulk Density (B.3.15)	3	Bulk density is within natural range of variability	Bulk density is slightly higher than natural range of variability	Bulk density is higher than natural range of variability	Bulk density is much higher than natural range of variability
SIZE	Absolute Size	Absolute Size (B.4.1)	1	> 1.5 linear miles	1.0 to 1.5 ;linear miles	0.5 to 1.0 linear miles	< 0.5 linear miles
	Relative Size	Relative Size (B.4.2)	1	Wetland area = onsite Abiotic Potential	Wetland area < Abiotic Potential; Relative Size = 90 – 100% ; (< 10% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc.	Wetland area < Abiotic Potential; Relative Size = 75 – 90%; 10-25% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc	Wetland area < Abiotic Potential; Relative Size = < 75%; > 25% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc

A.4 Scorecard Protocols

For each metric, a rating is developed and scored as A – (Excellent) to D – (Poor). The background, methods, and rationale for each metric are provided in section B. Each metric is rated, then various metrics are rolled together into one of four categories: Landscape Context, Biotic Condition, Abiotic Condition, and Size. A point-based approach is used to roll-up the various metrics into Category Scores.

Points are assigned for each rating level (A, B, C, D) within a metric. The default set of points are A = 5.0, B = 4.0, C = 3.0, D = 1.0. Sometimes, within a category, one measure is judged to be more important than the other(s). For such cases, each metric will be weighted according to its perceived importance. Points for the various measures are then added up and divided by the total number of metrics. The resulting score is used to assign an A-D rating for the category. After adjusting for importance, the Category scores could then be averaged to arrive at an Overall Ecological Integrity Score.

Supplementary metrics are not included in the Rating Protocol. However, they could be incorporated if the user desired.

A.4.1 Landscape Context Rating Protocol

Rate the Landscape Context metrics according to their associated protocols (see Table 3 and details in Section B). Use the scoring table below (Table 4) to roll up the metrics into an overall Landscape Context rating.

Rationale for Scoring: Adjacent land use, buffer width, and connectivity of the riparian corridor are judged to be more important than the amount of fragmentation within 1 km of the wetland since a wetland with no other natural communities bordering it is very unlikely to have a strong biological connection to other natural lands at a further distance.

Thus, the following weights apply to the Landscape Context metrics:

Table 4. Landscape Context Rating Calculation.

Measure	**Definition**	**Tier**	**A**	**B**	**C**	**D**	**Weight**	**Score** (weight x rating)
Adjacent Land Use (B.1.1)	Addresses the intensity of human dominated land uses within 100 m of the wetland.	1	5	4	3	1	0.30	
Buffer Width (B.1.2)	Wetland buffers are vegetated, natural (non-anthropogenic) areas that surround a wetland.	1	5	4	3	1	0.30	

Measure	Definition	Tier	A	B	C	D	Weight	Score (weight x rating)
Percentage of unfragmented landscape within 1 km. (B.1.3)	An unfragmented landscape has no barriers to the movement and connectivity of species, water, nutrients, etc. between natural ecological systems.	1	5	4	3	1	0.10	
Riparian Corridor Continuity (B.1.4)	Indicates the degree to which the riparian area exhibits an uninterrupted vegetated riparian corridor.	1	5	4	3	1	0.30	
Landscape Context Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

A.4.2 Biotic Condition Rating Protocol

Rate the Biotic Condition metrics according to their associated protocols (see Table 3 and details in Section B). Use the scoring table below (Table 5) to roll up the metrics into an overall Biotic Condition rating.

Rationale for Scoring: The Floristic Quality Index (FQI) metric is judged to be more important than the other metrics as the FQI provides a more reliable indicator of biotic condition.

Scoring for Biotic Condition is a bit more complex. For example, the Floristic Quality Index (FQI) may or may not be assessed, depending on resources (since it is a Tier 3 metric). If it is included then the weights without parentheses apply to the Biotic Condition metrics. If FQI is not included then the weight in parentheses is used for the Tier 2 metrics.

Table 5. Biotic Condition Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Percent of Cover of Native Plant Species (B.2.1)	Percent of the plant species which are native to the Western Great Plains	2	5	4	3	1	0.20 (0.50)	
Floristic Quality Index (Mean C) (B.2.2)	The mean conservatism of all the native species growing in the wetland.	3	5	4	3	1	0.60 (N/A)	
Presence and abundance of invasive species. (B.2.3)		2	5	4	3	1	0.10 (0.25)	

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Saplings/seedlings of Native Woody Species (B.2.4)	Estimates the amount of regeneration of native woody plants.	2	5	4	3	1	0.10 (0.25)	
Biotic Condition Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

* The weight in parentheses is used when metric B.2.2 is not used.

A.4.3 Abiotic Condition Rating Protocol

Rate the Abiotic Condition metrics according to their associated protocols (see Table 3 and details in Section B). Use the scoring table below (Table 6) roll up the metrics into an overall Abiotic Condition rating.

Rationale for Scoring: Quantitative water table data are judged to more reliable than the other metrics for indicating Abiotic Condition (shaded metric in Table 6). However, if such data are lacking then stressor related metrics (Land Use & Hydrological Alterations) are perceived to provide more dependable information concerning Abiotic Condition.

Table 6. Abiotic Condition Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Land Use Within the Wetland (B.3.1)	Addresses the intensity of human dominated land uses within the wetland.	1	5	4	3	1	0.20	
Upstream Surface Water Retention (B.3.3)	Measures the percentage of the contributing watershed which drains into water storage facilities capable of storing surface water from several days to months	1	5	4	3	1	0.20	
Upstream/Onsite Water Diversions (B.3.4)	Measures the number of water diversions and their impact in the contributing watershed and in the wetland.	1	5	5	0	0	0.20	
Floodplain Interaction (B.3.5)	Indicates the amount of interaction between the stream and floodplain by assessing whether any geomorphic modifications have been made to the stream channel.	2	5	5	0	0	0.20	
Bank Stability (B.3.8)	Assesses the stability and condition of the streambanks.	2	5	4	3	1	0.20	

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Index of Hydrological Alteration (B.3.7)	Uses daily streamflow data to determine trends at one site or determine differences between pre- and post-impacts of sites.	3					N/A *1.0*	
Abiotic Condition Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

* B.3.7 is a more accurate and reliable measure than the other metrics. Thus, if B.3.7 is used no other metrics are needed for the assessment.

A.4.4 Size Rating Protocol

Rate the two measures according to the metrics protocols (see Table 3 and details in Section B). Use the scoring table below (Table 7) to roll up the metrics into an overall Size rating.

Rationale for Scoring: Since the importance of size is contingent on human disturbance both within and adjacent to the wetland, two scenarios are used to calculate size:

(1) When Landscape Context Rating = “A”:
Size Rating = Relative Size metric rating (weights w/o parentheses)

(2) When Landscape Context Rating = “B, C, or D”.
Size Rating = (weights in parentheses)

Table 7. Size Rating Calculation.

Measure	Definition	Tier	A	B	C	D	Weight*	Score (weight x rating)
Absolute Size (B.4.1)	The current size of the wetland	1	5	4	3	1	0.0 (0.70)	
Relative Size (B.4.2)	The current size of the wetland divided by the total potential size of the wetland multiplied by 100.	1	5	4	3	1	1.0 (0.30)	
Size Rating	A = 4.5 - 5.0 B = 3.5 – 4.4 C = 2.5 – 3.4 D = 1.0 – 2.4							**Total = sum of N scores**

* The weight in parentheses is used when Landscape Context Rating = B, C, or D.

A.4.5 Overall Ecological Integrity Rating Protocol

If an Overall Ecological Integrity Score is desired for a site, then a weighted-point system should be used with the following rules:

1. If Landscape Context = *A* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]** **Note:** For this calculation ONLY consider Relative Size for Size Score

2. If Landscape Context is *B*, *C*, or *D* AND Size = *A* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Size Score * (0.25)] + [Landscape Context Score * (0.15)]**

3. If Landscape Context is *B*, *C*, or *D* AND Size = *B* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.20)] + [Size Score * (0.20)]**

4. If Landscape Context is *B*, *C*, or *D* AND Size = *C* or *D* then the Overall Ecological Integrity Rank = **[Abiotic Condition Score *(0.35)] + [Biotic Condition Score *(0.25)] + [Landscape Context Score * (0.25)] + [Size Score * (0.15)]** **Note:** For this calculation use both Absolute and Relative Size for Size Score.

The Overall Ecological Rating is then assigned using the following criteria:

A = 4.5 - 5.0
B = 3.5 – 4.4
C = 2.5 – 3.4
D = 1.0 – 2.4

B. PROTOCOL DOCUMENTATION FOR METRICS

Note: Most of the following discussion is adapted from Rocchio (2006).

B.1 Landscape Context Metrics

B.1.1 Adjacent Land User

Definition: This metric addresses the intensity of human dominated land uses within 100 m of the wetland.

Background: This metric is one aspect of the landscape context of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The intensity of human activity in the landscape has a proportionate impact on the ecological processes of natural systems. Each land use type occurring in the 100 m buffer is assigned a coefficient ranging from 0.0 to 1.0 indicating its relative impact to the wetland (Hauer et al. 2002).

Measurement Protocol: This metric is measured by documenting surrounding land use(s) within 100 m of the wetland. This should be completed in the field then verified in the office using aerial photographs or GIS. However, with access to current aerial photography and/or GIS data a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use within 100 m of the wetland edge.

To calculate a Total Land Use Score estimate the % of the adjacent area within 100 m under each Land Use type and then plug the corresponding coefficient (Table 4) with some manipulation to account for regional application) into the following equation:

$$\textit{Sub-land use score} = \sum \mathrm{LU} \text{ x } \mathrm{PC}/100$$

where**:** LU = Land Use Score for Land Use Type; PC = % of adjacent area in Land Use Type.

Do this for each land use within 100 m of the wetland edge, then sum the Sub-Land Use Score(s) to arrive at a Total Land Score. For example, if 30% of the adjacent area was under moderate grazing (0.3 * 0.6 = 0.18), 10% composed of unpaved roads (0.1 * 0.1 = 0.01), and 40% was a natural area (e.g. no human land use) (1.0 * 0.4 = 0.4), the Total Land Use Score would = 0.59 (0.18 + 0.01 + 0.40).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating

Excellent	Good	Fair	Poor
Average Land Use Score = 1.0-0.95	Average Land Use Score = 0.80-0.95	Average Land Use Score = 0.4-0.80	Average Land Use Score = < 0.4

Data:

Table 8. Current Land Use and Corresponding Land Use Coefficients

Current Land Use	Coefficient
Paved roads/parking lots/domestic or commercially developed buildings/gravel pit operation	0.0
Unpaved Roads (e.g., driveway, tractor trail) / Mining	0.1
Agriculture (tilled crop production)	0.2
Heavy grazing by livestock / intense recreation (ATV use/camping/popular fishing spot, etc.)	0.3
Logging or tree removal with 50-75% of trees >50 cm dbh removed	0.4
Hayed	0.5
Moderate grazing	0.6
Moderate recreation (high-use trail)	0.7
Selective logging or tree removal with <50% of trees >50 cm dbh removed	0.8
Light grazing / light recreation (low-use trail)	0.9
Fallow with no history of grazing or other human use in past 10 yrs	0.95
Natural area / land managed for native vegetation	1.0

based on Table 21 in Hauer et al. (2002)

Scaling Rationale: Land uses have differing degrees of potential impact. Some land uses have minimal impact, such as simply altering the integrity of native vegetation (e.g., recreation and grazing), while other activities (e.g., hay production and agriculture) may replace native vegetation with nonnative or cultural vegetation yet still provide potential cover for species movement. Intensive land uses (i.e., urban development, roads, mining, etc.) may completely destroy vegetation and drastically alter hydrological processes. The coefficients were assigned according to best scientific judgment regarding each land use's potential impact (Hauer et al. 2002).

Confidence that reasonable logic and/or data support the index: Medium.

B.1.2 Buffer Width

Definition: Wetland buffers are vegetated, natural (non-anthropogenic) areas that surround a wetland. This includes forests, grasslands, shrublands, lakes, ponds, streams, or another wetland.

Background: This metric is one aspect of the landscape context of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The intensity of human activity in the landscape often has a proportionate impact on the ecological processes of natural systems. Buffers reduce potential impacts to wetlands by alleviating the effects of adjacent human activities (Castelle et al. 1992). For example, buffers can moderate stormwater runoff, reduce loading of sediments, nutrients, and pollutants into a wetland as well as provide habitat for wetland-associated species for use in feeding, roosting, breeding and cover (Castelle et al. 1992).

Measurement Protocol: This metric is measured by estimating the width of the buffer surrounding the wetland. Buffer boundaries extend from the wetland edge to intensive human land uses which result non-natural areas. Some land uses such as light grazing and recreation may occur in the buffer, but other more intense land uses should be considered the buffer boundary. Irrigated meadows may be considered a buffer if the area appears to function as a buffer between the wetland and nearby, more intensive land uses such as agricultural row cropping, fenced or unfenced pastures, paved areas, housing developments, golf courses, mowed or highly managed parkland, mining or construction sites, etc. (Mack 2001).

Measurement should be completed in the field then verified in the office using aerial photographs or GIS. Measure or estimate buffer width on four or more sides of the wetland then take the average of those readings (Mack 2001). This may be difficult for large wetlands or those with complex boundaries. For such cases, the overall buffer width should be estimated using best scientific judgment.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Wide > 100 m	Medium. 50 m to <100 m	Narrow. 25 m to 50 m	Very Narrow. < 25m

Data: N/A

Scaling Rationale: Increases in buffer width improve the effectiveness of the buffer in moderating excess inputs of sediments, nutrients, and other pollutants from surface water runoff and provides more potential habitat for wetland dependent species (Castelle et al. 1992). The categorical ratings are based on data from Castelle et al. (1992), Keate (2005), Mack (2001), and best scientific judgment regarding buffer widths and their effectiveness in the Western Great Plains.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.1.3 Percentage of Unfragmented Landscape Within One Kilometer

Definition: An unfragmented landscape is one in which human activity has not destroyed or severely altered the landscape. In other words, an unfragmented landscape has no barriers to the movement and connectivity of species, water, nutrients, etc. between natural ecological systems. Fragmentation results from human activities such as timber clearcuts, roads, residential and commercial development, agriculture, mining, utility lines, railroads, etc.

Background: This metric is one aspect of the landscape context of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The intensity of human activity in the landscape often has a proportionate impact on the ecological processes of natural systems. The percentage of fragmentation (e.g., anthropogenic patches) provides an estimate of connectivity among natural ecological systems. Although related to metric B.1.1 and B.1.2, this metric differs by addressing the spatial interspersion of human land use as well as considering a much larger area.

Measurement Protocol: This metric is measured by estimating the amount of unfragmented area in a one km buffer surrounding the wetland and dividing that by the total area. This can be completed in the office using aerial photographs or GIS.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Embedded in 90-100% unfragmented, roadless natural landscape; internal fragmentation absent	Embedded in 60-90% unfragmented natural landscape; internal fragmentation minimal	Embedded in 20-60%% unfragmented natural landscape; Internal fragmentation moderate	Embedded in < 20% unfragmented natural landscape. Internal fragmentation high

Data: N/A

Scaling Rationale: Less fragmentation increases connectivity between natural ecological systems and thus allow for natural exchange of species, nutrients, and water. The categorical ratings are based on Rondeau (2001).

Confidence that reasonable logic and/or data support the index: Medium.

B.1.4 Riparian Corridor Continuity

Definition: This metric indicates the degree to which the riparian area exhibits an uninterrupted naturally vegetated riparian corridor.

Background: This metric is one aspect of the landscape context of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Riparian areas are typically comprised of a continuous corridor of intact natural vegetation along the stream channel and floodplain

(Smith 2000). These corridors allow uninterrupted movement of animals to up- and down-stream portions of the riparian zone as well as access to adjacent uplands (Gregory et al. 1991). These corridors also allow for unimpeded movement of surface and overbank flow, which are critical for the distribution of sediments and nutrients as well as recharging local alluvial aquifers. Fragmentation of the riparian corridor can occur as a result of human alterations such as roads, power and pipeline corridors, agriculture activities, and urban/industrial development (Smith 2000).

Measurement Protocol: This metric is measured as the percent of anthropogenic patches within the riparian corridor. Anthropogenic patches are defined as areas which have been converted or are dominated by human activities such as heavily grazed pastures, roads, bridges, urban/industrial development, agriculture fields, and utility right-of-ways. The riparian corridor itself is defined at the width of the geomorphic floodplain. Using GIS, field observations, and/or aerial photographs the area occupied by anthropogenic patches is compare to the area occupied by natural vegetation with the riparian corridor.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
< 5% of riparian reach with gaps / breaks due to cultural alteration	> 5 - 20% of riparian reach with gaps / breaks due to cultural alteration	>20 - 50% of riparian reach with gaps / breaks due to cultural alteration	> 50% of riparian reach with gaps / breaks due to cultural alteration

Data: N/A

Scaling Rationale: As fragmentation increases the continuity of natural vegetated patches in the riparian decreases, along with corresponding changes in species, sediment, nutrient, and water movement. The categorical ratings are based on Smith (2000).

Confidence that reasonable logic and/or data support the index: Medium/High.

B.2 Biotic Condition Metrics

B.2.1 Percent of Cover of Native Plant Species

Definition: Percent of the plant species which are native to the Western Great Plains

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Wetlands with excellent ecological integrity are generally dominated by native species. This metric is a measure of the degree to which native plant communities have been altered by human disturbance. With increasing human disturbance, non-native species invade and can dominate the wetland.

Measurement Protocol: A qualitative, ocular estimate of cover is used to calculate and score the metric. The entire occurrence of the riparian system should be walked and a qualitative ocular estimate of the total cover of native species growing in the riparian area should be made. Alternatively, if time and resources allow a more quantitative determination of species presence and cover such methods (i.e. Peet et al. 1998) are encouraged to be used. The metric is calculated by dividing the total cover of native species by the total cover of all species and multiplying by 100.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
100% cover of native plant species	85-< 100% cover of native plant species	50-85% cover of native plant species	<50% cover of native plant species

Data: N/A

Scaling Rationale: The criteria are based on data and descriptions in CNHP (2005), and best scientific judgment. These are tentative hypotheses as they have not been validated with quantitative data. The Colorado Natural Heritage Program is currently developing a Vegetation Index of Biotic Integrity. Data from this project will likely provide the necessary information to confirm, validate, and improve the criteria.

Confidence that reasonable logic and/or data support the index: High

B.2.2 Floristic Quality Index (Mean C)

Definition: The mean conservatism of all the native species growing in the riparian area.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Plants are generally adapted to biotic and abiotic fluctuations associated with the habitat where they grow (Wilhelm and Masters 1995). However, when disturbances to that habitat exceed the natural range of variation (e.g. many human-induced disturbances), only those plants with wide ecological tolerance will survive. In contrast, conservative species (e.g. those species with strong fidelity to habitat integrity) will decline or disappear according to the degree of human disturbance (Wilhelm and Master 1995).

The Floristic Quality Index (FQI) is a vegetative community index designed to assess the degree of "naturalness" of an area based on the presence of species whose ecological tolerance are limited (U.S. EPA 2002). See discussion in Rocchio (2007) for additonal information on this method.

Measurement Protocol: Species presence/absence data need to be collected from the riparian area. Although, quantitative measurements are preferred, depending on time and financial constraints, this metric can be measured with qualitative or quantitative data. The two methods are described as follows: (1) Site Survey (semi-quantitative): walk the entire occurrence of the riparian system and make notes of each species encountered. A thorough search of each macro- and micro-habitat is required. (2) Quantitative Plot Data: The plot method described by Peet et al. (1998) is recommended for collecting quantitative data for this metric. This method uses a 20 x 50 m plot which is typically established in a 2 x 5 arrangement of 10 x 10 m modules. However, the array of modules can be rearranged or reduced to meet site conditions (e.g. 1 x 5 for linear areas or 2 x 2 for small, circular sites). The method is suitable for most types of vegetation, provides information on species composition across spatial scales, is flexible in intensity and effort, and compatible with data from other sampling methods (Mack 2004; Peet et al. 1998).

The metric is calculated by referencing only native species C value from the Colorado FQI Database (Rocchio 2007), summing the C values, and dividing by the total number of native species (Mean C).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
> 4.5	3.5-4.5	3.0 – 3.5	< 3.0

Data: Colorado FQI Database (Rocchio 2007)

Scaling Rationale: In the Midwest, field studies using FQI have determined that a site with a Mean C of 3.0 or less is unlikely to achieve higher C values thus this value was used as the Restoration Threshold (between Fair and Poor). In other words, those sites have been disturbed to the degree that conservative species are no longer able to survive and or compete with the less conservative species as a result of the changes to the soil and or hydrological processes on site (Wilhelm and Masters 1995). Sites with a Mean C of 3.5 or higher are considered to have at least marginal quality or integrity thus this value was used as the Minimum Integrity Threshold (between Good and Fair) (Wilhelm and Masters 1995). The threshold between Excellent and Good was assigned based on best scientific judgment upon reviewing the FQI literature. Although it is not know if these same thresholds are true for the Western Great Plains, they have been used to construct the scaling for this metric. As the FQI is applied in this region, the thresholds may change.

Confidence that reasonable logic and/or data support the index: High

B.2.3 Presence and abundance of invasive species.

Definition: This metric estimates the presence and abundance of invasive tree species with the potential to alter system functioning.

Background: This metric evaluates one aspect of the biotic condition of an individual occurrence of the ecological system.

Rationale for Selection of the Variable:

Measurement Protocol: This metric is measured by determining the presence and rough abundance of system altering invasive species (*Tamarix* spp. and *Elaeagnus angustifolia*) in the occurrence. This is completed in the field and ocular estimates are used to match the categorical ratings in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
System altering invasive species, such as *Tamarix* spp. and *Elaeagnus angustifolia* are either not present or occupy less than 1 percent of the occurrence, with no patches larger than 1 acre.	System altering invasive species, such as *Tamarix* spp. and *Elaeagnus angustifolia* occupy no more than 1-3% of the occurrence with no patches larger than 1 acre.	System altering invasive species, *Tamarix* spp. and *Elaeagnus angustifolia* occupy 3-5% of the occurrence, with some patches larger than 1 acre	System altering invasive species, such as *Tamarix* spp. and *Elaeagnus angustifolia* occupy >5% of the occurrence.

Data: N/A

Scaling Rationale: The criteria are based on best scientific judgment.

Confidence that reasonable logic and/or data support the index: Medium/Low

B.2.4 Saplings/seedlings of Native Woody Species

Definition: This metric estimates the amount of regeneration of native woody plants.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Intensive grazing by domestic livestock and/or alteration of natural flow regime can reduce to eliminate regeneration by native woody plants (Elmore and Kauffman 1994). Species such as willows and cottonwood depend on episodic flooding to create new bare surfaces suitable for germination of seedlings (Woods 2001). Lack of regeneration is indicative of altered ecological processes and has adverse impacts to the biotic integrity of the riparian area.

Measurement Protocol: This metric is measured by determining the degree of regeneration of native woody species present along the streambank and edges of beaver ponds/dams. This is completed in the field and ocular estimates are used to match regeneration with the categorical ratings in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Saplings/seedlings of native woody species (cottonwood/willow) present in expected amount; Obvious regeneration.	Saplings/seedlings of native woody species (cottonwood/willow) present but less than expected; Some seedling/saplings present.	Saplings/seedlings of native woody species (cottonwood/willow) present but in low abundance; Little regeneration by native species.	No reproduciton of native woody species

Data: N/A

Scaling Rationale: The criteria are based on best scientific judgment.

Confidence that reasonable logic and/or data support the index: Medium

B.2.5 Biotic/Abiotic Patch Richness

Definition: The number of biotic/abiotic patches or habitat types present in the riparian area. The metric is not a measure of the spatial arrangement of each patch.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Ecological diversity of a site is correlated with biotic/abiotic patch richness (Collins et al. 2004). Unimpacted sites have an expected range of biotic/abiotic patches. Human-induced alterations can decrease patch richness by homogenizing microtopography, altering channel characteristics, etc.

Measurement Protocol: This metric is measured by determining the number of biotic/abiotic patches present at a site and dividing by the total number of possible patches for the specific riparian type (see Table 9). This percentage is then used to rate the metric in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
> 75-100% of the possible patch types are evident in the occurrence	> 50-75% of the possible patch types are evident in the occurrence	25-50% of the possible patch types are evident in the occurrence	< 25% of the possible patch types are evident in the occurrence

Data:

Table 9. Patch types for Western Great Plains Riparian Woodland and Shrubland.

Patch Type
Mature cottonwood dominated (> 6-m height and >10 cm dbh)
Immature pole cottonwood 2-6 m in height and <10 cm dbh. May also have interspersion of willow.
Cottonwood or willow seedlings and early seral stages up to 2 m in height.
Filled or partially filled abandoned channel dominated by mix of willows, alder, shrubs, and interspersed herbaceous cover.
Herbaceous vegetation dominated, but may have interspersion of an occasional shrub (<10% of cover).
Exposed riverbed during base flow and inundated during most annual high flows. May have very sparse herbaceous vegetation or an occasional cottonwood or willow seedling composing <10% cover.
Main-channel surface during base flow, may be in a single channel or may be braided w/ islands.
Off main channel, water at the surface during base flow; includes springbrooks, oxbows, scour depressions and ponds, non-flow-through downstream connected side channels, and disconnected side channels.
Debris jams (woody debris) in stream
TOTAL = 9

Adapted from Hauer et al (2002).

Scaling Rationale: The scaling criteria are based on Collins et al. (2004); however, best scientific judgment was used to modify patch types to correspond with Western Great Plains riparian areas.

Confidence that reasonable logic and/or data support the index: Medium

B.2.6 Interspersion of Biotic/Abiotic Patches

Definition: Interspersion is the spatial arrangement of biotic/abiotic patch types within the wetland, especially the degree to which patch types intermingle with each other (e.g. the amount of edge between patches).

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Spatial complexity of biotic/abiotic patches is indicative of intact ecological processes (Collins et al. 2004). Unimpacted sites have an expected spatial pattern of biotic/abiotic patches. Human-induced alterations can decrease this complexity and homogenize patch distribution.

Measurement Protocol: This metric is measured by determining the degree of interspersion of biotic/abiotic patches present in the riparian area. This can be completed in the field for most riparian areas, however aerial photography may be beneficial for larger sites (Collins et al. 2004). The metric is rated by matching site interspersion with the categorical ratings in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Horizontal structure consists of a very complex array of nested and/or interspersed, irregular biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a moderately complex array of nested or interspersed biotic/abiotic patches, with no single dominant patch type	Horizontal structure consists of a simple array of nested or interspersed biotic/abiotic patches,	Horizontal structure consists of one dominant patch type and thus has relatively no interspersion

Data: See B.2.3 for list and definitions of Biotic Patches.

Scaling Rationale: The scaling criteria are based on Collins et al. (2004), however best scientific judgment was used to modify criteria to correspond with Western Great Plains riparian areas.

Confidence that reasonable logic and/or data support the index: Medium

B.3 Abiotic Condition Metrics

B.3.1 Land Use Within the Wetland

Definition: This metric addresses the intensity of human dominated land uses within the riparian area.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The intensity of human activity in the riparian area often has a proportionate impact on the ecological processes occurring onsite. Each land use type is assigned a coefficient ranging from 0.0 to 1.0 indicating its relative impact to the riparian area (Hauer et al. 2002).

Measurement Protocol: This metric is measured by documenting land use(s) within the riparian area. This should be completed in the field then verified in the office using aerial photographs or GIS. However, with access to current aerial photography and/or GIS data a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use within 100 m of the riparian area edge.

To calculate a Total Land Use Score estimate the % of the riparian area under each Land Use type and then plug the corresponding coefficient (Table 5) with some manipulation to account for regional application) into the following equation:

Sub-land use score = $\sum$ LU x PC/100

where**:** LU = Land Use Score for Land Use Type; PC = % of adjacent area in Land Use Type.

Do this for each land use, then sum the Sub-Land Use Score(s) to arrive at a Total Land Score. For example, if 30% of the riparian area was under moderate grazing (0.3 * 0.6 = 0.18), 10% composed of unpaved roads (0.1 * 0.1 = 0.01), and 40% was a natural area (e.g. no human land use) (1.0 * 0.4 = 0.4), the Total Land Use Score would = 0.59 (0.18 + 0.01 + 0.40).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Average Land Use Score = 1.0-0.95	Average Land Use Score = 0.80-0.95	Average Land Use Score = 0.4-0.80	Average Land Use Score = < 0.4

Data: See Table 8 in Section B.1.1.

Scaling Rationale: The coefficients were assigned according to best scientific judgment regarding each land use's potential impact (Hauer et al. 2002). Land uses have differing degrees of potential impact. Some land uses have minimal impact, such as simply altering the integrity of native vegetation (e.g., recreation and grazing), while other activities (e.g., hay production and agriculture) may replace native vegetation with nonnative or cultural vegetation yet still provide potential cover for species movement. Intensive land uses (i.e., urban development, roads, mining, etc.) may completely destroy vegetation and drastically alter hydrological processes.

Confidence that reasonable logic and/or data support the index: Medium.

B.3.2 Sediment Loading Index

Definition: The sediment loading index is a measure of the varying degrees to which different land uses contribute excess sediment via surface water runoff and overland flow into a riparian area.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The type and amount of each land use in the riparian area and contributing watershed affects the amount of sediment that enters into a riparian area. Excess sediment can change nutrient cycling, bury vegetation, suppress regeneration of plants, and carry pollutants into the riparian area.

In a functional assessment of slope and depressional wetlands associated with the Great Salt Lake, Keate (2005) developed a HGM assessment model primarily based on land use as a surrogate for human impacts on wetland functions. Coefficients from Nnadi (1997) were used to represent the sediment, nutrient loading, runoff, and wildlife impacts associated with various land uses. The functions considered included hydrologic, geochemical and habitat characteristics. The same coefficients used in the Keate (2005) method are used for this metric.

Measurement Protocol: Identify and estimate the percentage of each land use within the riparian area and the contributing watershed (within 100 m of the riparian area). This is best completed in the field, however with access to current aerial photography a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use. Once the percentage of each land use is identified, multiply it by the corresponding Sediment Loading coefficient found for each land use in Appendix B, then sum for the Sediment Loading Index Score.

For example, if 50% of the riparian area and contributing watershed (within 100 m of the riparian area) was multi-family residential, 20% had a dirt/local roads, and 30% natural vegetation the calculation would be (0.5 * 0.61) + (0.2 * 0.97) + (0.3* 1.0) = 0.79 (Sediment Loading Index Score). Referring to the scorecard, this would give the metric a "Fair" rating.

The contributing watershed can be calculated or digitized using Digital Elevation Models in a GIS. Surface water divides are determined using topography and although groundwater divides do not always coincide with these same hydrological divides, groundwater movement is assumed to do so, unless other data for the site is available.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Average Score = 0.9 – 1.0	Average Score = 0.8 – 0.89	Average Score = 0.75 – 0.79	Average Score = < 0.7

Data: Appendix.

Scaling Rationale: The scaling is based on best scientific judgment. Scores below 0.7 are assumed to have crossed a threshold in which loading impacts are considered to not be restoreable (based on the land uses that have coefficients below 0.7). Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Low/medium.

B.3.3 Upstream Surface Water Retention

Definition: This metric measures the percentage of the contributing watershed which drains into water storage facilities (e.g., reservoirs, sediment basins, retention ponds, etc.) that are capable of storing surface water from several days to months (Smith 2000).

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Ecological processes of riparian areas are driven to a large degree by the magnitude and frequency of peak flows and the duration and volume of base flows (Poff et al. 1997). The biotic and physical integrity of riparian areas are dependent on the natural variation associated with these flow characteristics (Gregory et al. 1991; Poff et al. 1997). The amount of water retained in upstream facilities has a direct effect on these flows and subsequent effects on the continued biotic and physical integrity of the riparian area (Poff et al. 1997). For example, retention of surface water can decrease or eliminate episodic, high intensity flooding, decrease seasonal high flows (e.g., spring snowmelt) and increase base flows during seasonal dry periods causing a shift in channel morphology and altering the dispersal capabilities, germination, and survival of many plant species dependent on those flows (Poff et al. 1997).

Measurement Protocol: This metric is measured as the percent of the contributing watershed to the riparian area that occurs upstream of a surface water retention facility. First the total area of the contributing watershed needs to be determined. Next, the area of the contributing watershed which is upstream of the surface water retention facility furthest downstream is calculated for each stream reach (e.g., main channel and/or tributaries) then summed, divided by the total area of the contributing watershed, then multiplied by 100 to arrive at the metric value. For example if a dam occurs on the main channel, then the entire watershed upstream of that dam is calculated whereas if only small dams occur on tributaries then the contributing watershed upstream of each dam on each of the tributaries would be calculated then summed.

These calculations can be conducted using GIS themes of surface water retention facilities, USGS 7.5 minute topographic maps, and/or Digital Elevation Models. The contributing watershed can be calculated or digitized using Digital Elevation Models in a GIS. The percentage of the contributing watershed upstream of surface water retention facilities is simply “cut” from the original contributing watershed layer and its area is then calculated then compared to the total area.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
< 5% of drainage basin drains to surface water storage facilities	>5 - 20% of drainage basin drains to surface water storage facilities	>20 - 50% of drainage basin drains to surface water storage facilities	> 50% of drainage basin drains to surface water storage facilities

Data: A GIS layer of surface water retention facilities can be downloaded from the Colorado Division of Water Resource’s Decision Support Systems website: http://cdss.state.co.us/

Scaling Rationale: The scaling is based on Smith (2000) and best scientific judgment. Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Medium.

B.3.4 Upstream/Onsite Water Diversions

Definition: This metric measures the number of water diversions and their impact in the contributing watershed and in the riparian area relative to the size of the contributing watershed.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Ecological processes of riparian areas are driven to a large degree by the magnitude and frequency of peak flows and the duration and volume of base flows (Poff et al. 1997). The biotic and physical integrity of riparian areas are dependent on the natural variation associated with these flow characteristics (Gregory et al. 1991; Poff et al. 1997). The amount of water imported, exported, or diverted from a watershed can affect these processes by decreasing episodic, high intensity flooding, seasonal high flows (e.g., spring snowmelt), and base flows (Poff et al. 1997).

Measurement Protocol: This metric can be measured by calculating the total number of water diversions occurring in the upstream contributing watershed as well as those onsite. The number of diversions relative to the size of the contributing basin is considered and then compared to the scorecard to determine the rating.

Since the riparian area may occur on a variety of stream orders and since the corresponding upstream or contributing watershed differs in area, it is difficult to set standard guidelines. Thus, the user must use their best scientific judgment regarding the number of diversions and their impact relative to the size of the contributing watershed. If available, attributes such as capacity (cubic feet/second) of each diversion can be considered in the assessment.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
No upstream or onsite water diversions present	Few diversions present or impacts from diversions minor relative to contributing watershed size. Onsite diversions, if present, appear to have only minor impact on local hydrology.	Many diversions present or impacts from diversions moderate relative to contributing watershed size. Onsite diversions, if present, appear to have a major impact on local hydrology.	Water diversions are very numerous or impacts from diversions high relative to contributing watershed size. Onsite diversions, if present, have drastically altered local hydrology.

Data: A GIS layer of surface water diversions can be downloaded from the Colorado Division of Water Resource’s Decision Support Systems website: http://cdss.state.co.us/

Scaling Rationale: The scaling is based on best scientific judgment. Additional research is needed and may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Low/Medium.

B.3.5 Floodplain Interaction

Definition: This metric indicates the amount of interaction between the stream and floodplain by assessing whether any geomorphic modifications have been made to the stream channel.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Overbank flooding is a critical ecological process in riparian areas as it replenishes floodplain aquifers, deposits and/or removes sediment, detritus, and nutrients in the floodplain. Stream channels affected by geomorphic modifications (e.g., channel incision, dikes, levees, roads, bridges, rip-rap, etc.) lose their connection to the adjacent floodplain and the ability to migrate (Poff et al. 1997). The biotic and physical integrity of riparian areas are partially dependent on the natural variation associated with overbank flows (Gregory et al. 1991; Poff et al. 1997).

Measurement Protocol: This metric is estimated in the field by observing signs of overbank flooding, channel migration, and geomorphic modifications that are present within the riparian area. From these observations, best scientific judgment is used to assign the metric rating in the scorecard.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Floodplain interaction is within natural range of variability. There are no geomorphic modifications (incised channel, dikes, levees, riprap, bridges, road beds, etc.) made to contemporary floodplain.	Floodplain interaction is disrupted due to the presence of a few geomorphic modifications. Up to 20% of streambanks are affected.	Floodplain interaction is highly disrupted due to multiple geomorphic modifications. Between 20 – 50% of streambanks are affected.	Complete geomorphic modification along river channel. The channel occurs in a steep, incised gulley due to anthropogenic impacts. More than 50% of streambanks are affected.

Data: N/A

Scaling Rationale: The scaling is based on best scientific judgment. Additional research is needed and may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Low/Medium.

B.3.6 Surface Water Runoff Index

Definition: The surface water runoff index is a measure of the varying degrees to which different land uses alters surface water runoff and overland flow into a riparian area.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The type and amount of each land use in the riparian area and contributing watershed affects the timing, duration, and frequency of surface water runoff and overland flow into a riparian area. These flows alter the hydrological regime of the riparian area and can result in degradation of biotic integrity, change nutrient cycling, and potentially affect physical integrity.

In a functional assessment of slope and depressional wetlands associated with the Great Salt Lake, Keate (2005) developed a HGM assessment model primarily based on land use as a surrogate for human impacts on wetland functions. Coefficients from Nnadi (1997) were used to represent the sediment, nutrient loading, runoff, and wildlife impacts associated with various land uses. The functions considered included hydrologic, geochemical and habitat characteristics. The same coefficients used in the Keate (2005) method are used for this metric.

Measurement Protocol: Identify and estimate the percentage of each land use within the riparian area and the contributing watershed (within 100 m of the riparian area). This is best completed in the field, however with access to current aerial photography a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use. Once the percentage of each land use is identified, multiply it by the corresponding Surface Water Runoff coefficient found for each land use in Appendix B, then sum for the Surface Water Index Score.

For example, if 50% of the riparian area and contributing watershed (within 100 m of the riparian area) was under heaving grazing, 10% had a dirt road, and 40% natural vegetation the calculation would be (0.5 * 0.76) + (0.1 * 0.71) + (0.4* 1.0) = 0.85 (Surface Water Index Score). Referring to the scorecard, this would give the metric a "Fair" rating.

The contributing watershed can be calculated or digitized using Digital Elevation Models in a GIS. Surface water divides are determined using topography and although groundwater divides do not always coincide with these same hydrological divides, groundwater movement is assumed to do so, unless other data for the site is available

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Average Score = 0.9 – 1.0	Average Score = 0.8 – 0.89	Average Score = 0.75 – 0.79	Average Score = < 0.7

Data: Appendix B.

Scaling Rationale: The scaling is based on best scientific judgment. Scores below 0.7 are assumed to have crossed a threshold in which runoff impacts are considered to not be restoreable (based on the land uses that have coefficients below 0.7). Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Medium.

B.3.7 Index of Hydrological Alteration

Definition: This metric uses daily streamflow data to determine trends at one site or determine differences between pre- and post-impacts of sites.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The Index of Hydrological Alteration (IHA) is an easy to use tool for calculating the characteristics of natural and altered hydrologic regimes using any type of daily hydrologic data, such as streamflows, river stages, ground water levels, etc. Rather that review the entire method here, please refer to http://www.freshwaters.org/tools to download the IHA software as well as supporting documentation, including numerous published papers.

Measurement Protocol: Long-term daily streamflow data are required for this metric. If those are not available daily flow data may be generated using a hydrologic model or other simulation method (see Richter et al. 1997). The IHA statistics will be meaningful only when calculated for a sufficiently long hydrologic record. The length of record necessary to obtain reliable comparisons is currently being researched, however it is recommended that at least twenty years of daily records be used (Richter et al. 1997).

Some lake level and ground water well data are also available from the USGS, but much of this type of data is collected and managed by other local governmental entities.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
No significant change from Reference Hydrographs	Slight change from Reference Hydrographs	Moderate change from Reference Hydrographs	Large change from Reference Hydrographs

Data:

Index of Hydrologic Alteration Software and Supporting Documentation: http://www.freshwaters.org/tools

U.S. Geological Survey Streamflow Data: http://water.usgs.gov/usa/nwis. (data can be imported directly in the IHA)

The U.S. Forest Service, U.S. Bureau of Land Management, and local government agencies may have streamflow data for some of the streams located on the lands they manage.

Scaling Rationale: The scaling is based on best scientific judgment of deviation from the reference standard. Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.3.8 Bank Stability

Definition: This metric assesses the stability and condition of the streambanks.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Unstable or eroding banks are often the results of local and/or upstream impacts associated with channel incision induced by over grazing and/or upstream alterations in the hydrological and/or sediment regimes. The local impact from eroding or unstable banks is typically a drop in the local water table along with a change in composition of plant species growing along the streambanks.

Measurement Protocol: This metric is measured by walking along the streambanks in the riparian area and observing signs of eroding and unstable banks. These signs include crumbling, unvegetated banks, exposed tree roots, exposed soil, as well as species composition of streamside plants. Stable streambanks are vegetated by native species that have extensive root masses, including *Salix* spp., *Populus* spp., *Carex* spp., *Juncus* spp., and some wetland grasses (Prichard et al. 1998). In general, most plants with a Wetland Indicator Status of OBL (obligate) and FACW (facultative wetland) have root masses capable of stabilizing streambanks while most plants with FACU (facultative upland) or UPL (upland) do not (Prichard et al. 1998; Reed 1988).

Each bank is evaluated separately then averaged to assign the metric rating.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Banks stable; evidence of erosion or bank failure absent or minimal; < 5% of bank affected. Streambanks dominated (> 90% cover) by Stabilizing Plant Species (OBL & FACW)	Mostly stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion. Streambanks have 75-90% cover of Stabilizing Plant Species (OBL & FACW)	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods. Streambanks have 60-75% cover of Stabilizing Plant Species (OBL & FACW)	Unstable; many eroded areas; "raw". Areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars. Streambanks have < 60% cover of Stabilizing Plant Species (OBL & FACW)

Data:
Wetland Indicator Status: U.S. Fish and Wildlife Service, National Wetlands Inventory website: http://www.nwi.fws.gov/plants.htm or USDA PLANTS Database: http://plants.usda.gov/

The Colorado Floristic Quality Index Database also contains Wetland Indicator Status information.

Scaling Rationale: The scaling is based on Barbour et al. (1999), Prichard et al. (1998), and best scientific judgment of deviation from the reference standard. Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Medium.

B.3.9 Litter Cover

Definition: The percent cover of plant litter or detritus covering the soil surface.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Litter cover provides an indication of the amount of organic matter produced and recycled in the riparian area. Disturbed riparian areas often have different amounts of litter cover than reference sites due to a change in species composition, productivity, and decomposition.

Measurement Protocol: Litter cover is measured using the same protocols as vegetation. A qualitative, ocular estimate of litter cover is used to calculate and score the metric. The entire occurrence of the riparian system should be walked and a qualitative ocular estimate of the total cover of litter in the wetland should be made. Alternatively, if time and resources allow a more quantitative determination of species presence and cover such methods (i.e. Peet et al. 1998) are encouraged to be used. The metric is scored by comparing current litter cover values to those of reference or baseline conditions.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
No significant change from Reference Amount	Slight change from Reference Amount	Moderate change from Reference Amount	Large change from Reference Amount

Data: The Colorado Vegetation Index of Biotic Integrity project will likely provide the necessary data to establish the range of litter cover found in undisturbed examples.

Scaling Rationale: The criteria are based on best scientific judgment.

Confidence that reasonable logic and/or data support the index: Low/medium.

B.3.10 Nutrient/Pollutant Loading Index

Definition: The nutrient/pollutant loading index is a measure of the varying degrees to which different land uses contributed excess nutrients and pollutants via surface water runoff and overland flow into a riparian area.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: The type and amount of each land use in the riparian area and contributing watershed affects the amounts and types of nutrients and pollutants that enter into a riparian area. Excess nutrients can result in degradation of biotic integrity, change nutrient cycling, and potentially affect peat integrity.

In a functional assessment of slope and depressional wetlands associated with the Great Salt Lake, Keate (2005) developed a HGM assessment model primarily based on land use as a surrogate for human impacts on wetland functions. Coefficients from Nnadi (1997) were used to represent the sediment, nutrient loading, runoff, and wildlife impacts associated with various land uses. The functions considered included hydrologic, geochemical and habitat characteristics. The same coefficients used in the Keate (2005) method are used for this metric.

Measurement Protocol: Identify and estimate the percentage of each land use within the riparian area and the contributing watershed (within 100 m of the riparian area). This is best completed in the field, however with access to current aerial photography a rough calculation of Land Use can be made in the office. Ideally, both field data as well as remote sensing tools are used to identify an accurate % of each land use. Once the percentage of each land use is identified, multiply it by the corresponding Nutrient/Pollutant Loading coefficient found for each land use in Appendix B, then sum for the Nutrient/Pollutant Loading Index Score.

For example, if 50% of the riparian area and contributing watershed (within 100 m of the riparian area) was under heaving grazing, 10% had a dirt road, and 40% natural vegetation the calculation would be (0.5 * 0.87) + (0.1 * 0.92) + (0.4* 1.0) = 0.93 (Surface Water Index Score). Referring to the scorecard, this would give the metric a "Good" rating.

The contributing watershed can be calculated or digitized using Digital Elevation Models in a GIS. Surface water divides are determined using topography and although groundwater divides do not always coincide with these same hydrological divides, groundwater movement is assumed to do so, unless other data for the site is available

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Average Score = 0.9 – 1.0	Average Score = 0.8 – 0.89	Average Score = 0.75 – 0.79	Average Score = < 0.7

Data: Appendix B.

Scaling Rationale: The scaling is based on best scientific judgment. Scores below 0.7 are assumed to have crossed a threshold in which loading impacts are considered to not be restoreable (based on the land uses that have coefficients below 0.7). Additional research may suggest changes to the scaling criteria.

Confidence that reasonable logic and/or data support the index: Low/medium.

B.3.11 Nutrient Enrichment (C:N)

Definition: The carbon to nitrogen (C:N) ratio in the aboveground biomass or leaves of plants is used to determine whether there is excess N in the system (compared to reference standard). Increasing leaf N decreases the C:N ratio and indicates nitrogen enrichment.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Nitrogen enrichment causes vegetation to increase uptake and storage of nitrogen in plant tissue and generally results in increased productivity. These changes affect ecosystem processes including decomposition and accumulation of soil organic matter. Floristic composition may change as aggressive, competitive species take advantage of increased nutrients and displace less competitive species. All of these changes degrade the ecological integrity of the riparian area by altering energy flow, nutrient cycling, and potential habitat for fauna assemblages (U.S. EPA 2002).

Measurement Protocol: Herbaceous plants are preferentially sampled because they respond to nutrient enrichment quicker than woody species. Two or three dominant species should be selected for sampling. Samples should be collected from plants of a similar age and clipped from nodes a similar distance below the terminal bud (U.S. EPA 2002). The plants should be growing in similar habitats. If habitat is heterogeneous, then it is best to sample from each dominant habitat type. Multiple samples should be collected from several individual plants (5-10) to capture variability within the population. It is important to make collections from the same species at each site so that variation in leaf tissue nutrient concentrations is minimized (U.S. EPA 2002). See U.S. EPA (2002) for additional information.

Nitrogen is typically measured by dry combustion using a CHN analyzer. Each clipped sample should be placed in their own individual paper bag and sent to a laboratory for analysis of soil organic carbon (e.g., CHN Analyzer). Do not put the sample in a plastic bag as this could induce decomposition of the sample.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Leaf tissue C:N is equivalent to natural range of variability	Leaf tissue C:N is slightly less and outside of natural range of variability	Leaf tissue C:N is significantly lower than natural range of variability	Leaf tissue C:N is significantly lower than natural range of variability

Data: N/A

Scaling Rationale: Reference C:N ratios need to be established in undisturbed riparian areas. Thereafter, the scaling is based on best scientific judgment and an assumed linear relationship of the amount of deviation from the reference standard to level of nutrient enrichment. If data are collected from riparian areas across a disturbance gradient, quantitative criteria could be established.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.3.12 Nutrient Enrichment (C:P)

Definition: The carbon to phosphorous (C:P) ratio in the aboveground biomass or leaves of plants is used to determine whether there is excess P in the system (compared to reference standard). Increasing leaf P decreases the C:P ratio and indicates phosphorous enrichment.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Phosphorous enrichment causes vegetation to increase uptake and storage of phosphorous in plant tissue and generally results in increased productivity. These changes affect ecosystem processes including decomposition and accumulation of soil organic matter. Floristic composition may change as aggressive, competitive species take advantage of increased nutrients and displace less competitive species. All of these changes degrade the ecological integrity of the riparian area by altering energy flow, nutrient cycling, and potential habitat for fauna assemblages (U.S. EPA 2002).

Measurement Protocol: Herbaceous plants are preferentially sampled because they respond to nutrient enrichment quicker than woody species. Two or three dominant species should be selected for sampling. Samples should be collected from plants of a similar age and clipped from nodes a similar distance below the terminal bud (U.S. EPA 2002). The plants should be growing in similar habitats. If habitat is heterogeneous, then it is best to sample from each dominant habitat type. Multiple samples should be collected from several individual plants (5-10) to capture variability within the population. It is important to make collections from the same species at each site so that variation in leaf tissue nutrient concentrations is minimized (U.S. EPA 2002).

Phosphorous is typically measured by spectrophotometry in acid (H_2SO_4-H_2O_2) digests. Each clipped sample should be placed in their own individual paper bag and sent to a laboratory for analysis of soil organic carbon (e.g., CHN Analyzer). Do not put the sample in a plastic bag as this could induce decomposition of the sample.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Leaf tissue C:P is equivalent to natural range of variability	Leaf tissue C:P is slightly less and outside of natural range of variability	Leaf tissue C:P is significantly lower than natural range of variability	Leaf tissue C:P is significantly lower than natural range of variability

Data: N/A

Scaling Rationale: Reference C:P ratios need to be established in undisturbed riparian areas. Thereafter, the scaling is based on best scientific judgment and an assumed linear relationship of the amount of deviation from the reference standard to level of nutrient enrichment. If data are collected from riparian areas across a disturbance gradient, quantitative criteria could be established.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.3.13 Soil Organic Matter Decomposition

Definition: This metric indicates the amount of decomposition of soil organic matter present in the soil and thus is an indicator measure of nutrient cycling.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Soil organic matter generally refers to the organic fraction of the soil, including plant and animal residues at various stages of decomposition, as well as substances synthesized by the soil organisms. Organic matter plays an extremely important role in the soil environment, including increasing water holding capacity, encouraging soil structure, has a high cation exchange capacity, and supplies essential nutrients (Brady 1990).

Soil organic matter is accumulated in both the O and surface soil (either A or E) horizons in the soil profile. In some riparian areas, soils can be poorly developed, thus the A and E horizons are lumped into a “surface mineral soil horizon” (SMS-horizons) category for this metric (Hauer et al. 2002). The O horizon is found on the soil surface and is composed of various stages of decomposition. The SMS-horizons accumulate highly decomposed organic matter (e.g., humus), which often gives the horizon a dark, black color and high amount of colloids (Brady 1990).

Deviation of the depth of the O horizon from reference conditions indicate under- or over-abundance or too fast or slow of a decomposition rate (Hauer et al. 2002). The depth and color of the SMS-horizons is used in this metric as an index of the ability of the soil to store nutrients and thus changes from reference conditions are assumed to be indicators of changes in the input of organic matter as well in nutrient cycling (Hauer et al. 2002). For example, human disturbance may cause lower productivity resulting in thinner and lighter colored SMS-horizons (Hauer et al. 2002). Alternatively, thicker SMS-horizons than the reference standard may result from increased sedimentation (Hauer et al. 2002).

Measurement Protocol: The metric is calculated as an Organic Matter Decomposition Factor (OMDF) based on the depth of the O-horizon, the depth of the SMS-horizon, and the soil color value (from Munsell Soil Chart) of the SMS-horizon (Hauer et al. 2002).

Multiple soil pits should be dug in the riparian area to a depth where the lower boundary of the SMS-horizon is detected. If quantitative vegetation data are being collected, soil pits should be located within these plots to allow correlations with vegetation data. For example, if using the 20 x 50 m plots described by Peet et al. (1998), soil pits would be located within each of the intensive modules. The thickness of the O and SMS-horizons should be measured and the soil color estimated using a Munsell Soil Color Chart.

The OMDF is calculated as: OMDF = $\left[\left(DepthOhorizon \right) + \left(\frac{DepthSMShorizon}{SoilColorValue} \right) \right]$

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Mature Cottonwood areas: OMDF > 2.25; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF > 0.8	Mature Cottonwood areas: OMDF 1.1 - 2.25; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF 0.4 - 0.8	Mature Cottonwood areas: OMDF 0.5 - 1.1; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF 0.2 - 0.4	Mature Cottonwood areas: OMDF < 0.5; Immature cottonwood areas & cottonwood/ willow seedlings: OMDF < 0.2

Data: N/A

Scaling Rationale: The reference OMDF values are based on the work of Hauer et al. (2002) who found that riparian shrublands (e.g., willows and alders) and wet meadows in riverine floodplains in the Northern Rockies had OMDF values > 1.8. This reference value is tentatively used for Western Great Plains riparian woodlands and shrublands, but additional data collection may suggest alternative values.

The scaling is based on best scientific judgment and an assumed linear relationship of the amount of deviation from the reference standard to level of disturbance. If data are collected from riparian areas across a disturbance gradient, quantitative criteria could be established. Alternatively if "baseline" OMDF levels are known (from "pre-impact" conditions or from adjacent unaltered sites) then this metric can be used to determine change of OMDF with time.

Confidence that reasonable logic and/or data support the index: Medium.

B.3.14 Soil Organic Carbon

Definition: This metric measures the amount of soil organic carbon present in the soil.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Soil organic matter or carbon generally refers to the organic fraction of the soil, including plant and animal residues at various stages of decomposition, as well as substances synthesized by the soil organisms. Organic matter plays an extremely important role in the soil environment, including increases water holding capacity, encouraging soil structure, has a high cation exchange capacity, and supplies essential nutrients (Brady 1990).

Soil organic carbon is strong metric of soil quality due to its sensitivity to environmental disturbance. Given that soil organic carbon contributes to critical hydrologic, biogeochemical, and physical processes, a reduction in soil organic carbon from reference conditions serves as a strong indicator of loss of soil quality.

Measurement Protocol: Multiple soil pits should be dug in the riparian area to a depth of at least 40 cm. If quantitative vegetation data are being collected, soil pits should be located within these plots to allow correlations with vegetation data. For example, if using the 20 x 50 m plots described by Peet et al. (1998), soil pits would be located within each of the intensive modules. At least five replicate soil samples should be taken within the top 10 cm of the soil surface in each pit. The replicates are mixed together as “one” sample from the site. Each soil sample should be placed in their own individual plastic bag, packed on ice, and sent to a laboratory for analysis of soil organic carbon (e.g., CHN Analyzer).

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Soil C is equivalent to natural range of variability	Soil C is nearly equivalent to natural range of variability	Soil C is significantly lower than natural range of variability	Soil C is significantly lower than natural range of variability

Data: N/A

Scaling Rationale: Reference soil organic carbon levels need to be established in undisturbed riparian areas. Thereafter, the scaling is based on best scientific judgment and an assumed linear relationship of the amount of deviation from the reference standard to level of disturbance. If data are collected from riparian areas across a disturbance gradient, quantitative criteria could be established. Alternatively, if “baseline” soil organic carbon levels are known (from “pre-impact” conditions or from adjacent unaltered sites) then this metric can be used to determine change of soil organic carbon with time.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.3.15 Soil Bulk Density

Definition: Soil bulk density is a ratio of the mass/volume of the soil. This metric is a measure of the compaction of the soil horizons.

Background: This metric is one aspect of the condition of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Bulk density is a measure of the weight of the soil divided by its volume and provides an indication of the level of compaction. Compaction can result from any activity which compresses soil particles thereby increasing the weight to volume ratio. This can reduce the soil's water holding capacity, infiltration rate, water movement through the soil, and limit plant growth by physically restricting root growth (NRCS 2001). Bulk density of organic soils are typically much less than those of mineral soils, however as decomposition increases and/or organic soils are compacted from human activity, bulk density of organic soils will increase. This has corresponding negative impacts on ecological processes such as water movement through the peat body, decomposition, and nutrient cycling.

Measurement Protocol: Multiple soil pits should be dug in the riparian area to a depth of at least 40 cm. If quantitative vegetation data are being collected, soil pits should be located within these plots to allow correlations with vegetation data. For example, if using the 20 x 50 m plots described by Peet et al. (1998), soil pits would be located and samples collected within each of the intensive modules.

The samples are collected by taking a core sample within the top 15 cm of the soil. A cylinder of known volume should be used to collect samples. A PVC pipe of known dimensions will suffice. The cylinder is simply inserted into the soil profile, extracted, then shaved to eliminate any soil which is not contained within the cylinder. The soil remaining in the cylinder can then be placed into a plastic bag and then sent to a laboratory for analysis. Bulk density and soil texture (e.g., particle distribution) should be analyzed. Alternatively, texture can be determined in the field using the "field hand method", however lab analysis is preferable.

Once texture and bulk density are determined, use the information below to determine whether the soil's bulk density is less than, equal to, or greater then the minimum root-restricting bulk density values listed for the corresponding texture of the soil and assign the metric rating accordingly in the scorecard.

There are no root restricting values given for organic soils, thus if the riparian area is dominated by organic soil, reference bulk density measurements need to be established in undisturbed areas.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating

Excellent	Good	Fair	Poor
Bulk density value for riparian area is at least 0.2 (g/cm3) less than Root Restricting Bulk Density value for the soil texture found in the riparian area.	Bulk density value for riparian area is at least 0.2 (g/cm3) less than Root Restricting Bulk Density value for the soil texture found in the riparian area. (same as Very Good)	Bulk density for riparian area is between 0.2 to 0.1 (g/cm3) less than Root Restricting Bulk Density value for the soil texture found in the riparian area.	Bulk density for riparian area is = or > than Root Restricting Bulk Density value for the soil texture found in the riparian area.

Data: The data below are derived from a Natural Resource Conservation Service, Soil Quality Information Sheet — Compaction which can be found online at: http://soils.usda.gov/sqi/publications/sqis.html

Theses texture classes have the following Root Restricting Bulk Density values (g/cm3):

1. Coarse, medium, and fine sand AND loamy sand other than loamy very fine sand = 1.8 g/cm3
2. Very fine sand, loamy very find sand = 1.77 g/cm3
3. Sandy loam = 1.75 g/cm3
4. Loam, sandy clay loam = 1.7 g/cm3
5. Clay loam = 1.65 g/cm3
6. Sandy clay = 1.6 g/cm3
7. Silt, silt loam = 1.55 g/cm3
8. Silty clay loam = 1.5 g/cm3
9. Silty clay = 1.45 g/cm3
10. Clay = 1.4 g/cm3

Scaling Rationale: The scaling is based on best scientific judgment and an assumed linear relationship of the amount of deviation from the reference standard to level of disturbance. However, no distinction was made between Excellent and Good as there is no information to suggest that threshold. Alternatively if "baseline" bulk density levels are known (from "pre-impact" conditions or from adjacent unaltered areas) then this metric can be used to determine change of bulk density with time.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.4 Size Metrics

B.4.1 Absolute Size

Definition: Absolute size is the current size of the riparian area.

Background: This metric is one aspect of the size of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Absolute size is important to ecological integrity if the surrounding landscape is impacted by human-induced disturbances. When impacts to the surrounding landscape have the potential to affect the wetland, larger sized wetlands are able to buffer against these impacts better than smaller sized wetlands due to the fact they generally possess a higher diversity of abiotic and biotic processes allowing them to recover and remain more resilient. However, when the landscape is unimpacted (i.e. has an "Excellent" rating), then absolute size has little impact on ecological integrity since there are no adjacent impacts to buffer. Larger riparian areas tend to have more diversity; however, this is more pertinent to functional or conservation value than ecological integrity. Thus, absolute size is included as a metric but is only considered in the overall ecological integrity rank if the landscape is impacted. Regardless, absolute size provides important information to conservation planners and land managers.

Measurement Protocol: Absolute size can be measured easily in GIS using aerial photographs, orthophoto quads, National Wetland Inventory maps, etc. Absolute size can also be estimated in the field using 7.5 minute topographic quads, National Wetland Inventory maps, or a global positioning system. System occurrence boundaries are delineated by using guidelines for identifying the riparian ecological system type, and not by using jurisdictional methods.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
> 1.5 linear km	1.0 to 1.5 linear km	0.5 to 1.0 linear km	< 0.5 linear km

Data: N/A

Scaling Rationale: Scaling criteria are based on similar systems in Rondeau (2001) and best scientific judgment.

Confidence that reasonable logic and/or data support the index: Medium/High.

B.4.2 Relative Size

Definition: Relative size is the current size of the riparian area divided by the total potential size of the riparian area multiplied by 100.

Background: This metric is one aspect of the size of specific occurrences of wetland and riparian ecological systems.

Rationale for Selection of the Variable: Relative size is an indication of the amount of the riparian area lost due to human-induced disturbances. It provides information allowing the user to calibrate the Absolute Size metric to the abiotic potential of the riparian area onsite. For example, if a riparian area has an Absolute Size of 2 hectares but the Relative Size is 50% (1 hectare), this indicates that half of the original riparian area has been lost or severely degraded. Unlike Absolute Size, the Relative Size metric is always considered in the ecological integrity rank.

Measurement Protocol: Relative size can be measured in GIS using aerial photographs, orthophoto quads, National Wetland Inventory maps, etc. However, field calibration of size is required since it can be difficult to discern the abiotic potential of the riparian area from remote sensing data. However, the reverse may also be true since old or historic aerial photographs may indicate a larger riparian area than observed in the field. Relative size can also be estimated in the field using 7.5 minute topographic quads, National Wetland Inventory maps, or a global positioning system.

Metric Rating: Assign the metric an Excellent, Good, Fair, or Poor rating on the scorecard.

Measure (Metric) Rating			
Excellent	**Good**	**Fair**	**Poor**
Riparian area = onsite Abiotic Potential	Riparian area < Abiotic Potential; < 10% of riparian area has been reduced (destroyed or severely disturbed e.g change in hydrology) due to roads, impoundments, development, human-induced drainage, etc.	Riparian area < Abiotic Potential; 10-25% of riparian area has been reduced (destroyed or severely disturbed e.g change in hydrology) due to roads, impoundments, development, human-induced drainage, etc.	Riparian area < Abiotic Potential; > 25% of riparian area has been reduced (destroyed or severely disturbed e.g change in hydrology) due to roads, impoundments, development, human-induced drainage, etc.

Data: N/A

Scaling Rationale: Scaling criteria are based on similar systems in Rondeau (2001) and best scientific judgment.

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APPENDIX: SUPPLEMENTARY DATA

Coefficient Table (coefficients were calculated from numerous studies throughout the U.S. (Keate (2005)

Land Use	Surface Water Runoff	Nutrient/ Pollutant Loading	Suspended Solids
Natural area	1.00	1.00	1.00
Dirt Road (dirt or crushed or loose gravel, unpaved roads, local traffic)	0.71	0.92	0.90*
Field Crop (actively plowed field)	0.95	0.94	0.85**
Clearcut forest	0.83	0.93	0.98
Golf Course (area manipulated for golf, manicured grass)	0.75	0.86	0.94
High Intensity Commercial (area is entirely of commercial use and paved - shopping malls, construction yards)	0.13	0	0
High Traffic Highway (4 lanes or larger, railroads)	0.26	0.43	0.48
Industrial (intense production activity occurs on a daily basis - oil refineries, auto body and mechanic shops, welding yards, airports)	0.25	0.54	0
Feedlot, Dairy	0.62	0	0.81
Heavy grazing - Non-rotational grazing (year-round or mostly year-round grazing, vegetation is sparse and area trampled)	0.76	0.87	0.85***
Rotational Grazing (grazing is for short periods during the year, vegetation is allowed to recover)	0.96	0.95	0.98
Light Intensity Commercial (businesses have large warehouses and showrooms - large patches of vegetation occur between buildings)	0.19	0.64	0.02
Low Density Rural Development (areas of small structures in a farm or ranch setting - silos, barns)	0.87	0.92	0.98
Low Traffic Highway (2-3 lane paved highways)	0.26	0.69	0.16
Multi-family Residential (subdivisions with lots ½ acre or less)	0.38	0.55	0.61
Nursery (business where the production of nursery grade vegetation occurs including greenhouses, outbuildings and sales lots)	0.86	0.94	1.00
Orchards	0.86	0.93	0.99
Waterfowl Management Areas	0.86	0.91	0.98
Single Family Residential (residential lots are greater than ½ acre with vegetation between houses)	0.75	0.86	0.94
Surface Solid Waste (landfills and waste collection facilities)	0.71	0.87	0.61
Sewage Treatment Plants and Lagoons	0.60	0.61	0.71
Mining	0.76	0.94	0.80

* changed value from 0.97; ** changed value from 1.00; *** changed value from 0.98