Recovery Potential Metrics Summary Form

Indicator Name: WATERSHED LEGACY AGRICULTURE

Type: Stressor Exposure

Rationale/Relevance to Recovery Potential: A variety of impacts on waters are associated with agricultural uses in general, including increased loadings of nutrients, fine sediment, pesticides, herbicides, flow alteration, elevated water temperature, and others. A past history of agriculture in the watershed and/or riparian corridor can continue to account for adverse effects even after land use change (vegetational succession, transition to residential or other uses) has replaced the agriculture. Built-up nutrients and pesticides/herbicides in groundwater can continue to be discharged through influent groundwater connections for decades. Excess fine sediments and channel widening (which reduces channel habitat quality) caused during active agriculture can also persist for years to decades, as can channel destabilization and related erosion. Some studies suggest that a past history of agricultural use is more strongly correlated with impairment than current, other land use patterns.

How Measured: Percent by area within the watershed.

Data Source: Although geospatial data on past agriculture is date-limited, one national digital source (LUDA/GIRAS) characterized agricultural usage in the 1970s at coarse resolution. Locally older data may be available in isolated areas, or where historical aerial analyses back to the 1930s may have been conducted using airphotos. Historical land cover data is available through the USGS Land Cover Institute (See: http://landcover.usgs.gov/cropland/index.php). NLCD land cover data is available as far back as 1992 (http://landcover.usgs.gov/natllandcover.php). MRLC provides calculated data on the change for all of the NLCD land use classes between 2001 and 2006 (http://www.mrlc.gov/nlcd06_data.php).

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.

Examples from Supporting Literature (abbrev. citations and points made):

- (Potter et al 2004) Current land cover, however, may not be as important as past land use in predicting current stream invertebrate diversity, because sustained anthropogenic disturbance such as agriculture or urban development could profoundly alter biotic communities with lasting effects (Harding and others 1998).
- (Paul and Meyer 2001) Phosphorus stored in soils as a result of fertilization, however, can be mobilized by soil erosion and contribute to eutrophication of receiving waters. This effect has been called the “chemical time bomb” and is of particular concern when previously agricultural land is cleared for urban growth (Bennett et al. 1999) (343).
- (Norton and Fisher 2000) The difficulty of addressing diffuse N and P pollution from agricultural activities is compounded by the long residence time of groundwater. Studies conducted by the US Geological Survey (USGS) (Bohlke and Denver, 1995) on the Delmarva peninsula have demonstrated that current stream discharge originated from groundwater recharge more than 20 years ago. Since large increases in fertilizer application occurred during 1960–1980 (Bohlke and Denver, 1995), nutrient input to

Delmarva streams has increased (Fisher et al., 1998) and is expected to continue to increase during the next two decades (338).

- (Roy et al., 2007) Results from this study and other studies suggest that human alteration affects stream processes at multiple spatial extents. In addition to % land cover within catchments and riparian areas, the continuity of riparian forests (Stewart et al. 2001) and historic land use in the catchment (Harding et al. 1998) likely also influence fish assemblages (398-399).
- (Freeman and Marcinek 2006) Present and past land use, geomorphology and instream habitat structure, pollutants, species interactions, and stochastic variation may all influence the composition of local fish assemblages (445).
- (Gergel et al., 2002) Quantification of historical land cover can also contribute to useful landscape indicators. Harding et al. (1998) examined fish and invertebrates in 24 catchments in western North Carolina and found that percent forest in the catchment determined from 1950's aerial photographs explained current fish and invertebrate diversity better than land cover from the 1990's. Harding et al. (1998) suggest that in currently forested catchments, historic land use may be a more useful indicator than present land cover (122).
- (Lewis et al., 2007) However, agriculture or other land uses may have degraded stream habitat quality throughout the watershed prior to urbanization (Schleiger, 2000). Fish communities at both urban and rural sites in the Big Brushy Creek watershed were dominated by three species (L. macrochirus, N. leptocephalus, and N. lutipinnis) considered to be "pioneer" species that become established following habitat disturbance (Schleiger, 2000) or to be tolerant of degraded stream habitats (Weaver & Garman, 1994). The South Carolina piedmont has in fact undergone intensive agricultural land use which may have altered stream habitats in the past. In particular, intensive cotton farming was practiced in the region between the 1880s and the 1920s, resulting in widespread erosion and soil degradation (Edgar, 1998). In the southern Appalachian Mountains, agriculture measurably affects fish diversity and community structure for decades after reforestation (Harding, Benfield, Bolstad, Helfman, & Jones, 1998) (320).
- (Allmendinger et al., 2007) The erosion of floodplains storing sediment derived from the ''Agricultural Age'' (otherwise known as ''legacy'' sediment) is increasingly viewed as an important water quality problem (Merritts et al., 2005, 2006; Smith, 2006). These sediments are suspected of having high nutrient concentrations, raising concerns regarding eutrophication of receiving water bodies (such as the Chesapeake Bay) (Kemp et al., 2005) and elevated regional sediment yields (Gellis et al., 2005; Merritts et al., 2005) (1495).
- (Allmendinger et al., 2007) Following European settlement and the development of agriculture, excessive erosion occurred on upland surfaces of the small watersheds of the region [Maryland Piedmont] (Costa, 1975). This created sediment yields four times higher than they were prior to settlement by Europeans (Costa, 1975) (1485).
- (Roy et al., 2007) Results from this study and other studies suggest that human alteration affects stream processes at multiple spatial extents. In addition to % land cover within catchments and riparian areas, the continuity of riparian forests (Stewart et al. 2001) and historic land use in the catchment (Harding et al. 1998) likely also influence fish assemblages (398-399).
- (Gage et al., 2004) Changing land use patterns, including increases in impervious surfaces and construction near riparian zones, affect deposition of sediment, flow patterns (Oberlin et al. 1999), and stream communities (Décamps 1993, Thornton et al. 2000). Land use practices can strongly impact aquatic diversity well into the future; e.g., Harding et al. (1998) found that land use in the 1950s was the best predictor of present day diversity in streams (345).
- (Grau et al., 2003) Despite the rapid structural recovery, the legacy of pre-abandonment land use, including widespread abundance of exotic species and broadscale floristic homogenization, is likely to persist for centuries (1159).

- (Grau et al., 2003) The species composition of forests recovering from coffee plantations and pastures is often strikingly distinct, as indicated in more detailed analyses (Zimmerman et al. 1995, Rivera and Aide 1998, Pascarella et al. 2000,Marcano-Vega et al. 2002). Ordination analysis based on the species composition of forests of different regions and different previous land uses (figure 5) shows that forests with similar histories of pre-abandonment use follow consistent patterns along the first ordination axis, while the effect of the geographic location is evident along the second ordination axis. In addition, where there are relatively intact forests, their composition is very different from that of adjacent forest areas that have recovered from human land uses (Zimmerman et al. 1995, Pascarella et al. 2000, Thompson et al. 2002).

  While forest structure (density, basal area) recovers in a few decades after abandonment, differences in vegetation composition persist much longer, because early invaders differ among pre-abandonment land uses, promoting local-scale heterogeneity. The fact that early successional species in Puerto Rico are successful exotic invaders or widespread pioneers, typical of many areas in the tropics (Aide et al. 2000), supports the idea of a broadscale homogenization (1163).
- (Grau et al., 2003) Other consequences of large-scale deforestation on C dynamics, however,may persist even when forest structure is recovered. For example,CO2 soil efflux due to decomposition is positively correlated with earthworm activity (Camilo and Zou 2001). Consequently, the high density and biomass of exotic earthworms (a legacy of the broadscale transformation of forest into pastures) significantly accelerates the decomposition of plant litter and increases CO2 flux from the soil to the atmosphere (most likely through changes in microbial activity; Liu and Zou 2002), indicating an increase in the turnover of soil organic C (1165).
- (Grau et al., 2003) (1) Forest structure and the ecological factors depending on it (e.g., biomass, erosion rates, alpha diversity) recover in a few decades in conditions of small farm sizes and infrequent use of fire; (2) in spite of rapid forest recovery, large-scale human disturbances have effects on biotic communities that may last for several centuries; and (3) the invasion by exotic species plays a key role in these long-lasting ecological effects, which include a large-scale floristic homogenization (1167).
- (Iwata et al., 2003) The scatter plot of PCA (Fig. 3), as well as the comparisons of each habitat variable by *t* tests (Table 1), showed that depositional character distinctly differed between the primary- and secondary-forest reaches. The secondary-forest reaches had finer substrates, more eroded banks, and larger areas of depositional habitat and cover than the primary-forest reaches (467).
- (Iwata et al., 2003) Our results showed that past deforestation strongly influenced the abundance, diversity, and taxonomic composition of benthic assemblages, with the overall effects being apparently detrimental, leading to a reduction in biodiversity of the stream communities (469-470).
- (Iwata et al., 2003) In both tropical and temperate regions, logging activities dramatically increase sediment input into streams (tropical rain forests: Douglas et al. 1992, Baharuddin and Abdul Rahim 1994, Greer et al. 1995, Malmer 1996; temperate forests: Ryan 1991, Waters 1995). However, once a ground cover of vegetation is reestablished, rates of erosion generally revert back to the original conditions within several years (tropical rain forests: Douglas et al. 1992, Baharuddin et al. 1995, Greer et al. 1995, Malmer 1996; temperate forests: Beschta 1978, Gurtz et al. 1980). Consequently, effects of sedimentation on stream communities can be weakened within a short period following logging. For example, in temperate streams, detrimental effects of sedimentation on benthic invertebrates have often been observed immediately after clear-cut logging (Gurtz and Wallace 1984, see also Garman and Moring 1991, Ryan 1991, Waters 1995), whereas such negative effects have rarely been detected in streams with riparian forests 5 yr following logging (e.g., Newbold et al. 1980, Murphy and Hall 1981, Hawkins et al. 1983, Bilby and Bisson 1992) (470).
- (Iwata et al., 2003) In this case, although the logging activities, together with frequent tropical storms, dramatically increased sediment input into streams, such input and

sediment stored in the channels rapidly decreased within a few years, associated with rapid reestablishment of vegetation (Douglas et al. 1992, Greer et al. 1995). These findings strikingly contrast with our results that impacts of heavy sedimentation on the stream communities had still continued after some 9–20 yr following the cessation of agricultural activities (470).

- (Iwata et al., 2003) Such an intensive and extensive alteration regime of slash-and burn agriculture is suspected to produce a much larger yield of sediment than the transporting capacity of streams (Douglas et al. 1993). The findings of this study provide strong evidence that past slash-and-burn agriculture exerted a ''press disturbance'' (sensu Bender et al. 1984), which reduced community diversity over a long period, in the tropical streams (471).
- (Grau et al., 2003) The analysis of 71 plots of different ages, climates, and types of geology across the island showed that, after 40 years of succession, secondary forests growing in abandoned pasturelands cannot be distinguished from mature old growth forests in terms of stem density and basal area (figure 4; Aide et al. 2000). Initial forest recovery on some abandoned pastures is slower than that following other natural or anthropogenic disturbances (Aide et al. 1995), but recovery accelerates after 10 to 15 years, when woody vegetation shades out the dominant grasses. In the karst region, differences in pre-abandonment land uses produced little differences in basal area and diversity recovery rates (Rivera and Aide 1998) (1161).
- (Grau et al., 2003) The small size of the farms (< 30 hectares [ha]) and the infrequent use of fire seem to be the factors that facilitate rapid forest structure recovery in Puerto Rican abandoned lands (1161).
- (Grau et al., 2003) During the early stages of succession, species composition is controlled by the local microenvironmental conditions and by the effects of pre-abandonment land use. In particular, the availability of perches for seed dispersers and the presence of food resources (especially fruit) as attractors for dispersers play a major role in the future forest composition (Wunderle 1997). In the temperate ecosystems of New England, which experienced regional forest recovery caused by processes of industrialization and urbanization, the species composition in secondary forests is highly variable locally (from field to field) but very similar at broader scales. Foster and colleagues (1998) found that local-scale differences are caused by legacies of specific agricultural or management practices such as crop type and frequency of plowing, while broadscale floristic homogenization results from human disturbance and a relatively short recovery time.This homogenization process is reinforced by repeated human disturbance and by species introductions that favor a reduced group of secondary species whose propagules are widely available (e.g., Aragón and Morales 2003). Broadscale human disturbance and abundance of exotic species are both characteristics of Puerto Rican ecosystems (Aide et al. 2000, Chinea and Helmer 2003), which suggests that this model of broadscale homogenization and local scale heterogeneity due to previous land use should apply (1161-1162).
- (Grau et al., 2003) Within regions, the dominant species often differ among the two main types of abandoned land uses, shade coffee and pasture, providing evidence of increased local-scale heterogeneity in forest composition (1162-1163).
- (Grau et al., 2003) If this pattern is confirmed, then unlike the C balance, which is affected mostly by stand age, N fluxes are affected mostly by forest composition, which largely depends on land-use history (1165).
- (Grau et al., 2003) Chronosequence studies indicate that the vegetation structure and the local (alpha) diversity of several taxa have recovered in less than 50 years and are relatively independent from the pre-abandonment land use. Similarly, rates of soil erosion and C sequestration recover to levels comparable to those of mature forest ecosystems in a few decades through unmanaged forest succession. In contrast, the local-scale species composition of secondary forests is strongly affected by preabandonment land use, and some ecological processes, such as N effluxes, are very sensitive to forest composition. At a regional scale, there seems to be a homogenization of species

composition in which exotic species have profound and longlasting ecological impacts. These species, ranging from trees to earthworms, establish early in succession and are still dominant in the oldest secondary forests. This suggests that a period of little more than a century of intensive LUCC will continue to influence the ecology of the whole island for much longer periods of time, most likely several centuries (1166).

- (Stanley and Doyle 2003) In many Midwestern states, reservoir sediments frequently contain a similar chemical legacy in the form of nutrient-rich particles derived from past and present agricultural activity (Stanley and Doyle 2002). Removal may then reintroduce nutrients that had been stored for decades, causing enrichment of downstream rivers, lakes, and even coastal areas. In support of this prediction, Gray and Ward (1982) found that the flushing of sediments from the Guernsey Reservoir on the North Platte River caused a sixfold increase in downstream phosphorus concentrations and stimulated the growth of large filamentous green algal mats (18).
- (Stanley and Doyle 2003) The specific nature of the trade-offs [when deciding whether ot not to remove a dam] will depend on the size and configuration of the dam and reservoir, local legacies, and the composition of the resident biota (20).
- (Paul and Meyer 2001) PCBs are still frequently detected in urban areas of the United States, even though their use in manufacturing was outlawed because of their carcinogenic effects. These compounds are very stable and are still found in fish at concentrations exceeding consumption-level guidelines in urban rivers such as the Chattahoochee River below Atlanta, Georgia (Frick et al. 1998). PCB concentrations were highly correlated with urban land use in the Willamette Basin in Oregon as well (Black et al. 2000) (345).