Harry R. Hughes Center for Agro-Ecology, Inc.

FINAL REPORT

Assessing Forest Buffer Functions after Five Years

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EXECUTIVE SUMMARY

Restored forest buffers have multiple ecological functions that develop at different rates over time depending in part on tree survival and growth. These practices become more cost-effective as a restoration strategy if retained long-term. Maryland has planted over 1,300 miles of riparian forest buffers since 1996 to help restore the Chesapeake Bay and its tributaries. Thirty-four buffers, newly planted with trees, were monitored between 2000 and 2008 in the Monocacy, Catoctin, and Antietam watersheds. These are focus areas for buffer restoration in Maryland. Monitored buffers averaged over 100 feet in width. They were located in mostly small, rural watersheds, ranging from 38 up to 19,000 acres in drainage area. Impervious surfaces were mostly between 2 to 11% of the watershed, but ranged up to 66%. Forest cover in the catchment drainage areas ranged from 2 to 85%, and stream buffers upstream of the monitoring locations ranged from 0 to 91% forest.

Vegetation- Tree survival was measured across all species as the most basic element for establishing function. More than 80% of the young trees survived the first year after planting. However, losses continued at up to 12% per year for four years. The losses were attributed to drought, grass competition and lack of maintenance. Survival stabilized by the fifth year at around 50%, averaging just over 200 trees per acre. Vegetation richness increased from 165 to 276 species, a 67% increase, with most gains from new woody species. Invasive exotic weeds also increased, with some initially entering the watershed during the study period.

Water and Stream Quality- Nitrate and phosphate generally showed improving trends, but variability among sites and years resulted in differences that were not considered significant at five to seven years of age. Average instream nitrate declined 1 to 2 mg/l from 2001, averaging less than 4 mg/l in 2008. Turbidity did not show any discernable trends. Dissolved oxygen levels were consistently in the healthy ranges for aquatic life, and pH values were neutral to slightly alkaline, reflecting the limestone geology in the valleys. For macroinvertebrate studies, an average of two additional taxa per site were found in 2006, a significant increase only five years after buffer establishment. Index of Biotic Integrity increased on 64% of forest buffer sites, but the modest changes were not statistically significant at this time. The Pfankuch Streambank Stability rating significantly improved between 2003 and 2008, although the more urbanized watershed with 66% impervious surfaces upstream was consistently less stable.

Values per acre: Hardwood buffers were modeled for growth and product value on 14 sites. Three pine-dominated buffers on the Eastern Shore also were measured to provide a wider range of potential forest products. The pine-dominated buffers had already reached crown closure and would be suitable for thinning by the end of a 15-year Conservation Reserve Enhancement Program (CREP) contract. Potential income at 30 years averaged \$974/acre for pines, with thinning. Hardwoods averaged \$1170/acre at 80 years and ranged up to \$4300/acre, but most sites had little potential for thinning. Half of the hardwood sites sampled had such low stocking (<60 ft^2/ac.) that they were unlikely to yield enough to be harvested economically. To compare the different time frames and compare to other investments, net present value (NPV) of harvestable timber in the buffers was calculated using a 4% alternative rate of return. NPV averaged \$51 for hardwoods harvested at 80 years, and \$541 for pines at 30 years with thinning. Both estimates assumed leaving required trees by streams for shading. The NPV of CREP

payments was about $2500, and would preclude commercial harvest until after contracts expired. Values for water quality and air quality were estimated at $419/year and $60/year, respectively. Adding some hunting lease income for $10/year and annualizing timber income ($15/year for hardwoods) gives $504/acre/year for these values alone.

Practices for Growing Benefits: Based on these results and other longer-term studies, faster growth, denser tree stocking, and greater biomass appear to be associated with earlier production of expected benefits. Hardwoods on sites with heavy grass competition experienced lower survival and growth. Significant benefits may take 15 to 20 years to develop, coinciding with expected crown closure by the young trees. Timely riparian restoration and development of expected ecological functions depend on sufficient site preparation, matching species to site conditions and actively maintaining good growing conditions around planted trees for at least 3 to 5 years. Given the array of existing and new pests and diseases that are likely to attack common riparian species, planting a diversity of species is an important step to build in long-term resilience. Natural regeneration can add even more species and diversity, but shifting ecological conditions, particularly in deer browse levels and fire exclusion, mean that some important native species are sparse or absent unless planted. For example, oaks are species that have advantages for both wildlife and water quality but are declining in abundance. The advantages of fast-growing species in developing forest conditions should be balanced with pursuit of diversity for long-term resilience and native species suited to the site conditions. Damage from deer browse and invasive weeds was common, suggesting that these are important factors to address long-term to improve riparian forest restoration and future condition. Good maintenance practices that encourage greater survival and more rapid tree growth of all species support more rapid development of environmental functions and greater potential for future income from forest products.

Cost-effectiveness: Using conservative calculations for four categories of benefits, investments in riparian forest buffers have a positive payback within the first decade. Using typical cost of a CREP contract of over $3700 per acre over 15 years for a hardwood buffer and an average $504/acre/year in benefits suggests a positive return within eight years. Comparing annualized per acre costs of a 15-year CREP contract ($206) with conservative annualized benefits of $504 yields twice as many benefits as costs, a ratio that improves with the continued growth of benefits for multiple decades and with consideration of additional benefits like flood control and temperature reduction for trout streams. Some benefits such as nutrient reduction associated with the change in land use offer immediate return. Other benefits such as timber and greater filtering of upland runoff would increase gradually over 15 years or more. To further increase cost-effectiveness of public investments and to generate long-lasting environmental benefits, it is important to develop policies and incentives that encourage retention of recently restored buffers for multiple decades. Targeting practices to locations with high nutrient loading also improves cost-effectiveness where riparian forest buffers are an appropriate practice. Allowing harvest of buffers using appropriate sediment control practices and continuing to permit fast-growing early successional species like native pines, sycamore, or black walnut as components for conservation plantings can help create long-term incentives for landowners to retain wider buffers. Harvest BMPs can maintain water quality functions and shade near waterbodies while regenerating new trees beyond 50 feet, and appropriate silvicultural treatments can encourage young trees that allow the forest buffers to perpetuate themselves for continued benefits. Cost-effectiveness and greater environmental function are both supported by long-term retention of forest buffers.

Policy implications: Riparian forest buffers are important and cost-effective components in long-term nutrient reduction strategies like Watershed Implementation Plans to meet Total Maximum Daily Load limits because of 1) the pattern of increasing functions over decades without annual investments and 2) the potential to self-regenerate with minimal future investment if designed with sufficient width and managed correctly. Benefits from riparian forest buffers can be expected to build over time in relationship to growth and biomass of vegetation, usually becoming significant within 15 years of establishment. The increase in buffer function over time and likely survival beyond the minimum practice life can help provide reasonable assurance that nutrient reduction benefits will be maintained over time. Policies supporting adequate maintenance of newly planted buffers for at least five years are important to rapidly achieve full buffer function and the desired range of benefits. Targeting can further improve cost-effectiveness, because the expected nutrient reduction can vary greatly depending on land use/nutrient loading, soil/site characteristics, and shallow groundwater flow paths, and water quality is a substantial portion of the public value of a forest buffer. When establishing forest buffers, landowners should consider balancing fast growth rates and desired species with a diversity of species to minimize the risk of losing function to new pests or diseases. The commitment to control weeds around planted trees for several years should be made clear to landowners, and there should be sources of assistance to support good maintenance during the critical early years, which can make the difference between a barely functional buffer and a forest buffer resilient to the changes in climate and nutrient loading that are expected. Management should include attention to controlling invasive species, keeping active growth, and assuring new tree regeneration over time, whether volunteer seedlings or planted.

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INTRODUCTION

Maryland has planted over 1,300 miles of riparian forest buffers (RFBs) since 1996 to help restore the Chesapeake Bay and tributaries. Mature RFBs have been widely shown to substantially reduce nutrients such as nitrogen and phosphorus (Mayer et al. 2007, Lowrance et al. 1997, Peterjohn and Correll 1984). Other riparian forest buffer functions that develop over time include shading, bank stability, carbon sequestration, and wildlife habitat, both aquatic and terrestrial (Naiman et al. 2005). The rate of development of buffer functions in newly restored buffers is not well-studied. Substantial public investments and land acreage has been and continues to be devoted to the practice, and policymakers and managers need better information on the likely time frames for desired functions.

Estimates of time for buffers to develop water quality functions have varied, depending on region and forest type. Newbold et al. (2010) found significant water quality functions by 15 years in eastern Pennsylvania, but these results followed a period of rapid tree growth and were not significant prior to 10 years. Vellidis et al. (2003) found that restored pine/hardwood riparian areas as well as mature buffers could effectively reduce nutrients, with up to 78% N reduction within nine years on the Georgia Coastal Plain. Licht and Schnoor (1990) found significant nitrate reduction only one year after establishing a dense, fast-growing poplar buffer in Iowa. Sutton (2006) found significant nitrate reduction in pine/hardwood buffers as young as seven years old in the Choptank watershed of Maryland, with greater reductions in an older planting and mature buffers. Fennessy and Cronk (1997) reviewed nutrient removal functions and restoration potential of buffers, estimating that buffer functions could take 20 years to develop in a newly restored area. Previous work evaluating survival and height growth at riparian forest buffer sites around Maryland suggested that crown closure, creating shaded forest conditions, is likely to occur at about 10 years after planting (Pannill et al. 2001). This study evaluated functions of buffers between five and eight years old.

Measures were designed to characterize a range of attributes of the developing forest buffers, particularly since more than one attribute may contribute to a desired function. For example, forest buffers support nutrient reduction in the near-stream area, but also support greater nutrient reduction within the stream itself, which is related to larger areas of suitable benthic habitat (Sweeney et al. 2004). Benthic macroinvertebrates were used to assess aquatic habitat since they are the base of the food chain and are sensitive to organic pollution, reduced oxygen concentrations in stream water, and sedimentation. Biotic indicators such as benthic macroinvertebrates rely on favorable stream conditions throughout their life cycle, so their community composition provides an assessment of stream health that includes the past and present, while a chemical snapshot assesses only the present (Vannote et al. 1980). The Maryland Biological Stream Survey (MBSS) Index of Biotic Integrity (IBI) is based upon extensive study of specific benthic macroinvertebrate taxa and their sensitivity to various levels of organic pollution (Stribling et al. 1998). Fish IBIs were not used because the small size of many of the buffered streams limited the potential for a diversity of fish species. Other metrics of stream health from the standard MBSS methods were used to characterize aspects of the stream habitat and augment understanding of trends in IBI.

The value of riparian forest buffer functions is important information for policymakers and managers. Costs expended in dollars are readily quantified; most of the multiple benefits of buffers are not as easily assessed or valued. Much of the public investment in forest buffers to date has been related to the nutrient reduction function. In addition to values associated with nutrient reduction, buffers are simultaneously providing other potential economic benefits from fiber, recreation, and air quality. Some of the major benefits can be estimated with the use of established models, so the measured characteristics of the buffers, installed using standard practices, were used to develop benefit estimates for a range of functions.

METHODS

Site Locations

Thirty-four newly planted buffers were monitored between 2000 and 2009 in the Monocacy and Antietam watersheds, which are long-term focus areas for buffer restoration in Maryland based on the high nutrient loading and low percentage of forest buffers in these basins. Sites were located in the Piedmont, Blue Ridge and Ridge and Valley physiographic provinces of Maryland. The buffer locations were adjacent to agricultural land, usually pasture in a limestone valley setting. Average precipitation for the region is 42 inches annually, arriving primarily as rainfall and generally well-distributed throughout the year, with occasional summer droughts. Deer browse is significant at most sites, and tree shelters were used to limit browse on a portion of seedlings at most sites, usually about a third of the planting stock.

The buffer sites were planted with a variety of hardwood trees, primarily seedlings, between 1999 and 2002, and monitoring began the year of establishment. The sites were located in Frederick, Washington and Carroll Counties in the focus watersheds of Monocacy, Antietam, Catoctin and adjacent direct drainages to the Potomac River. The larger watersheds in which the buffer monitoring sites were located are priority areas for establishing forest buffers because the streams had fewer forest buffers than many other areas of the state and the watersheds contain both significant stream impairment and important natural resource areas. An additional three sites planted with loblolly pine and mixed hardwoods were measured just for tree growth in the Coastal Plain on the Eastern Shore in Somerset County to establish a wider range of perspective for growth rates, canopy closure, and forest product potential. Buffer sites were all on private lands with riparian forest buffers created through the Conservation Reserve Enhancement Program (CREP) using standard practices, planting densities, and reinforcement planting as needed. Two sites were lost when landowners withdrew from the CREP program and additional sites were added to replace them. Restored buffers averaged over 100 feet wide.

The 34 sites combined two buffer monitoring efforts. Fourteen sites were measured for baseline conditions in 2000 (Hairston-Strang et al. 2001) and were only remeasured after five years (referred to as RFB sites). One of these sites, RFB-8, was never planted to trees but active agriculture was not practiced. The RFB sites had detailed benthic macroinvertebrate sampling to develop an Index of Biotic Integrity, and full herbaceous and woody species plot sampling to develop a detailed plant species list. Twenty sites were measured annually as part of the Potomac Watershed Partnership effort (referred to as PWP sites). The PWP sites' annual measurements allowed a better look at development through time; these sites had an additional fixed plot area (1/2 acre) for calculating survival of planted trees. Both used plot data to evaluate naturally regenerating trees as well as planted trees.

Methods are detailed in Appendix A. Measured characteristics included:

- tree survival, stocking, height, and diameter,
- invasive exotic plant presence,
- stream cross-sections, bank pins, and visual assessment for bank stability,
- benthic macroinvertebrates,
- stream temperature with temp loggers active spring through fall,
- spring and summer instream water grab samples analyzed for N and P,
- instream turbidity, pH, and dissolved oxygen

Water quality was measured in the spring and fall using grab samples sent to professional labs for analysis of nitrogen and phosphorus. The pH, dissolved oxygen and turbidity were measured on-site with meters.

Watershed Metrics

Land use is an important consideration when evaluating watersheds and water quality. Forest cover, extent of buffers, impervious surfaces, and percent agricultural land have been found to be related to stream health and quality (Snyder et al. 2005, Booth et al. 2002). Watershed boundaries were identified for the areas draining to the forest buffer monitoring sites using delineation tools in ArcView 9.3. Landscape characteristics likely to affect water quality were calculated for each drainage area (Figure 1). These contributing watersheds had only 27% forest on average (Table 1), although they ranged from none up to 85% forested. Where forests were present, they were more likely to be along the streams. The waterways upstream of monitoring sites averaged only 38% forest, ranging from none in some of the small contributing areas up to 91%.

Impervious surfaces greatly affect stormwater runoff and other hydrologic functions, with increased storm flows and decreased summer flows being common in watersheds over 10-15% impervious surfaces (Booth et al. 2002). Effects on brook trout, a native cold-water fish sensitive to water quality, have been seen in watersheds with less than 5% impervious surfaces (Boward et al. 1999). Most sites had contributing watersheds with less than 5% impervious surfaces (Figure 2). Only three sites were 10% and above for impervious surfaces, and only one was comparatively urbanized, the PWP-5 site in Carroll County at 66%. Agriculture was the dominant land use in most of the contributing areas for these monitoring sites, averaging 65% and ranging from a low of 11% up to entirely agricultural.

The linkages between buffer sites and their watersheds are complex, and many factors throughout the watershed can influence instream water quality and habitat (Allan 2004). Impervious surfaces, agricultural lands, road runoff, and in-channel erosion can all alter stream quality irrespective of riparian conditions. The scale of investigation can also affect observed relationships (Strayer et al. 2003), as can the regional and hydrologic context (Poff et al. 2006). Buffer effects have been consistently measured at the site scale (e.g., Mayer et al. 2007), but effects at the watershed scale have been more difficult to identify and analyze (e.g., Richards and Host 1994, Omernik et al. 1981). Soil type, slope, and landscape position all affect nutrient reduction ability (Vidon and Hill 2004). Sutton et al. (2009) could not distinguish water quality improvements at the watershed scale in Maryland's Choptank watershed, even though up to 25% of the waterways had been planted to buffers and significant nutrient reductions were found in shallow groundwater of forest buffers at the site scale (Sutton 2006). Greater levels of implementation and longer time frames could be needed to discern a watershed-scale response. King et al. (2005) identified the spatial arrangement as an important factor in analyzing effects of land cover on streams, and Tran et al. (2010) factored in spatial proximity to identify the relatively greater importance of near-stream land use.

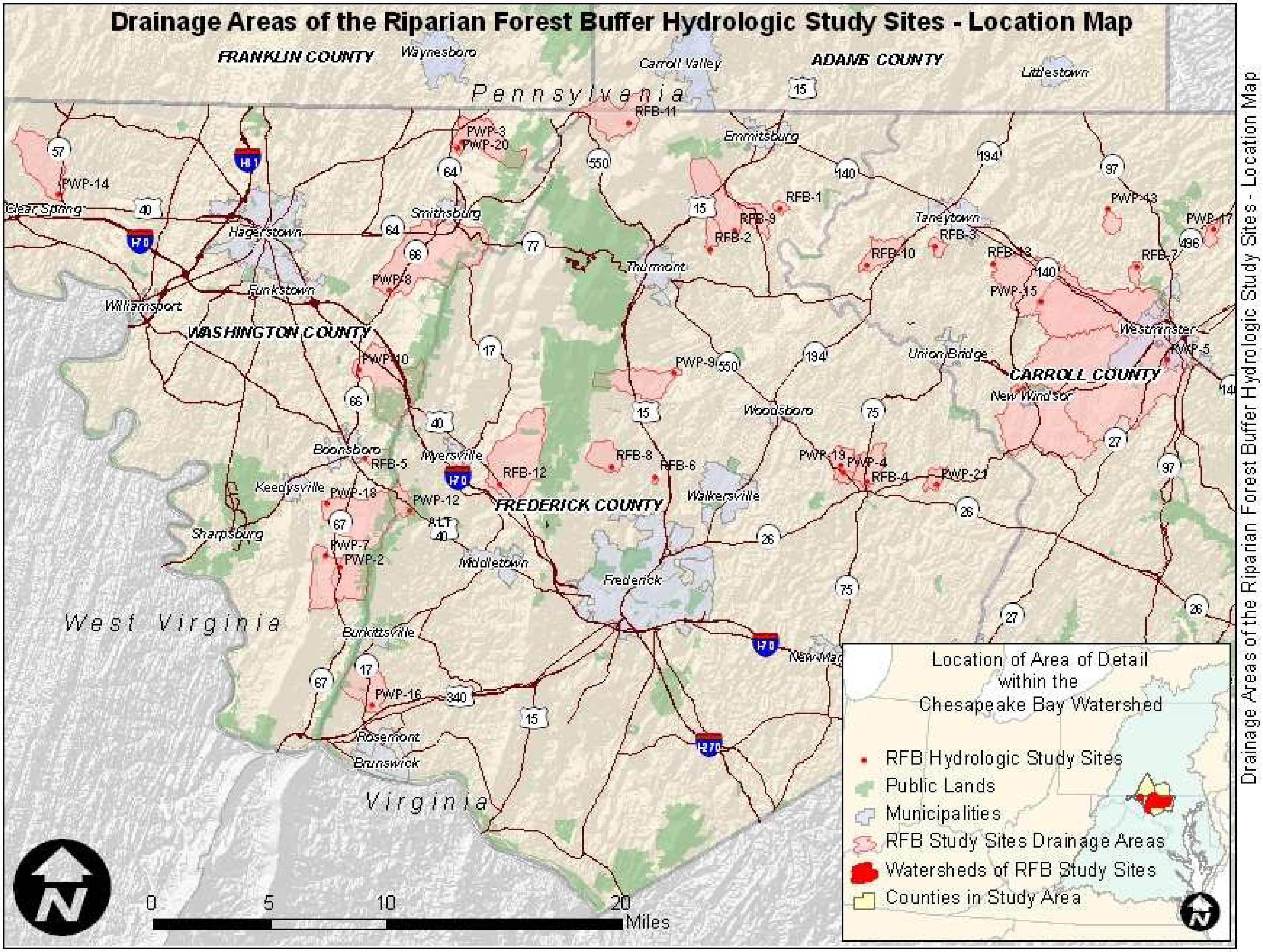

Figure 1: Defined watersheds for 34 forest buffer monitoring sites in Carroll, Frederick, and Washington Counties, MD

Table 1: Watershed Metrics by Site

Site	*County*	*Watershed Acres*	*Forest Acres*	*Forest Percent*	*Buffers upstream(ac)*	*Forested buffers(ac.)*	*Forested buffers(%)*	*Impervious Surface(Ac.)*	*Imperv. Surface(%)*	*Ag. Land(Ac)*	*% Ag. Land*
RFB-5	Washington	344	291	**85%**	25	18	70%	4	1%	37	11%
PWP-10	Washington	3594	2430	**68%**	400	289	72%	119	3%	967	27%
PWP-12	Frederick	657	427	**65%**	21	16	77%	11	2%	149	23%
RFB-12	Frederick	4043	2391	**59%**	173	95	55%	44	1%	1357	34%
RFB-11	Frederick	2039	1104	**54%**	96	39	40%	53	3%	753	37%
PWP-2	Washington	1582	766	**48%**	82	39	48%	34	2%	734	46%
RFB-8	Frederick	944	422	**45%**	87	37	42%	28	3%	443	47%
PWP-18	Washington	3208	1414	**44%**	499	224	45%	59	2%	1636	51%
PWP-7	Washington	3197	1408	**44%**	415	201	48%	77	2%	1592	50%
RFB-9	Frederick	2498	1094	**44%**	141	71	50%	62	2%	1243	50%
PWP-8	Washington	6047	2422	**40%**	361	155	43%	248	4%	2887	48%
PWP-3	Washington	2065	726	**35%**	157	49	31%	43	2%	1228	59%
PWP-20	Washington	2110	727	**34%**	172	49	29%	44	2%	1271	60%
RFB-7	Carroll	270	79	**29%**	6	5	91%	9	3%	190	70%
PWP-9	Frederick	2013	537	**27%**	157	60	38%	31	2%	1308	65%
PWP-19	Frederick	904	212	**23%**	120	19	16%	52	6%	681	75%
PWP-16	Frederick	1693	376	**22%**	115	26	23%	28	2%	1218	72%
PWP-13	Carroll	339	65	**19%**	19	4	23%	11	3%	274	81%
PWP-15	Carroll	6492	1082	**17%**	406	135	33%	445	7%	5050	78%
PWP-6	Carroll	13753	2023	**15%**	866	219	25%	1481	11%	10139	74%
RFB-13	Carroll	9476	1395	**15%**	593	176	30%	554	6%	7667	81%
PWP-14	Washington	2435	345	**14%**	179	47	26%	36	1%	1980	81%
PWP-1	Carroll	19161	2580	**13%**	1129	282	25%	1798	9%	14858	78%
RFB-10	Carroll	968	94	**10%**	57	16	29%	17	2%	845	87%
RFB-4	Frederick	1035	98	**9%**	86	19	23%	49	5%	925	89%
PWP-17	Carroll	298	24	**8%**	0	0	na	12	4%	275	92%
PWP-5	Carroll	300	22	**7%**	11	8	72%	197	66%	50	17%
RFB-14	Frederick	720	26	**4%**	14	1	3%	18	3%	659	92%
RFB-2	Frederick	445	11	**2%**	20	4	19%	9	2%	414	93%
PWP-21	Frederick	397	8	**2%**	4	0	0%	12	3%	382	96%
RFB-3	Carroll	252	6	**2%**	0	0	na	10	4%	244	97%
RFB-6	Frederick	38	1	**2%**	0	0	na	1	2%	26	67%
PWP-4	Frederick	215	0	**0%**	20	0	0%	21	10%	206	96%
RFB-1	Frederick	168	0	**0%**	0	0	na	4	3%	168	100%
Average		**2756**	**724**	**27%**	**189**	**68**	**38%**	**165**	**5%**	**1819**	**65%**

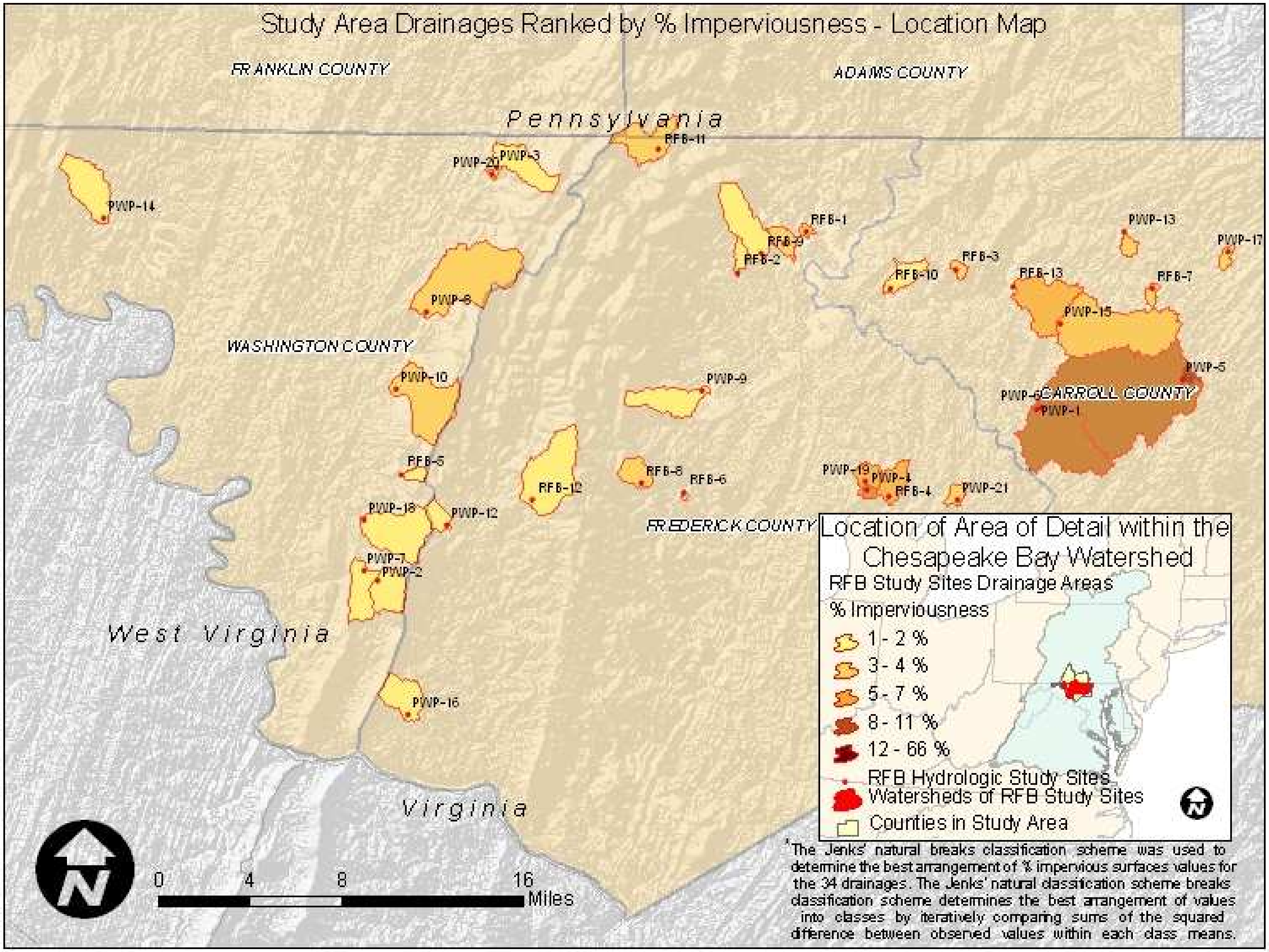

Figure 2: Percent impervious surfaces within drainage areas of riparian forest buffer monitoring sites

RESULTS AND DISCUSSION

Vegetation trends

Tree survival and growth are necessary first steps in restoring forests and their associated functions. Many of the multiple ecological functions of forest buffers depend on the development of sufficient height, leaf area, and biomass production, so rates of tree survival and growth fundamentally affect rates of increases in functions. Over 80% of seedlings survived during the first year based on 2001-2007 data. These results indicate very good survival during the period typically used to evaluate successful establishment of riparian forest buffer restoration. However, survival continued to decline at about 12% per year for two more years, and another 5% per year for the following two years (Fig. 3).

Figure 3: Percent survival of all species of seedlings planted in riparian forest buffers on old pasture sites in Potomac Watershed Partnership (PWP) focus watersheds (Year 1, n=4862; Year 2, n=4399; Year 3, n=4144; Year 4, n=4253; Year 5, n=2894; Year 6, n=3049; Year 7, n=1057). Trees were established on 22 sites in different years and not all trees were measured every year.

Many of the buffers were planted in 2001 and 2002, which were dry years, and reinforcement planting was needed at numerous sites. Study sites were pasture where fescue was a strong competitor for nutrients and water. These factors suggest that growth and survival might be greater in some other settings with less competitive weeds or more rainfall. Nonetheless, the longer-term survival pattern suggests that further reductions in survival after the critical first year should be expected. Survival has been relatively stable at just under 50% after five years, several of which were very dry.

Some follow-up survival checks and greater support for replanting after 4 years may be prudent to encourage more rapid development of forest conditions and greater landowner satisfaction with practice success. These sites were all on private lands with landowners following normal protocols and the sometimes normal departures from recommended maintenance practices like mowing or spraying for weed control. CREP program restrictions on mowing during the nesting season can also limit maintenance, particularly after the first year or two when more frequent maintenance is allowed for initial establishment. These tasks are rarely funded for cost-share, and rely on further landowner investments and attention. Buffers without maintenance appear to have had very low tree survivorship.

Although the study was not designed to rigorously test the effects of shelters on seedling survivorship, it does provide some general insights regarding effects of tree shelter use. Shelters appeared to offer some advantages for survival in the first few years, although differences in survival of sheltered versus unsheltered seedlings were less clear after 7 years. Overall, 55% of 3038 sheltered seedlings survived, compared to 44% of 1824 unsheltered seedlings. Previous research had identified species that benefit more from shelters (Sharew and Hairston-Strang 2005). In practice, tree shelters often are used on a portion of the seedlings to keep costs reasonable. Foresters usually recommend using shelters on vulnerable species like oaks and not sheltering fast-growing, unpalatable species such as sycamore and black walnut. While this is efficient in practice, it complicates analysis of the effect of shelters on survival. Differences in survival would be expected to be greater if the same mix of species were used in the sheltered versus unsheltered trees. Advantages of shelters have been shown in other trials, although at varying levels (Sweeney and Czapka 2004; Conner et al. 2000; Sweeney et al. 2002; Stange and Shea 1998, Lantagne 1995).

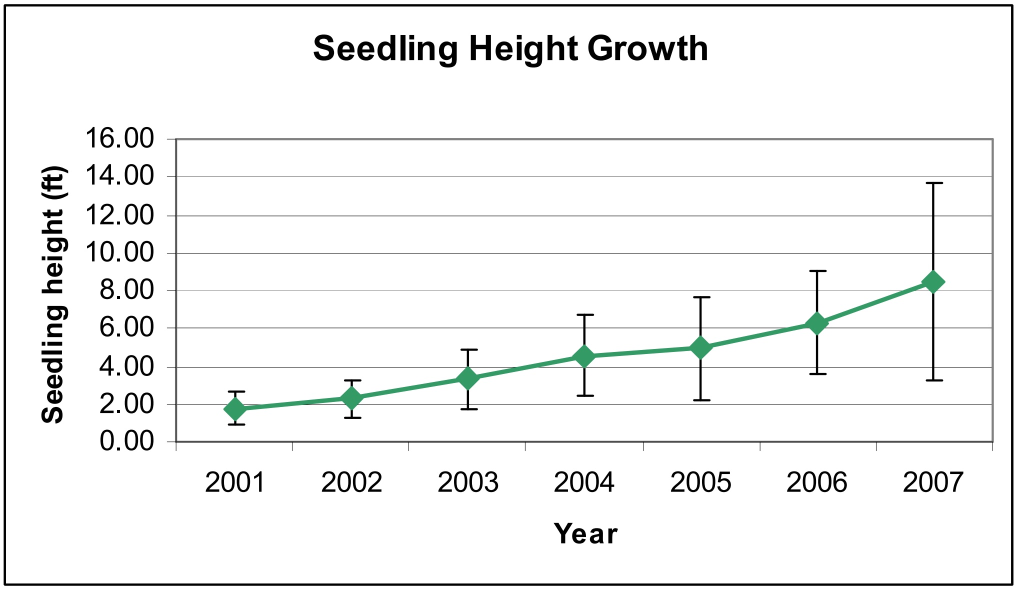

Figure 4: Height growth of seedlings from 2001 to 2007, representing mean and standard deviation as measured across all species and all PWP sites

Average height growth of seedlings was 1.1 feet/year for the seedlings that survived (Figure 4). This was lower than the average 1.8 feet/year measured statewide on 1 to 15-year-old buffers in 1999 (Pannill et al. 2001). The lower height growth may have been affected by the dry summers in the 2001/2002 period when many of these buffers were being established, as well as the dominance of fescue competition on many of the long-term monitoring sites. Species composition also varied among sites and studies, and the natural species-specific height growth rates could be contributing to observed differences. Typical practice for planting hardwood tree seedlings was planting on a spacing of 10 feet by 10 feet, a density of 436 trees per acre. Because just under half of the seedlings have not survived, tree density averaged about 210 trees/acre with an average spacing of 14 feet. Based on the growth rate and average spacing, canopy closure would be expected at about 15 years; it would be expected to vary between 10 and 20 years depending on actual spacing and patchiness of mortality.

In 2007, 276 plant species were found at 14 riparian forest buffers sites, up from 165 species in 2000, just after being planted to trees (Table 2, Figure 5). This is a 67% increase in number of species, contributing to plant diversity that is valued for supporting broader ranges of insects and wildlife and thought to contribute greater resilience and productivity over time for vegetative communities. This diversity is also key to maintaining health over time as conditions change, like climate and exotic pests.

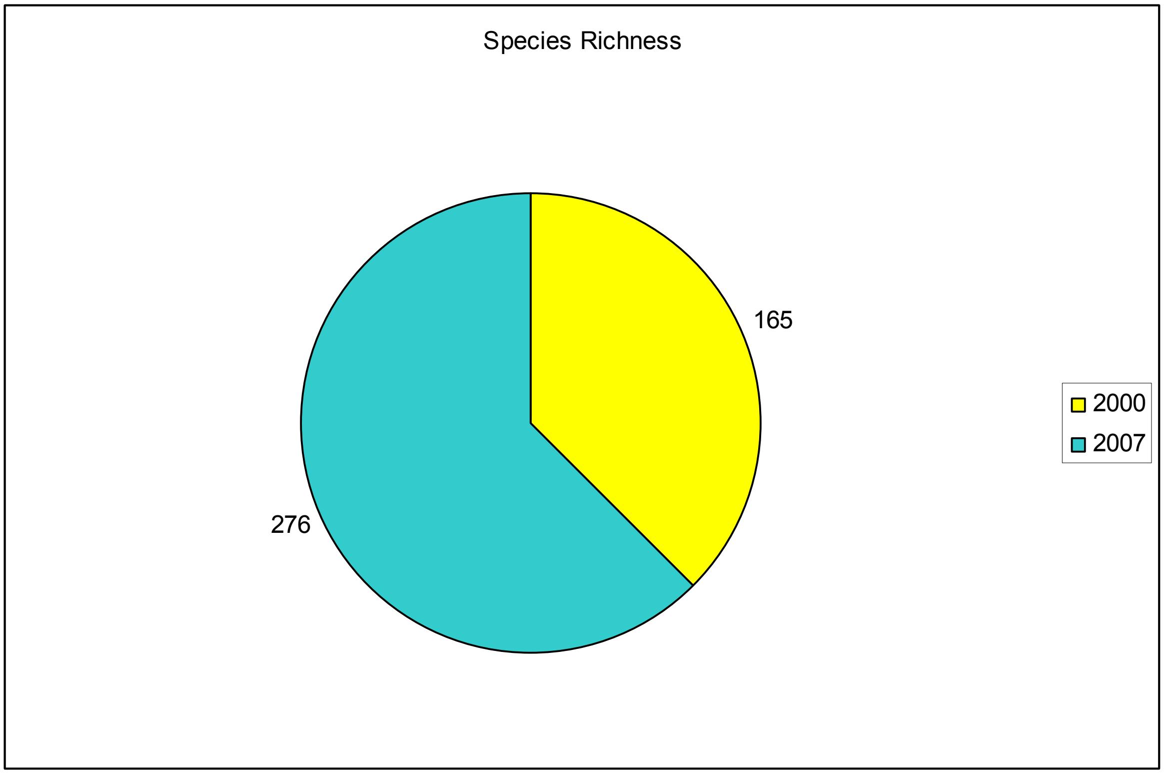

Figure 5: Species Richness of plants in monitoring plots on 14 Riparian Forest Buffer monitoring sites

Table 2: Species Richness on 14 Riparian Forest Buffer (RFB) Monitoring Sites, Monocacy, Catoctin, and Antietam watersheds, Maryland

	2000	**2007**	**% Increase**
Species Richness	165	276	67%
No. of Exotic Invasive weeds	34	59	74%
No. of Noxious weeds	4	5	25%

Some invasive weeds are so troublesome that they are regulated as noxious weeds and control is required. Maryland law regulates 4 species of thistles, Johnsongrass, and shattercane. The noxious weeds originally found in 2000 usually remained in the riparian areas, and were seen on more plots. Thistles were the noxious weed most frequently seen in the study area, including Canada thistle (*Circium arvense*), bull thistle (*Circium vulgare*), and musk thistle (*Carduus nutans*). In 2007 one additional species of thistle, the plumeless thistle (*Carduus acanthoides*), was identified, increasing by 25% the number of noxious species found. Exotic invasive weeds increased more significantly, and made up 25 of the 111 new species. Exotic invasive weeds are problematic for restoring native plant communities but are not required to be removed by Maryland law as are the regulated noxious weeds. Earlier studies found that just over half of the restored buffer sites have some occurrence of exotic invasive plants (Pannill et al. 2001), but that they generally averaged less than 20% of cover (Wrabel 2003). The common occurrence of invasive weeds suggests that ongoing evaluation of site conditions should be planned as a routine part of forest buffer restoration, and corrective maintenance applied if severity of infestation and threat to tree growth warrants.

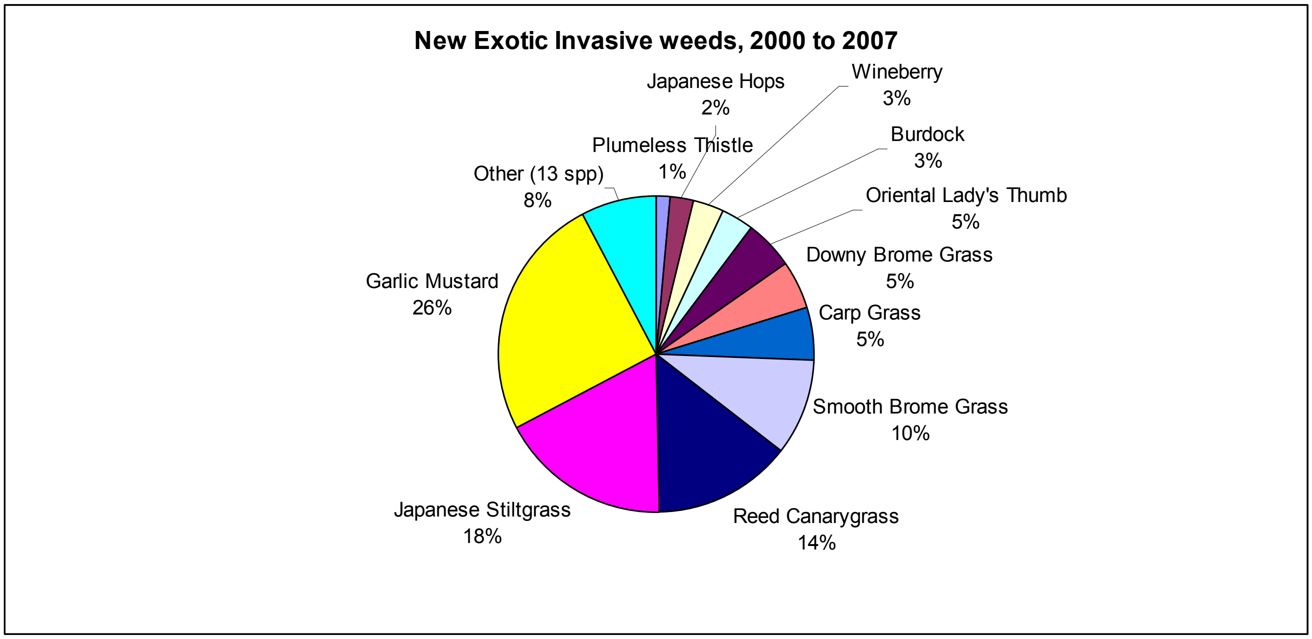

Figure 6: Exotic invasive plants newly observed in 2007 plant inventory on 14 Riparian Forest Buffer planting sites

A few of the exotic invasive plants were much more frequently seen on study plots (Figure 6). These include garlic mustard (*Alliaria petiolata*), Japanese stiltgrass (*Microstegium vimineum*), and reed canarygrass (*Phalaris arundinacea*). Invasive exotic species that moved into the region during the study time period, such as Japanese hops (*Humulus japonicus*), made up some of the new species. Japanese stiltgrass and garlic mustard had been in the area, but were spreading rapidly during the time period; these were not initially observed in the riparian areas in 2000.

Investments in control of invasive weeds can limit spread early on, and usually require several years of treatment. Persistent treatment can greatly reduce impact of invasive species and allow native species to more fully occupy the site. Some species can be expected to decline over time as shade increases. The trees on the sites have not reached crown closure, so sun-loving exotic species can still thrive there. As shading increases, some shade-intolerant species like multiflora rose and mile-a-minute may become less abundant or vigorous if they have not prevented tree growth. New curbs on growth of problem species also could help diminish effects over time, such as the rose-rosette disease spreading naturally through the multi-flora rose population, or the weevil being cultivated as a biological control for the mile-a-minute vine. Shade-tolerant species like stiltgrass and garlic mustard would be expected to remain problematic even after forested conditions are established.

Water Quality Data Summary

Water quality sampling offered a snapshot of conditions at or close to baseflow because sampling was avoided during rain or high runoff. PWP sites were sampled twice a year in spring and late summer between 2001 and 2008. RFB sites were sampled in 2001, 2007 and 2008 only. Collection sites were located at the upstream and downstream ends of the restored buffer area. Water levels were generally higher in the spring, avoiding missed samples due to dry streams, and downstream values were considered more likely to incorporate any effect of the young buffer, so spring downstream measurements have been used for displaying values to the extent possible. Comparisons were made of upstream and downstream values where streamflow permitted, but variation among sites was too great for observed declines in nutrients to be significant.

Nitrogen (Nitrate) and Phosphorus

The average instream nitrate at 14 RFB sites was 3.38 mg/l in 2001, and declined 1 mg/l to 2.45 mg/l in 2008 (Figure 7). These differences were not considered significant at a 95% level of confidence (p=0.11).

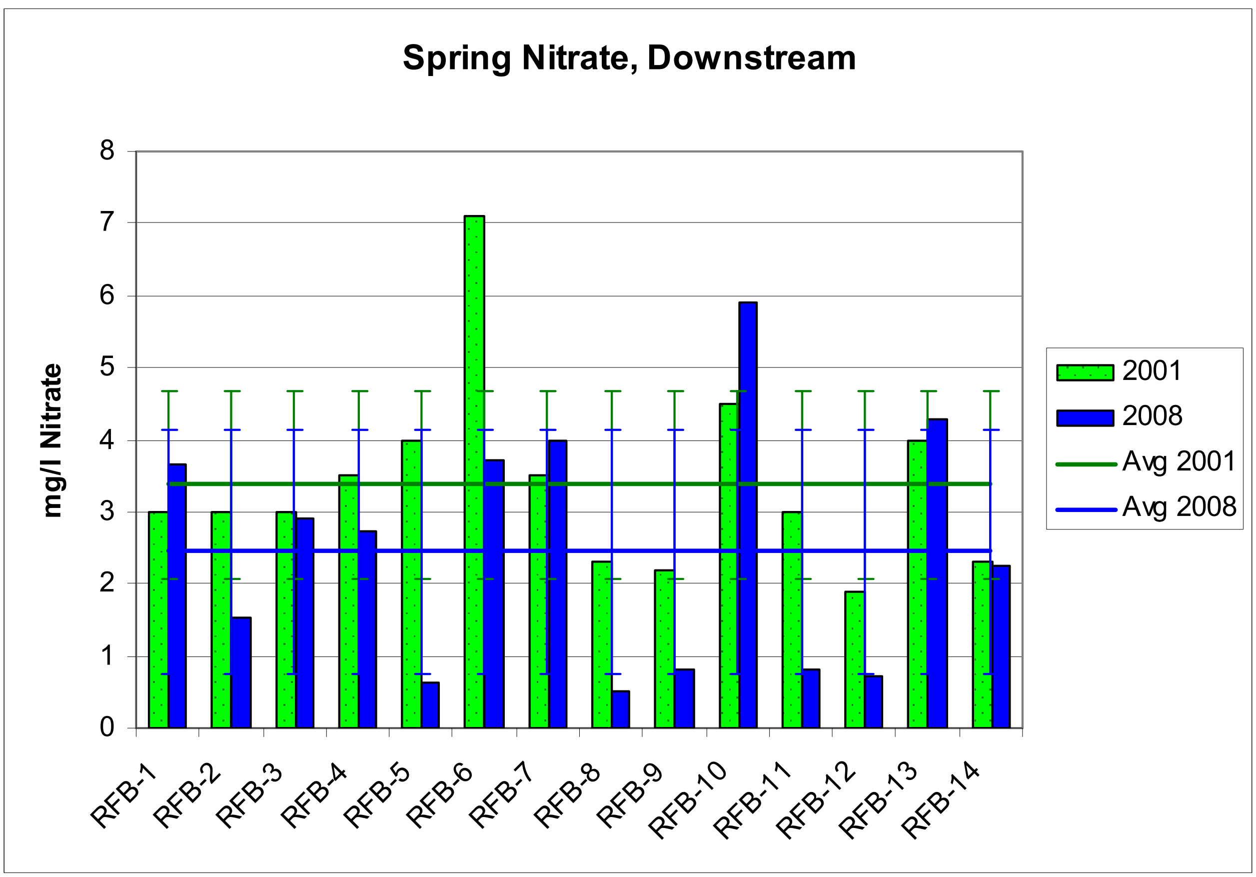

Figure 7: Instream nitrate at downstream locations on 14 riparian forest buffer sites, Spring sampling period in 2001 and 2008, with mean and standard deviation

For the annual measurement of PWP sites, the average nitrate value was 3.6 mg/l in 2008, lower than the average of 6 mg/l in 2001 (Figure 8). However, these differences were not significant (p=0.12), with substantial variability among sites and years. Patterns for either set of sites were not consistent and not closely correlated with tree stocking, which may not be surprising given the relatively small biomass of the young trees. The water quality values are based on grab samples from the stream and so reflect conditions throughout the watershed upstream of the buffers.

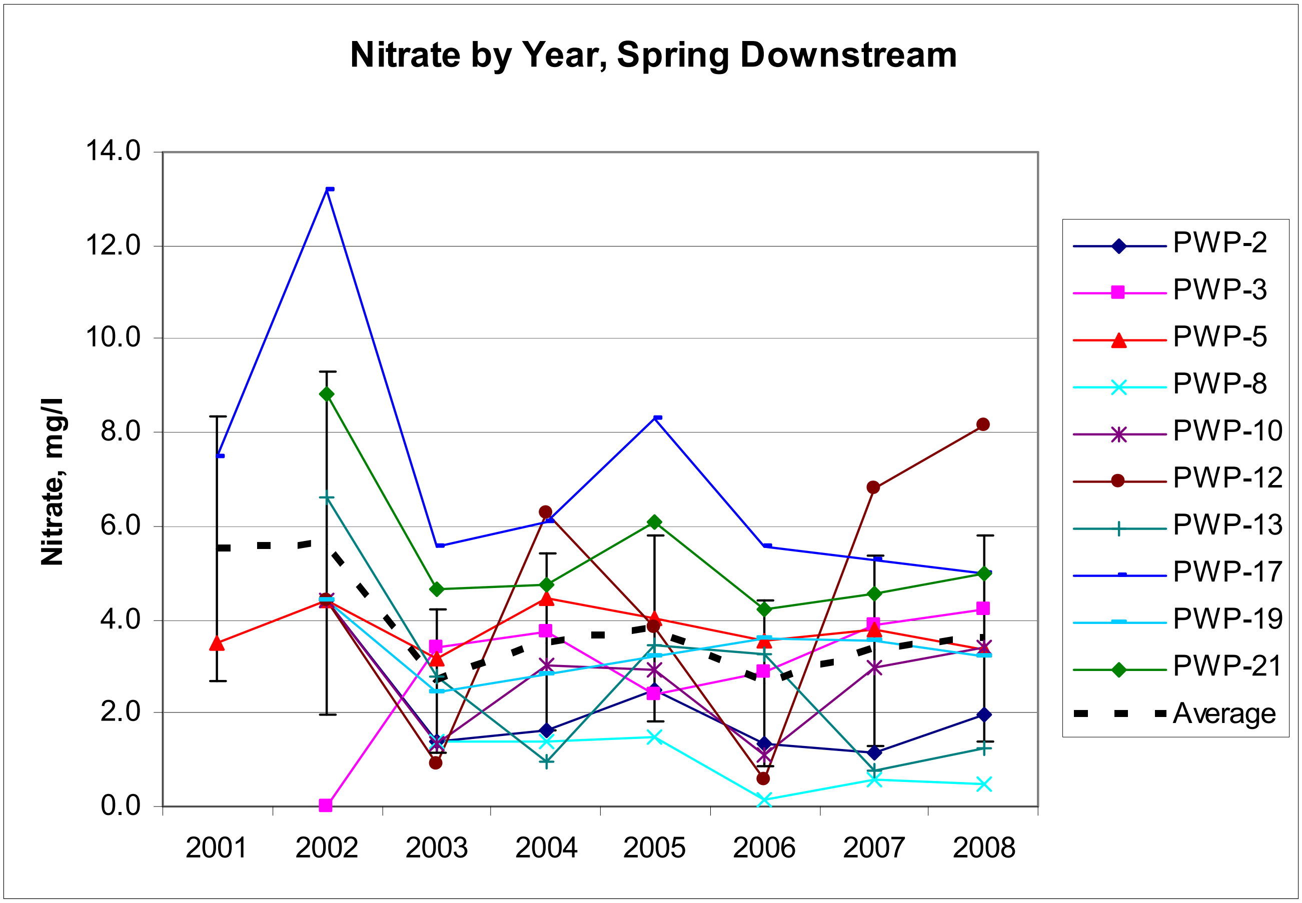

Figure 8: Instream nitrate at 10 Potomac Watershed Partnership sites, downstream locations of forest buffer plantings, spring grab samples from 2001 to 2008, with mean and standard deviation

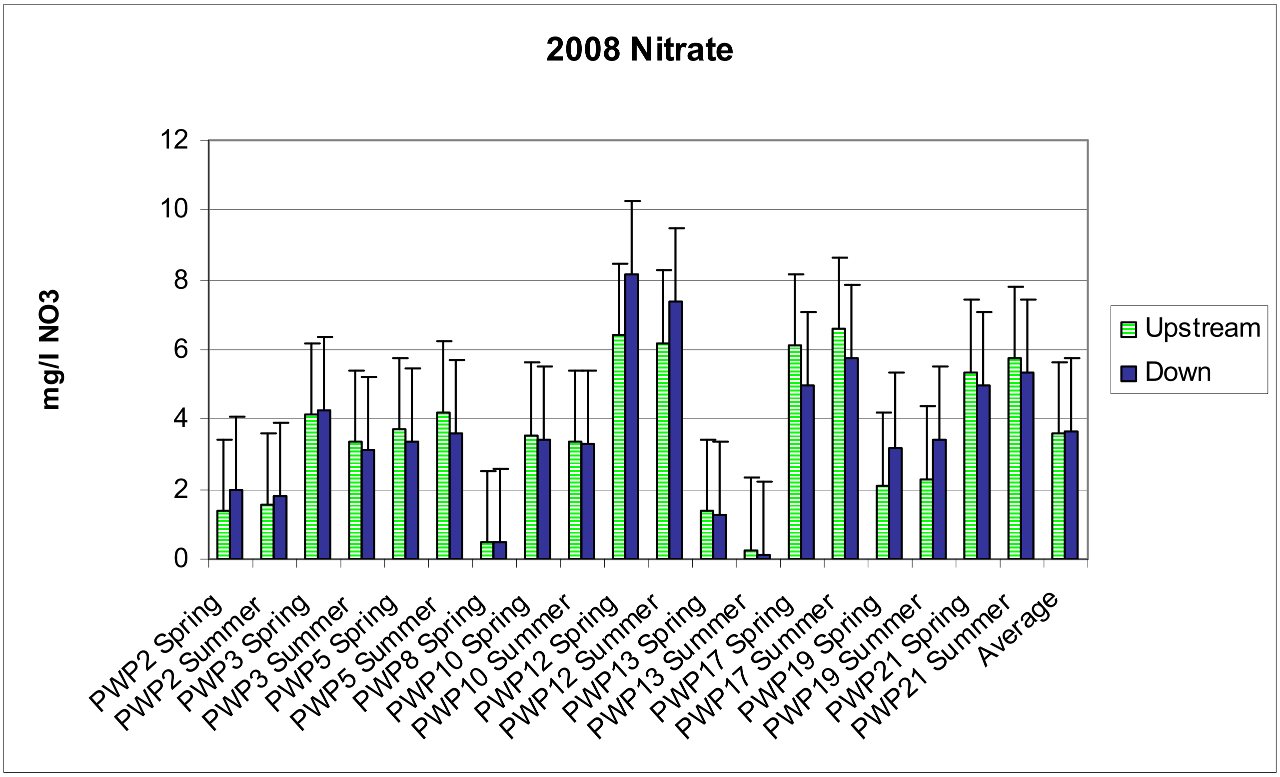

Figure 9: Comparison of upstream and downstream locations at Potomac Watershed Partnership sites for 2008 spring and summer sampling of instream nitrate, with standard deviation for annual mean

The upstream and downstream values of nitrate were not significantly different by 2008 (Figure 9). The average nitrate was 3.6 mg/l upstream and 3.7 mg/l downstream, and standard deviation exceeded 2 for the sample. Averages comparing upstream and downstream locations over all years of measurement were similarly close, and greater (4.0 and 4.1, respectively). The decrease in averages by 2008 suggests that nitrogen concentrations are declining over time, likely due to a combination of BMPs in the watersheds, but variability among sites is large and patterns are not consistent. Spring and summer values were generally close (Figure 9), and were larger some places and smaller others. Significant changes are unlikely to be seen until trees have grown much larger. Studies where early differences in water quality were seen typically had high tree stocking and very fast growing trees such as pine and hybrid poplar (e.g., Vellidis et al. 2003, Licht and Schnoor 1990). The challenging survival conditions with deer browse and dense fescue competition resulted in lower stocking and slower growth, even though most buffers appear likely to develop forest conditions over several decades.

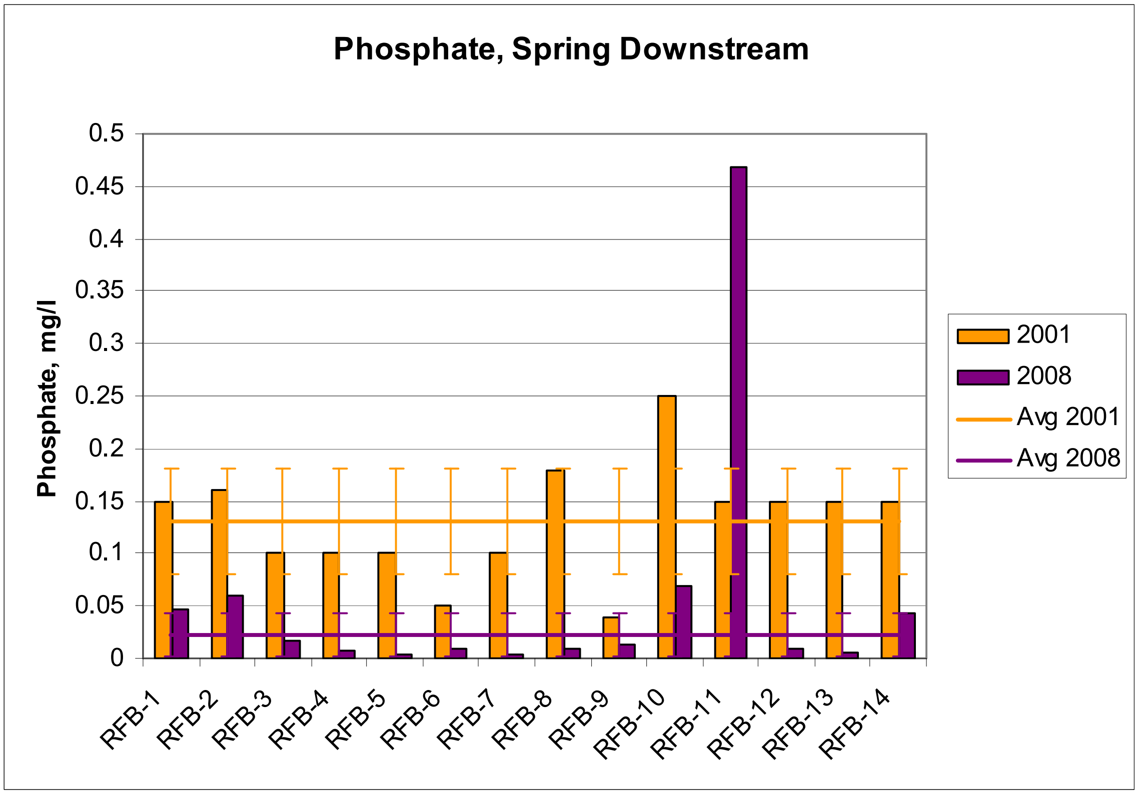

Figure 10: Instream phosphate at downstream locations on riparian forest buffer sites, Spring sampling period in 2001 and 2008 (RFB-11 outlier in 2008 excluded from mean and standard deviation)

At the RFB sites, phosphate was significantly lower ($p=0.045$) seven years after planting at all but one site, despite substantial variability among sites (Figure 10). The relationship was complicated by improvements in analysis methods over the time frame. The limits of detection were lower for the 2008 sampling with laboratory analysis, although the 2001 test-kit readings show limits of detection well below many of the measured values in 2007 and 2008. The high phosphate seen at RFB-11 in Spring 2008 was not present that fall or in the samples from 2007, suggesting it was an anomaly during the spring runoff. Like most of the sites, the watershed for RFB-11 is predominantly rural with over a third of the basin in pasture or crop, making an unusual addition from an upstream source possible. Average phosphate concentrations declined from 0.13 mg/l in 2001 to 0.03 in 2007 and 0.05 in 2008, including the unusually large value.

For the annual measurements on PWP sites, phosphorus was generally lower in later years, but was high in 2005 (Figure 11). The decline in 2003 may be related to a dilution effect of higher rainfall experienced that year and the fact that grab samples were taken from baseflow, when storm-generated sediment and attached phosphorus would not have been elevated. Decline could also be related to use of more precise analytical methods after 2002, although the sites that were higher during the first two years with scientific kits were also relatively the highest in later years. Increases in 2005 were not explained by average annual rainfall, although a locally strong storm could have changed patterns that year. Both 2001 and 2005 had above-average March rainfalls, which could affect phosphorous levels since P is often associated with sediment runoff and rainfall. March rainfall in 2002 and 2003 was near normal, and in other years, March rainfall was below the long-term average, typically associated with lower nutrient levels. Other measures, including dissolved oxygen and Pfankuch bank stability rating, show poorer conditions in 2005 and subsequent improvements.

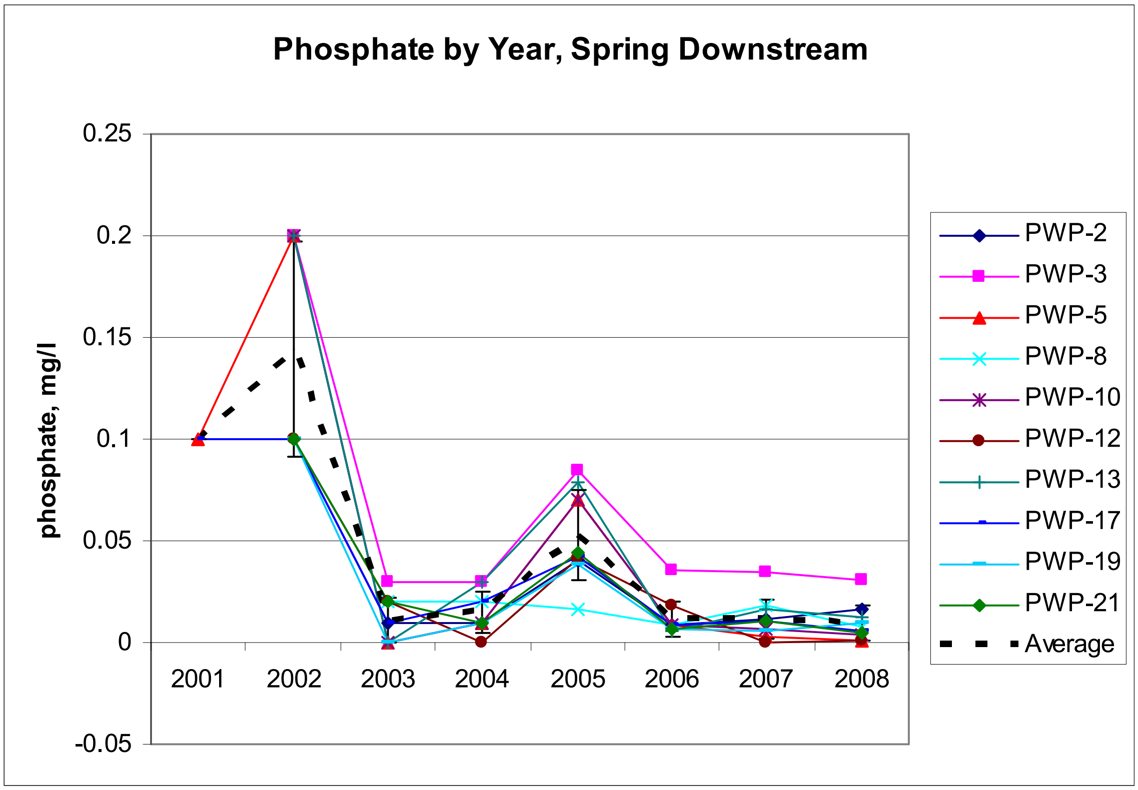

Figure 11: Instream phosphate at downstream locations on 10 PWP buffer sites, spring grab samples from 2001 to 2008, with mean and standard deviation

Dissolved Oxygen, pH, and Turbidity

Dissolved oxygen remained well above healthy levels most years (Figure 12). Values below 4 or 5 mg/l are considered unhealthy for most aquatic life, but some species and life stages, usually eggs or young, are more sensitive to decreases in dissolved oxygen. In 2005, several streams had oxygen levels that might be limiting for sensitive species or life stages, but still in tolerable ranges for most aquatic life. The lower dissolved oxygen levels occurred the same year that higher levels of phosphate were observed in the spring. Dissolved oxygen levels tend to drop as water warms and flow slows. Values tended to drop later in the summer as expected, but levels were not limiting to aquatic life even for the summer measurements. Greater limits for aquatic life were associated with the streams drying up entirely, leaving only the deeper pools.

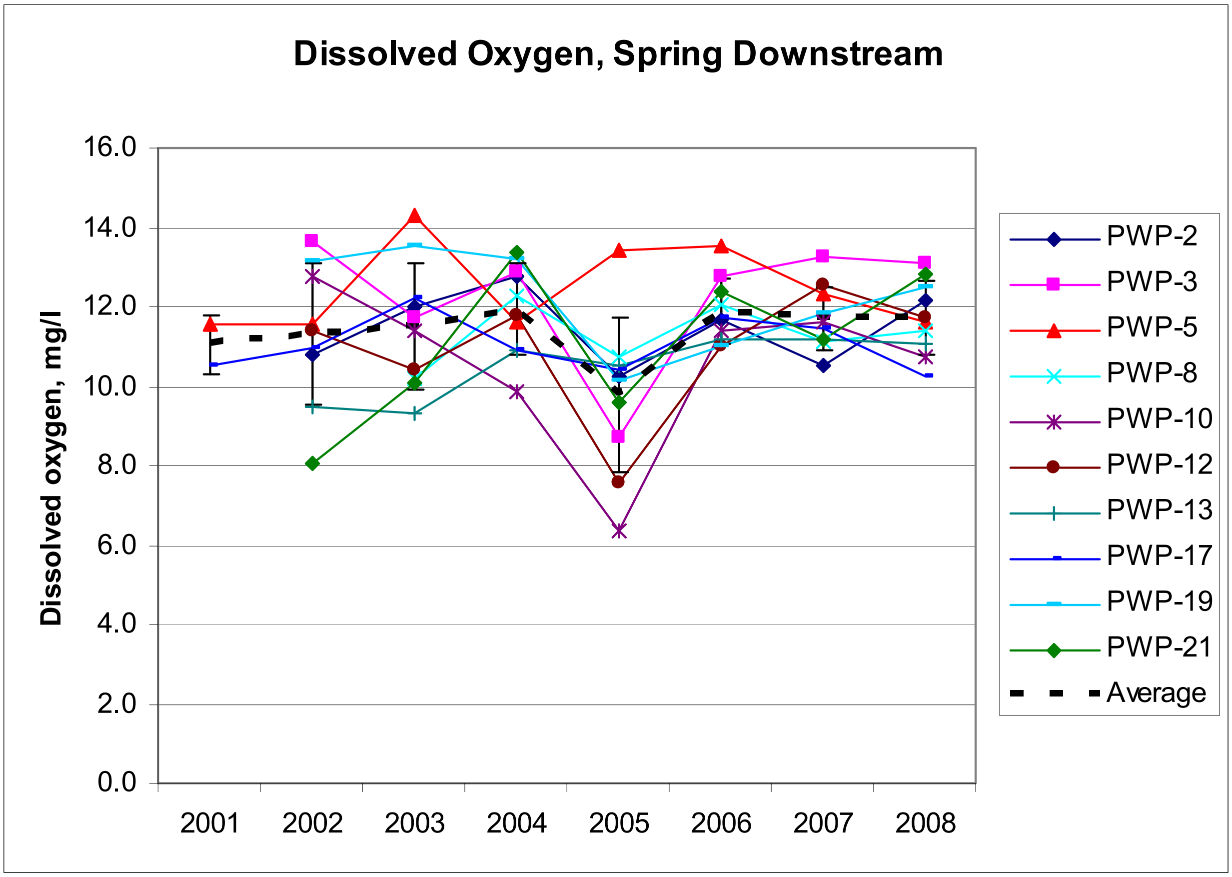

Figure 12: Dissolved oxygen (mg/l) in streams by 10 PWP riparian forest buffer sites, spring measurements at downstream end of buffer, with mean and standard deviation for 2001 to 2008

Dissolved oxygen is not expected to change dramatically as the forest buffers mature since most of the streams are at or above saturation already. Dissolved oxygen can decrease as water temperatures increase. This does not appear to be a widely limiting factor in these streams, even though warm temperatures were observed in many streams.

Stream pH averaged above 7, reflecting the predominance of limestone geology in the valleys where the monitored buffers were located. The pH values ranged up to 9, higher than expected, and varied from year to year (Figure 13). The increase in 2004 may be related to groundwater recharge from the wet year in 2003 (heavy spring rains and Hurricane Isabel in the fall brought rainfall well above long-term averages). Changes in pH as buffers mature are not expected; however, many instream processes are affected by pH.

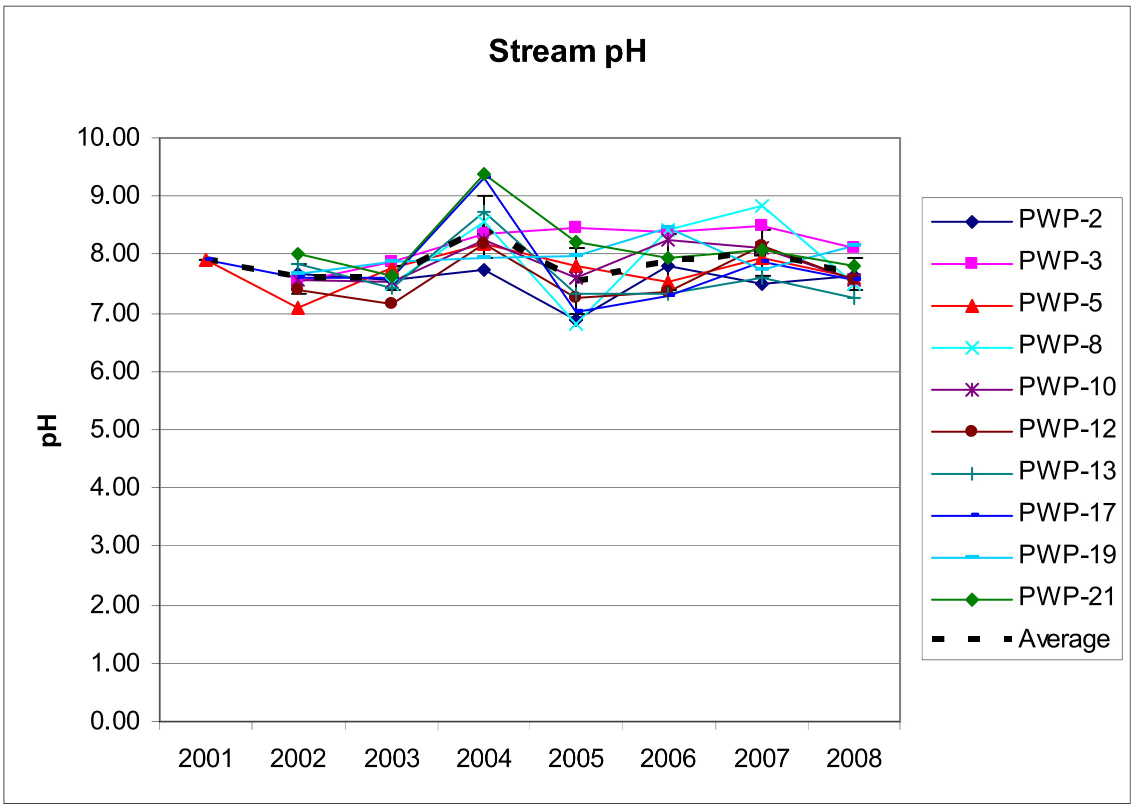

Figure 13: Instream pH by 10 PWP newly planted riparian forest buffers, spring measurements at downstream end of sites from 2001 to 2008, with mean and standard deviation

Stream turbidity was quite variable (Figure 14), even though periods immediately after rainfall were avoided to better capture normal values during baseflow. Turbidity was not related to any buffer characteristics over the observation period.

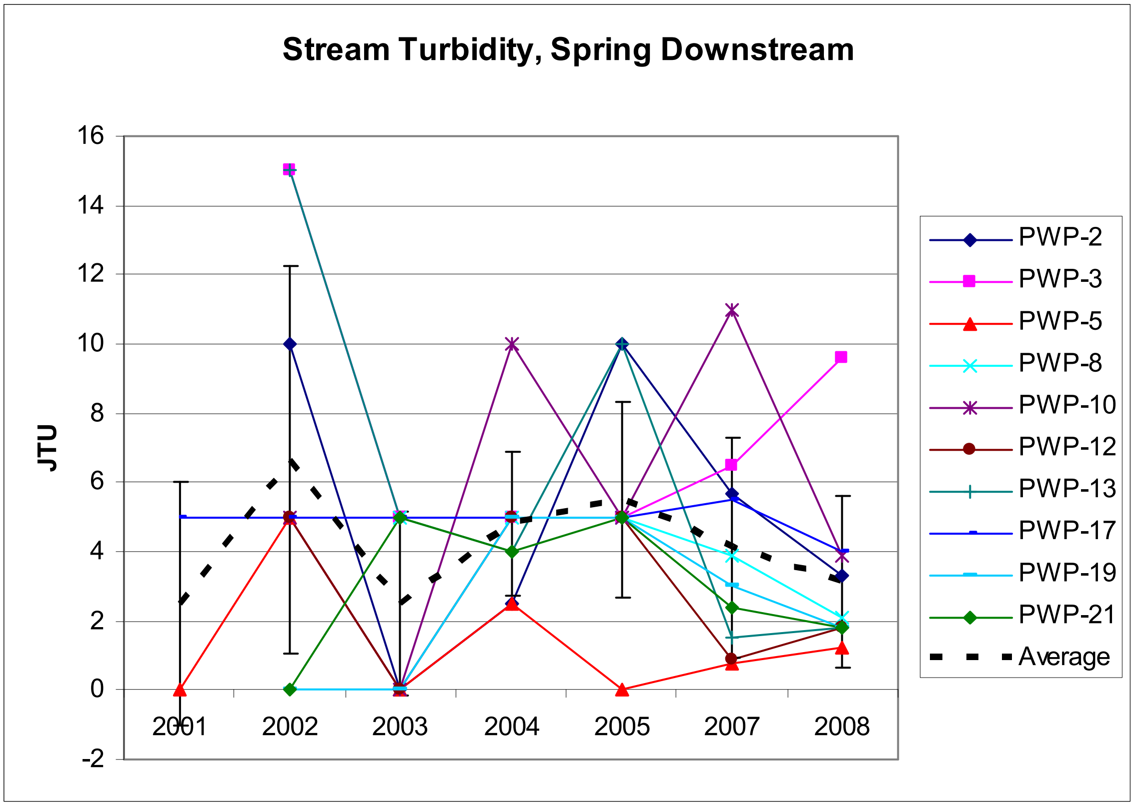

Figure 14: Instream turbidity measurements at 10 Potomac Watershed Partnership forest buffer monitoring sites, spring grab samples at downstream end of sites from 2001 to 2008, with mean and standard deviation

Stream Geometry:

The newly planted riparian buffer sites were monitored for changes in stream morphology between 2001 and 2007. Denser vegetation on banks can protect soil and affect the speed of water flow by increasing channel roughness. Some adjustment in stream morphology is common following changes in vegetation near the stream or in a major part of the watershed (McBride et al. 2008). The stream cross-section can also reflect other changes upstream, whether it is increased runoff from new buildings and roads or decreased sediment flow and runoff from new Best Management Practices.

Permanent channel cross-sections were used to assess changes in morphology. This method of assessment is quantitative and when measurements are taken using a monumented permanent transect they become repeatable. Olson-Rutz and Marlow (1992) set up indices for interpreting the changes that occur in a permanent transect by determining the percent change in the measurements. The measurements that were taken were the width of the stream and the elevational changes in the bank and bed of the stream.

The results derived from transect or cross-sectional data at the riparian sites monitored are as variable as the dynamics of each stream. Stream water quality conditions have been correlated with macro-invertebrate populations, nutrient loading and reduction as well as land cover (Karr 2006; Wang et al. 1997). However, correlation of stream morphology with these parameters is difficult over short periods of time. Streams do respond quickly to severe changes of land cover in a watershed like the clearing of forest, or intense increases in imperviousness (e.g., new roads), but they respond slowly to the adjacent change of land cover such as planting tree seedlings.

Discernable changes in width/depth ratio reflect the change in the mean depth and the width of the stream. At some of the sites, banks have eroded as much as 5 ft. and depositional areas have increased by 6 inches to as much as 1.5 ft. These changes are likely responses to livestock being fenced out of the stream. The deposition related to the animal movement in and out of the stream has been stemmed and the stream is cutting and depositing sediment from within the channel to compensate for the reduced sediment load supplied by the cattle activity. The percent change for 18 sites can be found in Figure 15.

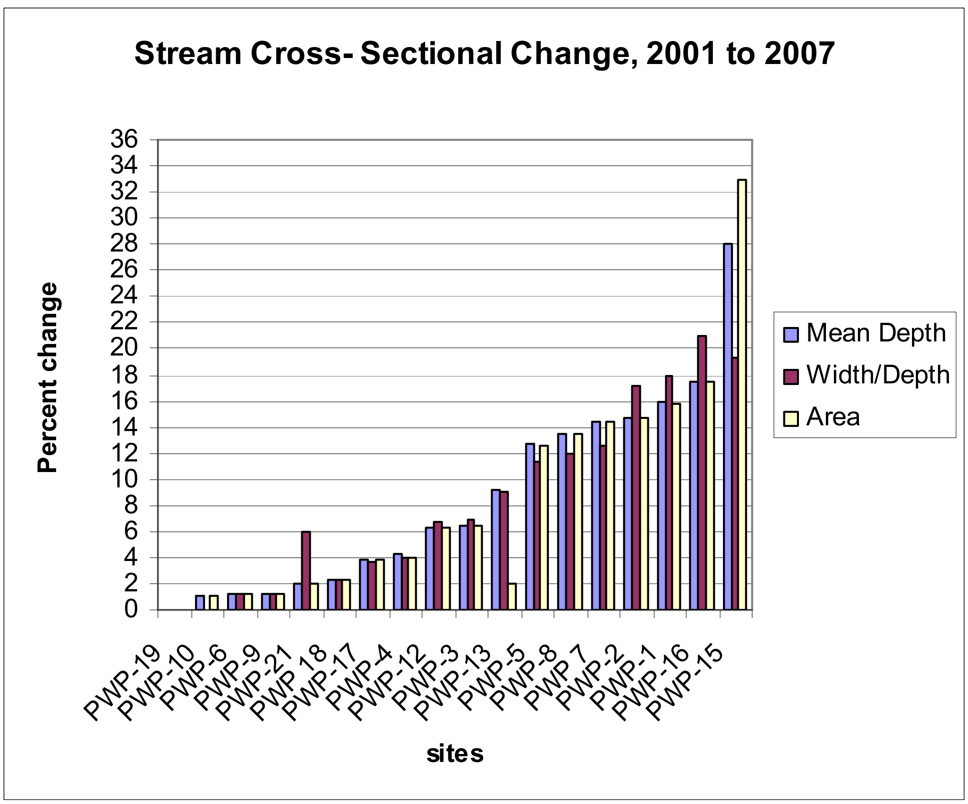

Figure 15: Percent change in mean depth, width/depth ratio, and cross-sectional area for 18 sites, Potomac Watershed Partnership monitoring sites

The percent change in width and depth for any of the sites were not closely correlated to imperviousness, forest cover or agricultural land use. Evaluation of riparian buffer function for hardwoods in the Mid-Atlantic region has generally found significant influence of a riparian planting by 15 years (Newbold et al. 2009, Orzetti et al. 2010). These plantings, at 6 to 7 years old, are still a few years away from the time when more measurable changes have been detected in other settings with hardwood trees.

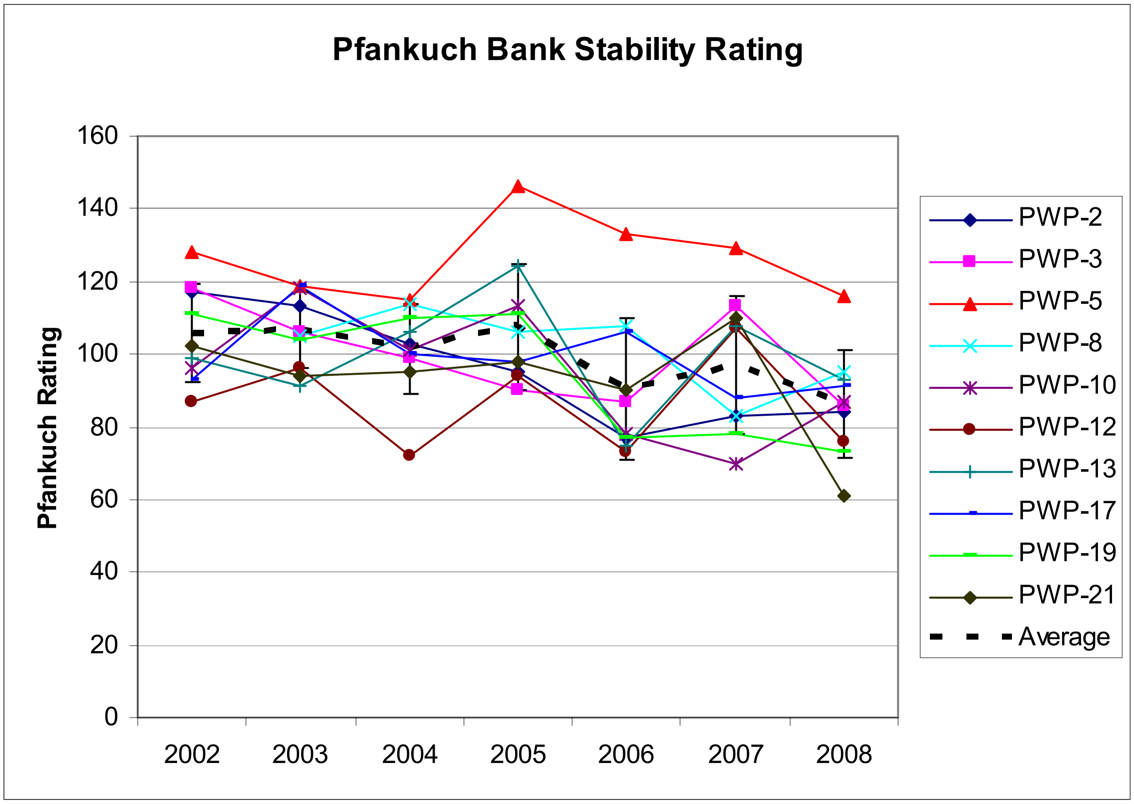

Figure 16: Pfankuch Bank Stability Rating for PWP sites, 2002 to 2008, with average and standard deviation

The Pfankuch bank stability rating was evaluated each spring for the PWP sites. The Pfankuch rating system evaluates upper and lower banks and bottom condition using visual assessment (Pfankuch 1975). Pfankuch scores have been shown to be very consistent with measured values and mechanistic estimates of streambank stability (Riedel et al. 2006). The Pfankuch rating system has also been modified for use with Rosgen stream classifications (Rosgen 2008).

Ratings for the PWP sites with records through 2008 are graphed in Figure 16. The original Pfankuch score considers ratings less than 38 to be excellent, 39-76 to be good, 77-114 to be fair, and greater than 115 to be poor. The average score dropped from 107 in 2003, the first year with complete records, to 86 in 2008. This significant decrease (p=0.001) in the bank stability rating indicated an improvement in observed bank stability. Improvements are likely due to removal of animals from the stream areas and increased levels of natural vegetation on the banks. Tree roots would not be expected to be adding significant bank protection and tensile strength at their current size. Despite this improvement, overall scores moved only from the worse part of fair to the better part of fair. Substantial room for improvement remains, and will occur if trends continue as expected with continued tree growth.

One site, PWP-5 was consistently less stable than the others. This site is in a watershed with very high impervious surfaces (66%), downstream from an urban area. All other sites have less than 12% impervious surfaces, with most less than 5%. Upstream influences and flashy hydrology are likely to continue to dominate observed patterns at PWP-5, and influences due to vegetation changes and tree roots may take much longer to take effect. This site showed particular decreases in 2005, the same year that higher phosphorus and lower dissolved oxygen were noted at many sites.

Stream Health with Benthic Macroinvertebrates

Benthic macroinvertebrates were used as biotic indicators to assess the effectiveness of riparian forest buffers to improve stream water quality. Epifaunal substrate and benthic macroinvertebrate taxa richness were statistically different by 2006. Trends in most other IBI metrics or habitat parameters were not significant by the 5th year. Mean epifaunal substrate scores increased by 4.29 (±1.37, $p=0.01$) between 2001 and 2006 ($n = 14$). Mean benthic macroinvertebrate taxa richness increased by 2.43 (±2.40, $p=0.04$) between 2001 and 2006. An average of 2.43 additional taxa were found in each buffered stream in 2006 compared to 2001.

To provide a watershed context for the buffer sites, the Index of Biotic Integrity (IBI) measures were compared to the IBIs of the closest local stream from the MBSS County Results between 2000 and 2004 (Kazyak et al. 2005) (Table 3). The comparisons are made by descriptive category rather than numeric rating because of the differences in stream sizes and reach length sampled. Descriptions of physical habitat indices (PHI) from the closest local streams to each of the 14 RFBs (Kazyak et al. 2005) are included. Nine of the 14 RFBs were located in Frederick County where only 2% of stream IBIs were described as good. Overall physical habitat in Frederick County was 56% partially degraded, 29% severely degraded, and 15% degraded. Four of the 14 RFBs were located in Carroll County where 33% of stream IBIs were described as good. Overall physical habitat in Carroll County was 48% partially degraded, 37% severely degraded to degraded, and 21% minimally degraded. Only 1 RFB was located in Washington County where 9% of stream IBIs were described as good. Overall physical habitat in Washington County was 37% severely degraded to degraded, 35% partially degraded, and 28% minimally degraded (Kazyak et al. 2005).

Table 3: Index of Biotic Integrity and surrounding stream health measures for RFB sites in the Monocacy, Antietam, and Catoctin watersheds from Maryland Biological Stream Survey (MBSS) County Results 2000 – 2004, relative to RFB sites (Kazyak et al. 2005; Rivers 2006).

County	**RFB Stream and its Watershed**	**RFB Site**	**RFB (IBI) 2006**	**Nearest Local Stream (IBI) 2000 - 2004**	**Nearest Local Stream (PHI) 2000 - 2004**
Frederick	Tributary of Stoney Branch to Motter Run - Upper Monocacy	RFB-1	poor	Fair	Degraded
Frederick	Tributary of Owens Creek - Upper Monocacy	RFB-2	fair	fair - good	degraded – partially degraded
Frederick	Town Branch of Linganmore Creek - Lower Monocacy	RFB-4	fair	Poor	degraded – partially degraded
Frederick	Tributary to Muddy Run - Upper Monocacy	RFB-6	poor	Fair	degraded
Frederick	Tributary to Tuscarora Creek - Upper Monocacy	RFB-8	poor	Fair	degraded
Frederick	Beaver Branch - Upper Monocacy	RFB-9	fair	Fair	degraded – partially degraded
Frederick	Tributary to Friends Creek - Upper Monocacy	RFB-11	fair	Fair	partially degraded
Frederick	Little Catoctin Creek -Catoctin Creek	RFB-12	fair	fair - good	partially degraded
Frederick	Motters Run -Upper Monocacy	RFB-14	fair	Fair	degraded
Carroll	Tributary of Big Pipe Creek - Upper Monocacy	RFB-3	poor	Poor	partially degraded
Carroll	Tributary to Bear Branch to Big Pipe Creek - Upper Monocacy	RFB-7	fair	Poor	partially degraded
Carroll	Tributary to Big Pipe Creek - Upper Monocacy	RFB-10	fair	fair - poor	partially degraded
Carroll	Meadow Branch of Big Pipe Creek -Upper Monocacy	RFB-13	fair	fair - poor	partially degraded
Washington	Mousetown Run to Tributary of Little Antietam Creek - Antietam Creek	RFB-5	poor	Fair	minimally degraded

Suitable bottom habitat for benthic macroinvertebrates to occupy is important for the extent and variety of species found. If the surface area that aquatic organisms can inhabit is greater, then the functions those organisms can provide is greater. The greater ability of forested buffers than grass buffers to support benthic macroinvertebrates and their instream nutrient processing found by Sweeney et al. (2004) was related to the greater surface area found in forested streams. Epifaunal substrate, one of several physical habitat parameters, improved significantly in 2006 from 2001. The mean score increased 4.29 (±1.37, p=0.01) (Figure 17).

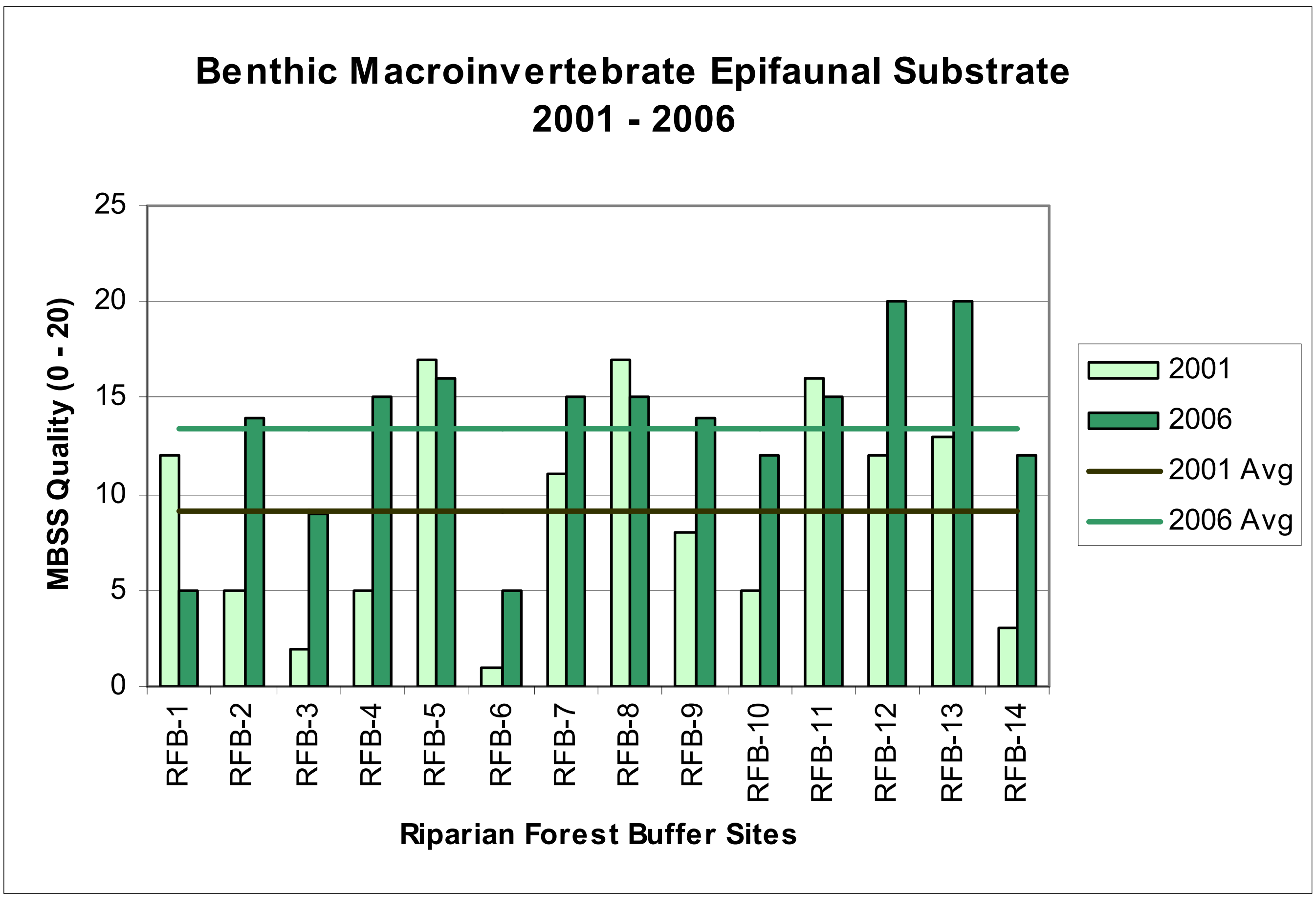

Figure 17: Epifaunal substrate from RFB sites in 2001 and 2006.

The 2006 MBSS benthic macroinvertebrate IBI was compared to the IBI from the baseline study in 2001 (Table 4, Figure 18). There was no significant difference (p=0.096) between the means of the total IBI scores between 2001 and 2006. IBIs improved for 64%, declined for 21% and stayed the same for 14% of the buffered sites in 2006.

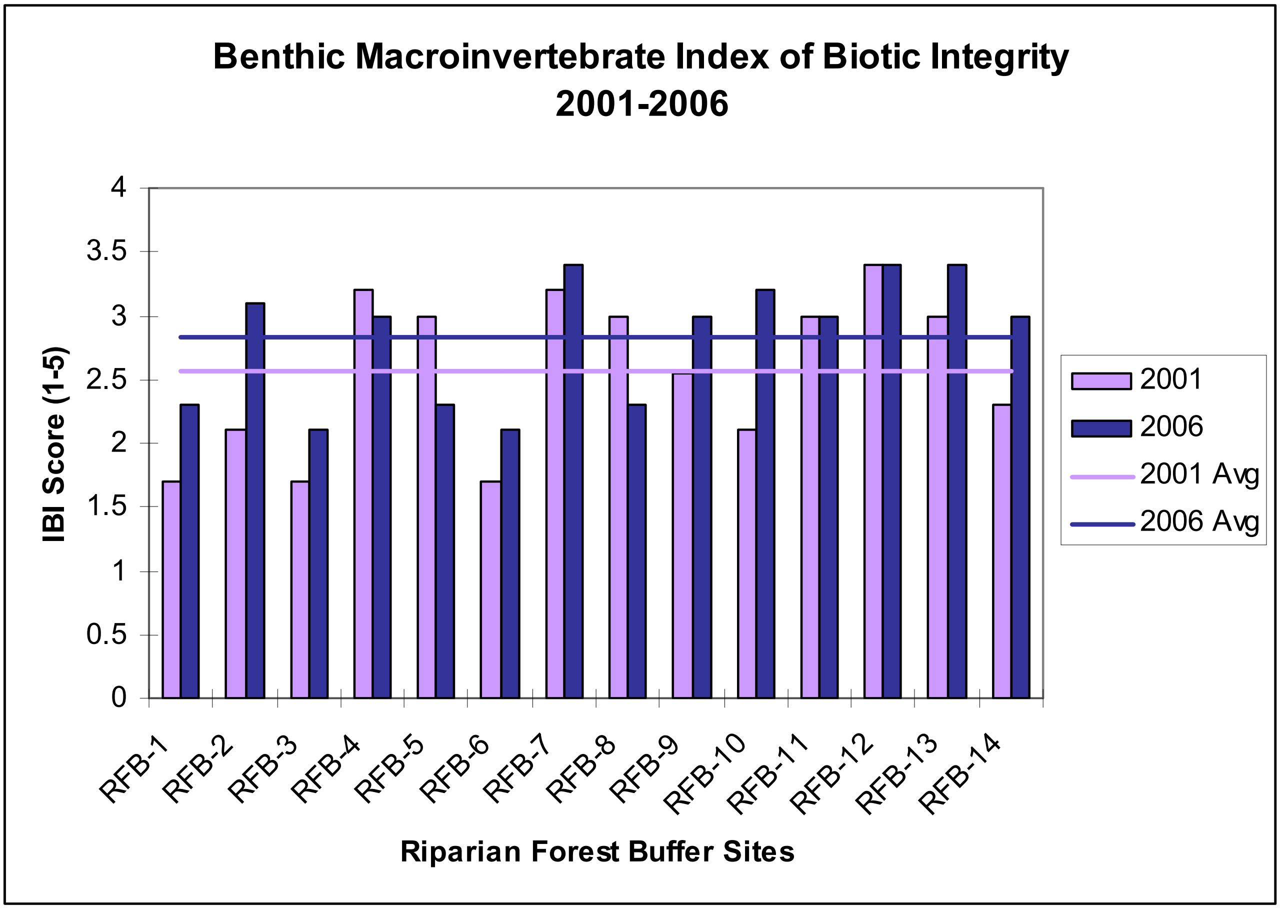

Figure 18: Comparison of RFB 2001 and 2006 Index of Biotic Integrity scores for Benthic Macroinvertebrates (no sig. dif., p=0.096)

The IBI score is described in Table 4 by its relationship to reference streams. Biological metrics in the upper half of reference stream conditions score between 4 and 5. Metrics in the lower half (10% - 50%) of reference conditions score between 3 and 4. Metrics below 10% of reference conditions score between 2 and 3 (Roth et al. 2000). Differences in stream water quality are noted for each site between 2001 and 2006, followed by the size of the stream.

IBI scores declined at 3 sites. The RFB-5 site has an established buffer with good maintenance but the IBI score declined between 2001 and 2006 (Table 4). Upstream activities may have influenced trends. The IBI score for the RFB-8 site, which was never planted with trees, also declined. The RFB-4 site declined slightly from 3.2 to 3.0. Although epifaunal substrate scores increased at most sites, the RFB-1 site declined. Influences at this site that may be affecting stream health include a 1/3 mile long roadside ditch that drains into the stream just above the buffer and a small residential area just upstream of the buffer. A beaver pond exists just upstream of the RFB-7 buffer which may not have existed in 2001.

Table 4: Maryland Biological Stream Survey (MBSS) Index of Biological Integrity (IBI) Comparison 2001 and 2006.

RFB Site Owner	**2001 IBI**	**2006 IBI**	**2006 Description and Comments**
RFB-1	1.7 very poor	**2.3 poor**	Deviation from reference streams. IBI improved without RFB maintenance. Small stream.
RFB-2	2.1 poor	**3.1 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved from fencing sheep and cows without RFB maintenance. Small stream.
RFB-3	1.7 very poor	**2.1 poor**	Deviation from reference streams. IBI improved. Good RFB started with excellent maintenance. Small stream.
RFB-4	3.2 fair	**3.0 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI declined. No maintenance of large RFB. Cows fenced out. Large stream.
RFB-5	3.0 fair	**2.3 poor**	Deviation from reference streams. IBI declined. Examine upstream influences. Good RFB started with good maintenance. Small stream.
RFB-6	1.7 very poor	**2.1 poor**	Deviation from reference streams. IBI improved. Sampled near spring source of very small first order stream which falls between the cracks of MBSS IBI scores. Good RFB started with good maintenance. Adjacent herbicides.
RFB-7	3.2 fair	**3.4 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved. Large beaver dam and pond upstream. Westminster airport to take family farm by eminent domain for landing/take off buffer. Small stream.
RFB-8	3.0 fair	**2.3 poor**	Deviation from reference streams. IBI declined. Control; no RFB. Small stream.
RFB-9	2.55 poor	**3.0 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved. Good RFB started with good maintenance in addition to mature trees. Adjacent corn field. Large stream.
RFB-10	2.1 poor	**3.2 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved without maintenance of RFB, some trees survived; cows fenced out. Large stream.
RFB-11	3.0 fair	**3.0 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI stayed the same. Good RFB started with good maintenance. Examine upstream influences; # intolerant taxa declined. Medium stream.
RFB-12	3.4 fair	**3.4 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI stayed the same. No maintenance of RFB, some trees survived. Large stream.
RFB-13	3.0 fair	**3.4 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved with cows fenced out without maintenance of RFB, some trees survived. Large stream.
RFB-14	2.3 poor	**3.0 fair**	Comparable to reference streams; some aspects of biological integrity not resembling reference streams. IBI improved. Good RFB started with maintenance but no mowing. Adjacent conservation. Small stream.
Total IBI	**2.57 poor**	**2.83 poor**	Deviation from reference conditions with many aspects of biological integrity deviating from the qualities of minimally impacted streams.

Mean benthic macroinvertebrate taxa richness increased significantly in 2006 from 2001 by 2.43 (±2.40) at the 96% confidence level (Figure 19). An average of 2 additional taxa was found in each buffered stream in 2006 compared to 2001. A larger number of species or taxa indicates improved conditions, since degraded streams with poor water quality and simplified physical habitat tend to have fewer numbers of organisms that can tolerate the conditions.

Reduced sedimentation from buffer filtering of agricultural runoff and exclusion of livestock from streams may have caused significant improvement in epifaunal substrate. Improved epifaunal substrate may have led to the significant increase in benthic macroinvertebrate taxa richness. The increased biodiversity suggests improved stream water quality for aquatic life.

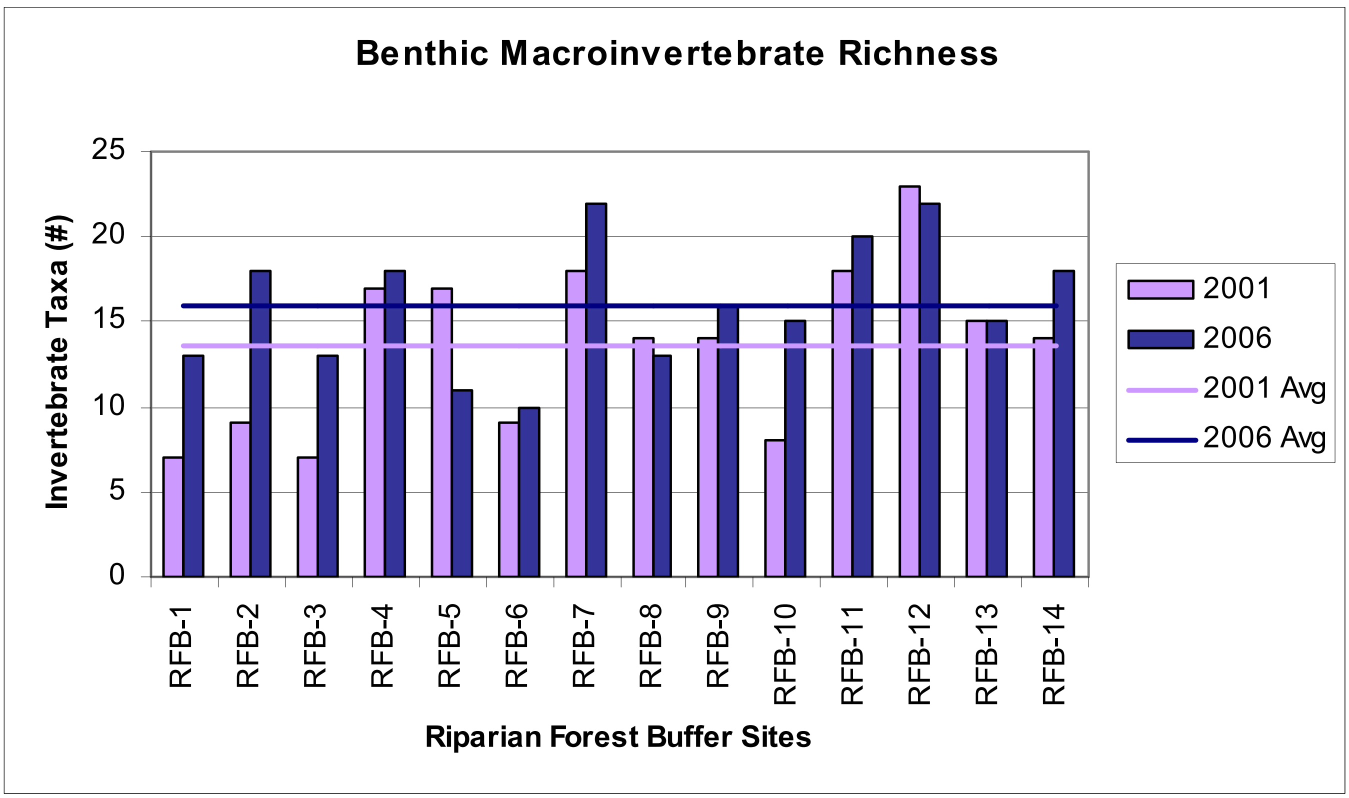

Figure 19: Benthic macroinvertebrate taxa richness in 2001and 2006 (sig. diff., p=0.04)

Some groups of stream organisms are more sensitive to pollution and other stresses, characteristics that are factored into the IBI score. The EPT taxa (*Ephemeroptera*-mayflies, *Plecoptera*-stoneflies, and *Tricoptera*-caddisflies) are all considered indicators of good water quality and habitat conditions. The RFB sites showed a trend towards an increasing number of EPT taxa (Figure 20), but the higher average number in 2006 was not significantly different (p=0.11).

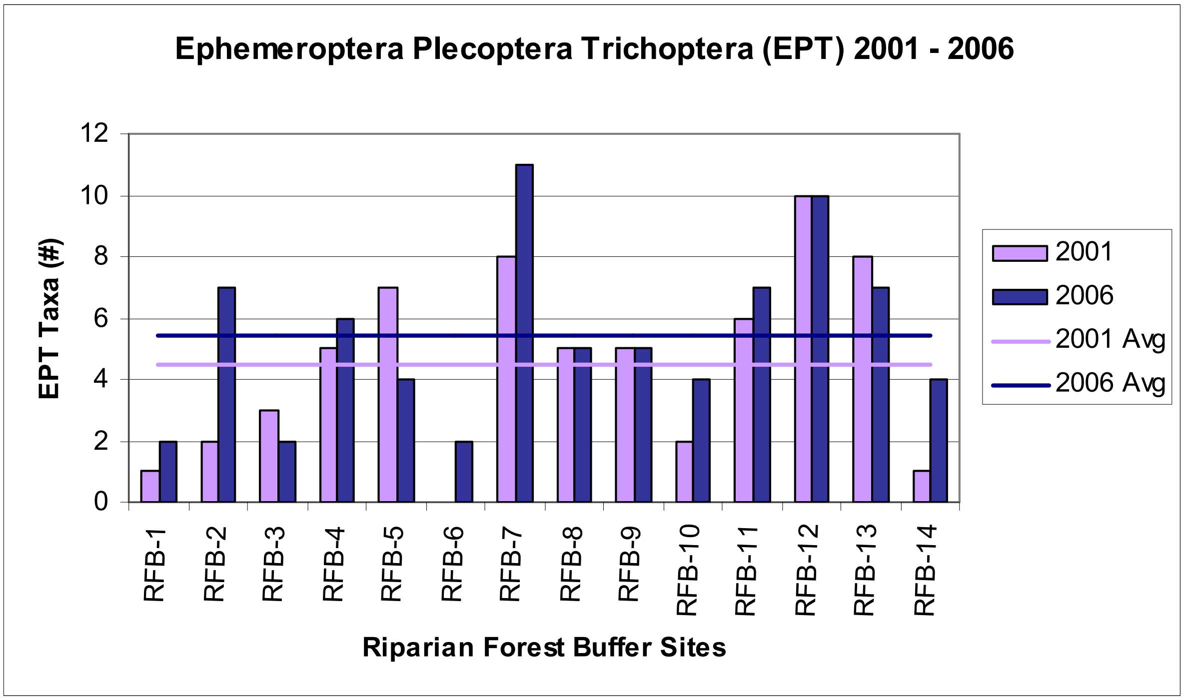

Figure 20: Taxa Richness of Pollution Sensitive Benthic Macroinvertebrates (EPT) in 2001 and 2006

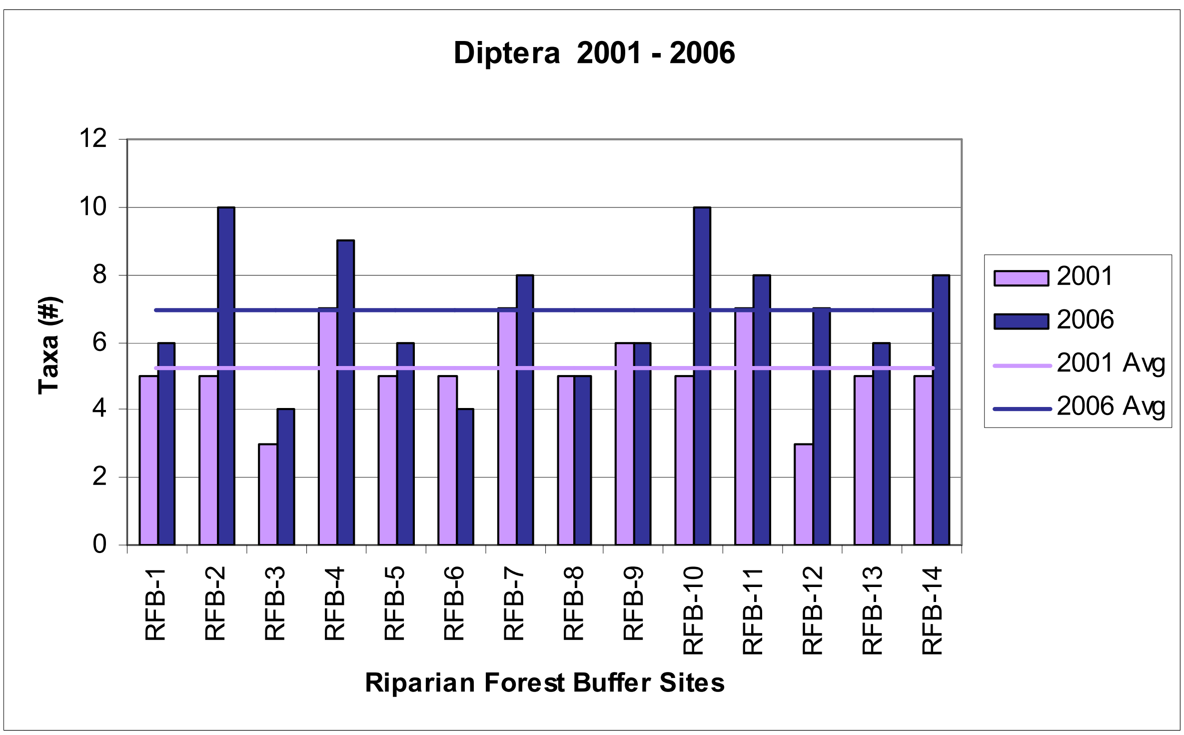

Figure 21: Number of Taxa of Diptera (flies) on RFB sites in 2001 and 2006

Another measure included in the IBI was the number of taxa on Diptera, or flies. Some Diptera larva are not pollution-sensitive, while others depend on better habitat and water quality. Increases in the number of taxa found in Diptera were significant (Figure 21; $p<0.01$). The clearer trend in the more tolerant taxa probably reflects the variable nature of the water quality, since nutrients remain fairly high at many sites.

The effect of maintenance on number of taxa was examined. Well-maintained buffers usually have better planted tree survival, but the vegetation control efforts also mean that natural tree regeneration and other vegetation can be reduced. Good tree survival and growth from good maintenance can mean more rapid development of buffer functions, but reductions in vegetation and vegetation height could also mean less overall organic input and shading for streams during early years before crown closure. Half of the 14 RFB sites were maintained by mowing between young trees, and spraying herbicide or weeding to establish the trees and diminish competition from weeds, vines and invasive species; the other half had no maintenance. Invertebrate taxa richness in maintained buffers was compared to buffers without maintenance using the 2006 data. No significant difference ($p=0.79$) existed between buffers with maintenance (average of 15.7 taxa) and without maintenance (average of 16.3 taxa). There was no evidence to suggest that buffers without maintenance differ in benthic invertebrate taxa richness from those with good maintenance. Despite the overall increase in benthic macroinvertebrate taxa richness, young roots and trees in the seven maintained buffers may be too immature to effect a noticeable change in invertebrate taxa richness during their establishment period.

Other measures of quality of aquatic habitat are the diversity of velocity and depth and riffle run quality, part of the Physical Habitat Index measures in the MD Biological Stream Survey. Streams with deeper pools, well-defined riffle habitat, and more types of flow velocities provide a greater variety of useful habitats for stream organisms. Greater variety in habitat can provide opportunities for more different types of organisms and multiple niches in along stream lengths. Stable pools are critical habitat during summer low flow when they serve as refuges from stream drying and high water temperatures.

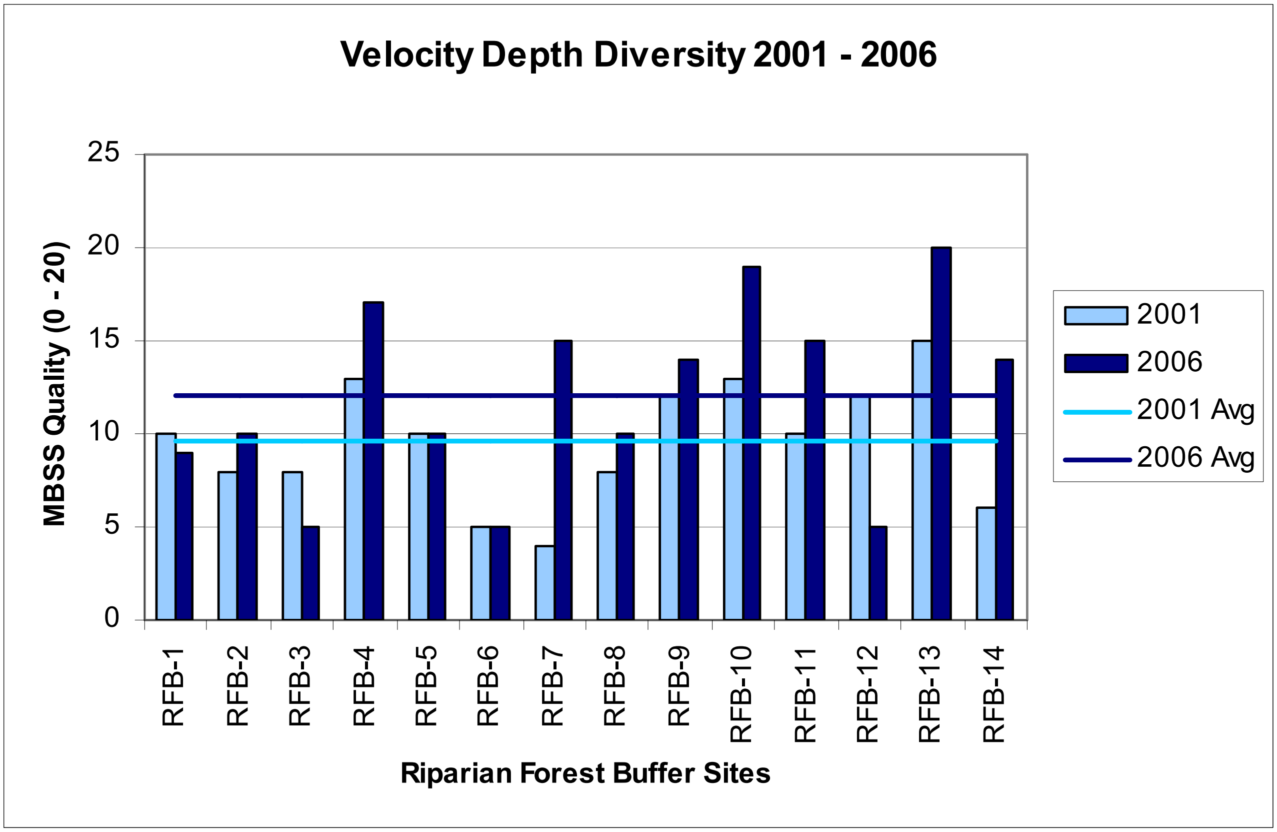

Figure 22: Velocity/Depth Diversity Scores from Maryland Biological Stream Survey Habitat Index, RFB sites in 2001 and 2006 (no sig. diff., p=0.07)

The average velocity depth diversity score rose during the 2001 to 2006 period from ratios of 9.6 (± 3.3 standard deviation) to 12.0 (± 5.1 s.d.), but sites varied too greatly for the difference to be significant (p=0.07) (Figure 22). Removal of animals and increases in natural vegetation on the bank may have contributed to improvements. Long-term, trees can contribute large woody debris that can form the basis of stable pools with enough depth to last through a summer drought. Assessment scores for riffle run quality did not change much between 2006 and 2001, and may take greater changes in streamside vegetation, bank stability, and woody debris inputs over longer periods of time.

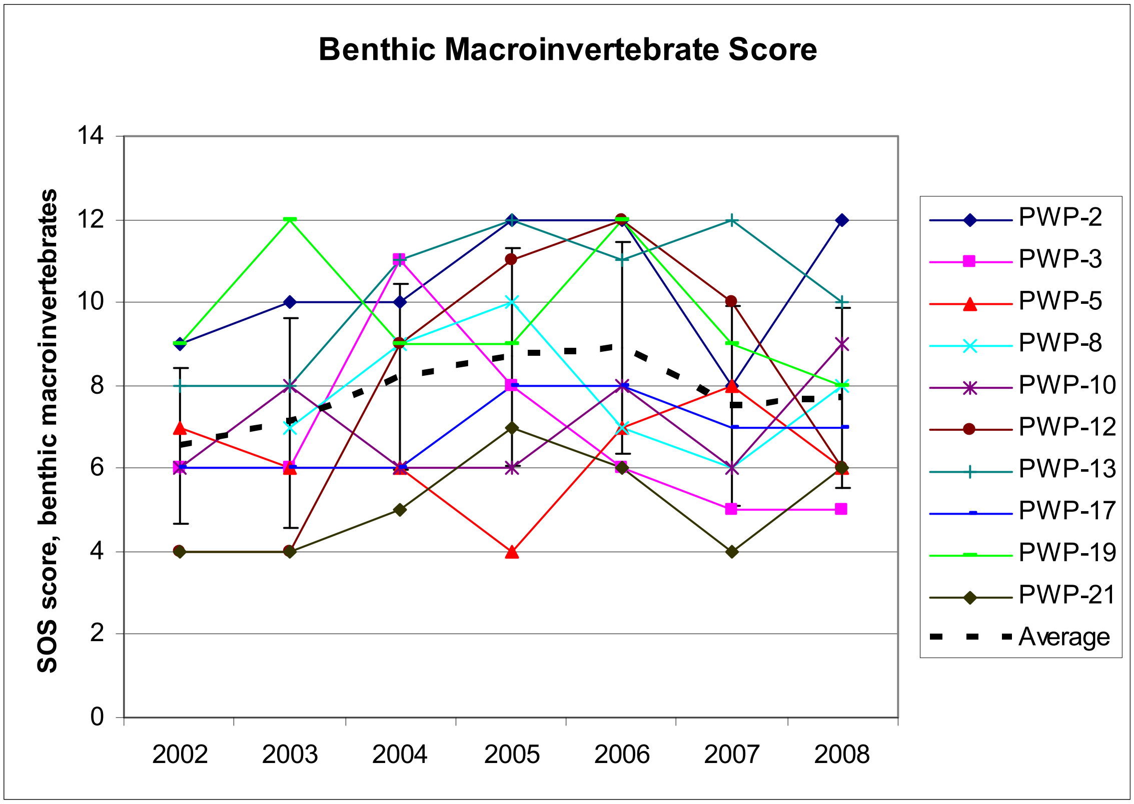

Figure 23: Benthic macroinvertebrate scores (Save Our Streams protocol) for PWP sites, 2003 to 2008, with average and standard deviation

PWP sites were assessed annually for benthic macroinvertebrate assemblages using the the Save Our Stream (SOS) methodology (after http://www.dep.wv.gov/WWE/getinvolved/sos/Pages/SOP1macrocollect.aspx). The SOS score is a coarser measure of benthic macroinvertebrate populations than the MD DNR IBI but it can be carried out more rapidly in the field by existing staff with appropriate training, allowing more frequent evaluation. The score was based on a similar number of organisms (about 100), but identification was not done below taxonomic order. The annual scores can offer some insight about patterns from year to year. SOS scores showed an improving trend until 2007, rising from an average of 6.5 to 7.7 overall, differences that were not significant (p=0.34) given the large variation among sites and years (Figure 23). Even with the slight trend of improvement, the average is still at the lower level of scores considered acceptable by SOS (7-12). 2007 was a drought year, although the spring, when many stream organisms are maturing and emerging to reproduce, was not especially dry; it followed an exceptionally dry March in 2006, which may have affected populations the following year.

Stream Temperature Trends

The average daily maximum temperature dropped about 1.5^{o} Celsius between 2001 or 2002 and 2008 for most sites (Figures 24, 25). However, temperature declines varied from site to site and were not significantly different at this point in time. 2003 was the wettest year in the time period, with almost 50% more precipitation than normal, and although air temperatures were close to the long-term average, the increased streamflow seems to be reflected in slightly cooler average water temperatures (Figure 24). The sites with higher growth rates and tree stocking were not correlated with these modest temperature changes, suggesting that the temperature changes are not related to tree shading. The trees have not yet reached canopy closure, and were not fully shading the streams at age 6 to 7 in hardwood stands. The pine-dominated stands measured for growth had reached canopy closure by age 8, but the waterways were typically flanked by the hardwood component of the project and were not yet fully shading the water body. Wider streams or water bodies also limited the influence of trees early in the establishment period.

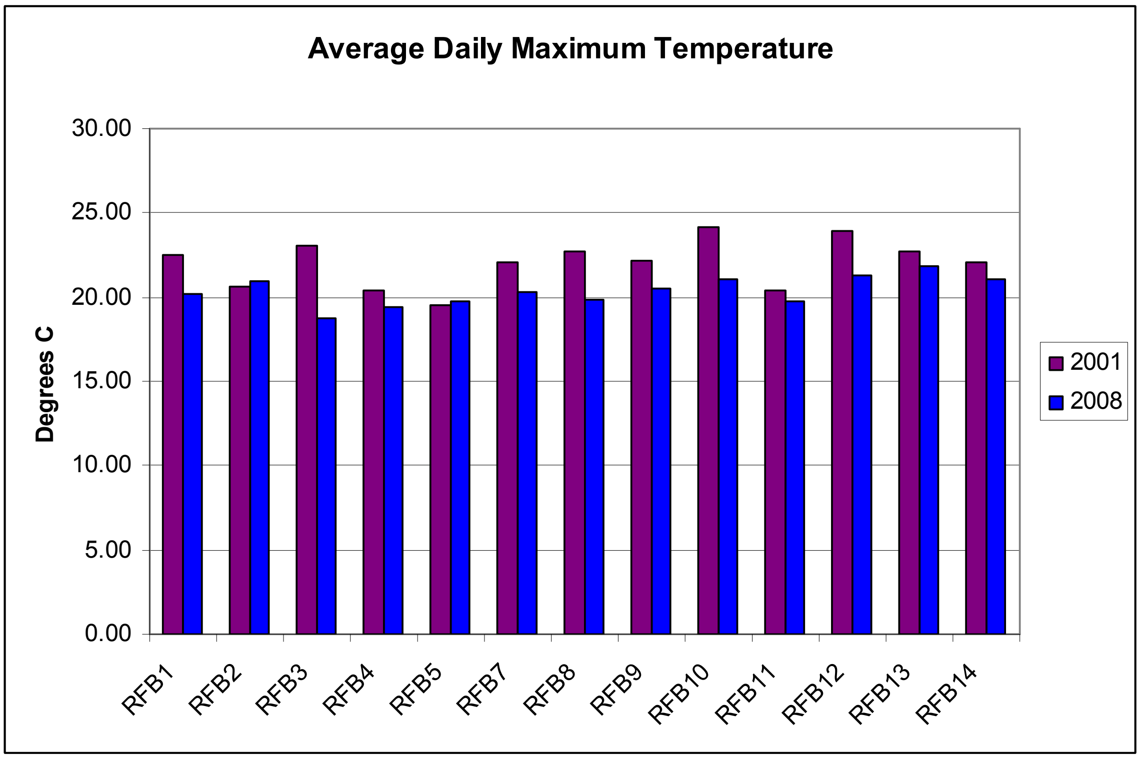

Figure 24: Average daily maximum stream temperature at 13 Riparian Forest Buffer Monitoring sites

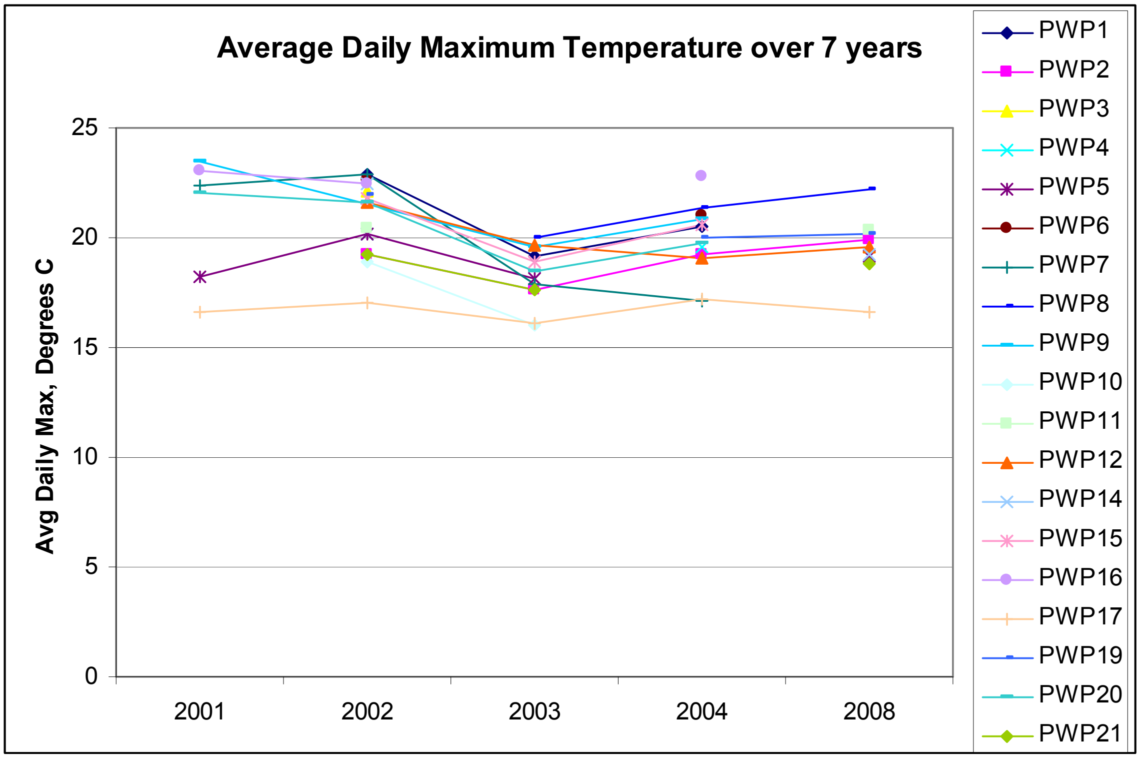

Figure 25: Average daily maximum stream temperature at 19 Potomac Watershed Partnership Monitoring sites

The temperature decline, while modest, is in a very significant range. The statutory temperature limits that cold-water fisheries use are 23°C for adults and 20°C for reproduction of natural trout. The average daily maximum is the warmest temperature of every day, so it tends to convey a better picture of temperature stress than the daily average where extreme highs could be masked by unusual low temperatures in another part of the day. The temperature limits are a threshold, beyond which cold-water fish will only survive if they can find a refuge like a deep cold pool or cold groundwater seep. The PWP sites went from an average daily maximum of 21°C in 2001 or 2002 to 19.5°C in 2008. The RFB sites went from an average daily maximum of 22°C in 2001 to 20.3°C in 2008. These temperatures are very near the thresholds for cold water fisheries. When trees are more fully grown and offering significant shade, even modest temperature declines could bring more of these streams into functional habitat for trout reproduction, increasing the area of available habitat or extending portions of the year where suitable habitat is available. If regional summer temperatures increase as predicted, the shade from forested buffers will be critical for maintaining any trout habitat.

Measuring Market and Non-market Values of Riparian Forest Buffers.

Riparian forest buffers (RFBs) generate a variety of benefits, some of which accrue to owners of the land where they grow, and some of which accrue more broadly. For example, while the value of timber growing in RFBs can be captured by landowners through harvests, RFB effects on biotic integrity and water quality – the ecosystem services which have been the subject of this assessment – benefit a wider population. Because RFB ecosystem services are not generally traded in markets, it is challenging to place a dollar value on the services. However, estimates of dollar values are needed to allow comparisons of the different types of benefits and the relationship to easily quantified costs like planting expenses and foregone crop income.

General costs and benefits of riparian buffers for Maryland landowners have been described in Lynch and Tjaden (2000). The fact sheet details potential payments from the Conservation Reserve Enhancement Program (CREP), a United State Department of Agriculture (USDA) Farm Service Agency incentive program that has supported a majority of forest buffers established in the state. More recently, Wieland and others (2009) reported establishment costs from a limited survey of stock and planting service providers. Both of these studies note large variances in the costs of establishing and maintaining RFBs, depending on the site and how the practice is implemented. When tree protection is employed, planting results can be significantly different but costs are significantly higher as well.

Economists have developed methods for estimating environmental and natural resource values for environmental benefits that are not traded in markets (for a general description see Freeman, 2003, or for a Maryland-specific example, see Wieland, Horowitz and Strebel, 2008). However, those methods are generally limited by context, and economists typically do not presume to have captured "all" value of non-market ecosystem services in their estimates. The discussion below is limited to ecosystem benefits that are most frequently sought in restoring forest buffers and those that are the most amenable to valuation, while recognizing that there are additional benefits outside the analysis. Major values addressed here are the potential future timber value, water quality benefits, air quality benefits and recreational hunting. Income from CREP, the major publicly-funded program supporting forest buffer establishment, is presented first for comparison.

Incentive Program Payments

Since 1998, the Conservation Reserve Enhancement Program (CREP) has been the most commonly used program for establishing forest buffers. Some other programs offer similar rates of cost-share for installing buffers, but CREP has the added advantage to the landowner of paying a soil rental rate (SRR), and additional bonuses that compensate for the lost income from crops or animals during the length of a contract. CREP contracts are available for 10 to 15-year terms. Most people choosing to install a forest buffer have opted for the full 15 years. All CREP contract acres are eligible for renewal for an additional 10 to 15 years, so lands currently in CREP contracts will be able to re-enroll and receive soil rental and bonus payments for another 15 years. One-time payments at the beginning of the contract are also paid, a signing bonus at the start of the contract, and a Practice Incentive Payment (PIP) based on 40% of eligible establishment costs, paid after the practice is installed and successfully survived (after year 1). The PIP is a bonus rather than a cost-share payment, but also compensates landowners for establishment costs.

RFB establishment costs were based on average costs of CREP RFB establishment (CP-22 practice category) in targeted regions of the state in 2001. The costs of planting pine RFBs were approximated by using the establishment cost share average for CP-22 in Somerset and Worcester Counties. In 2001 this was $301. The costs of establishing hardwood RFBs were approximated using the establishment cost share average for Frederick and Garrett Counties, and that was $580 in 2001. Since the CREP cost share is one half the establishment cost, actual establishment costs were assumed to be twice the cost share value. Soil rental rates were calculated using $66/acre for pine (Eastern Shore) and $59/acre for hardwood (Western Region), average soil rental rates for these regions.

While landowners might face costs of $600 or $1,160 to establish RFBs, the combined cost share payments and bonuses mean that they receive a premium of at least 27.5 percent on those costs through the CREP program. Cost-share reimbursement adds up to 87.5% from the combination of CREP cost-share of 50% paid by USDA and the Maryland Agricultural Cost-Share (MACS) of 37.5%. The premium comes from the addition of the 40 percent of establishment costs for the Practice Incentive Payment (PIP) paid by USDA since June of 2000. Additional cost share was provided by private groups such as Ducks Unlimited and the Chesapeake Bay Foundation prior to 2004, but these additional payments are not considered here because they are no longer available.

In addition to the establishment incentives, CREP RFB adopters received a $200 signing bonus starting in 2001. This, along with the establishment premium, was treated as a benefit that accrues at the end of the first year of adoption and so was discounted back one period in the table. Another RFB cost and consequent benefit paid under CREP is the lost value of the land from agricultural production. This was approximated by the land's rental value, or what the owner might hope to make in renting the land to a different operator. In 2001, CREP paid both the land's rental value and a 100% bonus of the rental value. Prior to 2001, the premium, or bonus, had been 80% of the rental value. From 2004 to 2009, payments were changed to a staggered system related to buffer width, but recent program changes returned it to flat rates per acre and even greater premiums.

Table 5 reports a "present value" for CREP contracts, distinguishing between pine and hardwood plantings. The estimate only counted income that would not have accrued without the contract and, because a considerable part of this value accrues over 15 years, future payments were discounted to obtain their present value. This is reported as the present value of the incentive payment (PV An. Inc.), calculated as the sum of a stream of 15 discounted payments using a 4% discount rate per year. Thus the present values quantify how much additional payment the landowner would receive in CREP rather than renting the land, assuming that soil rental rates do not rise. Landowners farming their own land may realize much more or much less than the average soil rental rate, depending in part on commodity prices and weather.

The monetary value of the CREP contract to the land owner is made up of: a 27.5% bonus over establishment costs, signing bonuses worth $200, and annual payments of 100% of the soil rental value over the 15 year life of the contract. While the 2001 CREP contract pays twice the soil rental value each year of the contract, soil rental that the landowner would have received if not enrolled in CREP was subtracted to calculate only the additional value from the contract. In addition to the 15 year contract, a 30 year term was modeled to estimate value if the CREP land is re-enrolled for a second 15-year contract. By looking at a 30 year buffer payment, we can begin to compare the CREP contract values with timber values, which are also paid in the future. Total value sums the up-front payments and the present value of the incentive payments for the two lengths of term, subtracting the land rent the owner otherwise would have gotten.

Table 5: Net present values for pine and hardwood buffers for CREP incentive payment, evaluated at 15 and 30 years with 4% interest rate

Composition of Present Values for CREP Contracts at 15 and 30 years							
	Establish Incentive	Signing Bonuses	Annual Incentive	PV An.Inc. @15yr	PV An.Inc. @30yr	Total Contract PV @15yr	Total Contract PV @ 30yr
Pine	$161.70	$200.00	$124.00	$1,378.68	$2,144.21	$1,740.38	$2,505.91
Hardwood	$327.25	$200.00	$113.00	$1,256.38	$1,954.00	$1,783.63	$2,481.25

Pine and hardwood contract values are counter-balanced by the higher establishment incentive for hardwoods on the one hand and the lower average soil rental rate for those counties on the other. The higher up-front payment for hardwood establishment nearly balances the lower value generated from the stream of annual payments.

Timber Values

The ability to receive recurring income from timber sales provide incentive for private landowners to maintain a forest buffer over time, long past when conservation program payments have expired. Removal of trees in harvesting represents an opportunity for some nutrient removal and can contribute to buffers being able to maintain long-term nutrient reduction capacity; normal harvesting practices leave a majority of nutrients on site because they are concentrated in leaves, needles, and twigs, so effects of removing some tree boles are likely to be modest in most cases. Of greater import may be the ability to maintain forest health by applying appropriate silvicultural practices through the harvesting operation. Thinning trees and giving more growing space to the more desirable trees can improve tree vigor, forest diversity, and wildlife habitat (greater understory growth). Harvesting can be used to select for important native species like oaks that are declining in abundance without active management. Harvesting BMPs, required in Maryland, have been shown to be effective in protecting streams from sediment, the greatest potential pollutant on timber harvests, so the protective functions of the buffers can be maintained during commercial timber harvesting.

Timber values were calculated from projected pulpwood and sawtimber volumes, average product prices, and subtractions for trees required to be left in buffers. State harvesting best management practices (BMPs) require at least 60 ft^2/acre of basal area to be kept in a minimum 50-foot streamside management zone; this is usually at least half the trees in a fully stocked stand, and is important to maintain shade over streams. Where the projected tree stocking did not exceed 60 ft^2/acre, it was assumed that no timber sale would take place. Even though harvesting could occur on part of the buffer area because most buffers are 100 feet or more, the limited acreage and low per acre volume would make it unlikely to be a viable commercial timber harvest. Actual values would vary significantly based on timber quality, species, access from roads and market fluctuations. For sawtimber, the average price per thousand board feet (mbf) was calculated from 10 years of sales on State Forests. Pine sawtimber was based on State land timber sales from the Eastern Shore of Maryland and Southern Maryland Forests ($283/mbf), and hardwood sawtimber was based on sales from Western Maryland Forests ($328/mbf). Pulpwood was valued at $5/ton, below the $10/ton average for the Southern and Southeastern United States because the market in Maryland is more limited than in much of the South and typical prices are lower. Conversion factors of 2.6 tons/cord for pine and 2.9 tons/cord for hardwood were used to develop per ton values from the cord predictions from the NED-2 model.

Pine-dominated buffers

For counties on the Eastern Shore of Maryland where loblolly pine is a native species, buffers can be planted with up to 80% pine. The remainder (20% or more) is a mixture of hardwood trees and shrubs, commonly planted closest to the waterways. The pine survival is typically high and growth rates are fast. Additionally, most of the pine-dominated buffers were planted on prior cropland, and did not face the substantial root competition from established fescue that was common for hardwoods planted on pasture sites. Many of these buffers are large enough and have enough volume to be harvested as a stand by itself. The growth data on the pine-dominated buffers were collected to capture the higher end of potential values in forest buffers and product mixes with earlier income streams from thinning. Many buffers would yield less than these estimated values.

Growth was modeled on three sites in Somerset County on the Eastern Shore of Maryland using NED-2 from the USDA Forest Service. The growth model selected for the southern Eastern Shore was the Southern variant of the FVS (Forest Vegetation Simulator) associated with NED-2. Site index was measured on-site and entered into the model, which accounts for local variation in soil productivity; the model uses this site-specific data to adjust predicted growth rates for local conditions.

Three potential harvest scenarios were evaluated. A common scenario is to thin mid-rotation and allow faster growth on the remaining trees for higher-value sawtimber products. Thinning at 15 years (row thin of every 3rd row) and harvest at 30 years were modeled, considering the rapid early growth of the buffers, and average basal area of more than 115 ft^2/acre at age 8. Partial and clearcut harvest (with partial volume left in the closest 50 feet) were modeled at 20 years. The partial harvest was modeled as a thin from below to 70 square feet of basal area, leaving the larger trees to grow to more sawtimber-sized products. The rotations are likely to be longer for some other locations with more modest growth rates, but the density and fast growth rates of the measured pine stands did not lend itself to a 30-year harvest schedule that is more typical for the region.

The greatest total value was created with the thinning approach (Table 6). The thinning option also had the advantage of some income at an earlier age, even though income from thinning young trees is much less than for final harvest.

Table 6: Potential forest product income per acre for three management scenarios, pine-dominated forest buffers (reserves left for harvesting BMPs)

Loblolly Pine, Average of 3 sites	2016	2021	2031	Total-30yrs	Total with residual value
Thin at 15 years, harvest at 30	$254	$0	$720	$974	$974
Partial Harvest at 20 years	$0	$544		$544	$846
Clearcut at 20 years	$0	$714	$0	$714	$714

Values represent harvesting allowed by state buffer regulations with a minimum 50-foot buffer. Most Coastal Plain sites were very flat, and slope expansions of harvest buffers were considered minimal. The average value of timber left in the buffers was $94/acre at these young stand ages. For buffers narrower than 240 feet, the proportion of harvest value left in the buffer would be higher.

The partial harvest option also has substantial value left in the residual stand. This value would be other future income. Average value of a similar future harvest, discounted back 15 years to be comparable to values from the other harvest scenarios, was $302/acre. When the additional value of future harvest of the allowable uncut volume was added, the partial harvest option was closer to the values for the thinning at 15 years. Because the pines used here require high light levels to regenerate, repeated partial harvests are unlikely to maintain a well-stocked pine-dominated stand. Some other harvesting option that encourages greater regeneration may need to be used for a future harvest, or species encouraged that can regenerate with some shade.

Hardwood Buffers

The stocking (trees/acre) of hardwood buffers varied widely, which greatly affected future harvest values. The hardwood buffers evaluated were planted mostly in prior pasture sites, and most had very substantial fescue competition that limited survival and growth, in addition to vigorous deer browse and damage from voles and mice. The most common site preparation was mowing. Mowing was also the most common form of maintenance, though a few of the locations also had some herbicide spraying to reduce weed competition and noxious weeds.

The hardwood buffers grew more slowly than pine buffers and had lower survival rates, near minimum standards for stocking. With slower growth and lower stocking, these buffers accumulated forest product value more slowly. Time horizons of 40 years did not yield significant forest products in the hardwood buffers, although the better stocked, productive stands had accumulated enough density and volume to support a commercial thinning.

The forest product volume and potential product value for hardwood buffers were evaluated at 2080, about age 80 (Figures 26, 27). Growth was modeled in NED-2 with the use of the Northeast FVS model, the selection most suited to the oak-hickory and Appalachian hardwood area. Modeling that attempted to thin the hardwoods at 40 years were not successful since most of the buffers did not have dense enough stands to thin. Given the low trees/acre and basal area that characterized most of the hardwood buffers, intermediate forest operations like thinning were not modeled since they would not be appropriate to the stand conditions. Approximately half of the buffers did not have sufficient density or basal area to be suitable for thinning or a regeneration harvest at 2060 or 2080. RFB-8 was not planted to trees, and RFB-7 had a failed planting that left very few surviving trees. These did not have any potential for forest products income, as would be expected. Differences in growth and product volume varied from less than 2 cords per acre to over 12. These differences were primarily related to differences in tree stocking (density). Most of the value for products was associated with trees that were allowed to reach sawtimber size (Figure 27).

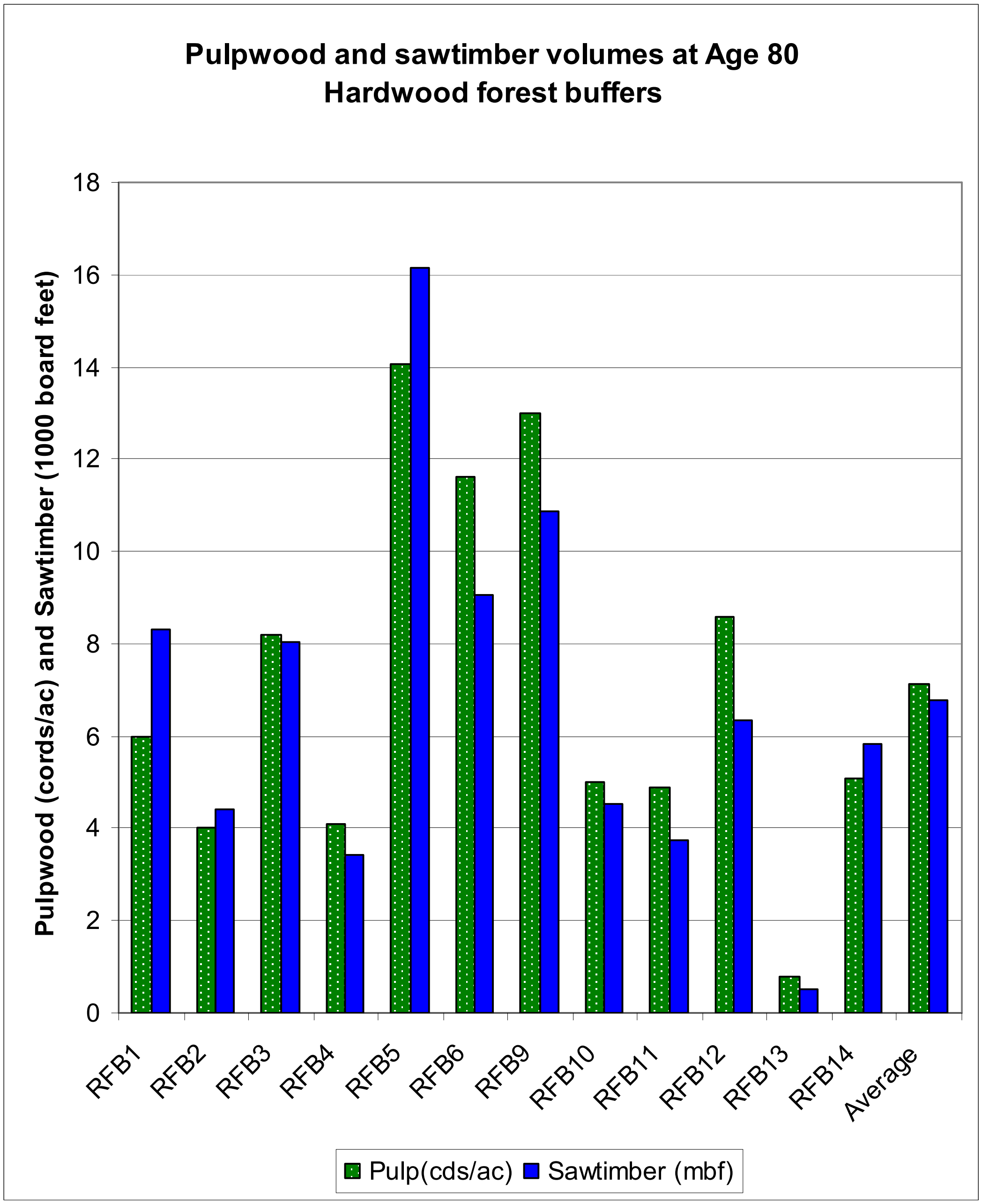

Figure 26: Volumes of pulpwood (cords/acre) and sawtimber (mbf/acre) on 12 hardwood buffer sites modeled at age 80, with timber reserved from harvest on 60 sq.ft./ac. on half of buffer

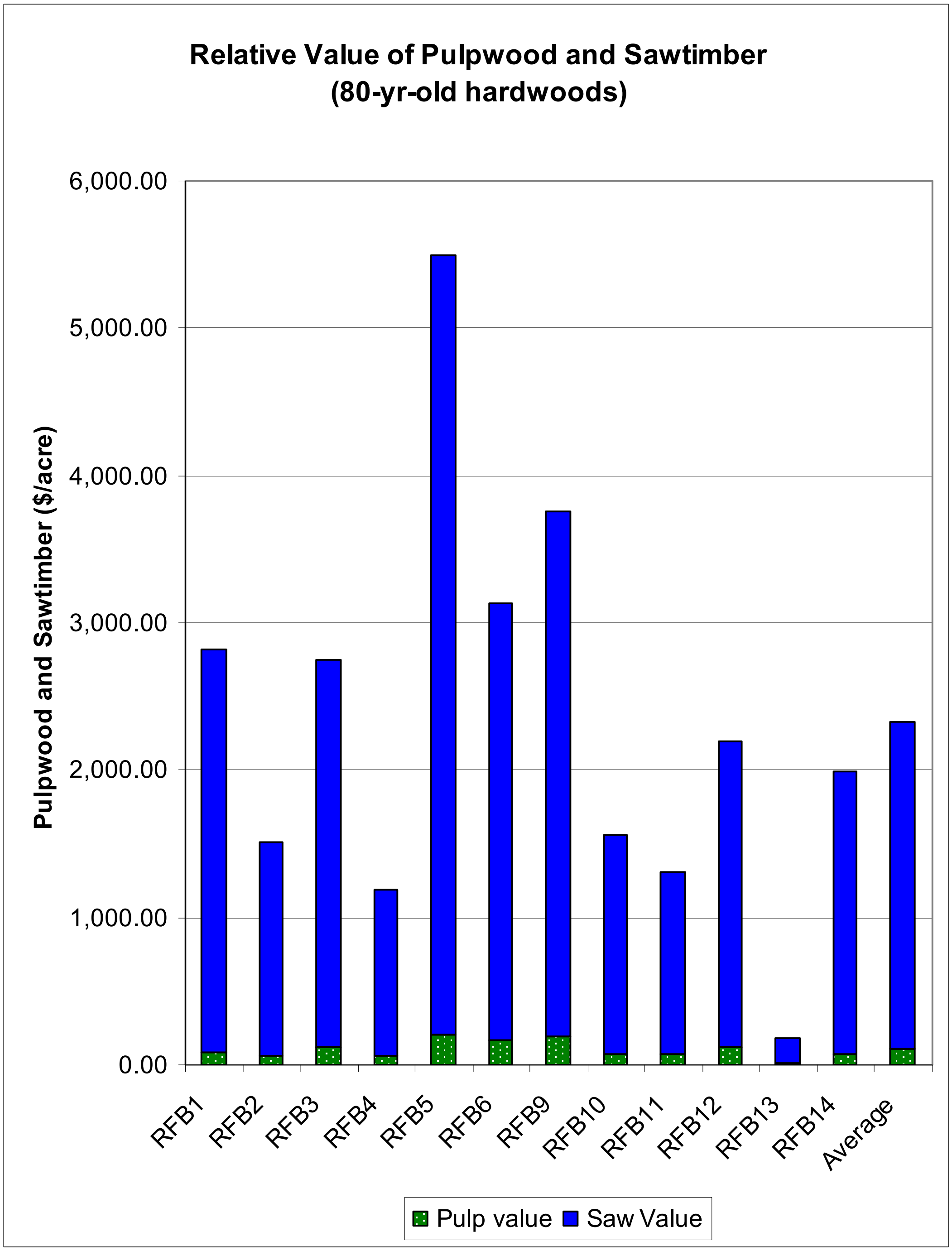

Figure 27: Values of pulpwood and sawtimber ($/acre) on 12 hardwood buffer sites modeled at age 80, with timber reserved from harvest on 60 sq.ft./ac. on half of buffer

For considering future product value in forest buffers, a reserve of 60 square feet per acre of basal area was kept on half of the buffer. This is based on the average buffer width of just over 100 feet, and a State minimum requirement for harvest buffers of keeping 60 ft^2/acre of basal area within a buffer of 50 feet or more if required for slope protection. Some of the forest buffers planted in Maryland are wider than 100 feet, but if slopes are present on the site, streamside management zones with limited harvest will be required beyond the minimum 50 feet. Slope expansions are common in the Piedmont and Mountain provinces where hardwoods have been frequently planted, reflecting the native species in the regions. Most of the buffers were less than 10 acres in size. The small size of buffer plantings and the fact that more than half of the tree volume is likely to be left on site within the 50+ feet nearest the stream affect chances for a profitable commercial harvest. Potential harvests of the buffer areas are likely to be feasible with current harvesting systems and costs only if the buffer is harvested along with another larger area on or near the property. Harvest values were assigned only if basal area was greater than 60 $ft^{2/}$acre for the entire area. While there would be harvestable wood outside the 50 ft (or greater) harvest buffer, the volumes would be low and unlikely to be practical to harvest.

Table 7: Average, maximum, and minimum values of 12 planted riparian forest buffers in the Monocacy, Catoctin, and Antietam watersheds of Maryland

Growth modeled at Age 80	**Average**	**Max**	**Min**
Trees / area (stems/ac)	172	330	70
Basal area (sq.ft/ac)	67	147	7
Avg. dbh (in)	14	18	8
Pulp cds/ac	7	14	1
Saw Bdft/ac	6,772	16,150	521
Pulpwood value/acre	$103	$204	$12
Sawtimber value/acre	$2,221	$5,297	$171
Total value/acre	$2,325	$5,501	$182
Value/acre retained on site for BMPs	$832	$1,272	$91
% merchantable	64%	77%	0%
Net Value/acre with harvest reserve for BMPs	**$1,170**	**$4,381**	**$0**

Average net value of timber able to be harvested in the forest buffer was $1,170 per acre (Table 7). The most value was realized when trees reached sawtimber size. Other fiber markets may develop over time, such as biomass, but product values are not expected to be greater than those for sawtimber. At age 60, expected harvestable value averaged almost $800/acre.

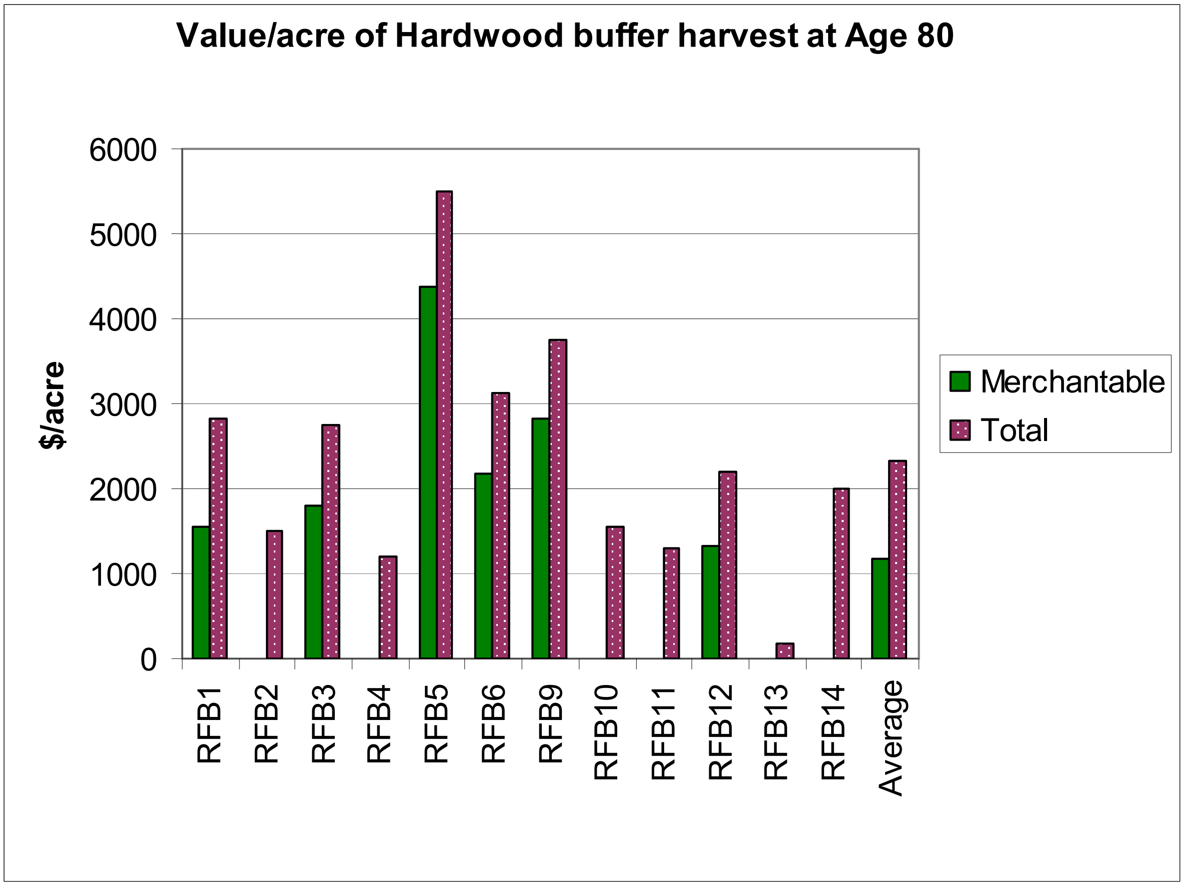

Figure 28: Per-acre value of forest products in hardwood buffers, age 80, based on modeled growth and timber reserves left for harvesting BMPs

The value of timber left in the buffer to meet stream protection requirements averaged over $800 per acre for harvests conducted in 2080 (Figure 28). Value in reserved trees was only $443 per acre at age 60, but values increase as the trees grow.

Comparing Timber Income and CREP Income

Timber income and CREP income both directly benefit the landowner but the timing of payments can vary greatly over time. Present values were used to compare net values, discounting future income based on the length of time the landowner would have to wait. Estimates of average additional income of CREP contract illustrate the substantial monetary benefits of that program, over $1700/acre for a 15-year contract and up to $2500/acre over a 30-year contract with re-enrollment. The timber that grows in those restored RFBs can also provide value to the land owner, to the extent that it is available for harvest. Commercial harvest is not allowed under CREP contracts, although management practices like noncommercial thinning can be practiced. Table 8 reports the discounted future values of thinning and harvests reported in Tables 6 & 7, using a discount rate, or alternative rate of return, of 4%. For pine RFBs, the values reported in Table 6 for thinning at 15 years and harvest at 30 years, a total of $974 over the 30 years, were entered into the discount formulas for net present value. For hardwood RFBs, the average per acre harvest value given in Table 7, $1,170/acre at 80 years, was used to calculate net present value.

Table 8: Net Present Value of Pine and Hardwood timber harvest, 4% interest rate

Present Value of Future Timber Harvests ($/acre)			
	Thin @ 15yr	Harvest @ 30yr	Harvest @ 80yrs
Pine	$141.04	$399.79	na
Hardwood	na	na	$50.75

The average present value of pine timber income at 15 and 30 years ($541/acre) was more than ten times greater than for hardwoods at 80 years ($51/acre). The great difference is related to the much longer time frame for commercial harvest of hardwoods. NPV analysis of hardwood income at 60 years ($157.04 value for the $797 income) was three times as high as that at 80 years. The 4% alternative rate of return used to discount future income to present values was modest, and even greater differences would be apparent if more aggressive desired rates of return were selected.

While the estimates of combined income of a 15 year thinning and a 30 year harvest on the pine sites were better, in present value terms, than the harvest of hardwoods at 60 years or even the pine harvest at 30 years without thinning income, it must be kept in mind that capturing the thinning value at the earlier time requires leaving the CREP program at the end of 15 years. The additional 15-year contract is worth another $766/acre in present value to the landowner, larger than timber income from either option. While simply leaving the pine buffers to grow and harvesting at 30 years without a thinning might look attractive, the timber growth modeling indicates that such management could be repaid with very low returns due to crowding, and greater risk of mortality to insects or disease. One alternative may be a noncommercial thin, where the pulpwood value could cover the cost of the thinning practice but no additional timber income for the landowner. The landowner could participate in the incentive program and realize the greater growth and health of the thinned forested areas.

Calculating the value of the CREP contract in net present value terms allows one to consider additional values that the landowner might derive from a RFB, as long as these too are calculated as present value. Such values include hunting benefits, which would accrue annually, or timber/pulpwood harvesting after the CREP contract(s) finish. While CREP agreements preclude resource extraction from the buffer during the life of the contract, this does not include hunting along the buffer. Like timber harvesting, realizing value from a hunting lease on buffer lands will depend on it being part of a larger area. Hunting leases on State Forest lands on the Eastern Shore of Maryland averaged just over $10/acre in 2009. Lease prices can vary depending on size of holding and quality of habitat.

Nutrient Reduction Value

Water quality trading markets are in their infancy in the Chesapeake Bay states, and very few trades dealing specifically with riparian forest buffers have occurred even in states where the institutional structure is in place and operating. Trades with non-point source reduction techniques like riparian forest buffers are often a secondary option, with point source trades given first priority. The water quality trading market should serve to realize efficiencies in reducing nutrient loads in a watershed, but the dearth of trades with buffers means that these markets are not currently revealing a "market price" for water quality from RFBs. Another approach is to use values being paid for other methods of reducing nutrients, such as wastewater treatment plants, stormwater facilities, nutrient management planning, and cover crops. Average nutrient reduction costs were estimated by the Chesapeake Bay Commission (CBC 2004); these included treatment plants, nutrient management planning, and cover crops, but did not include stormwater controls due to the high and variable costs of many of the stormwater practices.

The hardwood buffer sites whose ecosystem attributes are assessed above were primarily in the Ridge and Valley-marble and limestone and Piedmont Limestone Lowland physiographic provinces of Maryland. This was confirmed by the neutral to alkaline pHs in the water samples. Removal efficiencies were based on the recently revised percentages for riparian forest buffers in the Chesapeake Bay Program model. Percentage efficiencies for RFBs are described in Simpson and Weammert (2008). Because of the karst topography and variability in flow paths for shallow groundwater and streams, the removal efficiencies are lower than in some areas of the Bay watershed. Research has shown reductions from 80 to 90+% of nitrate traveling through a mature forest buffer, but not all areas have that level of efficiency, so rates are reduced where shallow groundwater has less certainty of flowing through the tree root zone. Removal efficiencies used for estimates were 34% for total nitrogen, 30% for total phosphorus, and 40% for total suspended solids for estimating treatment of 4 upland acres. The nitrogen loading rates from the Chesapeake Bay Model were used to estimate potential benefits from riparian forest buffers (Figure 29).

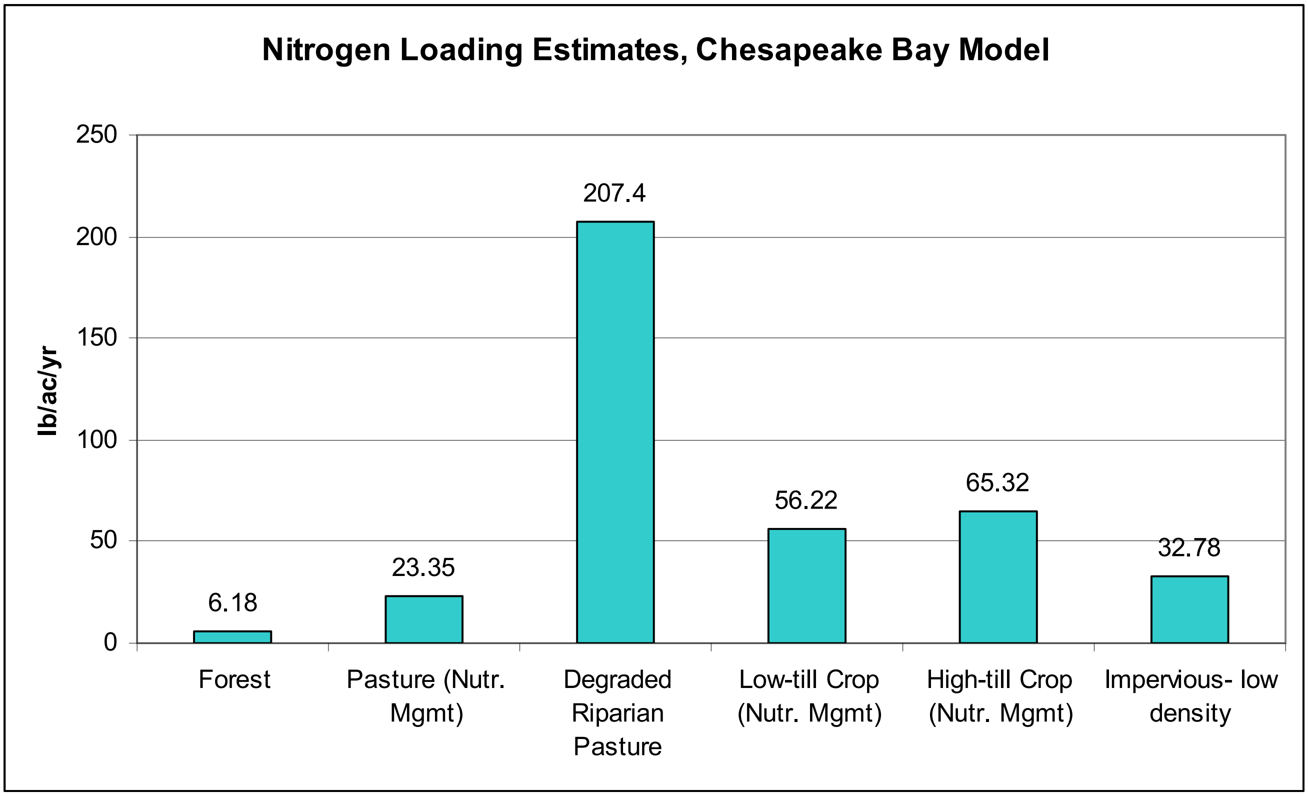

Figure 29: Nitrogen loading by land use, Chesapeake Bay Model, Non-Coastal Plain

Nutrient benefits are realized first from the land conversion to forest use, calculated as the difference between the converted land use, such as pasture, and forest. This benefit is based on removal of the nutrient additions from the land use, and should be realized at the time of establishment of the buffer. Additional benefits are realized within buffers based on their ability to treat nutrients within the riparian area. This value is likely to be lower at first, and grow over time as the trees mature and crown closure occurs (between 5 and 25 years depending on planting density, survival, and growth rate). Additional benefits will be realized over longer time periods as the trees contribute to in-stream nutrient processing (Sweeney et al. 2004), but these are not calculated here. The significant increases in epifaunal substrate and trends towards improving benthic macroinvertebrate Index of Biotic Integrity suggest that the instream processes that would reduce additional nutrients are expanding their function.

Several scenarios were evaluated to capture the range of likely nutrient reduction in hardwood buffers planted on sites previously used for pasture. Where pastures had eroding areas near streams and on the streambanks, the loadings associated with degraded riparian pasture would be addressed on the buffers converted to forest use and removed from grazing pressure. The degraded riparian pasture values were not used for treating upland acres since those areas would not be contributing at the high rate of eroding streambanks. Areas immediately upland of the planted buffers were commonly more pasture or cropland. Nutrient management is required in Maryland and other conservation practices are commonly applied, so nutrient loadings for pasture and crop practices with nutrient management were used. If nutrient management guidelines are not being properly applied as assumed, the actual nutrient reductions from the buffer practice would be greater. The three scenarios were:

- Forest buffer established in a degraded riparian pasture, treating upland acres in pasture under nutrient management
- Forest buffer established in a pasture under nutrient management, and treating upland acres being cropped using low-till conservation practices and nutrient management
- Forest buffer established in a pasture under nutrient management, and treating upland acres in similar pasture

Buffers are expected to reduce at least 50 pounds/acre/year of nitrogen, even when planted on pastures that are not eroding quickly (Figure 30). Areas where tree planting and removal of cattle from streams allow the stream to revegetate and stabilize its banks would realize much higher nutrient benefits, over 200 lb/acre/year.

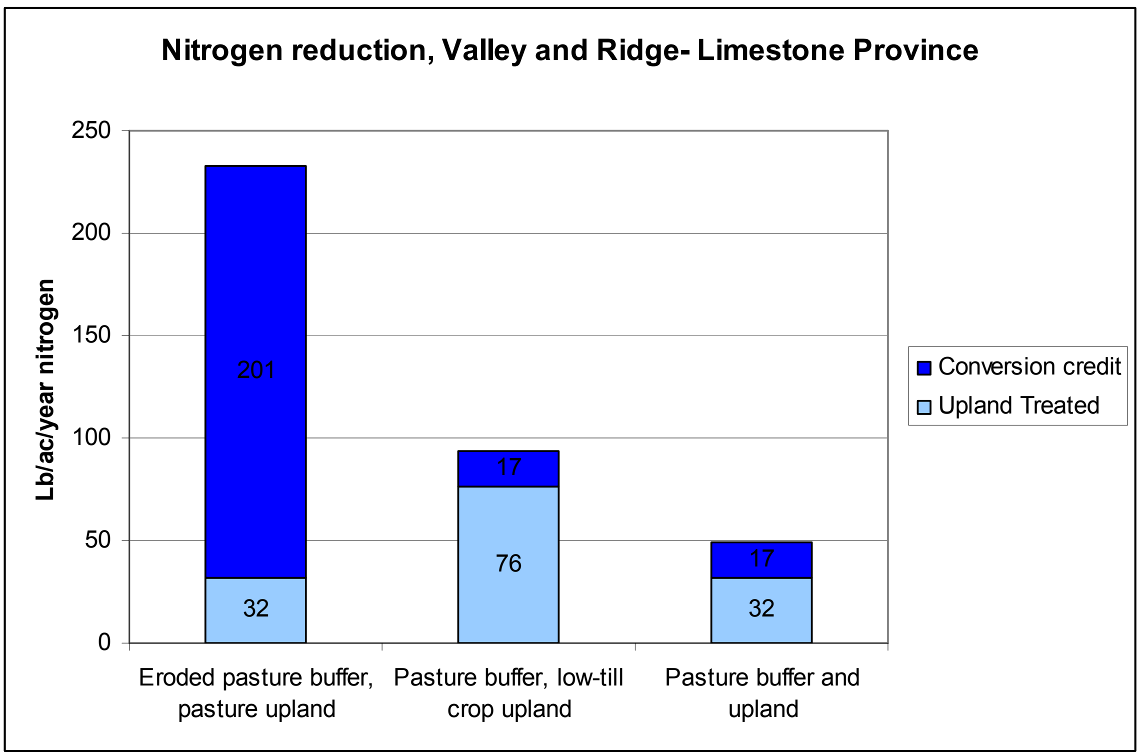

Figure 30: Nitrogen reduction estimates for buffers on old pasture, Ridge and Valley

One method of assessing the value of nutrient reduction is to use cost per pound of nutrient reduction using other means. Three alternative practices for nutrient reduction in the Chesapeake Bay are sewage treatment plant (STP) upgrades, nutrient management on agricultural land, and cover crops on cropland. Average annual costs including capital costs, operation, and maintenance were calculated in a Chesapeake Bay Commission report (CBC 2004). Average costs per pound of nitrogen reduced were $8.56 for STP upgrades, $4.41 for nutrient management and $3.13 for cover crops. These estimates from 2004 were also compared to Maryland's FY2010 investments in sewage treatment plants and planned nitrogen reduction (MD FY2010 budget analysis). The average value of nutrient reduction from the five sewage treatment plant upgrades budgeted for Fiscal year 2010 was $22.56 per pound of nitrogen, although costs vary almost an order of magnitude depending on project size and other site-specific factors. Like riparian forest buffers, the treatment also addresses other pollutants such as phosphorus. The lowest costs were associated with the largest project at the nearby Patapsco treatment plant, at $8.40/lb, similar to the 2004 average estimate for projects in the Chesapeake Bay region (CBC 2004). While the nutrient reductions would not be realized for 5 to 15 years during planning and construction, riparian forest buffers also take time to reach capacity. Nutrient reduction values were calculated using average and low-cost estimates (Figure 31).

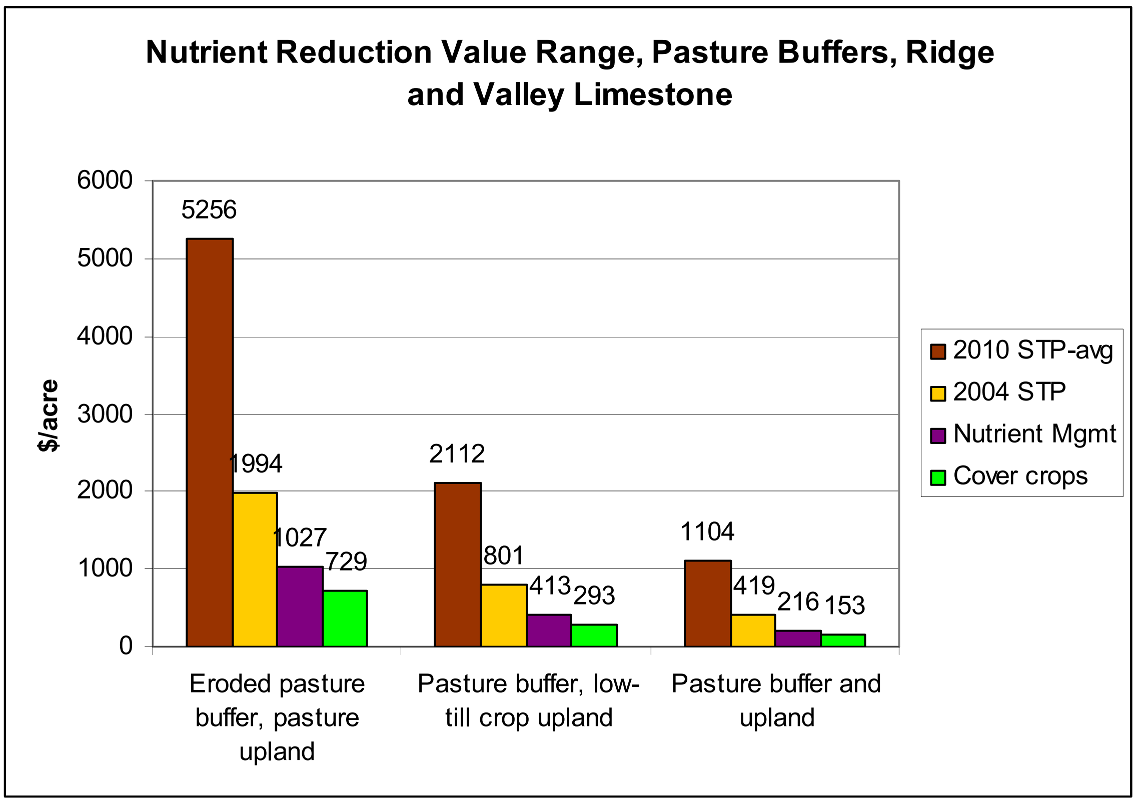

Figure 31: Value of riparian forest buffer nutrient reduction based on alternative costs of reduction through sewage treatment plant upgrades, nutrient management on agricultural land, and cover crops

While it is difficult to place a dollar value on a given unit of nutrient reduction, it is possible to estimate the costs of generating it. Those include the up-front cost of establishing and maintaining a forested site where trees did not previously exist, plus the loss in production value from the land's prior use. Under the CREP program, federal and state payments of up to 127% of establishment costs are available to farmers willing to establish a RFB. In addition, the lost production value of RFBs is paid annually (at a significant premium) each year of the 15-year CP-22 CREP contract. From the adopter's point of view, the value of a CREP contract is the sum of the up-front payment, plus the discounted value of all the annual payments.

Payments made to adopters to establish RFB constitute a price paid to achieve, among other things, nutrient load reductions. If we consider this "price paid" per acre in terms of the differing levels of nutrient reduction estimated in Figure 31, it becomes apparent that the value varies considerably across acres, depending on the land use change on the RFB acres and the land use of upslope acres. Using public investment costs from CREP (average annualized 2001 CREP costs of $206/acre), a price per pound of nitrogen reduction can be estimated for the three scenarios (Figure 32). Costs of establishment are assumed to not vary in any consistent way across scenarios.

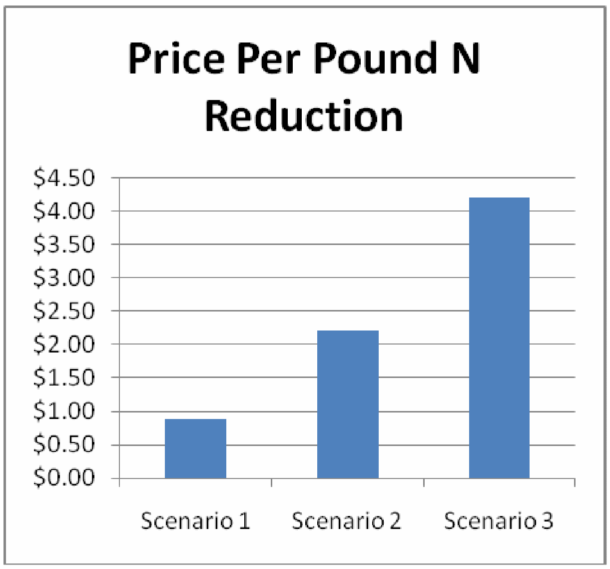

Figure 32: Cost per pound on nutrient reduction on pasture buffers with 1) eroding banks, 2) degraded pasture, and 3) pasture with nutrient management, assuming equivalent costs and pasture in nutrient management upslope

The cost of nutrient reduction (as measured by nitrogen reduction at CBP efficiency rates) differs widely across scenarios. Scenario 1 acres (buffers on degraded pastureland with upland acres in nutrient management pasture) deliver nitrogen reduction at a unit price of $0.88 per pound, while scenario 3 acres (buffers on nutrient management pasture land treating upland acres also in nutrient management pasture) provide reduction at a price of $4.20 per pound. At any given value for a pound of nitrogen reduction, scenario 1 acres would be preferred over both alternatives and scenario 2 acres would be preferred over scenario 3 acres. Although targeting is used to identify cooperating private landowners for incentive programs, the current payment structure does not have higher incentives for locations more likely to provide higher nutrient reduction benefits. Benefits other than nutrient reduction may be realized at higher levels in some of the areas with higher costs/pound of nutrient reduction, and the practice will need to be applied broadly to be effective at the watershed scale. Program policies also need to balance cost-effectiveness with clearly understood benefits to potential participants.

Air Quality Value

Analysis of tree growth in young riparian buffers identified substantial carbon sequestration value. Most of the higher values were associated with the pre-existing trees in the buffers. The young trees will provide greater values in the future as leaf area and biomass increase. Wieland and Strebel (2008) estimated that Maryland forests could sequester from 4.13 MgC/acre/year on average, and up to 5.68 MgC/acre/year if managed to optimize carbon storage. Using white oak as a proxy for hardwoods and pine as a proxy for softwoods, they found that the long-term carbon sequestration values of State Forests in Maryland were dependent on the length of time that forests were allowed to grow. In their study, the range of time forests were allowed to grow did not include rotations shorter than would maximize species' biomass production, but, over that range expected average annual carbon sequestration decreased as the length of rotation increased. This suggests that as the values of riparian buffers differ across specific acres with respect to nutrient mitigation, they also differ in carbon sequestration values, depending on how long RFBs are left to grow.

Carbon sequestration benefits for current stocking in hardwood buffer sites is estimated in Table 9. Current benefits are dominated by existing larger trees, but the potential future for future growth is clear.

Table 9: Carbon sequestration by species, buffer planting sites

	Trees/acre	Carbon (lb/ac.)	Leaf Area (ft2/ac.)	Leaf Biomass (lb/ac)	Value ($)
Green ash	20.44	577.78	3049.2	40.77	$2,561.70
Black walnut	13.44	164.52	4590.35	75.39	$953.40
Am. Sycamore	7.53	54.24	2121.81	21.06	$327.80
Black locust	6.43	107.42	2174.95	24	$459.70
Swamp white oak	5.91	10.53	395.09	7.41	$260.20
Pin oak	4.9	12.76	393.35	7.32	$158.60
River birch	3.2	9.8	350.22	5.53	$112.90
White ash	2.67	8.3	211.27	2.5	$80.50
Honeylocust	2.14	20.25	263.1	5.62	$102.80
Red mulberry	1.6	3.39	59.24	1.25	$50.60
Hackberry	1.09	2021.32	4406.97	46.93	$4,006.00
Flowering dogwood	1.09	1.34	59.24	0.71	$34.00
Sawtooth oak	1.09	3.3	73.18	1.34	$42.90
Boxelder	0.53	54.96	110.21	2.05	$192.60
Tree of heaven	0.53	51.12	441.26	6.78	$245.60
Eastern redbud	0.53	1.43	39.64	0.54	$17.00
Eastern red cedar	0.53	14.1	183.82	10.44	$90.60
American plum	0.53	0.62	36.59	0.54	$12.10
Black cherry	0.53	1798.54	1733.25	27.57	$2,252.90
Total	74.75	4915.82	20693.18	287.64	$11,962.10

Having a diversity of species is important for maintaining long-term resiliency of the forest buffers. With the younger trees dominated by green ash and black walnut, the advent of new pests and diseases creates increased risk of tree death. The spread of the emerald ash borer (EAB) is likely over the next decade or two unless effective controls are developed. Many of the ash trees now helping to develop forest conditions could be killed as EAB spreads in the region. The thousand-cankers disease, an insect-borne fungus, has started spreading from the Western United States to black walnut's native range in the Midwest and further east and may pose a significant threat in upcoming decades. Unthinned pines may be vulnerable to the exotic *Sirex* wood wasp and its associated disease moving south from New York. Other species may have similar but unknown vulnerabilities in the future. Planting a diverse range of species is one strategy to address the risks associated with epidemics affecting a particular species. The role of fast-growing trees as a nurse crop for new generations of trees should be considered; fast-growing trees that start shading and development of a forest floor more quickly can create growing conditions conducive to continued forest growth, even if pests cause some shifts in species surviving. Most of the species present are found over a wide range in the Eastern U.S., so predicted climate change patterns may not directly limit future health over the typical lifespan of the trees.

The tree benefit calculator at http://www.trees.maryland.gov/calculator.asp was used to estimate in general terms the other air quality functions and values based on the climate and conditions in Frederick County and existing trees. The model generated values for air quality improvement both through direct deposition on leaf surfaces and also for avoided air pollution associated with reduced heating and cooling costs (Figure 33). Pollutants addressed were ozone, volatile organic compounds, nitrogen dioxide, sulfur dioxide, and particulate matter. Most of the riparian buffers measured were not in locations close to houses or other facilities, so avoided costs of heating and cooling buildings were not included in estimates. The avoided costs categories would only be functions that would apply if buffers were in a developed setting (significant impervious surface or shading buildings) and could reduce the urban heat island effect. One of the monitored buffers was in an urbanized watershed (66% impervious surface), but most had less than 10% impervious surface. An approximate per acre value is $120/acre, summed across multiple pollutants and cumulating values from individual trees. To be conservative and account for the proximity of the trees to each other, only $60/acre was attributed for air quality. The majority of trees were still very small with low leaf area, and individual values were calculated at less than $1/tree. Larger trees (e.g., over 10 inches DBH) were estimated to contribute ten times that amount. These benefits would be expected to grow significantly over time, and would be greater for larger trees that produce greater leaf area for deposition.

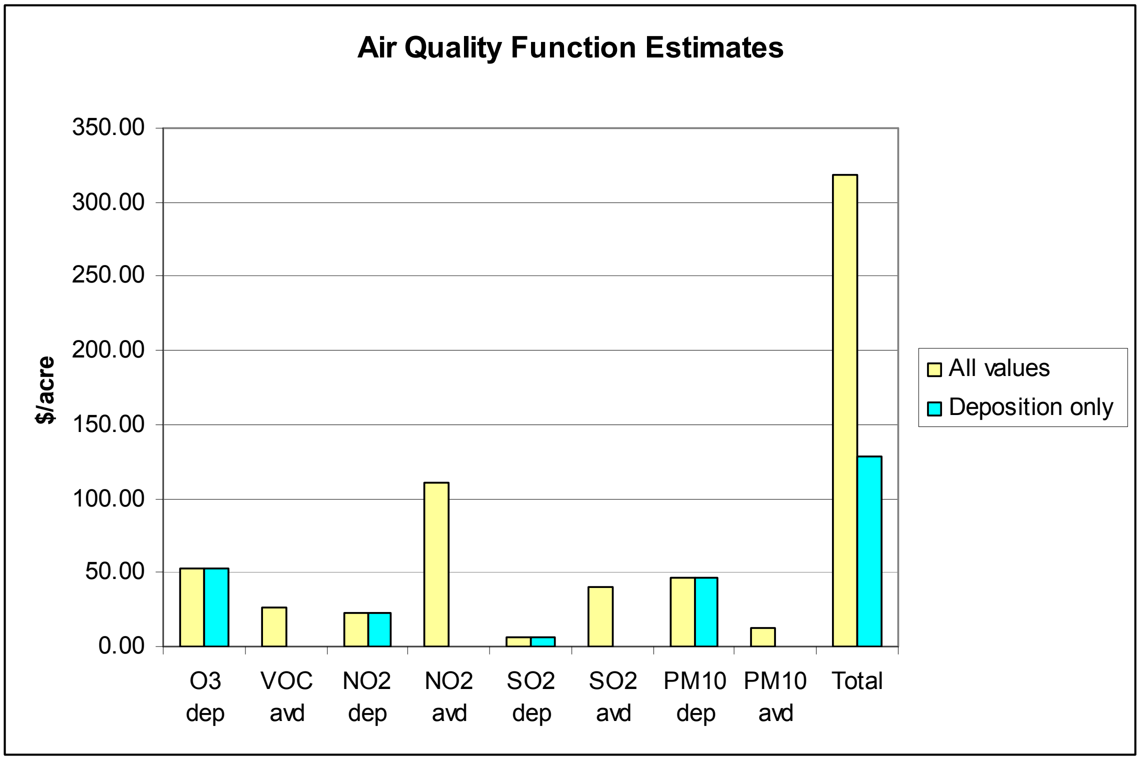

Figure 33: Estimated air quality improvement from riparian forest buffers adjusted to per acre values

Many of Maryland's restored forest buffers are in the airsheds for areas with air quality impairments like ozone (counties surrounding Washington, D.C. and Baltimore) and particulate matter (Hagerstown Valley area). Values of trees for improving air quality have been estimated for Washington, D.C. and Baltimore City (Nowak et al. 2006). Air pollution reduction values within the cities were estimated at between $40 and $50/acre, considering only reductions in ozone, sulfur, nitrogen dioxide, carbon monoxide, and particulate matter. Values of avoided heating and cooling costs from shaded buildings were exceeded that for pollutant removal by a modest amount, but these values would not be applicable to most riparian buffer plantings. Additional value is associated with carbon storage and annual sequestration; D.C estimates were $863/acre stored and $27/acre/year sequestered.

Combined Values

Riparian forest buffers provide an exceptionally wide variety of public and private benefits from water and air quality to timber and recreation. Generally, these benefits can be provided simultaneously and are well-supported by similar conditions of vigorous tree growth. Estimates of several types of values were developed to help evaluate public investments in forest buffers. These estimates, detailed above, were based on measured buffer characteristics from long-term monitoring and quantified through well-established models, such as NED-2 for forest growth and UFORE for air quality (now part of iTree).

Water quality reductions were valued using common alternative practices for nutrient reduction.

Pine-dominated buffers on previously fertilized cropland on the Eastern Shore of Maryland were assessed to demonstrate the upper limits of growth rates and stocking. Hardwood buffers on prior pasture with heavy grass competition and deer browse were the typical sites in the long-term monitoring effort; these sites represented harsher growing conditions, ones that are common in the focus areas for buffer restoration. Timber values were calculated assuming buffers would be harvested in conjunction with other nearby stands, and that trees required to meet State harvesting rules would remain uncut. Tree growth and future timber value were primarily controlled by tree density, or stocking. Hardwood buffers with low survival and stocking were not predicted to grow sufficient volume to allow harvest beyond the 60 square feet per acre of basal area required to be left in harvest buffers. Hardwood buffers that had better survival had the potential for substantial timber income (average of $1170/ac at 80 years), with values ranging over $4300 per acre. Values for pine timber averaged $974/acre with thinning at 15 years and harvest at 30 years, and income would be realized by landowners much more quickly. These substantial differences in timing of income were evidenced in the large differences in net present value (NPV) for the timber, even using a modest 4% discount rate. NPV for pine buffer timber was $541/acre, harvesting by thirty years, over ten times the $51/acre value for timber from hardwood buffers harvested by eighty years.

Benefits of buffers vary greatly from site to site, and valuation methods for most income streams and functional values are not precise. A conservative estimate that only assesses four functions, nutrient reduction, air quality improvement, recreational hunting, and timber value is $504/ac/year (Table 10). Water quality values would be substantially higher if the riparian forest buffer practice was applied to acres with higher nutrient loadings than pastures in good condition. Air quality values would be higher for buffers planted in more urban settings with higher pollutant concentrations.

Table 10: Estimates and ranges of annual per acre values for common riparian forest buffer functions

	Typical	*High Range*	*Low Range*
Water Quality (pasture buffer)	**$419**	$5,256	$153
Air Quality	**$60**	$320	$20
Recreation (hunting fee)	**$10**	$20	$5
Timber (hardwood avg., pine high)	**$15**	$69	$0
Total	**$504**	$5,628	$178

Additional functions such as instream nutrient reduction, flood control, aesthetics, aquatic habitat, wildlife habitat, and other recreational uses also have value. Protecting riparian forest buffers important for flood control has been used to avoid much more costly structural solutions and provide a more long-lasting solution (Schwartz 2006); the ratios of cost savings using permanent protection of riparian areas ranged from a third the cost to 1/200th the cost in various communities and settings. The value of recreational fisheries has been quantified, although the portion attributable to newly restored buffers is difficult to assess. The shading from riparian forest buffers could help reduce stream temperatures enough to restore trout to additional reaches or maintain native trout in existing reaches, but some marginal value would have to be used to translate that to a per acre value for a buffer.

Recently established buffers are likely to be reaching mature function and size in 20 years or less, and could reasonably be expected to survive as an actively growing buffer for decades afterward. In practice, forest buffers have the capacity to sustain tree growth, and usually remain in a forested condition unless actively cleared. Many trees have the biological capacity to live 70 to 100 years or more, and many forest types typically regenerate new trees during that time. Over 80% of buffers enrolled in incentive programs are likely to remain, based on previous tree planting cost-share programs and landowner surveys elsewhere in the Chesapeake Bay watershed (Cooper 2005, Kurtz et al. 1994). A 60-year practice life is considered reasonable for a hardwood forest buffer, well within normal rotations and life spans, although the practice could be extended for much longer with a minimum of investment in management. Harvesting that leaves elements needed for riparian protection and avoids sediment delivery to streams can be part of ongoing management to sustain healthy buffers.

Annualized costs for a 15-year CREP contract were calculated at $206/acre, factoring in public investments in incentives as well as actual establishment costs. The conservative value of $504/acre for four RFB functions alone is twice the cost. Any years beyond fifteen that the buffer remains in place increases cost-effectiveness. Assessment of additional functions that may relate to some buffers (e.g., buffers appropriate for flood control or for protecting cold-water fisheries) would further improve the cost/benefit ratio. RFBs become more cost-effective over time, because the practice can be readily sustained with minimal further investments. Other BMPs such as cover crops and sewage treatment plants are effective and necessary but require significant investment annually.

Speed of achieving benefits seems related to rate of increase in tree cover, arguing for faster growing species. However, the benefits of fast growth should be balanced with the strategic value of using a diversity of species that maintain buffer functions over time despite some losses due to pest and disease outbreaks. Ability to maintain keystone native tree species like oaks also should be considered. Difficulty in regenerating native oaks has been documented throughout the Eastern United States, usually attributed to increased deer populations, which preferentially browse many oaks, and lack of wildfire, which used to thin out thin-barked competing hardwoods like maples and gums (Alexander and Arthur 2010, Abrams 2005). Oaks provide essential winter food for many wildlife species, especially since the loss of the American chestnut to chestnut blight in the early 1900s. Watersheds dominated by oak-hickory forests have been found to have lower nitrogen outputs than basins covered with maple, beech, and birch (Lovett et al. 2002), although any forest cover yields fewer nutrients than other land uses. Although many oaks are slower growing than some species, the opportunity to encourage young oaks in critical locations in watersheds may help maintain low nutrient outputs and support higher quality wildlife habitat. Using native trees that are initially slower growing seems correlated to slower achievement of some functions, but it may be important to achieve the eventual full range of benefits that include improved stream quality and wildlife habitat.

Some situations may realize greater benefits from establishing forest buffers. Matteo et al. (2006) found that watersheds that were starting to become urbanized were more responsive to practices like forest buffers than were more urbanized drainages. Targeting buffers in areas important for additional functions like flood control or protecting stream temperatures for native trout could further leverage public investments and benefits.

CONCLUSIONS

Forest buffers, an essential tool for meeting water quality and habitat goals in the Chesapeake Bay region, can be expected to gain function proportional to growth and increase in biomass. This project quantified riparian forest buffer functions on buffers from five to eight years old, and estimated values for future wood products, nutrient reduction, and air quality improvement. It used two datasets from the forest buffers restored on private land in the Monocacy, Antietam, and Catoctin watersheds. One dataset had detailed vegetation and stream benthic macroinvertebrate data, collected in 2000 or 2001 with follow-up data in 2006 or 2007. The second dataset had a variety of tree survival, water quality, and stream data that were collected annually from 2001-2008 through the Potomac Watershed Partnership.

Significant differences were expected to occur for vegetation/habitat, shade, and benthic macroinvertebrate communities between time of planting and 5 years later. Results indicate that vegetation diversity and woody species significantly increased. The trees in the RFBs had not reached canopy closure at six or seven years of age, so neither shading nor stream temperature was significantly different. Drought conditions during the early years of the study and heavy grass competition on the former pasture sites may have contributed to slow tree growth and lower survival.

Benthic macroinvertebrate taxa richness and epifaunal substrate increased significantly, but the observed increases in the Index of Biotic Integrity were not statistically significant, even with a majority of sites (64%) realizing higher IBIs. Variability from site to site was significant for most metrics, highlighting the great variability in the landscape and watersheds.

Instream water quality grab samples were not expected to differ significantly in buffers less than 10 years old, even though nutrient reductions have been shown in younger buffers that had fast-growing trees. The trends of declining nitrate (1-2 mg/l lower) and phosphate were not significantly different between 2001 and 2008, and variability among sites and years was greater than the modest rates of nutrient decreases. Other studies with more detailed water quality monitoring of shallow groundwater would be a valuable supplement, particularly if both Coastal Plain and Piedmont Provinces were represented.

Estimates were developed for a range of RFB functions, including non-market benefits like water and air quality improvement and potential income sources for the landowners adopting the practice. For timber values, both pine- and hardwood-dominated buffers were evaluated to encompass the significant ranges in values and growth rates for the different species. Timber values were calculated assuming buffers would be harvested in conjunction with other nearby stands, and that trees required to meet State harvesting rules would remain uncut. Tree growth and future timber value were primarily controlled by tree density (stocking). Hardwood buffers with low survival and stocking were not predicted to grow sufficient volume to allow harvest beyond the 60 square feet per acre of basal area required to be left in harvest buffers. Hardwood buffers that had better survival had the potential for substantial timber income (average of $1170/ac at 80 years), with values potentially ranging over $4300 per acre. Values for pine timber would be realized much sooner, averaging $974/acre in income if thinned at 15 years and harvested at 30 years. These substantial differences in timing of income were evidenced in the large differences in net present value (NPV) for the timber, even using a modest 4% rate for evaluating alternative investments. NPV for pine buffer timber was $541/acre at 30 years, over ten times the value for hardwood buffers of $51/acre at 80 years. Hardwood buffers had significant potential for timber value, but the long time frame for harvestable products meant that it did not compare favorably as an investment alternative. Nonetheless, it would offer tangible value to those landowners who see the land as a resource to hand down to future generations.

A conservative estimate that only assessed water and air quality functions, hunting, and timber value was calculated at $504/ac/year. However, reasonable valuations ranged from over $5500/acre to less than $180/acre, highlighting the substantial differences in site conditions, growth rates, environmental conditions addressed, and values of alternate practices.

The pattern of results from this project and other studies of RFB functions over time suggested that growth rate and tree density affect speed of development of functions. Use of fast-growing trees, species well-suited to site conditions, and good maintenance practices during early years is likely to support more rapid development of desired benefits like water quality improvement and potential forest products. Competing weeds and deer browse are major issues limiting tree survival and development of healthy forest buffers. Developing longer-term and wide-spread strategies to more effectively manage deer populations and invasive weeds could improve rate of development of RFB functions, long-term forest health, and ability to regenerate new trees in the future.

The advantages of using fast-growing trees should be balanced by strategies for resilience in the face of threats to forest health and maintaining important native species like oaks. The occurrence of pests and diseases creates significant risk for durability of buffers as they mature. Trees that have survived the rigors of establishment (drought, weeds, deer browse) may be damaged by existing or new pests, like gypsy moth for oaks, emerald ash borer for ash, thousand cankers for black walnut, and *Sirex* wood wasp for pines. The pivotal role of oaks in winter food for wildlife and maintaining naturally low nitrogen outputs from watersheds also call for consideration of favoring this species group that is otherwise slow to regenerate under current ecological conditions. Planting a diversity of species and allowing additional species through natural regeneration can build in a hedge against losses or any particular species.

Several principles are useful to broadly support development of robust buffer functions:

- Invest in maintenance for good survival and early growth, reinforcing plantings as needed to maintain density;
- Combine fast-growing trees with a diversity of species and, where suited to site conditions, keystone native species like oaks;

- Develop long-term responses to significant stressors such as heavy deer browse, new insect pests, and weed competition from invasive plants and State-listed noxious weeds;
- Encourage policies that support long-term retention (>20 years) of restored buffers for more cost-effective investments and maintenance of required nutrient reductions;
- Continue to allow a proportion of buffer plantings to be in pine or other fast-growing species within their native ranges, supporting shorter time frames for economic returns to landowners and greater incentive to retain buffers in forest use.

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APPENDICES

APPENDIX A: Procedures for Potomac Watershed Partnership Buffer Monitoring and the Riparian Forest Buffer Baseline Monitoring Sites

Part I. Potomac Watershed Partnership Buffer Monitoring Protocol

RIPARIAN PLANTING MONITORING: Planted tree survival and natural regeneration of trees was evaluated within a monumented area 250 feet long, parallel to the stream, and a minimum of 100 feet wide. Within that area, each planted seedling was observed to determine species, survival, and height. For woody natural regeneration, 1/100th acre plots (11.78 ft. radius) were established along three transects perpendicular to the stream (Figure A). At least three plots per transects were measured, starting 11.78 feet from the stream and spacing them 33 feet apart to avoid measurement overlap. Subplots with the same plot center and a 5.27 ft radius were used to record % cover of herbaceous vegetation by category (rush, sedge, broadleaf, fern, grass and vines) and invasive plant cover by species.

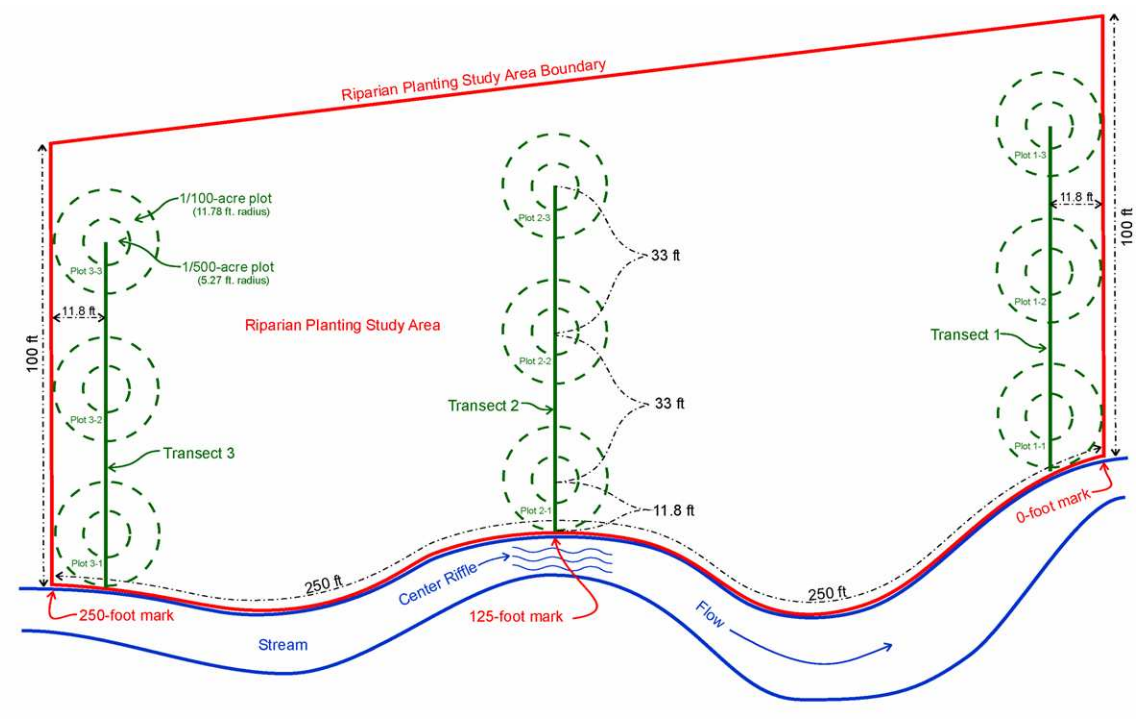

Figure A. Transect and plot set up for Potomac Watershed Partnership tree regeneration monitoring.

STREAM STABILIZATION MONITORING: Sites for the stream stabilization monitoring was selected using the following criteria:

- A wadable riffle area of the stream representative of the general stream features
- An area within the 250 ft. length of stream adjacent to the planting site being monitored.
- An area a minimum of 50 ft from a bridge, culvert, fallen tree, or other permanent structure.
- The riffle should be within a 2 meander length reach if possible (two bends of the stream).

Site maps and permanent benchmarks were used to locate the same riffle for annual visits. The measurements for a cross-section were started on the left side of the stream looking downstream.

Bank and toe pins were used to facilitate the measurement of active bed and bank erosion, using a combination of a bed/toe pin and a bank pin where possible, leaving 6 inches exposed. The toe pin was placed in the deepest flowing portion of the channel. The bank pin was placed perpendicular to the stream into the bank at bankfull height. Some of these were lost in large storms. Pins were located directly under and adjacent to the cross-section line used for the measurements when possible. Change was measured by the difference from the initial exposed length of 6 inches.

Streambank stability was assessed annually for the 250 ft. reach of stream within the planting site being monitored. The methodology of Pfankuch (1975) was used to assess the reach; the visual procedure has been shown to correlate to measured changes in streambank stability and has been used over a wide range of areas. Training on ranges and conditions in the assessment procedure was provided to new observers to maintain consistency in the assessments.

Stream velocity was assessed using a flow meter or timing of a buoyant object to float along 20 feet of stream.

Pfankuch D.J. 1975. Stream reach inventory and channel stability evaluation. USDA Forest Service Northern Region, Montana.

UPPER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Landform slope	Bank slope gradient <30%	2	Bank slope gradient 30-40%	4	Bank slope gradient 40-60%	6	Bank slope gradient >60%	8
Mass-wasting (existing or potential)	No evidence of post or any potential for future mass-wasting into channel.	3	Infrequent and/or very small. Mostly healed over. Low future potential.	6	Moderate frequency and size, with some raw spots eroded by water during high flows.	9	Frequent or large, causing sediment OR imminent danger of same.	12
Debris jam potential (floatable objects)	Essentially absent from immediate channel area.	2	Present but mostly small twigs and limbs.	4	Present, volume and size are both increasing.	6	Moderate to heavy amounts, mainly larger sizes.	8
Vegetative bank protection	>90% plant density. Vigor and variety suggests a deep, dense, soil binding root mass.	3	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	6	50-70% density. Lower vigor and species form a somewhat shallow and discontinuous root mass.	9	<50% density plus fewer species and vigor indicate discontinuous and shallow root mass.	12
Channel capacity	Ample for present plus some increases. Peak flows contained. Width to Depth (W/D) ratio <7.	1	Adequate. Overbank flows rare. W/D ratio 8 to 15.	2	Barely contains present peaks. Occasional over-bank floods. W/D ratio 15 to 25.	3	Inadequate. Overbank flows common. W/D ratio >25.	4
LOWER BANKS								
Bank rock content	65% with large, angular boulders 30cm numerous.	2	40 to 65'%, mostly small boulders to cobbles 15-30cm.	4	20 to 401, with most in the 7.5-15cm diameter class.	6	<20% rock fragments of gravel sizes, 2.5-7.5 cm or less.	8
Obstructions (flow deflectors Sediment traps)	Rocks and old logs firmly embedded. Flow pattern without cutting or deposition. Pools and riffles stable.	2	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	4	Moderately frequent, unstable obstructions and deflectors move with high water causing bank cutting and filling of pools.	6	Frequent obstructions and deflectors cause bank erosion. Sediment traps' full channel migration occurring.	8
Undercutting	Little or none evident. Infrequent raw banks <150cm high.	4	Some, intermittently at outcurves and constrictions. Raw banks <30cm.	8	Significant. Cuts 15-30cm high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some >30cm high. Failure of overhangs	16
Deposition	Little or no enlargement of channel or point bars.	4	Some new increase in bar formation, mostly from coarse gravels.	8	Moderate deposition of new gravel and coarse sand on old and some new bars.	12	Extensive deposits of predominantly fine particles. Accelerated	16
STREAM BED								
Rock angularity	Sharp edges and corners, plane surfaces roughened.	1	Rounded corners and edges. Smooth and flat.	2	Corners and edges wel1 rounded in two dimensions.	3	Well rounded in all dimensions.	4
Brightness	Surfaces dull, darkened or stained. Not "bright".	1	Mostly dull, but may have up to 35% bright surfaces.	2	Mixture, 50-50% dull and bright i.e. 35-65%.	3	Predominantly bright, 65%, exposed surfaces.	4
Consolidation or particle packing	Assorted sizes tightly packed and/or overlapping.	2	Moderately packed with some overlapping.	4	Mostly a loose assortment with no apparent overlap.	6	No packing evident. Loose, easily moved.	8
Bottom size distribution & stable	No change in sizes evident. Stable materials 80-100%	4	Distribution shift slight. Stable materials 50-80%.	8	Moderate change in sizes. Stable materials 20-50%	12	Marked change. Stable materials 0-20%	16
Scouring and deposition	<5% of the bottom affected by scouring and deposition.	6	5-30% affected. Scour at constrictions and where steep. Pool deposition.	12	30-50% affected. Deposits and scour at obstructions, constrictions, and bends.	18	> 50% of bed in a state of flux or change nearly year-long.	24
Clinging aquatic vegetation (moss and algae)	Abundant, growth largely moss, dark green, perennial. In swift water too.	1	Common. Algal forms in low velocity and pool areas. Moss and swifter waters.	2	Present but spotty, mostly in backwater areas. Seasonal blooms	3	Perennial types scarce or absent. Yellow-green, short term bloom present.	4
COLUMN TOTALS								

Reach score of: <38 = Excellent, 39-76 = Good, 77-114 = Fair, 115+ = Poor

BIOLOGICAL MONITORING: The biological macro-invertebrate monitoring was done in spring (April or May) to coincide with the Chemical monitoring. Where available, sampling was done in riffles with shallow, fast-moving water with a depth of 3-12 inches and stones cobble size or larger. The protocol developed by Save Our Streams was used, using a kick seine and sampling a 1 foot by 1 foot area. Areas were sampled for 20 seconds, lifting and rubbing large rocks to dislodge clinging organisms and shifting small rocks and sediments on the streambed to dislodge any burrowing macro-invertebrates. A minimum of 200 organisms were counted, sampling up to three additional areas if necessary and for up to 90 seconds. Macroinvertebrates were tallied by taxonomic groups and metrics were calculated using the SOS keys and ecological condition scores.

CHEMICAL MONITORING: Chemical monitoring took place twice annually, in the spring and fall at the upstream and downstream ends of the reach. Temperature, pH, and turbidity were measured with meters, with duplicate readings (3 for pH) averaged for a final result. Testing for nitrogen (nitrate and nitrite) and phosphorus was taken as grab samples that were stored in coolers on ice and transported to the Appalachian Lab testing laboratory. If samples could not be transported within a day, they were frozen for brief periods until transport could be arranged on a business day. Controls, blanks, and duplicates were used for quality control.

STREAM-TEMPERATURE MONITORING: Temperature loggers were installed in spring, typically with the spring water quality collection visit. Loggers were securely fastened with cables to roots, tree trunks on the bank, or around rebar or a large rock in the channel. Locations were flagged to facilitate removal in the fall (usually the end of October). Calculations included daily maximum, overall average, and hours of time exceeding temperature thresholds, state standards set at 20^{o}C for reproducing trout waters (Class III) and 23.9^{o}C for recreational trout waters (Class IV).

Temperature records were screened for dry periods. Data where temperatures exceeded 30 degrees C or had a daily temperature range in excess of 15 degrees were presumed to be taken during periods the thermometer was outside water. Temperature records with dry periods excluded were included in the data summary and identified as such, but averages should not be directly compared to sites with complete records. Percent of record exceeding thresholds was calculated to allow some comparison among sites.

Part II: Methods for Riparian Forest Buffer Sites
(14 sites measured in 2000 and 2007/2008)

RFB sites used the same methods for the monitoring except for vegetation sampling and benthic macroinvertebrates. The vegetation sampling was based on the plot layout used for natural regeneration for the PWP sites, 100th/acre plots placed along 5 transects perpendicular to the stream flow. These transects provide a way to standardize the procedures and a set location to return to in order to repeat the study. All five lines are parallel to each other and run roughly perpendicular to the average direction of stream flow. They extend from one edge of the buffer to the other, or from one edge of the floodplain to the other, whichever is shorter.

When placing the lines, the first two were placed 25 meters apart and located based on a random start, defining between them the reach of the stream to be used in the macroinvertebrate sampling and habitat analysis. These lines were marked by placing a white pole in the ground near the stream where the lines cross. The remaining three lines were located at intervals of 2 chains (approx. 40m) from each other and from the first two lines. These three lines were placed in such a way as to sample a variety of reach characters (gradient, floodplain, slope, constraint) and plan characters (meanders, straight sections, tributary junctions). The transect lines were each numbered 1-5, with #1 being the farthest downstream and #5 being the farthest upstream. For ease of future reference, all five transect lines at most sites have been marked by driving a metal fencepost at the end of each line. The fenceposts are painted yellow and have an aluminum tag attached to them with the line number engraved on it.

Vegetation Data Collection

In this study, the vegetation inventory took place along the entire length of each of the five transects. This was done by connecting 1/100th acre plots such that the plot centers were on the transect line and the edges of adjacent plots were tangent at a point on the line and halfway between plot centers. The radius of a 1/100th acre plot is 11.78 feet, making the plot centers 23.56 feet apart. When the inventory of a line began, the first plot was located 11.78 feet from the end of the line, such that the edge of the plot was at the end of the transect. When the other end of the transect line was reached, but there was only enough room for a partial plot, the plot was laid out in a different way, depending on the circumstances.

If the center of the plot could be included before the end of the line, then the distance from the plot center to the end of the line was measured and recorded as an "A" value. If the center of the plot was beyond the end of the line, then the plot center was moved to be tangent to the edge of the previous plot and on the line. Now the plot would consist of a half-circle in which the flat side (which is 23.56 ft. long) was tangent to edge of the previous plot and perpendicular to the transect. Since the plot was partial, however, the other end of the half-circle would also be truncated. The distance from the new plot center to the end of the line was then recorded as an "R" value. The resulting "A" and "R" values were used to calculate the area of the partial plot.

In each plot along the transects, an inventory of the herbaceous and woody vegetation was taken. For each plot, any notable features or characteristics were written down (e.g., if the stream were contained in the plot). A visual estimate of the percent ground cover was then made. This was an estimate of the percent of the ground covered or shaded by vegetation, excluding canopy (only non-overhead vegetation). If that cover was dominated by a particular species, it was noted by estimating the percentage <u>of the coverage</u> that that species represents. If the coverage was dominated by a sod of dense grass, that was also noted.

Benthic Macroinvertebrate Sampling

Like the PWP sites, benthic macroinvertebrate samples on the RFB sites were collected following the MBSS sampling procedure (Kazyak 2001), with one modification. Because of the nature of some of the first order streams in this study, the macroinvertebrate samples were collected in a 25 meter reach of the stream, rather than the 75 meter reach called for by the MBSS protocol. All other collection procedures were consistent with the MBSS methodology, which uses a kick seine procedure with a D-net over the designated reach.

Benthic macroinvertebrates were collected in early March from twenty square feet of riffle habitat using a 600 micron mesh wire-frame D-net. The D-net was placed firmly on the bottom of the stream and the substrate was disturbed down to the hardpan for 1-2 feet upstream of the net. Any large rocks or pieces of debris were scraped off into the net. Rootwads, macrophytes, and undercut banks were sampled by working the net along or through them in such a way as to dislodge any macroinvertebrates. These procedures were repeated until approximately 20 ft^2 of substrate was sampled. The samples were then washed through a sieve bucket, placed in a sample container, and covered with 95% denatured ethanol.

Habitat assessments were made according to the MBSS Sampling Manual (Kazyak 2001). Three MBSS worksheets were completed for each of the 14 RFB sites: the Spring Habitat Data Sheet, the Spring Index Period Data Sheet and the Summer Habitat Data Sheet (Kazyak 2001). Stream width, buffer and adjacent land cover data were recorded on the Spring Habitat Data Sheet. Habitat data and photo documentation were recorded on the Spring Index Period Data Sheet. Stream depth, character and physical habitat assessment data were recorded on the Summer Habitat Data Sheet. Habitat assessments were made without knowledge of previous scores.

Macroinvertebrate Identification and Analysis

A sample of approximately 100 benthic macroinvertebrate specimens was picked from a gridded tray according to MBSS Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy (Boward et al. 2000). In the lab, the samples were mixed and the contents were placed in a pan of tap water to separate the specimens from the debris. Specimens were removed until 100 individuals were collected, the MBSS protocol procedure. It was found, however, that many of the larger organisms clung to the debris and did not appear in the specimen sample to be identified. For this reason, we chose to expand the sample by following the Freshwater Fisheries protocol. In this procedure the sample was mixed and separated until 4 consecutive subsamples were collected with no new species. The specimens in the expanded sample were then identified, down to genus where possible. These samples were used to calculate the number of individuals within each benthic macroinvertebrate taxon collected and from that, the MBSS Index of Biotic Integrity (IBI) (Stribling et al. 1998) was calculated. It was modified by further expanding the specimen sample by following the New York State Department of

Environmental Conservation Freshwater Fisheries protocol (Bode et al. 1988). Invertebrates were identified to genus in 2006 with the exception of annelids, bivalves, crayfish and an aquatic mite; these were identified to family. The Index of Biotic Integrity was calculated by Maryland Fisheries Service in 2001 and 2006.

Benthic macroinvertebrate data were compiled according to the nine metrics that comprise the MBSS Non-Coastal Plain Index of Biotic Integrity (IBI) (Stribling et al. 1998). These metrics are: total number of taxa; number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa; number of Ephemeroptera taxa; number of Diptera taxa; number of intolerant taxa; % Ephemeroptera; % Tanytarsini; % tolerant; and % collectors. A score (of 1, 3 or 5) was given to each of the nine metrics according to Stribling et al. (1998). The average score of the nine metrics is the IBI score for each site and can range from 1 – 5. The nearest local Physical Habitat Indices (PHI) and IBIs were taken from MBSS County Maps (Kazyak et al. 2005).

Data from the identification of the specimen samples were analyzed using both the MBSS and Freshwater Fisheries protocols. This provided the maximum breadth of information and feedback from the samples. The small alterations in the MBSS method based on stream size, additional benthic macroinvertebrate identification, and tolerance values from Bode et al., 1998 could introduce some changes from statistics calculated for the Maryland Index of Biotic Integrity; the metrics from Stribling et al., 1998 on the IBI method should not be directly applied to this dataset. Average values for these monitoring sites can be compared among themselves and regional averages for the larger watershed can be used for a general context.

APPENDIX B: Characteristics of 14 Riparian Forest Buffer Sites

	General Information									
Site	County	Watershed	Dainage Basin	ADC Map	ADC Grid	Centroid Lat.	Centroid Long.	Stream Name	Site Area (ac)	Pltg Area (ac)
RFB-1	Frederick	U. Monocacy	M. Potomac	4	A-13	39° 39' 37"	77° 18' 39"	Trib. to Stoney Branch	2.7	2.7
RFB-2	Frederick	U. Monocacy	M. Potomac	8	B-5, C-5	39° 37' 56"	77° 21' 54"	Trib. to Owens Creek	3.4	2.3
RFB-3	Carroll	U. Monocacy	M. Potomac	9	J-6	39° 38' 11"	77° 11' 09"	Trib. to Big Pipe Creek	10.9	7.9
RFB-4	Frederick	L. Monocacy	M. Potomac	24	A-5	39° 29' 28"	77° 14' 25"	Trib. to Town Branch	36.8	36.3
RFB-5	Washington	Antietam Crk.	U. Potomac	32	F-4	39° 30' 14"	77° 38' 26"	Mousetown Run	3.0	3.0
RFB-6	Frederick	U. Monocacy	M. Potomac	21	F-5	39° 29' 34"	77° 24' 32"	Trib. To Muddy Run	4.4	4.0
RFB-7	Carroll	U. Monocacy	M. Potomac	12	C-8	39° 37' 30"	77° 01' 25"	Trib. To Bear Branch	8.9	8.6
RFB-8	Frederick	U. Monocacy	M. Potomac	21	A-4	39° 29' 54"	77° 26' 40"	Trib. to Tuscarora Creek	3.1	0
RFB-9	Frederick	U. Monocacy	M. Potomac	8	E-3	39° 38' 46"	77° 20' 47"	Beaver Branch	11.4	7.6
RFB-10	Carroll	U. Monocacy	M. Potomac	8	K-8	39° 37' 26"	77° 14' 25"	Trib. to Big Pipe Creek	22.6	21.6
RFB-11	Frederick	U. Monocacy	M. Potomac	2	B-4, C-4	39° 42' 43"	77° 25' 49"	Trib. To Friends Creek	21.9	21.9
RFB-12	Frederick	Catoctin Crk.	M. Potomac	19	H-6	39° 29' 11"	77° 32' 01"	Little Catoctin Creek	11.5	9.2
RFB-13	Carroll	U. Monocacy	M. Potomac	10	F-8	39° 37' 33"	77° 08' 13"	Meadow Branch	8.0	4.6
RFB-14	Frederick	U. Monocacy	M. Potomac	8	H-2, J-2	39° 39' 08"	77° 19' 39"	Motters Run	13.4	7.5
						TOTALS :		SUM :	162.0	140.3
								AVERAGE :	11.6	10.0
								MEDIAN :	9.9	7.6

Site Name	Order	Stream Gradient (%)	Constraint	Sinuosity	Stream Character: Bankfull Measurements Width (m)	Bankfull Measurements Depth (m)	Av. Wetted Width (m)*	Av. Thalweg Depth (cm)*	Maximum Depth (cm)*	Av. Thalweg Velocity ($^m/_s$)*
RFB-1	2	2.18	Unconstrained	1.033	4.6	0.5	1.2	12	33	0.17
RFB-2	2	1.08	Unconstrained	1.030	4.3	0.4	2.6	31	48	0.15
RFB-3	1	1.48	Unconstrained	1.067	6.2	0.9	1.1	15	34	0.14
RFB-4	3	0.60	Unconstrained	1.250	5.7	0.8	1.7	33	54	0.29
RFB-5	2	2.81	Partially Constr.	1.069	9.1	1.5	1.5	24	30	0.64
RFB-6	1	1.97	Unconstrained	1.043	2.1	0.7	0.5	6	9	0.15
RFB-7	2	1.89	Partially Constr.	1.060	6.8	0.8	0.5	16	20	0.45
RFB-8	2	1.72	Unconstrained	1.095	4.0	0.6	0.8	13	20	0.45
RFB-9	4	0.34	Unconstrained	1.338	9.5	1.1	4.2	39	53	0.26
RFB-10	4	0.23	Unconstrained	1.412	6.8	1.3	1.1	34	80	0.50
RFB-11	3	1.01	Unconstrained	1.173	12.4	1.0	3.1	33	52	0.61
RFB-12	4	0.48	Unconstrained	1.049	26.1	2.3	4.4	45	86	0.32
RFB-13	4	0.55	Unconstrained	1.217	17.1	1.2	8.0	38	43	0.69
RFB-14	3	0.47	Unconstrained	1.248	10.4	0.6	2.0	27	60	0.14
AVERAGE :	2.6	1.20		1.149	8.9	1.0	2.3	26.1	44.4	0.35
MEDIAN :	2.5	1.05		1.082	6.8	0.9	1.6	29	46	0.31

* Values derived from Macroinvertebrate Habitat Assessment sheet and therefore only reflect the 25 meter section of stream used in the Macroinvertebrate study.

			Character of Adjacent Land			
Site Name	Order	Average Slope of Adjacent Land (%)	Soil Type	Soil Type Name	Woodland Capability Group	Soil Hydrologic Group
RFB-1	2	5.05	CtB	Croton Silt Loam	Vw-2	D
RFB-2	2	2.05	RgA	Rowland Silt Loam	Vw-1	C
RFB-3	1	4.87	ArA ; PhC2	Abbottstown Silt Loam ; Penn Shaley Silt Loam	IIIw-1 ; IVe-10	C ; C
RFB-4	3	2.06	WcA	Wehadkee Silt Loam	VIw-1	D
RFB-5	2	3.28	LaA	Laidig Gravelly Loam	I-4	C
RFB-6	1	7.15	PaC2	Penn Gravelly Loam	IIIe-10	C
RFB-7	2	10.40	Ht ; MtC2 ; MtD2	Hatboro Silt Loam ; Mt. Airy Channery Loam	IIIw-7 ; IVe-10 ; VIe-3	D ; A ; A
RFB-8	2	9.18	RgA	Rowland Silt Loam	Vw-1	C
RFB-9	4	4.04	RgA ; PdD2	Rowland Silt Loam ; Penn Shaley Loam	Vw-1 ; VIe-3	C ; C
RFB-10	4	0.12	Be	Bermudian Silt Loam	I-6	B
RFB-11	3	1.23	WcA ; HgB2	Wehadkee Silt Loam ; Highfield Channery Loam	VIw-1 ; IIe-25	D ; B
RFB-12	4	1.86	CrA	Congaree Silt Loam	I-6	B
RFB-13	4	3.24	Ch	Codorus Silt Loam	IIw-7	C
RFB-14	3	3.63	PdB2	Penn Shaley Loam	IIIe-40	C
AVERAGE :	2.6	4.15				
MEDIAN :	2.5	3.46				

APPENDIX C: Average annual precipitation, 1996 to 2009, at Baltimore and Dulles Airports

Table C-1: Average annual precipitation in inches by year, 1996 to 2009

Year	Dulles	Baltimore	Average
1996	58.04	58.31	*58.18*
1997	36.52	38.34	*37.43*
1998	37.41	34.37	*35.89*
1999	43.60	43.94	*43.77*
2000	36.79	41.91	*39.35*
2001	36.96	34.57	*35.77*
2002	38.12	39.60	*38.86*
2003	65.69	62.66	*64.18*
2004	38.69	45.67	*42.18*
2005	44.55	49.13	*46.84*
2006	45.97	43.24	*44.61*
2007	27.02	34.97	*31.00*
2008	43.98	44.97	*44.48*
2009	42.64	47.51	*45.08*
All years	**42.57**	**44.23**	

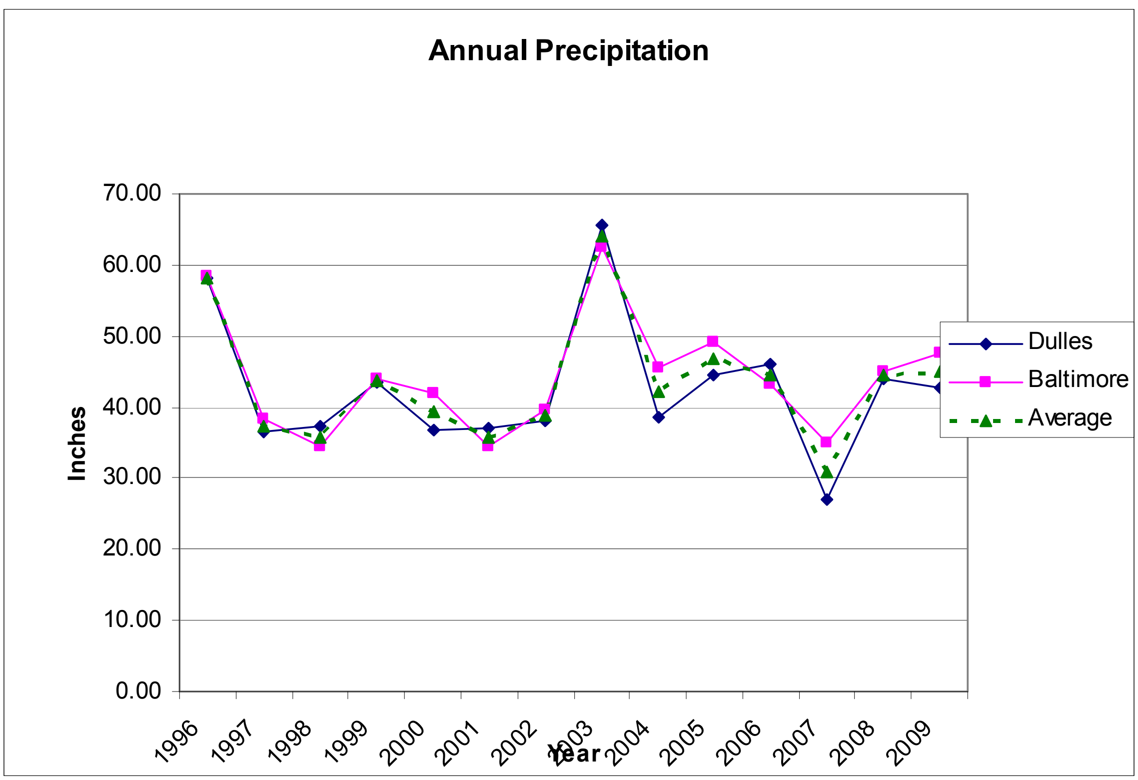

Figure C-1: Average annual precipation at Baltimore-Washington International Airport and Dulles Airport from 1996 to 2009