Recommendations for an Inland Bays Watershed Water Quality Buffer System

January 2008

The Delaware Center for the Inland Bays

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January 15, 2008

This document provides alternative, science-based recommendations for a riparian buffer system that will protect and improve water quality in the Inland Bays and their tributaries. The document focuses on the long-term water quality function of buffers with respect to the total maximum daily load (TMDL) reductions needed for nitrogen and phosphorus. The Pollution Control Strategy (PCS) is responsible for meeting these reductions in a timely fashion. The PCS is a major tactic of the Inland Bays Comprehensive Conservation and Management Plan (CCMP) which additionally requires maximizing open space in developments, shoreline setbacks that maintain tidal marshes, and maximum protection for wetlands and waterways. The condition of the watershed's network of wetlands and waterways are discussed in light of their capacity to reduce pollution now and in the future. Water quality functions of Coastal Plain riparian buffers are reviewed and the scientific literature is synthesized to recommend effective buffering alternatives by waterbody type and buffer system component. The alternatives are then applied to eleven randomly selected developments to determine acreage of buildable developments within buffer zones. The buffer system recommendations are then refined based on these results.

Executive Summary

1. The exceptionally large reductions of nutrients needed to restore the Inland Bays, combined with considerable uncertainty in their achievement due to changing landuse patterns and climate suggests that an extensive and highly effective riparian buffer system is necessary to restore the Bays themselves and the water quality functions of the watershed's degraded wetlands and waterways.
2. Per the Inland Bays CCMP, full implementation of a buffer system that will provide the maximum protection of wetlands and waterways will require flexibility in development site design and minimum lot size to accommodate buffers.
3. Coastal Plain buffers of small watersheds have been shown to remove 23 to 65 lbs. of nitrogen and 1.1 to 2.6 lbs of phosphorus per acre of buffer per year. Buffers remove pollutants from groundwater, surface water runoff, and from in-stream flow while improving the ecological condition of the wetland and waterway they buffer.
4. Forested buffers are on average 36% more effective at nitrogen removal than grassed buffers. Forested buffers also greatly improve in-stream processing of nutrients.
5. Wider buffers remove more pollutants, and buffers over 150 feet are more likely to meet their maximum potential for nitrogen removal.
6. Variable width buffers remove lower levels of pollutants than fixed width buffers of the same average width. Precision placement of more buffer nearest the biggest pollution source can improve variable width buffers.
7. To adequately protect all wetlands and waterways a) buffers should be required on all subdivisions and redevelopments, b) be forested, c) begin from the wetland-upland boundary of a riparian area, d) and be of sufficient width to allow tidal wetlands to migrate inland with sea level rise.
8. Two alternative width buffer systems are provided. The sufficient protection alternative provides buffers of 80' on non-tidal waterways, 80' on riparian wetlands, 80' on tidal areas by steep uplands, 300' on tidal areas by gradual uplands, and 50' on freshwater flats and depressional wetlands. The optimum protection alternative provides buffers of 150' on non-tidal waterways, 150' on riparian wetlands, 150' on tidal areas by steep uplands, 500' on tidal areas by gradual uplands, and 100' on freshwater flats and depressional wetlands.
9. Buffer acreage was highly variable and based on the underlying differences in the type, amount, and distribution of wetlands and waterways on a development. On average, buffer area fell within the range of County open space requirements for both protection alternatives. Those developments with tidal areas by gradual uplands, those in the southern region of the watershed, and those that are smaller, will more often have to implement flexible site designs to accommodate buffer acreage.
10. Predictions of increased sea-level rise and current development patterns near tidal areas strongly argue for optimum protection of tidal waters and wetlands.
11. Shallow ditches can be afforded narrower buffers so that buffers of natural wetlands and waterway features can be better accommodated. Governments should encourage cooperation within and among developments to reduce ditch networks and further improve nutrient reduction in remaining ditches.

Table of Contents

Abbreviations: CCMP, Comprehensive Conservation and Management Plan; CIB, Center for the Inland Bays; DNREC, Department of Natural Resources and Environmental Control; ERES Exceptional Recreational and Ecological Significance; PCS, Pollution Control Strategy; STAC, Scientific and Technical Advisory Committee

Introduction

The Inland Bays are degraded Waters of Exceptional Recreational and Ecological Significance (ERES) that are committed to being restored, by all levels of government, to their previously healthy and productive condition. The ERES designation affords the Bays a level of protection that goes beyond most other waters of the State. Commitments to the protection and restoration of the Bays are detailed in the Comprehensive Conservation and Management Plan (CCMP) for these estuaries of national significance. In this guiding document, buffers for waterways and wetlands are essential to numerous CCMP tactics including implementing the Pollution Control Strategy (PCS), maximizing open space for environmentally sensitive development, and establishing shoreline setbacks to protect tidal ecosystems. Specifically, the CCMP requires as one of its most important goals, the maximum protection of waterways, groundwater, natural areas, open space, and tidal and non-tidal wetlands. Riparian buffers are undoubtedly a critical component of restoring the Inland Bays because they protect habitat and can accomplish huge reductions of pollutants for the long-term, with little maintenance costs or risk of failure.

The water quality functions of buffers have received an outstanding amount of scientific study. An ongoing bibliography cited 890 buffer publications including dozens of reviews [3]. However, variation in buffer function among different regions of the globe complicates the use of all the studies to inform local policy. To develop an Inland Bays Watershed specific buffer system, this review is focused on studies conducted in the Atlantic Coastal Plain,[1] and is complemented where needed by wider reviews of buffer effectiveness.

In 2006, the Scientific and Technical Advisory Committee (STAC) of the Center for the Inland Bays (CIB) provided eight recommendations for the Delaware Department of Natural Resources (DNREC) to consider in redeveloping the buffer section of the PCS (Appendix 1). This report elaborates on the science behind those recommendations and provides two alternative buffer systems in relation to the goals of the PCS and the Inland Bays CCMP. This report specifically considers the provision of buffers on developing lands in the Inland Bays watershed.

[1] The Atlantic Coastal Plain is a physical region of the United States where similar geology, hydrology, and resulting patterns of landuse makes ecological comparisons more relevant.

Why a Comprehensive System of Riparian Buffers is Necessary for Clean Water

To restore the fragile ecology of the Inland Bays, huge reductions in pollutant loads (40 – 85 %) are needed. The CIB, DNREC, and the public have helped to create the PCS to meet the challenge. But many important PCS provisions are voluntary and it currently overlooks protecting the natural ecosystems that improve and protect water quality. Figure 1 conceptualizes how the PCS could complement its existing strategy of controlling the sources of pollution by improving protection of the watershed's natural or green filters. Both reduction of pollution sources and the restoration and protection of the watershed's wetlands and waterways will be necessary to restore the Bays.

One must consider that, since pollution reduction targets were developed using data from the early 1990s, explosive growth without the benefit of PCS protections has occurred and will continue to occur in critical areas of the watershed far into the future. Additionally, predictions of increasing runoff, nitrogen loading[2], and saltmarsh loss resulting from climate change provide added obstacles not considered during the development pollution reduction targets (see [4, 5]). This adds great uncertainty to the question of meeting the reductions and restoring the Bays. Despite these challenges, huge advances have been made in agricultural management of nutrients and the Indian River Inlet flushes greater amounts of water each year[6]. Hope remains that eelgrass will once again thrive in the open waters and widgeon grass in the tributaries. But for this to happen a grand reduction in nutrients must be accompanied by an extensive protection of the wetlands and waterways that filter and transport pollutants

Condition of the Watershed Stream Network

Streams are the arteries and wetlands the kidneys of the watershed. Together they supply and filter water on its way downstream. The more prolific and healthy these ecosystems are, the greater the potential to restore the Bays. The PCS should address the capacity of the network of ditches, streams, and wetlands to control pollution, and improve their current state of disrepair.

[2] Climate change during this century is likely to have a profound effect on nutrient loading to estuaries. Predictions for increased precipitation in the mid-Atlantic suggest that both river flows and the fraction of land-applied nitrogen entering estuaries will increase. This would increase the number of "wet years" our estuary experiences when nutrient pollution and its affects are more severe (see citations in text above).

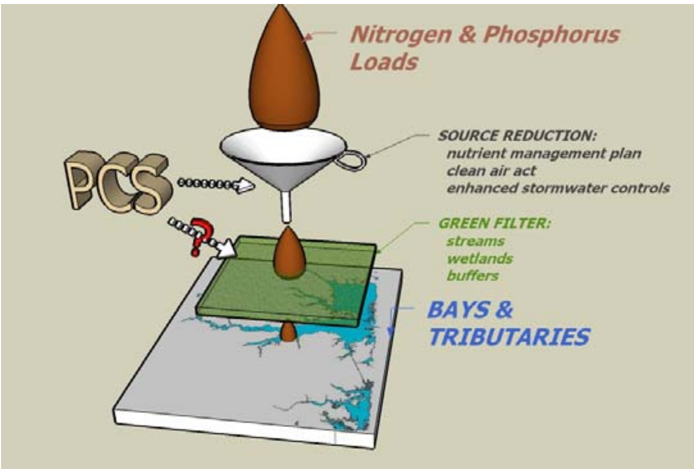

Fig. 1. Two components of pollution control and their relation to the Inland Bays Pollution Control Strategy (PCS).

Sixty percent of the watershed's freshwater wetlands were eliminated since European settlement [7]. Further, a quarter of the watershed's tidal wetlands were eliminated between 1938 and 1980[6]. The conversion of wetlands to development and agriculture has severely reduced the nutrient processing capacity of the watershed and speeded the delivery of nutrients to the Bays. The function of remaining wetlands is in no way pristine. The condition of all Inland Bays wetlands is being assessed currently. Preliminary information shows that over 75% of riverine (streamside) wetlands have highly degraded hydrologic and water quality functions [7]. These wetlands tended to have had inadequate buffers and hydrologic modifications such as stream channelization that increase the delivery of nutrients to streams and disconnects streams from their adjacent wetland filters. The condition of the watershed's streams themselves is also remarkably poor with only 29% supporting their designated uses [8]. Nutrient and bacteria pollution, inadequate enforcement of existing regulations, ditching and stream channelization practices, and the lack of buffers has led to this current situation. In the Inland Bays Watershed, DNREC estimates that 78% of rivers, streams, and ditches are inadequately buffered [9].

Effects of Development on Waterways

Our watershed is at a critical point where the dominant source of influence on natural resources is transitioning from agriculture to development. The watershed is the fastest growing region of the State with development increasing by 35% from 1992 to 2002 [8]. In the mid-Atlantic, the more development that occurs and the closer it is to a waterbody, the greater chance those aquatic resources will be degraded [10]. As a watershed's impervious cover exceeds a certain percentage, permanent degradation of rivers and streams occurs (see Miltner et al. 2004 and references therein) [11].

Impervious surfaces degrade waterways by increasing channel erosion and the speed at which pollutants are delivered downstream. This results in streams downcutting their channels and losing connection with their streamside wetland filters. It also reduces the capacity for riparian areas to filter nutrients from groundwater and the in-stream processing of nutrients [12, 13]. In total, the nutrient processing capacity of our waterways should become reduced as our watershed develops [13, 14].

To protect the watershed's network of streams so that they may filter water entering the Bays, action must be taken prior to development. A highly protective buffer system accompanied by stormwater controls will reduce nutrient loads entering streams and maintain the capacity of streams to process those pollutants.

To date, development without riparian buffers and adequate sediment and stormwater controls have placed great stress on waterways (Figure 2). Buffers of tidal wetlands and waters have particularly been affected by lax enforcement of existing regulations. It is important to remember that all riparian areas not only filter pollutants from new development but can also filter delayed discharges of high nitrogen groundwater from previously existing agricultural operations and distant, ongoing farms [15].

The Case for Riparian Buffers

Mass balance studies that measure all watershed pollution inputs and outputs are the most accurate estimate of buffer effectiveness. The Atlantic Coastal Plain is fortunate to have some of the earliest and best mass balance studies of buffers. In small coastal plain watersheds with well buffered waterways, riparian zones retained from 23 to 65 pounds of nitrogen per acre of buffer per year (67 – 89% of inputs) and 1.1 to 2.6 pounds of phosphorus per acre of buffer per year (24 – 81% of inputs) [16, 17]. Uncertainty remains in determining the amount of pollutants an individual buffer will remove due largely to the great amount of natural variability among riparian areas [18]. On the whole, overwhelming evidence exists for the use of buffers to restore water quality, and the characteristics of buffers that best accomplish this are defined sufficiently to inform management. The fact is that riparian buffers are a long term investment that can reduce enormous amounts of pollution with little maintenance.

Figure 2. Typical examples of inadequate riparian buffers and sediment and erosion control from the Inland Bays watershed, 2006/2007. A. Chronically silted ditch on construction site with fertilized turf grass buffer. B. Sediment control failure and lack of buffer near White's Creek. C. Excessive turbidity from runoff in White's Creek and construction site with minimal buffer. Parts of the buffer here leaves little if any room for wetland migration with rising sea levels. D. Fertilized turfgrass buffer and exposed sediment near freshwater wetland. E. Lack of buffer on new development on Dirickson's Creek. F. Seamless transition from saltmarsh to golfcourse.

Planning Buffers for the Whole Watershed: Why Different Waterbody Types Require Different Buffers

Watersheds have a number of different waterbodies, all with their own unique characteristics and functions. Figure 3 illustrates these waterbodies and describes some of their important ecological services. There are the Bays themselves, their tidal tributaries, the freshwater streams of varying sizes, and the network of ditches that extends the natural drainage system. There are also wetlands of various types including tidal marshes, riverine or streamside wetlands, flats wetlands such as the Great Cypress Swamp, and depressional wetlands such as our Delmarva bays (Figure 4). Because these wetland and waterway types occur at different positions on the landscape, they get their water from different sources and thus behave somewhat differently. For example, tidal wetlands move inland with rising sea levels while nontidal wetlands generally do not. People also interact with each waterbody type differently and tend to rely on different functions. For example, most homeowners would like a view across the waters of a tidal marsh, but would not be interested in a view across the waters of a drainage ditch. All these factors amount to the fact that different waterway and wetland types are best given individual consideration when planning a buffer system.

The classification suggested for buffering is shown in Table 1. Tidal wetlands and waters are separated from nontidal wetlands and waterways because tidal systems move with rising sea levels. Headwaters are separated from larger streams because they are the most important for water quality protection and can be so dense that their buffers may regularly affect development of parcels. Ditches are separated from natural streams because they can, and perhaps should, be filled or converted to stormwater where feasible during site development. Riparian wetlands are separated from flats and depressional freshwater wetlands because they are more directly connected to flowing waterways.

The literature review of this document focuses on buffers of waterways and their associated wetlands, which are generally called riparian areas. Less study and thus less review is given to water quality buffers of flats and depressional wetlands. However, these wetlands remain very important to water quality protection, because they make up over three quarters of all freshwater wetland acreage.

Table 1. Wetland and Waterway Classification for a Buffer System.

Tidal Wetlands and Waters
Gradual Upland/Wetland Boundary
Steep Upland/Wetland Boundary
Nontidal Wetlands and Waterways
Wetlands
Flats and Depressional Wetlands
Riparian Wetlands
Headwaters
Larger Streams
Constructed Ditches

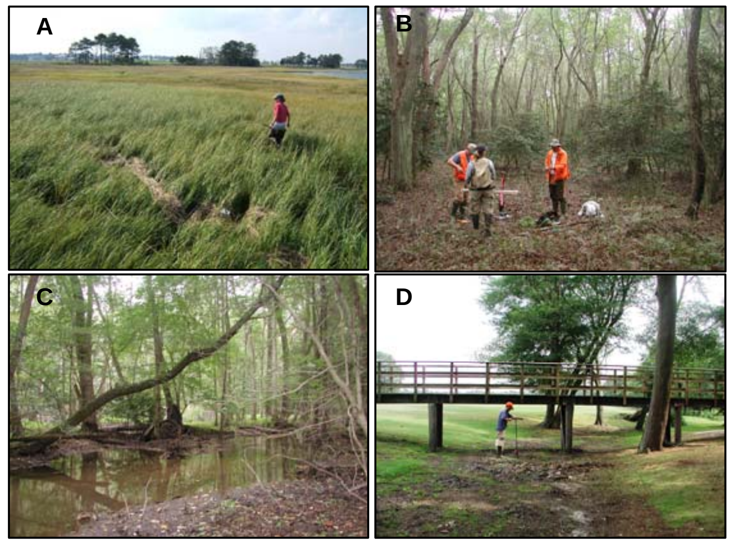

Fig. 4. Examples of wetland and waterway types in the Inland Bays watershed. A. Tidal marsh with gradual upland-wetland boundary in background. B. Freshwater flats wetland. C. Larger natural stream with extensive riparian wetlands. D. Headwaters without adjacent wetlands.

Sources of Water and Pollution to Riparian Ecosystems

Riparian areas receive water primarily from groundwater, runoff, and upstream flow (Figure 5). Tidal areas also receive water from the Bays, and direct precipitation also supplies water to all wetlands. While buffers act to remove pollution from all water sources, nitrogen primarily enters and is removed from groundwater flow [19] and phosphorus primarily from surface runoff [20] (*but see Box 1*). Once through a buffer, much of the remaining nitrogen and phosphorus winds up in ditch or stream channels on its way to the Bays. This requires that a buffer system be developed to control pollution from upstream flows, adjacent surface water runoff, and groundwater; not just runoff as is often focused on.

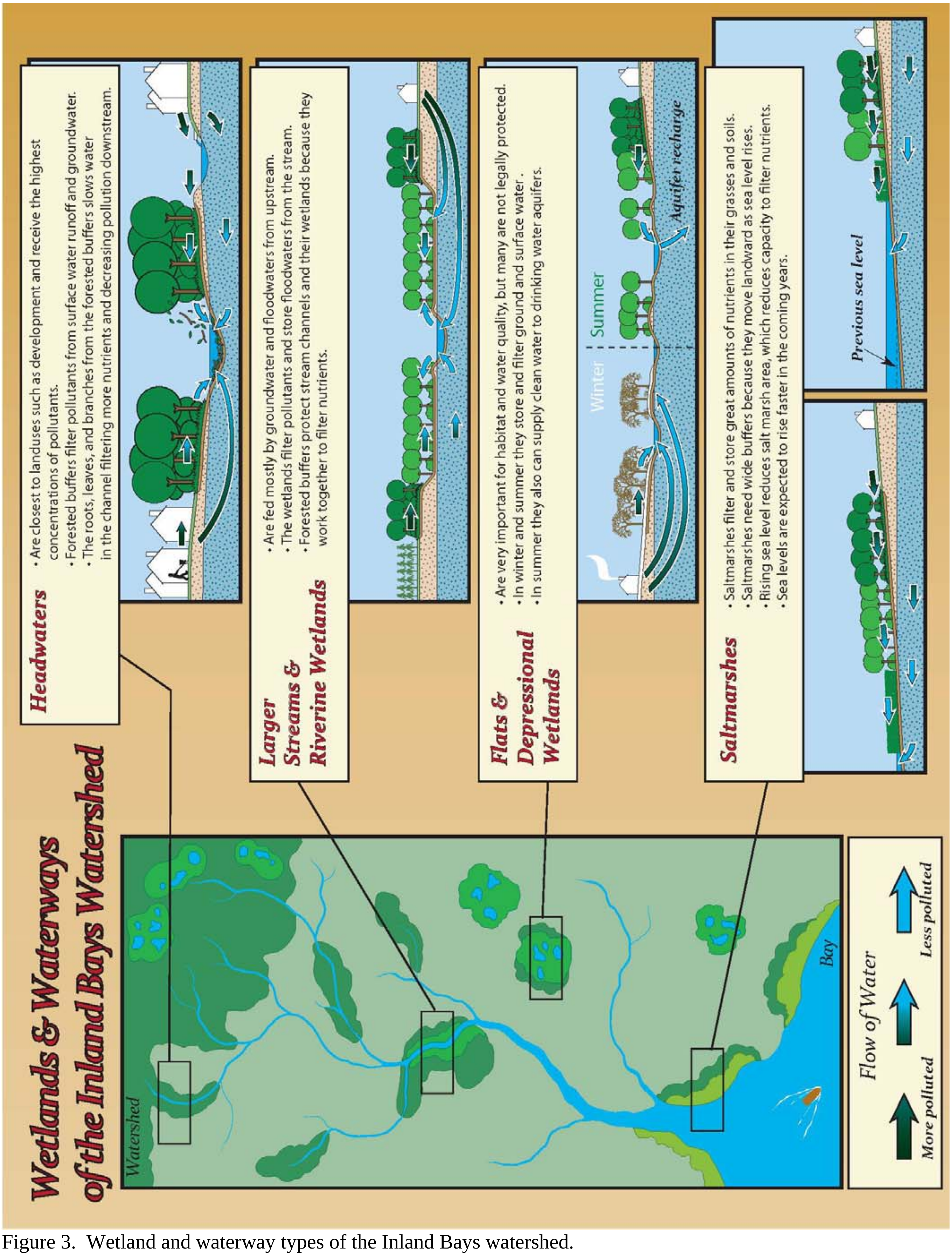

Figure 3. Wetland and waterway types of the Inland Bays watershed.

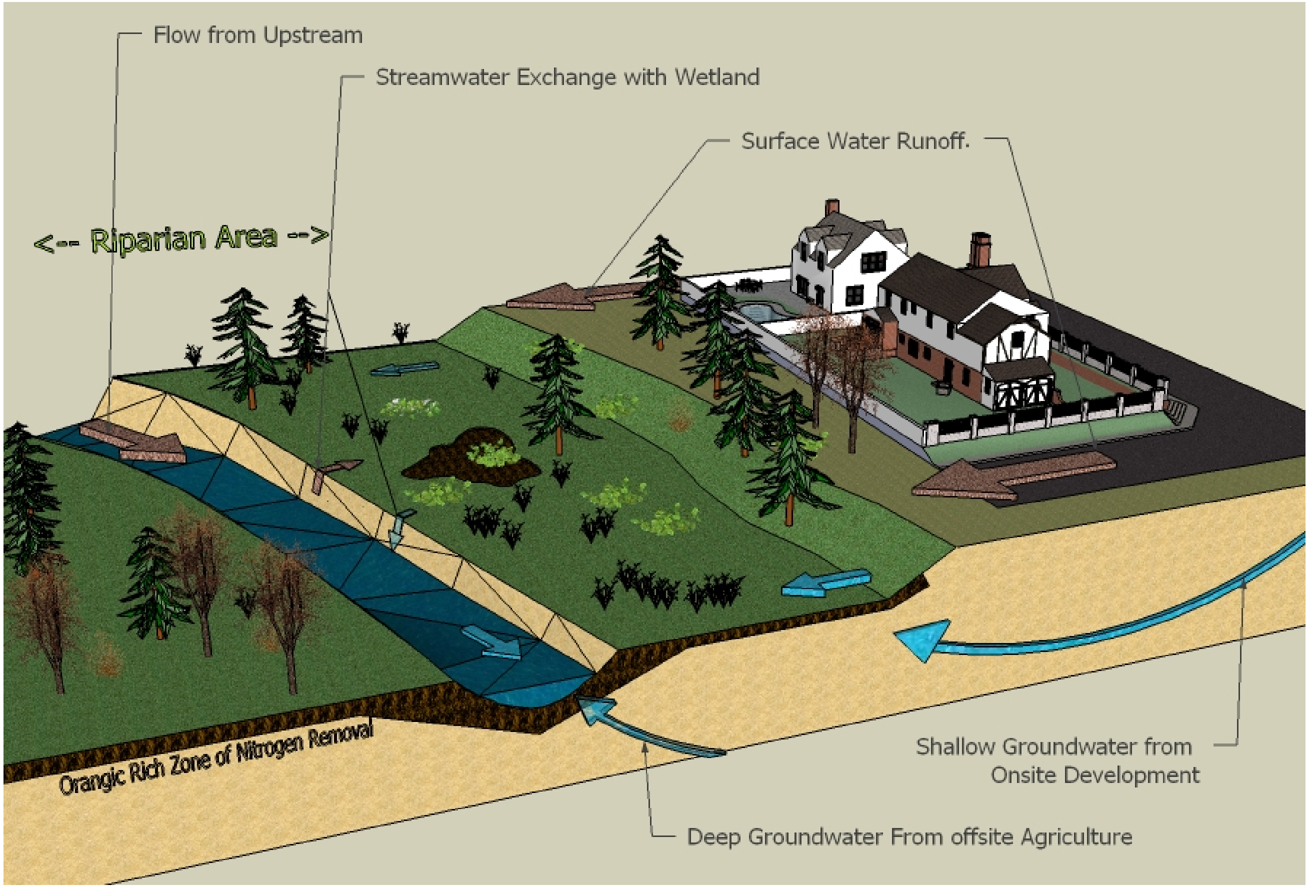

Fig 5. Primary sources of water and pollution to riparian areas. Arrows indicate flows.

> **BOX 1. Phosphorus In Groundwater.**
>
> Phosphorus in groundwater is a particular concern for our watershed. Phosphorus can leach into ground water to be later absorbed by riparian buffers [1]. But this function of buffers has been overwhelmed in some areas by over application of phosphorus rich poultry manure on agricultural fields. Certain soils in our watershed are naturally susceptible to phosphorus leaching and because they are phosphorus-saturated, will do less to control this pollutant even after converted to development [2]. Identification of these areas by soil type and phosphorus status could be used to prioritize areas of wider buffers or soil amendments that might make up for this deficiency. The laboratory of Tom Sims at the University of Delaware has been working to identify these soils and developing methods to better bind excess phosphorus to soils.

In fact, if buffers were only planned to trap pollutants in surface water, we'd be missing the boat. As much as 80% of precipitation that falls on the watershed infiltrates into the earth to become groundwater on its way to the Bays. Similarly, nearly three quarters of all nitrogen is delivered to Rehoboth Bay through groundwater [21]. Nitrogen truly is a non-point source problem and to fix it the focus must be on groundwater.

Groundwater

Groundwater flows are often classified as shallow and deep groundwater. Shallow ground water comes from lands close to a waterbody, even the buffer itself, and discharges within a few months to a few years. Shallow groundwater is the most plentiful and passes through zones of nitrogen removal in healthy riparian areas. Deep groundwater takes longer flow paths from lands more distant from waterbodies, and may take 20 to 50 years to discharge. Deep ground water may discharge directly to the bottom of a waterbody, bypassing important areas of nutrient removal in certain riparian zones of well drained landscapes [22, 23]. Deep groundwater means that decades may pass before reduction in some pollutant loads finally begin to improve surface water quality. But it also means that buffers installed now can treat pollution from years when managing nutrients was unimportant.

Not all groundwater discharges evenly along riparian zones. Some ground water follows preferential flow paths, where discharge concentrates into a riparian area. Preferential flow paths may form due to small differences in soil texture along a riparian zone or they may form due to larger features such as lateral ditches [24-27]. These relatively small areas of the total riparian zone can be responsible for a great amount of nitrogen discharge to a waterway[26]. Buffer systems should avoid gaps and maintain a consistent minimum effective width for maximum protection [28], partly to protect against preferential flow paths.

In-stream Processing of Nutrients

The power of stream channels to treat pollutants is often overlooked. Waterways are not just drains but complex ecosystems with high capacities to retain pollution from waters flowing downstream [29-31]. And their capacities to do so vary based on their condition [13, 32-34], with healthier streams retaining more pollutants. Healthy streams are critical to containing the pollution already within their channels. For example, much of the sediment loads to downstream waters originate from within the channels of eroding waterways [35, 36]. This may be especially so in watersheds where development and stream channelization has increased the hydrologic energy of waterways. This in-channel sediment and its attached pollutants can only be trapped and treated by processes within the channel.

"Not only do forest buffers prevent nonpoint source pollutants from entering small streams, they also enhance the in-stream processing of both nonpoint and point source pollutants, thereby reducing their impact on downstream rivers and estuaries" – Sweeney et al. 2004. Proceedings of the National Academy of Sciences of the United States of America

Developing A Buffer System One Component at a Time

This section uses the best available literature to develop recommendations for a buffer system with maximum efficiency to reduce pollutants. Each component of a buffer system including extent, vegetation, width, tidal wetland concerns, and buffer restoration and management is treated separately by asking and answering important questions.

Buffer Extent

What Waterways are the Most Important to Buffer?

Headwater streams have long been recognized for their great importance in reducing nitrogen loads downstream. Rates of nitrogen removal are higher in headwaters relative to larger waterways [30, 31, 37, 38]. Headwaters make up approximately 75% of total waterway length in watersheds [39, 40]. They tend to have the highest nutrient concentrations because they are in the closest connection with the surrounding landuse. And their small and shallow geometry allow water the greatest opportunity to interact with areas of the highest nutrient removal on the bottom and sides of the channel (Figure 7).

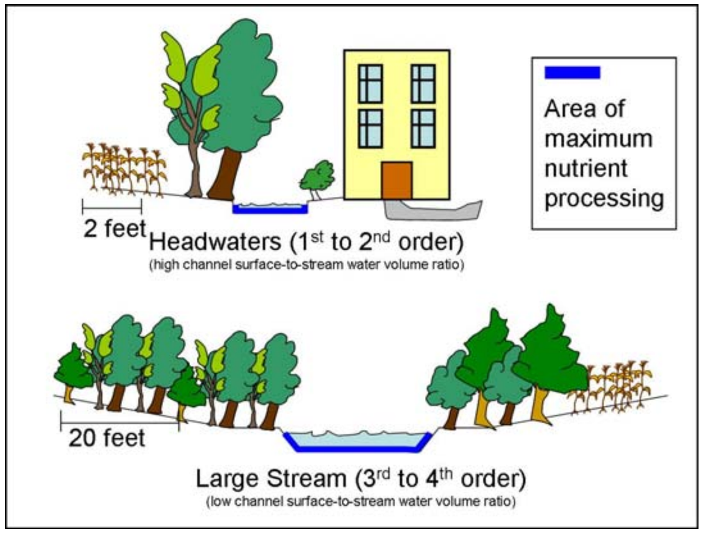

Fig. 7. Headwaters are smaller, more numerous, more closely connected to the surrounding landuse, and provide proportionately greater areas of nutrient processing than larger streams. For stream order explanation see section directly below.

Should Headwaters be differentiated from Larger Streams? If so, How?

Because headwaters in southern portion of the watershed may be very dense, a narrower buffer on these waterways may be required to allow orderly development. The 2006 CIB recommendations to DNREC state that the traditional management categorization of intermittent versus perennial streams be reconsidered. Rapid determination of a waterway as intermittent or perennial is difficult due to great variation in the flow patterns of the upstream drainage network and due to short and long term changes in weather. An alternative approach is to map the drainage network and assign waterways as either headwaters or larger streams. Unfortunately, many headwaters are not mapped and thus their protection cannot be ensured from plan review. Accurate, detailed and standardized maps of headwaters should be developed prior to regulation (see Baker et al. 2007) [41]. North Carolina is an example of a State that has undertaken this work.

During the mapping process, natural streams should be differentiated from ditches. This will allow land planners the flexibility to fill those ditches that will not significantly impact on or off site drainage. Filling of unnecessary ditches will also help to restore the pre-settlement stream network hydrology, reduce pollutant transport, and reduce buffer requirements. A number of different methods for locating natural headwaters and differentiating them from ditches are available. One such tested method from the Coastal Plain of North Carolina is included as Appendix 2.

The Strahler stream order method [42] is suggested for designating headwaters. Using this approach, first order streams have no tributaries. Second order streams start at the confluence of two first order streams. The confluence of two second order streams is a third order stream, and so on. Together first and second order streams are often designated as headwaters [43, 44].

In a Riparian Ecosystem, Where Should the Buffer Begin: From the Edge of the Wetland or the Edge of the Channel?

Wetlands have great capacity to filter pollution. And natural channels and their streamside wetlands are inextricably linked in their capacity to do so [45]. Even very small streams in our watershed naturally support wetlands. Because the slopes of our streams are so gradual, channels regularly flood their banks after rains allowing the wetlands to store water and filter pollutants. Ground water also discharges laterally into streamside wetlands where it is filtered and this can occur preferentially at the landward edge of the wetland [25]. Buffers must therefore protect the entire wetland and stream system and not just the channel. Figure 8 illustrates this concept. Buffering from the channel may not even include the existing streamside wetlands, while buffering from the upland/wetland edge provides the wetland shelter by protecting the adjacent riparian forest. This approach eliminates a fixed width buffer failing to protect the wider wetlands in the watershed.

Former floodplains that have drained and are no longer wetlands but are within stream valleys should also be protected. Providing a buffer around these former wetland areas, easily identified by valley slopes, offers the opportunity for future restoration of the former floodplain [46].

A wide ranging review found that, on average, forested buffers reduced 36% more nitrogen than grassed buffers

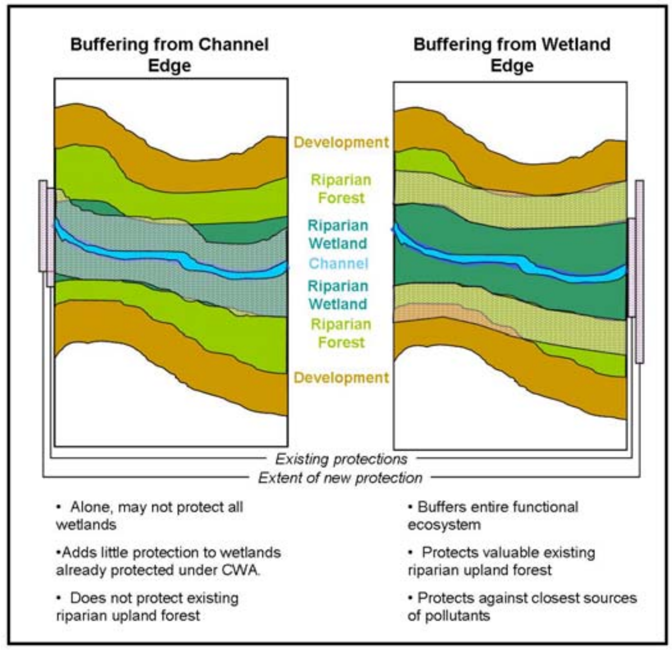

Fig 8. The effect of buffering from channel or wetland edge in riparian areas. CWA = federal Clean Water Act.

Buffer Vegetation Type

The type of vegetation in a buffer greatly influences the hydrology of riparian areas and how much nitrogen and phosphorus they can remove. Since coastal plain streams have no rocks, the roots, logs, and branches of a forest provide the structure that controls how streams flow. Forests hold the sediments of streams in place and provide the coarse and dissolved organic material that helps remove nitrogen.

What Type of Vegetation Reduces the Most Nutrients?

Most studies of this question have focused on the efficiency of native grass versus forested buffers at reducing pollutants (Figure 9). In general, forests reduce more nitrogen than other buffers [47, 48], but little Coastal Plain specific information is available. A wide ranging review found that, on average, forested buffers reduced 36% more nitrogen than grassed buffers[3]. This difference may be somewhat smaller when corrected for differences in width. Another comprehensive study in the Piedmont found that headwaters with forested buffers had dramatically higher rates of in-stream nitrogen uptake than those without forests in their buffers[49].

[3] Forested buffers are the weighted average of forested and forested wetland buffers for 29 studies (mean reduction = 88.8%); grassed buffers were from 22 studies (mean reduction 53.3%).

Why Do Forested Buffers Reduce more Nutrients than Turf or Grass Buffers?

1. Forests have greater long term nutrient storage than grass buffers because they have more biomass. Coastal Plain riparian forests uptake 11 to 37 pounds of nitrogen and 1.5 to 4.5 pounds of phosphorus per acre each year into their woody biomass [16, 50-52]. Grass or turf buffers do not.
2. Forests continue increasing their aboveground biomass until about 90 years of age [32] (Figure 10) Root and soil biomass likely continues to increase beyond 90 years.
3. Soil organic matter is over twice as high in forested buffers than grassed buffers, providing more potential for nitrogen removal [32].
4. The presence of an adequate carbon supply [(organic matter)] is the most commonly identified critical factor for nitrogen removal in a riparian area[53].
5. Forested buffers provide well developed zones of organic rich material directly below and adjacent to streams that remove nitrogen in groundwater [48]. These zones are smaller and sparse in non-forested buffers (Figure 11).
6. The large roots of forest trees provide solid physical structure to stream channels, preventing erosion, slowing water, and increasing water flowpaths (e.g. [54]) which increases nitrogen removal

Coastal Plain riparian forests uptake 11 to 37 pounds of nitrogen and 1.5 to 4.5 pounds of phosphorus per acre each year into their woody biomass [16, 50-52]. Grass or turf buffers do not.

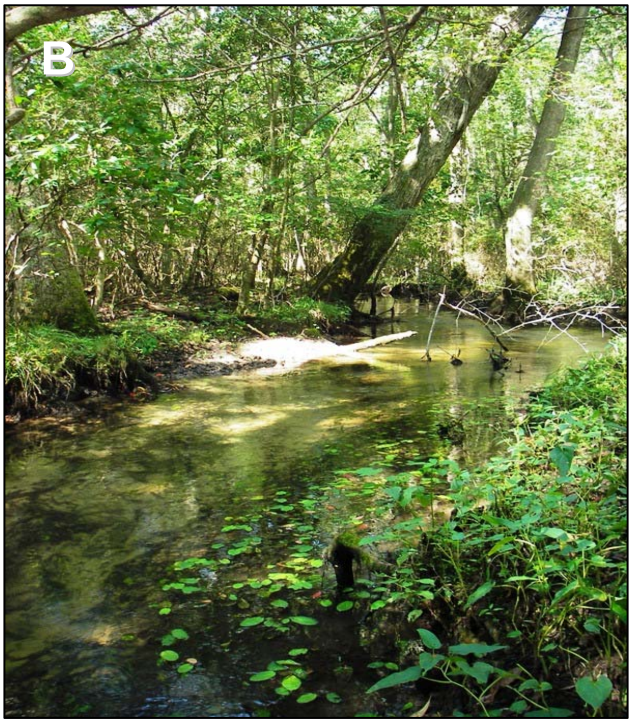

Fig 9. Turfgrass (A) versus forested (B) buffers. Note the differences in complexity, aboveground nutrient storage, and habitat quality.

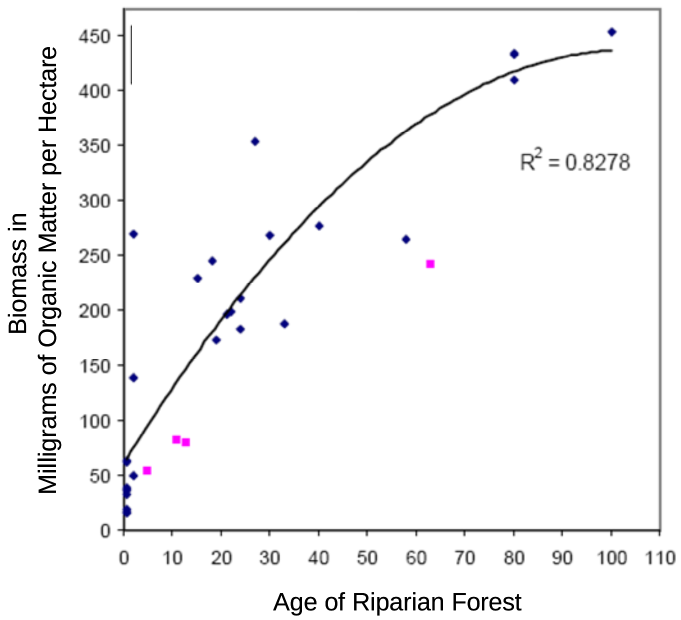

Fig. 10. Increase of headwaters riparian forest biomass with age in the North Carolina Coastal Plain. Blue diamonds are from Brinson et al. 2006 [32] and pink squares are from Giese et al. 2003 [55]. Adapted from Brinson et al. 2006.

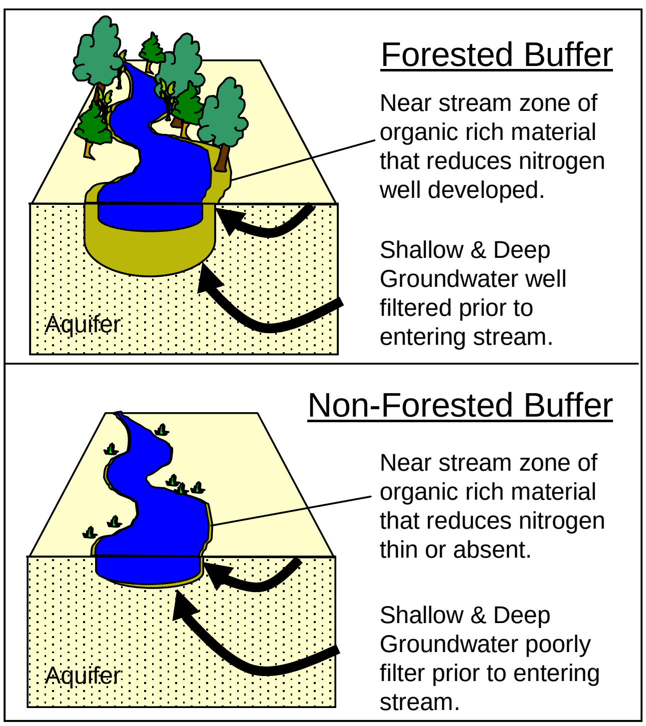

Fig. 11. Differences in the near stream zones nitrogen removal between forested and non-forested riparian buffers. Adapted from Spruill 2000 [48].

Buffer Width

Next to extent, width is the most important buffer ecologic and economic characteristic of a buffer system, because it affects pollutant removal efficiency and where development can occur. A number of independent scientific reviews have recommended widths whereby buffers generally meet their potential for removing nitrogen and phosphorus. The recommended widths are consistently around 100 feet (Table 2).

Table 2. Recommended buffer width for water quality protection from scientific reviews.

Study	Recommended Width (ft)	Comments
Environmental Law Institute 2003 [56]	82	Recommended minimum width
Schueler & Holland 2000 [57]	100	Typical mean width recommended
Christensen 2000 [58]	100	
Wenger & Fowler 2000 [59, 60]	100	Recommended minimum

The consistency of these recommendations is likely the reason DNREC recommended 100 foot wide buffers in the 2005 version of the PCS. However, it is important to note that these and other reviews include studies from around the globe. To reduce the variation resulting from such different areas of the nation and world, studies from the Atlantic Coastal Plain were analyzed separately below.

Nitrogen

Seventeen coastal plain buffers were analyzed for the affect of width on nitrogen removal[4]. Most information was taken from a comprehensive review conducted by Mayer et al. 2007[19]. A single rectangular hyperbola curve demonstrated the best fit to the plotted data. A surprisingly strong relationship between buffer width and efficiency was found that was not observed for Mayer et al.'s wider study (R^2 = 0.67 and 0.09 respectively)(Figure 12). The data indicates a point of diminishing returns between 80 and 90 feet, where only about a 2% increase in removal efficiency is gained with each additional foot of width. At 80 feet wide, buffers averaged nearly 80% nitrogen removal, with at least 67% removal occurring for most buffers (95% confidence interval lower bound). The data also suggests a threshold of 150 feet and above where

[4] Buffers adjacent to manure or treatment effluent application were not included in this analysis and one 656 foot wide buffer was not included as its width was an outlier, over twice as the width of the next widest buffer.

buffers more consistently reach their maximum potential for nitrogen removal. Figure 13 shows the significantly greater and more consistent nitrogen removal for buffers over 150 feet, here replicating Mayer et al's. results.

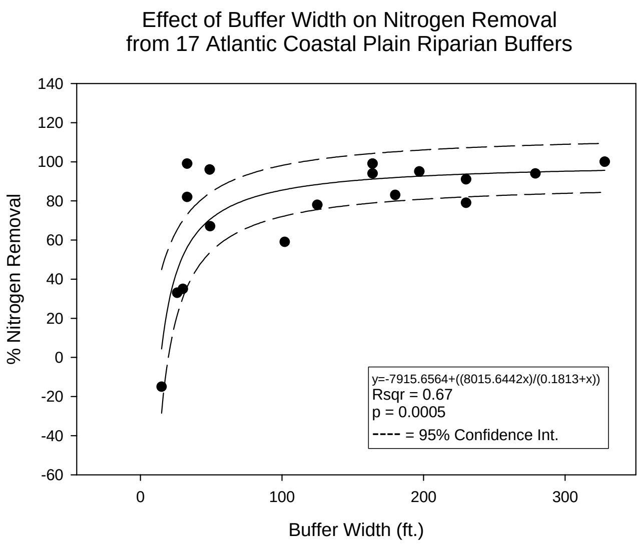

Fig. 12. Effect of buffer width on nitrogen removal from 17 Atlantic Coastal Plain riparian buffers. Appendix 3 includes a table of study references.

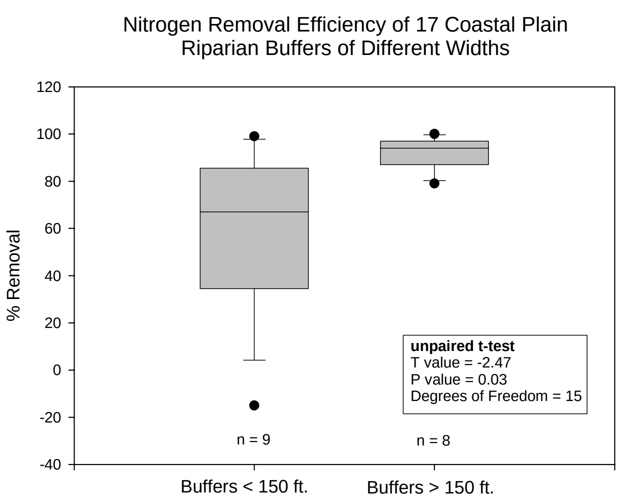

Figure 13. Nitrogen removal efficiency of 17 Coastal Plain riparian buffers of different widths. Boxplots lines are the median, 25th percentile, 75th percentile, whiskers are the 10and 90th percentiles, and dots are the outliers of the distributions for buffers less than and greater than 150 feet.

Phosphorus

Only six studies comparing buffer width to phosphorus removal were found for the Coastal Plain. No significant relationship was found and buffers were highly variable in their removal (Figure 14). Desbonnet et al.'s [61] review of 27 studies from multiple regions found a stronger relationship here plotted as Figure 15. Overall phosphorus removal by buffers appears more variable relative to nitrogen removal. Desbonnet et al.'s data suggest a threshold where variation in phosphorus removal greatly decreases near 80. At around 80 feet removal averaged 67%.

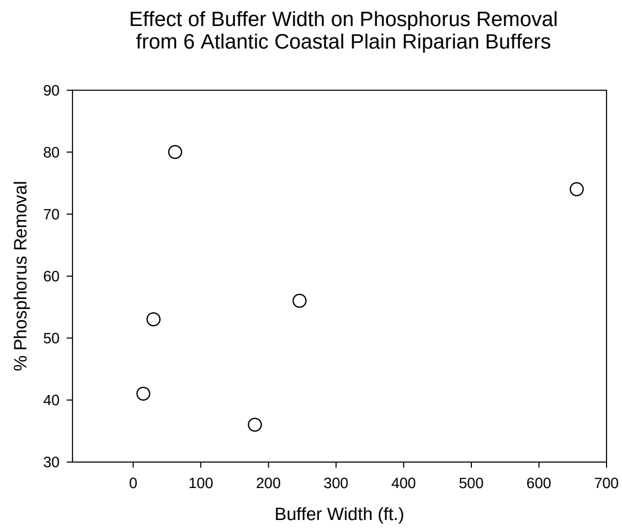

Figure 14. Effect of buffer width on phosphorus removal from 6 Atlantic Coastal Plain riparian buffers. Appendix 3 includes a table of study references.

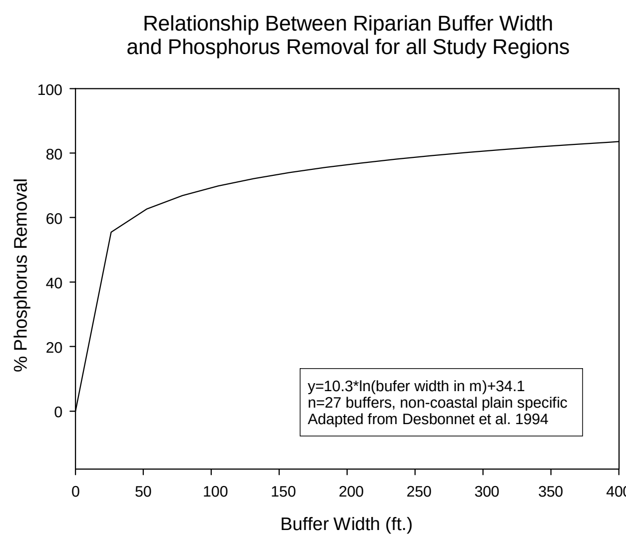

Figure 15. The relationship between riparian buffer width and phosphorus removal for many study regions. Adapted from Desbonnet et al. 1994 [61].

What is the absolute minimum recommended width for a variable width buffer on a single wetland or waterway?

A variable width buffer that is of a specified average width and that is along a single wetland or waterway should have an absolute minimum buffer width that will be able to maintain pollution removal for the long term. This minimum width should not be exceeded so that buffer function is not reduced or overwhelmed by sediment inputs or invasive species. However, no known empirical studies exist on these specific questions. One recent review commented that little experimental evidence is available for the efficiency of narrow buffers [62]. The Chesapeake Bay Program cites an absolute minimum buffer width of 35 feet to provide sustainable protection of aquatic resources [63]. Wenger recommends an absolute minimum width of 30 feet for trapping sediment [59].

Variable versus Fixed Width Buffers

Variable and fixed width buffer systems each have their own environmental and regulatory pros and cons. Buffers of a sufficient fixed width are easier to regulate and do a better job of controlling pollution, but provide lower flexibility for siting homes. On the other hand, variable width buffers are more difficult to regulate and do less to control pollution, but provide a more flexibility for home siting. However, variable width buffers, if implemented with regards to watershed and site-level differences in hydrogeology, can be an efficient and highly-protective pollution control measure.

Why are Variable Width Buffers Less Effective?

Don Weller and his colleagues at the Smithsonian Environmental Research Center in Edgewater, MD investigated how the efficiency of buffers changed between variable and fixed width systems [28]. Variable width buffers remove lower levels of pollutants than fixed width buffers of equivalent average width. This is so because narrow or absent buffers contribute relatively high levels of pollution. The extra pollutant discharge from below average width buffers is more than the extra pollutant retention from above average width buffers. So to reduce the same amount of pollutants a variable width buffer must be wider on average than a fixed width buffer. The difference between fixed width and variable width buffers was greatest for narrow buffers. The amount by which variable width buffers contribute more pollution changes with the quality of the buffer, based on a factor such as vegetation type. Work in Wisconsin also suggests that uniform buffers are most important for phosphorus removal [64].

The importance of minimizing gaps in buffers and inefficient buffer widths is echoed throughout the literature. To the extent that the minimum effective buffer width is maintained, it is more effective to have continuous but narrow riparian buffers, than wider but intermittent buffers [28, 46]. David Correll, also of the Smithsonian Environmental Research Center, remarked after a career studying riparian zones that, “Perhaps the most important guiding principles to emerge from the current scientific literature that should be considered when implementing riparian setback regulations are: (1) The importance of contiguity in riparian protection and (2) The great value and importance of protecting the least disturbed riparian corridors in communities[65].”

What can be done to Maximize the Effectiveness of Variable Width Buffers?

At the watershed level, minimum buffer widths can be assigned based on the characteristics of different parts of the watershed (see The Two Regions of the Watershed and What they Mean for Riparian Buffer Width). At the site level, buffers can be planned using precision information [66]. This approach uses topographic, hydrologic, soils, and landuse information to maximize the effectiveness and efficiency of buffers on a site. Pollutants may enter waterways through buffer hotspots or preferential flow paths. The precision approach can enhance buffers on a site by placing more buffer in these areas. In a simple example, buffers are widest along waterways where surface and subsurface drainage patterns route a large fraction of pollutants. Figure 16 compares the fixed width buffer approach with the variable width precision approach. Soils information, specific pollutant source location, and on site groundwater flow studies can be applied to increase the precision of buffer placement. In concert with an overall minimum buffer width and a policy of eliminating gaps this is an effective and flexible approach, but one that requires detailed study of certain site characteristics.

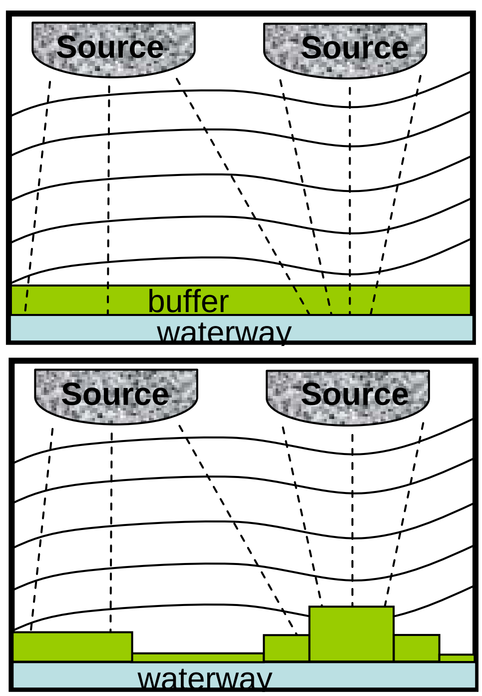

Figure 16. A comparison of two approaches to buffer width, fixed at top and precision variable width at bottom. Relatively high sources of pollutants discharge to waterways across topographic contours. Adapted from Dossekey et al. 2005[66].

The Two Regions of the Watershed and What they Mean for Riparian Buffer Width

The geology, hydrology and resulting patterns of landuse differ between the northern and southern areas of the watershed. These areas have been previously defined as hydrogeomorphic regions by the USGS [22], and their regions are simplified and presented here for the purposes of a buffer strategy [22][5] (Figure 17). The differences between these regions are summarized in Table 3. The northern region or the Well Drained region has a gently rolling topography, soils that are well drained and low in organic matter, few ditches, and high groundwater nitrogen. The southern region or the, Poorly Drained region, is flat, has higher water tables, less permeable soils with high organic matter content, many ditches, and lower groundwater nitrogen. From a buffering perspective, this would suggest that the capacity of buffers to treat groundwater would be higher in the Poorly Drained region and perhaps could justify a smaller minimum buffer width. This is so because the low-permeability, highly organic soils provide longer residence times in the near surface area of buffers where nitrogen removal is high [67].

Table 3. Relative characteristics of two simplified hydrogeomorphic regions of the Inland Bays Watershed.

Characteristic	Well Drained	Poorly Drained
Topography	Very gently rolling	Flat
Riparian Slope	Steeper	More gradual
Water table	Low	High
Groundwater flow	Rapid	Slower
Soil Permeability	High	Low
Soil Organic Matter	Low	High
Drainage Ditch Density	Low	Very High
Wetlands Area	Low	High
Subsurface Confining Areas	Few	More
Groundwater Nitrogen	High	Low
Potential for Groundwater Nitrogen Removal by Buffers[22, 67]	Medium	High

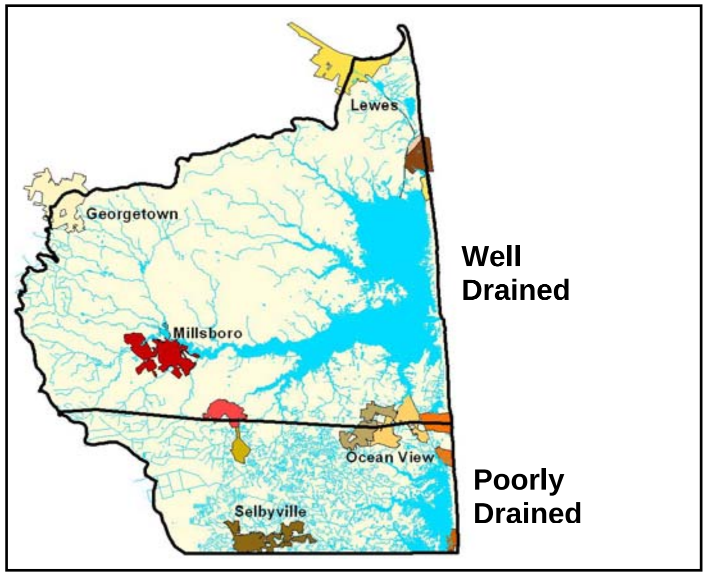

Figure 17. The two simplified hydrogeomorphic regions of the Inland Bays watershed. Water features are in blue. Note the differences in drainage density between the two regions.

Tidal Wetlands & Waters

Tidal wetlands have an enormous capacity to remove nitrogen inputs [68]. They can do so even when their width is very narrow, arguing that all tidal wetlands be protected with buffers. New information suggests that as much as 75% of the nitrogen from the Rehoboth Bay watershed moves as groundwater that regularly discharges near and within tidal wetlands [21, 69]. This reinforces the need for their protection. Tidal wetlands and waters require special concern for buffering because they migrate inland with sea level rise, reducing the width of buffers over time. This places tidal wetlands under extraordinary pressure from development because their survival depends on this migration. Appendix 4: Planning Buffers for Tidal Wetlands provides data to justify recommendations for tidal wetland buffer width. Buffers of freshwater flats wetlands adjacent to tidal wetlands should be considered tidally influence and buffered accordingly. Because the influence of tides rapidly moves upstream as sea level rises, a length of freshwater stream and adjacent wetlands that are upstream and adjacent to a tidal stream should be afforded special buffer widths. The widths should be equal to tidal systems for a length that is equal to the linear migration of tidal influence over a set planning horizon.

How Should Viewscapes be Addressed in Buffers of Tidal Areas?

Considerable social pressure exists to allow viewscapes across tidal areas. Views would likely not be possible across forested buffers at the width necessary to protect tidal wetlands and waters. Only requiring forested

[5] Well Drained Uplands is mostly well-drained upland with some poorly drained upland and coastal wetland and beach region from the USGS categorization. Poorly Drained Lowlands is mostly surficial confined with some poorly drained lowland and coastal wetland and beach regions from the USGS.

vegetation nearest to the upland wetland/waterway boundary would maintain viewscapes. The forested zone should be as wide as possible while still allowing acceptable views. Further, management can enhance selected view corridors while allowing denser forest in other sections. In the very wide buffers, non-permanent landuse and structures could be located further landward from the buffered feature. A management plan should require tree planting in the non-forested part of the buffer relative to the rate of estimated landward migration of the wetland.

Figure 18. Example of maintained forested buffer that provides a viewscape onto White's Creek and its marshes in early spring.

Freshwater Flats and Depressional Wetlands

No research could be found that specifically recommended a minimum buffer width to protect the water quality functions of freshwater flats and depressional wetlands. However, it is well documented that the direct and indirect impacts of development and deforestation near a wetland can cause detrimental and irreversible changes to its hydrology and species composition [70, 71]. Development also leads to increased nutrient loading of wetlands [72]. Together these impacts may results in changes to the nutrient processing capacity wetlands. Wetlands can "dry out" and their capacity for nitrogen removal can decrease, or they can become wetter reducing their capacity to hold runoff [70, 73]. Requiring forested buffers will likely provide the greatest protection of these resources and remain consistent with other waterbody buffer types.

Restoration and Management

Restoration of the riparian network to improve and maintain water quality is of critical importance and should be part of implementing a buffer system. At development, restoration of native vegetation (typically native forest) should be required in all areas of required buffer that are not already in native vegetation. A few coastal plain studies have shown rapid and substantial pollutant removal by buffers shortly after restoration. One buffer was increased from 30 to 98 feet resulting in nitrate removal efficiencies from shallow groundwater increasing from an average 44% to 94% [74]. A mass balance study of another restored riparian wetland showed that within the first 8 years following restoration the buffer was highly effective and reduce huge nitrogen and phosphorus loads [24]. On average, restored buffers should have a substantial effect on nitrate removal within 5 – 10 years [67].

Requiring buffers at site development poses a fleeting and choice opportunity to implement further restoration of degraded waterways. After site development, incentives for cooperation opportunities to access sites with heavy equipment decline. Incentives and cost-share agreements should be formulated to take advantage of this opportunity by encouraging developers to cooperatively plan and implement restoration with public and private restoration practitioners. This can be accomplished with a number of active and low cost waterway restoration techniques including controlled drainage, check dams, addition of logs, channel reformation, and controlled beaver population restoration. Incorporating future restoration of riparian areas necessitates widths sufficient to accommodate improved hydrologic connection of channels with streamside areas.

How Does Forest Management Affect Buffers?

A coastal plain study found that management of an existing forest (clear cut vs. thinning vs. mature) that was adjacent to a mature streamside forest had no effect on subsurface nitrate removal [75].

Recommendations

The following recommendations for the major characteristics of a buffer system are based on the above review of the scientific literature. The first set of recommendations applies to the entire buffer system and is critical to realize the pollution removal potential of buffers.

1. All wetlands and waterways have high potential to filter significant amounts of nutrients and should be buffered[6].

[6] This excludes farm ponds or other man-made bodies of water not located on or within tidal areas or non-tidal waterways and wetlands per the January 2005 PCS.

2. Headwaters and those existing natural waterways and wetlands that are in the best ecological condition should receive the most protective buffers.

3. Because buffers provide substantial and cost effective long-term removal of pollutants, they should be required for all but the smallest new subdivisions and redevelopments.

4. Governments should allow flexible site planning alternatives to ensure implementation of the buffer system for small and large subdivisions.

5. A formal variance procedure should be developed to resolve rare instances where buffer requirements may preclude any development of the property, especially for small subdivisions.

6. Buffers should begin at the upland edge of streamside wetlands where they are present, not from the stream banks.

7. Forested riparian buffers provide much greater potential for long term improvement and protection of water quality than non-forested buffers and should be the required vegetation type for all buffers.

8. Drainage ditches should be given special consideration. Minor drainage ditches, because of their great density, may be difficult to buffer and could act more as pollution conveyances. Filling of minor drainage ditches or their conversion to stormwater controls during development should be encouraged where hydrologically feasible especially in the southern portion of the watershed.

9. Where forested buffers are required but do not exist, restoration of native vegetation (typically native hardwood or mixed-pine hardwood forest) should occur per Appendix I and J of the August 2006 PCS.

10. No new structures including stormwater features should be allowed in the buffer zone. Excluded from this are public utilities and other necessary structures detailed in the 2005 PCS.

11. Incentives and cost-share agreements should explored to encourage developers to cooperatively plan and implement restoration of degraded wetlands and waterways with public and private restoration practitioners.

The second set of recommendations is for two alternative buffer systems with different levels of protection based on vegetation type and width (Table 4). The sufficient protection alternative removes the least nutrients, meets the point of diminishing returns on pollutant removal for buffer width, provides sufficient short term protection to tidal wetlands, but still includes risk that buffers will not meet their potential for maximum protection of resources. The optimum protection alternative maximizes the efficiency of buffer width, greatly reduces risk that buffers will not meet their potential, provides long-term protection to tidal wetlands, and may sufficiently protect and restore other important functions of buffers such as wildlife habitat. The optimum protection alternative is most consistent with the goals of the Inland Bays CCMP.

Development Analysis

This watershed-level GIS analysis explores the dimensions of the two recommended buffer systems on developments listed by the Preliminary Landuse Service between February 2004 and January 2007. The distribution of development size was used to develop a stratified random sample of 3 to 4 small developments and 2 large developments each in both the northern and southern region of the watershed. This sampled approximately 10% of the total population of developments in the data set, allowing inference to contemporary developments in the watershed. The average areas of buffers were determined by the wetland and waterway type buffered. Buffer area was compared between watershed regions and between small and large developments. Further recommendations were developed on how to accommodate the buffer alternatives.

Table 4. Alternative buffers systems for the Inland Bays watershed with different levels of resource protection. Years next to tidal wetland and waters widths indicate average number of years buffer of said width will provide protection. Notes below indicate levels of nutrient removal associated with widths where data is available.

Buffer System Characteristic	**Sufficient Protection Alternative**	**Optimum Protection Alternative**
Buffer Width Variation	Variable Width	Fixed Width
Vegetation Type	Dominance of Native Forest†	All Native Forest†
Buffer Width by Type		
Tidal Wetlands & Waters		
Gradual Upland/Wetland Boundary	300 feet (53 yrs)	500 feet (88 yrs)
Steep Upland/Wetland Boundary	80 feet (71 yrs)	150 feet (132 yrs)
Nontidal Wetlands and Waterways		
Flats and Depressional Wetlands	50 feet	100 feet
Riparian Wetlands	80 feet‡‡	150 feet‡‡‡
Headwaters Streams & Ditches	80 feet‡‡	150 feet‡‡‡
Larger Streams & Ditches	80 feet‡‡	150 feet‡‡‡

† Dominance corresponds to the vegetation requirements of the 2005 version of the PCS. See Tidal Wetlands & Waters section for elaboration on a recommended vegetation type for these buffers.

‡‡ 82% nitrogen removal on average with at least 67% removal for most buffers. 79% phosphorus removal on average with moderate variability.

‡‡‡90% nitrogen removal on average with at least 78% removal for most buffers. 86% phosphorus removal on average with low variability.

Methods
Developments listed with the State's Preliminary Land Use Service (PLUS) from February 2004 to January 2007 were obtained and clipped to the Inland Bays Watershed using ArcView 3.2 GIS software. From the distribution of development size, 3 or 4 small developments (under the median acreage of the distribution) and 2 large development (over the 75th percentile of acreage) were randomly selected from the northern and southern regions of the watershed.

For each development, the Delaware SWMP wetlands layer and a detailed hydrography layer were used to determine the dimensions of wetlands and waterways onsite and offsite whose buffers might intersect the development. Due to the scale of the analysis, the hydrography layer was not updated to include unmapped headwaters and ditches. Ditches were separated from natural waterways. Ditches totally within wetlands were not recorded but ditches on wetland boundaries were recorded. Ditches were considered to be minor when they had small drainage areas. Minor ditches were evaluated to determine if they were fillable or otherwise able to be disconnected from the drainage network without causing drainage problems upstream. The slope of uplands adjacent to tidal wetlands was estimated as gradual or steep using USGS hypsography data layers and best professional judgement. Both protection alternatives were applied to the developments. Areas of properties isolated by buffers such that development was unlikely were recorded and added to the buffer area. Larger areas surrounded by buffer were assumed buildable with access roads permitted through the buffer. The percent of the developable acreage each buffer alternative would take up was calculated. The contributions of buffer acreage from buffers of different wetland and waterway types were determined. The amount of buffer acreage to be restored to forest was determined using the 2002 State landuse data layers. For tidal buffers, only the first 80 or 150 feet from the water or wetland boundary was considered to be required to be restored for the sufficient and optimum alternatives respectively. Statistics were compiled by development size and hydrogeomorphic region. The GIS analysis workflow is included as Appendix 5.

Results
GIS Data Layer Accuracy. The hydrography and wetlands data layers demonstrated errors that likely resulted in inflated estimates of buffer acreage on developments. These errors resulted from incorrect mapping of waterways near property boundaries, the over-mapping of freshwater wetlands (inherent to the SWMP data layer), and the assumption that no wetlands would be filled. On the other hand, certain waterways that were not mapped did not receive buffers, low-balling the estimate of buffer acreage. However, unmapped waterways are typically small terminal ditches that would likely be filled or converted to stormwater controls. Finally, tidal wetlands with gradually sloping adjacent uplands were likely overestimated on sites due to the scale of analysis. Therefore, it is likely that this analysis resulted in a small but considerable net overestimation of buffer acreage.

Development Distribution. One hundred and ten developments in the watershed were recorded by the PLUS for the roughly two years of available data. The distribution of development size is depicted as a histogram in Figure 19. The median development size was 61 acres. The 25th and 75th percentiles were 25 and 106 acres respectively. While the few very large developments generate the most media attention and environmental concern, the majority of development acreage results cumulatively from smaller developments. Nine of the eleven developments (82%) randomly selected for study were located in the Environmentally Sensitive Development Area (Figure 20). Nine of the developments were residential and two were commercial.

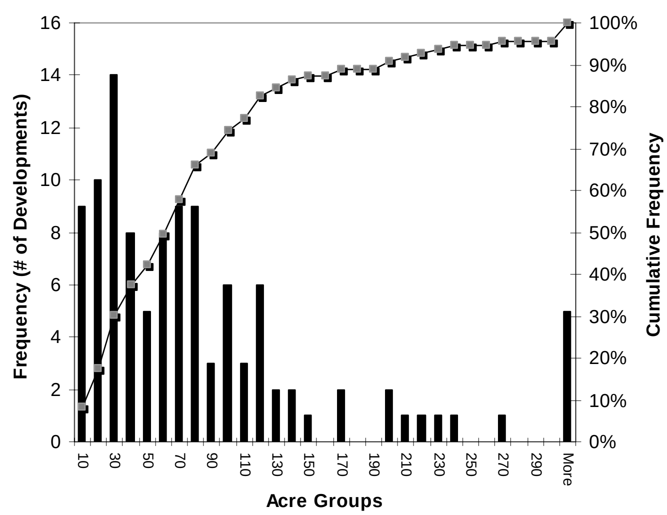

Figure 19. Histogram of development size with cumulative frequency for developments proposed in the Inland Bays watershed from February 2004 to January 2007.

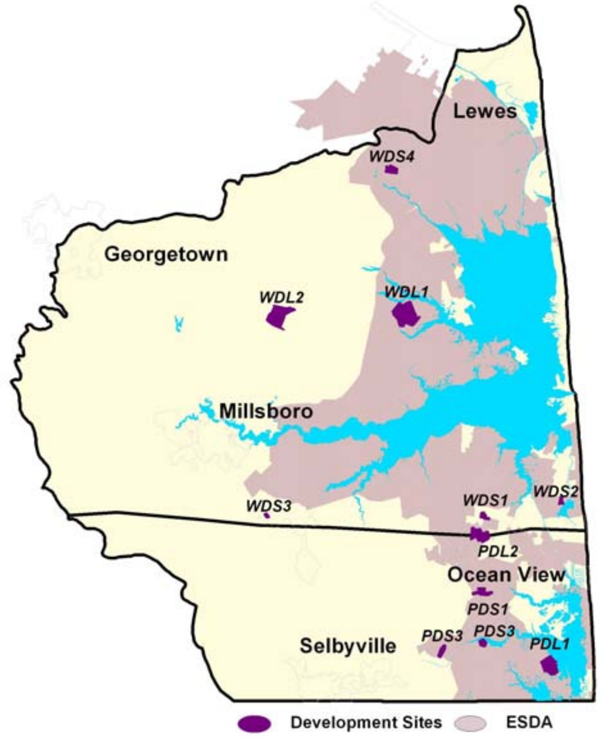

Figure 20. Location of PLUS application development sites analyzed showing the Environmentally Sensitive Development Area (ESDA).

Development Characteristics. Dimensions of the 11 developments, their waterways and wetlands, and their buffers by protection alternative are presented together and individually as color maps and tables in Appendix 6. Small developments ranged in size from 9 to 52 acres and large developments ranged from 128 to 314 acres. Development characteristics for all sites are summarized in Table 5. The percentage of developments as wetlands had a median value of 12% and ranged from 0% to 67%. Non-tidal wetlands dominated the wetland acreage. Only three sites had tidal wetlands. Developable acreage prior to buffering had a median value of 88% and ranged from 33 to 100% of a site. Total waterway length was highly variable and ranged from 0 to 3,362 feet with a mean of 1,615 feet. Only one site had a natural stream so the vast majority of waterway length was as ditches. About half of the ditches (51%) were considered minor ditches. About half of these minor ditches (45%) were considered fillable or otherwise able to be disconnected from the drainage network so that they did not require buffers.

Table 5. Site characteristics for eleven study developments.

Site Characteristics	Min	Max	Mean	Median
Site Acreage	8.7	314.0	94.0	50.2
Total Wetland Acreage	0.0	99.7	14.9	4.0
Nontidal Wetlands	0.0	16.4	6.4	3.2
Tidal Wetlands	0.0	88.9	8.5	0.0
Developable Acreage	8.7	308.7	79.0	37.1
Waterway length (ft)	0.0	3362.0	1615.0	1653.0
Stream Length	0.0	150.0	30.0	0.0
Ditch Length	0.0	3362.0	1448.7	1562.0
Minor Ditch Length	0.0	2996.0	979.1	681.0
Fillable Ditch Length	0.0	1993.0	615.8	799.0

Sites in the poorly drained region had more ditches and more nontidal wetlands than sites in the well drained region (means = 2,220 feet vs. 805 feet and 10.1 acres vs. 3.3 acres, respectively) (Table 6). As a result of the greater wetland acreage, the percent developable acreage of sites in the poorly drained region (68%) was about 20 percentage points less than that of sites in the well drained region (89%). Ditch density, or the ratio of ditch length to developable site acreage, was surprisingly similar between sites in the poorly drained and well drained regions (means = 65.3 and 70.0 respectively)[7] (Appendix 6 & Table 7). Small developments had a much higher ditch density (98.3) than did larger developments (14.8).

Buffer Characteristics. The percentage of developable acreage as buffer varied widely for both protection alternatives (Table 8). The median percentage of developable acreage as buffer for the sufficient protection alternative was 13.8% and this ranged from 1.8% to 60.6%. For the optimum protection alternative the median was 33.2% with a range of 3.7% to 89%. The breakdown of buffer type was evenly distributed between buffers on ditches, freshwater wetlands, and tidal areas. No particular wetland or waterway type contributed a disproportionate amount of buffer. Sites of the poorly drained region had a considerably greater mean percentage of developable area as buffer (32%) than did sites of the well drained region (18%) (Table 9). Small developments had about twice as much of their developable acreage as buffer than did larger sites (Table 10). The two sites with tidal wetlands adjacent to gradually sloping uplands had the greatest percentages of developable area as buffer for the sufficient protection alternative. Acreage of buffer requiring restoration to forest was generally low with a mean acreage of 2.6 for

[7] Calculating the same parameter using actual development acreage, and thus including wetlands where many ditches occur, shows a much greater ditch density in the poorly drained region as expected.

the sufficient protection alternative and 5.2 for the optimum protection alternative (Table 8).

Table 6. Site characteristics by watershed hydrogeomorphic region. Five sites are in the poorly drained and six are in the well drained regions.

	Poorly Drained				Well Drained			
Site Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Site Acreage	27.2	148.0	77.6	52.0	8.7	314.0	107.7	37.0
Total Wetland Acreage	3.3	99.7	27.9	12.5	0.0	12.9	4.0	2.7
Nontidal Wetlands	3.2	16.4	10.1	10.8	0.0	12.9	3.3	2.1
Tidal Wetlands	0.0	88.9	17.8	0.0	0.0	2.5	0.7	0.0
Developable Acreage	16.5	120.3	49.7	39.5	8.7	308.7	103.4	29.0
Waterway length (ft)	389.0	3362.0	2250.2	2851.0	0.0	2371.0	1085.6	1113.5
Stream Length	0.0	150.0	50.0	0.0	0.0	0.0	0.0	0.0
Ditch Length	238.0	3362.0	2220.0	2851.0	0.0	1915.5	805.9	679.0
Minor Ditch Length	171.0	2996.0	1784.2	2291.0	0.0	1040.0	308.2	0.0
Fillable Ditch Length	171.0	1993.0	985.0	972.0	0.0	1040.0	308.2	0.0

Table 7. Site characteristics by development size. Seven sites are small (< 61 acres) and four sites are large (>61 acres).

	Small				Large			
Site Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Site Acreage	8.7	52.0	29.5	27.2	128.0	314.0	207.0	193.0
Total Wetland Acreage	0.0	16.4	7.2	3.3	1.8	99.7	28.3	5.8
Nontidal Wetlands	0.0	16.4	6.8	3.2	1.8	10.8	5.7	5.1
Tidal Wetlands	0.0	2.5	0.4	0.0	0.0	88.9	22.6	0.8
Developable Acreage	8.7	39.5	22.2	20.9	48.3	308.7	178.4	178.3
Waterway length (ft)	0.0	3362.0	1749.5	1915.5	0.0	2996.0	1379.5	1261.0
Stream Length	0.0	150.0	21.4	0.0	0.0	0.0	0.0	0.0
Ditch Length	0.0	3362.0	1612.4	1562.0	0.0	2996.0	1162.3	826.5
Minor Ditch Length	0.0	2782.0	1013.3	809.0	0.0	2996.0	919.3	340.5
Fillable Ditch Length	0.0	1040.0	544.1	799.0	0.0	1993.0	741.3	486.0

Table 8. Buffer characteristics by protection alternative for eleven randomly selected sites.

	SUFFICIENT				OPTIMUM			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	0.6	24.4	8.0	5.7	1.4	33.7	13.5	11.5
Ac. on Ditches	0.0	9.7	2.5	0.6	0.0	17.3	5.0	1.9
Ac. on Natural Waterways	0.0	4.7	0.5	0.0	0.0	7.6	0.8	0.0
Ac. on Freshwater Wetlands	0.0	6.8	2.9	3.3	0.0	14.2	5.3	4.7
Ac. on Tidal Wetlands	0.0	20.9	2.8	0.0	0.0	31.1	4.4	0.0
Ac. Confined by Buffer	0.0	0.4	0.1	0.0	0.0	2.3	0.2	0.0
Ac. Overlapping Buffers	0.0	6.0	0.9	0.1	0.0	17.7	2.3	0.9
Developable Acreage With Buffer	3.4	303.1	71.0	23.9	1.0	297.2	65.5	14.6
% Developable Acreage as Buffer	1.8	60.6	24.3	13.8	3.7	89.0	39.3	33.2
Acreage of Buffer to be Restored	0.0	11.4	2.6	0.6	0.0	20.6	5.2	1.4

Discussion.

This analysis clearly shows that the amount of buffer required to maximize the protection of water resources is highly variable among developments. This variation is driven by the underlying differences in the type, amount, and distribution of wetlands and waterways on a development. In general smaller developments, developments in the poorly drained region, and developments with tidal wetlands adjacent to gradually sloping uplands will have more buffer area. Larger developments and developments in the well drained region will have less buffer area. To offer adequate and consistent resource protection, buffer acreage must vary in response to the landscape, and thus cannot ensure even responsibility for protection with each development situation.

On average, the percentage of developable land as buffer under the sufficient protection alternative (13.8%) would be expected to be included into current Sussex County open space requirements for development, which can range from 25 to 40%. Including the acreage of non-tidal wetlands with buffers reveals that together they amount to 32% of a development eligible for inclusion as open space, still within the range of requirements. Tidal wetlands are not eligible for inclusion as open space, and only some developments currently include freshwater wetlands in their open space calculations. At the time of this report, the County was considering whether to remove freshwater wetlands from inclusion in open space calculations (*personal communication* Lawrence Lank, Sussex County Planning and Zoning). Acreage of buffers of the optimum protection alternative on average also fall within the open space requirements.

For certain developments, requiring buffers will result in a significantly reduced area on which to develop. These affects will be most pronounced in the poorly drained region where tidal wetlands are present. Bayville Point (PDL1) is a good example of this case (Appendix 6). Here buffers take up 50.5% and 69.8% of the developable area for the two alternatives. The majority of the buffer acreage is of tidal wetlands. This site is a particularly poor choice for dense residential development because it is in the direct path of migrating wetlands. At application to PLUS, Bayville Point was a proposed residential planned community of 242 units. To maintain this number of units with buffers that provide optimum protection, greater than 17 units per acre would be required.

Small developments had about twice as much of their developable acreage as buffer than did larger developments. The Woodlands (PDS1) is a good example of a small development in the poorly drained region where buffers of both sufficient and optimum protection would alter site design. Nearly one quarter of the property is designated wetlands and the site is criss-crossed by drainage ditches, most of which appeared unable to be disconnected from the drainage network. The percent developable acreage was 35.9% and 63.0% for the two protection alternatives. About two thirds of the buffer acreage was of the ditches. The Woodlands was a proposed community of 88 units. To maintain this number of units with buffers that provide sufficient protection, greater than 2.5 units per acre would be required. This density still falls within what is currently permitted by the County.

Table 9. Buffer characteristics by protection alternative and hydrogeomorphic region for eleven randomly selected sites.

	SUFFICIENT								OPTIMUM							
	Poorly Drained				Well Drained				Poorly Drained				Well Drained			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	3.2	24.4	12.2	10.5	0.6	5.9	4.6	5.3	6.9	33.7	19.6	20.5	1.4	12.3	8.4	8.9
Ac. on Ditches	0.0	9.7	4.8	5.4	0.0	2.9	0.6	0.1	0.0	17.3	9.1	8.3	0.0	5.9	1.5	0.7
Ac. on Natural Waterways	0.0	0.8	0.2	0.0	0.0	4.7	0.8	0.0	0.0	1.7	0.3	0.0	0.0	7.6	1.3	0.0
Ac. on Freshwater Wetlands	1.4	6.8	4.0	4.3	0.0	5.1	1.9	1.5	3.0	14.2	7.5	7.8	0.0	10.0	3.5	3.2
Ac. on Tidal Wetlands	0.0	20.9	4.5	0.0	0.0	5.2	1.5	0.0	0.0	31.1	6.9	0.0	0.0	7.7	2.4	0.0
Ac. Confined by Buffer	0.0	0.4	0.2	0.1	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.4	0.0
Ac. Overlapping Buffers	0.0	6.0	1.5	0.6	0.0	1.6	0.3	0.0	0.2	17.7	4.2	0.9	0.0	2.9	0.7	0.0
Developable Acreage With Buffer	8.0	109.8	37.5	23.9	3.4	303.1	98.8	24.1	4.4	99.8	30.1	14.6	1.0	297.2	95.1	19.3
% Developable Acreage as Buffer	8.7	51.5	32.0	35.9	1.8	60.6	18.0	10.2	17.0	73.3	50.4	63.0	3.7	89.0	30.0	24.6
Acreage of Buffer to be Restored	0.4	11.4	5.3	6.5	0.0	1.8	0.4	0.0	1.4	20.6	10.2	7.6	0.0	4.4	1.0	0.0

Table 10. Buffer characteristics by protection alternative and development size for eleven randomly selected sites. Large developments are <61 acres, small are >61 acres.

	SUFFICIENT								OPTIMUM							
	Large				Small				Large				Small			
Buffer Characteristics	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median
Acreage of Buffer	5.7	24.4	11.6	8.2	0.6	14.2	6.0	5.1	9.8	33.7	18.9	16.0	1.4	24.9	10.4	8.1
Ac. on Ditches	0.0	6.3	2.2	1.3	0.0	9.7	2.7	0.6	0.0	13.6	4.9	3.1	0.0	17.3	5.0	1.9
Ac. on Natural Waterways	0.0	4.7	1.2	0.0	0.0	0.8	0.1	0.0	0.0	7.6	1.9	0.0	0.0	1.7	0.2	0.0
Ac. on Freshwater Wetlands	0.9	6.8	3.5	3.2	0.0	5.1	2.5	3.3	2.2	14.2	7.3	6.4	0.0	10.0	4.2	4.1
Ac. on Tidal Wetlands	0.0	20.9	6.1	1.8	0.0	5.2	1.0	0.0	0.0	31.1	9.4	3.3	0.0	7.7	1.6	0.0
Ac. Confined by Buffer	0.0	0.4	0.2	0.2	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.3	0.0
Ac. Overlapping Buffers	0.0	6.0	1.6	0.3	0.0	1.6	0.4	0.1	0.0	17.7	4.7	0.4	0.0	2.9	1.0	0.9
Developable Acreage With Buffer	23.9	303.1	166.8	170.1	3.4	32.0	16.2	16.2	14.6	297.2	159.5	163.1	1.0	24.8	11.8	13.8
% Developable Acreage as Buffer	1.8	50.5	15.9	5.6	6.7	60.6	29.2	22.5	3.7	69.8	23.7	10.6	16.1	89.0	48.2	34.0
Acreage of Buffer to be Restored	0.0	6.5	2.0	0.8	0.0	11.4	3.0	0.6	0.0	14.9	5.4	3.3	0.0	20.6	5.1	1.4

Buffers of ditches made up a large portion of total buffer acreage in this study. This occurred even after half of minor ditches were considered filled, piped, or converted to stormwater features. On many sites, buffers of ditches will contribute considerably to changes in home citing and development design necessary to accommodate buffers in general. Ditches are important conduits for nitrogen, phosphorus, and sediments[76]. Like streams, they have complex hydrology, receiving variable inputs of surface water and groundwater with associated pollutant loads [77]. And forested buffers of ditches result in lower nutrient inputs and an increased capacity of ditches to slow or reduce pollutants [78]. However, many ditches are shallow (~ ≤ 2 – 3 feet deep) and receive only localized inputs of primarily surface water [79]. These shallow ditches may receive less benefit from buffers than deeper ditches (> 2 – 3 feet deep) [79]. Further, small ditches provide much lower levels of other wetland services than do natural wetlands and waterways. Reducing the minimum buffer width on shallow ditches could provide the flexibility needed by developers to cite homes and more adequately buffer natural wetlands and waterways. It is recommended that widths on these ditches not fall below 35 feet (*see Width above*). Forested buffers are still recommended for shallow ditches, and may help to minimize phosphorus export through floating algal blooms; a potentially important export in ditches [80]. In light of the fact that ditches remain the dominant waterways even after site development, it is recommended that 1) governments further encourage cooperation within and between developments to reduce ditch networks through fill and conversion to stormwater features while continuing to manage for adequate drainage and 2) incentives be developed which take advantage of the opportunity that development provides to address the drainage network by encouraging practices that further improve nutrient reduction in ditches. These practices include channel regrading to simulate flood plains, small scale controlled drainage, and in-line wetlands [81-83].

Both protection alternatives resulted in low acreages and costs for required buffer restoration. Recommended restoration practices for buffers are detailed in the August 2006 version of the PCS [8]. The cost to install Conservation Reserve Enhancement Program (CREP) forested buffers range from $125 -- $725/acre. Since buffers installed in developments often use better quality plant material than typical CREP projects, a cost of $1,000/acre is applied here. This results in an average of $2,600 to $5,200 in restoration costs per development.

This study suggests that, in general, most developments in the well drained region can accommodate buffers of the optimum protection alternative with little or no decrease in housing units or commercial space relative to a no-buffer alternative. Example developments in this regard include Bridlewood (WDL1) and Savannah Square (WDS3) (Appendix 6). Certain small developments and developments in the poorly drained region will have to substantially adapt site designs to accommodate buffers. Adaptations could include smaller lot sizes, smaller street widths, alternative parking options, and perhaps increased densities. Cooperation of Sussex County to develop ordinances that facilitate flexible site designs will be critical to developments accommodating buffers. Where buffer extent must be reduced, shallow ditches should be addressed first, followed by flats and depressional wetlands. Reductions in width are likely to have less impact on buffer efficiency in the Poorly Drained region.

Additional Recommendations

After review of actual proposed developments a number of additional recommendations were formulated.

1. Given the level and type of development already permitted on the most environmentally sensitive land of the watershed, given that this development has been permitted without pollution control strategy requirements and without adequate buffers, and given that sea level rise and tidal wetland migration is predicted to increase, perhaps drastically[84-86][8], it is strongly recommended that the optimum protection alternative be afforded to tidal waters and wetlands.
2. Additionally, it is recommended that a special low density zoning be developed and implemented for developable properties with tidal wetlands adjacent to gradually sloping uplands.
3. If buffers of wetlands and waterways on adjacent properties are more than half the buffer width on the developing property and the adjacent properties are not developed or under long term agricultural preservation, then buffers should be required on the developing property.

[8] Recent information suggests that sea-level rise has a high probability of increasing rapidly over the next 100 years such that sea-level could be 45 to 145 cm higher by 2100 These increases in the rates of sea level rise will increase rates of wetland migration inland. Furthermore, increased stresses on tidal wetlands are placing greater importance on their capacity to migrate inland to maintain themselves (*see citations in text above*).

4. Shallow ditches could be afforded smaller buffer widths, not to fall below 35 feet, so that buffers of natural wetlands and waterway features can be better accommodated.
5. Governments should encourage cooperation within and among developments to reduce ditch networks and implement additional nutrient reduction techniques in remaining ditches.
6. Ordinances and incentives that facilitate flexible development site designs to accommodate buffers are likely critical for implementing a watershed level buffer system.

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Appendix 1.

White Paper on the August 2006 Revisions to the Buffer Section of the draft Inland Bays Pollution Control Strategy and Proposed Regulations

The Delaware Center for the Inland Bays Scientific and Technical Advisory Committee

Christopher Bason, Science & Technical Coordinator
Kent Price, Vice Chair

September 27, 2006

This paper characterizes the effectiveness of the buffer system of the August 2006 draft Pollution Control Strategy (PCS) to reduce nutrient loads to the Inland Bays. The intent of this paper is also to advise the Board of Directors of the Center for the Inland Bays (CIB), lawmakers, and the public on the components of a buffer system that can reduce the greatest nutrient loads and still allow for profitable conversion of land to development. This paper was developed partly from a discussion among a volunteer subcommittee meeting of scientists and resource managers of the CIB Scientific and Technical Advisory Committee (STAC) on September 15, 2006 (Table 1), and partly from a comparative GIS analysis of the May 2005 and August 2006 drafts of the PCS as prepared by Christopher Bason (CIB) available online at http://www.inlandbays.org/cib_pm/pdfs/uploads/bufferstratreview.pdf

Riparian Buffers

Riparian buffers are areas adjacent to waterbodies that provide valuable services including flood control, biodiversity, and nutrient retention. While buffers are best managed for all of their important services, the PCS, and thus this paper focus only on nutrient retention. The PCS addresses a number of components of a buffer system as listed in (Table 2). All of these components contribute to the capacity of a buffer to retain nutrients and should all be considered when discussing the effectiveness of a buffer system.

PCS Buffer Comparison

The revised August '06 PCS buffer section differed substantially from that of the May 2005 draft in all its components. The May '05 draft proposed 100 foot buffers of primarily native forest along all wetlands, tidal waters, and intermittent and perennial waterways with few structural variances and was applicable to all subdivisions. The August '06 draft proposed a 50 foot buffer with no vegetation requirements along only tidal wetlands, tidal waters, and perennial streams and ditches with more structural variances and is applicable only to major subdivisions (Table 3).

To determine differences in buffer nutrient load reductions between PCS drafts, two subwatersheds representing different regions of the Inland Bays watershed were compared using GIS. The comparison only considered the application of buffers at a change in landuse and moderate assumptions about the intensity of development were used[1]. *On average, the nitrogen and phosphorus load reductions provided by the August 2006 draft were 98% less than those of the May 2005 draft. For example, in one ~ 6,000 acre subwatershed the May '05 buffer system reduced 769 pounds of nitrogen per year and the current August '06 system reduced 8 pounds per year* (Table 4). These differences were largely due to the rescission of buffers from intermittent waterways (see Table 5). The estimates of nutrient loads reduced are conservative for both buffer systems but especially low for the May 2005 draft for a number of reasons[2]. It is apparent that the revisions to the PCS have rendered the proposed buffer system poorly effective at its intended task. However, examination of the May 2005 draft also revealed that its extensive buffer system would not allow for orderly development in the southern portion of the watershed. It is clear that a buffer system based on a large body of regional scientific research and excellent local understanding can still be achieved.

Relation of the Buffer System to Achieving TMDLs

DNREC has estimated that the PCS will meet the Total Maximum Daily Load reductions for non-point source nutrients without reductions from the proposed buffer system (Figure 1). However, no assurances exist that the many voluntary actions of the Strategy will be fully implemented. Further, the high cost of individual septic system upgrades calls into question the timely attainment of this regulatory requirement. These uncertainties place greater emphasis on the provision of a highly effective buffer regulation that would make up for the potential shortcomings of the other sections of the PCS.

STAC Recommendations

The STAC provided a number of different recommendations for the formulation of a buffer system for the Inland Bays. Some of the most recurring themes of the discussion are listed below. The STAC advises that DNREC and CIB jointly examine the PCS to determine if the buffer section may be enhanced per these recommendations.

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[1] It was assumed that 50% of the agricultural land within the total buffer area was converted to development, that agricultural requirements of the PCS were 50% complete, and that all new development met the stormwater requirements of the PCS. Minor ditches were not buffered in one of the subwatersheds to approximate a realistic development situation.

[2] 1) The increase in nutrient retention by newly buffered waterways themselves were not quantified, 2) the greater load reductions of buffers on intermittent relative to perennial waterways were not quantified, 3) the allowance of fertilized turfgrass buffers in the August 2006 draft was not quantified, 4) protection of currently unregulated wetlands under the May 2005 draft was not addressed.

1. Buffer width must be variable based on the type of waterway to be buffered and its condition. A one size fits all approach is not appropriate to maximize nutrient retention.[3]

2. The creation a buffer system must focus foremost on the types and condition of waterways to be buffered, and secondly on width and vegetation requirements. Existing natural waterways and wetlands that are in the best ecological condition should receive priority for buffering.[4] Buffers should begin at the upland edge of streamside wetlands where they are present, not from streambanks. Headwater streams and any adjacent wetlands deserve the greatest amount of protection from buffers.[5] Isolated wetlands, though currently not regulated, filter nutrients from recharging and discharging groundwater and should also be a priority for buffering.

3. Drainage ditches should be given special consideration. Minor drainage ditches, because of their great density, may be difficult to buffer and could act more as pollution conveyances. Filling of minor drainage ditches should be encouraged especially in the southern portion of the watershed. Wide buffers on deep drainage ditches may not greatly increase nutrient filtration because groundwater entering the ditch may bypass the root zone of the buffer where maximum filtration occurs.

4. Buffers on deeply incised streams or streams channelized for agricultural drainage should have widths that allow for the hydrologic reconnection of the stream with its floodplain, either through natural evolution of the channel or wetland restoration.

5. The categorization of waterways as intermittent or perennial for the purpose of assigning different buffers should be reconsidered. Rapid determination of a waterway as intermittent or perennial is difficult due to great variation in the flow patterns of the upstream drainage networkds and to short and long term changes in weather. A mapping approach is recommended.

6. Among buffer vegetation types, native forest provides the greatest amount of nutrient retention and should be required with provisions for viewscapes.

7. Incentives for developers that favor wider buffers and native forests should be offered. These may include tax rebates for preservation, cost assistance for restoration, and compensation for buffering in addition to minimum requirements in the form of added density of homes.

8. Rapid infiltration basins (RIBs) should be placed far from waterways to allow for nutrient filtration in the surficial aquifer prior to discharge into a waterway. Waterways that eventually intercept RIB discharge from groundwater should be maintained in a healthy condition with wide forested buffers to provide maximum nutrient processing.

<u>Tables and Figures</u>

Table 1. Attendees of the buffer subcommittee meeting of the CIB STAC, September 15, 2006.
One individual submitted written comments in lieu of attendance.

Name	Affiliation
Kent Price	Center for the Inland Bays
Tom McKenna	Delaware Geological Survey
Scott Andres	Delaware Geological Survey
Judy Denver	United States Geological Survey
Ben Anderson	DNREC – Watershed Assessment Section

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[3] For example, smaller flowing waterways may require only a narrow buffer, perhaps 25 feet. Tidal wetlands at the base of steep slopes may require wider buffers, perhaps 100 feet. Tidal marshes with gradual transition into uplands may require wider buffers still, perhaps 300 feet, to maximize retention and allow for marsh migration with rising sea level.

[4] These least-altered ecosystems have the greatest capacity to reduce nutrient concentrations and provide clean water to the Bays.

[5] Headwaters, tend to flow intermittently, and because of their great number (~75% of total waterway length [Table 5.]) and high nutrient loads, are the most important for protecting water quality.

Sergio Huerta	DNREC – Environmental Laboratory
Christopher Bason	Center for the Inland Bays
Edythe Humphries	DNREC – Environmental Laboratory
Harry Haon	Citizen, Fenwick Island
Ed Lewandowski	Center for the Inland Bays
Kathy Bunting-Howarth	DNREC – Division of Water Resources
John Schneider	DNREC – Division of Water Resources
Lyle Jones	DNREC – Division of Water Resources
Jennifer Volk	DNREC – Division of Water Resources
Bruce Vasilas	University of Delaware – Dept. Plant & Soil Science
Bill Ullman	University of Delaware – College of Marine & Earth Studies
Terry Higgins	Wesley College (rtd.)
A.G. Robbins	Citizen
Paul Sample	Technical Advisory Office
William Moyer	Duffield Associates
Joe Farrell	University of Delaware Sea Grant
Robin Tyler	DNREC – Division of Water Resources
Jeff Tinsman	DNREC – Fisheries Section
Ed Whereat	University of Delaware Sea Grant Citizens Monitoring Program

Table 2. Description of the components of a buffer system to protect water quality.

Buffer Component	Description	Importance
Waterways Buffered	The type of water features buffered. Categorized as wetlands, tidal waters, and intermittent and perennial streams and ditches.	Different waterways provide different levels of nutrient retention and may require wider or more-narrow buffers to perform the best.
Width of Buffer	In feet, from the upland edge of a wetland or tidal water, or the bank of a stream or ditch.	Wider buffers increase nutrient retention to a point based on other buffer components
Vegetation in Buffer	Structure and species composition of the buffer. Ranges from simply the presence of turfgrass to a native forest.	Forested buffers provide the best nutrient retention in buffers and in streams and ditches themselves.
Variances Allowed in Buffer	Allowable structures in the buffer and departures from the requirements of the other buffer components.	Example: Viewscapes over tidal waters or presence of stormwater facilities.

Table 3. Comparison of the buffer provisions of the Pollution Control Strategy drafts and current Sussex County Code. *PCS 05/05 offers *de facto* protections of isolated wetlands.

	PCS 5/05	PCS 8/06	Sussex Co.
Tidal Waters/Wetlands	100’	50’	50’
Isolated Wetlands	100’*	No Buffer	No Buffer
Federal Reg. Wetlands	100’	No Buffer	No Buffer
Perennial Streams	100’	50’	50’
Perennial Ditches	100’	50’	No Buffer
Intermittent Waterways	100’	No Buffer	No Buffer
Vegetation Requirements	75% Native Forest	Any Vegetation	Natural Vegetation

Table 4. Comparison of nutrient load reductions from buffers systems of two drafts of the Pollution Control Strategy in two subwatersheds of the Inland Bays Watershed.

		Nitrogen			Phosphorus		
		PCS 5/05	PCS 8/06	% Difference	PCS 5/05	PCS 8/06	% Difference
Load Reduction (lbs/year)	Hopkins Prong	769	7.90	99.0	47.5	0.6	98.8
	Dirickson Creek	5,030	114.50	97.7	310.4	8.2	97.3

Table 5. Comparison waterway length for two Inland Bays subwatersheds representing different regions. Length is in feet.

	Hopkins Prong Watershed		Dirickson Creek Watershed	
Region	Northern		Southern	
Watershed Area (ac)	5,908		7,858	
Intermittent Waterway Length	15,802	(58%)	181,619	(93%)
Perennial Waterway Length	4,472	(16%)	9,773	(5%)
Tidal Stream Length	7,113	(26%)	3,959	(2%)
Total Waterway Length	27,388	(100%)	195,352	(100%)

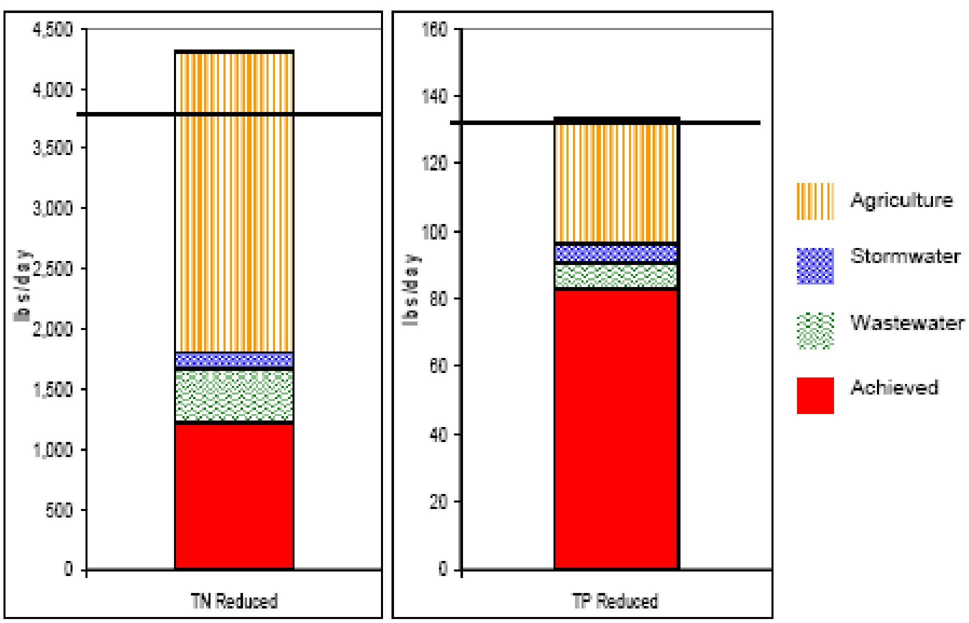

Figure 1. Pollution Control Strategy's progress towards implementation and modeled reduction by source. From the 3rd Workshop Draft of the Inland Bays Pollution Control Strategy and Proposed Regulations (August 2006).

Appendix 2: Excerpt from Rheinhardt et al. 2005 detailing an approach to mapping unmapped natural headwaters. From Rheinhardt, R.D., et al., Applying Ecological Assessments to Planning Stream Restorations in Coastal Plain North Carolina. 2005, North Carolina Department of Environment and Natural Resources: Raleigh, NC. p. 39.

Several approaches for extending the stream network were tested. First, we manually digitized additional headwater streams from county soil survey maps (USDA Soil Conservation Service, now Natural Resources Conservation Service), which often show headwater streams not included on USGS quads. (Digital soil survey hydrographic data are not presently available for most counties in NC.) In a test using one of the six assessed watersheds (Cow Swamp), we determined that manually digitizing additional streams would be too time consuming.

In the second method tested, we used digital elevation models (DEMs) constructed using high-resolution LIDAR data available from the NC Floodplain Mapping Program (a cooperative program involving local governments, agencies of the State of North Carolina and the Federal Emergency Management Agency (FEMA) (*http://www.ncfloodmaps.com*)). LIDAR DEMs were processed using ArcGIS 9 and a geospatial hydrologic modeling extension (HEC-GeoHMS) developed by the U.S. Army Corps of Engineers (*http://www.hec.usace.army.mil/software/hec-hms/hechms-geohms.html*). The resulting stream network was ground-truthed with another watershed in the study area (Green Mill Run). Despite manipulation of model parameters (primarily the flow-initiation threshold), we were unable to reasonably replicate the stream network. At low values of the flow-initiation threshold, many streams were generated by the model that did not exist. Raising the threshold would reduce the number of non-existent streams added, but would also increase the number of true streams not identified. A suitable intermediate threshold could not be found that would prevent the addition of non-existent streams without removing streams known to exist. The flat topography of the coastal plain is probably the main reason this method failed to reliably identify the true stream network.

The third method tested, and eventually adopted, was to predict additional streams from existing topographic maps. Most unmapped streams observed by us in previous surveys had occurred in topographic linear depressions (visible on topographic maps as a crenulation, or "draw"). From this observation, and previously collected slope data for headwater streams (Rheinhardt et al. 1998, Brinson et al. in preparation), we developed

criteria for manually extending streams headward and removing ditches, based on topography. For a linear depression to indicate the presence of an intermittent or perennial stream it had to have: (1) two or more topographic contours showing a v-shaped deflection of <90° from the general trend of the contour line (i.e., lines tangent to the inflection point of the deflected portion of the contour line had to intersect at an angle of <90°), (2) a slope of greater than 0.5%, and (3) a downstream connection to a mapped stream not more than two stream orders higher than the added stream (i.e., 1st order added streams could connect to a 1st, 2nd or 3rd order stream, but not to a 4th or higher order stream and 2nd order added streams could not connect to 5th or higher order streams). This connection rule was developed to avoid adding streams where groundwater tables, controlled (lowered) by the higher order stream, would have been too deep to contribute to flows of an added tributary. However, a few additional streams may have been missed using this criterion. Figure 1 shows an example of streams added using the topographic rules outlined above. Figure 2 shows the resulting digital stream network for the Cow Swamp watershed.

Appendix 3. References for the Effect of Width on Nitrogen and Phosphorus Removal in Coastal Plain Riparian Buffers.

Vegetation Type	Flow Wype	N Species	Width (ft)	% N Removal	Study
grass	surface	total N	15	-15	Magette et al. 1989 [1]
grass and forest	subsurface	nitrate	26	33	King 2005 [2]
grass	surface	total N	30	35	Magette et al. 1989 [1]
grass	subsurface	nitrate	33	99	Schoonover & Williard 2003 [3]
forest	subsurface	nitrate	33	82	Schoonover & Williard 2003 [3]
forest	subsurface	nitrate	49	96	Hubbard & Sheridan 1989 [4]
grass and forest	subsurface	nitrate	49	67	King 2005 [2]
forestwetland	subsurface	nitrate	102	59	Hanson 1994 [5]
forestwetland	subsurface	nitrate	125	78	Vellidis et al. 2003 [6]
forest	subsurface	nitrate	164	94	Lowrance 1992 [7]
forest	subsurface	nitrate	164	99	Jacobs & Gilliam 1985 [8]
forest	subsurface	nitrate	180	83	Lowrance et al. 1984 [9]
forest	subsurface	nitrate	197	95	Jordan et al. 1993 [10]
grassforest	subsurface	nitrate	230	91	Hubbard & Lowrance 1997 [11]
forest	surface	nitrate	230	79	Peterjohn & Correll 1984 [12]
forest	subsurface	nitrate	279	94	Peterjohn & Correll 1984 [12]
forest	subsurface	nitrate	328	100	Spruill 2004 [13]

Buffer Width (ft.)	% P Removal	Study Reference	Notes
15	41	Magette et al. 1987 [14]	
30	53	Magette et al. 1987 [14]	
62	80	Peterjohn & Correll, 1984 [12]	
180	36	Lowrance et al. 1984 [9] Desbonnet et al. 1994 [15] Mayer et al. 2007 [16]	Values compiled from multiple sources. Used median removal value.
246	56	Lowrance & Sheridan 2005 [17]	
656	74	Casey & Klaine 2001 [18]	

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Appendix 4.
Planning Buffers for Tidal Wetlands
Christopher Bason, Scientific & Technical Coordinator, Center for the Inland Bays
(Updated October 05, 2007)

This paper uses existing local data to describe rates of tidal wetland migration into upland areas potentially regulated as wetland buffers. It is based on the concept that tidal wetlands move inland by processes of erosion at their bayward edges and by migrating over uplands at their landward edges.

1. Shoreline erosion in Rehoboth Bay during 1938-1981 ranged from 0.66 to 5.25 feet per year and was highly variable [1 and references therein].
2. The landward migration of tidal wetlands is surprisingly rapid and is controlled primarily by the slope of the adjacent upland, with wetlands migrating faster over gradually sloping uplands (Table 1.) [1].
3. Tidal wetlands also migrate in the upstream direction of stream or creek valley axes at even faster rates. But here, newly established tidal wetlands are generally confined to the narrow stream valley (Table 1.) [1].

Table 1. Rates of landward migration of tidal wetlands by adjacent upland slope from 1944-1989. Gradual Slope = <0.08 rise/run, Steep Slope = >0.09 rise/run *(pg. 131 [1])*.

Slope	**Indian River Bay**	**Rehoboth Bay**
Gradual	5.25 ft/yr	6.07 ft/yr
Steep	1.44 ft/yr	0.82 ft/yr
Valley Axis	16.40 ft/yr	4.56 ft/yr

3. The above historical rates of migration are likely conservative compared to today's rates of migration because:
   a. The Indian River Inlet has increased greatly in cross section and thus transmits a greater volume of water per tidal cycle thus increasing tidal amplitude, or the range of high and low tides[2]. The highest tides begin the conversion of adjacent uplands to tidal wetlands.
   b. Storm frequencies nearly doubled over the last century, creating more frequent and sometimes more powerful tidal surges inland [3].
   c. Certain tidal wetlands may be submerging under increased rates of sea-level rise, allowing surges to attenuate less on their path over marshes towards uplands [4, 5].

4. Using these conservative rates of migration, the minimum period of time (in years) upland buffers of different widths may be reasonably assumed to protect wetlands or shorelines are calculated (Table 2).
5. The rates of migration of tidal wetlands up stream or creek valleys are also presented to allow for anticipation of future extent of tidal wetlands (Table 3).

Table 2. Years upland buffers of different widths will provide any protection to tidal wetlands or waters

	Indian River Bay		Rehoboth Bay	
Upland Buffer Width	**Gradual Slope**	**Steep Slope**	**Gradual Slope**	**Steep Slope**
50’	10	35	8	61
75’	14	52	12	91
100’	19	69	17	122
200’	38	139	33	244
300’	57	208	49	366
400’	76	278	66	488
500’	95	347	82	610

Table 3. Length a tidal marsh moves upstream for different planning horizons. Mean marsh migration up tidal creeks (10.48 ft/yr) is the average of 4 locations in Indian River and Rehoboth Bays from 1944-1989.

Upstream Movement of Tidal Wetlands (ft)	Years
105	10
262	25
524	50
786	75
1048	100

5. Once these time periods have past, wetlands will have migrated through buffers into built or production lands and loss of these lands will begin. Two general scenarios will then occur: 1) the upland will be bulk-headed or diked or 2) the built or production land will be abandoned. The first scenario will prevent the tidal wetlands from migrating inland and will result in their loss at a rate equal to its bayshoreline erosion rate (see above) (Figure 1). The second scenario will allow the wetlands to maintain themselves but is unlikely as most private lands adjacent to the Bays are, or will soon be, developed with substantial economic investments.

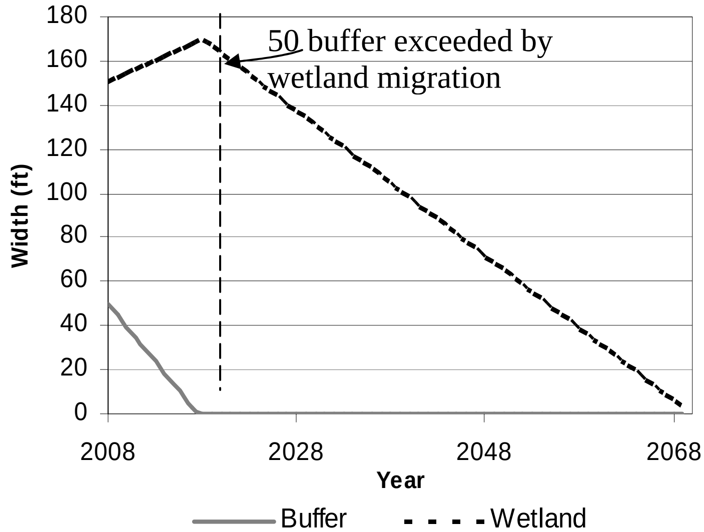

Figure 1. Conceptual change in width of upland buffers and tidal wetlands due to landward migration and erosion of tidal wetlands under for tidal wetlands with gradually sloping adjacent uplands and somewhat above average bayshoreline erosion.

6. Large-scale loss of tidal wetlands under this scenario will eliminate large acreages of existing biofilters and will release of huge amounts of stored nutrients into the Inland Bays. Loss of fish and bird nursery habitat, carbon storage and sequestration capacity, and other functions would likely change the entire nature of the Inland Bays.
7. Currently, many Inland Bays marshes appear unable to maintain their elevation with sea-level rise [1, 6-8] and may submerge in the near future, likely causing rates of inland migration to increase. Emerging stressors such as sudden wetland dieback may exacerbate this process.

Recommendation

To adequately protect the nutrient filtration and storage capacity of tidal wetlands under predictions of rising sea-level, upland buffers sufficient to allow inland wetland migration near a 100 year time horizon should be mandated. Special consideration should be afforded to the conservative estimates of wetland migration presented here, new estimations of the rates of future sea-level rise[9, 10], and the sensitivity of tidal wetlands to this process. Regulations should be developed based on the slope of adjacent uplands. Attention should be given to rates of migration up stream or creek valleys so that appropriate buffer widths may be allowed for in advance of migration.

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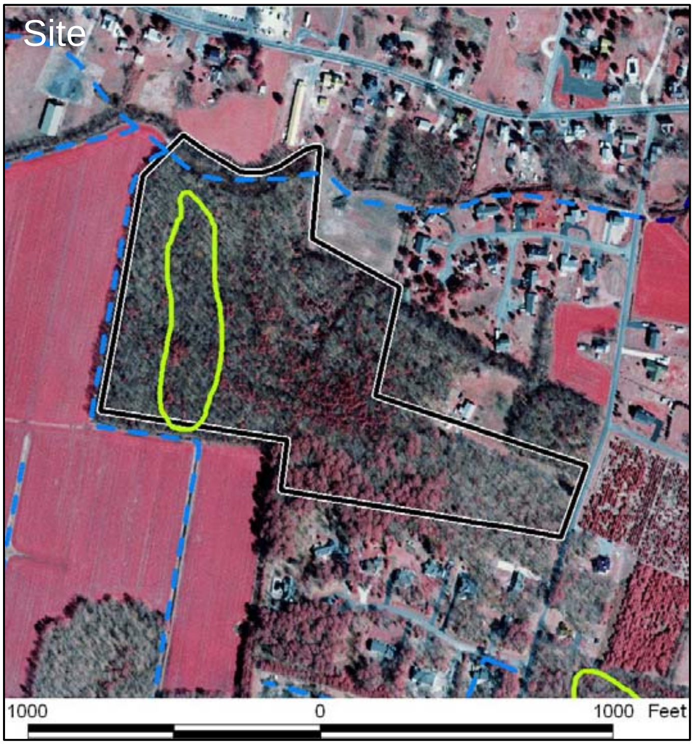
Appendix 5. GIS Analysis Workflow

1. Roughly determine onsite and offsite waterway and wetland features whose buffers would affect development
2. Determine what features would be provided buffers. If over half of the width of the potential buffer of the feature on an adjacent property is itself on the developing property and the adjacent property is not developed nor under long term agricultural preservation, then a buffer should be required on the developing property.
3. Classify waterways as ditches or natural waterways.
4. Classify ditches as minor or major.
5. Classify minor ditches as fillable (or otherwise able to be disconnected from the drainage network) or not.
6. Union wetland features whose buffers will affect development. *This may be unnecessary but sometimes the contiguity function of the buffer command on arcview does not work.*
7. Clip wetlands to developing property on PLUS layer.
8. Erase clipped wetlands layer and County Ag buffer from developing property to create developable area shapefile.
9. Buffer non-fillable ditches.
10. Buffer natural waterways.
11. Buffer freshwater wetlands.
12. Buffer tidal features.
13. Further determine if buffers of offsite features would be required on development.
14. Determine what if any areas will not be buildable due to buffer arrangement. If areas were very small and access to them was not conducive based on the layout of buffers on the site then they were considered isolated. This means that the buffer would not be altered to allow access to these pieces of the development and they would functionally be part of the buffer. If they were situated such that access through the buffer would be reasonable based on other site features such as existing roads and layout then they were not considered isolated. For example road access across natural waterways in their natural condition was generally assumed to not occur. Road access across ditches or natural waterways where the stream was channelized and wetlands were filled was assumed to occur in all cases.
15. Create a shapefile for areas not buildable due to buffer arrangement.
16. Batch Clip all shapefiles to the development area.
17. Merge all the clipped shapefiles.
18. Calculate the acreage of the total buffer and by feature type using the merged shapefile's table.
19. Determine the amount of nonforested buffer to restore by clipping buffer to areas that are both not forested and not likely to remain in their current developed state.
20. If tidal wetlands with gradually sloping adjacent uplands are present, buffer tidal areas with 150' buffers for the optimum recommendation and 80' for the sufficient recommendation. These are the portions of the tidal buffer to be restored to forest, call them tidalrestoreclip.
21. Merge the clipped nontidal waterways, wetlands and the tidal buffer restoration shapefiles.
22. Union the features of this merged shapefile.
23. Determine the amount of nonforested buffer to restore by clipping this buffer to areas that are both not forested and not likely to remain in their current developed state.
24. Calculate area of buffer to be restored.

Appendix 6. Maps and descriptive statistics for two buffer systems applied to eleven randomly selected developments

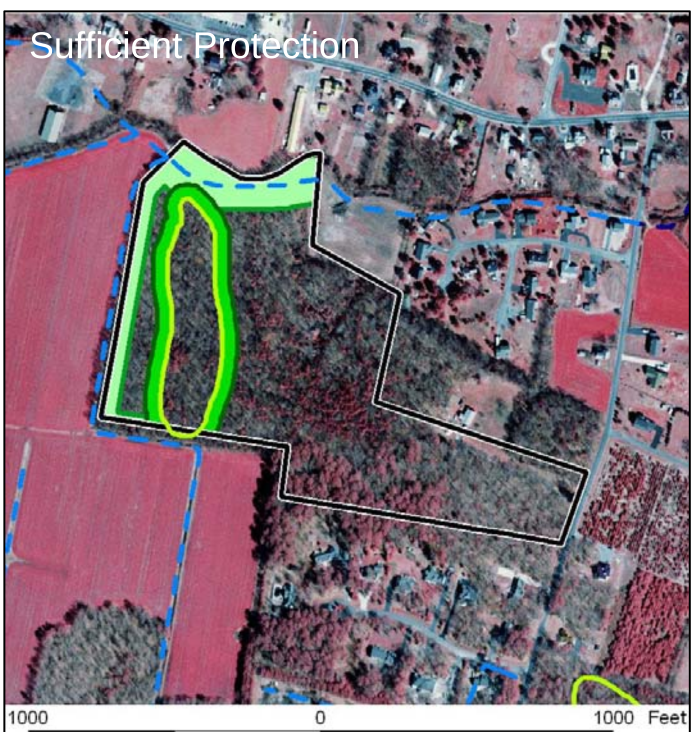
Windhurst Manor

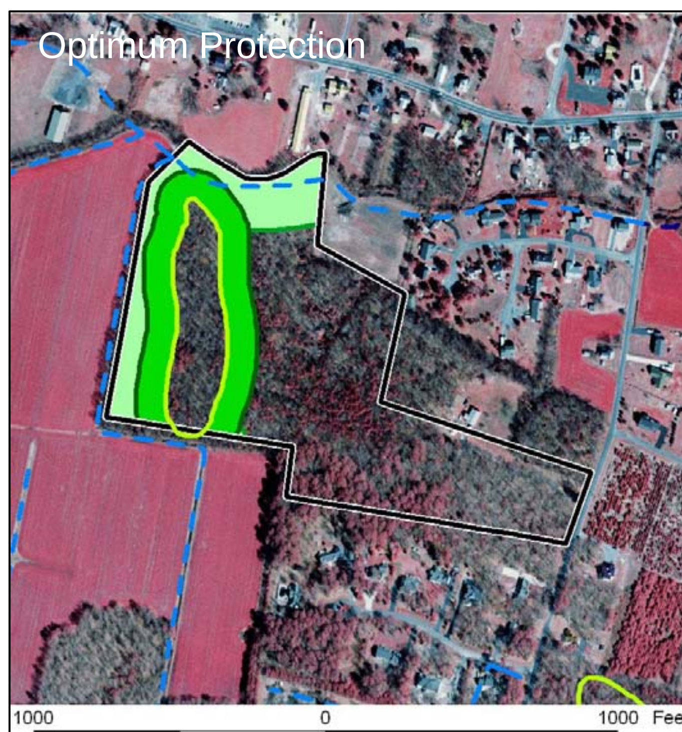
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	23.7
Total Wetland Acreage	2.8
Nontidal Wetlands	2.8
Tidal Wetlands	0.0
Developable Acreage	20.9
Waterway length (ft)	1915.5
Stream Length	0.0
Ditch Length	1915.5
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	4.7	7.1
Ac. on Ditches	2.9	5.9
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	3.4	4.1
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	1.6	2.9
Developable Acreage With Buffer	16.2	13.8
% Developable Acreage as Buffer	22.5	34.0
Acreage of Buffer to be Restored	0.0	0.0

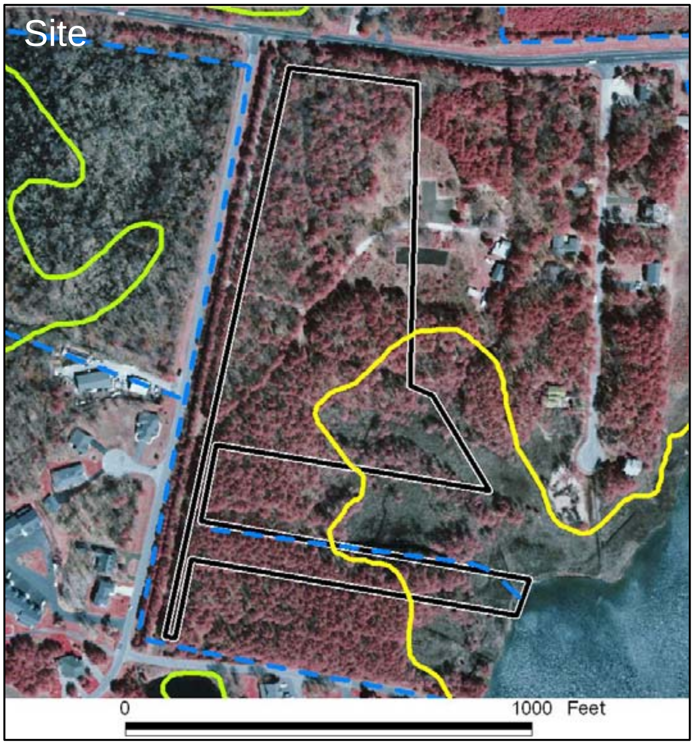




Development Outline
Tidal Waters
Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

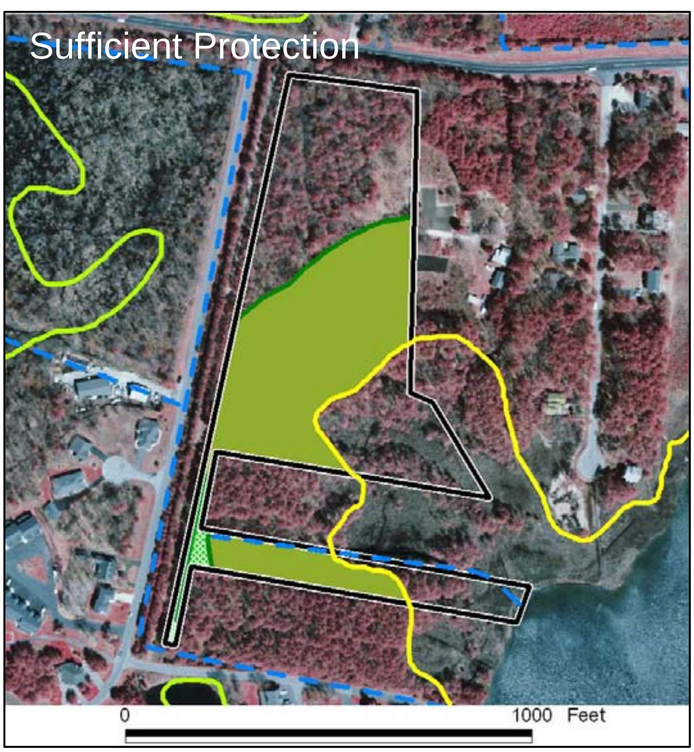
Bethany Woods

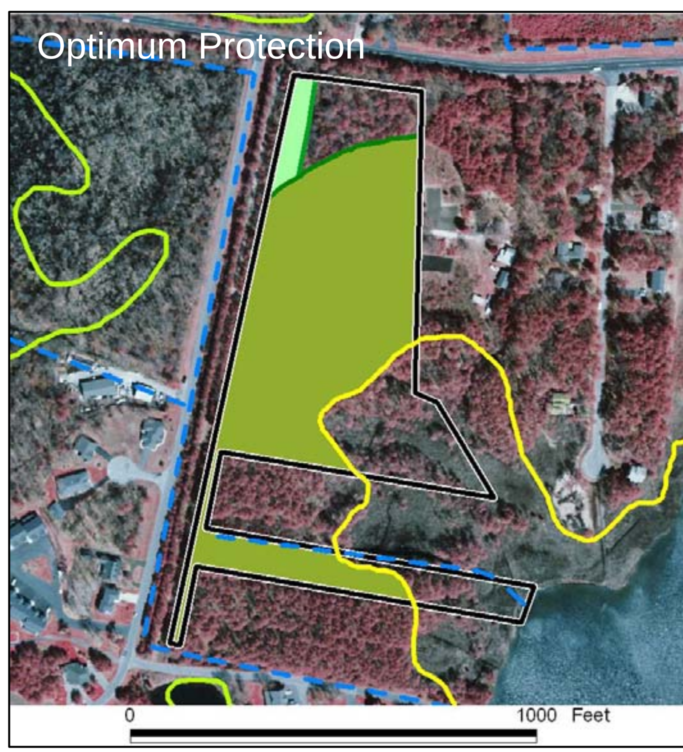
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	11.6
Total Wetland Acreage	2.5
Nontidal Wetlands	0.0
Tidal Wetlands	2.5
Developable Acreage	9.1
Waterway length (ft)	2371.0
Stream Length	0.0
Ditch Length	1562.0
Minor Ditch Length	809.0
Fillable Ditch Length	809.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	5.5	8.1
Ac. on Ditches	0.1	1.9
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	0.0	0.0
Ac. on Tidal Wetlands	5.2	7.7
Ac. Confined by Buffer	0.2	0.0
Ac. Overlapping Buffers	0.1	1.5
Developable Acreage With Buffer	3.4	1.0
% Developable Acreage as Buffer	60.6	89.0
Acreage of Buffer to be Restored	0.0	0.0





Development Outline
Tidal Waters
Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Savannah Square

Small Commercial Development in the Well Drained Region

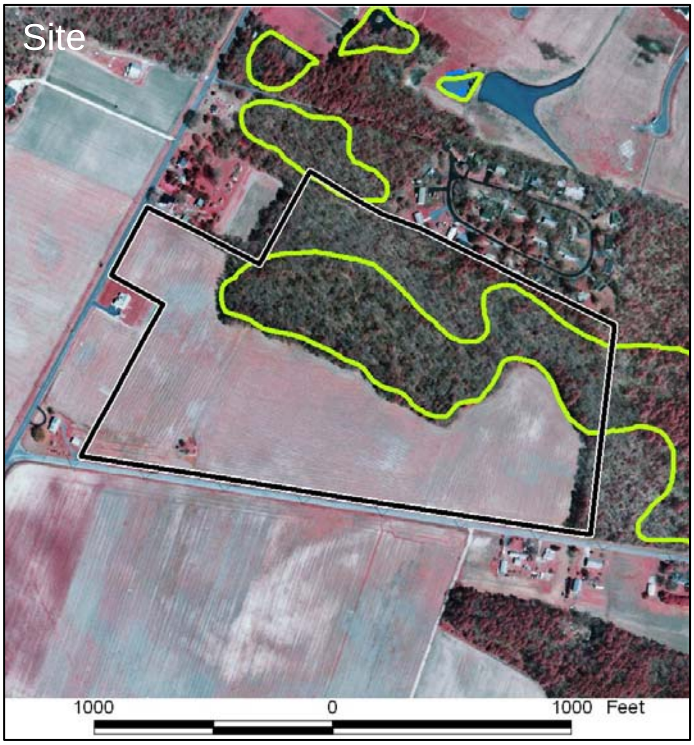
Site Characteristics	
Site Acreage	8.7
Total Wetland Acreage	0.0
Nontidal Wetlands	0.0
Tidal Wetlands	0.0
Developable Acreage	8.7
Waterway length (ft)	1358.0
Stream Length	0.0
Ditch Length	1358.0
Minor Ditch Length	1040.0
Fillable Ditch Length	1040.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	0.6	1.4
Ac. on Ditches	0.6	1.4
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	0.0	0.0
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	8.1	7.3
% Developable Acreage as Buffer	6.7	16.1
Acreage of Buffer to be Restored	0.6	1.4

Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

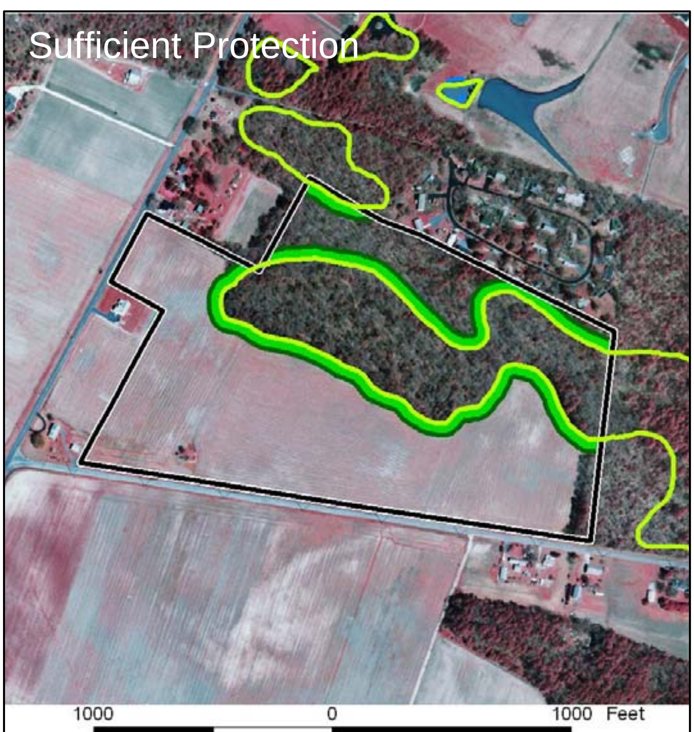
Land of Givens

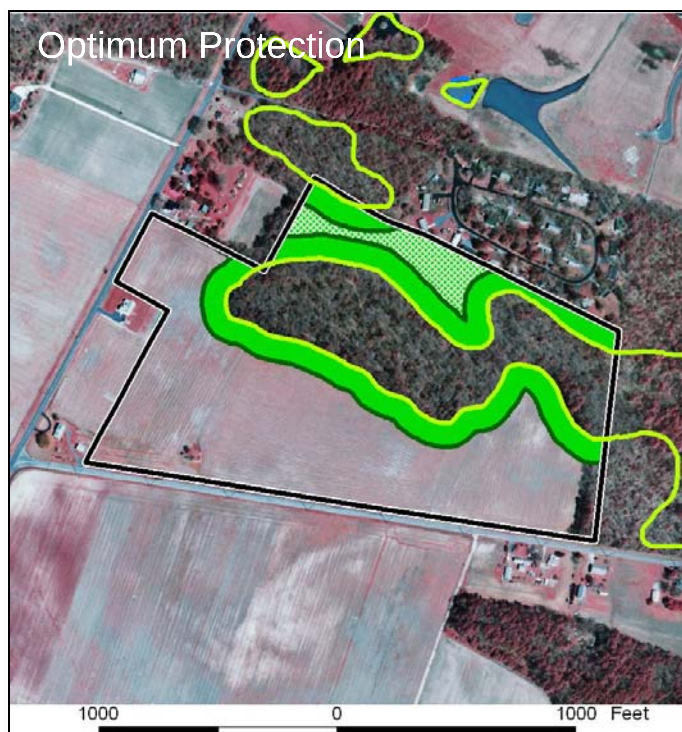
Small Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	50.2
Total Wetland Acreage	12.9
Nontidal Wetlands	12.9
Tidal Wetlands	0.0
Developable Acreage	37.1
Waterway length (ft)	0.0
Stream Length	0.0
Ditch Length	0.0
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	5.1	12.3
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	5.1	10.0
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	2.3
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	32.0	24.8
% Developable Acreage as Buffer	13.8	33.2
Acreage of Buffer to be Restored	1.8	4.4

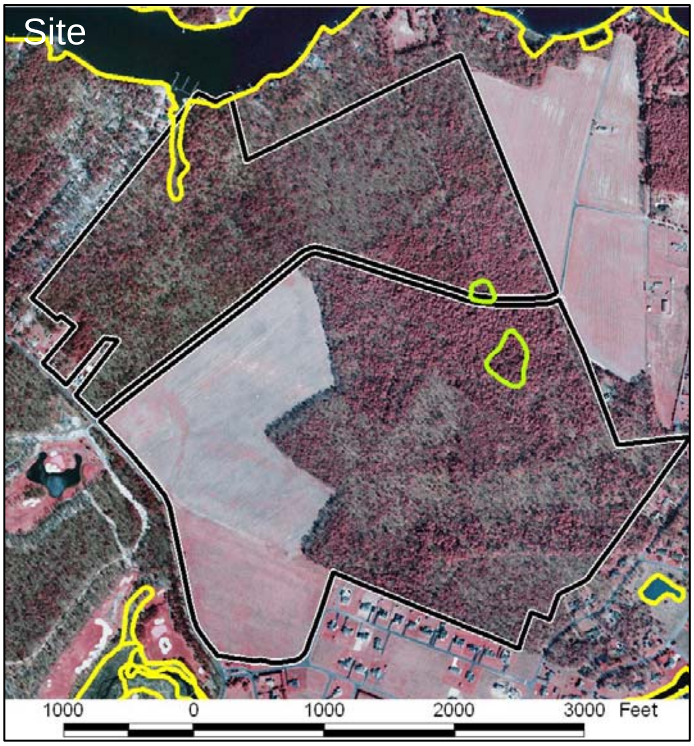




Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

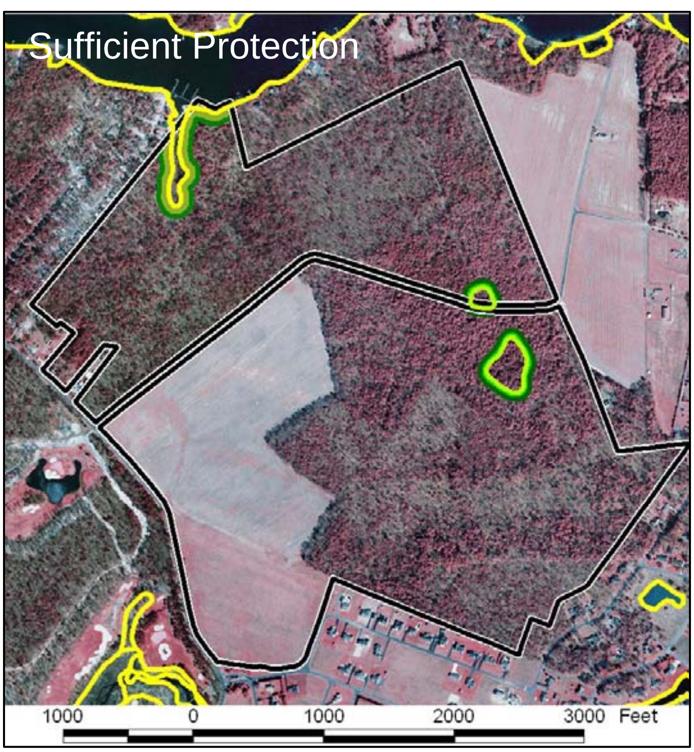
Bridlewood

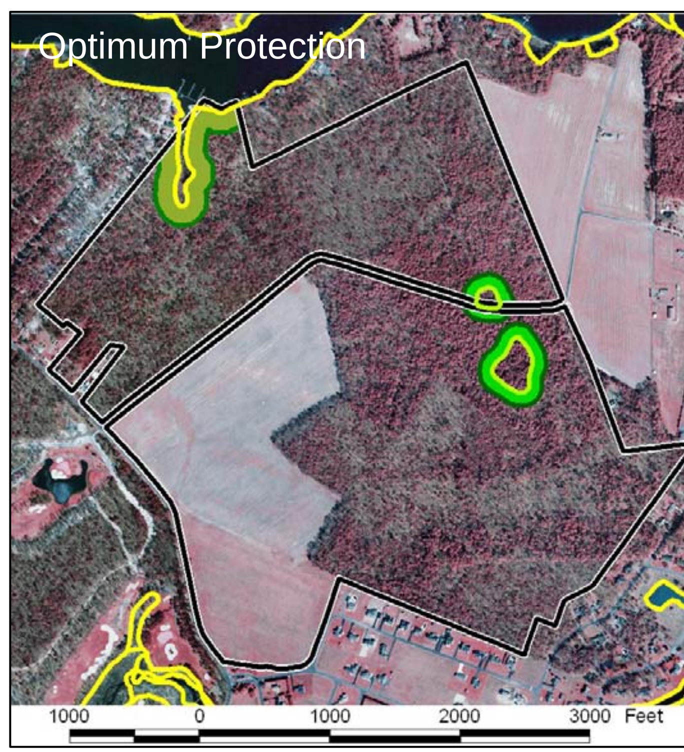
Large Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	314.0
Total Wetland Acreage	4.0
Nontidal Wetlands	2.5
Tidal Wetlands	1.5
Developable Acreage	308.7
Waterway length (ft)	0.0
Stream Length	0.0
Ditch Length	0.0
Minor Ditch Length	0.0
Fillable Ditch Length	0.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	5.7	11.5
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	2.1	5.0
Ac. on Tidal Wetlands	3.6	6.5
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.0
Developable Acreage With Buffer	303.1	297.2
% Developable Acreage as Buffer	1.8	3.7
Acreage of Buffer to be Restored	0.0	0.0



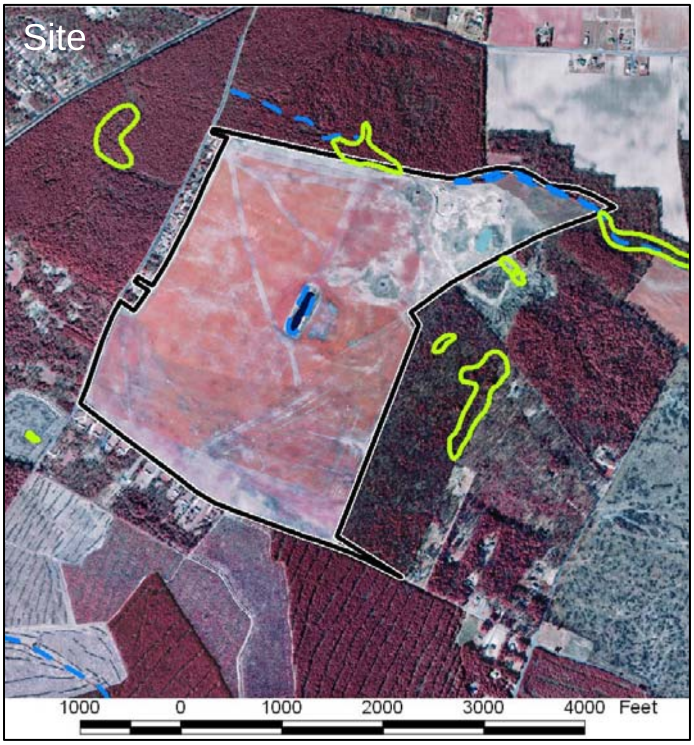


- Development Outline
- Tidal Waters
- Stream
- Filled Ditch
- Ditch
- Freshwater Wetlands
- Tidal Wetlands
- Non-tidal Waterway Buffer
- Freshwater Wetland Buffer
- Tidal Buffer
- Areas isolated by buffer

Avebury

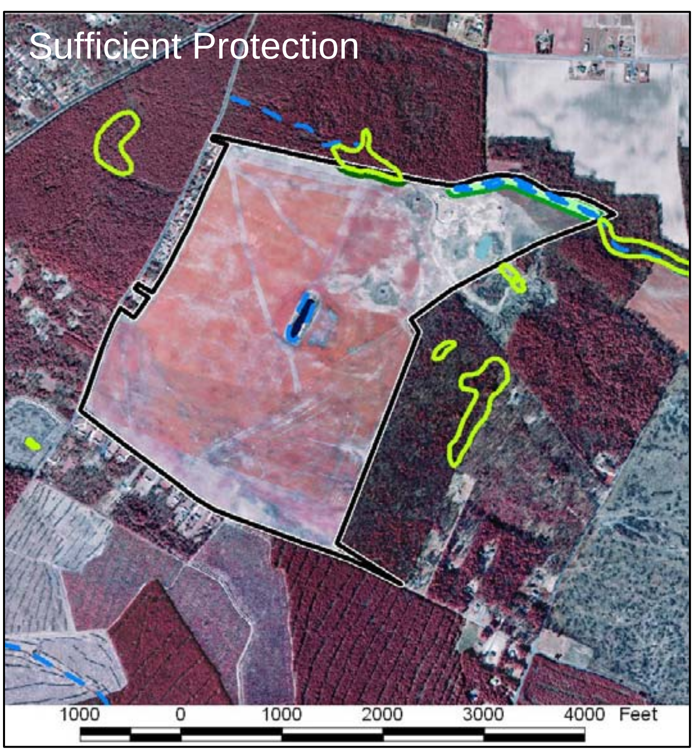
WDL2

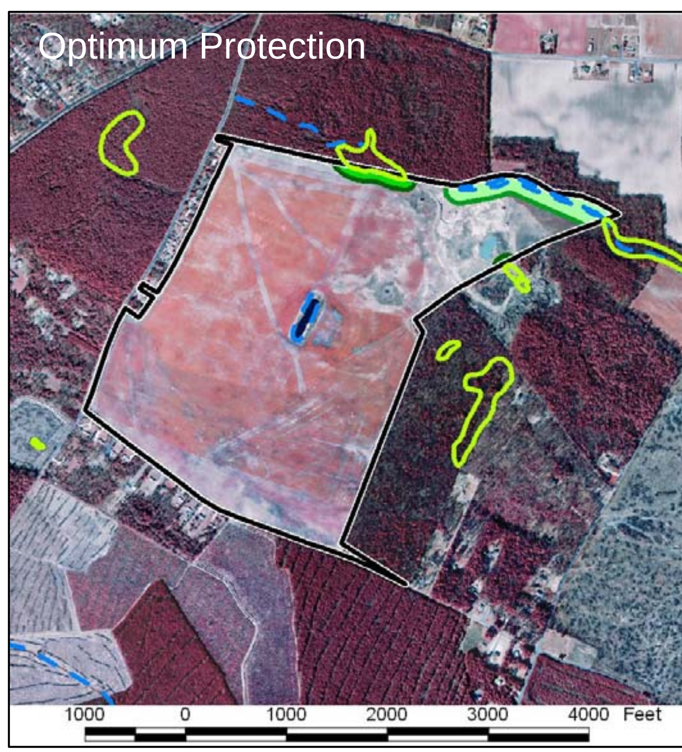
Large Residential Development in the Well Drained Region



Site Characteristics	
Site Acreage	32.9
Total Wetland Acreage	16.4
Nontidal Wetlands	16.4
Tidal Wetlands	0.0
Developable Acreage	16.5
Waterway length (ft)	2851.0
Stream Length	0.0
Ditch Length	2851.0
Minor Ditch Length	2291.0
Fillable Ditch Length	990.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	8.5	12.1
Ac. on Ditches	5.4	8.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	3.3	4.7
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.4	0.0
Ac. Overlapping Buffers	0.6	0.9
Developable Acreage With Buffer	8.0	4.4
% Developable Acreage as Buffer	51.5	73.3
Acreage of Buffer to be Restored	6.9	7.6



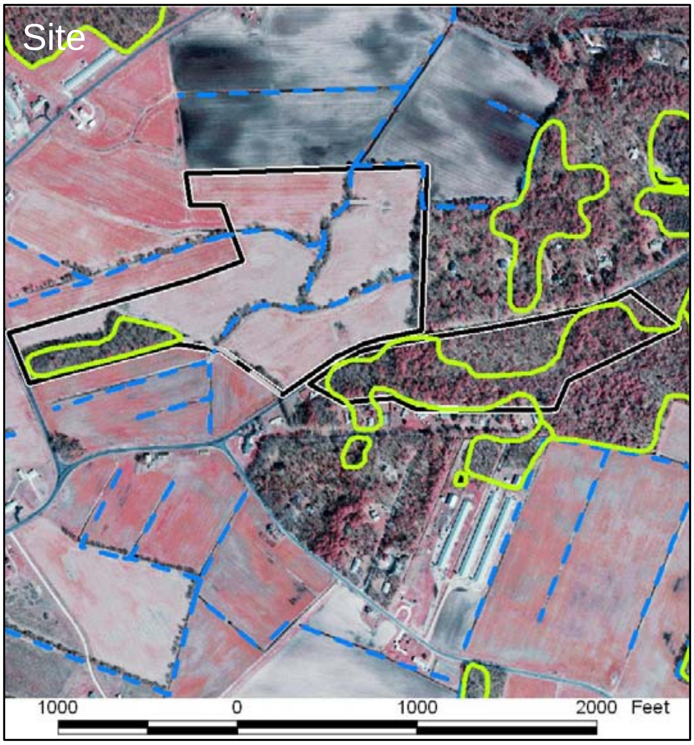


Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

The Woodlands

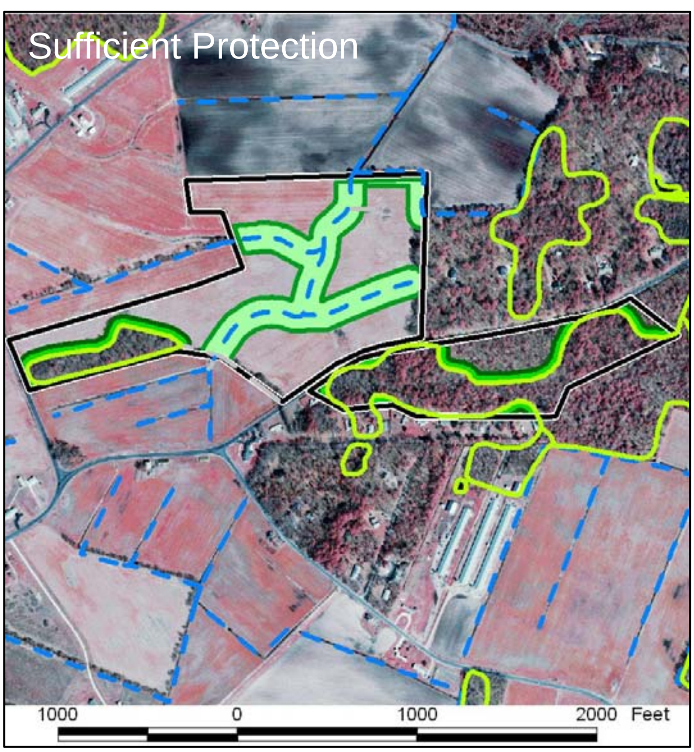
PDS1

Small Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	52.0
Total Wetland Acreage	12.5
Nontidal Wetlands	12.5
Tidal Wetlands	0.0
Developable Acreage	39.5
Waterway length (ft)	3362.0
Stream Length	0.0
Ditch Length	3362.0
Minor Ditch Length	2782.0
Fillable Ditch Length	799.0

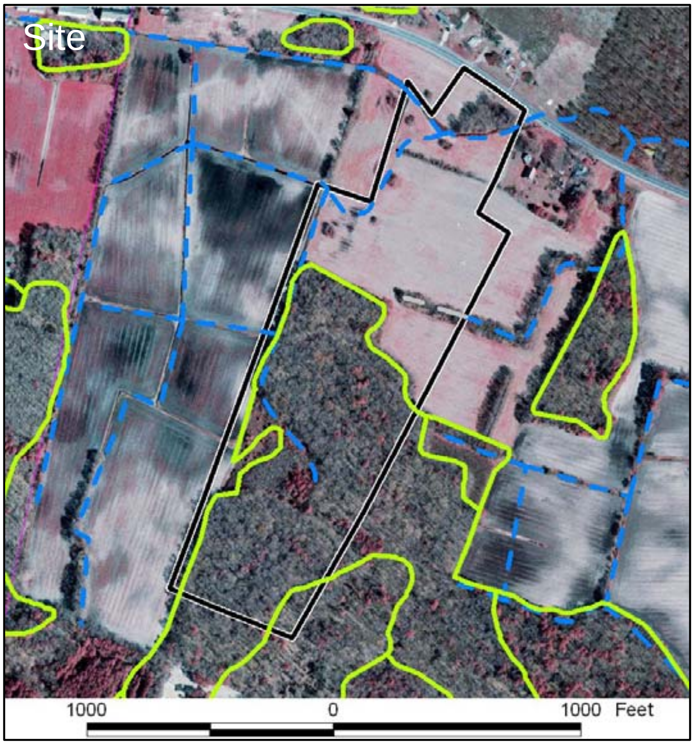
Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	14.2	24.9
Ac. on Ditches	9.7	17.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	4.4	7.8
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.2
Developable Acreage With Buffer	25.3	14.6
% Developable Acreage as Buffer	35.9	63.0
Acreage of Buffer to be Restored	11.4	20.6



Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

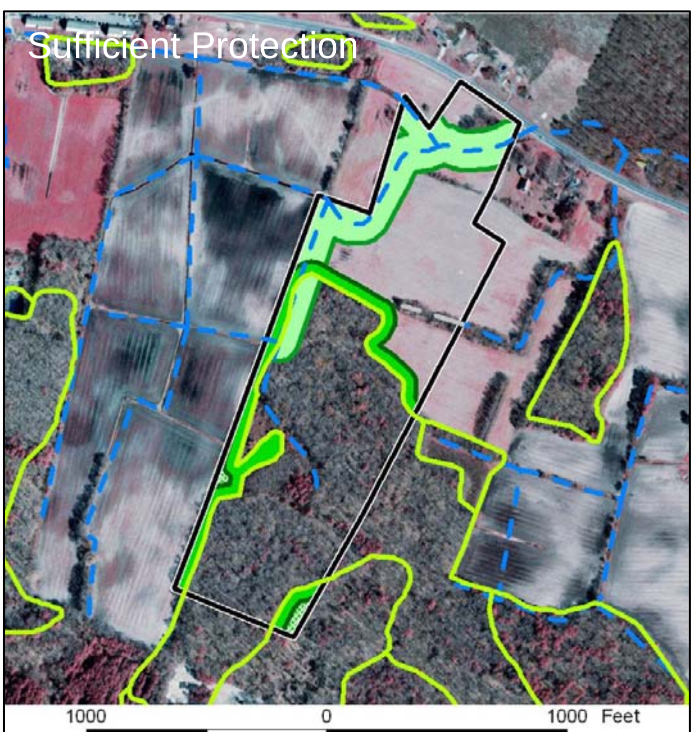
Fenwick Medical Complex

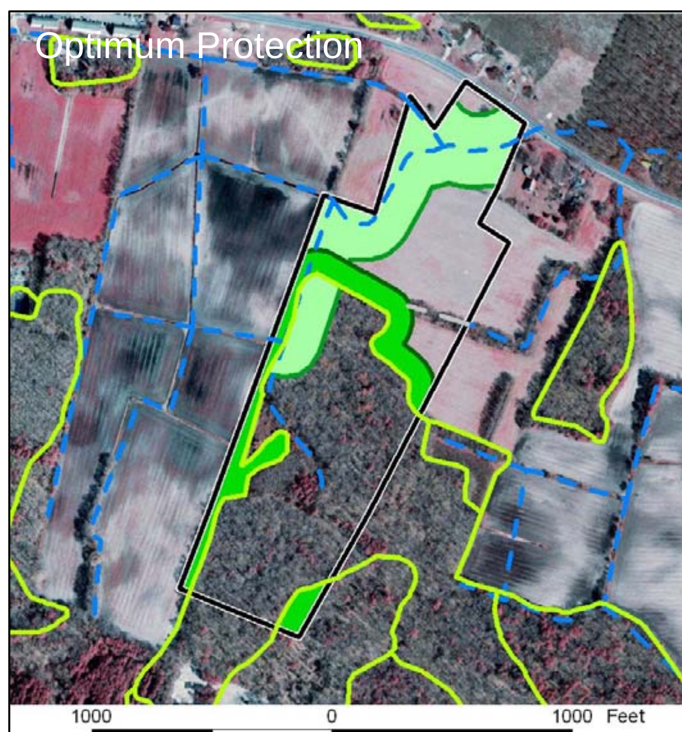
Small Commercial Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	52.0
Total Wetland Acreage	12.5
Nontidal Wetlands	12.5
Tidal Wetlands	0.0
Developable Acreage	39.5
Waterway length (ft)	3362.0
Stream Length	0.0
Ditch Length	3362.0
Minor Ditch Length	2782.0
Fillable Ditch Length	799.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	14.2	24.9
Ac. on Ditches	9.7	17.3
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	4.4	7.8
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.0	0.2
Developable Acreage With Buffer	25.3	14.6
% Developable Acreage as Buffer	35.9	63.0
Acreage of Buffer to be Restored	11.4	20.6

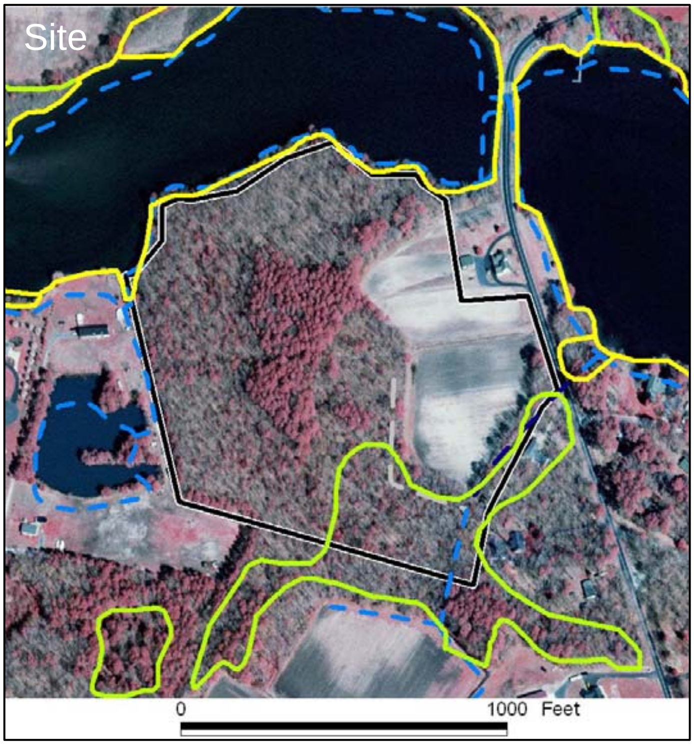




Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

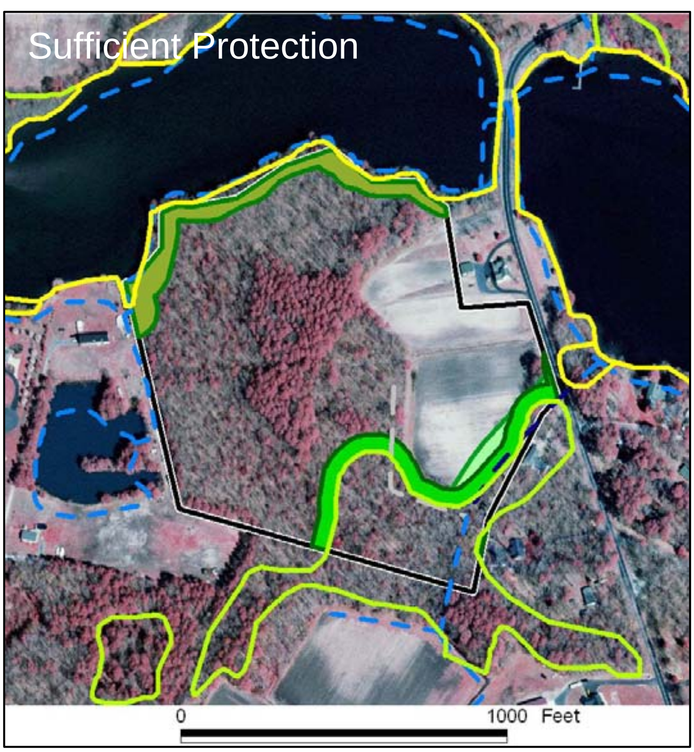
Water's Run

Small Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	27.2
Total Wetland Acreage	3.3
Nontidal Wetlands	3.2
Tidal Wetlands	0.0
Developable Acreage	23.9
Waterway length (ft)	389.0
Stream Length	150.0
Ditch Length	238.0
Minor Ditch Length	171.0
Fillable Ditch Length	171.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	3.2	6.9
Ac. on Ditches	0.0	0.0
Ac. on Streams	0.8	1.7
Ac. on Freshwater Wetlands	1.4	3.0
Ac. on Tidal Wetlands	1.5	3.6
Ac. Confined by Buffer	0.0	0.0
Ac. Overlapping Buffers	0.6	1.5
Developable Acreage With Buffer	20.7	17.0
% Developable Acreage as Buffer	13.2	28.9
Acreage of Buffer to be Restored	0.4	1.4

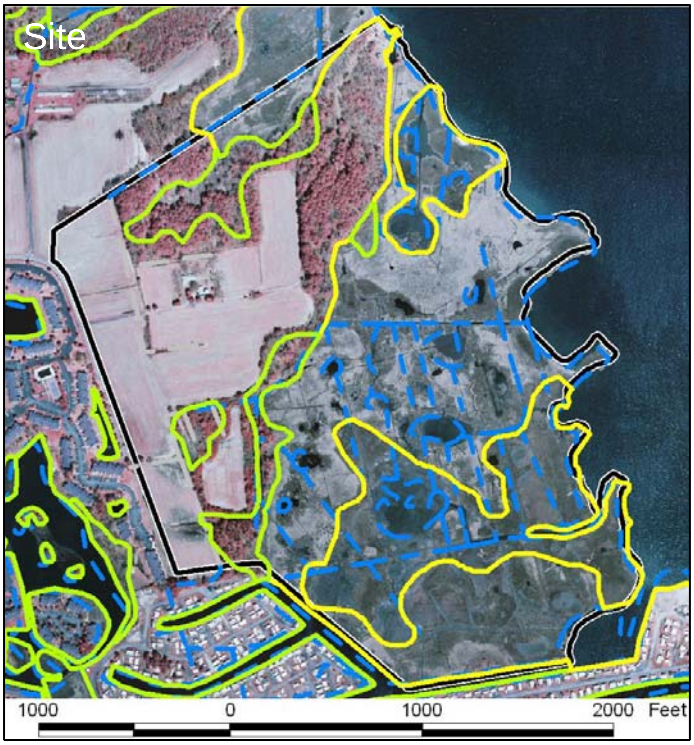


Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Bayville Point

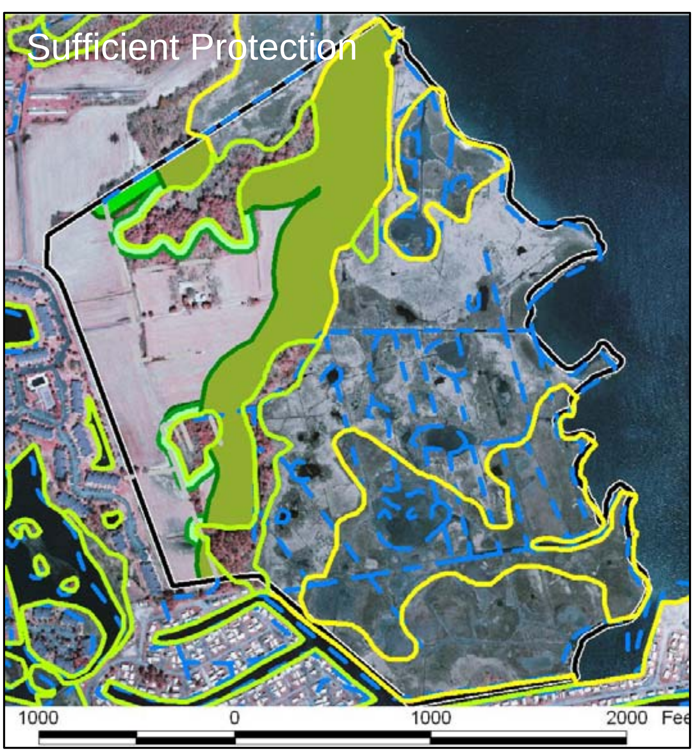
PDL1

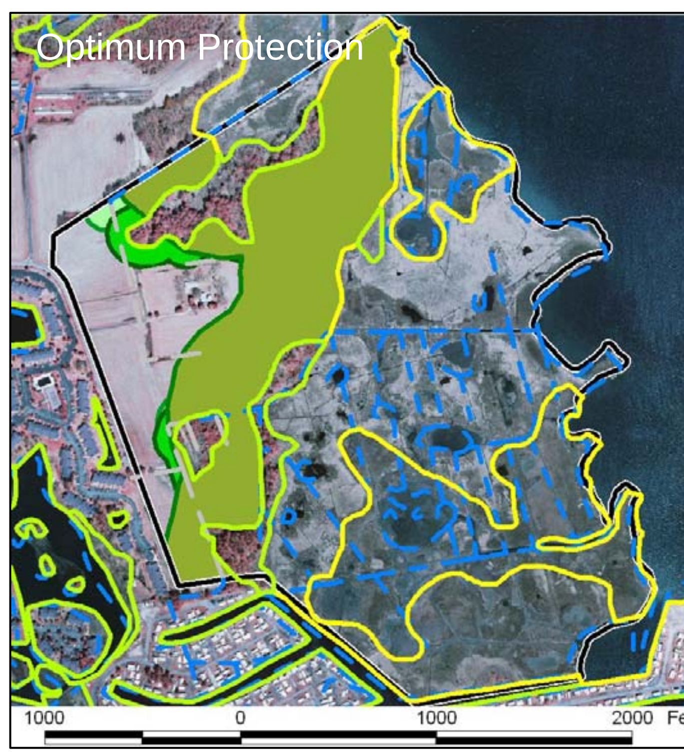
Large Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	148.0
Total Wetland Acreage	99.7
Nontidal Wetlands	10.8
Tidal Wetlands	88.9
Developable Acreage	48.3
Waterway length (ft)	1653.0
Stream Length	0.0
Ditch Length	1653.0
Minor Ditch Length	1653.0
Fillable Ditch Length	972.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	24.4	33.7
Ac. on Ditches	2.7	6.1
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	6.8	14.2
Ac. on Tidal Wetlands	20.9	31.1
Ac. Confined by Buffer	0.1	0.0
Ac. Overlapping Buffers	6.0	17.7
Developable Acreage With Buffer	23.9	14.6
% Developable Acreage as Buffer	50.5	69.8
Acreage of Buffer to be Restored	1.5	6.5



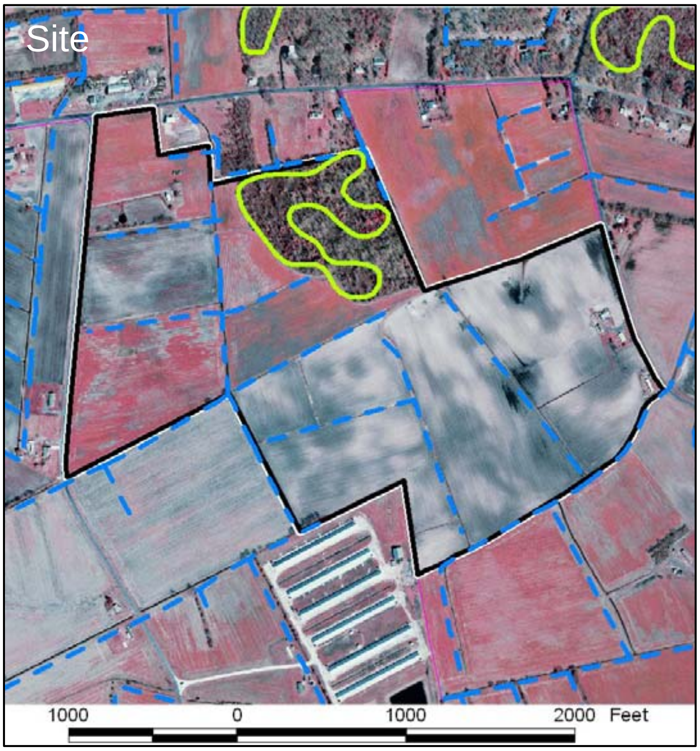


Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Barrington Park

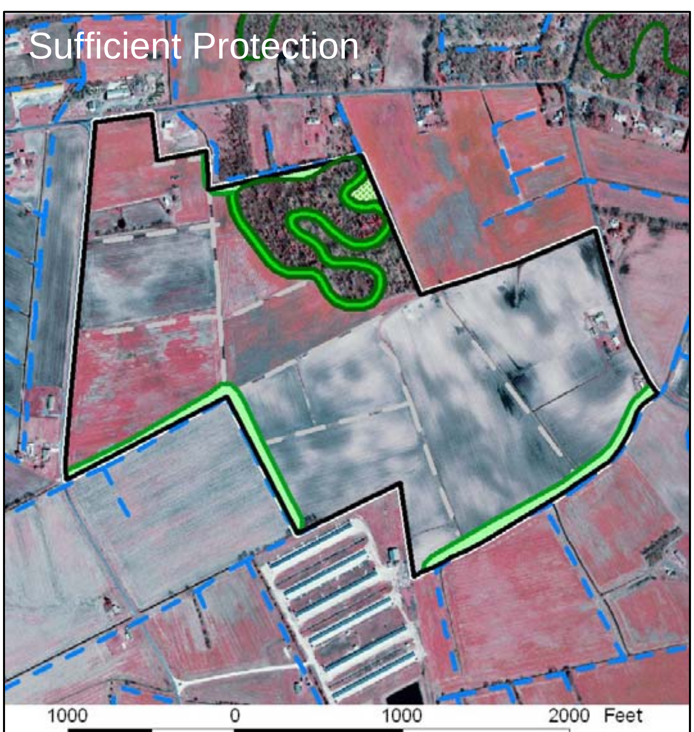
PDL2

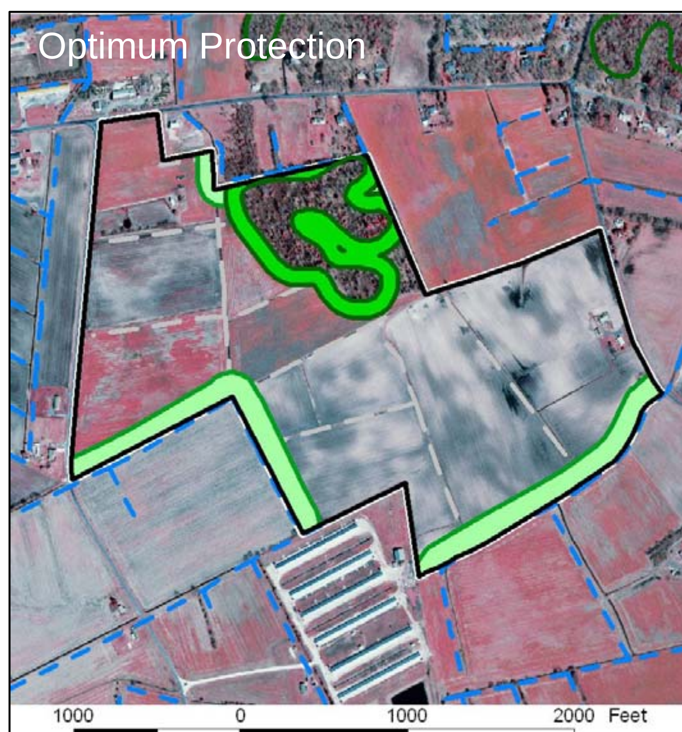
Large Residential Development in the Poorly Drained Region



Site Characteristics	
Site Acreage	128.0
Total Wetland Acreage	7.7
Nontidal Wetlands	7.7
Tidal Wetlands	0.0
Developable Acreage	120.3
Waterway length (ft)	2996.0
Stream Length	0.0
Ditch Length	2996.0
Minor Ditch Length	2996.0
Fillable Ditch Length	1993.0

Buffer Characteristics		
Protection Alternative	*Sufficient*	*Optimum*
Acreage of Buffer	10.5	20.5
Ac. on Ditches	6.3	13.6
Ac. on Streams	0.0	0.0
Ac. on Freshwater Wetlands	4.3	7.8
Ac. on Tidal Wetlands	0.0	0.0
Ac. Confined by Buffer	0.4	0.0
Ac. Overlapping Buffers	0.5	0.9
Developable Acreage With Buffer	109.8	99.8
% Developable Acreage as Buffer	8.7	17.0
Acreage of Buffer to be Restored	6.5	14.9





Development Outline
Tidal Waters
Freshwater Stream
Filled Ditch
Ditch
Freshwater Wetlands
Tidal Wetlands
Non-tidal Waterway Buffer
Freshwater Wetland Buffer
Tidal Buffer
Areas isolated by buffer

Table 1. Development Site Characterisitcs and Buffer Characteristics for the Optimum Protection Alternative

Site Descriptions											
Site ID (this study)	WDS1	WDS2	WDS3	WDS4	WDL1	WDL2	PDS1	PDS2	PDS3	PDL1	PDL2
PLUSID	2006-09-04	2006-01-05	38300	2006-10-05	2005-08-01	2004-07-08	2005-04-14	2006-07-06	2005-05-16	2006-03-04	2004-03-08
Name	Windhurst Manor	Bethany Woods	Savannah Square	Land of Givens	Bridlewood	Avebury	The Woodlands	Fenwick Med. Cmplx.	Waters Run	Bayville Point	Barrington Park
Watershed Region†	WD	WD	WD	WD	WD	WD	PD	PD	PD	PD	PD
Size	Small	Small	Small	Small	Large	Large	Small	Small	Small	Large	Large
Site Characteristics											
Site Acreage	23.7	11.6	8.7	50.2	314.0	238.0	52.0	32.9	27.2	148.0	128.0
Total Wetland Acreage	2.8	2.5	0.0	12.9	4.0	1.8	12.5	16.4	3.3	99.7	7.7
Nontidal Wetlands	2.8	0.0	0.0	12.9	2.5	1.8	12.5	16.4	3.2	10.8	7.7
Tidal Wetlands	0.0	2.5	0.0	0.0	1.5	0.0	0.0	0.0	0.0	88.9	0.0
Developable Acreage	20.9	9.1	8.7	37.1	308.7	236.2	39.5	16.5	23.9	48.3	120.3
Waterway length (ft)	1915.5	2371.0	1358.0	0.0	0.0	869.0	3362.0	2851.0	389.0	1653.0	2996.0
Stream Length	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150.0	0.0	0.0
Ditch Length	1915.5	1562.0	1358.0	0.0	0.0	0.0	3362.0	2851.0	238.0	1653.0	2996.0
Minor Ditch Length	0.0	809.0	1040.0	0.0	0.0	0.0	2782.0	2291.0	171.0	1653.0	2996.0
Fillable Ditch Length	0.0	809.0	1040.0	0.0	0.0	0.0	799.0	990.0	171.0	972.0	1993.0
Ratio of Ditch Length:Site Acreage	91.7	172.2	156.1	0.0	0.0	0.0	85.1	172.8	10.0	34.2	24.9
Percentage of site as wetlands	0.12	0.22	0.00	0.26	0.01	0.01	0.24	0.50	0.12	0.67	0.06
% Developable Acreage Before Buffer	0.88	0.78	1.00	0.74	0.98	0.99	0.76	0.50	0.88	0.33	0.94
Buffer Characteristics											
Acreage of Buffer	7.1	8.1	1.4	12.3	11.5	9.8	24.9	12.1	6.9	33.7	20.5
Ac. on Ditches	5.9	1.9	1.4	0.0	0.0	0.0	17.3	8.3	0.0	6.1	13.6
Ac. on Natural Waterways	0.0	0.0	0.0	0.0	0.0	7.6	0.0	0.0	1.7	0.0	0.0
Ac. on Freshwater Wetlands	4.1	0.0	0.0	10.0	5.0	2.2	7.8	4.7	3.0	14.2	7.8
Ac. on Tidal Wetlands	0.0	7.7	0.0	0.0	6.5	0.0	0.0	0.0	3.6	31.1	0.0
Ac. Confined by Buffer	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ac. Overlapping Buffers	2.9	1.5	0.0	0.0	0.0	0.0	0.2	0.9	1.5	17.7	0.9
Developable Acreage With Buffer	13.8	1.0	7.3	24.8	297.2	226.4	14.6	4.4	17.0	14.6	99.8
% Developable Acreage as Buffer	34.0	89.0	16.1	33.2	3.7	4.1	63.0	73.3	28.9	69.8	17.0
Acreage of Buffer to be Restored	0.0	0.0	1.4	4.4	0.0	0.0	20.6	7.6	1.4	6.5	14.9

† WD = Well Drained, PD = Poorly Drained

Table 2. Development Site Characterisitcs and Buffer Characteristics for the Sufficient Protection Alternative

Site Descriptions											
Site ID (this study)	WDS1	WDS2	WDS3	WDS4	WDL1	WDL2	PDS1	PDS2	PDS3	PDL1	PDL2
PLUSID	2006-09-04	2006-01-05	2004-11-09	2006-10-05	2005-08-01	2004-07-08	2005-04-14	2006-07-06	2005-05-16	2006-03-04	2004-03-08
Name	Windhurst Manor	Bethany Woods	Savannah Square	Land of Givens	Bridlewood	Avebury	The Woodlands	Fenwick Med. Cmplx.	Waters Run	Bayville Point	Barrington Park
Watershed Region†	WD	WD	WD	WD	WD	WD	PD	PD	PD	PD	PD
Size	Small	Small	Small	Small	Large	Large	Small	Small	Small	Large	Large
Site Characteristics											
Site Acreage	23.7	11.6	8.7	50.2	314.0	238.0	52.0	32.9	27.2	148.0	128.0
Total Wetland Acreage	2.8	2.5	0.0	12.9	4.0	1.8	12.5	16.4	3.3	99.7	7.7
Nontidal Wetlands	2.8	0.0	0.0	12.9	2.5	1.8	12.5	16.4	3.2	10.8	7.7
Tidal Wetlands	0.0	2.5	0.0	0.0	1.5	0.0	0.0	0.0	0.0	88.9	0.0
Developable Acreage	20.9	9.1	8.7	37.1	308.7	236.2	39.5	16.5	23.9	48.3	120.3
Waterway length (ft)	1915.5	2371.0	1358.0	0.0	0.0	869.0	3362.0	2851.0	389.0	1653.0	2996.0
Stream Length	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150.0	0.0	0.0
Ditch Length	1915.5	1562.0	1358.0	0.0	0.0	0.0	3362.0	2851.0	238.0	1653.0	2996.0
Minor Ditch Length	0.0	809.0	1040.0	0.0	0.0	0.0	2782.0	2291.0	171.0	1653.0	2996.0
Fillable Ditch Length	0.0	809.0	1040.0	0.0	0.0	0.0	799.0	990.0	171.0	972.0	1993.0
Ratio of Ditch Length:Site Acreage	91.7	172.2	156.1	0.0	0.0	0.0	85.1	172.8	10.0	34.2	24.9
Percentage of site as wetlands	0.12	0.22	0.00	0.26	0.01	0.01	0.24	0.50	0.12	0.67	0.06
% Developable Acreage Before Buffer	0.88	0.78	1.00	0.74	0.98	0.99	0.76	0.50	0.88	0.33	0.94
Buffer Characteristics											
Acreage of Buffer	4.7	5.5	0.6	5.1	5.7	5.9	14.2	8.5	3.2	24.4	10.5
Ac. on Ditches	2.9	0.1	0.6	0.0	0.0	0.0	9.7	5.4	0.0	2.7	6.3
Ac. on Natural Waterways	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.8	0.0	0.0
Ac. on Freshwater Wetlands	3.4	0.0	0.0	5.1	2.1	0.9	4.4	3.3	1.4	6.8	4.3
Ac. on Tidal Wetlands	0.0	5.2	0.0	0.0	3.6	0.0	0.0	0.0	1.5	20.9	0.0
Ac. Confined by Buffer	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.4	0.0	0.1	0.4
Ac. Overlapping Buffers	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.6	0.6	6.0	0.5
Developable Acreage With Buffer	16.2	3.4	8.1	32.0	303.1	230.3	25.3	8.0	20.7	23.9	109.8
% Developable Acreage as Buffer	22.5	60.6	6.7	13.8	1.8	2.5	35.9	51.5	13.2	50.5	8.7
Acreage of Buffer to be Restored	0.0	0.0	0.6	1.8	0.0	0.0	11.4	6.9	0.4	1.5	6.5

† WD = Well Drained, PD = Poorly Drained