# Recovery Potential Metrics
# Summary Form

**Indicator Name:** STREAM SIZE (STRAHLER ORDER)

**Type:** Ecological Capacity

**Rationale/Relevance to Recovery Potential:** see selected cites below. Stream size is strongly related to many condition-relevant attributes but the recovery potential of different stream sizes varies with the attribute. The smallest headwater streams appear to be most sensitive to riparian stresses, suggesting lower recovery potential, yet their small size and high disturbance regime may imply greater resiliency and more rapid recovery than larger orders, as well as less complex and expensive restoration needs. Generally higher biodiversity associated with small to moderate orders ($2^{nd}$ to $4^{th}$ order) may imply a more complex and resilient biotic community structure that may respond well to restoration efforts. Another recovery factor favoring a focus on the recovery of smaller orders is their favorable downstream influence on the condition of larger order streams.

**How Measured:** Strahler stream order is manually calculable from topographic maps as well as available as a feature of the NHDplus value-added attributes data.

**Data Source:** NHDplus (See: http://www.horizon-systems.com/nhdplus/) added attributes include stream order based on 1:100,000 NHD, which misses many finer order streams; thus orders may be lower than field-measured data, but may show relative rather than absolute differences in order adequately for general comparisons. Streams with Strahler stream order > 2 are compiled for the Mid-Atlantic region in the Mid-Atlantic Landscape Atlas (See: http://www.epa.gov/emap/html/cdrom/maia_dlg/). If high resolution DEM is available it is possible to use ArcGIS tools to derive the stream raster network and run “Stream Order” tool within Spatial Analyst toolbox to calculate Strahler Order for the network. Local datasets may also be available.

**Indicator Status (check one or more)**

______ Developmental concept.
___x__ Plausible relationship to recovery.
______ Single documentation in literature or practice.
___x__ Multiple documentation in literature or practice.
______ Quantification.

**Comments:** General association between smaller orders/scales and greater recovery potential is indirect and based on numerous scale-related drivers, some social. Easily measured but complex to interpret.

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**Supporting Literature (abbrev. citations and points made):**

- (Morgan and Cushman 2005) Fish assemblages in small (1st- to 3rd-order) perennial streams are particularly at risk from urbanization impacts. These streams often exhibit naturally low fish richness, and thus are highly susceptible to loss of species and overall diversity from urbanization-induced changes in water quality, hydrologic regimes, or both. In addition, the relatively close proximity of land use changes to small streams may have harsh, immediate effects on fish assemblages, including loss of breeding, feeding, and resting habitat (Paul and Meyer 2001, Bunn and Arthington 2002) (643).
- (Morgan and Cushman 2005) However, 2nd- and 3rd-order sites appeared more resistant to increasing urbanization than 1st-order sites, possibly because of greater habitat size and species complexity in these streams, where abundance was not dominated by any single tolerant species (Table 2). These results suggest that fish

assemblages in the smallest streams are sensitive to urbanization, where fish abundances may be more variable than expected. With increasing size of the habitat and the fish species pool, assemblages in larger streams (2nd- and 3rd-order streams in our study) may be resistant to low levels of catchment urbanization (10–25%), but eventually become altered at higher urbanization (.25%) (652).

- (Voelz et al., 2005) The analyses of the macroinvertebrate metrics indicate that urban impacts occur in both the Big Thompson and Cache la Poudre Rivers. It was expected that the macroinvertebrate responses in the Big Thompson River would be less than in the Cache la Poudre given, for example, that the City of Loveland is smaller and has fewer housing units. However, in general this was not the case. Although the population growth of the City of Loveland has been lower than Fort Collins, it is possible that because the stream is smaller (e.g., lower average discharge) any increase of runoff may have a greater effect (195).
- (Gage et al., 2004) Since small headwater streams are particularly susceptible to development and disturbance, incorporation of erosion control methods, clean construction practices, and restoration and preservation of wide riparian forests should be considered to reduce runoff and preserve water quality of streams (355).
- (Mykra et al., 2004) It has been shown repeatedly that stream size is, indeed, a major factor influencing the taxonomic composition of macroinvertebrate assemblages, with distinctly different communities in, for example, headwaters versus mid-sized streams (Malmqvist and Ma¨ki 1994; Wiberg-Larsen and others 2000) (342).
- (Mykra et al., 2004) Variation among stream size classes was significant for number of taxa, EPT scores, ASPT scores, and scraper abundance (345).
- (Mykra et al., 2004) Macroinvertebrate assemblage structure varied mainly among ecoregions, although variation among drainage systems and stream size classes was also significant (348).
- (Freeman et al., 2007) Productivity, particularly in forested landscapes, generally increases along the river continuum from headwaters to larger rivers. However, the large aggregate length of headwater streams means that, even though local production may be relatively low, headwaters may still contribute a substantial proportion of total system productivity. For example, total macroinvertebrate production per unit length of stream may increase by 1,000 times from first- to seventh- order streams along a longitudinal gradient in a southern Appalachian River (Grubaugh et al., 1997). However, because of their large cumulative lengths, the smaller streams (i.e., drainage area < 10 km2) still contribute at least 10% of the total macroinvertebrate production in this system (Figure 2). This calculation underestimates the proportion of total production contributed by headwaters because at least half of the network comprises streams draining less than 0.1 km2 (Hansen, 2001), for which production estimates are unavailable. Also, secondary production estimates for the seventh-order sites in this example are among the highest ever measured (Grubaugh et al., 1997) and are driven by production in shallow, rocky, vegetated habitats that are limited to a portion of the total length of larger channels (e.g. about 33% in the upper Conasauga River, also in the southern Appalachian Highlands; Argentina, 2006). Production in deeper habitats with finer bed sediments may be substantially lower than in bedrock and cobble habitats of larger rivers; for comparison, invertebrate production on submerged woody debris in rivers may be 3-4 times that in sand and mud substrates (Benke et al., 1984). Adjusting the production estimates for the seventh-order sites downward to account for contributions from less productive larger channel habitats would further increase the relative contribution of low-order streams (9-10).
- (Dodds and Oakes 2008) We hypothesized that land use adjacent to small headwater streams would have a disproportionately large impact on water quality, because these streams provide the predominant hydrologic contributions to the watershed (Lowrance and others 1997), and substantial in-stream nutrient processing and retention in upland streams and rivers can regulate downstream water quality (Alexander and others 2000; Peterson and others 2001) (368).

- (Dodds and Oakes 2008) Total N and NO3- were most closely correlated with first-order riparian land cover (Fig. 5). In general, the most variance was explained by riparian land cover adjacent to first-order streams and less variance was explained by riparian cover near larger-order streams closer to sampling sites.
- (Barker et al., 2006) ANOVA demonstrated increase in fish IBI with stream order, emphasizing the influence of location in the stream network. These results were consistent with past studies, in which stream order and instream habitat were highly correlated to fish IBI (Osborne, 1992; Roth *et al.*, 1998) (9).
- (Ekness and Randhir 2007) Headwaters and lower order subwatersheds have a higher concentration of habitat for most vertebrates, and need conservation policies through zoning and incentives to conservation (1478).
- (Ekness and Randhir 2007) It was found that headwaters and lower order subwatersheds are vital in maintaining the habitat potential (1480).
- (Dodds and Oakes 2008) Our results were consistent with previous studies (Johnson and others 1997; Jones and others 2001; Osborne and Wiley 1988; Sliva and Williams 2001), suggesting that agricultural and/or urban lands were the most important predictors of water quality variability.

  Maintaining buffers or other passive land uses in headwater streams may effectively reduce diffuse pollution downstream. The importance of these streams and their riparian zones is due in part to their sheer numbers; small streams often comprise the majority of stream miles within a drainage network (Horton 1945; Leopold and others 1964), and in this study the smallest (first-order) streams on average comprised more than 60% of the stream miles in the study watersheds. Riparian land cover near the firstorder streams of watersheds explained greater variance in TN, NO3-, and TP concentrations than did riparian land cover immediately upstream from sampling sites. Firstorder riparian land cover was statistically related to most water quality measures, even when all potential correlation related to watershed land cover was controlled for. Our results suggest that headwater riparian areas could have an important impact on downstream water quality (375).
- (Morgan and Cushman 2005) For both CP [Coastal Plain] (Table 3) and EP [Eastern Piedmont] (Table 4), fish richness and abundance in sites at the lowest urbanization level increased with increasing stream order. Richness in EP sites also decreased as catchment urbanization increased within each order (Table 4), whereas richness in CP sites did not (Table 3). Similar to richness, fish abundance increased at the lowest urbanization level as stream order increased in both ecoregions (Tables 3, 4); however, there was a general decline in abundance in EP sites within each order as catchment urbanization increased (Table 4) (647).
- (Ekness and Randhir 2007) All habitat potentials showed a strong influence along spatial dimensions and disturbance. The habitat potential for all vertebrate groups studied decreased as the distance from the riparian zone increased. Headwaters and lower order subwatersheds had higher levels of species diversity compared to higher order subwatersheds. It was observed that locations with the least disturbance also had higher habitat potential (1468).
- (Ekness and Randhir 2007) A spatially variable policy that is based on stream order, riparian distance, and land use can be used to maximize watershed ecological benefits. Wider riparian zones with variable widths, protection of headwaters and lower order subwatersheds, and minimizing disturbance in riparian and headwater areas can be used in watershed policy. These management objectives could be achieved using targeted economic incentives, best management practices, zoning laws, and educational programs using a watershed perspective (1468).
- (Wall et al., 2004) Furthermore, protecting headwater areas may temper large-scale factors (e.g., stream power, sediment load, flow regime) that can negate the benefits of restoration measures farther downstream (Frissell et al. 1986; Frissell and Nawa 1992). Conservation activities should be implemented to unite fragmented high-priority segments (969).

- (Mykra et al., 2004) According to a basic tenet of the River Continuum Concept (RCC), changes in the production base from headwaters to large rivers should result in corresponding longitudinal shifts in macroinvertebrate assemblage composition (Vannote and others 1980). Most previous studies, however, have examined a wider gradient of stream sizes than we did. RCC treats all first-order to third-order streams as headwaters, with no predictable size-related changes in macroinvertebrate assemblage composition among these streams (Vannote and others 1980). According to this scheme, all of our study sites are headwater streams, yet surprisingly distinct differences attributable to stream size were observed for several macroinvertebrate metrics, including species richness, EPT ASPT index, and scraper abundance.

  Therefore, it seems that, even within this relatively narrow size range, the influence of the riparian zone on macroinvertebrate assemblage composition decreases rapidly with increasing stream size. Algal biomass generally increases as the riparian canopy gets more sparse (e.g., Hawkins and Sedell 1981), potentially accounting for the increased abundance of scrapers observed in this study. Interestingly, Li and others (2001) found for Oregon streams that virtually no variability in assemblage metrics could be attributed to stream size, although their study spanned a similar range of stream sizes (first to third order) to ours. Their study sites, however, exhibited little size-related variability in riparian canopy cover, thus providing little scope for longitudinal shifts in the resource base of macroinvertebrate consumers (349-350).
- (Ducros and Joyce 2003) Many first-order streams were included in the Yorkshire WFO scheme, and such minor streams are valued highly in the evaluation as they can be buffered effectively, but most were too open to meet the requirements for optimum levels of shading for wildlife (262).
- (Dodds and Oakes 2008) The data suggest that riparian cover near sampling sites is generally less well correlated with water quality parameters than riparian cover or land use in first-order streams (376).
- (Dodds and Oakes 2008) Our results suggest a statistically significant effect of riparian cover of first-order streams on water quality because partial correlations among riparian land cover classifications were significant predictors in regression models when controlling for predictor catchment land cover classifications (376).
- (Dodds and Oakes 2008) The effect of first-order land cover may not be too surprising; first-order streams make up the majority of stream length in watersheds. Our approach shows that a correlation with land uses in small headwater streams does hold, and holds even in seasons when many of the first-order stream channels are not flowing (376).
- (Filipe et al., 2004) Stream order and location in the basin played an important role in the occurrence of species (Table 1), as illustrated by maps of the predicted distribution (Appendix 2) (194).
- (Lewis et al., 2007) In addition, there may have been less dilution of coliforms in the small urban headwaters compared to the much larger main channel of Big Brushy Creek (318).
- (Ekness and Randhir 2007) These results indicate that longitudinal policies (Policy B) should first be targeted to headwaters followed by second- and third-order subwatersheds (1479).
- (Ekness and Randhir 2007) This study demonstrates that having wider protected riparian zones in the headwaters and lower stream order subwatersheds are important for maintaining the biotic potential of a watershed (1479).
- (Ekness and Randhir 2007) Habitat potential for amphibians, mammals and birds are lower in first-order than second-order streams. The second-order streams have the highest potential for amphibians, mammals and birds. The lowest values for the amphibians, mammals and birds occur in the sixth-order (lower) streams. The relationship for reptiles is different from other vertebrate groups. The lowest habitat values for reptiles occur in secondorder streams and the highest in the sixth-order streams (1475).
- (Palmer et al., 2005) Different restoration activities should be selected based on the extent and type of damage, land-use attributes of the catchment, the size and position of

the river within the catchment, and stakeholder needs and goals. Even when constraints are significant, there are almost always choices that are more or less ecologically sound, as illustrated by the following four examples (212).

- (Ekness and Randhir 2007) In general results show that subbasins with a first- , second- and thirdorder streams and maximum possible riparian width are key areas for targeting watershed protection policies at this watershed-scale (1479).
- (Ekness and Randhir 2007) Focusing on the headwaters and limiting the number and types of land uses with high disturbance values could be beneficial to the whole drainage system. Some longitudinal policies could improve regional connectivity in open space and low disturbance areas. Longitudinal restoration can be increased by using greenways to establish regional connectivity in watersheds (Wenger and Fowler, 2000) (1480).
- (Ekness and Randhir 2007) The study supports protection of headwaters and lower order subwatersheds from high disturbance and encourages maximum possible riparian buffer along water bodies (1480).
- (Ekness and Randhir 2007) Spatial variations created by different riparian distance, stream order, and land use affect the type and quality of habitat potential at a particular position within a watershed. The buffer is often critical in the flow of mass and energy into and out of water bodies. The longitudinal dimension reflects upstream-downstream linkages, which is a key factor in watershed ecology. Various land uses contribute to the type and level of disturbances in a watershed. The intensity and the extent of land disturbance affect the habitat potential of a watershed (1471-1472).
- (Ekness and Randhir 2007) The amphibian model shows that amphibian habitat decreased for 0.0046 units (number of potential species supported) for each increase in riparian distance. Along the longitudinal dimension, there is a decrease of 0.2009 in species diversity. There is a decrease in 0.4584 units in amphibian habitat for each increase in the land use disturbance. An increase in potential amphibian habitat by 0.0636 units is observed for increases in species diversity for other vertebrates, indicating a complementary relationship. The quadratic effect of stream order is convex to the origin with a value of 0.0561, while the quadratic effect of disturbance is convex to the origin with a value of 0.3153. Potential amphibian habitat degrades slightly by 0.0006 units by the combined influence of increased riparian distance and stream order. This indicates that riparian protection is more critical in lower order subwatersheds. Potential amphibian habitat degrades slightly by 0.0006 units by the combined influence of increased riparian distance and stream order. This indicates that riparian protection is more critical in lower order subwatersheds. Potential amphibian habitat decreased by 0.0016 units by the combined effect of riparian distance and disturbance. This indicates the importance of protecting riparian zones from disturbance. An increase in both disturbance and stream order decrease amphibian habitat by 0.3306 units. This highlights the need to protect headwaters from disturbance (1476).
- (Ekness and Randhir 2007) The estimated model show that potential reptile habitat showed a decline of 0.0256 units for each increase in riparian distance. Potential reptile habitat decreases by 0.696 units for each increase in stream order. The potential reptile habitat increased by 0.293 units for each increase in the land use disturbance, which could be attributed to the intermediate disturbance hypothesis (Dial and Roughgarden, 1998) or higher species diversity in cropland and urban open environments. Potential reptile habitat increases with increases in habitats of other vertebrates by 0.036 units. The quadratic effect of buffer width change has a slight positive value of 0.0001 units on potential reptile habitat. The quadratic effects of stream order on reptile habitat are convex to the origin with a value of 0.219 units. The quadratic effect of disturbance is concave to the origin with a value of 0.092 units. Interaction terms indicate that the combined effect on potential reptile habitat is: (1) a slight positive increase of 0.002 units for riparian distance and land disturbance; (2) a decrease of 0.002 units for riparian distance and stream order; and (3) a decrease of 0.213 units for land disturbance and stream order, representing the second largest decrease for this interaction, next only to amphibians. Both amphibians and reptiles are influenced negatively by the combined increase in disturbance and stream order (1477).

- (Ekness and Randhir 2007) The bird model shows that potential bird habitat declined slightly by 0.023 units for each increase in riparian distance. It was observed that potential bird habitat decreases by 2.05 units for each increase in stream order. There is an increase of 4.488 units of potential bird habitat for each increase in the land use. Increases in species numbers at intermediate disturbance levels could be attributed to the disturbance hypothesis of Dial and Roughgarden (1998), which predicts higher biodiversity at median levels of disturbances. Potential habitat for birds increases with increase in suitability for other vertebrates by 1.044, indicating a complementary relationship. Quadratic effects indicate a slightly convex shape with a value of 0.00001 for buffer width, convex with a value of 0.259 for stream order, and concave to the origin with a value of 1.341 for land disturbance. The interactive effects on potential bird habitat indicate: (1) a slight increase of 0.005 units with respect to riparian distance and land disturbance; (2) an increase of 0.002 units with respect to riparian distance and stream order; and (3) an increase of 0.1142 units with respect to land disturbance and stream order (1477).
- (Ekness and Randhir 2007) The mammal model shows that there is a slight decline of 0.007 units in potential mammal habitat for each increase in riparian distance. An increase in stream order shows an increase of 1.484 units of potential mammal habitat. Potential habitat for mammal species decreases by 2.072 units for each increase in land disturbance. Mammal habitat increases by 0.198 units for each increase in habitat of other vertebrates. Quadratic effects indicate concavity with a value of 0.315 for stream order and convexity with a value of 0.309 for land disturbance. Riparian distance and stream order have a positive combined influence of 0.001 units on potential mammal habitat. The combined effect of riparian distance and land disturbance on potential mammal habitat is positive at 0.0001 units. The combined effect of land disturbance and stream order on potential mammal habitat is positive at 0.1029 units. To summarize, potential habitat of vertebrate species declined with an increase in land use disturbance. Potential habitat decreased as the riparian distance increased within the study watershed. Headwaters and lower order subwatersheds have a higher concentration of habitat for most vertebrates (1477).
- (Ekness and Randhir 2007) Maintaining land use in the riparian corridor within the lower disturbance categories along the whole longitudinal dimension of the watershed can benefit habitat potentials for multiple species. Policies can target lower order subwatersheds to achieve maximum benefits for habitat potential (1479).