Maryland's

Green Infrastructure Assessment

A Comprehensive Strategy for Land Conservation and Restoration

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GENERAL OVERVIEW

What is green infrastructure?

Maryland has been called "America in miniature". From east to west, Maryland varies from ocean, to barrier island and beaches, to tidal marshes and estuaries, to fertile low-lying farmland, to pastoral rolling hills, to mountains, valleys and plateaus. North and South also meet in Maryland: historically, culturally, and ecologically. Ecologically, Maryland is the northernmost limit of many southern species, and the southernmost limit of many northern species. Like America, the state contains both big cities and small towns, and regions varying from forested to agricultural to urban. In short, Maryland is extraordinarily diverse for a state its size, and reflects conditions found in the nation as a whole.

Like America as a whole, Maryland's diversity and vitality depend on the composition of its landscape: its geology, climate, water, soils, flora, and fauna. These characteristics have shaped the history of the region, and still affect the state today. Maryland's most important natural lands comprise its "green infrastructure," and provide the bulk of the state's natural support system. Ecosystem services, such as cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, sequestering carbon, protecting areas against storm and flood damage, and maintaining aquifers and streams, are all provided by the existing expanses of forests, wetlands, and other natural lands. These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. They serve as vital habitat for resident and migratory species, maintain a vast genetic library, provide scenery, and contribute in many ways to the health and quality of life for Maryland residents.

When wetlands and forest are developed into human-centered uses, there are costs incurred that are typically not accounted for in the marketplace. The losses in ecosystem services are hidden costs to society. These services, such as cleansing the air and filtering water, are fundamental needs for humans and other species, but in the past, the lands providing them have been so plentiful and resilient, that they have been largely taken for granted. In the face of a tremendous rise in both population and rate of land use conversion, many people now realize that these natural or ecosystem services must be afforded greater consideration. The breakdown in ecosystem functions causes damages that are difficult and costly to repair, as well as taking a toll on the health of plant, animal, and human populations.

Where is green infrastructure found in Maryland?

Maryland's green infrastructure was mapped using satellite imagery, road and stream locations, biological data, and other information, with the results reviewed by scientists, local government officials, and conservation groups. Although even backyards and street trees provide some benefits, like shading and air purification, the state's most important natural lands are those that are large and intact enough to provide a full range of environmental functions.

The first step in the assessment of the State's green infrastructure identified the heart of the green infrastructure, called "hubs." These are typically unfragmented areas hundreds or thousands of acres in size, and are vital to maintaining the state's ecological health. They provide habitat for native plants and animals, protect water quality and soils, regulate climate, and perform other critical functions.

The second step connected hubs with "corridors" - linear remnants of natural land such as stream valleys and mountain ridges that allow animals, seeds, and pollen to move from one area to another. They also protect the health of streams and wetlands by maintaining adjacent vegetation. Preserving linkages between the remaining blocks of habitat will ensure the long-term survival and continued diversity of Maryland's plants, wildlife, and environment.

Examples of Maryland's green infrastructure are found throughout the state:

- The large expanses of unbroken forest around Savage River and Green Ridge State Forests in Western Maryland;
- The Youghiogheny Wild River in Garrett County;
- The Catoctin Mountains in Frederick County;
- The tidal marshes at Blackwater National Wildlife Refuge and Fishing Bay Wildlife Management Area on the Eastern Shore;
- The Assateague Island National Seashore, and Chincoteague Bay marshes;
- The mature hardwood forest along the Potomac River in southern Charles County;
- The forested lands surrounding Seneca Creek in Montgomery County;
- The Zekiah Swamp in Southern Maryland;
- The state and local parklands along the Patuxent River; and
- The Gwynns Falls/Leakin Park in Baltimore City and Baltimore County.

What is the status of Maryland's green infrastructure?

Before colonization by Europeans, Maryland was 95% forested, the other 5% being tidal marsh. By 1993, both forest and wetlands had decreased by half. The area converted to development is increasing even more rapidly now, as suburbs expand outward and large-lot houses are built in formerly rural areas. The scattered pattern of modern development consumes an excessive amount of land and fragments the landscape.

As forests are divided and isolated by roads, houses, and shopping malls, wildlife habitat and migration corridors are lost, and normal ecosystem functions such as absorption of nutrients, recharging of water supplies, and replenishment of soil are disturbed or destroyed. Water quality has been degraded in numerous streams and rivers, as well as in the Chesapeake Bay itself. Many of Maryland's remaining wetlands have been drained, filled, polluted, or otherwise degraded. Habitat loss and fragmentation have contributed greatly to a continuing loss of biodiversity in Maryland. At least 180 plant and 35 animal species have been extirpated from Maryland. Another 310 plant and 165 animal species are rare, threatened, or endangered.

Today, Maryland has only two million acres of ecologically significant land that has not been consumed by some kind of human development. Of these two million acres of green infrastructure, almost three-quarters are unprotected. Billions of dollars are spent each year to construct or maintain the state's built infrastructure of roads, bridges and utilities that we depend on for modern life. By contrast, the state's green infrastructure, which exists naturally, is under tremendous pressure from development, yet is virtually ignored in public policy. Left unprotected, the remaining green infrastructure is vulnerable and will be further reduced and fragmented.

Focusing conservation efforts on green infrastructure will help protect the ecological health found in each region of the state, including forests, streams, and wetlands, preserving and enhancing this heritage for future generations. By acting now, Maryland can ensure cleaner air and water for its citizens, safeguard habitat needed to spare native animals and plants from extinction, and preserve outdoor recreational opportunities that a large and increasing number of people enjoy.

What are the benefits of green infrastructure?

Green infrastructure benefits all Maryland citizens. For some people, like watermen, those who harvest and process timber, and those who cater to outdoor recreation, it provides their livelihood. For farmers, it provides insect control by birds. For city dwellers, it provides clean drinking water. For those living or farming near shorelines, streams, or steep hillsides, it protects their land from erosion. The green infrastructure provides places for hobbies, recreational activities, and learning opportunities. Children and teachers can, together, learn the wonders of nature by using the green infrastructure as a living classroom. Nature lovers can enjoy hiking, camping, observing, and photographing an impressive diversity of plants and wildlife.

Studies have shown that if the values of ecological services are considered, natural lands show a net gain in cost-benefit analyses. While residential areas require public services, natural areas need little, other than protection. Further, they make public construction of many engineered facilities unnecessary.

In addition to their ecological and economic contributions, these lands provide a sense of place and a unique identity. Natural landscapes make communities more comfortable and appealing; they link current generations to their heritage and cultural past. For everyone who lives in or visits Maryland, protecting green infrastructure helps to preserve our rich quality of life and safeguard, for future generations, Maryland's Chesapeake Bay and the legacy of Maryland's special natural landscapes, including the picturesque mountains of Western Maryland; the forests and wetlands of Southern Maryland; the expansive tidal marshes of the Eastern Shore; and the stream valleys of the Western Shore and Piedmont region.

Ninety percent of respondents in a 1999 national poll agreed that "open spaces make our communities more livable", and 85% said that "parks and open spaces contribute to the property values and economic stability of neighborhoods." In Maryland, polling surveys in 1995 and 2001 revealed that the vast majority of the state's citizens support public land conservation programs.

Can green infrastructure be protected?

Land protection is often first on the chopping block when budget cuts are considered. Yet, protection of natural land is a vital investment. Preserving open space stimulates spending by local residents, increases property values, increases tourism, attracts businesses, and reduces public costs. Biodiversity is responsible for at least $1.9 billion in economic and environmental services in Maryland. In fact, if the values of ecological services are considered, the benefits from conserving natural land gives a return on investment of at least 100 to 1!

Because much of the state's key natural resource land has been lost, Maryland needs to protect as much as possible of what remains. A focus on permanent protection of green infrastructure provides multiple benefits:

- It provides a balance to protecting land for recreation and agriculture with protection of ecological services;
- It ensures the continuation of natural services in each region that help clean the air and water;
- It supports Maryland's economy, especially the forest products industry, seafood industry, nature tourism, and outdoor recreation.
- It reduces the need for expensive stormwater management, flood control, and restoration projects by protecting water resources including streams, wetlands, and riparian corridors; and
- It addresses commitments in the new Chesapeake Bay Agreement to protect 20% of the watershed and to reduce the rate of sprawl development by 30%.

Over the past several decades, the State of Maryland has enacted several effective land conservation programs. These include Program Open Space and Rural Legacy, a variety of agricultural preservation efforts, private conservation easement agreements, and regulations that help preserve wetlands and shorelines. As a result, Maryland is known nationally as a leader in land conservation and natural resource protection. While these initiatives proved effective in addressing specific needs related to wetlands, endangered species, recreation, or farmland, they were not designed to protect a comprehensive network of ecologically sensitive lands. Despite our successes, only 26% of the identified green infrastructure was protected as of 2000.

Focusing on protection of green infrastructure builds upon existing conservation programs by:

- Conserving and connecting large contiguous areas of natural land, containing important natural resources;
- Providing a focal point to coordinate existing conservation programs and increase their overall effectiveness; and
- Guiding and coordinating land conservation and preservation efforts.

Developers, private landowners, and others benefit from having a clear understanding of where the most ecologically valuable lands are located, and where targeted conservation activities will be directed. Citizens interested in increased stewardship activities will know where their efforts are most needed. Land planners and developers can use the green infrastructure maps as a reference in the development of site plans and management objectives.

Using green infrastructure maps and data, local governments can enhance their efforts to provide open space, recreation lands, and natural areas that retain the unique character of their communities and rural landscapes. This can complement their efforts to direct growth to specified areas.

Private land trusts can also benefit. Conservation groups, and their members, will find that focusing on green infrastructure will give them a greater overall impact. It not only identifies large blocks of habitat and linkages, it gives a sense of how each given place fits into the larger landscape.

The approach to protecting green infrastructure involves four steps:

- Identify, using state-of-the-art computer mapping techniques, the most important natural lands in the state;
- Connect these lands through a system of corridors or linkages;
- Verify the presence and value of these lands on the ground; and
- Save those lands that are currently not protected through targeted acquisitions and easements.

The first three parts of this approach are known as the Green Infrastructure Assessment. Maps and other data from this assessment are distributed by the Maryland Department of Natural Resources to parties interested in land stewardship, as well as the general public. The fourth and most important part, actual land protection and management, is performed by various state programs, county governments, land trusts, and other entities.

In a sense, we are in a race against time. Once an area is developed, it will remain so indefinitely. And development is proceeding at a rapid rate, all across the state. Action is needed now to ensure that our children, our grandchildren, and generations to come, have the same opportunities to enjoy Maryland's outstanding natural resources and high quality of life that we do today.

Landscape assessment procedures

To identify and prioritize Maryland's green infrastructure, we developed a computer tool called the Green Infrastructure Assessment (GIA). The GIA was based on principles of landscape ecology and conservation biology, and provides a consistent approach to evaluating land conservation and restoration efforts in Maryland. It specifically attempted to recognize: (1) a variety of natural resource values (as opposed to a single species of wildlife, for example), (2) how a given place fits into a larger system, (3) the ecological importance of natural open space in rural and developed areas, (4) the importance of coordinating local, state and even interstate planning, and (5) the need for a regional or landscape-level view for wildlife conservation.

The GIA identified two types of important resource lands - "hubs" and "corridors." Hubs are typically large contiguous areas, separated by major roads and/or human land uses, that contain one or more of the following:

- Large blocks of contiguous interior forest (containing at least 250 acres, plus a transition zone of 300 feet)
- Large wetland complexes, with at least 250 acres of unmodified wetlands
- Important animal and plant habitats of at least 100 acres, including rare, threatened, and endangered species locations; unique ecological communities; and migratory bird habitats
- Relatively pristine stream and river segments (which, when considered with adjacent forests and wetlands, are at least 100 acres) that support trout, mussels, and other sensitive aquatic organisms
- Existing protected natural resource lands which contain one or more of the above (for example, state parks and forests, National Wildlife Refuges, locally owned reservoir properties, major stream valley parks, and Nature Conservancy preserves)

In the GIA model, the above features were identified from Geographic Information Systems (GIS) spatial data that covered the entire state. Developed areas and major roads were excluded, areas less than 100 contiguous acres were dropped, adjacent forest and wetland was added to the remaining hubs, and the edges were smoothed. The average size of all hubs in the state is approximately 2200 acres.

Corridors are linear features connecting hubs together to help animals and plant propagules to move between hubs. Corridors were identified using many sets of data, including land cover, roads, streams, slope, flood plains, aquatic resource data, and fish blockages. Generally speaking, corridors connect hubs of similar type (hubs containing forests are connected to one another; while those consisting primarily of wetlands are connected to others containing wetlands). Corridors generally follow the best ecological or "most natural" routes between hubs. Typically these are streams with wide riparian buffers and healthy fish communities. Other good wildlife corridors include ridge lines or forested valleys. Developed areas, major roads, and other unsuitable features were avoided.

The GIA also provides an approach for ranking or prioritizing land protection efforts. Hubs and corridors were assessed for a variety of ecological parameters, and then ranked within their physiographic region. Physiographic regions have a characteristic geology and climate, which shapes the ecosystems and communities within them. We wanted to protect the best examples of each of these regions, ensuring ecosystems adapted to different climates and substrates were represented in the top ranking hubs. The hubs were also grouped by physiographic region because natural conditions and communities vary greatly between the Coastal Plain and the Appalachian mountains. For example, tidal marsh is not found outside the Coastal Plain, and high gradient streams are not found inside it.

The GIA can also help evaluate specific local areas. Individual "grid cells" were pixels determined by the resolution of the satellite imagery we used. The cells were squares corresponding to an area of 0.314 acre. Each cell in Maryland was given an ecological score based on both its local significance and its landscape context. Part of the cell ecological score was the rank of the landscape feature in the Green infrastructure network (i.e., whether it fell within a hub or corridor, and the relative ecological importance of that component), and part of the cell rank was based on local features (e.g., proximity to streams or rare species habitat). The cell-based evaluation permits more detailed site comparisons and prioritizations.

Green infrastructure hubs and corridors were also examined for their level of protection, management status, and risk of development. The vast majority (74%) of the Green infrastructure is unprotected. And only 13% of hubs, and less than 1% of corridors, were in areas managed primarily for natural values . Some of the factors used to estimate relative development risk included land ownership, regulatory restrictions, zoning, water and sewer service, population trends, parcelization, commuting distances, land value, proximity to roads, presence of waterfronts, and proximity to parks or other preserved open space. A hub or corridor's risk of development can be combined with its ecological score to help prioritize conservation efforts. Individual cells were also examined for their development risk.

Gaps are developed, agricultural, mined, or cleared lands within the Green infrastructure network that could be targeted for restoration. These were evaluated for their potential restoration to forest, wetland, or riparian buffers, by considering watershed condition, landscape position, local features, ownership, and programmatic considerations. Gaps with hydric soils were probably once wetlands, and could be restored as such. Reforestation of gaps along streams would not only benefit wildlife, but improve water quality and stream stability. Dredged, filled, or drained wetlands can also be restored. Roads in the Green infrastructure can be modified to mitigate some of their negative impacts. Structures such as underpasses or bridges can be designed to assist wildlife movement where roads and railways form barriers across corridors and hubs. Similarly, stream blockages can be examined for fish ladders, bypasses, or other structures that allow fish passage.

The results of the GIA were reviewed by field ecologists and county planners, and compared to other inventories of important natural resources in Maryland. Hub and corridor locations identified by the model were largely consistent with existing natural areas, although some small features, like some streams and isolated wetlands, were missed. Although only about a third of the land in the state were identified as being in the Green infrastructure network, most of Maryland's important natural resources were captured.

Setting priorities for parcel acquisition

In 2001, the Maryland General Assembly passed legislation establishing the GreenPrint program. GreenPrint is a targeted program that attempts to preserve the most ecologically valuable natural lands in Maryland, its Green infrastructure hubs and corridors, by purchasing land from willing sellers. These purchases can be either fee simple (ownership transferred to the state or a county) or conservation easements (original owner keeps the property, but sells the rights to develop it). A protocol was developed to help select and prioritize parcels for GreenPrint acquisition. This was a four tier process:

Tier 1: Identification of candidate properties for acquisition, either proactively in focus areas (hubs and corridors that are highly significant ecologically, and under significant threat from development); or opportunistically from existing pools of willing sellers and other sources. The parcel boundaries are then digitized from tax maps.

Tier 2: Evaluation of the property to determine: (1) if the project contains green infrastructure as delineated in the Green Infrastructure Assessment model, (2) the amount, percentage, and ecological significance of green infrastructure present, (3) proximity to existing protected lands and contribution to further protection of the green infrastructure hub or corridor the property lies in, (4) an overall ecological score for the project, and (5) the presence of other conservation features on the property.

Tier 3: For those properties rating highly in Tier 2, a cursory or "drive-by" field visit to areas easily accessible by roads or trails, to: (1) verify the Green Infrastructure Assessment model, (2) identify potential restoration needs, and (3) estimate the threat of development the property faces if fee or easement acquisition is not pursued. This step was performed by helicopter for areas on the Eastern shore and southern Maryland.

Tier 4: In some cases, performance of a detailed field assessment, which: (1) maps all natural communities on the site, (2) collects data for each community; (3) rates each community according to its ecological condition; (4) gives the property an overall ecological field rating based on an area-weighted sum of community conditions; (5) accounts for high-quality natural communities on site, which may make a property more desirable; (6) accounts for impacted or heavily degraded communities on site, which may make a property less desirable; (7) identifies restoration needs on the site; and, (8) helps identify easement or management requirements.

The Green Infrastructure Assessment methodologies, along with relevant background material, are contained in the following chapters. The finer details are found in the Appendices. Further information can be obtained by contacting the Maryland Department of Natural Resources, Watershed Services Unit.

Chapter 2
BACKGROUND

The importance of natural land

Maryland's undeveloped lands provide the bulk of the state's natural support system. Ecosystem services, such as cleaning the air, filtering and cooling water, storing and cycling nutrients, conserving and generating soils, pollinating crops and other plants, regulating climate, protecting areas against storm and flood damage, and maintaining hydrologic function, are all provided by the existing expanses of forests, wetlands, and other natural lands (Conservation Fund, 2000). These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. They serve as vital habitat for wild species, maintain a vast genetic library, provide scenery, and contribute in many ways to the health and quality of life for Maryland residents.

When wetlands and forest are taken for development, there are costs incurred that are typically not accounted for in the marketplace. The losses in ecosystem services are hidden costs to society. These services, such as cleansing the air and filtering water, meet fundamental needs for humans and other species, but in the past, the resources providing them have been so plentiful and resilient that they have been largely taken for granted. In the face of a tremendous rise in both population and land consumption, we now realize that these natural or ecosystem services must be afforded greater consideration. The breakdown in ecosystem functions causes damages that are difficult and costly to repair, as well as taking a toll on the health of plant, animal, and human populations (Moore, 2002).

All ecosystems can be visualized as a web of materials and organisms, interconnected by flows and transformations of energy, matter, and information. Since physics tells us that energy and matter are equivalent, all storages and flows can be defined in energy (or embodied energy) terms. Looking from outside the ecosystem, the flows and transformations in an ecosystem can also be visualized as emergent properties or functions, e.g., by noting where outputs from the system differ from the inputs. These differences can be spatial, temporal, transformative, or a combination of these. Functions can also be defined internally to the system. The National Research Council (1995) broadly defined functions as all processes and manifestations of processes that occur in an ecosystem.

In one example, Rheinhardt et al (1997) defined four ecosystem functions for wetlands:

- maintain characteristic hydrologic regime: e.g., evapotranspiration, long and short-term surface water storage, and subsurface storage;
- maintain characteristic nutrient and elemental cycling processes: biotic and abiotic processes that convert elements from one form to another;
- maintain characteristic plant community: species composition and structure of strata typical of unaltered conditions; and

- maintain characteristic physiognomic structure: physical habitat and structure.

Values, in contrast, are defined by society, and are usually associated with goods and services that society recognizes. Society does not necessarily attach value to all functions (National Research Council, 1995). Ecosystem values are often subjective, and not always scientifically defined. Ecological values are often considered public goods or services, such as clean air and water.

Public ecosystem goods and services, not usually dealt with by markets, will be described in more detail below. Costs associated with compensating for their loss are commonly borne by governments, rather than in the private economy. A subsequent chapter will outline the market values of ecosystem goods and services that are commonly considered in standard private accounting.

Carbon sequestration

Forests help remove large amounts of carbon dioxide (CO_2) from the air. Burning of fossil fuels produces large amounts of carbon dioxide, one of the greenhouse gases. Greenhouse gases trap the heat of the sun, and as these gases build up, temperature rises. During photosynthesis, trees convert CO_2 into oxygen; carbon is also stored in the body of the tree, in the soil surrounding its roots, and in debris that falls to the ground. Barford et al (2001) found a mean sequestration rate around 2.0 MgC/ha/yr for a mature northern red oak stand.

According to Strebel (2002), Maryland's vegetation absorbs about 55 million metric tonnes (MMT) of CO_2 from the atmosphere annually through photosynthesis. About 20% of this net primary productivity (NPP), or 10.6 MMT, is permanently sequestered by wetlands or forests, with little to no sequestration by other land uses. Unmanaged forest stores about 24% of its NPP in large, long-term soil reservoirs. Disturbing mature forests frees this carbon. However, frequent harvesting in degraded areas, if good soil management practices are followed, can result in carbon sequestration both in the soil and in wood products. Wetlands are the most highly productive terrestrial ecosystems, and do not turn over organic matter quickly, accumulating it in the soil or as peat. Thus, if undisturbed, they may sequester CO_2 better than any other ecosystem type (Strebel estimated 50% of NPP), although this depends on hydroperiod and other parameters. While reforesting abandoned land, restoring wetlands, and preserving natural areas help to reduce and maintain CO_2 levels, developing these lands produces the opposite effect and increases CO_2 by releasing previously stored carbon into the atmosphere (Strebel, 2002).

There is growing interest in the monetary value of forests for carbon sequestration. Internationally, industries and governments have a growing concern about rising greenhouse gases, and there are initiatives to substantially reduce or mitigate emissions. The World Bank Prototype Carbon Fund, created to fund projects that reduce emissions, currently seeks to trade carbon sequestration credits at $20 per ton of carbon. It is estimated that Maryland’s 2.9 million acres of forests sequester from 1.8 to 4.1 million metric tons of carbon per year. Using the World Bank’s figure, Maryland’s forests have the ability to store from $23 million to $84 million worth of carbon on an annual basis (Moore, 2002).

<u>Pure air</u>

The more forested land in Maryland, the cleaner the air. Cleaning the air is a basic service of trees (Moore, 2002). They absorb carbon dioxide and release oxygen. They also absorb sulfur dioxide and nitrogen oxide, two major components of acid rain (Moore, 2002). In addition they can trap particles in the air and ozone that can be harmful to humans (Moore, 2002). Air purification functions of forests are particularly important in urban environments where air pollution is greater (Moore, 2002). According to a study by American Forests (1999), trees lost in the Baltimore-Washington urban corridor between 1973 and 1997 would have removed 9.3 million pounds of air pollutants annually at a value of $24 million per year.

Air quality affects the health of everyone and is a major factor in illnesses ranging from cardiovascular disease to cancer and respiratory ailments. The average American breathes 3,400 gallons of air each day. According to the *State of the Air 2001* report issued by the American Lung Association, 10 Maryland counties and Baltimore City received an air quality grade of "F." This is of critical concern to those with respiratory problems. In the U.S., respiratory illnesses such as asthma are on the rise. Maryland, in particular Baltimore City, has one of the highest asthma rates in the country. Nationally, asthma accounts for an estimated three million lost work days annually, and the annual direct health care cost of asthma is estimated at $8.1 billion (American Lung Association, 2001; Moore, 2002).

<u>Flood protection and stormwater management</u>

Conserving forests and wetlands can help local governments and other public agencies reduce costs from flooding and other natural hazards (McQueen, 2000). Nationwide, floods cause over $4 billion in damages in an average year (Salzman et al, 2001). In 1999, a single flood resulted in damages to government properties estimated at $6,408,180 (Howard, 2002).

Natural lands, such as Maryland's green infrastructure, can absorb stormwater and recycle it through the hydrologic system, with the potential to control runoff and flooding. Floodplains and wetlands can absorb and store stream and river overflows, and also reduce flow velocity through friction. Heavy vegetation can slow the runoff of precipitation into waterways, permitting some of the runoff to seep into groundwater aquifers and reducing peak flows. An analysis by American Forests (1999) estimated that the total storm water retention capacity of the remaining forest in the Baltimore-Washington region in 1997 was worth $4.68 billion. This was down from 1973's value of $5.7 billion (American Forests, 1999).

In contrast to natural land, developed land has little ability for absorption, and instead creates a large volume of fast moving (and more polluted) runoff. American Forests (1999) estimated that between 1973 and 1997 tree losses in the Baltimore-Washington area resulted in a 19% increase in stormwater runoff - an estimated 540 million cubic feet of extra water. Replacing the lost stormwater retention capacity with engineered systems would have cost $1.08 billion (American Forests, 1999).

Any topographic depression in the landscape has the potential to store water, and thereby play a role in flood control. Wetland basins not already filled to capacity can mitigate flooding by storage, slowing flood waters, and reducing peaks and increasing the duration of flow. Characteristics of wetlands cited as helping control flood waters include size (the larger the wetland, the more area for flood storage and velocity reduction), location within the drainage basin, texture of the substrate, and type of vegetation. Groups of wetlands in a watershed are more effective at flood control than isolated wetlands. In Wisconsin, watersheds with 30% wetland or lake area had flood peaks 60-80% lower than watersheds with no wetland or lake area (Sather and Smith, 1984). The reduction was 60-65% if the watershed was 15% wetland or lake (Sather and Smith, 1984).

Water supply and hydrologic regulation

Clean water from forested watersheds is important to all Marylanders. Almost two million people get their water from the Baltimore City reservoirs, and much of the Washington metropolitan area depends upon reservoirs as well. Most municipalities outside of the metropolitan areas depend on ground water sources. In addition, MDE reports that approximately half of all stream flow in Maryland originates as ground water (Moore, 2002).

As mentioned in the previous paragraphs, forests and wetlands slow surface runoff during rainfalls, and catch some of this water. Some of the trapped rainfall is absorbed by plant roots, some is stored in depressions or soil, and some percolates into surficial, intermediate, or deep aquifers. The rate of infiltration depends on a number of factors, including land use, geology, soils, and precipitation (Moore, 2002). Water stored on the surface or below ground keeps plants alive, provides drinking water for humans and wildlife, and helps maintain stream base flow in dry periods.

The effect of wetlands on ground water recharge and discharge is variable. Some wetlands recharge ground water, but most do not (Sather and Smith, 1984). Most wetlands occur where water is discharging to the surface (Sather and Smith, 1984). Wetlands may recharge less than natural uplands because of greater evapotranspiration and less permeable soils. Temporary or seasonal wetlands seem more likely to recharge than permanent or semi-permanent wetlands (Sather and Smith, 1984). Wetland features affecting groundwater recharge include hydroperiod, substrate, presence of surface outlets, amount of edge, and type and amount of vegetation.

By the process of transpiration, trees take in groundwater through their roots and release it to the atmosphere through their leaves. From there, water vapor can be carried by air currents over large distances, and then returned to the ground through precipitation (Bacon, date unknown). A large tree can return 10 gallons of water a day to the atmosphere (Moore, 2002). Evaporation of surface water in wetlands, streams, and ponds also contributes to the hydrologic cycle. Water evaporates more slowly from shaded forest soil than bare soil exposed to the sun.

The natural hydrologic cycle contrasts with what happens when impervious developed areas prevent water infiltration. In fact, the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) estimated that water runoff develops ten times faster on developed land as compared to unaltered landscape (Moore, 2002). Rain water that falls on developed land is therefore not recycled. NRCS states that the management of precipitation is a major factor in whether or not there is sufficient quantity and quality of drinking water (Moore, 2002). Studies of desertification have shown that vegetation is a controlling factor in the exchange of water and energy between the land and the atmosphere, and that large-scale deforestation dries up an area's climate (Alusa, 1997 in Moore, 2002). For example, a study in Brazil showed that forests returned three-fourths of rainfall to the atmosphere, with only one-fourth running into streams and rivers. When land is deforested, however, the ratio is roughly reversed, with a quarter of the rainfall returned to the atmosphere and three quarters running quickly off the land (DeGroot, 2002).

The increase in drought conditions of recent years has been suspected as a direct effect of tree losses over the last two centuries (Olson, L, date unknown). Eighteen of Maryland's counties were on drought watch in fall 2001, making it the third driest autumn season since 1871 (US Water News, 2002). In January 2002, Baltimore's reservoirs were at the lowest point on record, and the city had to start pumping 50 million gallons of water a day from the Susquehanna River (US Water News, 2002). The Susquehanna itself was running at only 36% of its normal flow (US Water News, 2002). Additionally, low flows put the Monocacy River off-limits, drastically reducing the available water supply for the City of Frederick, one of the fastest growing cities in Maryland (US Water News, 2002).

A well-functioning hydrologic cycle is not only important for proper ecosystem function and drinking water supplies, it is important for the growing hydroelectric industry in Maryland. Maryland has eight hydroelectric projects, with two stations (Conowingo and Deep Creek) that provide almost $123 billion worth of hydroelectricity each year. Stable stream flow helps hydroelectric managers predict and manage the water used for power generation. In contrast, highly fluctuating flows, such as those found in urban areas, can result in potential losses from dam spillovers (MdDNR, 2002).

<u>Clean water</u>

Natural lands protect bodies of water from pollutants and sedimentation by absorbing and filtering water. In contrast to forests and wetlands, urban landscapes have been shown to add seven times as much nitrogen and ten times as much phosphorus to surface waters (Stewart, 2002), and impervious lands like roads and parking lots carry pollutants such as oils, grease, heavy metals, and salts to streams. Agricultural runoff also contributes to heightened nutrient loads.

Excess nutrients are a key water quality concern in Maryland, for drinking water, for stream health, and for aquatic life, particularly in estuarine areas. Excess nitrogen and phosphorus can cause fish kills and algal blooms, and promote growth of "undesirable" aquatic plants. A recent study by DNR's water monitoring division found that about 57% of the state's non-tidal stream miles had unnaturally elevated nutrient concentrations, and these concentrations were generally higher in watersheds with more agricultural land use. The study reported that some sites with greater than 50% agricultural land use upstream contained nitrate concentrations as high as 24 mg/L (Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, 1999; Moore, 2002).

Background

The increased impervious surface associated with development has major impacts on stream biota. Loss of forest leads to fluctuating water levels, higher peak velocities, unstable stream banks and beds, increased sedimentation, loss of deep pools and coarse woody debris, and decreased water quality. According to the Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division (1999), when watershed imperviousness exceeds 25%, only hardy, pollution-tolerant organisms can thrive. Other species decline or become extinct. Above 15% impervious cover in a watershed, fish and benthic macroinvertebrate community condition, as measured by the indices of biotic integrity, is fair to poor (i.e., never good). Even very low levels of imperviousness can have detrimental effects. When upstream impervious land cover is above 2%, pollution-sensitive brook trout are never found (Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, 1999). Roads, a major contributor to imperviousness, have multiple impacts on living resources of all types, which are discussed in greater detail below.

By slowing surface runoff and providing opportunities for settling and infiltration, forests help remove nutrients, sediments and other pollutants. Infiltration rates 10-15 times higher than grass turf and 40 times higher than a plowed field are common in forests (Chesapeake Bay Program, 2000). Tree roots remove nutrients from settled runoff and groundwater, and store them in leaves and wood. Through the process of denitrification, bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air (Chesapeake Bay Program, 2000). In stream and river floodplains, vegetation traps and removes water-borne particulates during storms.

Riparian forest buffers have proven to be effective at reducing nutrient loads in areas that have largely been deforested. Studies have demonstrated reductions of 30 to 98 percent for nitrogen, phosphorus, sediments, pesticides, and other pollutants in surface and groundwater after passing through a riparian forest (Chesapeake Bay Program, 2000). Retaining buffers is one of the least expensive strategies for reducing nitrogen loads, costing approximately $5 per pound of nitrogen removed (Stewart, 2002). Stream buffers are most effective when they are continuous and sufficiently wide. (Issues of buffer width are discussed in greater detail a little later.)

General agreement exists that wetlands change water quality through retention and/or modification of sediments, toxins, and nutrients in the water (Sather and Smith, 1984). Water changes as it passes through wetlands because the velocity of the flowing water is reduced, large populations of microbes decompose organic substances, and particles are bound to sediments (Sather and Smith, 1984). Submerged and emergent plants help purify water indirectly, by supplying substrates for bacterial growth, providing a medium for physical filtration and absorption, and restricting algal growth and wave action. Restored wetlands have been shown to be effective at trapping significant amounts of nutrients and sediments (Jordan, 2002). Both natural and restored wetlands have been effective at treating wastewater (Sather and Smith, 1984).

Wetlands have also been shown to change some toxic substances (e.g., heavy metals and pesticides) to harmless states. Other substances may be temporarily buried in sediments in wetland areas. Heavy metals are removed from wastewater by ion exchange and adsorption to sediment clays and organic compounds; by precipitation as oxides, hydroxides, carbonates, phosphates and sulfides; and by plant uptake (Sather and Smith, 1984). Heavy metal removal varies 20-200% depending on the metal and the wetland. The fate of pesticides and other toxins is similar to heavy metals. Some are temporarily buried in sediments, some changed to harmless forms and some may enter the food web (Sather and Smith, 1984).

In Maryland, much drinking water is obtained from reservoirs, streams and rivers (Moore, 2002). National Drinking Water Regulations set maximum allowable concentrations for microorganisms, turbidity, and chemicals (U.S. Environmental Protection Agency, 2002). In spite of high standards and government oversight, each year almost a million Americans still become sick as a result of drinking contaminated water, and many people die (Salzman et al, 2001). When contamination levels are of concern, local governments have been forced to pump water from deeper aquifers or to create expensive water treatment facilities (Moore, 2002).

In some parts of the U.S. attention has focused on the benefits of protecting natural watersheds to assure safe and plentiful drinking water supplies, rather than on building expensive filtration plants to purify water from degraded watersheds (World Resources Institute, 1998). New York City recently avoided spending $6-8 billion in constructing new water treatment plants by protecting the upstate watershed that has traditionally accomplished these purification services for free (World Resources Institute, 1998). Based on this economic assessment, the city invested $1.5 billion in buying land around its reservoirs and instituting other protective measures, actions that will not only keep its water pure at a bargain price but also enhance recreation, wildlife habitat, and other ecological benefits (World Resources Institute, 1998).

<u>Erosion control and sediment retention</u>

Standing vegetation stabilizes soils, especially along stream banks, on steep slopes, and where soils are highly erodible. Forests and forest buffers help protect streams by sheltering and anchoring their banks. Trees and vegetation also intercept driving rain and slow the flow of water over the ground, thereby reducing scouring and preventing soil from eroding into water bodies and roads. Increased sediment loads in steams and lakes can impact fish and invertebrate populations and habitats, alter stream channels, and reduce water quality. Erosion also leads to poor soil productivity (Moore, 2002).

Wetland vegetation helps control erosion in coastal, lacustrine and riverine systems by binding and stabilizing substrates, dissipating wave and current energy and trapping sediments. Physical forces may prevent vegetation from establishing; wetland plants are usually found where waves, currents and wind are not too strong. Wetland erosion control effectiveness depends on the flood tolerance and resistance to undermining of plants, the width of the vegetated shoreline band, the efficiency of the shoreline band in trapping sediments, the soil composition of the bank or shore, the height or slope of the bank or shore, and the elevation of the bank toe with respect to mean storm high water (Sather and Smith, 1984). Silberhorn et al (1974) suggested at least a 2 ft. width of vegetated shoreline was necessary; Garbisch (1977), at least 10 ft. Reppert et al (1979) reported that the wider the wetland, the greater the shoreline protection.

One cost of increased sedimentation is the public dredging of channels. In fiscal year 2002, Congress appropriated over $50 million for U.S. Army Corps of Engineers projects in Maryland, including the annual maintenance dredging of Baltimore shipping channels; the maintenance dredging of the Ocean City Harbor, Inlet and Sinepuxent Bay; the dredged material use at Poplar Island; and new dredging projects in Dorchester, Wicomico, Charles, and Anne Arundel counties. State and local sources spend significant amounts as well. In fiscal year 2001, DNR's Waterway Improvement Fund provided over $1.4 million to applicants for dredging projects. Baltimore County reported spending about $6 million on dredging projects between 1988 and 2001. Sedimentation also reduces the capacity of reservoirs to hold water, requiring expensive periodic dredging (Moore, 2002).

Once a stream is degraded by erosion, it is very expensive to restore. According to DNR's Watershed Restoration Division and Baltimore County's Department of Environmental Protection and Resource Management, the unit cost for stream restoration, design, and construction averages $1.2 million per mile in urban and suburban watersheds. DNR estimates that stream restoration in non-urban watersheds costs approximately $0.6 million per mile (Moore, 2002).

Regulation of water temperature

Forest loss has been correlated with increased water temperatures in lakes and streams. Several factors contribute to this: increases in sediment loads change water depths, loss of canopy cover increases solar radiation, and pollutants change chemical composition and heat retention. Increasing temperatures affect the wildlife living in aquatic environments. These changes select for the few species that can adapt to the new conditions. Currently, very few Maryland streams are cool enough to support brook trout, particularly in the eastern half of the state. Once numbering more than three million, brook trout are now at just 10% of their former population. Loss of forests is a key factor in the decrease in brook trout habitat (Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, 1999).

Nutrient cycling

Wetlands and forests play an important role in maintaining a cycle of nutrient flow through their ecosystems. Wetlands tend to have higher net primary productivity (NPP) than other ecosystems (Sather and Smith, 1984). A number of factors influence NPP, including levels of nitrogen and phosphorus in the water and soil, pH (moderate levels being optimal), salinity, turbidity, climate and hydrology. Nutrient export from wetlands increases the nutrients that are available downstream. Coastal marshes and mangrove swamps export dissolved and particulate organic matter to adjacent estuaries and coastal waters. Floodplain wetlands contribute dissolved organic matter to streams and rivers.

Madritch and Hunter (2002) found that intraspecific tree diversity, as expressed in varying leaf litter chemistry, can affect the ecosystem processes of carbon and nitrogen cycling. Therefore, losses in genetic diversity can affect ecosystem functions.

Pest control and pollination

Large blocks of forest, especially those containing interior habitat, can help control pests in nearby agricultural fields or residential areas. Bats and insectivorous birds, which roost or nest in forests, prey on a large variety of invertebrates. Blankenship (2000) estimates the forest-pest control value of birds at $5000/acre. The most common bat found in Maryland, the little brown bat (*Myotus lucifungus*), can consume up to 600 mosquitoes in just one hour (Chesapeake Wildlife Heritage, 2001). Forest edge species consume insects on nearby crops. For example, the indigo bunting feeds on grasshoppers, beetles, cankerworms, flies, mosquitoes, cicadas, weevils and aphids (Chipper Woods Bird Observatory, 2001). In contrast, use of chemical pesticides to control insects is increasingly ineffective as pests evolve resistance to the pesticides. Pesticides can also poison groundwater and streams. Not only is a diverse wildlife population important for regulating agricultural pests, agriculture relies on the services of pollinators.

On occasion, when ecosystems are altered, wildlife species themselves can become pests, as will be discussed in the case of deer a little later.

<u>Wetlands as fish and wildlife refuges</u>

Some wildlife rely on wetland habitats throughout their lives, while others only reside in wetlands seasonally. The size, location relative to nearby aquatic or terrestrial landscape, substrate and vegetation of a wetland influence the species that will be found there.

Sixty-six to ninety percent of all commercially important fish and shellfish species on the Atlantic and Gulf coasts depend on coastal marshes or estuaries for at least part of their life cycle (e.g., food sources, spawning grounds, or nurseries for young). Many game species spawn in wetlands, however this is dependent on the water quality, quantity, cover, substrate and interspersion of wetlands. There are several mammalian species that are dependent on wetlands including muskrats and beavers. Nearly a third of North American bird species require wetlands at some time in their lives for food, cover, breeding, or molting or for resting grounds (Sather and Smith, 1984).

The value of ecosystem goods and services

For some ecosystem services, primarily those associated with private markets, standard accounting regularly calculates economic value contributed by natural lands and their resources.

<u>Food production and raw materials</u>

Natural lands provide a direct source of wood, food, and other products. These provide a livelihood for those in the timber and fishing industries, as well as contribute to the larger economy as these employees both spend their money in the community and add value to natural products to create furniture, houses, frozen food dishes, etc. Forestry and wood products are the fifth largest industry in Maryland. In 1996, the forestry and wood products industries generated 2 billion dollars in income, created 14,000 jobs and contributed 0.75 billion dollars in value-added economic activity. The long-term profitability of this industry is directly linked to a sustainable forest resource base.

Recreation

Natural areas not only provide a list of ecological services, they provide an array of recreational opportunities that contribute to our quality of life. These include hunting, fishing, hiking, bird watching, camping, rock climbing, canoeing, and many others. A study by Balmford et al (2002) reported that the economic value of retaining Canadian freshwater marshes for hunting, angling and trapping was 60% greater than the value derived from converting them to agriculture. This did not include other values such as nutrient cycling, water regulation, and peat accumulation.

The demand for outdoor recreation in the U.S. has greatly outpaced population growth. Visits to national parks jumped 134% between 1965 and 2000, to 284.1 million. Visits to national forests and wildlife refuges have also increased dramatically. According to a U.S. Forest Service survey, walking is the most popular outdoor recreational activity, with 133.7 million participants. Bird watching is the fastest growing outdoor activity, jumping an astounding 155% between 1982-3 and 1994-5, to 54.1 million participants. Other fast-growing activities included hiking, backpacking, and camping. In 1993, the 273 million visitors to national parks created more than $10 billion in direct and indirect expenditures, and generated more than 200,000 jobs. The National Park Service's operating budget was $1 billion in 1993, bringing taxpayers a 10 to 1 return on their investment (McQueen, 2001).

A survey by the U.S. Fish and Wildlife Service (1998) revealed that in 1996, 1.5 million Maryland residents 16 years old and older engaged in fishing, hunting, or wildlife-watching activities. Of these, 569,000 fished, 126,000 hunted, and 1.3 million (the majority) participated in the passive observing, feeding, and photographing of wildlife (U.S. Fish and Wildlife Service, 1998). In the same year, state residents and non-residents spent $1.1 billion on wildlife-associated recreation in Maryland (U.S. Fish and Wildlife Service, 1998).

It is important to recognize, however, that the presence of humans can disturb wildlife behavior. Nests may be abandoned or destroyed when adults are startled and flee. Juveniles may get displaced when humans approach. Also, trails compact the soils, making it impervious and difficult for seeds to germinate. They also create more edge habitat (Vandemann, date unknown), and opportunities for invasive species. Trails and logging roads are often havens for exotic, disturbance-adapted species like *Microstegium sp.*, garlic mustard, and multiflora rose. These can invade interior areas and displace native species with greater wildlife values. Proper management of recreational areas is necessary to prevent ecological degradation.

Economic significance of ecosystem goods and services

The more our natural resources are compromised the more we become aware of their ecological and economic significance. A study by Costanza et al (1997) estimated the economic value of 17 ecosystem services (see Table 2-1) for 16 biomes, based on published studies and original calculations. A minimum estimate of the global total was between $16-54 trillion per year (1994 U.S. dollars), with an average of $33 trillion per year, almost twice the global Gross National Product (GNP) (Costanza et al, 1997).

The average value for some ecosystems occurring in Maryland is listed in Table 2-2. These values were estimated by Costanza et al (1997), for select biomes occurring in Maryland. Numbers were adjusted from 1994 US$ to estimated mid-2001 US$ using the Gross Domestic Product Deflator inflation index. It should be emphasized that these are average global estimates, and not specific to the state. However, Pimentel (1998) estimated that biodiversity is responsible for at least $1.9 billion in economic and environmental services in Maryland. DNR is currently working with the University of Maryland to compute local ecosystem values to the economy.

Table 2-1
Ecosystem services and functions evaluated by Costanza et al (1997)

Ecosystem service	**Ecosystem functions**	**Examples**
Gas regulation	Regulation of atmospheric chemical composition.	CO_2/O_2 balance, O_3 for UVB protection, and SO_x levels.
Climate regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels.	Greenhouse gas regulation, DMS production affecting cloud formation.
Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations.	Storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure.
Water regulation	Regulation of hydrologic flows.	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation.
Water supply	Storage and retention of water.	Provisioning of water by watersheds, reservoirs and aquifers.
Erosion control and sediment retention	Retention of soil within an ecosystem.	Prevention of loss of soil by wind, runoff, or other removal processes; storage of silt in lakes and wetlands.
Soil formation	Soil formation processes.	Weathering of rock and the accumulation of organic material.
Nutrient cycling	Storage, internal cycling, processing and acquisition of nutrients.	Nitrogen fixation, N, P and other elemental or nutrient cycles.
Waste treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds.	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes.	Provisioning of pollinators for the reproduction of plant populations.
Biological control	Trophic-dynamic regulations of populations.	Keystone predator control of prey species, reduction of herbivory by top predators.
Refugia	Habitat for resident and transient populations.	Nurseries, habitat for migratory species, regional habitats for locally harvested species, or overwintering grounds.
Food production	That portion of gross primary production extractable as food.	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming, or fishing.
Raw materials	That portion of gross primary production extractable as raw materials.	The production of lumber, fuel or fodder.

Ecosystem service	Ecosystem functions	Examples
Genetic resources	Sources of unique biological materials and products.	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants).
Recreation	Providing opportunities for recreational activities.	Eco-tourism, sport fishing, hunting, birdwatching, hiking, camping, canoeing, and other outdoor recreational activities.
Cultural	Providing opportunities for non-commercial uses.	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems.

Table 2-2
Average economic value (U.S. dollars per acre per year) of ecosystem services

Biome	Average global value of annual ecosystem services ($/ac/yr)
Temperate/boreal forests	134
Tidal marsh	4,456
Swamps/floodplains	8,734
Lakes/rivers	3,790
Estuaries	10,184
Seagrass/algae beds	8,477
Continental shelf	719

Studies have shown that if the values of ecological services are considered, natural lands show a net gain in cost-benefit analyses. While residential, commercial, and industrial areas require public services, natural areas require little other than protection. Further, they provide services that prevent public costs (Moore, 2002). Some of these benefits of natural areas were described above in more detail, in a review that was brief and by no means exhaustive.

The health of Eastern forests

As a result of development over the past two centuries, there have been changes in the composition of animal and plant populations in eastern forests (Ray, 2000). A homogenization of forest structure has led to a simplified landscape hospitable to generalist predators, such as raccoons, coyotes, striped skunks and red foxes. Overabundant populations compete for resources, spread parasites and disease and further stress species that are impacted by habitat loss (Garrot et al., 1993). These pressures nearly decimated other mesocarnivore populations such as lynx, marten, fishers and river otters. The state of eastern forests has improved over the last century. As forest cover returns, some of these mammalian populations have in fact been rebounding (McKibben, 1995, Ray, 2000). This is also a result of successful reintroductions and range expansions (Ray, 2000). Wolf and cougar populations have larger range requirements, and have not rebounded to the same degree.

Eastern forests have also been negatively affected by insect outbreaks over the last century. This is a reflection of poor forest health, human encroachment and both intentional and unintentional introductions. Schowalter (2001) listed several reasons for the susceptibility of Pacific Northwest forests to insect epidemics: "poor forest health, overcrowding, over-use of chemicals, fire suppression, and the introduction of single species or non-native tree plantations." At normal densities, native insects play an important role in maintaining forest health by controlling crowding and competition for water and nutrients (Schowalter, 2001). However, these species have experienced population explosions because denser forest understories allow them to spread through areas that were previously unpassable (Schowalter, 2001). Another problem for forests has been that more than 24 harmful exotic plant pathogens and 400 harmful exotic insects have been introduced to the US eastern forests (Campbell, date unknown). For example, the chestnut blight, introduced in 1904 on imported nursery stock, dramatically changed the species composition of northern forests. Insects and diseases that are currently important problems in the Mid-Atlantic region include the gypsy moth, forest tent caterpillar, elm spanworm, hemlock wooly adelgid, butternut canker, beech bark disease, and dogwood anthracnase. Efforts to exterminate the Asian longhorned beetle, discovered in New York City in 1996, resulted in the removal of 5,500 hardwood trees at a cosy of $25 million by March 2000. These outbreaks have changed the structure of forests in the United States.

Maryland's changing landscape

The population and developed portions of Maryland have been growning rapidly. Between 1790 and 1990, Maryland's population grew from 320,000 to 4,780,000 (RESI, 1997). The increase was 13.4% between 1980 and 1990 alone (RESI, 1997). Maryland's population is projected to increase an additional 24.4% between 1995 and 2025 (RESI, 1997). Developed land has increased even faster than the population. Before colonization by Europeans, Maryland was 95% forested, the other 5% being marsh around Chesapeake Bay (Besley, 1916; Powell and Kingsley, 1980). By 1993, forest had decreased to 47% of land cover. Virtually all of this is secondary growth; as far back as 1916, less than 1% was virgin forest (Besley, 1916). Similarly, Maryland has lost 50% of its pre-settlement wetlands (Tiner and Burke, 1995). Since automobiles became the primary means of transportation, people began migrating from large cities like Baltimore, and suburbs have sprawled across the landscape. Between 1985 and 1990 alone, developed land use increased by 18.6%, to 921,000 acres (RESI, 1997).

The Maryland Department of Planning has projected that by 2020 urban land use will increase by more than 25% from 1997 levels. The growing trend of exurban development is transforming rural areas to low-density house lots and exclusive gated communities, which give their residents a sense of space, security, and exclusivity, as well as isolating them from neighbors and unwelcome visitors. Homeowners are more and more willing to commute long distances to their jobs in exchange for larger lots for lower prices. Development of vacation or second homes and of residences for retirees freed from the need to commute has added to sprawl.

This development has come primarily at the expense of agriculture and forest. American Forests (1999) found that average tree cover in the Chesapeake Bay watershed declined from 51% to 39% between 1973 and 1997. Natural tree cover (areas with at least 50% tree cover) declined from 55% to 38% of the total area (American Forests, 1999). The Maryland Department of Planning has projected forest cover to decrease a further 9% by 2020 from 1997 levels. Agriculture has also been projected to decrease by 9% during the same period. Bockstael (1996) stated that land use change due to human activity "is perhaps the single greatest factor affecting ecological resources." Wildlife habitat and migration corridors are being lost, and normal ecosystem functions such as absorption of nutrients, recharging of water supplies, and replenishment of soil are being disturbed or destroyed. Water quality has been degraded in numerous streams and rivers, as well as the Chesapeake Bay itself. Many of Maryland's remaining wetlands have been altered by filling, drainage, impoundment, livestock grazing, logging, direct discharges of industrial wastes and municipal sewage, freshwater diversions, and non-point discharges such as urban and agricultural runoff (Tiner and Burke, 1995).

The scattered pattern of modern development not only consumes an excessive amount of land, it fragments the landscape. Sorrell (1997) states, "the end result of fragmentation is often a patchwork of small, isolated islands of habitat in a sea of developed land". Numerous studies have shown the negative ecological effects of forest fragmentation in the landscape. Some generalist or ecotone species, like white-tailed deer and raccoons, can benefit from fragmentation. But according to Sorrell (1997), habitat fragmentation is perhaps the greatest worldwide threat to forest wildlife, and the primary cause of species extinction. Yahner (1988), Hansen and Urban (1992), Donovan et al (1995), and Robinson et al (1995) showed that fragmentation and increased edge have reduced the distribution and abundance of forest birds and other wildlife species throughout North America. As forest areas are divided and isolated by roads and development, interior habitat decreases, human disturbance increases, opportunistic edge species replace interior species, and populations of many animals become too small to persist.

Habitat patches and edge effects

A "patch" can be defined as a contiguous part of the landscape, with comparable length and width, that is distinguished by discontinuities in environmental characteristics with its surroundings (Wiens, 1976; White and Pickett, 1985; Forman and Godron, 1986). In wildlife ecology, these environmental gradients are ones noticeable to animals, and will be perceived differently by different species (Wiens, 1976; Lidicker, 1999).

A patch edge is the outer band of the patch that is influenced by surrounding environmental conditions, and is thereby significantly different from the interior (Forman and Godron, 1986). Edges are most pronounced between greatly dissimilar ecotypes, like forests and row crops, or wetlands and parking lots. Edges produced by humans tend to be straighter and more abrupt than those created naturally. For a given shape, the smaller the patch, the greater its perimeter-to-area ratio, and thus the more dominant boundary effects become.

Forest edges contain significant gradients of solar radiation, temperature, wind speed, and moisture between the forest patch interior and the adjacent land, especially if the adjacent land is developed (Forman and Godron, 1986; Brown et al, 1990). Increased solar radiation at the edge increases temperatures and decreases soil moisture and, with increased wind flow, decreases relative humidity (Forman and Godron, 1986; Brown et al, 1990). This can desiccate plants. Increased wind speed at a newly created edge commonly knocks down trees that are no longer buffered by adjacent canopy and not structurally prepared (Brown et al, 1990). This poses a problem especially for wetland trees, which have shallow roots and less stable soil (Brown et al, 1990). Wind can also carry dust or other small particles, which can adhere to vegetation (Brown et al, 1990). As discussed in a bit more detail below, noise from developed land disrupts natural activity in adjacent forest or marsh, by drowning wildlife cues for territorial boundary establishment, courtship and mating behavior, detection of separated young, prey location, predator detection, and homing (Yahner, 1988; Brown et al, 1990). Sudden loud noises can also cause stress to animals (Brown et al, 1990). Clearcuts adjacent to forest can also cause excess runoff, erosion, nutrient loss, and loss of wildlife (Harris, 1984). They can also increase the chance and severity of fire. For example, the weed-brush stage is the successional stage most subject to fire in Douglas fir forests (Harris, 1984).

Changes in insolation and other physical parameters at created edges change plant and animal communities there, and processes like nutrient cycling (Forman and Godron, 1986; Brown et al, 1990). Since the eastern U.S. was primarily unbroken forest prior to European colonization, many species are adapted to interior forest conditions. Edge habitat differs from interior forest in tree species composition, primary production, structure, development, animal activity, and propagule dispersal capabilities (Brown et al, 1990; Kapos et al, 1993). The edge communities shift to more shade-intolerant, more xeric tree and shrub species, and early successional species (Brown et al, 1990). These then broadcast propagules that invade the forest interior (Brown et al, 1990). Edges created by human or natural disturbances can favor invasive exotic species like reed canary grass (*Phalaris arundinacea*), garlic mustard (*Alliaria petiolata*), Japanese honeysuckle (*Lonicera japonica*), or multiflora rose (*Rosa multiflora*), which can then displace native species in adjacent areas (Lidicker, 1999; Maryland DNR Wildlife and Heritage Division,1999; USDA NRCS, 1999).

Opportunistic animals like raccoons, opossums, and cowbirds also colonize patch edges, and often invade the interior. These edge species often influence ecosystem dynamics by preying on, outcompeting, or parasitizing interior species (Reese and Ratti, 1988; Robinson, 1988; Brown et al, 1990; Dunning et al, 1992; Heske et al, 1999; Kurtz, 2000). Increased nest predation may extend 300 to 600 meters inside the forest (Reese and Ratti, 1988; Yahner, 1988; Brown et al, 1990). Cowbirds parasitize bird nests up to 1000 feet from the forest edge (Reese and Ratti, 1988; Brown et al, 1990). Several species of birds have been severely affected by cowbird parasitism, including the endangered Kirtland's warbler (*Dendroica kirtlandii*) and the possibly now extinct Bachman's warbler (*Vermivora bachmanii*) (Harris, 1988; U.S. Fish and Wildlife Service, 1997). Cats and dogs from developed areas can prey on or harass wildlife. House cats, which hunt on instinct, range large areas (30-228 ha); one cat studied with a regular diet of domestic food killed over 1600 mammals and 60 birds during an 18 month period (Brown et al, 1990).

Studds (2002) showed that the interface between forest and non-forest land affects the degree of nest predation and parasitism, possibly more than vegetation or patch size. Nest predation is higher in forests that abut suburban areas rather than agricultural land. On the other hand, parasitism is higher in forests adjacent to agricultural areas as opposed to suburban areas. Therefore, species composition within a patch is influenced by the landscape and the conditions at the patch's periphery.

Measures of edge and buffer widths

Harris (1984), Brown et al (1990), and Kapos et al (1993) cite a distance of 2-3 tree heights from the forest edge to reduce the effects of sunlight and wind penetration. This translates to about 100 m (300 feet) in Maryland, and could be considered the abiotic transition zone. However, some forest interior birds nest further from the edge than this (Bushman and Therres, 1988). Further, Gates and Evans, in a study of brown-headed cowbirds in 1996, detected 94% of female breeding fixes within 220 m of forest edges. They defined interior forest as $250 m from the edge. About 60% of telemetry fixes were within 50 m of the edge (Gates and Evans, 1996). Since females travel up to 10 km between breeding and feeding areas (averaging 2.3 km), they were abundant even in Western Maryland state parks (Gates and Evans, 1996). However, the abiotic transition zone is more applicable to forested ecosystems as a whole.

Wetland buffers also perform important functions, including (Brown et al, 1990; North Carolina State University, 1998):

- sediment removal and erosion control,
- nutrient transformation and removal,
- metals and other pollutant reduction,
- stormwater runoff reduction through infiltration,
- reduction of water temperature,
- reduction of human impacts by limiting easy access and by minimizing edge effects from noise, light, temperature, and other changes,
- protection against water table drawdown from adjacent ditches,
- providing a wetland-upland ecotone that is utilized by numerous species of wildlife,
- protection for interior wetland species, and
- a barrier to invasion of nuisance and exotic species.

The necessary buffer width will vary according to individual site by type of wetland, sensitivity to disturbance, intensity of adjacent land use, groundwater depth and hydraulic conductivity, proximity and characteristics of drainage ditches and other water control structures, slope and soil characteristics, species present, and buffer characteristics such as vegetation density and structural complexity, soil condition, etc. (Brown et al, 1990; North Carolina State University, 1998). Brown et al (1990) recommended varying buffer widths for wetlands in different landscapes of east central Florida. The distance to minimize groundwater drawdown varied from 20 to 550 feet; to control sedimentation, 75 to 375 feet; and to protect wildlife habitat, 322 to 732 feet (Brown et al, 1990). Brown et al (1990) recommended a wildlife buffer of 550 feet for forested wetlands and 322 feet for emergent wetlands. A literature search of studies on specific buffer performance "found that for sediment removal, necessary widths ranged from 10 to 60 m; for nutrient and metals removal, widths ran from 4 to 85 m; for species distribution and diversity protection, from 3 to 110 m was required; and for water temperature moderation, requirements ranged from 15 to 28 m" (North Carolina State University, 1998). Castelle et al. recommended minimum buffer widths around 30 m under most circumstances to provide both basic physical and chemical buffering to maintain biological components of wetlands and streams (North Carolina State University, 1998). They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis (North Carolina State University, 1998). A minimum 90 meter buffer around state and federal wildlife refuges and conservation areas has been recommended (North Carolina State University, 1998).

Streams are strongly dependent on the surrounding terrestrial environment, which serves as both a buffer and a source of organic matter, especially for small (low-order) streams (Harding et al, 1998). Natural vegetation in the riparian zone has been shown to stabilize stream hydrology; maintain the integrity of stream channels and shorelines; intercept nutrients, sediment, and chemicals; moderate water temperature; and supply food, cover and thermal protection to fish, amphibians, invertebrates, and other wildlife (Harding et al, 1998; Maryland Department of Natural Resources, 1999; Chesapeake Bay Program, 2000). The Chesapeake Bay Program (2000) recommends a three-zone buffer for streams, with the width of each zone determined by site conditions.

Riparian forests provide the best stream buffers. In addition to benefits of nutrient uptake and erosion prevention, discussed above, there are important additional habitat benefits, such as those quoted below from Chesapeake Bay Program (2000):

- <u>Canopy and shade</u>: Cool stream temperatures maintained by riparian vegetation are essential to the health of aquatic species. Shading moderates water temperatures and protects against rapid fluctuations that can harm stream health and reduce fish spawning and survival. Elevated temperatures also accelerate algae growth and reduce dissolved oxygen, further degrading water quality. In a small stream, temperatures may rise 1.5 degrees in just 100 feet of exposure without trees. The leaf canopy also improves air quality by filtering dust from wind erosion, construction or farm machinery.
- <u>Leaf food</u>: Leaves fall into a stream and are trapped on woody debris (fallen trees and limbs) and rocks where they provide food and habitat for small bottom-dwelling creatures (such as crustaceans, amphibians, insects and small fish), which are critical to the aquatic food chain.
- <u>Habitat</u>: Riparian forests offer a tremendous diversity of habitat. The layers of habitat provided by trees, shrubs, and grasses and the transition of habitats from aquatic to upland areas make these areas critical in the life stages of over half of all native Bay species. Forest corridors provide crucial migratory habitat for neotropical songbirds, some of which are now threatened due to loss of habitat. Also, many ecologically important species such as herons, wood ducks, and black ducks, as well as amphibians, turtles, foxes and eagles utilize the riparian forest. Streams that travel through woodlands provide more habitat for migratory fish by providing suitable spawning habitat for shad, herring, alewife, perch, and striped bass. The decline of these species is partly due to destruction of habitat, which for some, like shad and herring, extends well into small streams. Degradation of any portion of a stream can have profound effects on living resources downstream. While the overall impact of these riparian forest corridors may be greatest in headwaters and smaller order streams, there is a clear linkage all the way to the Bay. Trees and woody debris provide valuable cover for crabs, small fish and other aquatic organisms along the Bay's shoreline as well.

The impact of roads on natural communities

Roads can fragment natural habitat like forests and wetlands, and convert interior habitat to edge habitat. Roads are estimated to directly impact 19% of the total area of the U.S. (Forman, Estimate of the area affected ecologically by the road system in the United States). A secondary effect of roads is the conversion of nearby land to residential and commercial development. Provision of infrastructure like roads makes development easier, and facilitates economic activity and access. Bockstael (1996) found that commuting distances and distances to highways were significant variables in predicting residential development in the Patuxent watershed. A model by Bell and Bockstael (1997) had similar results for Howard County. Bell and Bockstael (1997) cited road improvements as partly responsible for increasing growth in western Howard County. New housing and commercial development in turn drives further road construction, and further sprawl.

It is irrefutable that roads are a necessity in our modern world, and provide many benefits; however, the negative impacts of roads on forest ecosystems are well documented. The effects of roads on adjacent landscapes include changes to hydrology, water and air quality, sediment transport, stream health, plant and animal dispersal, predation rates and patterns, disturbance regimes, amount of edge habitat, invasion by non-native species, forest access, and biodiversity (U.S. Forest Service, 1999; USDA, 2001). The density and distribution of roads in a landscape also plays a large role in the degree of their impact.

Microhabitats adjacent to one and two lane unpaved roads in a southern Appalachian mountain U.S. national forest were found to be altered relative to interior forest (Haskell, 2000). A gradient exists where macroinvertebrate soil fauna is significantly less abundant and less diverse close to forest roads. The effects of the roads on invertebrate abundance and leaf litter depth may be seen up to 100m from the road. In Haskell's words, "This may have additional consequences for the functioning of the forest ecosystem. Insects are significant components of the diets of the many vertebrates, especially birds and amphibians."

Roads can also promote the invasion of exotic species. The U.S. Forest Service (1999) reported:

> "Building roads into a forest's interior and subsequently maintaining them (including ditch clearing, road grading, and vegetation clearing) represent disturbances that create and maintain new edge habitat. These roadside habitats can be invaded by a suite of exotic (non-native) plant species, which may be dispersed by natural agents such as wind and water as well as by vehicles and other agents related to human activity. Roads may be the first point of entry for exotic species into a new landscape, and the road can serve as a corridor along which the plants move farther into the landscape. Some exotic plants may then be able to move away from the roadside into adjacent patches of suitable habitat. Invasion by exotic plants may have significant biological and ecological effects if the species are able to disrupt the structure or function of an ecosystem. Invasion may also be of concern to land managers if the exotic species disrupt management goals and present costly eradication problems."

Roads act as a barrier, blocking plant and animal migration routes, and leading to species isolation (U.S. Forest Service, 1999). The movement, both successful and unsuccessful, of animals along or across roads depends on the width of the roadway, vehicle traffic, and the mobility and behavior of the species (Forman, 1995). Where roads bisect wetlands or block streams, they inhibit the movement of aquatic or amphibian organisms. Roads were not found to be barriers to several species of Maine's frogs and toads. Habitats along roadsides may have even been selected for, which puts them in life-threatening scenarios (deMaynadier and Hunter, date unknown).

Narrow unpaved roads with few vehicles are often used at night by predators (Forman, 1995). However, paved roads strongly affect animal movement, from invertebrates to large mammals (Forman, 1995). Several studies show that the probability of small mammals crossing even lightly traveled roads of 6-15 m width is less than 10% of that for movement within the adjacent habitat (Forman, 1995). In another study, small forest mammals rarely crossed road corridors over 15 m wide (Forman, 1995). Mid-sized mammals crossed roadways up to 30 m wide, but never highway corridors of 118 and 137 m width (Forman, 1995). Large mammals cross most roads, but the rate of crossing is typically lower than movement in more favorable habitat (Forman, 1995). Amphibians and turtles exhibit reduced movement across roads (Forman, 1995). And some nesting birds and large mammals avoid the vicinity of roads altogether (Forman, 1995). Many studies have correlated increasing road density with wildlife avoidance, especially for large vertebrates (Forman, 1995; Mladenoff et al, 1995; U.S. Forest Service, 1999).

Roads separating home ranges or subpopulations may cause genetic isolation or local extirpation (Forman, 1995). Species with small populations, low reproductive rates and large home ranges, such as large vertebrates, are particularly at risk (Higgins, date unknown). In a study by Higgins (date unknown) it was shown that voles living adjacent to a four-lane highway were isolated populations with little genetic flow between them.

Road crossings are a common migration barrier to fish because of insufficient or improper culvert placement (U.S. Forest Service, 1999). Blockages affect anadromous fish like American shad, yellow perch, and river herring by removing spawning habitat. Freshwater fish species can become extirpated from runs isolated by blockages. In Maryland, Kenney et al (1992) found that stream blockages lowered fish diversity, numerical abundance, and biomass upstream. The main reason for these differences was the inability of fish to recolonize above a barrier after a catastrophic event like drought or pollution.

Road kills are a major population sink for terrestrial animals (Forman, 1995). An estimated one million vertebrates per day are killed on roads in the U.S. (U.S. Forest Service, 1999). The number of animal collisions with vehicles is directly related to the proximity of the nearest resting and feeding sites (U.S. Forest Service, 1999). Predators and scavengers may utilize sparsely-traveled roads as travel lanes, to seek prey where cover is interrupted, or to eat road-killed animals (Forman, 1995; U.S. Forest Service, 1999). They are thus vulnerable to vehicle collisions. Further, the large home ranges of carnivores often include road crossings (U.S. Forest Service, 1999). Road kill is a major source of bobcat mortality in Illinois (unpublished data). Small animals like amphibians, especially those that are slow moving or migratory, are even more vulnerable (U.S. Forest Service, 1999). Nearly all species of reptiles seek roads for cooling and heating, resulting in high mortality rates (U.S. Forest Service, 1999). Trombulak and Frissell (2000) cited studies that road kills are threatening populations of frogs and toads that need to cross roads to complete their life cycles. The state of Florida has been installing underpasses to limit vehicle collisions with panthers, bobcats, deer, raccoons, bear and alligators.

Geomorphic effects of road construction include sedimentation associated with chronic or catastrophic erosion, the trapping of material from erosional processes further upslope, direct altering of drainage channel morphology, or modifying channel flowpaths and extending the drainage network into previously unchannelized areas (U.S. Forest Service, 1999). For paved roads, sedimentation mainly occurs during construction, when soils are exposed to water and wind erosion. Runoff of sediments to surface waters can cause adverse biological and hydrological effects such as increased embeddedness and stream channel alteration.

The hydrologic effects of road construction not only include alteration of drainage morphology. Peak runoff volumes and flow rates from paved roads are greater than from vegetated soils due to the increased impervious surface area. Increased impervious surface also tends to decrease base flow downstream. Where roads bisect wetlands, ponding can occur on the uphill side, and drainage on the downhill side. This altered hydrology can affect plant and animal communities, nutrient cycling, soil development, and other wetland processes. Bridges, culverts, or other structures can mediate this problem if they make the roadway sufficiently permeable, and are maintained free of blockages.

The U.S. Forest Service (1999) found:

> "Roads have three primary effects on water: they intercept rainfall directly on the road surface and road cutbanks and subsurface water moving down the hillslope; they concentrate flow, either on the surface or in an adjacent ditch or channel; and they divert or reroute water from flowpaths that it would otherwise take if the road were not present. Most of the hydrologic and geomorphic consequences of roads result from one or more of these processes. For example, by intercepting surface and subsurface flow, and concentrating and diverting it into ditches, gullies, and channels, road systems effectively increase the density of streams in the landscape, thereby changing the amount of time it takes for water to enter a stream channel, altering the timing of peakflows and hydrograph shape. Similarly, concentration and diversion of flow into headwater areas can cause incision of previously unchanneled portions of the landscape and initiate slides in colluvial hollows."

Roads can impact water quality as well. Oil, fuel, grease, antifreeze, pavement materials and other contaminants from vehicles can be washed into streams after rainstorms. In the winter, road salts can enter the environment through runoff from roads and storage sites, as well as disposal or dumping of snow containing road salts into snow piles or water bodies (Elliott, 1998). There is evidence of adverse effects on ground water, plant and animal life, and aquatic ecosystems following exposure (Elliott, 1998; Trombulak and Frissell, 2000). Algae and benthic fauna have been shown to be particularly sensitive to changes in chloride ion concentrations, resulting in a reduction of fish populations (Elliott, 1998). Roads also increase delivery of nutrients to streams by replacing vegetation with impervious surface.

In addition to acting as fish migration barriers, roads can affect aquatic communities via sedimentation, altering stream flow or channel configuration, changing water temperature by loss of riparian shade cover or conversion of ground water to surface water, introducing disease or exotic species, lowering water quality, and increasing fishing pressure (U.S. Forest Service, 1999). At the landscape scale, roads can influence the frequency, timing, and magnitude of disturbance regimes, which can influence community structure and species diversity (U.S. Forest Service, 1999). Increased fine sediment composition in stream gravel has been shown to:

- decrease fry emergence;
- decrease juvenile fish density;
- lower winter carrying capacity by loss of concealment cover, increasing the likelihood of predation;
- reduce or eliminate populations of tailed frogs;
- reduce benthic organism populations;
- block interstitial spaces; and,
- reduce algal production (U.S. Forest Service, 1999).

Roads built adjacent to stream channels will increase water insolation and temperature if the riparian canopy is removed. This can sometimes have positive effects, such as increased food availability, but documented negative effects include elevation of stream temperatures beyond a species' tolerance, increased disease susceptibility, reduced metabolic efficiency, and shifts in species assemblages (U.S. Forest Service, 1999).

As noted, noise from roads can disrupt natural activity in adjacent areas (Yahner, 1988; Brown et al, 1990). Increases in night lighting either from roads, or adjacent development triggered by roadway expansion, also has a disruptive effect on wildlife (Schiller and DeLille, 1997). The effect of traffic noise and light depends on traffic volume and speed, height and density of adjacent cover, wind conditions, and other variables. Brown et al. (1990) reported that highway traffic noise is about 90 dB, and background noise levels in forested wilderness is about 35 dB under low wind conditions. Further, 15 dB below background noise is required to muffle human-caused sounds in wilderness areas (Brown et al., 1990). Vegetation may help to attenuate noise, but estimates for forest vary widely (between -1.5 dB per 100 feet and +15 dB per 100 feet), and attenuation by brush is negligible (Brown et al., 1990). Water can actually increase noise transmission (Brown et al., 1990). Ignoring the possible effects of adjacent cover and other factors, attenuation by spherical spreading is described by the equation

$$L_x = L_0 - 20 * \log(D_x/D_0)$$

where L_x is the decibel level of the source to be calculated at a desired distance,
L_0 is the decibel level of the source at a given distance,
D_x is the distance from the source for which L_x is to be calculated, and
D_0 is the given distance at L_0 is measured (Brown et al., 1990).

This gives a distance of 5 miles for highway noise to attenuate to background levels.

The U.S. Forest Service (1999) hypothesized that "measures of biodiversity provide the best integrative assessment of the effects of roads on ecosystems." Biodiversity, the relative complexity of an ecosystem or region as measured by the number of native species it supports, is important to long-term ecosystem function (U.S. Forest Service, 1999; McKnight, 2000). Human activities that decrease biodiversity, by eliminating sensitive native species, impair the associated ecosystems (U.S. Forest Service, 1999; McKnight, 2000). The U.S. Forest Service (1999) distinguished three aspects of road effects on biodiversity:

- "Road density: As road density increases, thresholds may be passed that cause some species to go locally extinct. The probability of extinction depends, in part, on body size, with larger animals requiring larger residual populations to prevent their becoming extinct.
- "Road location: Roads in otherwise large natural patches of vegetation, riparian areas, and major wildlife corridors, and with rare habitats and species, have greater effects than roads not in such areas.
- "Road-effect zone: Roads can have effects over some distance from their centers so that their effective width can be many times their actual width."

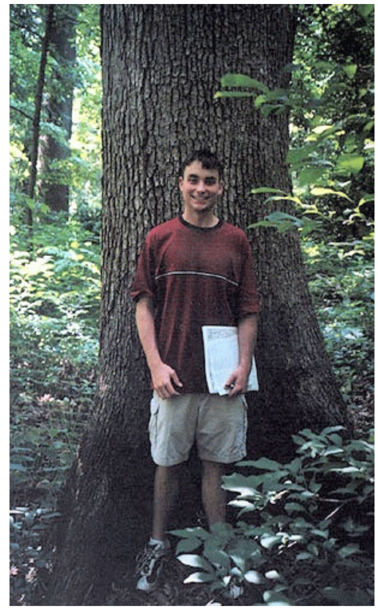
Landscape fragmentation and biological diversity

Habitat loss and fragmentation have contributed greatly to a continuing loss of biodiversity in Maryland. At least 180 plant and 35 animal species have been extirpated from Maryland, including elk, gray wolves, bison, and mountain lions (Williams, 1991). Another 310 plant and 165 animal species are rare, threatened, or endangered (Williams, 1991).

<u>Old growth forests</u>

Mature forests play a key role in maintaining biological diversity. They are also becoming extremely rare in the United States, especially in the east; however, many species are adapted to the conditions they provide. Old growth forest generally contains niches not found in younger forest, such as larger trees, higher canopies, greater vertical stratification, large snags and fallen logs, tree cavities, pit-and-mound microtopography, and a rich duff layer. Dead trees that have either fallen or remain standing as snags also provide important habitat. Up to 100 snags/hectare may be found in old growth forest. Large fallen logs can remain stuck in streams for more than 1000 years where they may gather sediment and nutrients and prevent erosion. On land, fallen logs have been shown to protect seedlings from pathenogenic fungus in the soil which can not live on dead wood (Suzuki, 2001). There is, therefore, sufficient microvariation in older landscapes to accommodate diverse wildlife populations.

The 20 to 70 year logging cycles in the eastern United States have threatened many forest plants and animals that thrive in mature forests, for example some species of lichens (DeGroot (4), date unknown). There are several species of trees that do not produce seeds until a mature age. For example, beech trees do not seed until they are approximately 40 or more years old (DeGroot (2), date unknown). Animals that den in trees need trees that are sufficiently large to house them. Young trees may not have sufficient girth to provide shelter. It is therefore important to consider not only the amount of forested habitat, but the type and age of the forest when managing land for biodiversity.



Old growth forest is extremely rare in the eastern U.S. It is useful as both habitat (many species are adapted to old-growth conditions, and these are often of conservation concern), and as reference ecosystems for scientific studies. Given its importance and rarity, it should be preserved where found. We used old growth forests in Maryland as reference sites for calibrating our upland forest field model. (See Chapter 11.)

Old growth forest supports species rarely found in younger forest, such as the barred owl, red-shouldered hawk, Acadian flycatcher, Blackburnian warbler, and brown creeper (Haney and Schaadt, 1996). A study of breeding birds in Pennsylvania (Haney and Schaadt, 1996) found both a higher density of individuals, and a greater number of species, in old growth as compared to younger or managed forest. This was especially true for neotropical migrants (Haney and Schaadt, 1996).

Leverett (1996) listed the following characteristics as indicative of old growth forest in the eastern U.S.:

- An abundance of old trees, recognizable by their asymmetrical shapes, relatively long trunks free of low branches (i.e., in-forest as opposed to open-grown shapes), deeply furrowed or plated bark, signs of heartwood decay, large prominent root structures, flattened crowns with protruding dead limbs, large thick limbs, and trunks often showing a twist that develops with age.
- Fallen logs in all stages of decomposition, crisscrossing the forest floor and lying in and across stream beds, covered by moss and lichens.
- Plentiful snags (standing dead trees).
- Canopy gaps large and small, formed from trees that have fallen.
- Undulating forest floor expressed in randomly scattered pits and mounds where trees have fallen over and decomposed.
- Multiple growth layers: overstory (trees that make up the canopy); understory (trees beneath the canopy); and shrub, herbaceous, and ground layers visible to one degree or another, all reflecting a broad spectrum of ages.

- Undisturbed soils with a relatively thick humus layer in some forest types.
- Large trees for the growing conditions.
- Well-developed herbaceous layer with a diverse composition, especially in neutral soils.
- Abundance of lichens and fungi, particularly in acid-based soils.

- Majority of tree species that fall into the late successional class and a conspicuous absence of multiple-stemmed trees (coppices).
- Absence of signs of human disturbance.
- A mosaic of age groupings left as imprints from many natural disturbances of varying sizes.

Whether an old growth stand exhibits any of the features above depends on numerous factors, including forest type, climate, soils, topography, and disturbance history (Leverett, 1996). One should note the influence of difficult growing conditions, where an old-growth community might not meet typical standards. For example, rocky soils, exposed ridge tops, dry, sandy soils, shale barrens, river scours, or maritime or saline conditions may retard forest growth, favor certain species, and affect ecosystem structure and functions.

<u>The effects of patch size and isolation on biodiversity</u>

Habitat loss and fragmentation has several deleterious effects on wildlife. First, there is a direct reduction in the area of available habitat. Conversion of natural area to intensive human use often reduces the population size of species dependent on that habitat type (Dramstad, 1996). It may also reduce diversity by eliminating certain habitats entirely (Dramstad, 1996). Species dependent on these lost habitats (for example, woodpeckers dependent on large snags; salamanders dependent on vernal pools; brook trout dependent on clean, cool streams) may disappear entirely from the affected area. Depending on the lifespan and other biological and demographic characteristics of the flora and fauna in question, local extinction may lag habitat destruction, even if this outcome is inevitable. Thus, the effects of habitat loss on biodiversity may not be immediately apparent.

A second effect of habitat conversion is related to the reduction of patch sizes. Large areas of natural vegetation are usually more effective than small areas for protecting aquifers and watersheds, sustaining viable populations of most interior species, providing core habitat and escape cover for wide-ranging vertebrates, and allowing natural disturbance regimes (Dramstad, 1996). Larger patches also have higher area to perimeter ratios, and thus have a lower degree of exposure to edge effects (Harris, 1989). The area to perimeter ratio is also dependent on patch shape.

According to island biogeography theory (MacArthur and Wilson, 1967; Harris, 1984; Forman and Godron, 1986), species richness in landscape patches depends on patch area:

$S = cA^z$;

where S is the species diversity,

A is the patch area, and

c and z are constants.

Larger patches support a larger variety of habitats, are more likely to be noticed or stumbled on by colonists, support larger populations, which are less vulnerable to extinction, and support animals that require large home ranges (Brown et al, 1990; Hanski, 1997; Tilman and Lehman, 1997). Because driving forces like the weather and reproductive success are variable, plant and animal populations fluctuate in size naturally, and smaller initial populations (i.e., constrained in size by available habitat) are less likely to withstand these oscillations over time. In the absence of compensating colonization, species become extinct in small patches faster than in larger patches (MacArthur and Wilson, 1967; Harris, 1984; Harris, 1988; Hanski, 1997).

Small patches in fragmented landscapes may act as ecological traps by concentrating populations of birds or other animals in areas with insufficient resources, as well as concentrating predators (Heske, 1999). Landscapes with a few, small, isolated patches can be dominated by edge effects, and provide little viable habitat for interior species (With and King, 1999). In simulations by Tilman and Lehman (1997), much more area had to be destroyed to drive a species extinct when large blocks were left intact than when the same undestroyed area was dispersed among many small blocks.

According to Bushman and Therres (1988), 250 acres is the minimum forest size to maintain a viable breeding population of 7 forest interior birds of Maryland. Eight required smaller contiguous forest blocks, and three required more. Top carnivores, many of which have been extirpated from Maryland, require large foraging areas. Brown et al (1990) lists home range requirements for individuals of many wildlife species. Viable populations require much more area than a single individual. A viable population is one that has a high probability (e.g., 95 or 99 percent) of persisting for a long time (e.g., for 100 to 1000 years) (Noss, 1992). In most cases, viable populations are generally on the order of thousands of individuals (Noss, 1992).

Each native species is uniquely adapted to transform and channel energy in an ecosystem, and each plays a role in ecosystem functioning. Ecosystems with higher diversity are generally more efficient (Odum, 1983). For example, diverse communities are more likely to contain species able to utilize different amounts and combinations of limiting resources like nutrients or light; and more likely to have symbiotic relationships. As species are lost from an ecosystem, those that depend on them for food, pollination, or other needs, also begin to disappear. Many interconnections between species are not even known (witness the difficulty of multi-species fishery management, for example). Ecosystem resistance and resilience to stresses is dependent on species composition and diversity. Diverse communities are more likely to contain species tolerant to disturbances like flooding, drought, or pests. The spread of pests is quicker among spatially contiguous hosts. Monocultures like corn or wheat fields are more susceptible to disease or pest outbreaks than diverse systems, and have to be maintained with intense management. Ecosystems with low diversity, like islands or agricultural fields, are also more susceptible to invasion by exotic or weedy species, because of empty niches.

Intermediate levels of disturbance often increase local diversity, especially if they are historic to the site. For example, canopy gaps from windthrow or tree senescence allow the persistence of lightloving and early successional plants in a forested landscape. Periodic flooding maintains hydrophytic vegetation. Predators, at the appropriate grazing efficiency (i.e., not overgrazing), keep prey populations from growing large enough for density-dependent competition. Dominance by the more competitive species is precluded (Denslow, 1985). For example, species-specific herbivory maintains high plant diversity in tropical rain forests (Denslow, 1985). Human management can disrupt the natural disturbance regime, favoring a new suite of species.

Another effect of habitat fragmentation is related to patch isolation. Species adapted to interior forest conditions tend to avoid open areas (and especially urban areas). Isolation is a function of both distance between suitable habitat patches, and the nature of the intervening matrix. For example, patches closer together are less isolated than patches further apart; and patches separated by silviculture or pasture are less isolated than patches separated by roads and development.

Computer simulations by Fahrig (1997) and With and King (1999) demonstrated that the total amount of available habitat had a much greater effect on extinction probability than fragmentation, until <20% of habitat remained, at which point fragmentation became increasingly dominant. Studies of beetles, birds, and mammals cited by With and King (1999) showed similar results: fragmentation effects became important at a threshold of 10-30% habitat remaining. Below this, inter-patch distances increase exponentially, and the spatial arrangement of patches becomes critical (With and King, 1999).

Harris (1984) studied the fragmentation of old-growth forest in the Pacific Northwest. He found that as old-growth habitat patches became isolated from similar surrounding habitat, species with ranges beyond the patch were extirpated, and the number of species reduced (Harris, 1984). Isolation also decreases plant diversity, which further decreases animal diversity (Harris, 1984). Fragmentation can also interfere with seasonal movements, such as salamanders moving to ponds to breed (Loehle, 1999).

The species most vulnerable to extinction in fragmented landscapes have small populations: large animals with large home ranges (e.g., top carnivores), ecological specialists (e.g., with unique habitat requirements), and species with variable populations that depend on patchy or unpredictable resources (Harris, 1984; Harris, 1988; Brown et al, 1990; Hanski, 1997; Tilman and Lehman, 1997). Models by Tilman and Lehman (1997) showed that habitat destruction tends to extirpate species that are superior competitors but poor dispersers. The Baltimore County Department of Environmental Protection and Resource Management (1996) summarized studies of species types most affected by forest fragmentation. These include naturally rare species, wide-ranging species, nonvagile species, species with low fecundity, species dependent on patchy or unpredictable resources, species that are highly variable in population size, ground nesters, and interior forest species. For example, Gibbs (1998) found that low densities, fluctuating populations, high mobility, and specialized habitat needs make woodland amphibians vulnerable to local extinction caused by habitat fragmentation.

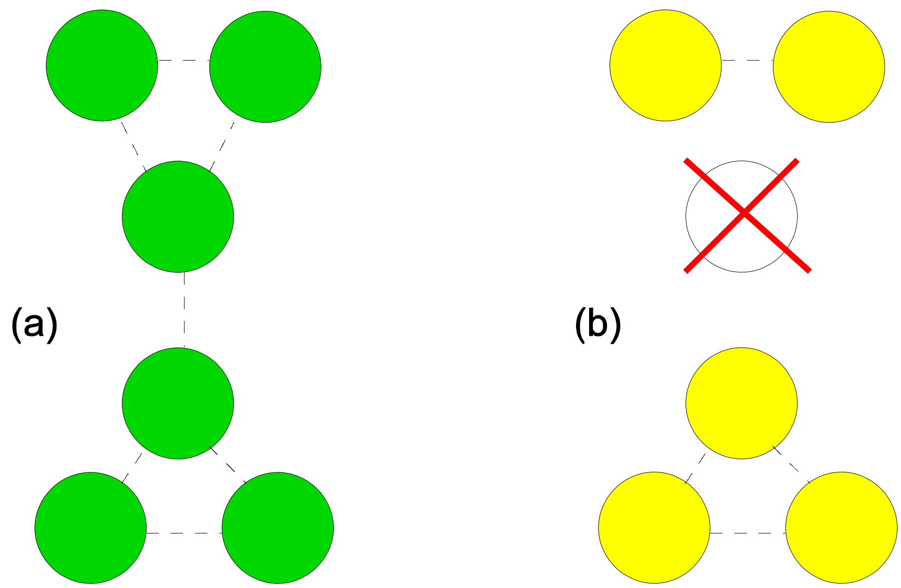
As patch size decreases, and as patches of habitat become more isolated, population sizes, especially of rare species, may decrease below the threshold needed to maintain genetic variance, withstand stochastic events and population oscillations, and meet social requirements like breeding and migration (Harris, 1984; Bowne et al, 1999). Demographic fluctuations can lead to extinction, if the population is too small (Tilman and Lehman, 1997). The size needed to prevent adverse genetic drift is probably higher than the size needed to withstand oscillations (Harris, 1984). Inbreeding within small populations increases the chance that progeny will receive duplicate alleles from a common ancestor, which can lower the vigor and fecundity of species within a few generations, and limit adaptation to changing environmental conditions (Brown et al, 1990). The population size needed to ensure genetic flexibility is even higher; this therefore determines the minimum viable population size (Harris, 1984; Vrijenhoek, 1985). Shrinkage and isolation of the Florida panther's range led to inbreeding and a 95% level of sperm infertility (Harris, 1988). Harris (1984) states that conservation should allow evolution of populations, species, and ecosystems, so they are more adaptive to change. Sufficient genetic variability is required for adaptive flexibility and future evolution; species should be conserved before their numbers drop low enough where they are endangered (Harris, 1984). Genetic information loss in a species as a whole is greatest when local populations go extinct.

Species richness in isolated "islands" depends on their distance to a "mainland" source of colonizers (MacArthur and Wilson, 1967), or in general, the probability of recolonization. Metapopulations are systems of local populations spread throughout the landscape, connected by dispersing individuals (Levins, 1969; Hanski and Gilpin, 1991). Many species with a formerly continuous spatial distribution are turned into metapopulations by habitat fragmentation, as long as they are able to maintain stable local populations somewhere, and disperse successfully enough to recolonize extirpated areas (Hanski and Gilpin, 1991; Robichaud et al, 2002). This is true for both animals and plants (Geertsema et al, 2002).

Some habitat patches support stable populations of a particular species, dependent on both deterministic characteristics (patch size, abiotic composition, biotic community, etc.) and stochastic events (disturbance, population fluctuations, etc.). Patches with stable populations become "sources" of dispersing individuals, whereas less favorable habitat patches may be "sinks", and maintain their populations only by immigration from source patches (Wiens, 1976; Pulliam, 1988; Hanski and Gilpin, 1991; Wells and Richmond, 1995). Large contiguous habitat blocks, such as forest or wetland, appear to be population sources, and smaller fragments appear to be population sinks (Donovan et al, 1995).

Local populations are often unstable, but new immigrants replace losses and revive the population (Smith, 1990). As a local population declines, a population elsewhere that is experiencing overcrowding supplies immigrants to other habitats (Smith, 1990). Increased distance between islands therefore decreases the survival chances of their populations (Smith, 1990; With and King, 1999). Numerous field studies have shown that the probability of a species colonizing an empty patch decreases with increasing isolation from existing nearby populations (Hanski, 1997). Loss of strategically located habitat can be especially devastating to a metapopulation. In the figure below, adapted from Dramstad (1996), a metapopulation is split by loss of key habitat into two smaller, isolated metapopulations, each of which has a greater chance of extinction than before.

Figure 2-1
A metapopulation in six interconnected habitat patches (a) is split by the loss of a key habitat patch into two smaller, isolated metapopulations (b), each of which has a greater chance of extinction than before (modified from Dramstad, 1996).



Habitat generalists seem less affected by forest fragmentation than specialists. Mech and Hallet (2001) compared the effects of corridors on red-backed voles and deer mice. One species is a closed canopy specialist, and requires contiguous closed canopy corridors to disperse and minimize genetic distance in the population. The habitat generalist maintained its population structure in isolated habitats and also in closed canopy forest. Therefore, the population structure of the specialist species was compromised by habitat fragmentation and the absence of connecting corridors.

<u>Dispersal strategies of animals</u>

Animal dispersal has potential genetic and somatic costs and benefits. It lowers inbreeding genetic depression, but also disrupts locally adapted genes, creates hybrid young that aren't as well locally adapted, and creates alleles less suited to the local environment. Dispersal increases individual fitness and fecundity by alleviating overcrowding, resource shortages, and competition with kin, but movement risks include predators, diseases, and unfamiliarity with the terrain. Also, a familiar social environment, locally adapted traditions, and kin associations are lost (Smith, 1990).

Presaturation dispersal is density-independent; it occurs before a population reaches the local carrying capacity. Dispersers are in good condition, are of any sex or age, and have a good chance of surviving to settle in a new area. In contrast, saturation dispersal is density-dependent; it occurs when a population exceeds the local carrying capacity. Dispersers in this case are mostly juveniles and subdominants that must leave to establish their own home ranges, or perish, or at a minimum not breed. Most of these dispersers die; "a few" settle in other areas (Smith, 1990).

Smith (1990) cites the rule of dispersal as "move to the first uncontested site you find and no further." A study of voles showed that if a barrier exists to prevent dispersal, or suitable habitat is not available for colonization, dispersers must return to their home area. Dispersers into optimal habitat had high survival and reproduction rates. Dispersers unable to colonize elsewhere, and having to return to their home area, had low survival rates. Females gained the most from decreased population density (Smith, 1990).

Successfully dispersing animals establish new territories usually several home range diameters away from the original (Forman and Godron, 1986). Animals rarely move in straight lines; rather, they meander (Forman and Godron, 1986). The route that permits the fastest movement is not always the shortest; for example, ridges and valleys are easier to navigate than slopes.

Interior species prefer cover as they travel (Forman and Godron, 1986). For example, forest birds are reluctant to venture into open areas, where the risk from raptor predation is greater and resources are fewer (Bélisle and Desrochers, 2002). Studies by St. Clair et al (1998) and Bélisle and Desrochers (2002) showed that over short distances, forest birds preferred wooded detours to open gaps, regardless of their efficiency. As distances increased, birds tended to employ shortcuts in the open when detour efficiency was low or initial distance in the open was high, but they almost always stayed within 25m of the nearest forest edge (St. Clair et al, 1998; Bélisle and Desrochers, 2002). This behavior may be genetically programmed. Models by Tilman and Lehman (1997) also showed that increased edge is more detrimental to poor dispersers. Animals avoid large inhospitable patches like parking lots (Forman and Godron, 1986). The success of individuals in locating suitable habitat depends on the scale of movement relative to the scale of landscape patchiness (With and King, 1999). Dispersal has a decreasing chance of success as the distance between habitat patches exceeds the ability of the organism to either locate habitat or traverse gaps of unsuitable habitat (With and King, 1999).

<u>Trophic balance in ecosystems</u>

Top predators are especially important because they act as ecosystem regulators (Soule and Terbough,1999). In their absence, trophic structures can become destabilized, with consumers and mesopredators becoming more abundant, and floral recruitment and diversity decreasing (Soule and Terbough,1999). In Maryland, the loss of top carnivores like cougar and wolves, along with increased edge habitat, has led to an overpopulation of white-tailed deer in many areas. Exceeding the regional carrying capacity, deer over-browse tree seedlings and herbs. The native herbs are often replaced by exotic invasives like Japanese stiltgrass (*Microstegium vimineum*) or garlic mustard (*Alliaria petiolata*), which the deer tend to avoid. The decreased plant diversity in turn affects animals dependent on them for food or cover. The reintroduction of top carnivores, or an increase in hunting (especially increased taking of does) might reverse this trend.

As development occurs, forest fragmentation has favored species that can take advantage of edge habitats and can tolerate range losses. These species exhaust and compete for resources, putting pressure on other native species. Large predators are often extirpated from these regions, letting uncontrolled prey populations become overabundant. As a result, the populations of many native species decline, and populations of nuisance species (e.g., Japanese honeysuckle, multiflora rose, starlings, and brown-headed cowbirds) grow.

Deer can be a problem in farm fields. The total estimated loss of corn, soybeans and wheat in Maryland was almost $38 million in 1996 (Curtis and McNew, 1997). The rise in white-tailed deer (*Odocoileus virginianus*) populations in the Northeast has also been associated with increased numbers of deer ticks, and the diseases they harbor, including lyme disease and ehrlichiosis (Moore, 2002). A 1998 DNR press-release reported that vehicle collisions with deer doubled between 1988-1996 (Md DNR, 1998). The property damage that resulted from these accidents was estimated at $9.7 million annually (Md DNR, 1998).

Deer overpopulation can also greatly decrease herbaceous cover and diversity, and prevent recruitment of tree seedlings. When deer densities exceed about 20 per square mile, plant diversity and abundance begin to decline. Many understory plants and tree seedlings are eliminated, including orchid, lily, may apple, white ash, yellow poplar, hemlock, pin cherry, oak, sugar maple, and aspen (Md DNR Forest Service, 2002). Native herbs may be replaced by exotic species like Japanese stiltgrass (*Microstegium vimineum*), garlic mustard (*Alliaria petiolata*), or Japanese honeysuckle (*Lonicera japonica*). Because seedlings are consumed, forests cannot regenerate from disturbances. Forests that survive repeated browsing develop slowly with widely spaced trees of low vigor, poor form, and few species (Md DNR Forest Service, 2002).

Deer thrive in a fragmented habitat such as that created by suburban sprawl. In fact, current deer populations throughout most of Maryland are at an all-time high, with an upward trend continuing (Md DNR Wildlife Division, date unknown). Decreasing fragmentation by protecting and restoring a hub-corridor network may decrease rather than increase deer populations, because network protection would lower the amount of edge habitat. Only in far western Maryland, where the forest is much less fragmented, is the deer population currently stable (Md DNR Wildlife Division, date unknown).

Before European colonization, deer numbers were controlled by much less suitable habitat (fewer forest-field edges) and predation by now-extirpated top carnivores like wolves and cougars. Under current conditions, Curtis and McNew (1997) stated that allowing hunting on farmland, either for free or for lease arrangements, is perhaps the most effective means for controlling local deer populations.

<u>The importance of corridors in a fragmented landscape</u>

Landscape elements that link patches of the same element type (e.g., forest or marsh) together, and have a much longer length than width, are defined as "corridors" (White and Pickett, 1985; Forman and Godron, 1986). Corridors allow wildlife (terrestrial, wetland, and/or aquatic) to pass more easily between habitat blocks, thus increasing available habitat and animal populations (Forman and Godron, 1986; Harris, 1989). They also ease movement of native plant seeds. Corridors linking habitat patches in a landscape are essential for organisms to recolonize unoccupied sites, and for the persistence of metapopulations in fragmented landscapes (Dunning et al, 1992; Tilman et al., 1997; van Dorp et al, 1997; With and King, 1999; Robichaud et al, 2002). The closer the corridors resemble the habitat patches they connect, the more effective they are likely to be as conduits for the widest range of species (Lidicker, 1999).

The importance of corridors to a given species depends on its behavior and habitat requirements, on the age and sex of the individual, on the time of year, and on the nature of the surrounding matrix (St. Clair et al, 1998; Bowne et al, 1999; Szacki, 1999). Many small mammals are not reliant on corridors, although this depends on the peripheral land cover (Mabry and Barrett, 2002). Corridors may be less important to species with movement distances that are very short or very long relative to the landscape, where habitat is ephemeral, or where mortality rates in the matrix are low. However, simulation studies by Söndgerath and Schröder (2002) showed that for species with limited dispersal ability, in a landscape with isolated habitats, stepping stone patches of habitat greatly increase their ability to move from one area to another.

Bier and Noss (1998) reviewed published studies of corridor impacts on population viability. The evidence from well-designed studies demonstrated positive impacts of wildlife corridors on immigration rates, colonization rates, patch occupancy, and species diversity (Bier and Noss, 1998). Ten of the 12 studies allowing meaningful inferences of conservation value offered persuasive evidence that corridors connecting habitats provide sufficient connectivity to improve population viability (Bier and Noss, 1998). None of the studies demonstrated negative impacts of conservation corridors (Bier and Noss, 1998). An important field study by Tewksbury et al. (2002) examined whether corridors are in fact important as links or rather for the increased area they provide. By controlling for patch area and testing alternative corridor functions (such as enabling butterfly movement, pollen movement and fruit set, and seed movement) they found that corridors do in fact enhance dispersal between isolated patches. Similarly, Bélisle and Desrochers (2002) and Robichaud et al (2002) found that woodland corridors can facilitate the movement of forest birds within a fragmented landscape.

Bennett (1999) reported advantages and disadvantages of corridors. Reported advantages included:

1. Assisting the movement of individuals through disturbed landscapes, including:
    a. wide-ranging species that move between habitats on a regular basis;
    b. nomadic or migratory species that move between irregular or seasonally-varying resources;
    c. species that move between habitats at different stages of their life cycle.
2. Increasing immigration rates to habitat isolates which could:
    a. maintain a higher species richness and diversity;
    b. supplement declining populations, thus reducing their risk of extinction;
    c. allow re-establishment following local extinction;
    d. enhance genetic variation and reduce the risk of inbreeding depression.
3. Facilitating the continuity of natural ecological processes in developed landscapes.
4. Providing habitat for many species including:
    a. refuge and shelter for animals moving through the landscape;
    b. plants and animals living within linkages.
5. Providing ecosystem services such as maintenance of water quality, reduction of erosion, and stability of hydrologic cycles.

Reported disadvantages included (Bennett, 1999):

1. Increasing immigration rates to habitat isolates which could:
   a. facilitate the spread of unwanted species such as pests, weeds and exotic species;
   b. facilitate the spread of disease;
   c. introduce new genes which could disrupt local adaptations and co-adapted gene complexes (outbreeding depression), and promote hybridization between previously disjunct taxonomic forms (races, sub-species).
2. Increasing exposure of animals to:
   a. predators, hunting or poaching by humans, or other sources of mortality (e.g., road kills).
   b. competitors or parasites.
3. Acting as 'sink habitats' in which mortality exceeds reproduction, and thus function as a drain on the regional population.
4. Facilitating the spread of fire or other abiotic disturbances.
5. Costs for establishment and management of corridors that could reduce the resources available for more effective conservation measures, such as the purchase of habitats for endangered species.

Bennett (1999) refuted some of the reported disadvantages, stating:

1. “Habitat connectivity is a characteristic feature of natural environments. Protection and restoration of connectivity is not an artificial change to the landscape: rather it is the loss of connectivity and the isolation of natural environments that is an artefact of human land use.
2. “The precautionary principle demands that where knowledge is limited, the prudent alternative is to retain existing natural linkages in case they are beneficial.
3. “The weight of evidence shows that isolation of populations and communities, through loss of intervening habitat, has a detrimental effect.
4. “There is little evidence, as yet, in support of some concerns such as increased mortality in linkages or spread of disease.
5. “Many concerns can be addressed through management, and by the location and dimensions of habitats protected as linkages."

Corridor arrangement and quality are also important to metapopulation survival. High connectivity, i.e., the arrangement of dispersal corridors between suitable habitat patches, allows organisms to better use a landscape's resources. Anderson and Danielson (1997) showed in simulations that connecting all patches with corridors, and maximizing the ratio of interior to peripheral patches, maximized metapopulation size. Adding additional connections had no effect. Patches connected by high-quality corridors (e.g., favorable habitat composition, sufficient width, few breaks, etc.) had few animals lost during dispersal, and stable metapopulations (Anderson and Danielson, 1997). In contrast, poor-quality corridors increased mortality, and decreased metapopulation size (Anderson and Danielson, 1997). Narrow corridors may be completely dominated by edge effects that expose native and migrating flora and fauna to reduced food availability, exotic species, increased predation, nest parasitism, human disturbance, and disease (Forman and Godron, 1986; Harris, 1989; Lidicker, 1999).

Van Dorp et al (1997) simulated the migration of perennial grassland species, and also demonstrated the importance of corridor presence and quality to the persistence of metapopulations. In narrow corridors, most of the dispersed seeds were deposited outside the corridor, which significantly reduced migration rates, especially for species with long-range seed dispersal (Van Dorp et al, 1997). In wide corridors, seed losses were much smaller, and migration rates approached those of continuous habitats (Van Dorp et al, 1997). Dispersal barriers such as corridor absence or gaps may prevent migration of short-range seed species (Van Dorp et al, 1997).

Percolation models by Tilman et al (1997) also showed the importance of corridors in fragmented landscapes. Corridor width was much more important than its length, especially for plant propagules and other organisms unable to adjust their behavior to stay within the corridor (Tilman et al., 1997). Passage of organisms may also be stopped if the corridor is too fragmented (Harris, 1989; Tilman et al., 1997; Lidicker, 1999), or if gaps in the corridor are too great (St. Clair et al, 1998).

The most successful corridors may be those that minimize transit times; this is a function of length, width, and presence of gaps (Lidicker, 1999). There may be an optimal width for each species. Too narrow, and use is inhibited (St. Clair et al, 1998). But too wide, transit time could be slowed by exploratory activity, or territories established and other individuals excluded (Lidicker, 1999). If true, this effect would be scale-dependent; a corridor could be too narrow for some species (e.g., black bears), and too wide for others (e.g., shrews). One solution to this dilemma might be considering width from an ecosystem perspective (e.g., forest with interior abiotic conditions) rather than species-specific perspectives.

Management implications

Noss (1992) listed four fundamental objectives necessary to maintain the native biodiversity of a region in perpetuity:

- Represent, in a system of protected areas, all native ecosystem types and seral stages across their natural range of variation.
- Maintain viable populations of all native species in natural patterns of abundance and distribution.
- Maintain ecological and evolutionary processes, such as disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions, including predation.
- Design and manage the system to be responsive to short-term and long-term environmental change and to maintain the evolutionary potential of lineages.

These objectives in mind, it is clear from the studies cited earlier that the most effective ecological management plan for a fragmented region like Maryland is to establish a system of large, contiguous habitat blocks serving as bioreserves ("hubs" or "core areas"), connected by corridors that allow successful dispersal between them. Different levels of ecosystem hierarchy should be considered (Harris, 1993). The main priority of conservation efforts should be preservation and restoration of breeding habitats. Increasing the quality of non-breeding habitat is also important. All ecosystem types and native species should be represented. Corridors should be strategically located, continuous, sufficiently wide, and with favorable abiotic and biotic composition, to allow successful dispersal of animals and seeds. It is at landscape and regional scales that connectivity is particularly important for conservation (Bennett, 1998). Besides maintaining populations of native species, hubs and corridors can protect water quality and soil, recharge aquifers, abate peak flooding, maintain stream baseflow, and provide human recreation opportunities and other benefits.

Delorme (1998) states, "a natural heritage system attempts to enhance and protect ecosystem structure and function by protecting representative natural areas... Such a system involves identifying natural areas of local or regional significance as nodes or core areas that may be joined through natural or enhanced linkages or corridors." Robinson (1988) recommended managing for native habitat specialists. Areas with a high diversity of habitat specialists, and containing key microhabitats like streams and steep slopes, should be set aside as "natural areas", while areas with few habitat specialists could be managed for other purposes (Robinson, 1988). The Baltimore County greenway plan (Baltimore County Department of Environmental Protection and Resource Management, 1996) gave highest priority to preserving large forest patches with low edge-to-interior ratios, and delineated corridors between them based on satellite data. Harris (1984) recommended a system of old-growth "islands" in the Pacific Northwest, of varying size, surrounded by buffers of long-rotation forest. He proposed that the "islands" vary in size from 62 ac to 1235 ac, with a log-normal size-frequency distribution, and connected in a dendritic pattern by riparian corridors (Harris, 1984). The Southern Appalachian Forest Coalition (1998) proposed maintaining natural ecosystems and viable populations of all native species in the southern Appalachian mountains, by conserving large, high quality core habitats, connecting these with riparian or roadless corridors, supplementing these with buffer areas, and targeting barriers to ecological processes and functions in the conservation areas for restoration or mitigation. Harris (1988) lists examples throughout the Americas where corridors and "stepping stone" habitat islands have been set aside for wildlife habitat and migration. Finally, reserve systems should consider the long-term movement of sessile and non-sessile organisms and communities, changes in climate and ecosystems, and evolution of species (Harris, 1984; 1993).

The National Park system is currently designing wildlife corridors from Yellowstone park in Wyoming to Canada and into Alaska. There is another plan to develop wildlife connecting corridors from Georgia to the Carolinas, into Virginia and West Virginia. It was suggested that Maryland's green infrastructure may be continuous with this network of green hubs and corridors (Degroot (1), date unknown).

Noss (1992) listed six guidelines to follow when designing a biological reserve system:

- Species well distributed across their native range are less susceptible to extinction than species confined to small portions of their range.
- Large blocks of habitat, containing large populations of a target species, are superior to small blocks of habitat containing small populations.
- Blocks of habitat close together are better than blocks far apart.
- Habitat in contiguous blocks is better than fragmented habitat.
- Interconnected blocks of habitat are better than isolated blocks; corridors or linkages function better when habitat within them resembles that preferred by target species.

- Blocks of habitat that are roadless or otherwise inaccessible to humans are better than roaded and accessible habitat blocks.

Public support for land preservation

Ninety percent of respondents in a 1999 national poll agreed that "open spaces make our communities more livable", and 85% said that "parks and open spaces contribute to the property values and economic stability of neighborhoods." (McQueen, 2001). An analysis of public attitudes toward environmental protection and economic growth found that during the 15 years of the study, a majority of Americans (always over 60 percent) valued the environment over the economy (Cordell and Overdevest, 2001). Trends in Maryland are consistent with the United States in general. The majority of Maryland residents support natural land protection to ensure ecological functions such as clean air and habitat, as well as for their natural beauty and the recreation opportunities they provide in Maryland.

A 1995 survey revealed that the majority of Maryland's citizens are in support of public land conservation programs (Maryland Greenways Commission, 1995). The survey results showed that :

- 89% of those surveyed felt that land conservation was a good use of public funds.
- 52% felt that state and local governments were not doing enough to preserve natural resources and open space in Maryland.
- 91% said that some parts of Maryland should be left in their natural state forever.
- Over 80% said that land conservation should keep pace with development.
- 80% felt that parks and natural areas increase the value of nearby properties.
- 76% said they would be willing to pay more for a house with natural areas close by.
- 77% felt that it is important to have natural areas close to where they work and live.
- 44% said they would be inclined to move if existing open space in their community was lost.

A 2001 Mason-Dixon survey of 625 registered voters (Mason-Dixon Polling and Research, 2001) showed overwhelming support for protection of wildlife, clean air and water, and recreation opportunities in state forests:

- 96% of voters felt that it was important to protect wildlife in state forests (82% very important, 14% somewhat important). 86% of voters supported additional public funding for the protection of wildlife.
- 98% of voters felt that it was important for state forests to provide clean water and air (89% very important, 9% somewhat important). 90% of voters supported additional public funding for the protection of clean air and water.
- 88% of voters felt that it was important for state forests to provide recreation and sightseeing. Support was lower for hunting, especially in the metro areas. 79% of voters supported additional public funding for additional recreation opportunities, and 33% for hunting.
- 82% of voters felt that protection of state forests should be a higher priority than logging. Only 3% felt logging should be a higher priority.

- 78% of voters wanted more areas in state forests to be designated as wildlands.
- These trends were consistent not only for the urban counties, but in rural Maryland as well, including Western Maryland and the Eastern Shore.
- Trends were similar for Democrats, Republicans, and Independents.

Economic support for land preservation

Preserving open space stimulates spending by local residents, increases adjacent property values, increases tourism, attracts corporations, and reduces public costs (McQueen, 2001). Odum (1970) estimated that managing 40 percent of the state of Georgia as natural, 10 percent as urban-industrial, 30 percent in food production, and 20 percent in fiber production would maximize ecological services while maintaining the current standard of living.

Investing in parks and greenways helps support local businesses and employment, including vendors of camping equipment, hunting and fishing gear, lodging, food, and other recreation-oriented services (McQueen, 2001). These cater to both local residents and tourists. Based on retail sales, if fishing, wildlife watching and hunting were private corporations, they would have ranked 18th ($37.7 billion), 23rd ($29.2 billion) and 36th ($22.1 billion), respectively, on the 1996 Fortune 500 list (McQueen, 2001). In 1996, nearly 38 percent of the U.S. population 16 years old and older (77 million people) participated in fishing, hunting, and wildlife observation, feeding and photography in the U.S. (McQueen, 2001). They spent over $100 billion on their activities (McQueen, 2001). In 1996, state residents and non-residents spent $1.1 billion on wildlife-associated recreation in Maryland (U.S. Fish and Wildlife Service, 1998). Furthermore, many studies have shown that parks and greenways increase adjacent property values (Bockstael, 1996; McQueen, 2001).

The quality of life of a community is an increasingly important factor in the location decisions of businesses. In one survey, corporate CEOs said that quality of life for employees was the third most important factor in locating a business, behind only access to domestic markets and availability of skilled labor. More than 80 percent of the 450 members of the Sierra Business Council in California and Nevada cited the region's rural landscape and wildlands as a significant attraction of the region. The Trust for Public Land found that access to open space, parks, and recreation was the number one factor used by small businesses in choosing a new location (McQueen, 2001).

Preserving natural ecosystems can help provide a solid tax base because these lands require significantly less in services from the local government (Moore, 2002). A cost-benefit analysis of development versus land preservation for a specific area tend to show a net loss over time for developed lands (Balmford et al, 2002; Moore, 2002). A study by the American Farmland Trust found that residential development costs local governments $1.15 in required public services for every dollar collected in taxes (McQueen, 2001). In contrast, farm and forest land cost only 37 cents for every dollar received from the landowners (McQueen, 2001). Numerous studies have shown that natural lands are not a drain on the local tax base and, in addition, provide ecological services that prevent or reduce public costs that might otherwise be incurred (e.g., water treatment, stream restoration, flood damage) (Costanza et al, 1997; McQueen, 2001; Moore, 2002).

Balmford et al (2002) found that conserving natural land is "a strikingly good bargain." They summarized studies that showed an economic value of land at least 14% to 75% greater when in a natural state, compared to after conversion to intensive human use. A globally effective network of protected areas would cover around 15% of land area in each biome, and 30% of the world's seas (Balmford et al, 2002). Balmford et al (2002) calculated that this would cost about $45 billion/year over a 30 year period, which could be met by redirecting less than 5% of existing perverse subsidies (government tax incentives and subsidies whose long-term costs exceed their short-term gains). Given the ecosystem service values reported by Costanza et al (1997), and subtracting the gains from converting to intensive human use, the benefits for conserving this land would give an annual net economic value of $4400-$5200 billion, a return on investment of at least 100 to 1 (Balmford et al, 2002). These authors considered this to be a conservative estimate.

Need for a green infrastructure focus

Ecosystem conservation and management should be proactive, recognize the importance of species interactions, ensure ecosystem integrity, preserve habitat, conserve biodiversity, recognize key species and their roles, establish refuges and protected areas, and be adaptive (Houde, 1999). Since the ability to predict ecosystem behavior is limited, management should be precautionary; when in doubt, protect natural systems rather than maximize product yield (Houde, 1999). Although holistic, far-seeing approaches may be politically unpalatable, the consequences of permanent or long-term environmental damage are far worse.

Mechanistic engineering solutions to ecosystem service losses often ignore the complexity of natural systems, and often therefore fail, or create new problems. Similarly, single species management fails to recognize the importance of other species, inter-species interactions, and interactions with the surrounding environment. It is no surprise that reductionist approaches such as maximizing yields of a single species create a vast host of problems, many of which adversely impact even the species of interest. Systems approaches, such as ecosystem management, systems ecology, or ecological economics, attempt to consider all important stages and processes within the area and time of interest, as well as influences from outside. Human interactions (management, markets, etc.) belong in these analyses.

Focusing on the conservation of habitats and multiple species is both cheaper and more likely to succeed than the targeting of single species or populations (Scott et al, 1993; Jennings, 2000). Jennings (2000) stated that "waiting until a species is actually endangered or threatened with extinction results in reactive management activities that are expensive, exhibit a low probability of success, and are often socially divisive."

A green infrastructure training program coordinated by the U.S. Forest Service provided the following problem statement (unpublished):

> "Conservation today suffers from a tyranny of specialization -- the death from a thousand cuts. Most conservation efforts in this country are still reactive not proactive; haphazard not systematic; piecemeal not holistic; single purpose not multi-

> functional; too focused on the local or project-level scale and not enough on the watershed, regional or landscape scales critical to understanding the environmental context. We seem to dwell on individual pieces of the land development-land conservation puzzle and fail to take advantage of the strategic linkages between resources, tools, programs and people. Conservation efforts too often result in protected 'islands' too isolated to deliver their promise."

While Maryland's Greenways Program has attempted to address many of the issues noted in the above statement, it was felt by many that more emphasis on an ecological network was warranted. The green infrastructure network attempts to identify the best remaining ecological lands in Maryland as well as potential restoration areas. The purpose of this work is to:

- Systematically identify and protect ecologically important lands;
- Address problems of forest fragmentation, habitat degradation and water quality;
- Emphasize the role of a given place as part of a larger interconnected ecological system;
- Consider natural resource and ecosystem integrity in the context of existing and potential human impacts to the landscape;
- Maximize the influence and effectiveness of public and private conservation investments;
- Promote shared responsibilities for land conservation between public and private sectors; and,
- Guide and encourage compatible uses and land management practices.

As Maryland's population expands, development increases. As of 2000, the majority of the state's important ecological lands were privately owned and without easements on development. Only 26% of these lands were in public ownership or easements (Moore, 2002). To preserve ecological functions, while accommodating development, we need to anticipate growth and protect the environment concomitantly. It is important to consider the scientific lessons learned when planning for future development. Through public land acquisition and appropriate land management, it is possible to protect Maryland's natural world while anticipating development.

Chapter 3
STUDY AREA AND METHODOLOGY OVERVIEW

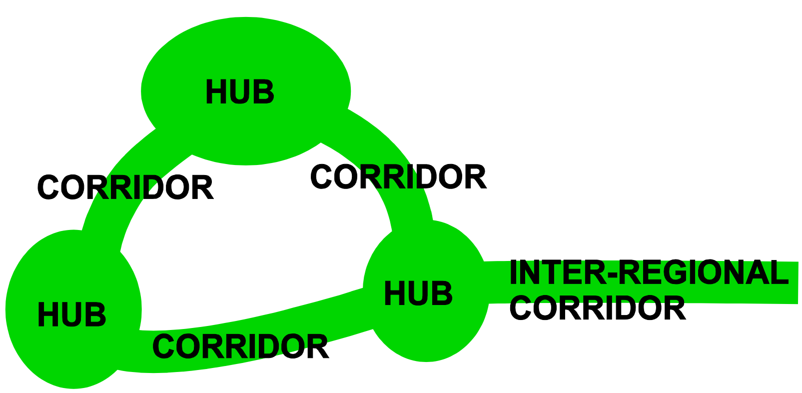
The Green Infrastructure Assessment was carried out within the state of Maryland, plus adjacent land up to the nearest paved road or major river in neighboring states. In western Maryland, the state boundary, which is not necessarily a natural boundary, was used where blocks of forest extended far into Pennsylvania, but not far into Maryland.

Maryland ranges from the Atlantic Ocean to the Appalachian Mountains, spanning five physiographic regions (Coastal Plain, Piedmont, Blue Ridge, Ridge and Valley, and Appalachian Plateau). Each region is defined by unique geology and varying climate, and thus different assemblages of flora. Maryland is important geographically, at the southern limit of many northern plant and animal species, and at the northern limit of many southern plant and animal species (Williams, 1991).

Network design overview

The concept underlying green infrastructure protection (see Fig.3-1) is to link large, contiguous blocks of ecologically significant natural areas (hubs) with natural corridors that create an interconnecting network of natural lands across the landscape. Such connection can help to offset the functional losses caused by fragmentation.

Fig. 3-1
Hub-corridor conceptual diagram.



The first step of this assessment was a review of pertinent ecological and environmental planning literature, and collection of relevant data. Some findings from the literature are summarized above in the Background chapter. Many of the data we used are listed in Appendix A. We were limited to data that could be placed in a Geographic Information System (GIS), such as satellite-derived land cover and elevation, locations of roads and streams, and ground-sampled animal and plant locations. Furthermore, for consistency, we considered only data available statewide. Some counties had created more accurate maps of streams, floodplains, etc. than those covering the entire state, but using these would have spatially biased the analyses.

Based on a review of the literature and available data, we performed a coarse-filter landscape analysis, striving to include a full range of ecosystem elements. This initial analysis, described in Weber and Wolf (2000), used GIS data to identify an interconnected network of hubs and corridors at a resolution of about 120 feet. Within the network, areas were evaluated and ranked within their physiographic region for a variety of ecological and development risk parameters, as well as composites of these. These relative rankings were done at two different scales: by individual hub or corridor, and by individual cell (about a third of an acre). The goal was to identify those areas most important ecologically, and most at risk of loss to development. From these spatial models, maps were created of both the entire network within a given region, and conservation priorities within the network.

The initial model's methodology and map output were reviewed by numerous scientists and planners both within and outside DNR, over about a one year period. Based on their recommendations and further literature reviews, the model was revised. Methodologies were also discussed with scientists and planners working on similar projects, such as the Florida Greenways Project, recently published in University of Florida Geo-Facilities Planning and Information Research Center (1999) and in Hoctor et al (2000).

The revised green infrastructure model, described in more detail in subsequent chapters and appendices, was also reviewed by scientists and planners within and outside DNR. Furthermore, areas were added or subtracted based on comments from county planners. The maps published in Maryland Greenways Commission (2000) are a result of this revised model and county feedback.

As before, areas within the revised network were evaluated and ranked within their physiographic region for a variety of ecological and development risk parameters, as well as composites of these. These relative rankings were again done at two different scales: by individual hub or corridor, and by individual cell. Furthermore, gaps, which are areas of agriculture, mining, or other human land uses within the ecological network, were evaluated for their restoration potential. These evaluations are discussed in greater detail in the following chapters.

Areas within the green infrastructure have been targeted for conservation and restoration activity, have been incorporated into the comprehensive plans of some counties, and have been used to guide other natural resource programs. Aerial and field validation of green infrastructure maps is performed before specific conservation or restoration action is taken, such as purchasing properties or development rights, or restoring lost wetlands.

The green infrastructure model and maps will continue to be revised based on the best available data. Because the computations are time-consuming, and because validation reviews are necessary, it is not projected that updates will occur more frequently than once every 3-5 years. The Green

Infrastructure Assessment was used as a prototype for developing conservation plans for the Delmarva peninsula (Delmarva Conservation Corridor) and the Chesapeake Bay watershed (Resource Lands Assessment). It has also inspired similar efforts in other states and regions. In turn, lessons learned from developing these models will be considered when the Maryland model is updated.

Chapter 4
IDENTIFICATION OF THE NETWORK

A multi-step, and iterative, process was used to arrive at the mapped green infrastructure identified in the Greenways Atlas and used to guide land acquisition activities of the Maryland Department of Natural Resources. The model that was developed was peer reviewed and its results tested against other approaches to identifying important natural resource lands. Some ground-truthing was also provided by local government review of both the model and the resulting maps, and additional on-the-ground verification is being carried out through field visits.

Identification of the components

As shown in the figure in the preceding chapter, there are two primary components of the network that were mapped in the Greenways Atlas. The need to protect the ecological functioning of the network from incompatible landscape surroundings suggests delineating a transitional buffer around the network.

Locating the hubs

Hubs in the green infrastructure network represent the most important large ecological patches remaining in Maryland. Maintaining them as open space and being careful about what sort of development happens around them are vital to retaining the state's biological diversity in the face of continued human transformation of the landscape. Hubs are areas critical to many species and/or to particular life stages of multiple species - interior forest, for example, is essential for nesting success for many species of songbirds, while sensitive species areas represent the presence of one or more rare, threatened or endangered species of plant or animal or other unique natural community. Large blocks of contiguous forest are necessary, too, to support forestry as a continuing, and regionally very important, economic activity.

Hubs contain one or more of the following:

- areas containing sensitive plant or animal species;
- large blocks of contiguous interior forest (at least 250 contiguous acres, plus a 300 foot transition zone);
- wetland complexes with at least 250 acres of unmodified wetlands;
- streams or rivers, and their associated riparian forest and wetlands, with:
    - aquatic species of concern,
    - representative populations of the full suite of native fish, amphibians, and reptiles (complementary watersheds from Southerland et al, 1998),
    - rare coldwater or blackwater ecosystems, or
    - importance for anadromous fish; and
- conservation areas already protected by public (primarily DNR or the federal government) and private organizations like The Nature Conservancy or Maryland Ornithological Society.

In the model, the above features were identified from GIS data (see Appendices), and combined. Intensive human land uses (development, agriculture, and quarries) and major roads were excluded, natural areas less than 100 contiguous acres were dropped, adjacent forest and wetland was added to the remaining hubs, and the edges were smoothed to eliminate narrow tendrils.

Finally, buffers were added around potential migration paths, wetlands, streams, and shorelines within hubs. This extended the boundaries of hubs up to 550 feet in some places. Many of these extensions contain agriculture or other intensive human land uses, and would benefit from restoration. For mapping purposes, these buffers were added to their associated hubs.

<u>Linking hubs with corridors</u>

Corridors in the green infrastructure network are linear features, at least 1,100 feet wide, linking hubs together to allow animal and plant propagule movement between hubs. The hope behind maintaining this pattern is that there will be enough populations of species in the discrete hubs within a region that any localized extinction will be offset by movement between hubs, with recolonization of the hub that experienced the extinction. The corridors delineated in many cases follow prominent features like streams or ridges. In other locations they may be less intuitive, based rather on remaining pathways of upland natural vegetation in a landscape dominated by human modification. An effort was made to avoid roads and urban areas in the methodology used to identify possible corridors. To function effectively, corridors should be wide enough to provide interior conditions for habitat specialists (favorable microclimate, protection from edge predators and invasive exotics, etc.), as well as protecting the hydrology and water quality of streams and wetlands contained within them.

Corridor identification and delineation (see Appendix B for details) were based on many sets of data, including land cover/land use, wetlands, roads, streams, slope, floodplains, Maryland Biological Stream Survey (MBSS) aquatic resource data, and fish blockages. Linkages were tailored to three different ecotypes: terrestrial, wetland, and aquatic. For each of these ecotypes, core areas were identified within hubs, and a "corridor suitability" layer was created based on land cover, stream presence, riparian area width, aquatic community condition, presence or absence of roads, slope, and land management "impedance" to animal and plant propagule movement. Impedance, which is the inverse of suitability, measures the degree to which the landscape parameter inhibits wildlife use and movement. For example, urban land cover has a much higher impedance than forest.

After creating a composite impedance or suitability layer for each ecotype, we used a GIS technique called least-cost path analysis to determine the best ecological paths between core areas and, thus, hubs. Here, cost refers to the difficulty for wildlife to traverse the landscape along a particular route. The pathway between two given core areas with the fewest obstacles (like roads and development), and the most favorable habitat (like forest and wetlands), was the least-cost path. A program was written in Arc Macro Language (AML), using the ARC GRID costdistance and costpath functions, the core layers, and the corridor suitability surfaces, to determine least-cost paths between core areas. The costdistance function calculates for each cell the least-accumulative-cost distance over the suitability surface to a source cell or a set of source cells (ESRI, 1997). The costpath function produces an output grid that records the least-cost path(s) from selected cell(s) in the destination grid, to the closest source cell in terms of cost distance (ESRI, 1997). The program delineated a 1-cell wide pathway between core areas with the lowest cumulative resistance to wildlife movement.

In general, corridor preference, based on literature reviews, was given to streams with wide riparian buffers and healthy aquatic conditions (e.g., Harris, 1984; Forman and Godron, 1986; Brown et al., 1990; see background chapter for more). Other good wildlife corridors included ridge lines, valleys, and forest. Urban areas, roads, and other unsuitable features were avoided. Since Maryland historically was dominated by forest (Besley, 1916; Powell and Kingsley, 1980), the terrestrial connections link large areas (at least 100 ac) of interior upland forest within hubs. Impedance values are listed in Table 4-1. These values were combined to create a composite corridor suitability layer (see Appendix B for details). Figure 4-1 shows the upland suitability surface and connections (least cost paths) for part of Maryland. Wetland linkages were between wetlands of special state concern (WSSC) or large, unmodified wetlands (at least 100 ac) within hubs. These core wetlands were best linked by natural waterways and wetlands (Table 4-2; Fig. 4-2). Salt marshes were also linked by estuaries and bays, which were not included explicitly in the analysis. Core areas for fresh-water aquatic communities were lakes and rivers, or streams with high biotic integrity, within hubs determined previously. These were best linked by natural waterways with riparian forest cover or adjacent wetlands, and without fish blockages (Table 4-3; Fig. 4-3).

Table 4-1
Impedance parameters and weightings for upland connections

Feature	Data source	Impedance value	Comments
Open water, within 500 feet of shore	NLCD	150	
Open water, greater than 500 feet from shore	NLCD	Infinite	Unsuitable for terrestrial wildlife. Distance of 500 feet was picked arbitrarily, but reflected the difficulty for many species to cross large rivers or bays.
Low intensity development	NLCD	Infinite	Considered impassable or avoided for most wildlife
High intensity residential	NLCD	Infinite	Considered impassable or avoided for most wildlife
High intensity commercial/industrial	NLCD	Infinite	Considered impassable or avoided for most wildlife
Bare rock/sand	NLCD	150	
Quarries/strip mines	NLCD	500	
Transitional barren	NLCD	150	
Deciduous forest	NLCD	50	
Evergreen forest on western shore	NLCD	50	probably should be increased
Evergreen forest on eastern shore	NLCD	100	high probability of pine plantation, with low structural and floristic diversity
Mixed forest	NLCD	50	
Hay/pasture	NLCD	150	
Row crops	NLCD	250	
Urban grass	NLCD	250	
Woody wetlands (except temporarily flooded)	NLCD, NWI	100	
Woody wetlands (temporarily flooded)	NLCD, NWI	50	
Emergent herbaceous wetlands	NLCD	150	

Feature	Data source	Impedance value	Comments
Riparian forest (adjacent to streams)	NLCD, MDP streams	subtract 25	reflects added suitability for water availability, and additional niches in riparian habitat. Ditches were not included.
Interior forest (>300 feet from edge)	NLCD	subtract 13	reflects added suitability for interior forest dwelling species, although edge species like deer, quail, bobcat, etc., would prefer edge habitat.
117 ft from high-intensity dev.	NLCD	add 950	Urban development is a source of disturbance, including runoff, pollutants, microclimate changes, noise, human disturbance, harassment of wildlife by pets, exotic species, etc. (Brown et al, 1990). We considered this disturbance effect to fall off with the inverse of distance from the source.
165 ft from high-intensity dev.	NLCD	add 518	
234 ft from high-intensity dev.	NLCD	add 212	
261 ft from high-intensity dev.	NLCD	add 134	
$300 ft from high-intensity dev.	NLCD	add 0	
117 ft from low-intensity dev.	NLCD	add 450	
165 ft from low-intensity dev.	NLCD	add 234	
234 ft from low-intensity dev.	NLCD	add 81	
261 ft from low-intensity dev.	NLCD	add 42	
$300 ft from low-intensity dev.	NLCD	add 0	
Primary state roads and interstate highways	SHA roads	5000	Significant barriers - virtually impassable
Secondary state roads	SHA roads	1000	Significant barriers
County roads	SHA roads	500	Significant barriers to many spp, although less so than major roads
Bridges	SHA roads	300	A source of disturbance, but can be passed under
0-8% slope	DEM	add 0	Areas of moderate or steep slope are more difficult to traverse. Ridgelines and valleys make good natural corridors.
9-15% slope	DEM	add 2	
16-25% slope	DEM	add 5	
>25% slope	DEM	add 10	
Protected land	Protected lands files	subtract 5	Reflects more favorable management
Hubs in top ecological tier	GI	subtract 6	Hubs are defined as blocks of suitable habitat, and would serve as favorable nodes in the network.
Hubs in middle ecological tier	GI	subtract 4	
Hubs in bottom ecological tier	GI	subtract 2	
Not in hub	GI	subtract 0	

Fig. 4-1
Upland corridor suitability surface and potential connections (least cost paths) for part of Maryland.

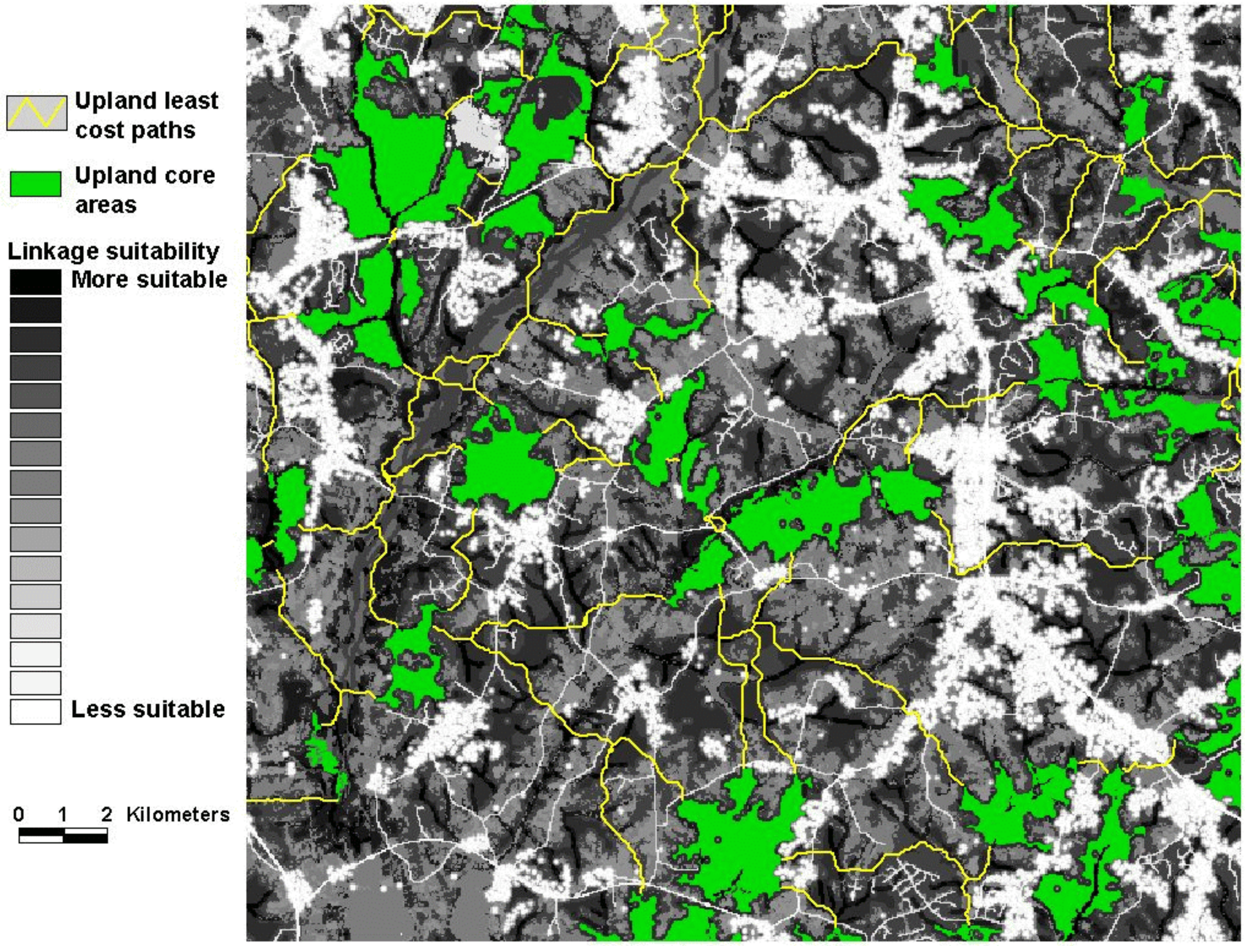


Table 4-2
Impedance parameters and weightings for wetland connections

Feature	Data source	Impedance value	Comments
Open water, within 500 feet of shore	NLCD	150	
Open water, greater than 500 feet from shore	NLCD	300	
Low intensity development	NLCD	Infinite	Considered impassable or avoided for most wildlife
High intensity residential	NLCD	Infinite	Considered impassable or avoided for most wildlife
High intensity commercial/industrial	NLCD	Infinite	Considered impassable or avoided for most wildlife
Bare rock/sand	NLCD	225	
Quarries/strip mines	NLCD	650	
Transitional barren	NLCD	275	
Deciduous forest	NLCD	225	
Evergreen forest	NLCD	225	probably should be increased
Mixed forest	NLCD	225	
Hay/pasture	NLCD	250	
Row crops	NLCD	325	
Urban grass	NLCD	325	
Woody wetlands	NLCD	50	
Emergent herbaceous wetlands	NLCD	50	
Wetlands of Special State Concern	WSSC	25	Contain rare wetland spp; try to include in the conservation network wherever possible
Unmodified wetlands	NWI	50	For NWI wetlands not identified by NLCD, they were added if not human-modified (ditched, drained, excavated, impounded, etc.)
$ 300 ft riparian buffer (forest or wetland)	NLCD, MDP streams	75	Streams or shorelines with riparian buffers were considered more suitable for wetland species. Calculated distance of each stream or shoreline cell to the nearest non-forest, wetlands, or water cell. Ditches were not included.
253 ft riparian buffer (forest or wetland)	NLCD, MDP streams	81	
234 ft riparian buffer (forest or wetland)	NLCD, MDP streams	84	
214 ft riparian buffer (forest or wetland)	NLCD, MDP streams	87	
144 ft riparian buffer (forest or wetland)	NLCD, MDP streams	96	
117 ft riparian buffer (forest or wetland)	NLCD, MDP streams	100	
no riparian buffer (forest or wetland)	NLCD, MDP streams	150	
Interior forest (>300 feet from edge)	NLCD	subtract 13	reflects added suitability for interior forest dwelling species.
117 ft from high-intensity dev.	NLCD	add 950	Urban development is a source of disturbance, including runoff, pollutants, microclimate changes, noise, human disturbance, harassment of wildlife by pets, exotic species, etc. (Brown et al, 1990). We considered this disturbance effect to fall off with the inverse of distance from the source.

Feature	Data source	Impedance value	Comments
165 ft from high-intensity dev.	NLCD	add 518	
234 ft from high-intensity dev.	NLCD	add 212	
261 ft from high-intensity dev.	NLCD	add 134	
$300 ft from high-intensity dev.	NLCD	add 0	
117 ft from low-intensity dev.	NLCD	add 450	
165 ft from low-intensity dev.	NLCD	add 234	
234 ft from low-intensity dev.	NLCD	add 81	
261 ft from low-intensity dev.	NLCD	add 42	
$300 ft from low-intensity dev.	NLCD	add 0	
Primary state roads and interstate highways	SHA roads	5000	Significant barriers - virtually impassable
Secondary state roads	SHA roads	1000	Significant barriers
County roads	SHA roads	500	Significant barriers to many spp, although less so than major roads
Bridges	SHA roads	300	A source of disturbance, but can be passed under
0-8% slope	DEM	add 0	Areas of moderate or steep slope are more difficult to traverse. Ridgelines and valleys make good natural corridors.
9-15% slope	DEM	add 2	
16-25% slope	DEM	add 5	
>25% slope	DEM	add 10	
Protected land	Protected lands files	subtract 5	Reflects more favorable management
Hubs in top ecological tier	GI	subtract 6	Hubs are defined as blocks of suitable habitat, and would serve as favorable nodes in the network.
Hubs in middle ecological tier	GI	subtract 4	
Hubs in bottom ecological tier	GI	subtract 2	
Not in hub	GI	subtract 0	

Fig. 4-2
Wetland corridor suitability surface and potential connections (least cost paths) for part of Maryland.

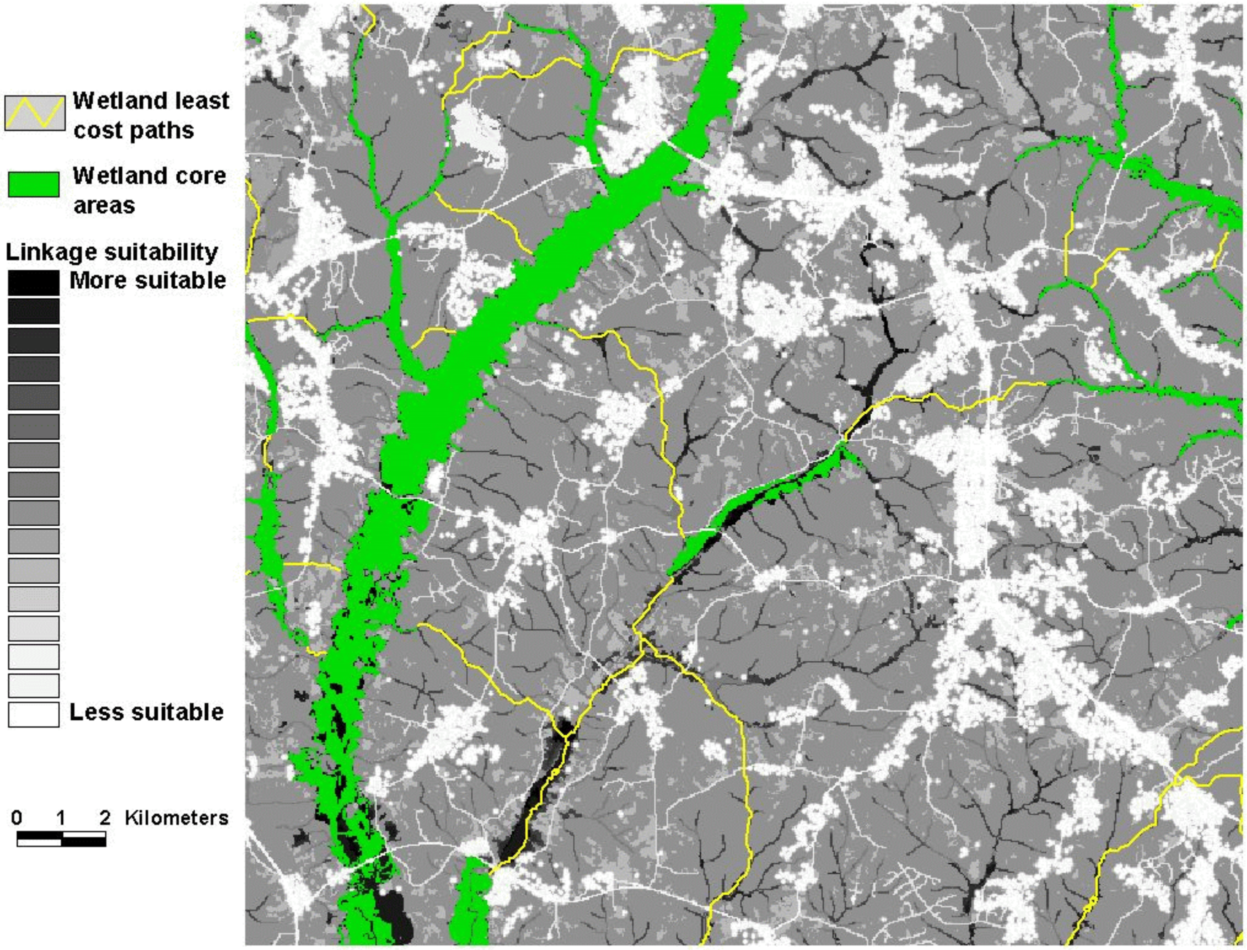
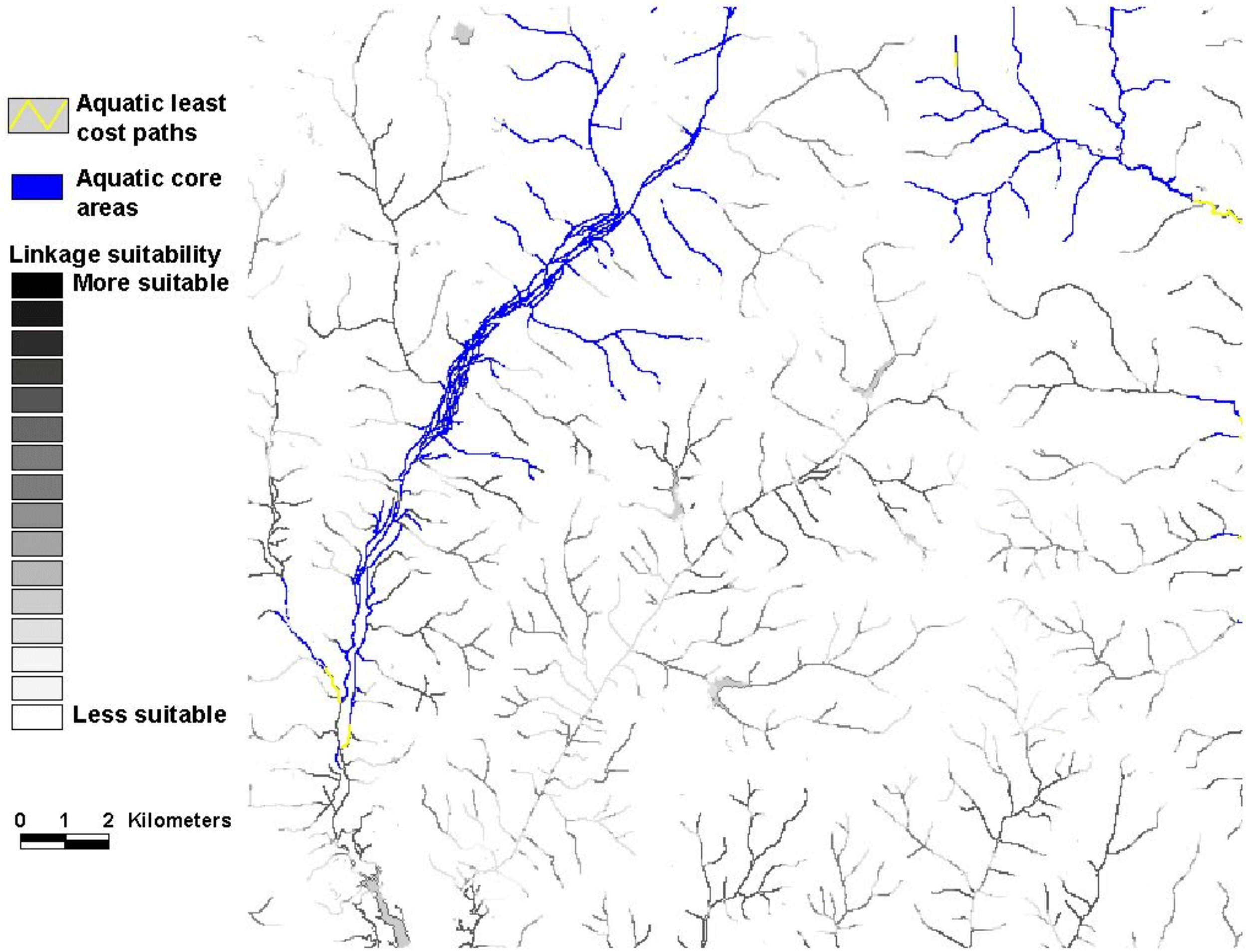


Table 4-3
Impedance parameters and weightings for aquatic connections

Feature	Data source	Impedance value	Comments
Open water	NLCD	100	
All other land classes	NLCD	Infinite	Fish and other water-dependent species cannot move over land.
Permanently flooded wetlands	NWI	150	most were classified as open water in NLCD
$ 300 ft riparian buffer (forest or wetland)	NLCD, MDP streams	25	Streams or shorelines with riparian buffers were considered more suitable for aquatic species. Riparian buffers stabilize shore banks, shade water (thus moderating water temperature), trap sediment and nutrients, increase instream habitat and detritus, etc. Calculated distance of each stream or shoreline cell to the nearest non-forest, wetlands, or water cell. Ditches were not included.
253 ft riparian buffer (forest or wetland)		31	
234 ft riparian buffer (forest or wetland)		34	
214 ft riparian buffer (forest or wetland)		37	
144 ft riparian buffer (forest or wetland)		46	
117 ft riparian buffer (forest or wetland)		50	
no riparian buffer (forest or wetland)		200	
Benthic Macroinvertebrate Index score = 8-10 (good)	MBSS	subtract 5	The Benthic Macroinvertebrate Index score was developed using Maryland Biological Stream Survey (MBSS), Targeted Watershed Project, and Rapid Bioassessment Program data. Comparable sampling and scoring methods were used to develop an index from these programs. If there were multiple sites on the stream reach, the score was obtained by averaging their IBI scores and converting back to a value between 1 and 10.
Benthic Macroinvertebrate Index score = 4-7.9 (poor to fair)	MBSS	add 0	
Benthic Macroinvertebrate Index score = 1-3.9 (very poor)	MBSS	add 5	
Fish Index of Biotic Integrity (IBI) score = 8-10 (good)	MBSS	subtract 5	The Fish Index of Biotic Integrity (IBI) score was developed using Maryland Biological Stream Survey (MBSS), Targeted Watershed Project, and Rapid Bioassessment Program data. Comparable sampling and scoring methods were used to develop an index from these programs. If there were multiple sites on the stream reach, the score was obtained by averaging their IBI scores and converting back to a value between 1 and 10.
Fish Index of Biotic Integrity (IBI) score = 4-7.9 (poor to fair)	MBSS	add 0	
Fish Index of Biotic Integrity (IBI) score = 1-3.9 (very poor)	MBSS	add 5	
One or more rare or endangered species present, or three or more threatened or candidate species present.	MBSS	subtract 10	The Aquatic Species of Concern Index was developed using Wildlife and Heritage division listing information for amphibian, fish, crayfish and mussel species. This variable was not averaged; if there were 3 sites on the reach, it was scored with the site that had the best combination of rare species. The index varied between 1-10.
1-2 threatened or candidate species present.	MBSS	subtract 5	
No threatened or candidate species present.	MBSS	subtract 0	
Brook trout present	MBSS	subtract 5	Indicator species of high water quality (for cold high-gradient streams)
Dam	Maryland fish passage program database	10000	Presence of known fish blockages. Only streams used by anadromous fish had data. Mostly on Coastal Plain.
Pipe Culvert		500	
Fishway		200	
Gaging Station Weir Having Vertical Drop		2000	
Gabion		5000	
Pipeline Crossing		200	
Arch Culvert		500	

Feature	Data source	Impedance value	Comments
Box Culvert		500	
Raised Culvert Present; Type Not Determined		2000	
Tide Gate		2000	
Beaver Dam		500	
Log/debris		200	
Other		5000	
Bridge		50	
117 ft from high-intensity dev.	NLCD	add 950	Urban development is a source of disturbance, including runoff, pollutants, microclimate changes, noise, human disturbance, harassment of wildlife by pets, exotic species, etc. (Brown et al, 1990). We considered this disturbance effect to fall off with the inverse of distance from the source.
165 ft from high-intensity dev.	NLCD	add 518	
234 ft from high-intensity dev.	NLCD	add 212	
261 ft from high-intensity dev.	NLCD	add 134	
$300 ft from high-intensity dev.	NLCD	add 0	
117 ft from low-intensity dev.	NLCD	add 450	
165 ft from low-intensity dev.	NLCD	add 234	
234 ft from low-intensity dev.	NLCD	add 81	
261 ft from low-intensity dev.	NLCD	add 42	
$300 ft from low-intensity dev.	NLCD	add 0	
Protected land	Protected lands files	subtract 5	Reflects more favorable management
Hubs in top ecological tier	GI	subtract 6	Hubs are defined as blocks of suitable habitat, and would serve as favorable nodes in the network.
Hubs in middle ecological tier	GI	subtract 4	
Hubs in bottom ecological tier	GI	subtract 2	
Not in hub	GI	subtract 0	

Fig.4-3
Aquatic corridor suitability surface and potential connections (least cost paths) for part of Maryland.



The corridors identified by the least-cost path analysis were then assigned a width according to the neighboring topography and land cover. Where corridors followed streams, we buffered streams 550 feet on each side. Thus, the corridor would contain 500 feet of interior conditions along its path, and 300 feet of edge transition on either side. If the floodplain exceeded this distance, the corridor was defined by the 100-year floodplain, up to a maximum of 1000 ft from the stream; or by ridge-to-ridge distance where floodplain data were unavailable. Where corridors were not along streams, we buffered the least-cost path a distance of 550 feet. The width of corridors was then extended to account for compatible landscape features, such as adjacent forest or wetlands. “Nodes” were defined as patches of interior forest, plus their edge transition; unmodified wetlands, with an upland buffer; sensitive species areas; or protected areas along linkages between hubs. Only natural cover was included. Nodes serve as “stepping stones” or “rest stops” for wildlife movement along corridors, making successful crossings between hubs more likely. For mapping purposes, nodes were added to their associated corridors.

Delineation of compatible land use buffers

A buffer of low-intensity land use was defined around the entire green infrastructure network. This compatible use buffer was defined as existing natural land, silviculture, agriculture, or lawns up to one mile from hubs or corridors, or to the nearest major road. This buffer was not mapped in Maryland Greenways Commission (2000), but could be used to help guide agricultural preservation activities. From an ecological perspective, preserving agriculture could protect the green infrastructure from high-intensity disturbances associated with urban development. From an economic perspective, it could protect a disappearing agriculture base from urban sprawl. And from an aesthetic perspective, a protected agricultural buffer area could maintain large swaths of rural landscape.

Review, evaluation and revision

Green infrastructure model output was reviewed by field ecologists and county planners, and compared to a forest reserve system proposed by Baltimore County's Department of Environmental Protection and Resource Management (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Hub locations were largely consistent with existing natural areas according to these sources, although some small features and undigitized rare species locations were missed.

Field investigations on the Eastern Shore showed that although, in general, the green infrastructure model did a good job of mapping blocks of forest and wetlands, it did not adequately identify mowed areas along ditches. These often failed to show up on satellite imagery. Further, the stream files missed many first-order streams and ditches. When these are adequately mapped, as was done by Ralph Tiner (Tiner, 2000) for the Nanticoke and Coastal Bays watersheds, the model, especially its restoration component, will be revised to reflect the presence of ditches and channelized streams.

County feedback

Maps of green infrastructure model output were reviewed by county planning and parks and recreation departments. Several dozen areas were suggested as additional inclusions, as either hubs or corridors. In most cases, these were county parks or other public lands missed by the model. If these areas contained at least 100 ac of contiguous natural area (forest, wetland, beach, etc.), or if they were adjacent to modeled hubs or corridors, they were added to the proposed network.

Otherwise, they were not added. Other additions included stream or river valleys being targeted by counties for conservation and/or restoration, such as Watts Branch, Southwest Branch, Winters Run, Little Bennett Creek, Deer Creek, and the Monocacy River. Some riparian corridors were adjusted to retain entire stream valleys. For example, Deer Creek was buffered along its entire mainstem, amending the modeled corridor, which jumped out of the riparian zone where the river passed through agriculture. Additions to mapped green infrastructure stemming from county comments totaled 34,947 acres (an increase of 1.32%).

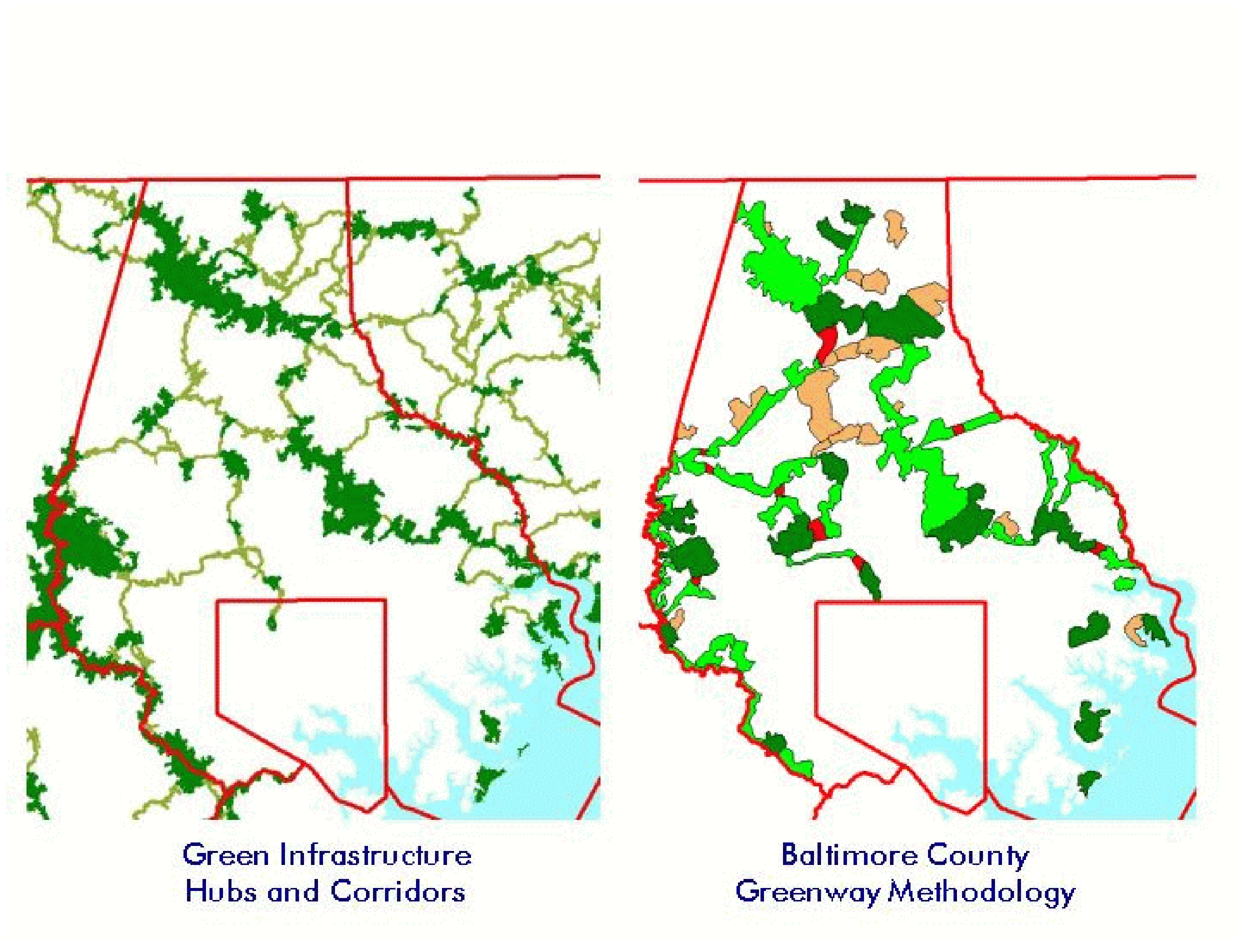
Conversely, several areas were suggested for deletion. Most of these were areas that had been developed since the model source data were acquired. In a few other cases, proposed corridors were too carved up into parcels to make implementing a protection program feasible, and alternative routes which were more protected were suggested. ADC street maps were also referenced to omit unfeasible corridors. Most of the 23 subtractions were in the fast-growing central and southern portions of the state. 9086 acres (0.34%) were subtracted from the model output.

Further additions came from the Baltimore County greenway model (see Baltimore County Department of Environmental Protection and Resource Management, 1996). Areas identified as hubs or corridors by this model (see Fig.4-4), as natural areas according to both NLCD and MDP 1997 land use/land cover, and not identified by the green infrastructure model, were added to the proposed network. These additions were relatively minor (3,553 additional acres, or 0.13%).

Finally, ecologically significant areas digitized by the Maryland DNR Heritage Division were added if they were adjacent to, but not entirely within, modeled hubs or corridors. These included Natural Heritage Areas (NHA), Wetlands of Special State Concern (WSSC) and 550 ft buffers, Habitat Protection Areas (HPA), Ecologically Significant Areas (ESA), and Geographic Areas of Particular Concern (GAPC). The ESA's, HPA's, and GAPC's were draft products at the time. Furthermore, not all areas containing observed rare species had been digitized (except the rough delineations of SSPRA's). The heritage areas totaled 189,798 acres, although some of these were buffers. 172,593 acres (91%) fell within GI hubs or corridors. Of the remainder, 11,649 acres were added to the proposed network, bringing the total to 184,242 acres. The increase in GI area was 0.44%; some of this overlapped with additions from other sources. Heritage areas falling outside the network should still be considered for protection.

Maps containing these revisions were mailed to the planning departments of each county for further review. The final product was published in Maryland Greenways Commission, 2000. The green infrastructure network published in this atlas was 43,604 acres (1.65%) larger than the model output.

Fig 4-4
Comparison of green infrastructure model output to a forest reserve system proposed by Baltimore County's Department of Environmental Protection and Resource Management.



Additions from the Delmarva Conservation Corridor

We examined hubs and corridors along the Delaware-Maryland border identified by a landscape model tailored for the entire Delmarva peninsula (the Delmarva Conservation Corridor - DCC), but not identified by the Maryland green infrastructure (version 5) model. The Delmarva model used different data and criteria, based on its multi state context. Additions from the DCC model were more significant for interstate corridors than for border hubs. These model discrepancies were compared to aerial photographs (DOQQ's), and if the areas identified were primarily forest or wetland, they were added to the green infrastructure.

We also added estuarine marsh along the Coastal Bays identified by the DCC model but not the GI model. These wetlands were partially drained by human activities, but nevertheless identified by Tiner et al (2000) as having high potential for fish, shellfish, and waterbird habitat. They also had high potential for nutrient transformation, sediment and other particulate retention, coastal storm surge detention, and shoreline stabilization (Tiner et al, 2000). The revised green infrastructure network was designated version 5.1 (see Fig. 4-5).

Composition of Maryland's green infrastructure network

Within state boundaries, Maryland's green infrastructure (version 5.1) is comprised of 1,777,475 acres of hubs and 252,997 acres of corridors in natural land cover (forest, wetland, and bare rock/sand/clay); totaling 2,030,471 acres. Open water was excluded from these calculations. In addition, altered open areas (agriculture, lawns, quarries, and cleared lands) comprise 375,546 acres in the potential green infrastructure land network. These "gaps" represent areas that could potentially be restored to a natural cover type. Developed areas (25,240 ac) were excluded from these calculations: they are usually difficult to restore, although many state parks contain abandoned (and usually ruined) buildings. The land cover composition of the green infrastructure network is listed in Table 4-4.

Within the green infrastructure in Maryland are:

- Forest (*from NLCD*): 1,827,187 acres
- Interior forest: 910,037 acres
- Wetlands (*from NLCD*): 475,843 acres *(note: some wetlands are also forests)*
- Unmodified wetlands from NWI: 450,291 acres
- Bare rock or sand, such as beaches: 1,643 acres
- Streams in interior forest: 2,468 miles
- Natural Heritage Areas: 39,100 acres
- Wetlands of Special State Concern: 59,381 acres

Fig. 4-5
Maryland's green infrastructure network

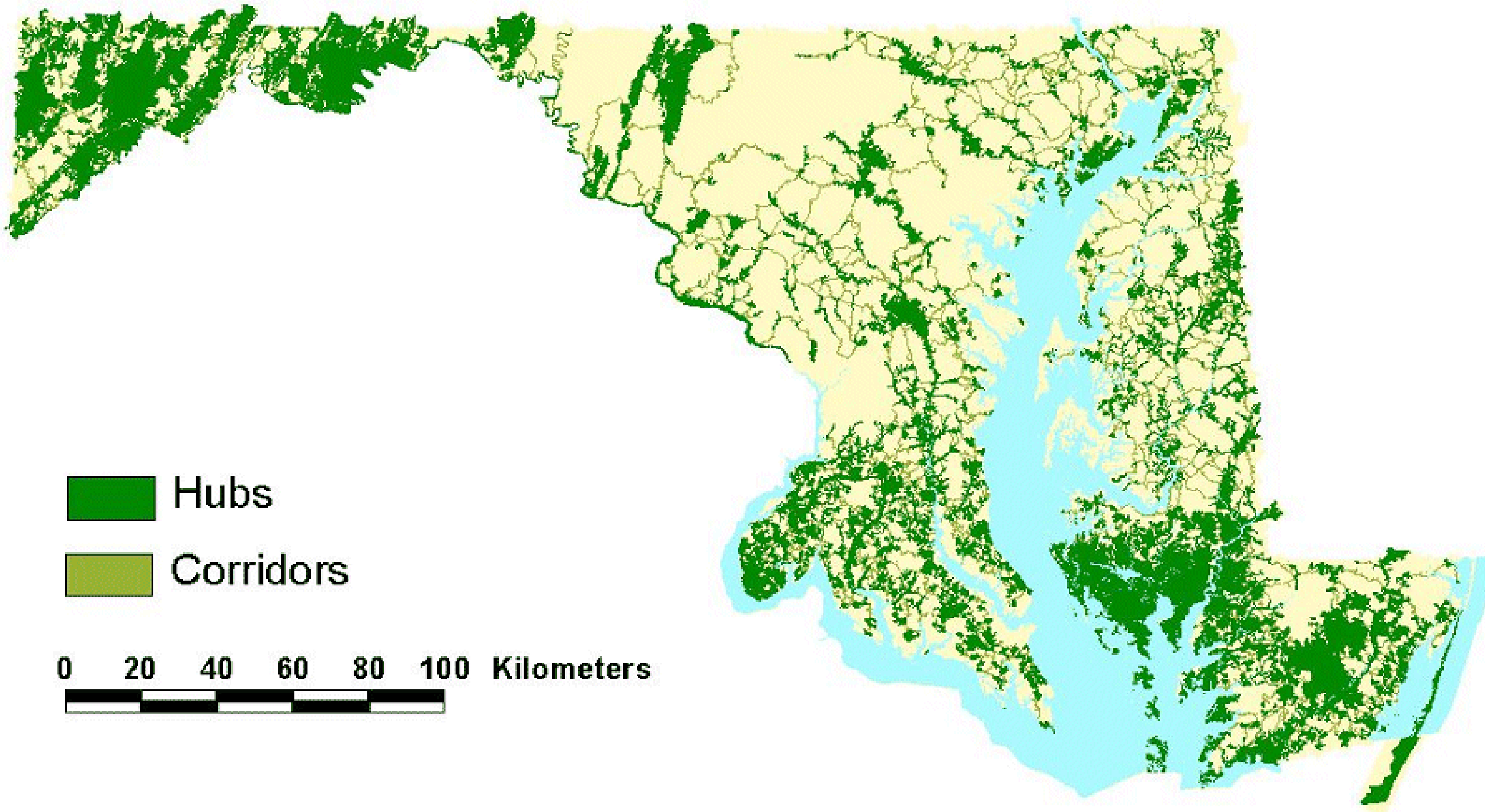


Table 4-4
Land cover in Maryland's green infrastructure (from NLCD)

Land cover	Within state of Maryland (ac)	Hubs in Maryland (ac)	Corridors in Maryland (ac)	Hubs outside Maryland (ac)	Corridors outside Maryland (ac)
Open Water	1,707,310	123,433	34,613	371	114
Low Intensity Residential	385,466	10,840	8,865	1	9
High Intensity Residential	36,424	174	446	0	0
High Intensity Commercial/Industrial/ Transportation	62,517	3,233	1,682	5	1
Bare Rock/Sand/Clay	2,107	1,639	4	0	0
Quarries/Strip Mines/Gravel Pits	22,237	3,759	698	7	6
Transitional barren	32,392	14,309	1,457	7	3
Deciduous upland forest	1,753,572	887,758	147,729	1,224	224
Evergreen upland forest	389,636	228,407	29,675	178	52
Mixed upland forest	462,684	218,416	41,000	184	51
Pasture/Hay	1,808,057	155,239	96,147	117	124
Row Crops	665,678	72,620	29,020	53	11
Urban/recreational grasses (e.g. parks, lawns, golf courses)	29,179	989	1,308	0	0
Woody Wetlands	322,338	248,265	25,937	164	32
Emergent Herbaceous Wetlands	229,923	192,989	8,652	24	0
TOTAL	7,909,521	2,162,070	427,233	2,335	626

Maryland's green infrastructure contains:

- 33% of Maryland's total land area (39% when gaps are included)
- 63% of Maryland's forest land, including 90% of the State's interior forest
- 87% of Maryland's remaining unmodified wetlands, including 99% of the Wetlands of Special State Concern
- 91% of Maryland's streams within interior forests
- 99.7% of Maryland's Natural Heritage Areas
- 88% of Maryland's occurrences of rare, threatened, or endangered species
- 87% of areas identified as Delmarva fox squirrel habitat *(note: only 72% of these DFS areas were classified as forest in NLCD)*
- 99.7% of interior forest in areas identified as Delmarva fox squirrel habitat
- 89% of Maryland's steep slopes ($25%)
- only 44% of Maryland's highly erodible soils
- 60% of Maryland's highly erodible soils with forest cover (retaining forest on highly erodible soil protects against erosion and stream sedimentation)
- 87% of MBSS sites with brook trout
- 89% of Maryland's streams with brook trout (429 of 480 mi)
- 73% of MBSS sites with high IBI scores or imperiled aquatic species

- 90% of Maryland's areas identified as high quality FIDS habitat (using definitions from the FIDS guidance paper for the Critical Area and GIS data)
- 99.9% of areas (257 ac) on Maryland's eastern shore identified by a USFWS GAP model as supporting all 18 area-sensitive forest birds (black-and-white warbler, northern parula, worm-eating warbler, Louisiana waterthrush, American redstart, brown creeper, hooded warbler, acadian flycatcher, blue-gray gnatcatcher, Kentucky warbler, ovenbird, pileated woodpecker, summer tanager, scarlet tanager, barred owl, red-shouldered hawk, yellow-throated vireo, and prothonotary warbler)
- 90% of areas on Maryland's eastern shore identified by the above GAP model as supporting at least 10 of 18 area-sensitive forest birds
- 75% of areas (521,575 of 693,418 ac) on Maryland's eastern shore identified by the above GAP model as supporting any (at least one) of the 18 area-sensitive forest birds

In general, the green infrastructure model is relatively efficient at capturing most of the state's biodiversity and natural resources. However, it missed some areas, such as isolated natural heritage elements, some streams and their riparian buffers (and many poorly buffered streams), some steep slopes, and some wetlands. The model performed most poorly at capturing highly erodible soils, many of which are not forested. Protection of natural resources outside the green infrastructure can be addressed by other programs, such as wetland, steep slope or floodplain regulations and ordinances; endangered species protection; stream protection and restoration; project reviews; zoning; etc.

Although most rare species locations digitally logged in Maryland fell within the green infrastructure network, 12% fell outside. Most of these locations were in small, isolated habitat (e.g., roadsides, small wetlands surrounded by farmland, beach dunes adjacent to development). This shows the need for continued conservation activity outside the GI network. These areas should be protected if possible. However, long-term population viability is more likely in larger, connected natural areas. For some of the small wetlands surrounded by farmland that provide habitat for globally rare species, DNR hopes to pursue acquisition or easement, allowing succession of adjacent farmlands, to restore the continuity with the remaining natural landscape. On the other hand, for areas bordered by residential or commercial development, the opportunity for restoring continuity is limited.

Chapter 5
ECOLOGICAL RANKING OF HUBS AND CORRIDORS

Using the Green Infrastructure Assessment in decision-making for protecting land through easement or fee simple acquisition requires some means of evaluating and comparing the importance of the various components and the urgency attaching to their protection. In the next section we describe how we evaluated threats to the continued presence of the green infrastructure in the landscape; this section describes the way in which we ranked the hubs and corridors according to their ecological value.

Both hubs and corridors were evaluated and ranked within their physiographic regions. Physiographic regions (see Fig.5-1) have a characteristic geology and climate, which shape the ecosystems and biological communities within them. We wanted to ensure that ecosystems adapted to these different climates and substrates were represented in the top ranking hubs, protecting the best examples in each region. Another reason for grouping hubs by region is that natural conditions and communities vary greatly between the Coastal Plain and the Appalachian mountains. For example, tidal marsh is not found outside the Coastal Plain, and high gradient streams are not found inside the Coastal Plain. A single ecological ranking of all hubs would compare "apples" to "oranges" and might not succeed in protecting the broad biological and geological diversity of the state.

Ranking of hubs by relative ecological importance

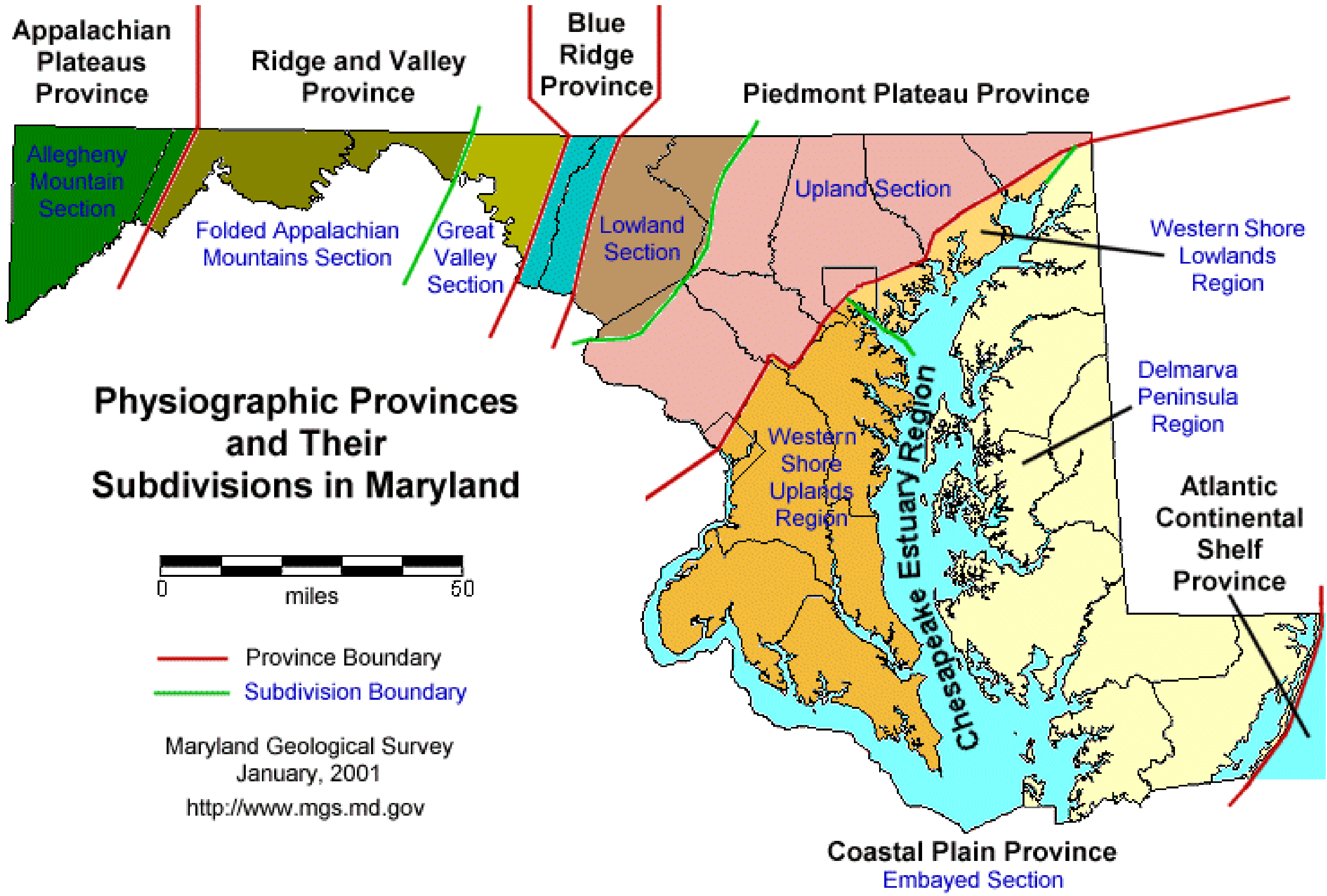
We calculated a wide variety of statistics for each hub. Twenty-seven parameters (see Table 5-1 and Appendix B) were selected and given an importance weighting according to feedback from biologists and natural resource managers; literature reviews; minimization of redundancy, area dependence, and spatial overlap; balancing different ecotypes; data reliability; and examination of output from different combinations. None of the parameters were highly correlated (>80%). The highest correlation was between area of upland forest and length of interior forest streams (75%).

Hubs were ranked within their physiographic region from best to worst for each parameter in Table 5-1. We calibrated these rankings by converting to percentiles (percentile = rank * 100 / maximum rank). We wanted to know how each hub compared to other hubs with similar climate and geology. For example, did a hub contain more interior forest than most other hubs in the physiographic region? Did it contain more rare species? Did it contain a wider diversity of vegetation and soil types? Was it less fragmented? Was it closer to other hubs? To derive a composite ecological ranking, the percentiles for the 27 ecological parameters were multiplied by an importance weighting (Table 5-1), and added together for each hub. The importance weightings were a function of the parameter's utility and data reliability. Some parameters were area-dependent (e.g., acres of interior forest), some were area-independent (e.g., proportion of interior natural area), and some were inversely area-dependent (the larger the hub, the less important metrics of isolation are). Relative weightings were adjusted by contrasting model output from different combinations.

Table 5-1
Parameters and weights used to rank overall ecological significance of each hub within its physiographic region.

Parameter	Weight
Heritage and MBSS element occurrence (occurrences of rare, threatened and endangered plants and animals; rated according to their global or range-wide rarity status; state-specific rarity status; and population size, quality, or viability)	12
Area of Delmarva fox squirrel habitat	3
Fraction in mature and natural vegetation communities	6
Area of Natural Heritage Areas	6
Mean fish IBI score	1
Mean benthic invertebrate IBI score	1
Presence of brook trout	2
Anadromous fish index	1
Proportion of interior natural area in hub	6
Area of upland interior forest	3
Area of wetland interior forest	3
Area of other unmodified wetlands	2
Length of streams within interior forest	4
Number of stream sources and junctions	1
Number of GAP vegetation types	3
Topographic relief (standard deviation of elevation)	1
Number of wetland types	2
Number of soil types	1
Number of physiographic regions in hub	1
Area of highly erodible soils	2
Remoteness from major roads	2
Area of proximity zone outside hub	2
Nearest neighboring hub distance	2
Patch shape	1
Surrounding buffer suitability	1
Interior forest within 10 km of hub periphery	1
Marsh within 10 km of hub periphery	1

Fig 5-1
Physiographic regions in Maryland



We used nonparametric ranking because we lacked information needed to evaluate thresholds (e.g., what density of stream sources or junctions is desirable?), or to standardize parameters (e.g., comparing acres of wetlands to feet of streams). The hubs were then divided into three tiers by their composite ecological score: tier 1 comprised the top 33% of hubs; tier 2, the middle 33%; and tier 3, the bottom 33%. Although all hubs are ecologically significant, the ranking system can help prioritize initial conservation efforts.

Hub ecological parameters are described in more detail in the following pages.

Rare plant and animal element occurrence

The scoring process outlined here was developed to assist in prioritizing important areas throughout Maryland based on the rarity of the species present, the number of rare species present, and the quality of the occurrences of those species. This was the most heavily weighted parameter. The parameter value equaled the weighted sum of scores for the occurrence of rare, threatened and endangered plants and animals from the Heritage Biological and Conservation Data (BCD) system. Saving rare species from statewide or global extinction is one of the main purposes of the Green Infrastructure Assessment. Explicit data on rare species occurrences are thus crucial to the assessment's success.

Originally developed and instituted by The Nature Conservancy, the BCD global and state rating system is used by all state Natural Heritage Programs and numerous Conservation Data Centers in other countries. Because they are assigned based upon standard criteria, the ratings, referred to as status ranks, can be used to assess the range-wide status of a species as well as the status within portions of the species' range. The primary criteria used to define these status ranks are the number of known distinct occurrences, with consideration given to the total number of individuals at each locality. Additional factors considered include the current level of protection, the types and degree of threats, ecological vulnerability, and population trends. Global and state status ranks are used in combination to set inventory, protection, and management priorities for species both at the state and regional levels.

Occurrences of rare plants and animals in Maryland were a point file derived from the element occurrence record (EOR) data set in the BCD system. Communities were excluded. The data set provided scores based on several variables maintained in the BCD, as well as several generalized habitat attributes. The file contained 3731 points, which comprised a subset of all element occurrence records in the BCD. The EOR score was calculated by summing numeric values assigned to three other fields: rounded Global, or range-wide, rarity status rank[1], rounded state-wide, state-specific rarity status rank, and an Element Occurrence (EO) rating, representing population size, quality, or viability. Where EO rating was null (no value assigned), and the sighting was 1980 or

[1]For purposes of assigning occurrence scores, Global status ranks and State status ranks were rounded up based on standard Natural Heritage Network rounding procedures (e.g., a G1G2 species became G1). Rounding was necessary because there would be far too many possible combinations otherwise (for example, there are over 40 values possible for Global status rank and about as many for State status rank).

later, an EO score of 15 (meaning extant) was assigned. Scores for Global and State Ranks and the Element Occurrence Rating, are found in Table 5-2.

Table 5-2
Scoring used for Element Occurrence Records for rare plants and animals in Maryland.

GLOBAL STATUS RANK	Description	Numeric Score
G1 or T1	Highly globally rare. Critically imperiled globally because of extreme rarity (typically 5 or fewer estimated occurrences or very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction.	500
G2 or T2	Globally rare. Imperiled globally because of rarity (typically 6 to 20 estimated occurrences or few remaining individuals or acres) or because of some factor(s) making it very vulnerable to extinction throughout its range.	250
G3 or T3	Either very rare and local throughout its range or distributed locally (even abundantly at some of its locations) in a restricted range (e.g., a single western state, a physiographic region in the East) or because of other factors making it vulnerable to extinction throughout its range; typically with 21 to 100 estimated occurrences.	100
G4 or T4	Apparently secure globally, although it may be quite rare in parts of its range, especially at the periphery.	25
G5 or T5	Demonstrably secure globally, although it may be quite rare in parts of its range, especially at the periphery.	10
GU or TU	Possibly in peril range-wide, but its status is uncertain; more information is needed.	25
G? or T?	The species has not yet been ranked.	50
GH or TH	No known extant occurrences (i.e., formerly part of the established biota, with the expectation that it may be rediscovered).	150
GX or TX	Believed to be extinct throughout its range (e.g., passenger pigeon) with virtually no likelihood that it will be rediscovered.	0
HYB	Hybrid	5
note: T Ranks containing a "T" indicate that the infraspecific taxon is being ranked differently than the full species. Species containing a "Q" in the rank indicates that the taxon is of questionable or uncertain taxonomic standing (i.e., some taxonomists regard it as a full species, while others treat it at an infraspecific level)		
STATE STATUS RANK	**Description**	**Numeric score**
S1	Highly State rare. Critically imperiled in Maryland because of extreme rarity (typically 5 or fewer estimated occurrences or very few remaining individuals or acres in the State) or because of some factor(s) making it especially vulnerable to extirpation. Species with this rank are actively tracked by the Heritage & Biodiversity Conservation Programs.	50
S2	State rare. Imperiled in Maryland because of rarity (typically 6 to 20 estimated occurrences or few remaining individuals or acres in the State) or because of some factor(s) making it vulnerable to becoming extirpated. Species with this rank are actively tracked by the Heritage & Biodiversity Conservation Programs.	40

STATE STATUS RANK	**Description**	**Numeric score**
S3	Watch List. Rare to uncommon with the number of occurrences typically in the range of 21 to 100 in Maryland. It may have fewer occurrences but with a large number of individuals in some populations, and it may be susceptible to large-scale disturbances. Species with this rank are not actively tracked by the Heritage & Biodiversity Conservation Programs.	25
S4	Apparently secure in Maryland with typically more than 100 occurrences in the State or may have fewer occurrences if they contain large numbers of individuals. It is apparently secure under present conditions, although it may be restricted to only a portion of the State.	15
S5	Demonstrably secure in Maryland under present conditions.	7
SU	Possibly rare in Maryland, but of uncertain status for reasons including lack of historical records, low search effort, cryptic nature of the species, or concerns that the species may not be native to the State. Uncertainty spans a range of 4 or 5 ranks as defined above.	30
S?	The species has not yet been ranked.	25
SH	Historically known from Maryland, but not verified for an extended period (usually 20 or more years), with the expectation that it may be rediscovered.	35
SE	Established, but not native to Maryland; it may be native elsewhere in North America.	0
SR	Reported from Maryland, but without persuasive documentation that would provide a basis for either accepting or rejecting the report (e.g., no voucher specimen exists).	10
SRF	Reported falsely (in error) from Maryland, and the error may persist in the literature.	0
SX	Believed to be extirpated in Maryland with virtually no chance of rediscovery.	0

ELEM. OCC. RATING	**Description (population condition of the occurrence)**	**Numeric score**
A	excellent	50
AB		45
AI	excellent, introduced	10
B	good	40
BC		35
BI	good, introduced	5
BU		20
C	fair	30
CD		25
CI	fair, introduced	3
CU		15
D	poor	20
D/H	poor / historical?	10
D/X	poor / gone?	5
DI	poor, introduced	2
DU	poor / unknown	10
E	exists	15
E/S	may exist / specimen	10
F	failed to find	10

ELEM. OCC. RATING	Description (population condition of the occurrence)	Numeric score
F/H	not found / historical?	8
F/X	not found / likely gone	5
H	historical, pre-1970	5
O	observation, non-breeding	5
S	specimen / mollusk shell	8
U	unknown, insufficient info.	10
X	known / likely extirpated	0

These data represented records entered into BCD as of 27 Feb 2001. Additional rare species data, both new locations and updates of existing records, were still to be processed. The point data were created by manually calculating latitude/longitude coordinates from USGS 7.5 minute quadrangle maps at 1:24000. These coordinates were later quality controlled to within 2 seconds and were assumed to be accurate to within about 200-300 feet with a 95% confidence level. We buffered element occurrence points 300 feet to account for the positional uncertainty.

Locations of rare species were also obtained from the Maryland Biological Stream Survey, using 1995-1997 data. Specifically, we selected collections of fish, mussels, crawfish, reptiles, and amphibians with state rarities of S1, S2, S3, or SU, plus American brook lamprey (*Lampetra appendix*) and Pearl dace (*Margariscus margarita*). These latter two species were not yet ranked, but according to Scott Stranko of Maryland DNR, were rare in Maryland. There were 82 MBSS sample locations with these species. These data were converted to the same format as the BCD points. Species Global and State rarity status ranks were appended. Because these data represented specimens sampled at a particular place at a particular time, they were given an EO rating of "E" (exists). The numeric value for this EO rating was 15. As with BCD data, we calculated an EOR score by summing numeric values assigned to three other fields: rounded Global status rank, rounded State status rank, and an EO rating representing its population size, quality, or viability. The positional uncertainty of MBSS sample locations was 100 ft; we buffered these points accordingly.

After combining BCD and MBSS buffered area, 84% of rare species locations (EO's) fell within hubs. Some of the remainder (5%) fell within corridors, but 12% fell outside the network entirely. Many rare species occurred in small, isolated habitat (e.g., roadsides, small wetlands surrounded by farmland, beach dunes adjacent to development). These areas should be protected, but long-term population viability is more likely in larger, connected natural areas.

The overall EOR score for each hub, given a weight of 12 when combined with scores for other parameters, was calculated as:

GLOBAL STATUS RANK + STATE STATUS RANK + ELEMENT OCCURRENCE RATING

summed for all elements (BCD and MBSS) found in the hub. Hub scores ranged from 0 to 41,364.

Area of Delmarva fox squirrel habitat

The Delmarva fox squirrel (*Sciurus niger cinereus*), a large, ground-ranging squirrel, is a federally listed endangered species, found only on the eastern shore of Maryland (Pennsylvania Department of Conservation and Natural Resources, 1998). Cutting of old growth forests and development are probably the primary causes of their disappearance from most of their former range (Pennsylvania Department of Conservation and Natural Resources, 1998). The preferred habitat of Delmarva fox squirrels (DFS) is generally described as forest with thick canopy closure accompanied by an open and sparsely vegetated understory (Pennsylvania Game Commission, 2001). Thus, the animal can also be considered an indicator species of mature forest. DFS occurrences were not included in the BCD data set, and spatial population data were unavailable, so acres of DFS habitat was treated as a separate parameter. This parameter was given a high importance rating, but was only relevant in the eastern Coastal Plain physiographic region.

The file of DFS locations was a merger of 33 separate quad-based and county-based files of DFS distributions, both current habitat and areas where the species has been released. The original files were developed to delineate forested areas known or highly likely to contain DFS for use in the Wildlife and Heritage Division's environmental review process, in conservation planning and management activities, and to evaluate changes in distribution and relative abundance over time.

The DFS polygons were delineated over 1992 SPOT satellite imagery to approximate the forests in areas known or thought to harbor Delmarva fox squirrels. The original 33 files were created by taking field survey data and reported sightings and locating those areas on county topographic maps. The vector data were created using heads-up digitizing in MIPS over digital county topographic maps. This draft dataset was then edited over 7.5 minute SPOT images or orthophoto 7.5 minute USGS quadrangles. Polygons were corrected to match actual vegetative extent as displayed on the images. These were then quality controlled for accuracy of initial interpretation. The boundaries of the actual areas will change as forests are cut or habitats are otherwise modified and as new information on inhabited areas is obtained. The DFS polygons were intended to be accurate at 1:24000; however, they were created over source material at 1:62500.

DFS habitat mostly occurred in hubs: 112,480 ac were in hubs, 3477 ac were in corridors, and 18,004 ac were outside the GI network. Many DFS polygons contained significant area that would require restoration (row crops, loblolly plantations, etc.).

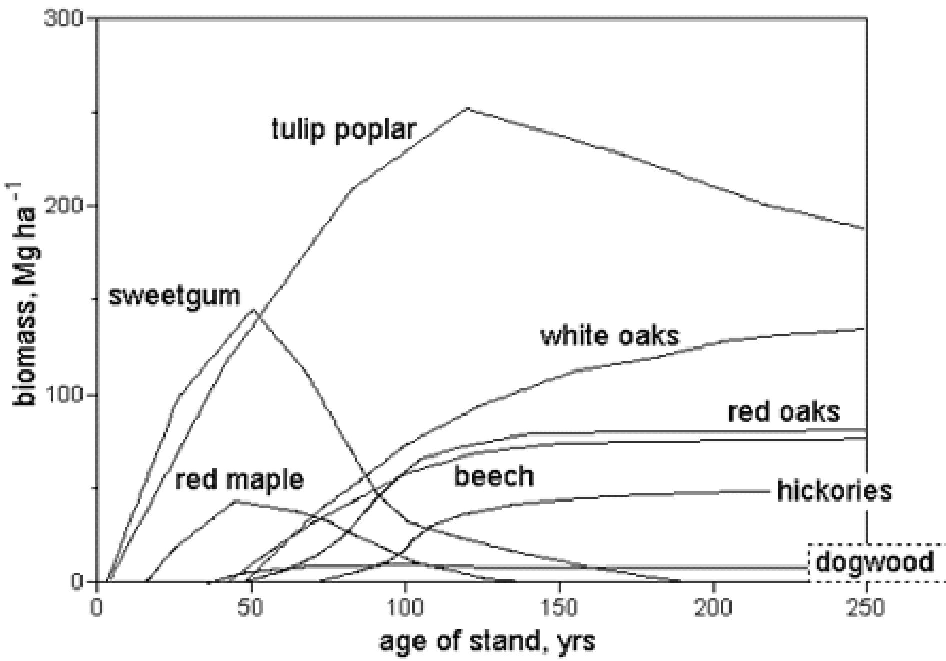
Fraction in mature and natural vegetation communities

This was one of the highest weighted hub parameters. We attempted to identify natural vegetation community alliances from the Mid-Atlantic Gap Analysis Project (GAP) (see Scott et al, 1993; National Gap Analysis Program, 1994). The purpose was to identify areas that had been in a natural condition for a relatively long time, to help prioritize areas of the green infrastructure for conservation efforts. Mature communities have had more time to recover from past disturbances, such as clearing for timber or agriculture. Many herbaceous plants, lichens, mosses, salamanders, and other organisms are slow to recolonize after such large-scale disturbance. Mature temperate forests usually have more biomass, more soil organic matter, better moisture and nutrient retention, greater structural diversity, and higher species diversity than early successional or plantation forests. They often contain more mast-producing trees, like oaks, hickories, walnut, and beech; which are important for many birds and mammals. E. P. Odum (1969) theorized that as post-disturbance ecosystems develop, biomass and diversity increase, food webs become more complex, protection of self and offspring becomes more important than rapid growth, long-lived niche specialists replace short-lived generalists, detritus and nutrients are cycled more efficiently, and the ecosystem becomes more stable and resilient. The importance of old growth forest is addressed in a following chapter; it generally contains niches not found in younger forest, such as larger trees, higher canopies, greater vertical stratification, large snags and fallen logs, tree cavities, pit-and-mound microtopography, and a rich duff layer.

Fig. 5-2 (Smithsonian Environmental Research Center, date unknown) depicts the change in tree dominance over time at a study site in the Smithsonian Environmental Research Center near Edgewater, MD. At first, the site was dominated by fast-growing sweetgums, tulip poplars, and red maples, but these were later replaced by slower-growing oaks, hickories, and beeches. This pattern of natural succession is fairly typical for mesic forests in Maryland's Coastal Plain and Piedmont regions, although Eastern red cedar (*Juniperus virginiana*) and Virginia pine (*Pinus virginiana*) are also early dominant trees. Pine plantations are maintained artificially, and generally have lower species and structural diversity than natural forests.

Human land uses, such as agriculture, mining, or silviculture, were not considered a high priority for GI targeting, nor were *Phragmites* stands nor early successional alliances like Virginia pine (*Pinus virginiana*) or sweetgum (*Liquidambar styraciflua*). Some vegetation types, such as beach communities or river scours, are maintained by regular natural disturbances and harsh growing conditions. These were considered mature natural communities, whereas early successional forests following agriculture or logging were not. An accuracy assessment of GAP was not available at the time. Further, vegetation is not only determined by time since disturbance, but by propagule availability, soil type and depth, moisture, nutrient availability, pH, salinity, etc. Thus, some alliances, like Virginia pine forest, may represent either post-clearing succession or conditions such as extremely nutrient poor soils. In the latter case, the community may be the result of fire suppression by modern humans. Some early successional areas may result from natural disturbance, but these are greatly outnumbered by human disturbance. We attempted to identify areas of natural disturbance from supplemental GIS layers. Field verification should be used to confirm specific site conditions.

Fig. 5-2
Natural succession at a study site near Edgewater, MD
(Smithsonian Environmental Research Center, date unknown)



In general, GAP vegetation classes were categorized as follows:

Human land uses or non-natural monocultures

CODE	GAP Vegetation Alliance	Acres in MD	% of MD land
429	Bare/Exposed Manmade Features	44,286	0.72%
430	Clearcuts/Transitional	120,836	1.96%
414	Cultivated Trees	10,663	0.17%
455	Non-Tidal Phragmites Marsh	3,001	0.05%
453	Pasture/Hay	1,725,752	27.94%
435	Red Pine Forest	2,513	0.04%
402	Row Crops	974,011	15.77%
411	Upland Loblolly Forest	168,264	2.72%
427	Urban	624,896	10.12%
452	Urban/recreational grassy areas	25,382	0.41%

Early successional natural communities
(in general, following relatively recent human land clearing or alteration)

CODE	GAP Vegetation Alliance	Acres in MD	% of MD land
410	Coastal Loblolly Pine Forest	38,787	0.63%
418	Coastal Plain Pine - Mixed Hardwoods Lowland Forest	244,834	3.96%

CODE	GAP Vegetation Alliance	Acres in MD	% of MD land
440	High Mountain Shrub Swamp	3,201	0.05%
415	Loblolly Pine - Mixed Wet Oaks Forest	66,931	1.08%
457	Non-tidal Maritime Shrublands	5,115	0.08%
444	Red Cedar Woodland	3,156	0.05%
423	Sweetgum Forest	66,342	1.07%
406	Tallgrass Marsh (*Phragmites* or *S. cynosuroides*)	11,753	0.19%
417	Virginia Pine - Mixed Oaks Forest	23,826	0.39%
416	Virginia Pine Forest	3,874	0.06%
422	Yellow Poplar Forest	31,422	0.51%

Natural communities generally mature for site conditions

CODE	GAP Vegetation Alliance	Acres in MD	% of MD land
413	Bare sand	777	0.01%
431	Beachgrass Shrublands	113	0.00%
439	Beech - Yellow Poplar Forest	962	0.02%
433	Cattail Marsh	1,627	0.03%
438	Chestnut Oak Forest	253,229	4.10%
437	Coastal Hardwoods Forest	3,153	0.05%
421	Coastal Plain Beech - Oak Forest	449,753	7.28%
454	Dune Grassland	10,372	0.17%
432	Dwarf Beach Shrublands	1,425	0.02%
443	Emergent Vegetation/Vegetated Water	29	0.00%
404	High Marsh	123,788	2.00%
428	Lowland Mixed Oaks	132,696	2.15%
407	Lowland Pine Woodland	36,709	0.59%
409	Maritime Shrublands	7,739	0.13%
408	Mixed grass - Low Shrubs	2,788	0.05%
426	Mixed Hardwoods - Conifer Swamp	7,926	0.13%
441	Mixed Oaks - Sugar Maple Forest	332,176	5.38%
420	Mixed Wet Oaks Forest	24	0.00%
460	Non-tidal Cattail Marsh	364	0.01%
412	Non-tidal floating or submerged herbaceous vegetation	1,207	0.02%
458	Non-tidal Maple-Green Ash Swamp	21,332	0.35%
456	Non-tidal Mixed Grass-Low Shrub	1,654	0.03%
459	Non-tidal Mixed Hardwoods Conifer Swamp	17,800	0.29%
445	Piedmont Beech - Oak Forest	1,245	0.02%
425	Red Maple - Green Ash Swamp	5,602	0.09%
436	Red Oak - White Oak Forest	371,140	6.01%
442	Rich Northern Hardwood Forest	78,638	1.27%
401	Shallow/Turbid/Vegetated Water	490	N/A

CODE	GAP Vegetation Alliance	Acres in MD	% of MD land
403	Sparsely Vegetated Beach Alliances	628	0.01%
419	Sweetgum Swamp	45,985	0.74%
424	Sycamore - Mixed Hardwood Riverside Forest	19,649	0.32%
405	Tidal Marsh	31,102	0.50%
400	Water	1,695,277	N/A
434	White Pine - Hemlock Forest	17,529	0.28%

Where areas of recurring natural disturbance were identified, early successional natural communities were considered generally mature for site conditions:

- Beach communities were identified from natural cover occurring on barrier islands. In Maryland, this was Assateague island.
- Beavers also disturb natural areas. Besides the land they clear directly, "beaver meadows" are created after beavers abandon a dam. When the dam gets broken, the pond behind it drains, allowing meadow plants to colonize. A beaver meadow can persist for 70 years, much longer than a clearing from wind or fire. Recently, it was discovered that trees are slow to invade beaver meadows because they lack a mycorrhizal fungus that supports the trees -- the fungus dies when the land is submerged. Wind and fire, on the other hand, do not kill off the fungus. Beaver-modified wetlands were selected from NWI (special modifier = “b”). However, the time of ground condition was 1981-2, much earlier than NLCD and GAP (ground condition 1991-3).
- River scours would have been included, but could not be identified from existing GIS data. As a minimum, we selected areas on the Potomac River upstream of the fall line. Scours from smaller rivers and streams may have been smaller than the GAP minimum mapping unit.
- Fire-prone areas were problematic. Before the appearance of Europeans, fires were started regularly by native Americans to clear undergrowth for hunting, gathering, agriculture, war, and by accident; perhaps since the end of the Wisconsinan Glaciation (the last ice age) and the flooding of the Chesapeake Bay. Maryland was inhabited by native Americans as early as circa10,000 B.C. Natural communities in many areas may have adapted to a human-caused fire regime, occurring every few years or less. Fires are generally suppressed now by humans, being less frequent and more intense where they occur. In any case, GIS data are insufficient to identify areas of recurring fire.
- Landslide-prone areas would have been included, but could not be reliably identified from existing GIS data. Such areas may have been smaller than the GAP minimum mapping unit. There were few early successional communities on steep slopes, and many of these were adjacent to human-cleared areas, from which we infer that they may have resulted from human rather than natural disturbance.

We then reclassed GAP vegetation communities as follows. Natural communities generally mature for site conditions were given a score of 2, early successional natural communities a score of 1, and human land uses or non-natural monocultures a score of 0. We discounted open water (classes 400 and 401), giving them a value of No Data. We summarized this grid within hubs, and recorded the mean value. There were no data within PA, WV, or DC. Hub scores for this parameter ranged between 0.0156 and 2.0000. Hubs with mean scores close to 0 were dominated by human land uses or non-natural monocultures. Hubs with mean scores close to 1 were either dominated by early successional natural communities, or contained mixture of conditions. Hubs with mean scores close to 2 were dominated by mature natural communities.

Area of Natural Heritage Areas (NHA)

The area of Natural Heritage Areas (NHA) within the hub was another one of the highest weighted ecological parameters. According to the state's Threatened and Endangered Species regulations (COMAR 08.03.08), to qualify as an NHA an area must: "(1) Contain one or more threatened or endangered species or wildlife species in need of conservation; (2) Be a unique blend of geological, hydrological, climatological or biological features; and (3) Be considered to be among the best Statewide examples of its kind." Designation of NHA was developed in conjunction with the Critical Area Law and most fell within the Chesapeake Bay Critical Area. Sites outside the Critical Area were already owned by a public agency. Because few (<5%) hubs contained NHA's, but this was a critical parameter, hubs without NHA's were given a rank equal to the number of hubs (i.e., at the bottom) rather than just below the rank of the hub with the least amount of non-zero NHA area. This calibrated the parameter to express a significant difference between hubs with NHA's and hubs without NHA's.

Mean Fish Index of Biotic Integrity (FIBI) score

This parameter identified streams with high biotic integrity. Not all streams were sampled, so it was given a low weighting. The parameter value equaled the mean FIBI score within the hub, if the stream width was greater than 1.5 meters. If there were no FIBI sample sites within the hub, we used the mean FIBI score for the 8-digit watershed in which the hub is located. If there were no FIBI scores for that watershed, the hub was assigned a neutral score (the FIBI midpoint, or 2.5). Most of these latter were tidal watersheds, which were not sufficiently sampled for non-tidal fish.

Mean benthic invertebrate Index of Biotic Integrity (BIBI) score

This parameter also identified streams with high biotic integrity. Not all streams were sampled, so it was given a low weighting. The parameter value equaled the mean benthic invertebrate IBI score within the hub. If there were no BIBI sample sites within the hub, the mean BIBI score for the 8-digit watershed was used. If there were no BIBI scores for that watershed, the hub was assigned a neutral score (the BIBI midpoint, or 2.5). Most of these latter were tidal watersheds, which were not sufficiently sampled for non-tidal invertebrates.

Presence of brook trout

Brook trout (*Salvelinus fontinalis*) are the only native Maryland trout. They are highly sensitive to watershed disturbance (require <2% impervious surface in the watershed and <22C water temperature), and a good indicator species in cool-water streams. Hubs were given a value of 1 if brook trout were sampled by MBSS within the hub, and 0 if not.

Anadromous fish index

Anadromous fish require streams and rivers for spawning. The parameter value equaled the anadromous fish index (AFI) score for the 8-digit watershed in which the hub is located. If the hub fell within more than one watershed, we used the highest AFI score. The AFI score varies between 1 and 10, with 1 being the worst condition and 10 the best (see CWAP report). If there were no AFI scores for that watershed, the hub was assigned a neutral score (the AFI midpoint, or 5). Most of these latter were nontidal watersheds. Data sampling was coarse, so this parameter was given a low weighting.

Proportion of interior natural area in hub

This was one of the highest weighted hub parameters, because it combined two factors: the contiguity of natural cover, and road density and placement. The parameter equaled the total hub area at least 300 ft from developed, agricultural, quarry, or transitional land cover, or primary, secondary, connecting, and county roads, divided by the total hub area. We preferred intact hubs, with minimal restoration needs. This parameter is a better measure of intactness than the proportion of gap area or road density alone, because it also considers the distribution of gaps and roads within the hub (human disturbance) as they affect natural habitat.

Area of interior forest

Interior forest, which is important habitat for many flora and fauna, was separated into upland and wetland. These were tabulated separately, to balance the two ecotypes but minimize spatial overlap. Interior forest was defined as forest at least 300 ft from the edge.

Area of other unmodified wetlands

This parameter value equaled the area of unmodified wetlands, other than those in interior forest, within the hub. These areas are still important, but we eliminated spatial overlap with wetland interior forest. Wetlands modified by humans (drained, ditched, farmed, filled, impounded, or excavated) were noted from NWI, and disregarded.

Length of streams within interior forest

Streams within interior forest are more likely to contain high-quality aquatic and riparian conditions than unforested streams. These areas provide important aquatic habitat, are a source of water, and improve water quality.

Number of stream nodes (sources and junctions)

This parameter value equaled the number of stream sources and stream junctions within the core area. The most probable location of a large node of native riparian vegetation is at a stream intersection (Forman 1995). Stream sources, which include intermittent streams, springs, or seepages, are unusual micro habitats in the basin (Forman 1995). They normally exhibit a high water table, slow water movement, and shady conditions, favoring some rare species (Forman 1995). Further, stream sources require vegetation buffering to maintain water quality.

Number of GAP vegetation types

This parameter value equaled the number of different GAP natural vegetation classes, using the 400 codes. Open water, row crops, upland loblolly forest, red pine forest, cultivated trees, urban, extractive mines, clear-cuts/transitional, urban grass, pasture/hay, non-tidal *Phragmites* marsh, and no data were omitted. This parameter was an indicator of community and habitat diversity. Hayfields can be important for some bird and butterfly species, but cannot be easily discriminated from row crops or single-grass pasture using satellite data.

Topographic relief

This parameter value equaled the standard deviation of elevation values for all cells in the hub. There is often a higher diversity of communities where there is topographic relief (vertical stratification). The parameter was given low weighting because standard deviation of elevation was only an approximate measure of this effect.

Number of wetland types

This was a contributing variable toward potential wetland complexity and diversity. The parameter value equaled the number of different NWI wetland types within the hub, using all codes except modifiers and haline/saline.

Number of soil types

This was a contributing variable toward potential diversity of plant communities. The parameter value equaled the number of different natural soil groups within the hub. There were no data available outside Maryland, nor in Baltimore City.

Number of physiographic regions in hub

This was an indirect measure of possible floristic and ecosystem diversity. The parameter value equaled the number of different physiographic regions within the hub. It was given a low weighting because of the small number of hubs affected.

Area of highly erodible soils

Soil loss to erosion can be predicted using the universal soil loss equation (Brandy, 1990):

$$A = RKLSCP;$$

where A = the predicted soil loss,
R = climatic erosivity (rainfall and runoff)

K = soil erodibility
L = slope length
S = slope gradient or steepness
C = cover and management
P = erosion control practice

Assuming rainfall is fairly constant within physiographic provinces, and that C and P can be controlled by management, we focused on K, L, and S. We used the Natural Soils Groups of Maryland, which is described in Maryland Department of State Planning (1973). A table was created with K values for these soils. Soils occurring on steep slopes were identified from Maryland Department of State Planning, 1973. B1c, B2b, B2c, B3, C2, and E2b soils (see Table 5-3) were targeted for remaining in natural vegetation, preferably wooded, because of their high erodibility. The small letter (a, b, c) is a slope modifier:

a–slopes range from 0 to 8 or 10 percent
b–slopes range from 8 to 15 or 10 to 15 percent
c–slopes are steeper than 15 percent.

We totaled the area of these soil types within each hub.

Table 5-3
Natural Soils Groups of Maryland (from Maryland Department of State Planning, 1973).

Soil code	Soil description
A1	sandy, and extremely susceptible to erosion by wind when dry and without vegetative cover. They are possible groundwater recharge areas.
A2	beach sands.
B1	well drained and permeable.
B2	well drained, but slowly permeable below 2-3 ft.
B3	clays with poor stability.
C1	rocky, shallow soils.
C2	well-drained and clayey.
D1	rocky, shallow soils.
E1	moderately well drained and sandy.
E2	saturated by a perched water table part of the year.
E3	deep, moderately well drained, silty soils.
F1	the wettest sandy soils in the state, with a water table at or near the surface much of the year.
F2	poorly or very poorly drained.
F3	poorly or very poorly drained.
G1	deep, well drained or moderately well drained riparian floodplain soils.
G2	deep, well drained or moderately well drained riparian floodplain soils.
G3	in marshes or swamps. They are saturated, and have standing water most or all of the year.

Remoteness from major roads

This parameter value equaled the mean distance to the nearest primary or secondary road for all cells in the hub. Roads are a source of disturbance (see background chapter for details). For example, many studies have correlated increasing road density with wildlife avoidance (Forman 1995).

Area of proximity zone outside hub

This parameter represented the degree of isolation from other hubs. We constructed Thiessen polygons (see Thiessen and Alter, 1911; ESRI, 1999) around each hub, and summed this area outside each hub. This is a crude measure of proximity to other hubs[2]. Hubs with large proximity zones did not have other hubs nearby; those with small proximity zones were surrounded by neighboring hubs.

This metric should be area-weighted; the larger the hub, the less important neighboring hubs are. However, dividing by area ranked the hubs primarily by their area. Thus, we decided to omit the area factor, and rely on the area relationships inherent in other parameters (e.g., amount of interior forest or wetlands).

Nearest neighboring hub distance

This is a rough measure of connection feasibility to other hubs. Hubs closer to other hubs would be easier for wildlife to move between, and easier to connect with corridors.

Patch shape

The shape index indicates the proportion of edge to interior of the hub (see background chapter for discussion). We used the shape index from FRAGSTATS (McGarigal and Marks, 1995). The shape index equaled the hub perimeter divided by the square root of hub area, adjusted by a constant (divided by 4). The shape index = 1 when the patch is circular (vector) or square (raster), and increases without limit as patch shape becomes more irregular. Perimeter is dependent on scale, but the cell size was reasonably small (about a third) compared to the edge transition width.

Like the proximity index, this metric should be area-weighted; the larger the hub, the less important patch shape is. However, dividing by area ranked the hubs primarily by their area. Thus, we decided to omit the area factor, and rely on the area relationships inherent in other parameters.

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[2]Originally, we planned to use the metric, "proximity index." This is described in McGarigal and Marks, 1995, and is based on a gravity model (Forman and Godron, 1986; Forman, 1995). It equals the sum of patch area divided by the nearest edge-to-edge distance squared between the patch and the focal patch, for all patches of the corresponding patch type whose edges are within a specified distance (say, 10 km) of the focal patch (McGarigal and Marks, 1995). Unfortunately, we could not calculate this proximity index metric for such a large data set, in either PC FRAGSTATS, LEAP II, or ARC*FRAGSTATS. A program to calculate the metric in GRID was too time-consuming.

<u>Surrounding buffer suitability</u>

The intensity of land use affects ecological processes in the core area. Forest surrounding the core serves as a buffer, and will increase wildlife habitat, whereas development surrounding the core will be a source of disturbance (noise, pollution, domestic animal intrusion, etc.). We reclassed land cover (NLCD) to reflect their suitability (Table 5-3).

Table 5-3
Buffer suitability of land cover types

Land cover class	Code	Buffer suitability score
Open water	11	33
Low intensity developed	21	5
High intensity residential	22	1
High intensity commercial/industrial	23	0
Bare rock/sand	31	33
Quarries/strip mines/gravel pits	32	10
Transitional barren	33	33
Deciduous forest	41	100
Evergreen forest	42	90
Mixed forest	43	100
Hay/pasture	81	33
Row crops	82	20
Urban grass	85	20
Woody wetlands	91	100
Emergent wetlands	92	50

We then gave road cells a buffer suitability score of 0 for primary roads, 1 for secondary roads, and 5 for county roads. For each hub, we calculated the mean buffer score for all cells within 300 ft of the hub. The greater the value, the better the buffer.

This metric should also be area-weighted; the larger the hub, the less important surrounding land use is. However, dividing by area ranked the hubs primarily by their area. Thus, we again decided to omit the area factor.

Interior forest within 10 km of hub periphery

This parameter value equaled the acres of interior forest within 10 km of the hub periphery. Robinson et al (1995) found that percent forest cover within 10 km of study sites was negatively correlated with cowbird parasitism and predation of neotropical migrant bird nests in the U.S. Midwest. DNR biologist Jim McCann (1999) wrote,

> "Consider adding the parameter 'surrounding landscape cover'... The importance weighting for this parameter should be high. There is ample evidence for forest birds (and to varying degrees, for other taxa; e.g., certain far-ranging mammals) that the ability of a forest tract or 'hub' to support viable populations of area-sensitive species is related not only to parameters that describe an individual forest tract (e.g., forest tract size, edge:area ratio, degree of isolation, etc.) but the percent of forest in the surrounding landscape. Although much less published information is available, similar relationships appear to exist for other land cover types (e.g., tidal marsh, upland grasslands). For forests, this parameter has been defined by some as the percent of forest cover within 10 km of the centroid of a forest or the percent of forest within 10 km of the periphery of the forest tract. I would suggest that, at least for forests, 'surrounding landscape cover' be defined as the percentage of forest interior habitat within 10 km of the hub periphery. Possible cover categories are: low = < 30%; medium = 30-60%; high = > 60%... but I'm not sure how a 'suitability' value might be derived. Similar categories have been used by researchers investigating bird-habitat relationships and their findings indicate that these categories have biological relevance (for forest birds). These categories also have been incorporated into a draft DNR guidance paper on timber harvesting guidelines for FIDS in the Critical Area."

This metric should be area-weighted; the larger the hub, the less important surrounding land cover is. However, dividing by area ranked the hubs primarily by their area. We therefore decided to omit the area factor, and rely on the area relationships inherent in other parameters (e.g., amount of interior forest or wetlands).

Marsh near hub periphery

The parameter value equaled the acres of marsh within 10 km of the hub periphery.

Reliability of hub ecological parameter data

Table 5-4 lists the relative reliability of the ecological parameters we calculated. This was a consideration when weighting them. Reliability was a function of spatial accuracy, sampling evenness and completeness, classification accuracy, and the directness of its ecological relevance.

Table 5-4
Reliability of hub ecological parameter data

Parameter	Data reliability
Heritage and MBSS element occurrence rank	relatively good at scale
Area of Delmarva fox squirrel habitat	relatively good at scale, but only relevant on east Coastal

Parameter	Data reliability
	Plain
Fraction in mature and natural vegetation communities	relatively good at scale
Area of Natural Heritage Areas	relatively good at scale
Mean fish IBI score	Not evenly sampled
Mean benthic invertebrate IBI score	Not evenly sampled
Presence of brook trout	relatively good at scale
Anadromous fish index	Sparsely sampled; only at 8-digit watershed level. Will bias toward coastal hubs.
Proportion of interior natural area in hub	relatively good at scale
Area of upland interior forest	relatively good at scale
Area of wetland interior forest	relatively good at scale
Area of other unmodified wetlands	relatively good at scale
Length of streams within interior forest	Many 1st order streams missed
Number of stream sources and junctions	Many 1st order streams (and therefore sources) missed
Number of GAP vegetation types	relatively good at scale
Topographic relief (standard deviation of elevation)	Indirect measure of topographic relief
Number of wetland types	Contributing variable toward potential wetland complexity and diversity
Number of soil types	Contributing variable toward potential diversity of plant communities
Number of physiographic regions in hub	Contributing variable toward potential diversity of plant communities
Area of highly erodible soils	Coarse soil classification
Remoteness from major roads	relatively good at scale
Area of proximity zone outside hub	relatively good at scale
Nearest neighboring hub distance	relatively good at scale
Patch shape	scale-dependent
Surrounding buffer suitability	relatively good at scale
Interior forest within 10 km of hub periphery	primarily factor for FIDS
Marsh within 10 km of hub periphery	primarily factor for wetland birds

Ranking of corridor segments by relative ecological importance

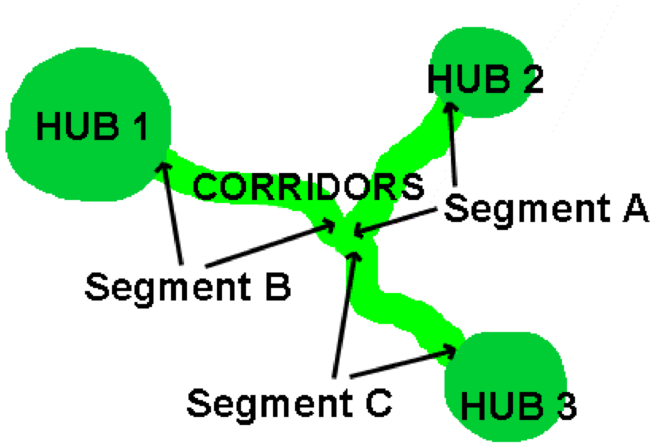
Corridors were also evaluated and ranked within their physiographic region for a variety of ecological parameters. Nodes were considered part of their corridors. Many of the ecological parameters used to rank corridor segments were similar to those used to rank hubs. However, the parameter weights emphasized more what the corridors linked, and how effective that linkage was. For example, corridors that connected high-ranking hubs were considered more important than those that connected low-ranking hubs. We therefore established two tiers of corridors: the top tier of corridors connected the top tier hubs (those with composite ecological scores ranking in the top third of hubs in their physiographic region). The second tier of corridors connected the middle and lower tier hubs (those with composite ecological scores ranking in the lower two-thirds of hubs in their physiographic region).

Corridor condition was also important. Corridors with breaks, road crossings (especially if they were major roads), or insufficient width were considered more difficult for wildlife and seeds to traverse. Corridor length was also a factor, although we had to use area as a proxy. Shorter connections were preferable if quality was otherwise equal.

Corridor Segments

Because corridors often intersected, they were separated into segments for comparative analysis (see Figure 5-3). A corridor segment was defined as that stretch of a corridor that terminated at either a hub or an intersection with another corridor.

Figure 5-3
Separation of corridors into segments for analysis



After unsuccessfully trying a variety of automated techniques, we manually created a shapefile of corridor intersections, converted this to a grid, and used it to separate corridors into segments. We gave each segment a unique ID, and calculated its size in acres. We removed segments <10 ac, and those that were erroneous (i.e., not connecting hubs). Some of these were parts of nodes. Others were cut or fragmented by recent development. Some segments not connecting hubs were retained, such as existing stream valley parks in Montgomery County, or linear nodes. Also, some segments connected to hubs in Delaware.

We then separated corridor segments into two size groupings, because shorter corridors were less likely to contain roads or other breaks. Corridor segments ranged from 10 to 3,197 ac. A size threshold of 154 ac divided the segments into two nearly equal groups numbering 910 and 912. After examining distribution of the data, we grouped them into either "short" (#154 ac; about 0.85 mile or shorter), or "long" (>154 ac).

The ecological rankings of corridor segments can help compare alternative linkages between hubs. One can average the rankings (when converted to percentiles) of corridor segments along a particular pathway, or note the segment with the lowest score. For example, if the segments along pathway A between hub #1 and hub #2 rank lower than those along pathway B between the same hubs, then pathway B would be a more viable linkage. Pathway A may have more breaks along its route, more road crossings, or less natural land cover.

Segment Ranking

We calculated 22 parameters for each corridor segment (Table x). None of these parameters were highly correlated (>80%); the highest were between gap proportion and vegetation maturity (70%). Corridor segments were then ranked from best to worst for each parameter, within their physiographic region and size class. Note that high values for some parameters would cause a segment to be highly ranked (better), while high values for others would cause a low (worse) ranking.

To derive a composite ecological ranking, we converted these rankings to percentiles, and multiplied the percentile for each parameter by an importance weighting (Table 5-5). We combined road crossings to improve resolution: road crossings = primary * 4 + secondary * 2 + county * 1 + railroad * 1. The weighting for combined road crossings was the sum of the individual weights (8). The linear combination of weighted percentiles ranked corridor segments from highest to lowest within their physiographic region and size class. As with hubs, we used nonparametric ranking because we lacked information needed to evaluate thresholds. Fig. x shows the composite hub and corridor ecological ranking for a portion of southern Maryland.

Table 5-5
Parameters and weights used to rank overall ecological significance of each corridor segment within its physiographic region.

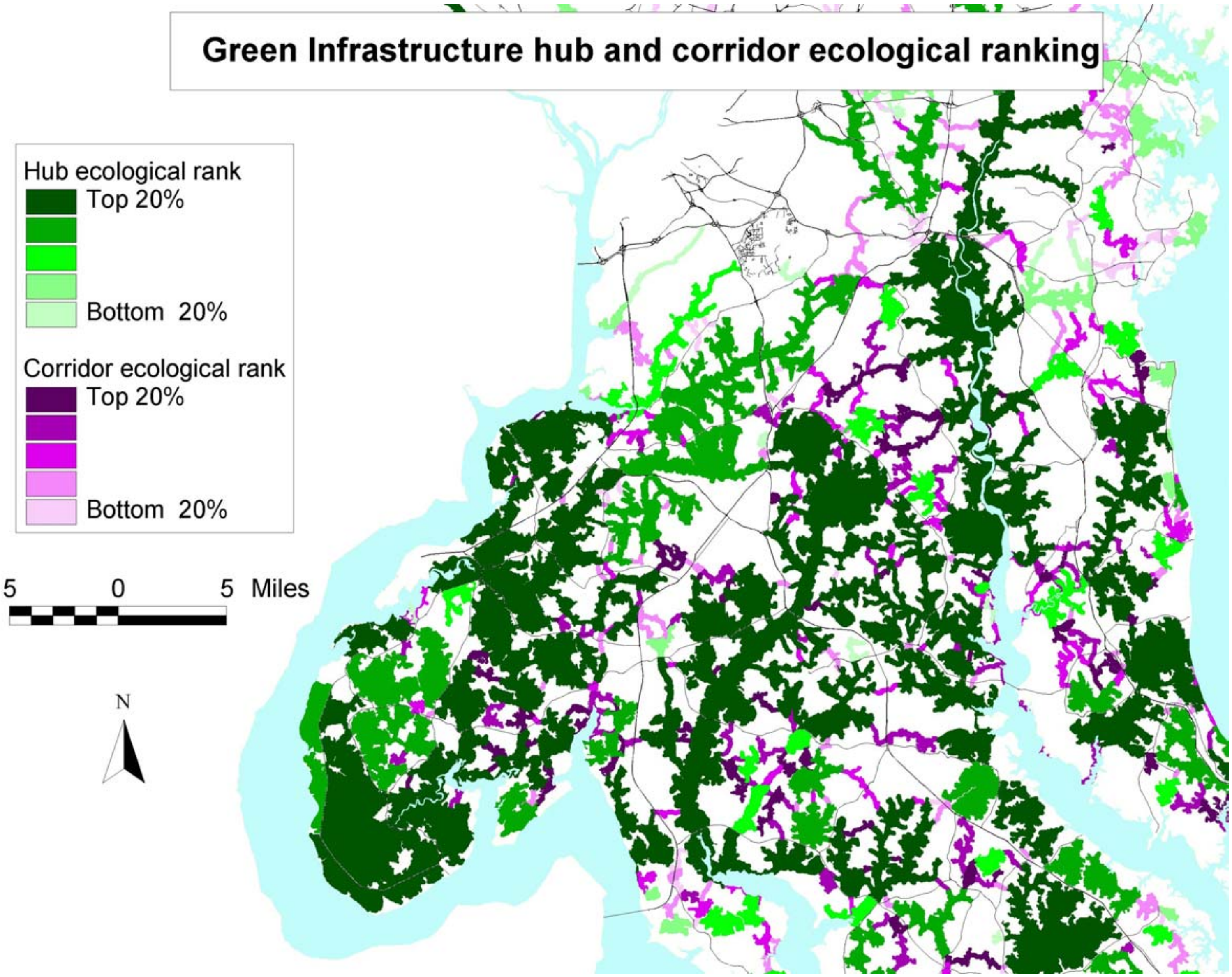
Parameter	Weight	% of score
Does corridor link hubs in top ecological tier?	8	14.5%
Top ecological ranking of hubs connected by corridor	4	7.3%
Mean upland impedance	4	7.3%
Mean wetland impedance	4	7.3%
Mean aquatic impedance	4	7.3%
Total area	1	1.8%
Number of corridor breaks	4	7.3%
Road crossings, weighted by road type	8	14.5%
Percent of gap area	2	3.6%
Sum of rare species scores	2	3.6%
Area of Delmarva fox squirrel habitat	1	1.8%
Fraction in mature and natural vegetation communities	2	3.6%
Fish IBI	1	1.8%
Benthic invertebrate IBI	1	1.8%
Presence of brook trout	1	1.8%
Area of upland interior forest	1	1.8%
Area of wetland interior forest	1	1.8%
Area of other unmodified wetlands	1	1.8%
Length of streams within interior forest	1	1.8%
Area of highly erodible soils	1	1.8%

Parameter	Weight	% of score
Mean distance to the nearest primary or secondary road	1	1.8%
Surrounding buffer suitability (within 300' of hub)	2	3.6%

Identification of corridors that link existing protected lands

Corridor segments that link existing protected lands should be a higher priority for limited acquisition or easement funds. If the hubs that a corridor links are lost, the corridor cannot function as a linkage. These segments were selected manually in ArcView, and annotated accordingly.

Fig. 5-4
Hub and corridor composite ecological ranking, for a portion of southern Maryland.



Chapter 6
RANKING THREATS TO MAINTAINING GREEN INFRASTRUCTURE

Threats to the continued existence of the green infrastructure arise from two, partially overlapping, sources. Of first importance is the simple conversion of natural lands into some form of urban use–residential, commercial, industrial or institutional–with consequent *loss* of virtually all natural resource value. In addition, lands currently protected from this sort of private development by some form of public control, either through fee ownership or through easements held by public or non-profit entities, is subject to change in its management status, with impacts on their *function* as green infrastructure. For example, natural lands held by the State Forest and Park Service may be subject to development of recreational uses which would negate much of their ecological value.

This chapter examines the many factors that together influence the risk that portions of the green infrastructure will be lost, primarily through their development into urban type uses. We also look at the potential for changes in the management status of lands protected by public or quasi-public ownership that might affect green infrastructure function.

Level of protection–development restrictions through ownership rights in land

Various restrictions on development are imposed through two primary mechanisms: public ownership rights of some sort and public regulation of private action. This section examines the restrictions on potential land conversion imposed by the ownership of full fee or partial (through easement) interest in land in the green infrastructure. Table 6-1 summarizes the amount of green infrastructure land in each county protected by these mechanisms.

Public and privately owned conservation lands

These are essentially protected from development, although management practices differ. We used protected lands data updated in 2000, including DNR lands; national parks, forests, and wildlife management areas; privately owned conservation lands (e.g., The Nature Conservancy); and large county parks (i.e., we excluded neighborhood parks).

Other publicly owned lands

These include county parks, military lands, etc., which are not managed for conservation. Private development may be discouraged here, although public development (ballfields, runways, etc.) is not necessarily prohibited.

Conservation easements

These are perpetual restrictions on development, although they do not prevent management practices such as clearing forest for agriculture. Maryland Environmental Trust (MET) conservation easements protect farmland, woodland, wetland, natural areas, scenic open space, and historic sites. We used protected lands data updated in 2000.

Agricultural easements

These are long-term easements (in practice, perpetual) on development, although they do not prevent management practices such as clearing forest for agriculture. They preserve Maryland farmland, by restricting use of land to agricultural use only. We used protected lands data updated in 2000.

Open water

Open water(lakes, rivers, and bays) is the property of the state and cannot be developed in general. For consistency, we used open water from the federal National Land Cover Data (NLCD), formerly referred to by the initials of the consortium that developed it, MRLC.

Current protection status

As of 2000, only 26% of Maryland's green infrastructure natural land cover was protected by federal, state, or local public ownership; ownership by private conservation organizations like The Nature Conservancy or the Izaak Walton League; or conservation easements held solely or jointly by the Maryland Environmental Trust. Table 6-1 shows protected and unprotected green infrastructure land by county. Gaps are included, but open water is not, since it is generally public domain. Agricultural easements were not included, but these fall mainly outside the green infrastructure.

Table 6-1
Current (as of 2001) protection of green infrastructure, by jurisdiction. Listing is in order of % unprotected GI land.

Political Jurisdiction	Total green infrastructure land (ac)	Protected green infrastructure land (ac)	Protected green infrastructure (% of GI land)	Unprotected green infrastructure land (ac)
ST MARY'S	88,225	5,071	5.7%	83,194
TALBOT	43,410	4,033	9.3%	39,377
CALVERT	57,193	6,131	10.7%	51,062
CHARLES	166,840	19,504	11.7%	147,336
QUEEN ANNE'S	74,186	9,626	13.0%	64,560
CAROLINE	75,865	12,451	16.4%	63,414
CECIL	73,744	12,435	16.9%	61,309
WICOMICO	117,986	21,871	18.5%	96,115
DORCHESTER	252,299	56,078	22.2%	196,221
KENT	42,131	9,371	22.2%	32,760
WORCESTER	179,135	41,809	23.3%	137,326
ANNE ARUNDEL	68,929	18,116	26.3%	50,813
GARRETT	286,241	81,682	28.5%	204,559
FREDERICK	91,375	30,257	33.1%	61,118

Political Jurisdiction	Total green infrastructure land (ac)	Protected green infrastructure land (ac)	Protected green infrastructure (% of GI land)	Unprotected green infrastructure land (ac)
WASHINGTON	84,577	28,020	33.1%	28,020
SOMERSET	126,137	41,829	33.2%	84,308
PRINCE GEORGE'S	102,929	35,220	34.2%	67,709
ALLEGANY	194,601	67,640	34.8%	126,961
CARROLL	25,102	9,983	39.8%	15,119
HARFORD	80,864	34,847	43.1%	46,017
HOWARD	33,491	15,351	45.8%	18,140
BALTIMORE	83,144	39,531	47.5%	46,613
MONTGOMERY	82,970	47,241	56.9%	35,729
BALTIMORE CITY	1,429	910	63.7%	519
TOTAL	**2,432,841**	**649,006**	**26.7%**	**1,783,835**

Note that the high percentages protected in the urban jurisdictions is in part an artifact of the definition of green infrastructure as including protected lands.

Level of Protection–development restriction through regulation

A number of state and local regulations and state incentives were identified as helping protect natural areas from development, to one degree or another. We lacked spatial data on all such mechanisms, so this analysis will be updated when such information is available. Data were not available outside the state. County-specific conservation measures were not included, but this also will be added in the future. Furthermore, it is anticipated that, over time, protected lands will increase and regulations will change.

Wetlands

Wetlands require permits to disturb extensively enough for development. Wetlands of Special State Concern (WSSC) are also given a 100-foot buffer from development.

Floodplains

County regulations prohibit most development in floodplains. Federal Emergency Management Agency (FEMA) 100-year floodplains were used. Data were unavailable for all counties.

Steep slopes

Steep slopes (defined here as $25%) require permits to develop; they are also difficult from an engineering standpoint. Slope was calculated from a Digital Elevation Model, or DEM.

Sensitive Species Project Review Areas

Sensitive Species Project Review Areas (SSPRA) provide little protection against development; only environmental reviews. These were based on USGS 7.5 minute quadrangles, and showed generalized areas primarily containing rare, threatened, and endangered species (Miller, 1997). Polygons also generally encompass, but do not delineate, such regulated areas as Habitat Protection Areas, Nontidal Wetlands of Special State Concern, Natural Heritage Areas, Colonial Waterbird Sites, and Waterfowl Concentration and Staging Areas (Miller, 1997).

Critical Area resource conservation areas

Resource conservation areas (RCAs) defined by the Chesapeake Bay Critical Area Program are within 1000 feet landward of the state tidal wetlands boundary or the shoreline of the Chesapeake Bay and its tributaries, and are nature-dominated environments such as wetlands, forests and abandoned fields or areas of resource utilization, such as agriculture, forestry, fisheries or aquaculture. They are also defined as areas where density is less than one dwelling unit per five acres; or areas with dominant land uses in agriculture, wetland, forest, barren land surface, water, or open space. Digital layers were only available for 3 counties (Anne Arundel, Baltimore, and Charles).

Land zoned for conservation by the counties

Generalized zoning was obtained from the Atlas of Agricultural Land Preservation in Maryland (Maryland Office of Planning, 1998). Those areas deemed most at risk were zoned for residential or non-residental development. The other zoning classes are agriculture, conservation, water, and wetlands. In Garrett County, all areas zoned 'unclassified' (not planned for development) were considered by Office of Planning (now Maryland Department of Planning, MDP) as zoned primarily for agriculture. Exemptions from zoning are frequent, so this was given a low weight for protection. Zoning requirements differ by county, but specifics were unavailable. 13 counties had “conservation” zoning according to Maryland Office of Planning (1998). It was assumed that for upland forests not on steep slopes, the strength of conservation zoning restrictions (Table 6-2) generally resembled that of agricultural zoning (from American Farmland Trust, 1998), unless additional information was available.

Land zoned for agriculture by counties

Generalized zoning was obtained from the Atlas of Agricultural Land Preservation in Maryland (Maryland Office of Planning, 1998). Since exemptions from zoning are frequent, this, like conservation zoning, was given a low weight. The level of protection for agricultural zoning differed by county (American Farmland Trust, 1998); this is summarized in Table 6-2.

Table 6-2
Conservation and agricultural zoning strength by county
(based on American Farmland Trust, 1998).

Counties	Agricultural zoning level of protection	Model value
Allegany, Baltimore, Frederick, Montgomery, Worcester	High	7
Anne Arundel, Caroline, Carroll, Kent, Queen Anne’s, Talbot	Moderate	8
Calvert, Cecil, Charles, Dorchester, Garrett, Harford, Howard, Prince George’s, Somerset, St. Mary’s, Washington, Wicomico	Low	9

Agricultural districts

The Maryland Agricultural Land Preservation Program's intent is to preserve productive agricultural land and woodland in Maryland in order to provide for the continued production of food and fiber, to curb the extent of random urban development, and to protect agricultural land and woodland as open space. The program is voluntary on the part of the landowners and is dependent upon the cooperation of local governments, which appoint five member Agricultural Land Preservation Boards. This program, created by the Maryland General Assembly in 1977, is governed by Section 2-505 of the Agricultural Article of the Annotated Code of Maryland. Agricultural easements are initiated by the owner. They must go through a 3 step process. Step 1: Ask the Board of Public Works to designate the concerned property a district. Step 2: After the land has been included in a district, apply to the Board of Public Works to buy an easement on the land. Step 3: If an easement is purchased, adhere to the laws and regulations governing agricultural easements. Agricultural districts were considered partially protected from development in our analysis because of landowner intention.

Rural Legacy areas

The Rural Legacy Program directs State funds into a focused and dedicated land preservation program specifically designed to limit the adverse impacts of sprawl on agricultural lands and natural resources. The Program allocates State funds to purchase conservation easements for large contiguous tracts of agricultural, forest and other natural resource areas subject to development pressure, and fee interests in open space where public access and use are needed. Local governments and private land trusts are encouraged to identify Rural Legacy Areas and to competitively apply for funds to complement existing land conservation efforts or create new ones. Rural Legacy Areas have more effect on development than Priority Funding Areas (PFAs), since county governments tend to zone Rural Legacy areas for agricultural and natural resource conservation. Rural Legacy data were not used in the composite score, because zoning was used instead. Rural Legacy area designation signals a local government’s intent to reinforce conservation zoning with active protection measures.

Composite score for development restrictions

To derive a composite score, restrictions on development, both through ownership rights and through regulation, were given a score between 0 and 1 for each mechanism, with 0 being the most restrictive (no development permitted), and 1 being the least restrictive (no restrictions on development). Scores (Table 6-3) were solicited from permitting experts. The restrictions are multiplied together for each 0.3 acre grid cell in Maryland; for example, a wetland falling within an SSPRA and Critical Area RCA would contain the restrictions of all three designations, with a resulting restriction score of 0.144. Fig. 6-1 maps the composite scores within Maryland. Both hubs and corridor segments were analyzed for their current level of protection, by averaging grid cell values within the hub or corridor.

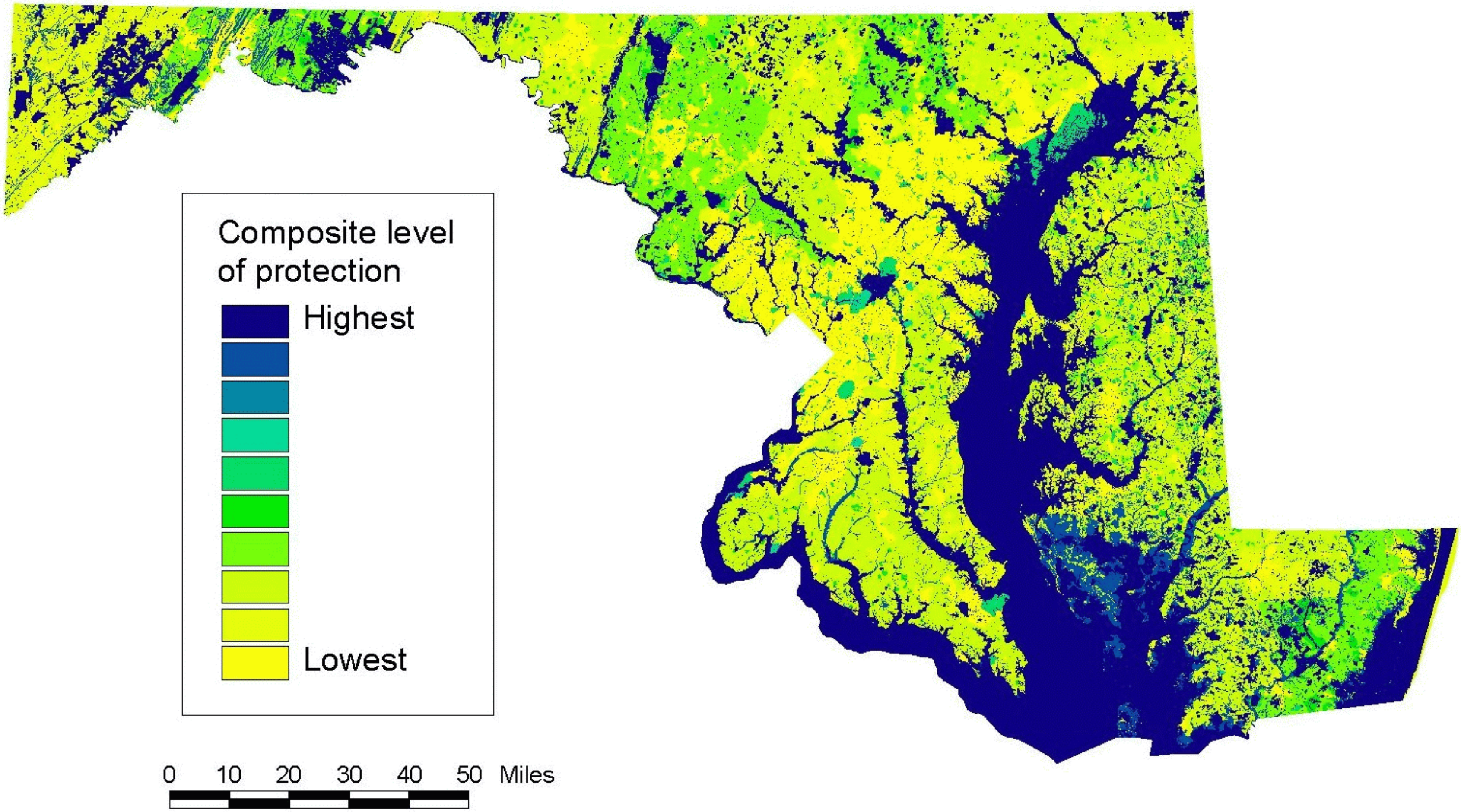
Table 6-3
Restrictions on development, and their relative strength (a score between 0 and 1).

Data layer	Restriction score
Public and privately owned conservation lands (as of 2000)	0.0
Other public ownership (as of 2000)	0.5
Conservation easements (as of 2000)	0.0
Agricultural easements (as of 2000)	0.0
Open water	0.0
Wetlands	0.2
Steep slopes ($25%)	0.3
100 year floodplains	0.8
SSPRA	0.9
CBCAC resource conservation areas	0.8
Zoned by county for conservation (as of 1994)	0.7-0.9
Zoned by county for agriculture (as of 1994)	0.7-0.9
Agricultural districts (as of 2000)	0.7

Current management status

In order to assess the potential for green infrastructure that is protected by ownership mechanisms to retain its ecological function, we examined the management status of Maryland's green infrastructure, according to the version published in Maryland Greenways Commission (2000), the GAP management criteria from Scott et al (1993), and protection data layers developed by Maryland DNR and others. These coverages of green infrastructure and protected lands pre-date those used in the preceding section, so numbers will differ slightly.

Fig 6-1
Restrictions on development in Maryland, and their relative strength (see text for details).



Ownership, easement, and regulatory mechanisms vary in their level of environmental protection, allowing different activities or management. For example, some public lands may emphasize logging, or construction of recreational facilities like golf courses or ball parks. GAP management status (Scott et al, 1993), refers to the degree to which an area is managed to maintain biodiversity. All land in the ownership data layers was assigned to one of the following management status classes (see Fig 6-2):

> Management Status 1 - an area with an active management plan in operation that is maintained in its natural state and within which natural disturbance events are either allowed to proceed without interference or are mimicked through management. In Maryland, only Cedar Island Wildlife Management Area (WMA) and South Marsh Island WMA met these stringent criteria.
>
> Management Status 2 - an area that is generally managed for its natural values, but which may receive use that degrades the quality of natural communities that are present. Designated wildlands, preserves, many parks, and heritage or water management areas of state forests were included in this class.
>
> Management Status 3 - most nondesignated public lands, including parks developed for recreation, general management areas of state forests, and military proving grounds. Legal mandates prevent permanent conversion to anthropogenic habitat types (with some exceptions, such as tree plantations) and confer protection to populations of Federally listed endangered, threatened, and/or candidate species.
>
> Management Status 4 - private or public land without an existing easement or irrevocable management agreement that maintains native species and natural communities and which is managed primarily or exclusively for human activity. Urban and agricultural lands, ballparks, golf courses, public buildings and grounds, and transportation corridors are examples of this class.

For the purposes of the green infrastructure assessment, Management Status 4 was split into three subgroups:

> Management Status 4A - MET and 25-year agricultural easements.
> Management Status 4B - Public lands managed primarily for active recreation or other intensive human activity.
> Management Status 4C - Private land with no permanent easements.

The different management zones were laid over the map of Maryland's green infrastructure published in Maryland Greenways Commission (2000), to examine its relative current protection (Table 6-4).

Fig. 6-2
Management status in Maryland (see text for details).

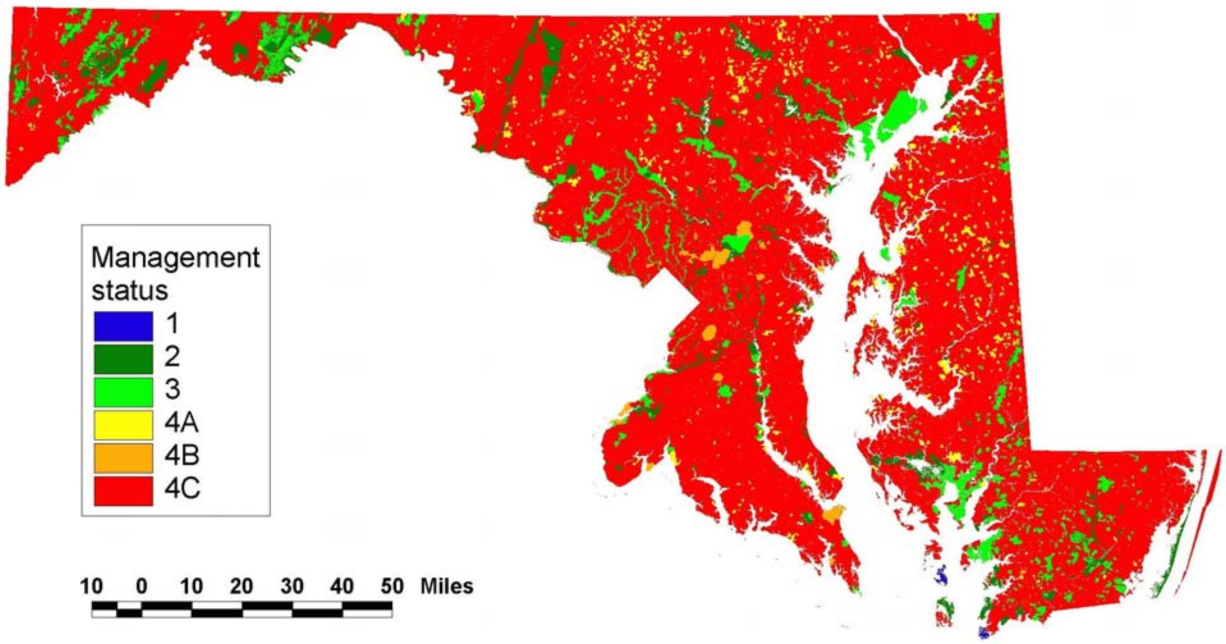


Table 6-4
Area and percent of Maryland's green infrastructure by management regime.

	Area (ac) in management status 1-4					
GI feature	**1**	**2**	**3**	**4A**	**4B**	**4C**
hub natural cover	5,767	242,580	294,023	22,320	12,268	1,319,931
corridor natural cover	0	2,098	12,842	7,333	2,183	267,154
developed gap	0	1,520	3,797	181	822	20,526
agriculture or lawn gap	0	10,200	31,776	11,946	2,695	297,983
barren gap	0	797	4,872	3	500	14,362
	Area (%) in management status 1-4					
GI feature	**1**	**2**	**3**	**4A**	**4B**	**4C**
hub natural cover	0.3	12.8	15.5	1.2	0.6	69.6
corridor natural cover	0.0	0.7	4.4	2.5	0.7	91.6
developed gap	0.0	5.7	14.1	0.7	3.1	76.5
agriculture or lawn gap	0.0	2.9	9.0	3.4	0.8	84.0
barren gap	0.0	3.9	23.7	0.0	2.4	69.9

The vast majority of the green infrastructure fell within Management Status 4C, meaning it has no protection at all. This was especially true for corridors. Only 13% of hub natural cover, and less than 1% of corridor natural cover, were in areas managed primarily for natural values (Status 1 or 2).

Next, we examined protection of hub and corridor natural areas (gaps not included) by physiographic region (Table 6-5). The majority of the green infrastructure was unprotected (Management Status 4C) within each physiographic region. Only the Blue Ridge region (which was the smallest region) had over 20% of its hubs and corridors managed primarily for natural values. The Coastal Plain was the least protected, especially the western shore. This area, along with the Piedmont, also has the highest human populations, and the fastest growth rates. The Maryland Department of Planning has projected the largest forest loss in watersheds in the Piedmont and western Coastal Plain by 2020 (unpublished).

Table 6-5
Area and percent of Maryland's green infrastructure
by physiographic region and management regime.

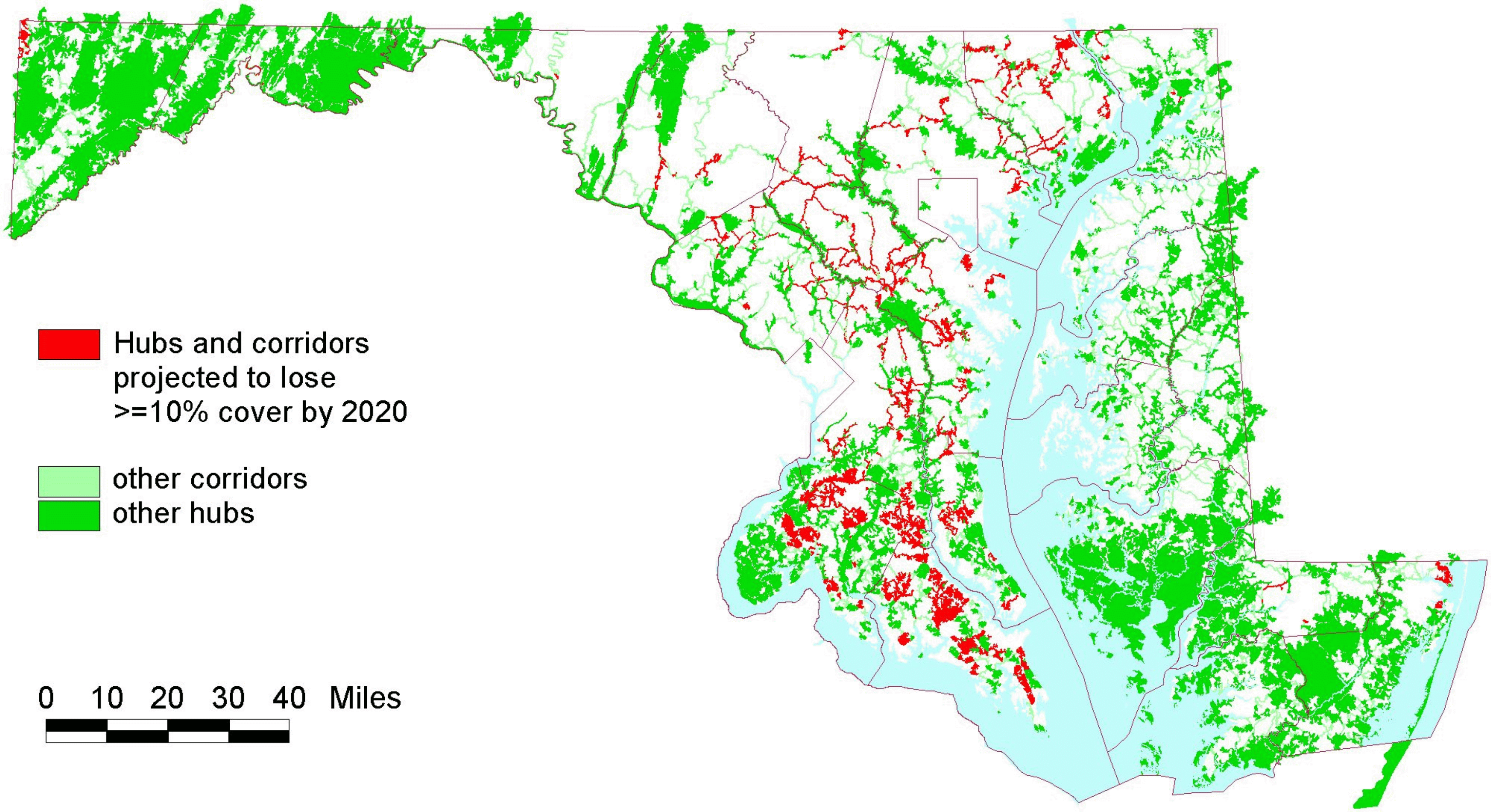
	Area (ac) in management status 1-4					
Physiographic region	**1**	**2**	**3**	**4A**	**4B**	**4C**
Appalachian Plateau	0	44,334	44,365	485	145	231,922
Blue Ridge	0	32,323	1,030	242	481	55,337
Coastal Plain, east	5,767	63,079	111,402	17,648	771	637,797
Coastal Plain, west	0	29,458	58,365	5,074	11,216	381,458
Piedmont	0	40,852	55,610	4,756	1,584	160,904
Ridge and Valley	0	34,632	36,094	1,448	254	119,667
	Area (%) in management status 1-4					
Physiographic region	**1**	**2**	**3**	**4A**	**4B**	**4C**
Appalachian Plateau	0.0	13.8	13.8	0.2	0.0	72.2
Blue Ridge	0.0	36.2	1.2	0.3	0.5	61.9
Coastal Plain, east	0.7	7.5	13.3	2.1	0.1	76.2
Coastal Plain, west	0.0	6.1	12.0	1.0	2.3	78.6
Piedmont	0.0	15.5	21.1	1.8	0.6	61.0
Ridge and Valley	0.0	18.0	18.8	0.8	0.1	62.3

Projected forest and wetland loss 1997-2020

2020 land use was projected by Maryland Dept. of Planning at the 12-digit watershed (subwatershed) level. See Maryland Department of Planning (2001) for methodology details. We compared 2020 land use with MDP 1997 land use. MDP predicted no net loss of wetlands (an optimistic projection), so we used the projected percent loss of forest (codes 41-44) by 12-digit watershed. Changes <5 ac in the entire watershed were rounded to 0%.

We converted percent forest loss to a grid, and summarized by hub. For consistency, we used MDP 1997 land use to determine the relative proportion of upland forest (codes 41-44) within each hub. Projected hub forest loss by 2020 was estimated by multiplying the percent projected upland forest loss by the percent upland forest not protected by public ownership, easements, or steep slopes

Fig 6-3
Hubs and corridors projected to lose at least 10% of their cover to development by 2020.



(>25%). This parameter was mainly based on demand for new housing, and would not capture commercial developments like rock quarries or industrial parks.

Parameters for ranking loss of hubs to development

Within each physiographic region, hubs were also ranked from highest to lowest for the development risk parameters listed below (also see Table 6-8). These rankings were combined linearly, as the ecological rankings were. All hubs are considered ecologically important, but initial conservation efforts might be directed toward those at the greatest risk of loss to development. A hub's risk of development can be combined with its ecological score to help prioritize efforts. Hubs ranking in both the top quantile (e.g., top third) of their physiographic region ecologically, and the top quantile threatened by development, should be candidates for immediate action. If field surveys verify the importance of these areas, conservation measures should take place before they are lost forever.

Development risk parameters are described in more detail below. For most we had only Maryland data.

<u>Level of protection from development</u>

The composite protection from development layer, described earlier, was converted to an integer between 0 (development prohibited) and 100 (no restrictions on development). This was averaged within each hub.

<u>Percent of hub zoned for development by county</u>

This parameter was not used in the composite ranking, because zoning was used for calculating protection level. Those areas most at risk were zoned for residential or non-residential development. The other zoning classes are agriculture, conservation, water, and wetlands. In Garrett County, all areas zoned 'unclassified' (not planned for development) were considered by MDP as zoned primarily for agriculture.

Percent of hub within Priority Funding Areas

Under Smart Growth legislation, state funding for projects in Maryland municipalities, other existing communities, industrial areas, and planned growth areas designated by counties will receive priority funding over other projects. Priority Funding Areas (PFAs) are locations where the State and local governments want to target their efforts to encourage and support economic development and new growth. These boundaries will limit development only indirectly, since only state funding is involved. We used August 2001 PFA boundaries, where 2 = inside designated PFA, 1 = inside uncertified PFA, and No Data = outside. Uncertified PFA's in most counties are second tier growth areas and are probably not being currently targeted by the local jurisdiction for growth (Eisenberg, 2001).

Percent of hub with existing or planned sewer service

Areas with existing or planned water or sewer service are more likely to be developed. County sewer service areas were digitized by Maryland Department of Planning from 1993-2000 MDE countywide master plans. The dates and classifications varied by county. Water service areas were not mapped for the state, but according to Eisenberg (2001), in most areas, where there is sewer service, there is water service. County sewer service areas were scored according to their service timeline. Timelines and designations differed by county. In general, we used the following table:

Table 6-6
Sewer service categories in Maryland.

Service category	Score
existing service area or system under construction	10
area in final planning stages	8
programmed for future service within 5 to 20 years	4-7, depending on time frame
future service area (not planned for service except as health problems demand)	2-3
no planned service area	0

County sewer service coverages were combined to a statewide data layer. All existing or planned sewer areas (scores >0) were given a value of 1. Baltimore City, which had no data, was also given a value of 1 (the city is almost entirely served by utilities). We calculated the acres and percentage of each hub inside existing or planned sewer areas.

Population growth or loss 1990-2000

We tried to identify rapidly growing areas by looking at the last decade of population growth. We compared 2000 human population density within Maryland census blocks (from 2000 TIGER data), to 1990 human population density within Maryland census blocks (from 1990 TIGER data). Census block change was averaged by hub.

Number of parcels

The number of forest landowners in the U.S. has been steadily increasing since the early 1900's, and thus the average parcel size is decreasing (Mehmood and Zhang 2001). In Maryland, the number of forest owners more than tripled between 1978 and 1994, increasing from 42,200 to 130,600 (Birch 1996). Total private forest land ownership increased only slightly, and the average parcel size decreased from 45 acres to only 17 acres. Parcelization often leads to forest fragmentation. As the number of landowners increases, their attitudes and objectives become more diverse, and many choose to convert their land to other uses, especially residential (Birch 1996, Mehmood and Zhang 2001).

Parcel centroids were obtained from Maryland's real property database, MdProperty View. We used only parcels at least 1 acre, to make the data set manageable. Parcels smaller than this were generally intensely developed, and located outside the green infrastructure network. The number of unique parcel ID's was summed within each hub.

Commuting time to town centers

Bockstael (1996), Geoghegan et al (1997), and Bockstael and Bell (1998) found that distance to urban centers such as Washington DC affects land value and the probability of housing construction on private parcels. Wickham et al (2000) found a strong correlation between forest fragmentation and a geographic gradient of urbanization pressure in central Virginia. Land demand pressure was interpolated as a ratio of urban center population, taken from the 1990 Census of Population for each Census Designated Place, over the distance along major roads from these urban centers (Wickham et al, 2000). The number of jobs in a city, especially the number of jobs commuted to, is a better measure of nearby development pressure than city population alone.

For each cell, the development pressure was influenced by the number of jobs in nearby urban centers, divided by the commuting time to these areas. Commuting time was estimated by road distance, weighted by the vehicle speed of the road type. A composite traffic impedance grid was created by roughly assigning vehicle speeds to four different road types (see Table 6-7). These speeds correspond mainly to posted speed limits; traffic signals and congestion were not considered, except to give highways a speed on the high end of that posted (65 mph), and other roads a speed on the low end (30-45 mph). Road intersections, except for highway ramps, overpasses, or underpasses, were given a low speed (10 mph) regardless of type. These were taken from SHA road coverage nodes (intersections or end points), which were buffered 1 grid cell. Obviously there is a great deal of variation according to location, time of day, weather, accidents, police activity, etc., but this would make the model unnecessarily complicated. Grid cells without existing interstate, state, or county roads were given a dummy value (10 mph) to account for local roads or places where roads could be built in the future. Locations where roads could not be built were considered impassable. Traffic impedance was calculated for each road type by converting speed to seconds per foot, taking the inverse, and multiplying by 2000 to convert to integers.

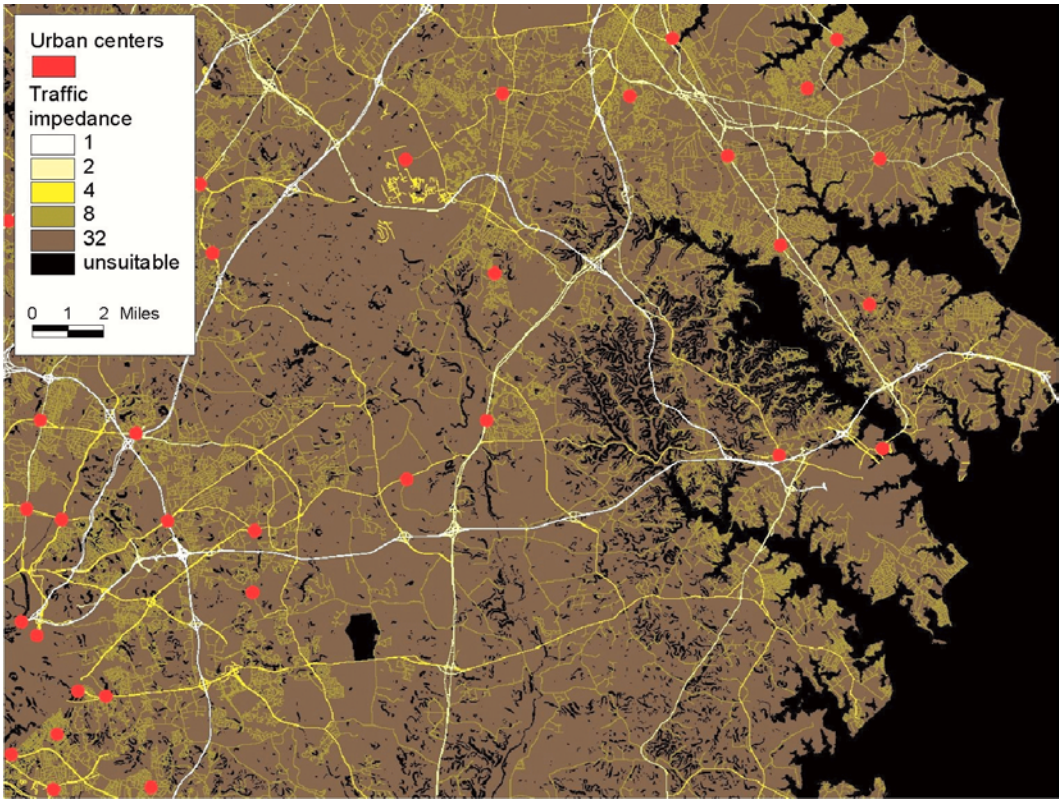
Table 6-7
Roads and Traffic Impedance

Type of road	Speed (mph)	Speed (ft/sec)	Traffic impedance
Interstate highway or other limited access road	65	95.33	21
Other primary roads	45	66.00	30
State secondary roads	35	51.33	39
County roads	30	44.00	45
Road intersections (except highways)	10	14.67	136
Areas where roads could be built (everywhere but exceptions listed below)	10	14.67	136
Areas not easily traversable (open water, slopes $10%, private conservation lands, or state designated wildlands)	0	0	No data (i.e., relatively impassable)

The cost-distance function calculates for each cell the least-cumulative-cost distance over a cost surface to a source cell or a set of source cells (ESRI, 1999). The cost values assigned to each cell are per-unit distance measures for the cell (ESRI, 1999). That is, if the cell size is expressed in feet, the cost assigned to the cell is the cost necessary to travel one foot within the cell. If the resolution is 117 feet, the total cost to travel either horizontally or vertically through the cell would be the cost assigned to the cell times the resolution (total cost = cost * 117). To travel diagonally through the cell, the total cost would be 1.414214 times the cost of the cell times the cell resolution (total diagonal cost = 1.414214 [cost * 117]). In this case, the cost-distance grid units would be in seconds of travel after dividing by 2000.

Roads data were obtained from SHA, and converted to a traffic impedance grid (Fig 6-4). A point shapefile of city centers was obtained from ESRI. This was reprojected, and cities in Maryland, DC, and Delaware were selected. We then added Ocean City, Easton, Stevensville, Edgemere, Owings Mills, and Lexington Park, MD. Positional accuracy was manually adjusted to conform to roads. DC points were placed at each major road into the District. We were unable to obtain data on commuters to each city. Census data were obtained from city residents rather than from commuters to a particular city. Therefore, they were all treated the same, except for DC and Baltimore, which were given additional weighting (see next parameter). We buffered points 2000 feet, and converted to a grid. A commuting cost-distance grid was created from each urban center. This was converted to commute time in seconds, and averaged by hub. The value per hub was the mean commute time to the nearest urban center in seconds, given the simplifications of the model. 10 hubs had no value; these were inaccessible by road.

Fig. 6-4
Traffic impedance grid used to determine commuting times



Land demand based on proximity to Washington DC and Baltimore

For Washington and Baltimore, we followed the methodology of Wickham et al (2000). Land demand pressure was interpolated as a ratio of urban center population, taken from the 1990 Census of Population for each Census Designated Place, over the distance along major roads from these urban centers (Wickham et al, 2000). We gave extra weighting for proximity to DC and Baltimore, which have by far the largest concentration of commuters in the state. Other cities were addressed in the previous metric, commuting time to urban centers. We calculated land demand from DC and Baltimore as the number of potential commuters divided by the commuting time to these areas. According to census data, the Washington DC Metropolitan Statistical Area (MSA) had 1,455,736 workers employed outside their place of residence in 1990. The Baltimore MSA had roughly half that: 701,690 workers employed outside their place of residence in 1990. The only other MSA in Maryland, Hagerstown, had only 21,639. This was comparable (same order of magnitude) to the number of commuters living in other Maryland cities, like Frederick, Annapolis, and Salisbury. Commuting time was calculated in the previous metric. We used the DC and Baltimore beltways as the destination, since destinations are spread throughout the urban areas. For each hub, the combined development pressure was equal to (number of DC workers) / (commute time to DC beltway) + (number of Baltimore workers) / (commute time to Baltimore beltway). The value was the mean of development pressure from DC and Baltimore, as number of workers in the cities, divided by the commute time to the beltways in seconds.

Market value of land

Bockstael (1996) and Bockstael and Bell (1998) found that the higher the land value of a parcel, the higher the probability of its conversion to residential use or other development. MdProperty View, which contains market land value, was interpolated to create a continuous cost surface.

Using MdProperty View (1997-1998 data), we first divided parcel unimproved land value by parcel total acres for each property centroid. We omitted parcels with land value or size fields equal to 0. We manually inspected the database for errors, and deleted questionable records. There were several property centroid shapefiles per county; these were merged by an Avenue program, and saved as a shapefile with parcel total acres, parcel unimproved land value, and parcel unimproved land value per acre.

From these data, we omitted parcels less than 10 acres, because: a) most small parcels are already developed or being developed; b) the average cost per acre of most small lots is very high, and distorts the cost surface grid; and c) the data set is too large when all parcels are included. We also omitted all protected land and land with conservation easements already in place.

We estimated land values between these parcel centroids using the POINTINTERP command in GRID, which interpolates a surface from point features in a specified neighborhood around each output grid cell, using a specified distance weighting function:

```
POINTINTERP(pointcover, item, cellsize, EXP_SMOOTH, decay, plateau,
radius)

newinterpolationgrid = pointinterp(eachcounty, costperac, 30,
exp_smooth, 1.5, 115, 2000)
```

EXP_SMOOTH: exponential distance weighted interpolation and a smoothing factor is applied to the z-values. Only a circular neighborhood can be used with this option. With the SMOOTH option, the weighting function is modified so that as the distance of a point from the grid cell center increases towards the radius value, its weight approaches 0. The result is a bell-shaped curve weight function with weight equals 1, where distance is 0, and weight equals 0, where distance equals radius.

Decay: controls how quickly the weighting of points diminishes, as they are further away from the output cell center. The value represents the distance at which a point's weight is diminished by half compared to a distance of 0.

Plateau: the weighting of points is constant for all points less than this distance from the output cell center. Plateau is defined so that the weight function has the value 0.5 when distance equals the value of decay. Our plateau was 115 meters, which is roughly 10 acres. So any points within a 115 radial distance from the centroid had the same value as the centroid. We removed all centroids that were valued less than 10 acres; so all the points in this part of the analysis have land acreage of 10 or more.

Radius: We used a maximum neighborhood radial distance of 2000 meters. A maximum radius of 2000 meters roughly translates to less than a 3000 acres. Thus the influence of a centroid's z-value (cost per acre) on the interpolated grid cell value will depend on how far the point is from the cell being interpolated. If the point is outside the neighborhood (greater than 2000 meters) it has no influence. If it is inside the neighborhood then its weighted value is calculated using an inverse exponential distance interpolation..

The result was a continuous cost surface grid for the state of Maryland. Each 30 x 30 m cell in the grid contained estimated land value per acre. Because the cost surface grid had too large a value range to display, values $$1,000,000/ac were reclassified to $999,999. Only 1382 ac were affected by this, in urban Montgomery and Baltimore counties. Lakes, rivers, and bays were subtracted, as were protected lands (as of 2000). These were undevelopable. Baltimore City was also subtracted, since no Baltimore City parcels were used. We then computed the mean land value per hub.

As a side note, the projected 1997-1998 cost of purchasing particular hubs or corridors was determined by multiplying the currently unprotected acres of the hub or corridor by the mean land value. Unprotected acres were calculated by subtracting lakes, rivers, and bays, and protected lands, from the total acres of the hub. The projected cost (after adjusting for inflation, or recalculating using 2001 data) could vary through negotiation, though.

<u>Distance from major roads</u>

The closer to a road, the more prone an area to development, because of decreased construction costs and increased access to existing infrastructure. Major roads (primary and secondary) improve general accessibility (Bockstael, 1996). Access to major roads is especially important to businesses;

most general access major roads are lined with commercial and industrial enterprises. We calculated the mean distance of each hub from all interstate and primary and secondary state roads.

Area of waterfront property

Waterfront property is generally more desirable to developers (Bockstael, 1996). We defined waterfront property as cells adjacent to (i.e., within 166 feet of) river, lake, or bay shorelines, excluding wetlands.

Proximity to preserved open space

Bockstael (1996) found that the amount of preserved open space surrounding a parcel increased its value, and thus its probability of conversion to residential use. We calculated the mean distance of each hub from all protected lands (public land, private conservation land, conservation easements, or agricultural easements).

Overall ranking of hubs by relative risk of development

We ranked hubs from highest to lowest for each parameter in Table 6-8 within their physiographic region, and converted these rankings to percentiles. We multiplied these percentiles by the parameter importance value, and added these together to give an overall ranking from highest to lowest risk of development. Rankings were both within the entire state, and within each physiographic region. As with ecological data, we used nonparametric ranking, because we lacked information needed to evaluate thresholds. All hubs were considered ecologically important, and all should receive protection, but the above parameters could be used for relative rankings.

Table 6-8
Parameters and weights used to rank overall development risk of each hub within its physiographic region.

Parameter	Importance	Weight
Mean level of protection from development	High	5
Percent of hub in inside designated Priority Funding Areas	High	3
Percent of hub with existing or planned sewer service	High	3
Population growth or loss 1990-2000	Medium	2
Number of parcel centroids in the hub, divided by hub area	Low	1
Commuting time to urban centers	Low	1
Land demand from proximity to Washington DC and Baltimore	Medium	2
Mean market land value	Medium	2
Mean distance to nearest major road	Medium	2
Area of waterfront property	Medium	2

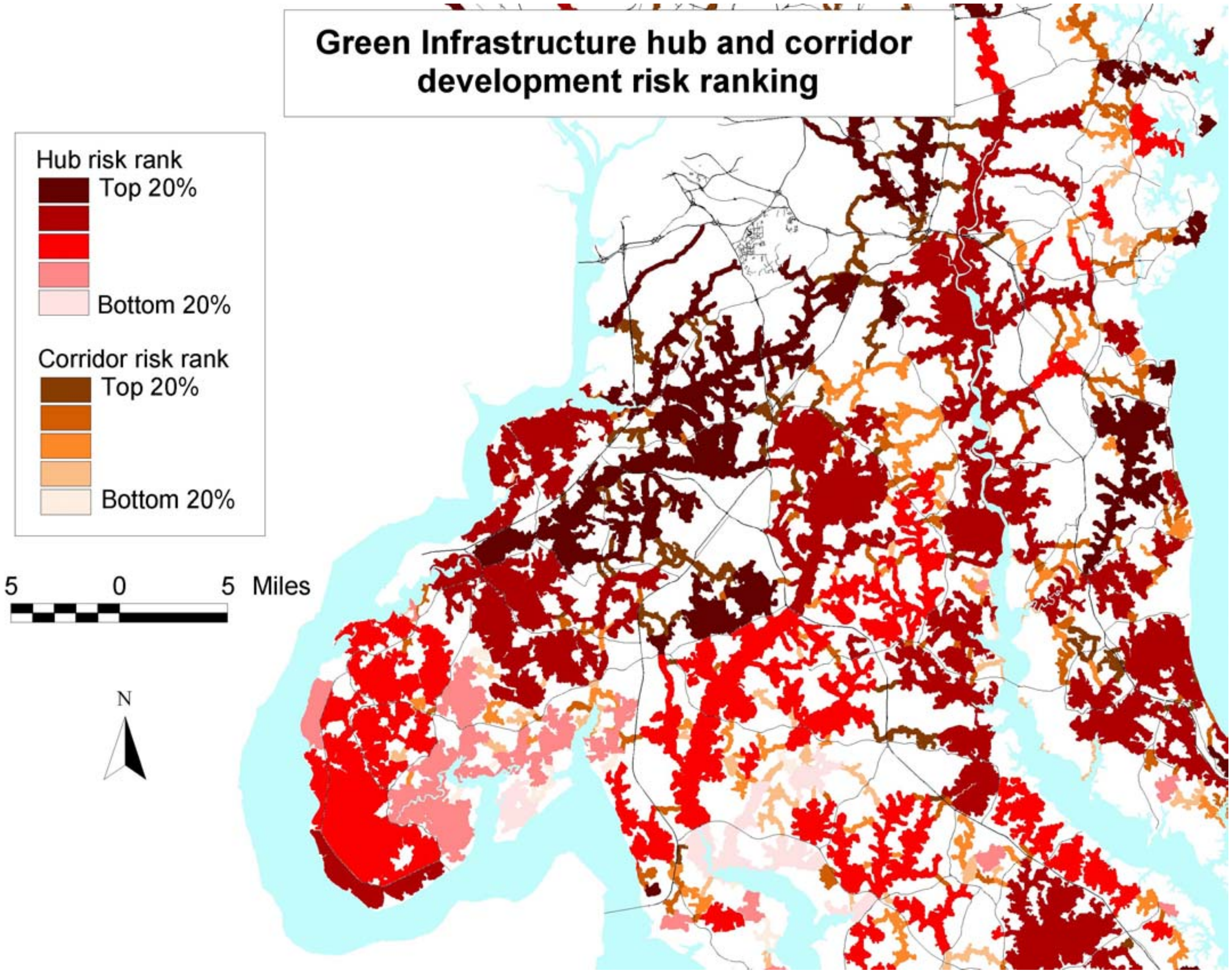
Parameter	Importance	Weight
Mean proximity to preserved open space	Medium	2

Ranking corridor segments by relative risk of development

Corridor segments were ranked using the same development risk parameters as hubs (Table 6-8). Corridors tend to cross more private land parcels than hubs, and may be at greater risk of development. This is especially true because loss of part of the corridor, if the break is significant, destroys the effectiveness of the entire linkage. One potential solution is to focus corridor protection more on development set-asides, eco-friendly design, or easements, rather than on land acquisition. The latter may be more effective and appropriate for hubs.

Fig. 6-5 shows the composite hub and corridor development risk ranking for a portion of southern Maryland.

Fig. 6-5
Hub and corridor composite development risk ranking, for a portion of southern Maryland.



Chapter 7
COORDINATING LAND USE AND CONSERVATION EFFORTS

The green infrastructure concept, operating at multiple scales, provides guidance to several distinct but related activities of both public and private organizations operating within natural landscapes:

- land developers and the local planners who regulate the development process;
- public providers of human-built infrastructure;
- public and private land conservation groups; and
- conservation interests targeting areas for environmental restoration.

The concept can be tailored to address a variety of interests and needs and can provide an overall framework that will lead to better orchestration of conservation and restoration activities in Maryland. DNR hopes that green infrastructure maps and associated data will lead to protection of more ecological hubs and corridors, thus expanding the ecological component of the statewide greenways network.

Green infrastructure and local planning and development

The green infrastructure concept has particular relevance to state and local land planning authorities. Representatives of these agencies had an opportunity over several months in 1999 and 2000 to review the green infrastructure concept, the models used to apply the concept to Maryland's landscapes, and the resulting maps as presented in the atlas (Maryland Greenways Commission, 2000). Continuing refinement can be expected as wider audiences are exposed to this work and consider the ways in which it might apply to their circumstances. DNR invites public officials and conservation organizations to utilize the green infrastructure data, and is pleased to see the concept already being incorporated into major planning activities in some counties and regional planning organizations.

The green infrastructure network mapped in Maryland Greenways Commission (2000) contains only hub, corridor, and gap locations. As mentioned in earlier chapters, supplemental information ranking hubs, corridors, gaps, and other geographic units at multiple scales is also available. Hubs and corridors have been ranked for a variety of ecological, current protection, management, and development risk parameters, as well as composites of these, within their physiographic regions. Each physiographic province represents a land area of similar underlying geology and, thus, expected similarities in plant communities and habitat types. Thus, all regions are represented in the analyses, and their contents ranked independently. The green infrastructure was also analyzed at the individual grid cell scale (approximately a third of an acre) for ecological importance and vulnerability to development. This finer scale (see the following two chapters) allows a more detailed analysis for site prioritization. Finally, gaps were analyzed and prioritized for restoration efforts, according to their ecological benefits, reclamation ease, and institutional opportunities.

It is common practice in local planning to require the dedication of a portion of a development site to permanent open space. What is dedicated may be the left-overs or remnant lands (e.g., land with severe development constraints, such as floodplains or steep slopes, along with other pieces with aesthetic disamenities or marginal development value). Each development site tends to be treated independently and individually, addressed only when someone proposes to develop it. Rather than continuing this ad hoc, site by site process, with each developer determining for himself the areas to be dedicated, planning theorists suggest that public officials be more intentional about open space protection. This can be accomplished through the prior identification of a larger, regionally conceived structure to knit together the various independent development sites and their open space elements. An identified green infrastructure network, with both areas to be protected and gaps needing restoration clearly identified, can provide this regional context for purely local development decisions. This also gives developers a greater degree of certainty about what may be required of them in this aspect of their activities.

Cost of purchasing hubs or corridors

A significant impetus to development of the Green Infrastructure Assessment was DNR's need to improve its land acquisition efforts to focus on the most important areas in which to spend available funds. At the same time that the Department's own plans can be more carefully targeted, the work of other land protection organizations in the private sector can be carried out to be complementary to the public protection actions when all are "singing off the same page." Clearly there is more than enough work for everyone to do.

As described in the development risk chapters, we interpolated a continuous land value surface from 1997-1998 Maryland PropertyView parcel centroids, the parcels' unimproved full market land value, and their size in acres. We selected only parcels of at least 10 acres. Since they could not be privately developed, areas currently owned by the public or with easements, plus lakes, rivers, and bays, were subtracted. This left privately owned land without easements. The interpolated land value of these areas was summed for each hub and corridor segment, to estimate the cost of purchasing them . We adjusted these numbers to 2001 US$ using the Gross Domestic Product Deflator inflation index. The cost of land may not have increased at the same rate as general inflation (6.2%), so these are to be considered interim numbers. As PropertyView data are updated, the land value surface can be updated. This analysis used the green infrastructure v5.1 network (described in this document), but at the time, the ecological and development risk rankings had not been updated yet; these were from the GI v5 model.

This model can help guide funds toward the most ecologically significant and most threatened areas, given a fixed budget. As Table 7-1 shows, the areas more at risk of loss to development were also the more expensive per acre. Conversely, areas with higher ecological value tended to be less expensive per acre, as well as generally less at risk. This is because rural regions (e.g., Western Maryland, lower Eastern Shore) tended to have both larger, less fragmented natural areas, and lower land values, as well as a lower development pressure. Corridors tended to be significantly more expensive per acre than hubs. The DNR's Program Open Space (POS) state estimate of cost for undeveloped land was $3,000/ac, which agrees with the MDPropertyView estimate for the entire network. However, using this fixed value regionally or locally may give misleading results.

Table 7-1
Estimated cost of protecting portions of the green infrastructure (see text for details).

Portion of green infrastructure network	Total land area (ac)	Total protected land (ac)	Total unprotected land (ac)	Estimated cost	Est. cost per unprotected acre
Entire green infrastructure network	2,541,414	639,287	1,902,127	$5.8 billion	$3,071
All natural cover	2,114,233	566,102	1,548,130	$4.1 billion	$2,676
All 656 hubs	2,143,979	610,853	1,533,125	$3.7 billion	$2,425
Hubs (78 of 656) with top 10% ecological score	1,194,057	344,798	849,259	$1.2 billion	$1,376
Hubs in top 10% ecological score and top 33% development risk (9 hubs; same for top 25% risk)	35,643	1,290	34,353	$89 million	$2,597
Hubs (6 of 656) in top 10% ecological score and top 20% development risk	20,145	677	19,469	$62 million	$3,164
Hubs (128 of 656) in top 20% development risk	120,543	4,520	116,023	$563 million	$4,859
Hubs (65 of 656) in top 10% development risk	57,179	1,708	55,471	$335 million	$6,042
All corridors (from Atlas)	409,077	72,004	337,072	$2.3 billion	$6,737
Corridor segments (182 of 1881) with top 10% ecological score	17,897	2,009	15,888	$45 million	$2,844
Corridor segments (35 of 1881) in top 10% ecological score and top 33% development risk	3,706	5	3,701	$15 million	$4,003
Corridor segments (18 of 1881) in top 10% ecological score and top 20% development risk	1,471	0	1,471	$8.5 million	$5,749
Corridor segments (373 of 1881) in top 20% development risk	52,654	803	51,850	$858 million	$16,544
Corridor segments (186 of 1881) in top 10% development risk	25,344	405	24,938	$647 million	$25,940

Defining focus areas

We combined the ecological and risk ranks of hubs and corridors to help focus protection efforts. We examined several combinations. It will not help if purchases or easements are scattered, and the remaining portions of the hubs or corridors are developed. Thus, we needed to balance flexibility and focus.

One version of these focus areas (Fig.7-1) was:

- hubs in the top ecological tier (composite ecological rank in the top third of hubs in the physiographic region), and with their unprotected portion in the top 50% development risk either statewide or within their physiographic region;
- corridors linking hubs in the top ecological tier, and in the top 50% development risk; and
- corridors linking existing protected green infrastructure land, and in the top 50% development risk.

More narrowly defined focus areas were also considered; looking at various ecological and risk rank combinations. Thematically based focus areas are currently under development, tailoring hub and corridor targeting to particular programmatic interests (e.g., biodiversity, water quality, forestry, recreation, etc.)

Maryland's GreenPrint program

In 2001, the Maryland General Assembly passed legislation (House Bill 1379) establishing the GreenPrint program. GreenPrint is a targeted program that attempts to preserve the most ecologically valuable natural lands in Maryland, its green infrastructure hubs and corridors, by purchasing land from willing sellers. These purchases can be either fee simple (ownership transferred to the state or a county) or conservation easements (original owner keeps the property, but sells the rights to develop it). Easements must be perpetual, and properties should retain their ecological values.

For fiscal year 2002 (July 1, 2001 - June 30, 2002), the Maryland legislature allocated $22,500,000 for green infrastructure land acquisitions and easements. The Department of Natural Resources (DNR) was given authority to spend 75% of the funds, and the Maryland Agricultural Land Preservation Foundation (MALPF), the other 25%. Local governments are required to approve acquisitions or easements. The first acquisitions are listed in Table 7-2. More are in the process of assessment, appraisal, or negotiation.

Fig. 7-1
Sample version of focus areas for a portion of southern Maryland (see text for details).

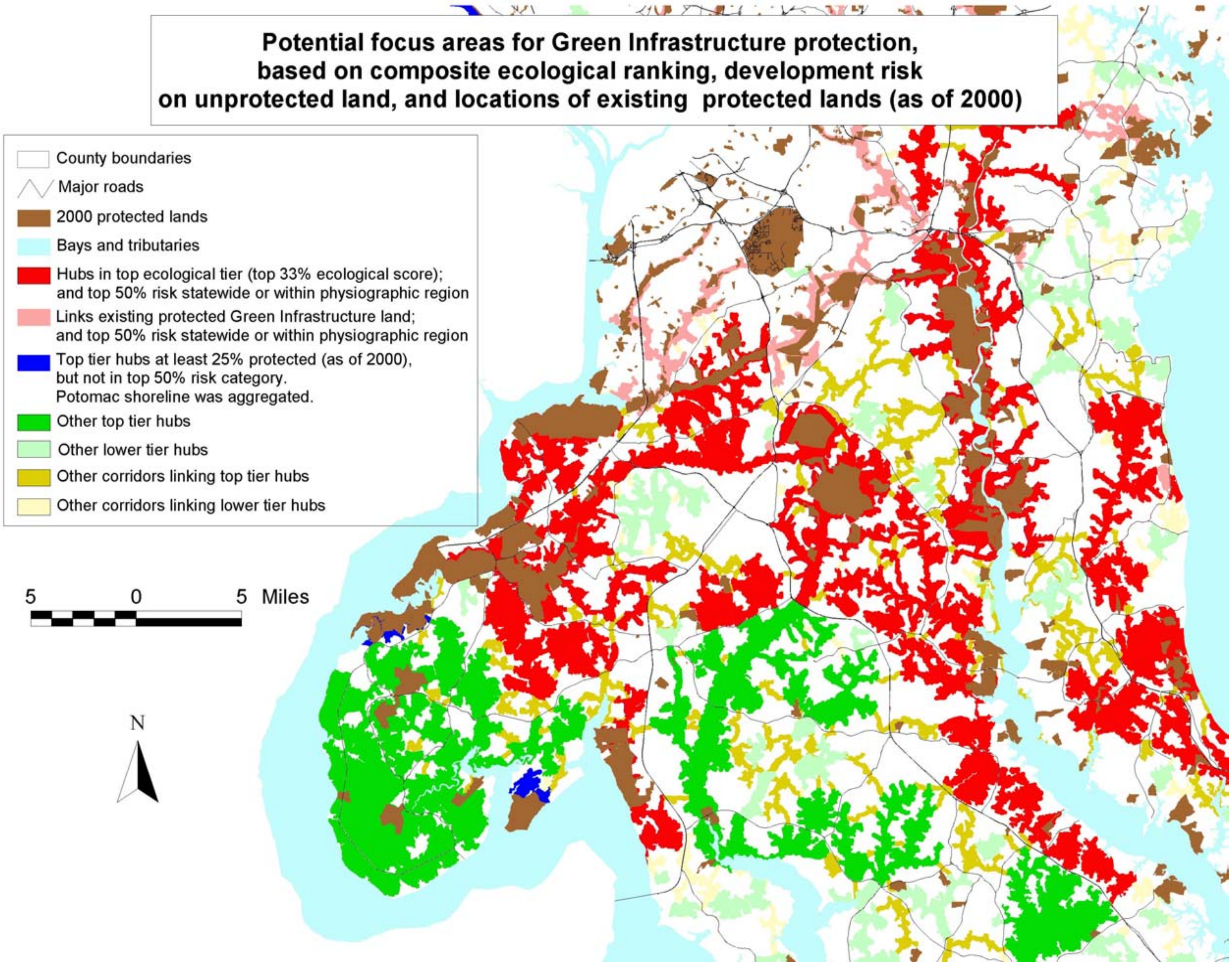


Table 7-2
GreenPrint acquisitions between Sep. 2001 and Feb. 2002.

Property	Description	Acres	County	Board action
Jacoby Development Corporation	Addition to Jug Bay Wetlands Sanctuary that includes 321 acres within the critical area, and 200 acres of high quality marsh, scrub-shrub, and forested wetlands along the Patuxent River. Within a hub in the top 1%.	611	Anne Arundel	September 2001
Douglas Point, PEPCO Property	High quality, mature forest along the Potomac River; includes 90 acres of wetlands and 1.8 miles of shoreline. Within a hub in the top 5%.	715	Charles	October 2001
Friends Meeting Quaker Camp Easement	Contains rare and endangered plants in a Wetland of Special State Concern, a well-buffered spring and first order stream (Buzzard Branch), and mature hardwood forest. Within the top-ranked hub in the Blue Ridge province.	382	Frederick	October 2001
Douglas Point Wilson Farm	Contains 112 acres of high-quality, mature forest; 24 acres of wetlands; and 13,208 feet of stream. Within a hub in the top 5%.	509	Charles	November 2001
Emmitsburg Watershed	Contains 306 acres of interior forest and 1,435 feet of streams.	520	Frederick	November 2001
Chaney	Heavily wooded land adjacent to the Myrtle Grove WMA. Includes 31 acres of wetlands, 242 acres of interior forest. Within a hub in the top 5%.	313	Charles	December 2001
Boyds-Bardon, Inc. property	Links more than 5,000 acres of protected land. Primarily forested, also has mineral resources and wetlands. Supports rare, threatened, endangered watchlist species found nowhere else in Montgomery County including the Mead's sedge and stellate sedge.	805	Montgomery	January 2002
Rozalyn Carlson/ Feltman properties	Heavily wooded tracts that provide additional protection of 500 feet along Gashey's Creek (a rare habitat area) and 3,000 feet along Swan Creek.	202	Harford	February 2002
Ridenour Swamp (Garden Property)	Located on Catoctin Mountain, one of the largest blocks of forest between Washington County and the Bay, and the top-ranked hub in the Blue Ridge province. Encompasses a forested wetland known as Ridenour Swamp, which is the headwaters of Middle Creek (designated as natural trout waters).	82	Frederick	February 2002
DNR total		4139		
MALPF easements		5466		
Total GreenPrint Acres Protected		9605		

Chapter 8
FINE SCALE ECOLOGICAL RANKING

Following the hub and corridor definition and evaluation, the Maryland landscape was also analyzed at a finer scale, to allow a more detailed site comparison and prioritization. Individual "grid cells" were pixels determined by the resolution of the satellite imagery we used (Landsat Thematic Mapper). The cells were squares corresponding to an area of 0.314 acres. The cell rank was based on both its local significance and its landscape context. Part of the cell ecological rank was the rank of the landscape feature in the green infrastructure network (i.e., whether it fell within a hub or corridor), and the relative ecological importance of that component (see Table 8-1 and Fig. 8-1), and part of the cell rank was based on local features (e.g., proximity to streams or rare species habitat; see Fig.8-2).

Landscape significance of cell

Any piece of land (e.g., a 0.314 ac cell) is a part of a larger landscape; it both contributes energy and matter to the larger system and is controlled by the larger system. There are no isolated ecosystems. We gave a higher weighting to cells in the green infrastructure hub-corridor network, because they contribute to the integrity of the network, and are potentially better functioning and more resilient as a part of a larger natural system. For example, a forested cell within a hub may have greater species richness, fewer human disturbances, fewer exotic species, etc., than a forested cell in a small, isolated woodlot outside the GI network.

The ecological ranking of hubs and corridors is described in an earlier chapter and is reviewed in Fig. 8-1. Where cells fell within a hub or a corridor, they received a score according to the composite ecological percentile of that hub or corridor within its physiographic region (see Table 8-1). Cells in hubs were given a slightly higher rating than cells in corridors, because they were generally in better condition. We used the formulas:

score of cells within hubs = 100 - [(hub composite ecological percentile) / 2.5]
score of cells within corridors = 80 - [(hub composite ecological percentile) / 3.334]

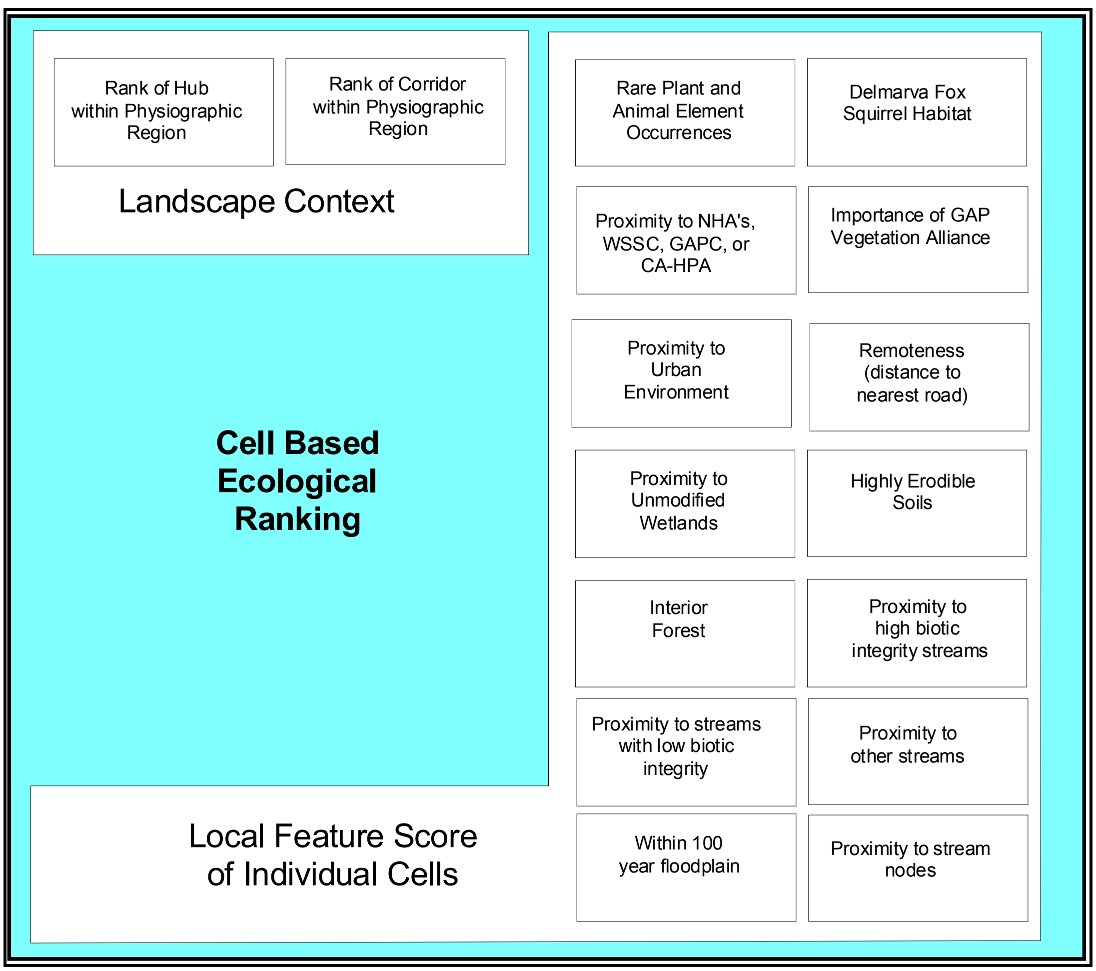
The added constant and the denominators were used to calibrate the scores between 60 and 100 for hubs, and 50 and 80 for corridors. Thus, even the lowest ranking corridor was differentiated from areas outside the GI, reflecting its inclusion in the overall landscape network. Cells in the highest ranking hubs were given twice the value of cells in the lowest ranking corridors.

Fig. 8-1
Factors used in the ecological ranking of hubs and corridors

Table 8-1
Scoring for landscape significance

Landscape feature	Score
Hubs	60-100, depending on hub rank within physiographic region
Corridors	50-80, depending on corridor rank within physiographic region
Not in GI network	0

Fig 8-2
Parameters used to create cell based ecological ranking



Local significance of cell

The patterns and processes at the local scale were also important, both for the individual cell and for their contribution to the larger landscape. Local variables are listed in Fig. 8-2, and described in more detail below.

Rare plant and animal element occurrences

The Heritage Biological Conservation (BCD) system and Maryland Biological Stream Survey (MBSS) rare species locations were described earlier. They were buffered 100 ft (for MBSS) or 300 ft (for BCD) for their positional uncertainty. As described for hub ranking, the Element Occurrence Record (EOR) score was calculated by summing numeric values assigned to three other fields: rounded Global status rank, representing its global or range-wide rarity; rounded State status rank, representing its state-wide, state-specific rarity; and Element Occurrence rating, representing its population size, quality, or viability. Values of the EOR score ranged from 12 to 600.

We rescored EOR values as follows (based on natural breaks in the data):

EOR score	Number of occurrences	Rescore
>350	38	5
201-350	141	4
136-200	599	3
91-135	1314	2
<91	1729	1

The closer a cell was to one of these EOR's, the greater its importance to these species. Thus, we calculated the distance from each EOR (after accounting for their positional uncertainty), and scored these distances as follows:

Distance to rare species location (ft)	Score
0	10
1-300	5
301-1000	2
1001-3000	1
>3000	0

We multiplied each distance score by its EOR score. Then, where there were overlaps, we used the maximum value.

Delmarva fox squirrel habitat

We gave Delmarva fox squirrel (*Sciurus niger cinereus*) cells a value of 10, other cells a value of 0.

Proximity to heritage areas

We first calculated the distances from designated Natural Heritage Areas (NHA). We then combined Wetlands of Special State Concern (WSSC), Ecologically Significant Areas (a.k.a. Geographic Areas of Particular Concern–GAPCs), and Critical Area Habitat Protection Areas (CA-HPA). ESA/GAPCs, which were rare species habitats and high quality natural communities surveyed and delineated by the DNR Wildlife and Heritage Division, were incomplete at the time. We calculated the distance from these areas separately from NHA's. We scored each of these distances as follows:

Distance to heritage area (ft)	Score
0	20
1-300	5
301-1000	2
1001-3000	1
>3000	0

We then weighted the distance scores as follows:

Parameter	Weight	Weighted distance scores
Distance to NHA's	5	0 - 100
Distance to other heritage areas	3	0 - 60

The total heritage area proximity value was the maximum of weighted distance scores from NHA's and weighted distance scores from other heritage areas.

Land cover

GAP vegetation alliances were classified and cells scored to reflect ecological importance:

GAP class	Score
Natural communities generally mature for site conditions	10
Early successional natural communities	5
Red Pine Forest; Upland Loblolly Forest	2
Cultivated Trees; Clearcuts/Transitional; Non-Tidal Phragmites Marsh;	1

GAP class	Score
Pasture/Hay; Row Crops; Urban/recreational grassy areas	
Bare/Exposed Manmade Feature; Urban	0

Proximity to urban development

Urban development is a source of disturbance, including runoff, pollutants, microclimate changes, noise, human disturbance, harassment of wildlife by pets, exotic species, etc. (Brown et al, 1990). We considered this disturbance effect to fall off with the inverse of distance from the source.

While modeling corridor impedances, we calculated the distance from high-intensity and low-intensity development (as identified in NLCD), and then converted these to impedance values (Tables 8-2 and 8-3).

Table 8-2
Impedance values calculated from high-intensity development proximity

Distance (cells)	Distance (ft)	Disturbance intensity	Impedance
0	0	2000	infinite
1	117	1000	950
sqrt(2)	165	568	518
2	234	262	212
sqrt(5)	261	184	134
	300	50	0

Table 8-3
Impedance values calculated from low-intensity development proximity

Distance (cells)	Distance (ft)	Disturbance intensity	Impedance
0	0	1000	infinite
1	117	500	450
sqrt(2)	165	284	234
2	234	131	81
sqrt(5)	261	92	42
	300	50	0

We combined low and high density development impedances by selecting the maximum value. For cell ranking, we converted the combined urban proximity impedances to a score between 0 and 10:

Urban proximity impedance	Score
$1000	0
900-999	1
500-599	4
400-499	5
300-399	6
200-299	7
1-199	8
0	10

<u>Remoteness (distance to nearest road)</u>

We calculated the distance separately from primary roads, secondary roads, county roads, and railroads. We then scored these distances as follows (in this case, high numbers are bad; this was reclassed later):

Distance to road (ft)	Score	Reason
0	10	roadway pavement
1-118 (1 cell)	9	adjacent to road
119-300	8	transition to interior habitat (value for forest)
301-1000	5	cowbirds parasitize bird nests up to 1000 feet from the forest edge (Reese and Ratti, 1988; Brown et al, 1990)
1001-3000	4	hydrologic, geomorphic, and biotic effects (U.S. Forest Service, 1999)
3001-26,400	2	effect of traffic noise
>26,400	0	attenuation of traffic noise to background levels (see below)

The effect of traffic noise and light depends on traffic volume and speed, height and density of adjacent cover, wind conditions, and other variables. Brown et al (1990) reported that highway traffic noise is about 90 dB, and background noise in forested wilderness is about 35 dB under low wind conditions. Further, 15 dB below background noise is required to muffle human-caused sounds in wilderness areas (Brown et al., 1990). Vegetation may help to attenuate noise, but estimates for forest vary widely (between -1.5 dB per 100 feet and +15 dB per 100 feet), and attenuation by brush is negligible (Brown et al., 1990). Water can actually increase noise transmission (Brown et al., 1990). Ignoring the possible effects of adjacent cover and other factors, attenuation by spherical spreading is described by the equation $L_x = L_0 - 20 * \log(D_x/D_0)$, where L_x is the decibel level of the source to be calculated at a desired distance, L_0 is the decibel level of the source at a given distance, D_x is the distance from the source for which L_x is to be calculated, and D_0 is the given distance at L_0 is measured (Brown et al., 1990). This gives a distance of 5 miles for highway noise to attenuate to background levels.

We combined the road distance scores, weighting them by road type as follows:

Parameter	Weighting	Weighted distance scores
Distance to nearest primary road	4	0 - 40
Distance to nearest secondary road	3	0 - 30
Distance to nearest county road	2	0 - 20
Distance to nearest railroad	2	0 - 20

Finally, we reclassified this to values with high = good, low = bad, by subtracting from 40.

Highly erodible soils

When ranking hubs and corridors, we identified highly erodible soils from the Natural Soils Groups of Maryland. We gave those cells with highly erodible soils a score of 10 and others a score of 0.

Proximity to unmodified wetlands

Cells within unmodified NWI wetlands were given a score of 10; those within 325 feet of marshes or 550 feet of woody wetlands were given a score of 3; others were given a score of 0.

Interior forest

Interior forest (at least 300 feet from the forest edge, and derived from NLCD, 1997 MDP land use, and SHA roads) was classified according to its GAP vegetation alliance:

GAP class	Score
Natural communities generally mature for site conditions	10
Early successional natural communities	5
Red Pine Forest	2
Upland Loblolly Forest	2
Other	1

Proximity to streams

Streams were placed into three groups according to their index of biotic integrity (IBI), or presence of aquatic species of concern or brook trout. We calculated the distance from each of these groups separately, and classified them as follows:

Distance to stream (ft)	Score
0-118 (1 cell)	10
119-300	5
301-550	3
551-1000	2
1001-2000	1
>2000	0

We gave cells within FEMA 100 year floodplains a score of 3, unless they were within 300 feet of a stream, in which case they received higher scores (5 or 10).

Stream distance scores were then weighted according to the biotic condition of the stream, as follows:

Biotic condition of stream	Weight
Streams with a high fish IBI, high benthic IBI, aquatic species of concern, or brook trout	6
Streams with a low fish IBI or low benthic IBI	2
Streams with a medium IBI, or not sampled by MBSS	4

The total stream proximity value was the maximum value of weighted distance scores from high integrity streams, from impaired streams, from other streams; and floodplain inclusion.

Proximity to stream nodes (sources and junctions)

We calculated the distance to nearest stream node, and reclassified this distance according to the stream distance table.

Combining local variables

We gave each local ecological parameter an importance weight (Table 8-4). We summed the weighted parameter scores to derive an overall local ecological score for each grid cell.

Table 8-4
Local ecological parameters and weighting

Parameter	Weight	Weighted score range
Rare plant and animal element occurrences	4	0-200
Delmarva fox squirrel habitat	6	0 or 60
Proximity to Natural Heritage Areas or other heritage areas	3 - 5	0-100
Land cover	4	0-40
Proximity to development	4	0-40
Distance to nearest road, weighted by road type	2 - 4	0-40
Highly erodible soils	2	0-20
Proximity to unmodified wetlands	4	0-40
Interior forest	4	0-40
Proximity to streams	2 - 6	0-60
Proximity to stream nodes	1	0-10

We first calibrated the combined grid by physiographic region. Using the SLICE command in GRID, we scaled from 0 to 100 within each region, thus giving each cell a percentage by area of the regional high score. To reduce the effect of outliers, the high score was the lower bound of the top ranking hectare within the physiographic region. We discounted cells outside Maryland, and open water. However, this approach gave counter-intuitive results. For example, because of their differing landscape matrices, agriculture in the Piedmont had similar scores to forest on the Appalachian plateau.

We abandoned the attempt to scale by physiographic region, and calibrated the distribution of cell scores statewide. Again, we discounted area outside Maryland, and open water. Cells were given an equal-area percentile ranking within state land, using the slice command in GRID.

To combine local and landscape ecological scores, both of which were on a scale between 0 and 100, we compared model output from different combinations of local and landscape weightings to field data and expert knowledge (Table 8-5). Weighting local conditions and landscape context equally gave the best results. Hubs and corridor delineations were apparent, and continuous gradients of environmental conditions were also apparent.

Table 8-5
Output of cell-based ecological model as a function of landscape context and local conditions.

Weighting of landscape feature	Weighting of local conditions	Comments
100	0	No resolution of local-scale differences.
55	45	Insufficient resolution within hub and corridor network.
50	50	This is probably the best weighting combination, because hubs and corridor delineations are apparent, and continuous gradients of environmental conditions are also apparent.
45	55	Connections and groupings are less apparent.
40	60	Connections and groupings are less apparent.
0	100	No consideration of the larger landscape context.

The final cell ecological score (see Figure 8-3) varied between 0 and 100, with 100 = most valuable ecologically, 0 = least valuable ecologically. Open water and area outside Maryland had no data.

One of the uses of cell-based ecological ranking was to evaluate individual parcels (see Figure 8-4). For example, we averaged the cell ecological scores within each Chesapeake Forest tract to help decide which tracts would be targeted for conservation, and which would be targeted for sustainable forestry. Other information was used in conjunction with this assessment, such as rare species locations; stand composition, age, and preparation; and proximity to existing DNR lands.

Fig 8-3
Cell ecological scores for part of Charles county in southern Maryland.

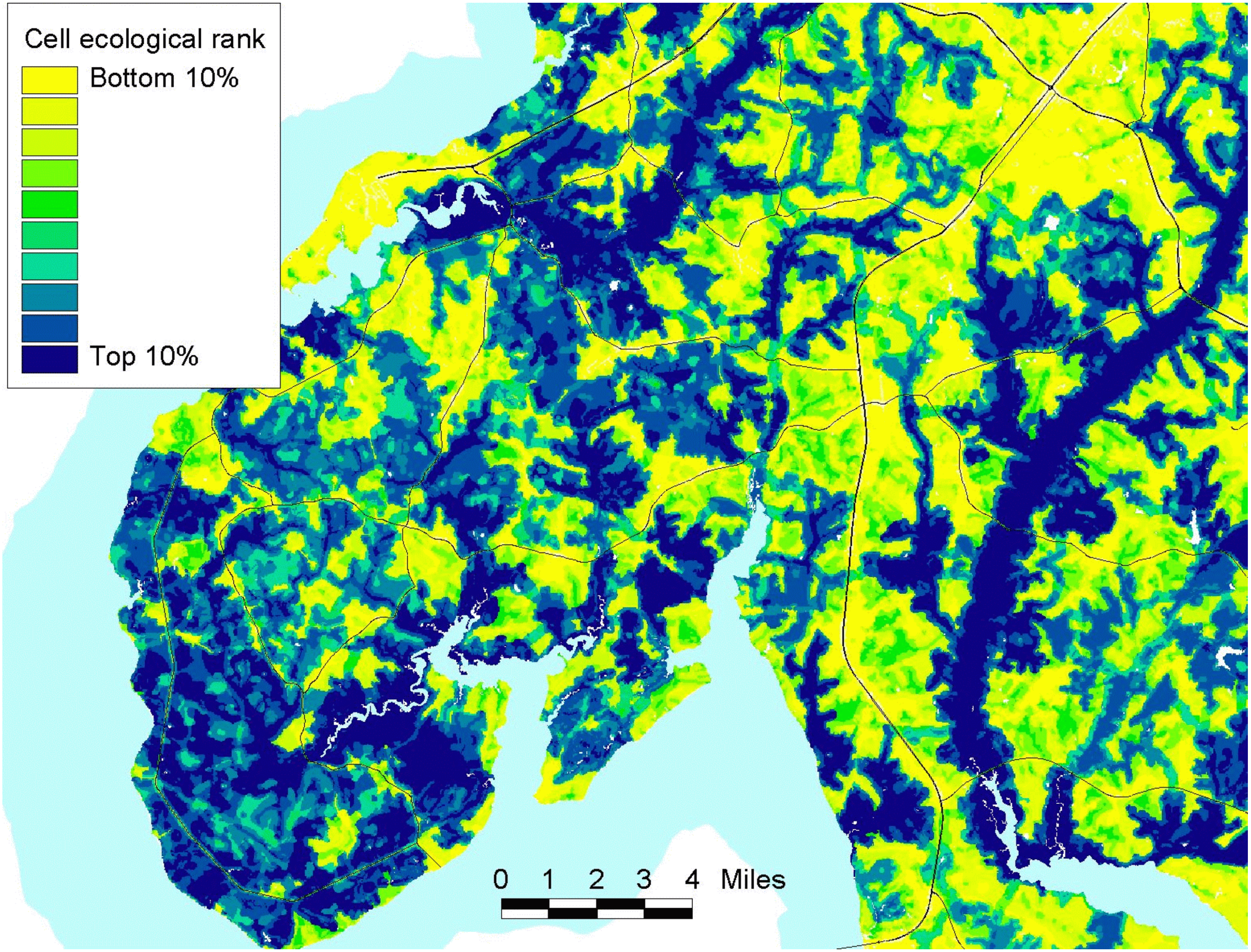
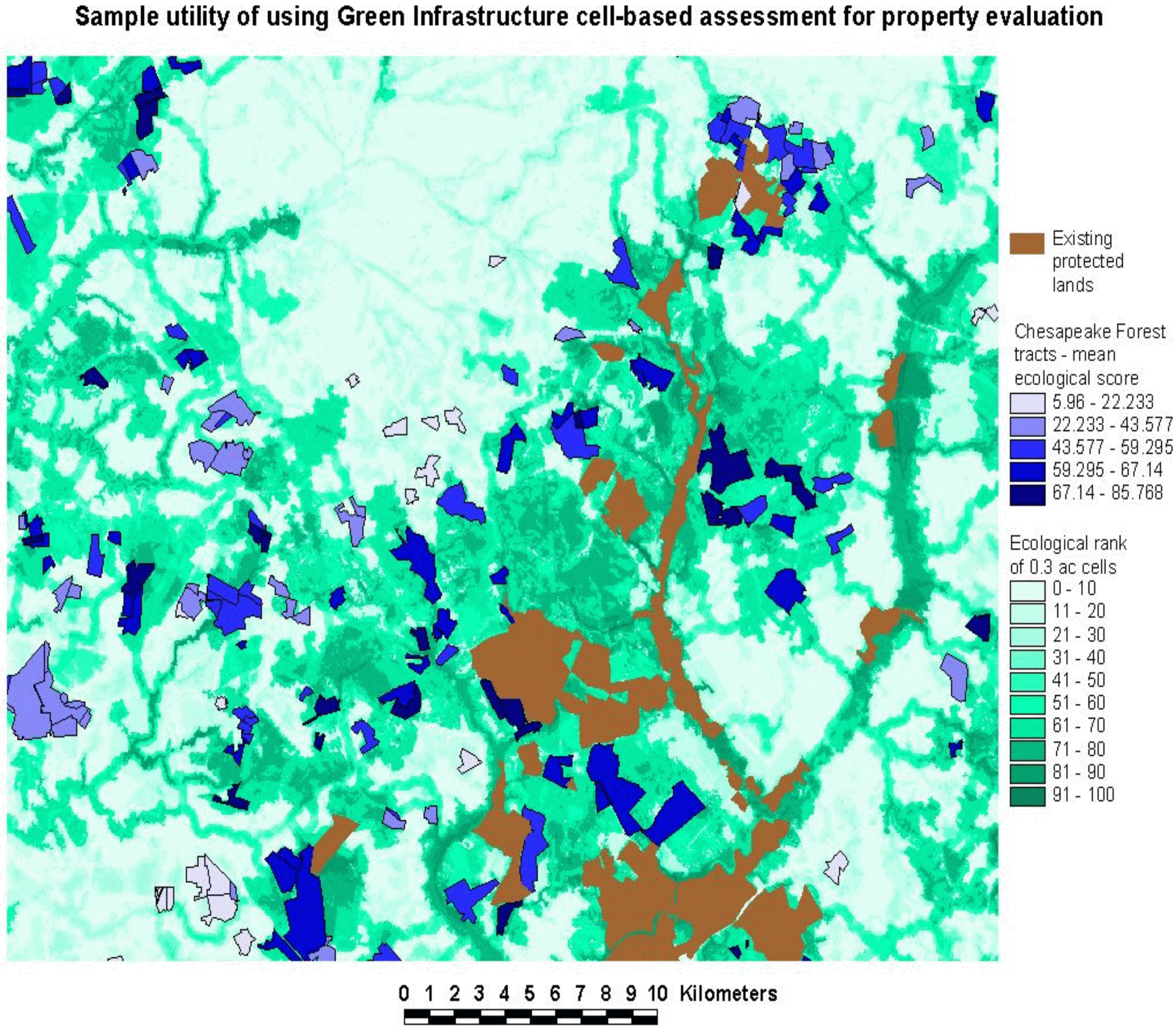


Fig. 8-4


Sample utility of using Green Infrastructure cell-based assessment for property evaluation
Existing protected lands
Chesapeake Forest tracts - mean ecological score
5.96 - 22.233
22.233 - 43.577
43.577 - 59.295
59.295 - 67.14
67.14 - 85.768
Ecological rank of 0.3 ac cells
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
0 1 2 3 4 5 6 7 8 9 10 Kilometers

Chapter 9
FINE SCALE EVALUATION OF DEVELOPMENT RISK

As with ecological value, we created a fine-scale, cell-based, model of development risk. The analysis was limited to cells within Maryland.

Assessment of individual grid cell risk

First, we identified land that was undevelopable (conservation land or open water). Public land not managed for conservation was considered publically developable. We used the same development risk parameters to assess each grid cell that we used to assess hubs and corridors, only at a finer scale. We reclassified these risk parameters (see Table 9-1 for summary, and chapter on hub development risk for descriptions) to an equal-area percentile distribution on developable land. Zero was considered the lowest probability of development for each parameter; 100 the highest. All federal land (including military bases) was removed during calibration of parameters, because these lands are not subject to local socioeconomic forces. County parks, on the other hand, are developed as local population increases, with ball parks and playgrounds installed. Commuting parameters lacked data where roads did not exist, or could not be built. However, these areas might still be developable. We interpolated commuting values for these cells.

Table 9-1
Cell-based development risk parameters, and reclassification methods

Parameter	Original value range	Reclassification method	Reclassified value range
Level of protection from development	0 - 100	none	0 - 100
Projected upland forest loss 1997-2020 *(MDP has projected no loss of wetland or barren cover)*	0 - (-100)	Multiply by -1	0 - 100
Projected agriculture loss 1997-2020	0 - (-100)	Multiply by -1	0 - 100
Zoned for development by county	0 (not zoned for dev.) or 10 (zoned for dev.)	Multiply by 10	0 - 100
Inside Priority Funding Areas	0 (not in PFA) or 1 (in PFA)	Multiply by 100	0 - 100
Existing or planned sewer service	0 (no planned service) to 10 (existing or under construction)	Multiply by 10	0 - 100
Inside Priority Funding Areas, or with existing or planned sewer service	0 (no planned sewer service) to 10 (service existing or under construction, or within PFA)	Multiply by 10	0 - 100
Population growth or loss 1990-2000	-100% to +1000%	Equal-area distribution	0 - 100

Parameter	Original value range	Reclassification method	Reclassified value range
Parcel size, interpolated from MdPropertyView centroids $1 ac	1 - 53,200 ac	Equal-area distribution	0 - 100
Commuting time to town centers	0 - 27,952 sec	Equal-area distribution	0 - 100
Land demand from proximity to Washington DC and Baltimore	84 - 10,000	Equal-area distribution	0 - 100
Market land value per acre, interpolated from MdPropertyView centroids $1 ac	$1 - $2,395,799 /ac	Equal-area distribution	0 - 100
Distance from major roads		Equal-area distribution	0 - 100
Distance from primary roads		Equal-area distribution	0 - 100
Distance from secondary roads		Equal-area distribution	0 - 100
Waterfront property	1 = waterfront, No Data = elsewhere	Reclassify waterfront = 100, elsewhere = 0	0 - 100
Proximity to preserved open space		Equal-area distribution	0 - 100

We added the calibrated parameters, multiplied by the importance weights in Table 9-2. We removed undevelopable areas, areas outside Maryland, and Baltimore City. We examined three different models, using different combinations of parameters and weights. Output from models 1 and 2 was very similar. Model 3 output was slightly different, placing greater emphasis on areas with existing or planned water and sewer. Comparing to 1997 MDP land use, with protected areas excluded, modeled development risk was significantly greater within developed areas than in undeveloped areas, for all 3 models (Table 9-3). Risk was also greater for areas developed between 1994 and 1997, than for areas not developed. However, land use was defined differently between 1994 and 1997 (the latter year included parcel data from MD PropertyView). Thus, these results were suspect. Model 3 seemed to perform the best, but better tests were needed. We later compared this model to areas developed between 1997 and 2000, and began constructing a logistic regression model.

Table 9-2
Parameter importance weights for cell-based development risk models.

Parameter	Scenario 1 weights	Scenario 2 weights	Scenario 3 weights
Level of protection from development	4	6	6
Projected upland forest loss 1997-2020 *(MDP has projected no loss of wetland or barren cover)*	3	4	0
Projected agriculture loss 1997-2020	3	4	0
Zoned for development by county	1	1	0
Inside Priority Funding Areas	0	2	0

Parameter	**Scenario 1 weights**	**Scenario 2 weights**	**Scenario 3 weights**
Inside Priority Funding Areas, or with existing or planned sewer service	0	0	4
Population growth or loss 1990-2000	0	0	1
Parcel size, interpolated from MdProperty View centroids $1 ac	1	1	1
Commuting time to town centers	1	1	1
Land demand from proximity to Washington DC and Baltimore	1	2	2
Market land value per acre, interpolated from MdProperty View centroids $1 ac	2	3	2
Distance from major roads	1	0	0
Distance from primary roads	0	2	2
Distance from secondary roads	0	1	1
Waterfront property	1	2	2
Proximity to preserved open space	1	2	2

Table 9-3
Comparison of development risk cell models to urban and non-urban private land (from 1997 MDP land use).

Model	**Mean development risk in non-urban areas**	**Mean development risk in urban areas**
1	44.1728	75.2729
2	44.1534	75.9219
3	43.4894	78.5005

Fig. 9-1 shows the model 3 cell development risk scores for part of Charles county in southern Maryland. They are only relative scores, rather than specific predictions of which cells will be developed in a particular year. Because of limitations in data resolution, the cell development risk scores should be averaged within areas at least 100 ac.

Aggregation of cell risk by unprotected portion of hubs

Hubs that were partly protected tended to have lower development risks, where this was modeled at the hub scale. Yet, the unprotected part of those hubs might have been in a high risk area. Therefore, we averaged the cell-based risk (model 3) within the unprotected portion of each hub.

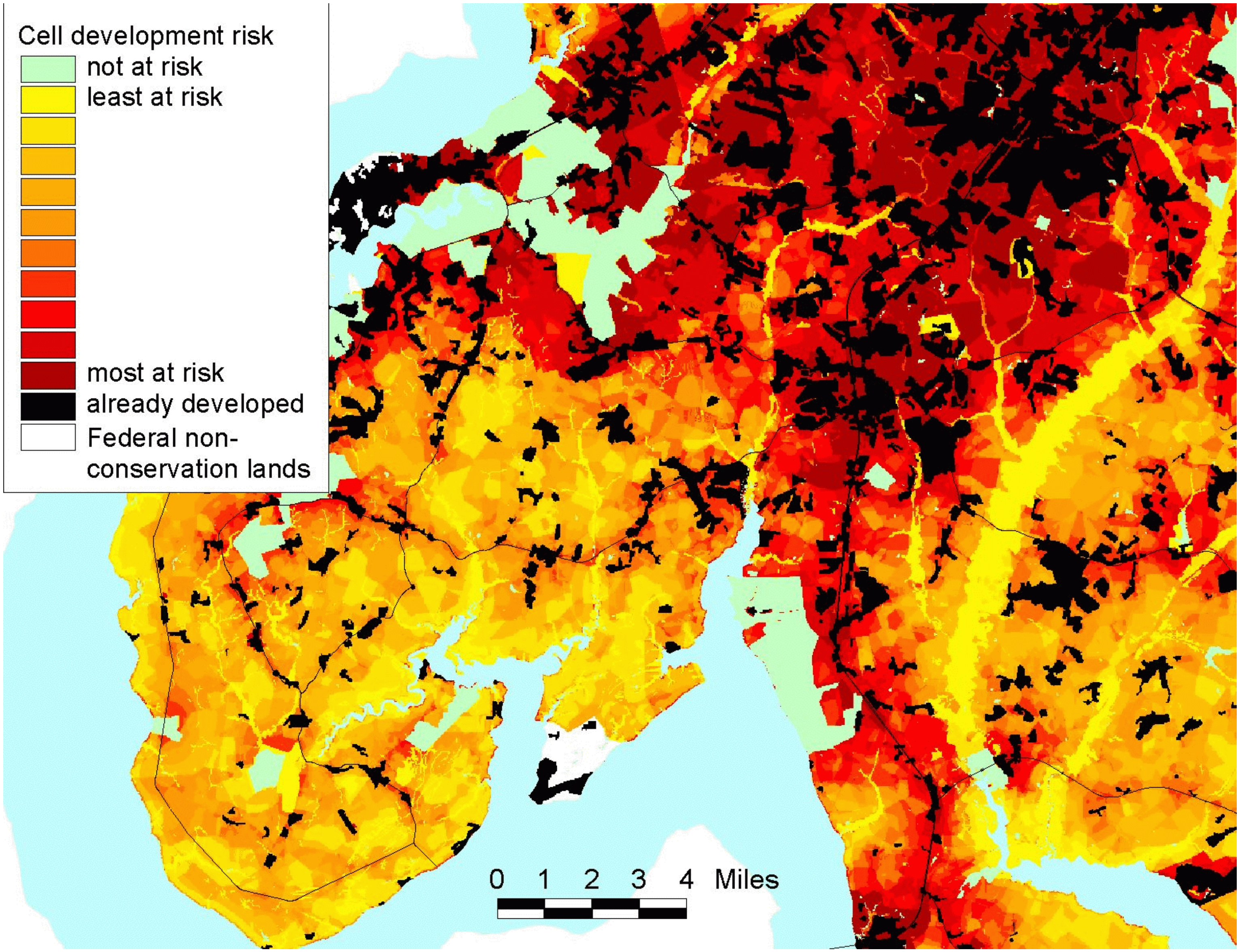
This was used to rank the hubs for predicted loss from their unprotected portion, both statewide and within their physiographic region.

Aggregation of cell risk by unprotected portion of corridors

We performed the same analysis above for corridor segments. Cell risk aggregated by unprotected hub and corridor portion helped define focus areas (described in a later chapter).

Fig 9-1

Cell development risk (model 3) scores for part of Charles county in southern Maryland.



Chapter 10
DESKTOP PARCEL EVALUATION

As noted above, in 2001, the Maryland General Assembly passed legislation establishing the GreenPrint program, expanding the state's land acquisition program to target, specifically, ecologically important lands identified in the Green Infrastructure Assessment. A protocol for selecting and prioritizing parcels for acquisition is still evolving, but some of the methods developed in 2001 are described in this chapter. This protocol incorporates into a single integrated system: real property tracking, mapping and GIS support, desktop ecological evaluation, and field assessment. The protocol was used to evaluate and track the Maryland DNR - Program Open Space (POS) GreenPrint land conservation projects and Maryland Agricultural Land Preservation Foundation (MALPF) agricultural easement proposals. The protocol has also been used to evaluate and track land conservation projects administered by other state programs.

Tier Evaluation Process

The tracking and evaluation process was accomplished, by multiple organizational entities in DNR, via tasks completed within five distinct stages or "tiers" (see Table 10-1). Each tier serves a unique purpose in the overall process, with results derived from the completion of that phase entered into a master land conservation tracking database. The database has been set up in such a way as to permit a variety of hard copy reports, including a "Project Profile" that provides summary information that can be extracted from each of the tier evaluations/reviews.

The tracking database was created using Microsoft Access database software, with data entry sheets corresponding to different facets of the land conservation property tracking and evaluation process. The tracking database included modifications to the Department's MERLIN Online internet-based mapping system that provided the ability for multiple users to create and manage targeted property information including parcel boundaries. The desktop evaluation of local and regional ecological parameters is accomplished using ArcView software with the Spatial Analyst Extension. A program was written to automate this task.

As described in an earlier chapter, hub and corridor ecological and risk rankings were used to define focus areas. Since the pool of parcels greatly exceeded available funds, we wanted to concentrate on the most ecologically important ones. Site visit information, because of the time required, was only employed for those parcels that passed the initial screenings (Tier 1 and 2). This chapter elaborates on the first two tiers–those preceding field evaluation.

Table 10-1
Land Conservation Tier Evaluation Process

ANALYSIS LEVEL	APPROACH	LEAD RESPONSIBILITY	OBJECTIVES	DESCRIPTION
Tier 1	Paper Form submitted to GIS	POS[3] Rural Legacy MALPF MET	a. Initiate evaluation process b. For multiple parcel projects, groups of parcels assigned to a given project are identified	POS/RL/MALPF/MET initiate process by completing form "Designation of Land Parcels Under Review for Acquisition" and submitting to GIS Division.
	Desktop - MERLIN/ PropertyView	WS-GIS	a. GIS Division digitizes parcel boundary b. GIS Division screens parcel for validation of GI Model (Tier 2) c. GIS Division begins database entry d. GIS Division submits parcel shapefile(s) and database to LWAD for Tier 2 Review e. GIS Division creates parcel site maps as Acrobat files and makes network accessible	GIS staff begin screening properties using MERLIN Online/Md Property View. Database entry is initiated and verification information is developed to determine if GIA model accurately reflects land cover characteristics as determined by DOQQ or other supplemental data.
Tier 2	Desktop - GIA Assessment	LWAD	a. LWAD documents parcel scores b. LWAD documents GI acreage statistics c. LWAD provides results to GIS for acquisition database d. GIS Division updates database e. GIS Division notifies agency initiating action that data are available.	Utilizing parcel boundaries digitized by GIS from information provided by POS, LWAD performs automated assessment of candidate parcels using existing ecological model
Tier 3	Field (Cursory)	POS	a. POS conducts field verification of land cover b. POS assesses local vulnerability conditions c. POS documents results on Tier 3 checklist and updates database	POS Staff perform cursory (e.g., - drive by or drive through) evaluation in field to verify accuracy of GIS data. Determine if additional evaluation is necessary.
Tier 4 (as appropriate)	Field (Detailed)	Regional Teams - Evaluation POS - Documentation Local Partners - Evaluation and Documentation	a. For lands identified for DNR ownership, POS/Regional Teams document additional conservation features of property as appropriate b. For lands identified for local government/partner ownership and management, POS consults with partner agency on need for additional documentation c. POS documents results in Tier 4 checklist for acquisition database	For lands identified for DNR ownership, POS contacts appropriate regional team members and coordinates field assessment. POS enters written/electronic feedback into Tier 4. For lands identified for partner ownership, POS contacts appropriate partner entities to determine need for field assessment.

[3]POS=Program Open Space; MALPF=Maryland Agricultural Land Preservation Foundation; MET=Maryland Environmental Trust; WS-GIS=Geographic Information Services division of Watershed Services; LWAD=Landscape and Watershed Analysis Division of the Watershed Services Unit. Regional Teams have been established by DNR in each of four regions of the state, comprised of representatives of all major units in the Department, for information sharing and coordinated review of projects.

ANALYSIS LEVEL	APPROACH	LEAD RESPONSIBILITY	OBJECTIVES	DESCRIPTION
Tier 5 (for DNR acquisitions only)	Post Acquisition Documentation	POS	a. Complete acquisition database fields for post-BPW actions b. POS notifies GIS of completion of acquisition for update to protected lands data sets c. POS notifies Resource Planning of acquisition	Following Board of Public Works action, POS completes remaining database fields documenting completion of acquisition process. POS notifies Resource Planning of completion of process.

Tier 1 - Property identification and delineation

The first step in the parcel evaluation process is the identification of candidate properties for acquisition. Ideally, willing sellers should be approached in green infrastructure focus areas. Focus areas, as described in an earlier chapter, are hubs and corridors that are highly significant ecologically, and under significant threat from development. It will not help if purchases or easements are scattered, and the remaining portions of the hubs or corridors are developed. Thus, we needed to balance flexibility and focus. In addition, willing sellers are identified opportunistically, from POS staff, county governments, and other sources.

Once identified, the boundaries of candidate properties or projects (combinations of properties or parcels) must be defined. Tier 1 encompasses the "capture" of the spatial boundary of a given project and the association of that georeferenced project boundary file to real property information contained in MDPropertyView. Land acquisition/protection staff from POS or MALPF initiate the process by providing Watershed Services - Geographic Information Services Division (WS-GIS) staff with property boundary information. The GIS Division then digitizes the boundary of the project and establishes the necessary links to the appropriate parcel information in MDPropertyView. Basic project information such as property owner and address, tax account ID, county, etc. is entered into the tracking database in Tier 1. The tax account ID serves as the common field which permits further data mining from MDPropertyView as necessary. Tier 1 concludes with the addition of the attributed project/parcel boundary into an ArcView shapefile.

Tier 2 - Desktop analysis and ranking of properties

Tier 2 begins with the delivery of the attributed land protection project shapefile to the Watershed Services- - Landscape and Watershed Analysis Division (LWAD). The primary objective of Tier 2 is to conduct a GIS-based "desktop" assessment of the ecological significance of the proposed project. The shapefile created in Tier 1 is evaluated to determine (1) if the project contains green infrastructure as delineated in the Green Infrastructure Assessment model, (2) the amount, percentage, and ecological significance of green infrastructure present, (3) proximity to existing protected lands and contribution to further protection of the green infrastructure hub or corridor the property lies in, (4) an overall ecological score for the project, and (5) the presence of other conservation features on the property. Once calculated, database tables with these ecological parameters are delivered to the GIS Division. The data contained within the tables are then used to populate the natural resource features component of the Access database. Figure 10-1 contains a sample GreenPrint project sheet, for the Jacoby property in Anne Arundel County. In addition, Natural Heritage staff can evaluate the property's contribution to rare species protection, by comparing the parcel boundaries to rare species locations in the Biological Conservation Database (BCD). This information was included in the green infrastructure model, but it was helpful to consider this more explicitly and in greater detail when evaluating parcels for acquisition.

In order to rank parcels for acquisition, we created an overall "desktop ecological score" for each property as part of the Tier 2 review. This was a composite of:

- Acres of green infrastructure within the parcel
- % of green infrastructure within the parcel
- Mean cell ecological score, for the portion of the parcel within the green infrastructure only
- Parcel position (acres of nearby protected lands)
- % protection gain to hub or corridor the parcel falls within.

Further details can be found in the document, *A simplified GIS methodology for rating parcels for GreenPrint acquisition*.

Fig. 10-1

Green infrastructure GIS information listed on GreenPrint project sheet, with data from a sample property

PROJECT NAME: __Jacoby Property______________________________

Property Owner: ____

Total Acres: 634

County: __Anne Arundel____

GREEN INFRASTRUCTURE CHARACTERISTICS - PROJECT

Green Infrastructure Characteristics

Total Acres of Green Infrastructure	548
Hub Acres	526
Corridor Acres	22
GI Gap Acres (within hub or corridor)	26
Percent of Parcel in Green Infrastructure	86%
Mean Ecological Score within Green Infrastructure	87.9 (out of 100)
Acres of other protected land within 1 mile	980
Percent of currently unprotected hub/corridor that this project would protect	4%
Overall Ecological Rating	Excellent

Other Conservation Features Acreage

Sensitive Species Review Area Acres	450
Wetland Acres	191
Interior Forest Acres	205
100 Year Flood Plain Acres	196
Feet of streams	14,275
Acres of highly erodible soils	31

GREEN INFRASTRUCTURE CHARACTERISTICS - LANDSCAPE (Hub #419)

Physiographic Region Coastal Plain, west

U HUB
CORRIDOR

Regional Hub Ecological Ranking

U 0-20 (Top 20%)
20-40
40-60
60-80
80-100 (Bottom 20%)

Total Area of Hub	26,682 Acres
Unprotected Land in Hub	15,003 Acres
Area of Hub Protected by Project	526 Acres
% of Hub Protected by Project	4%

Ecological Characteristics of Hub

Number of Rare Species Occurrences	30
Acres of Natural Heritage Areas	2005
Acres of Upland Interior Forest	5006
Acres of Wetland Interior Forest	1258
Feet of Streams in Interior Forest	159,618
Number of Wetland Types	49
Acres of Wetlands of Special State Concern	2109

Selection of sample points

To determine appropriate groupings for each parameter and their combination, we examined landscape characteristics around 40,000 property centroids in Maryland. First, using MdProperty View (1997-1998 data), we selected all property centroids for parcels at least 20 acres in size, and containing both parcel ID's and land value data. We omitted all currently protected land. We then buffered the remaining property centroids as a circle with radius = $(\text{parcel acres} * 43560 / \pi)^{1/2}$.

Total parcel centroids buffered: 40,856
Mean buffer size = 83.8 acres
Maximum buffer size = 4463.5 acres
Minimum buffer size = 19.9 acres
Standard deviation of buffer size = 115.3 acres
Number of centroids containing GI: 21,288

Acres of green infrastructure within parcel

We first calculated the acres of GI land in each parcel centroid buffer, as well as the acres of GI hubs and corridors, and gaps. Gaps are areas dominated by human use, such as agriculture or clearcuts, within hubs and corridors. These are explained further in the restoration chapter. The more green infrastructure in a parcel, the more valuable the parcel was thought to be. Based on the quartile distribution of parcels containing green infrastructure, we rated parcels as follows:

Acres of GI	Rating
>65	Excellent
32.1 - 65	Good
18 - 32	Fair
<18	Poor

Percent of parcel containing green infrastructure

We next calculated the percentage of each parcel centroid buffer that is in the green infrastructure. Again, the more green infrastructure, the more valuable. Based on the quartile distribution of parcels containing green infrastructure, but broadening the top category slightly, we rated parcels as follows:

% in GI	Rating
>90	Excellent
69 - 90	Good
34 - 68.9	Fair
<34	Poor

Mean cell ecological score (green infrastructure portion)

We then calculated the mean cell ecological score within the GI part of each parcel centroid buffer. The cell ecological score, as described in an earlier chapter, is a composite index for each 0.31 acre square of land in Maryland that incorporates elements of both regional (i.e., hub or corridor) and local ecological significance. The regional ecological score (the hub or corridor ranking) considered factors relating to biological diversity, aquatic integrity, terrestrial integrity (including remoteness and intactness of hubs and corridors), landform characteristics, and characteristics of the surrounding landscape. The local ecological score included similar metrics, but we calculated these metrics for the individual grid cell. For both the regional and local analyses, we assigned importance weights to each of the individual factors and developed a composite index. Finally, we combined the regional and local scores for each cell. Half of the cell ecological value was determined by the regional significance of the hub or corridor in which it lies, and half was determined by local ecological considerations.

By averaging the cell values within the parcel boundary, we derived a metric that considers the importance of the parcel given both its landscape context within the green infrastructure and the ecological values present on or in close proximity to the property. Higher values reflected greater ecological importance. We averaged only within the green infrastructure portion of the property, to avoid overlapping the metric, percent of parcel containing green infrastructure. Based on the quartile distribution of parcels containing green infrastructure, but broadening the top category slightly, we rated parcels as follows:

Mean cell ecological score within parcel GI	**Rating**
85.0 - 100	Excellent
76.0 - 84.9	Good
66.0 - 75.9	Fair
0.0 - 65.9	Poor

Acres of nearby protected lands

We gave preference to properties near existing protected lands, because, first, these areas were safe from development, and therefore could not adversely impact the subject property in the future. Perhaps more importantly, the parcel in question could add to a nucleus of already protected land, or help connect such lands. We wanted to focus rather than scatter our efforts.

We tabulated the area of protected land within 1 mile of each parcel centroid buffer containing green infrastructure. Based on quartiles, we rated parcels as follows:

Acres of protected land within 1 mile	**Rating**
>434	Excellent
152 - 434	Good
5 - 151	Fair
<5	Poor

<u>Percent protection gain to hub/corridor</u>

This parameter complements the previous parameter. Parcels that contributed more to protection of a hub or corridor were considered more important. We calculated the percentage of unprotected (as of 2000) green infrastructure hub and/or corridor that fell within the parcel centroid buffer. For example, for a 100 acre parcel inside a 5000 acre hub that contained a 2000 acre park, the parcel contribution would be 3.3%. If the parcel overlapped more than one hub or corridor, these contributions were summed.

Most parcels, by themselves, potentially protected only a small percentage of the hub or corridor they overlapped. A quantile distribution stratified the data insufficiently. Therefore, we grouped by equal area distribution instead:

% gain to hub or corridor	**Rating**
>10	Excellent
2.5 - 10.0	Good
1.0 - 2.4	Fair
<1	Poor

<u>Combination of parameters</u>

To facilitate developing the composite score, ratings for each parcel centroid buffer were assigned a value as follows:

Category	**Value**
Excellent / Most suitable	4
Good	2
Fair	1
Least suitable	0

We also weighted each of the parameters as follows:

Parameter	Weight
Acres of GI	2
% in GI	1
Mean cell ecological score in GI	3
Protected land within 1 mile	1
% gain to hub or corridor	1

We summed the weighted numerical rating values for each parcel centroid buffer, and grouped these by quartile:

Sum of scores	Overall Rating
21 - 32	Excellent / Most suitable
15 - 20	Good
9 - 14	Fair
0 - 8	Least suitable

Examination of final scores

Fig. 10-2 shows the composite rating of parcel centroid buffers in the vicinity of Pocomoke State Forest. The "Excellent" and "Good" parcels tended to be in the center of the green infrastructure, and "Fair" and "Poor" parcels on the periphery. Some of these areas had relatively low mean cell scores, because they were dominated by planted loblolly pine, contained clearcuts, or bordered roads. But if they contained a lot of green infrastructure, and were adjacent to existing protected lands, they may nevertheless have received an "Excellent" or "Good" rating. Because of their size and position, they would have been logical GreenPrint acquisitions, even if restoration might be required, or several decades of natural regeneration. All five parameters contributed to the ranking.

For the whole state, the acres of land within parcel centroid buffers are distributed fairly evenly, much more so than using cell-based ranking alone (see Table10-2). As a disclaimer, the rankings are based on statistical distributions within parcel centroid buffers, rather than actual parcel boundaries. Parcel boundaries had not been digitized for most of the state. Statistics calculated for centroid buffers do not represent conditions within the parcels, because they have different boundaries. However, when averaging over a large data set (over 40,000 points), these differences should be irrelevant.

Table10-2
Acres of parcel centroid buffers within each composite ecological rank.

Composite rank	Acres of land in parcel centroid buffers
Least suitable	420,783
Fair	463,371
Good	615,334
Excellent	586,428

To note further, the data distributions are calculated for parcels, rather than combinations of parcels. Many potential projects contain multiple parcels with a single owner. For contiguous parcel groups, this is not necessarily a problem. The acres of green infrastructure could be larger for a group of parcels, putting the group into a more desirable category, but this is consistent with program objectives: more is better, especially for ecologically important areas. The other parameters are not as directly area-dependent. For greatly discontiguous parcel groups, reviewers might want to examine each parcel separately, as well as their combination.

Tier 2 in practice

Kevin Coyne of Landscape and Watershed Analysis Division wrote an Avenue script to automate the GIS evaluation of parcels identified for potential acquisition. The program calculates the statistics used in the project profile, including the overall rating (Excellent, Good, Fair, or Poor), and exports these in dBASE format. High ranking properties were presumed preferable to low-ranking properties. They were considered for further action or evaluation, as described in the next chapter. Figure 10-3 shows the GreenPrint Tier 2 ratings for parcels in the Catoctin area.

Fig. 10-2
Desktop Project Ecological Score calculated for parcel centroid buffers, based on combination of acres of GI, % of GI, mean cell ecological score in GI, protected land within 1 mile, and % gain to hub or corridor.

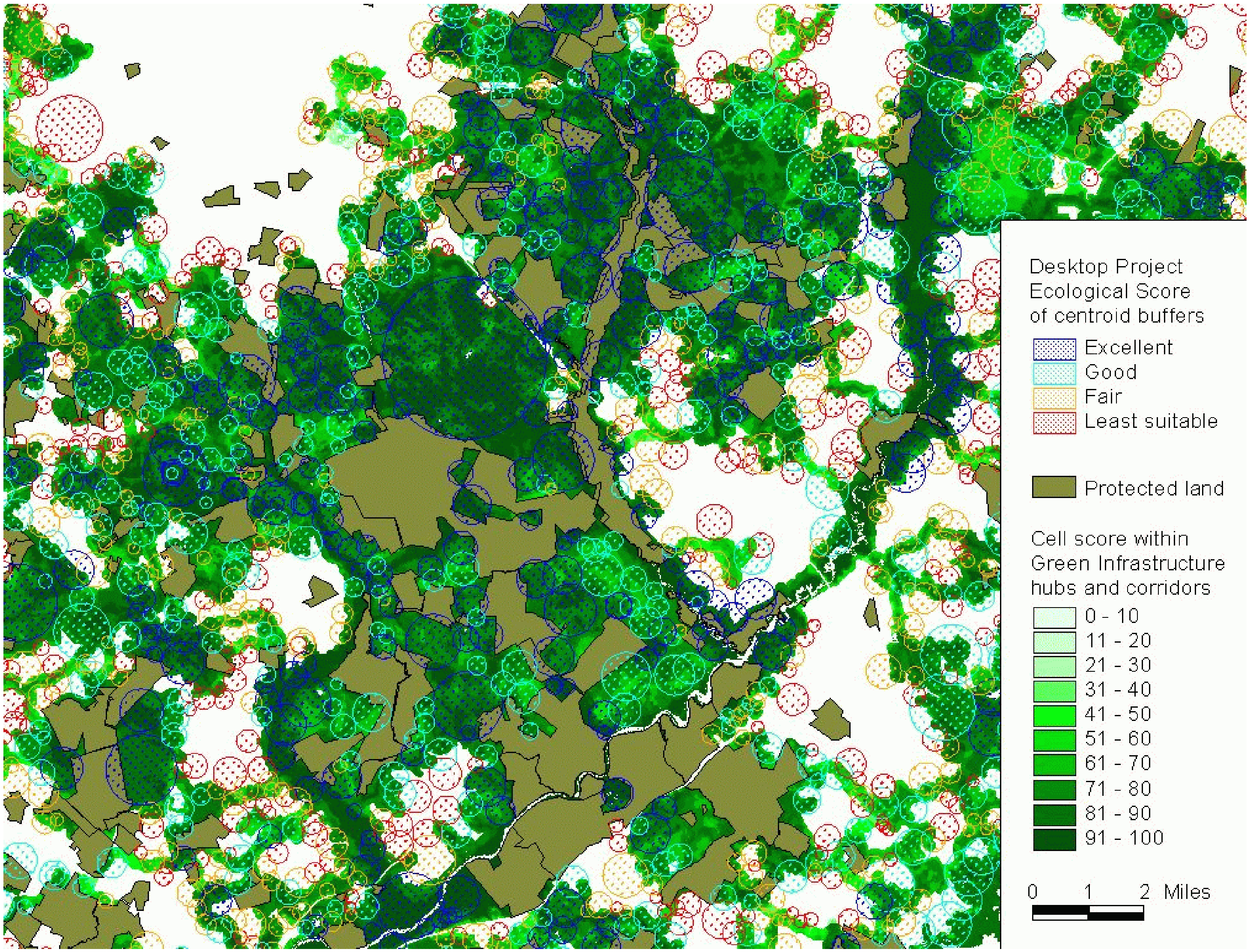
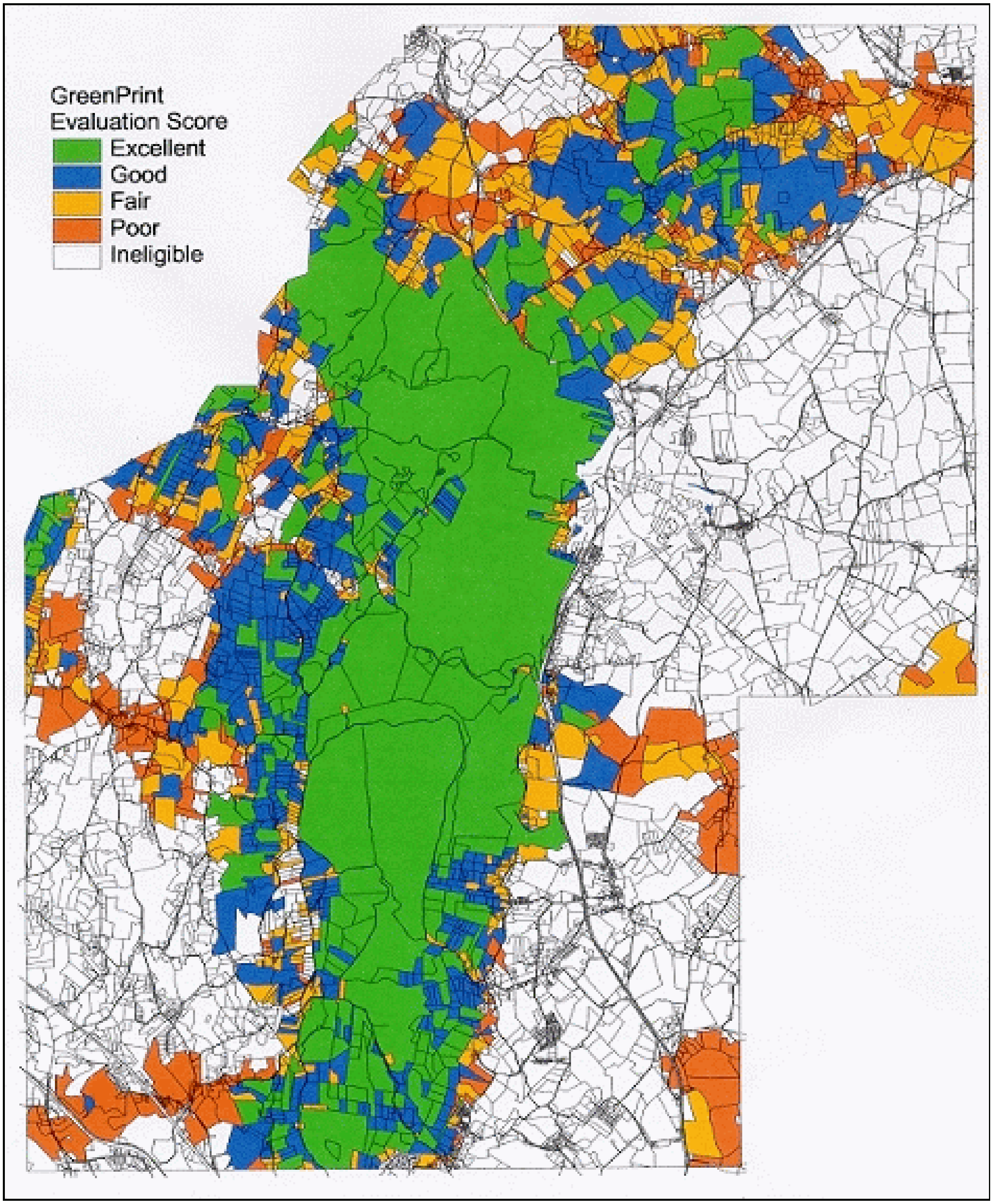


Fig.10-3
GreenPrint Tier 2 ratings for parcels in the Catoctin area.



Chapter 11
FIELD EVALUATION OF PARCELS

Field evaluation of potential GreenPrint projects was carried out according to the approach described in this chapter. The approach is also valid for determination of preferred projects to be funded under other mechanisms, at least until ongoing field exercises in wetlands and upland forest assessment techniques are completed.

Tier 3 – Cursory field verification of GI assessment and vulnerability

Rapid site visits

For the GreenPrint program, Tiers 1 and 2 were completed for all proposed projects identified by Program Open Space (POS) or the Maryland Agricultural Land Preservation Fund (MALPF). For those POS projects likely to move forward with an investment of public funds (fee or easement acquisition), additional documentation and model verification were needed.

The Tier 3 review, conducted by POS regional or field staff, had three purposes: (1) verification of the green infrastructure assessment model output for the parcel/project of interest, (2) identification of potential restoration needs based, in part, on the presence of gaps in the green infrastructure, and (3) estimation of the degree of threat of conversion the property faces if fee or easement acquisition is not pursued. These objectives were addressed through a cursory or "drive-by" field visit to areas easily accessible by roads or trails. Figure 11-1 shows a sample Tier 3 data input form.

Prior to the site visit, two site maps were produced by the Geographic Information Services (GIS) Division, with the property boundary displayed on an orthophoto base map -- one with the green infrastructure displayed and one without. These maps become the basis for verifying the accuracy of the green infrastructure model in the field. Figure 11-2 shows a sample site map that was provided for Tier 3 review of a potential GreenPrint project. Once completed, the information obtained through Tier 3 review is transmitted to the GIS Division for incorporation into the tracking database.

Rapid site visits should view as much of the property as possible (e.g., walk all roads, logging roads, and trails). However, the visit may be limited by time or lack of prior landowner permission.

Fig. 11-1
Tier 3 Cursory Field Review Data Input Form

Tier 3
Field Verification of Desktop Assessment
Identification of Restoration Opportunities
Assessment of Property Vulnerability

Utilizing Site Map, please answer the following:

(1) Are general land uses as depicted on site map (e.g. - agriculture, forest, wetland, water bodies, residential, etc.)?

" Yes
" No

(2) If answer to # 1 is No, please identify type of discrepancy

" Additional structures/development present
" New roads, driveways present
" Forest land has been cut
" Map shows more/less agricultural land than is apparent from field visit
" Other: ____

(3) Please estimate the magnitude any land use changes identified in #2

" Not applicable (no land use changes apparent)
" Less than 25% of forest or wetland cover has been modified or cleared
" 25% - 50% of the forest or wetland cover has been modified or cleared
" More than 50% of the forest or wetland cover has been modified or cleared

(4) Does the property appear to contain opportunities to expand or enhance the green infrastructure based on existing land uses and land management practices

" Yes
" No

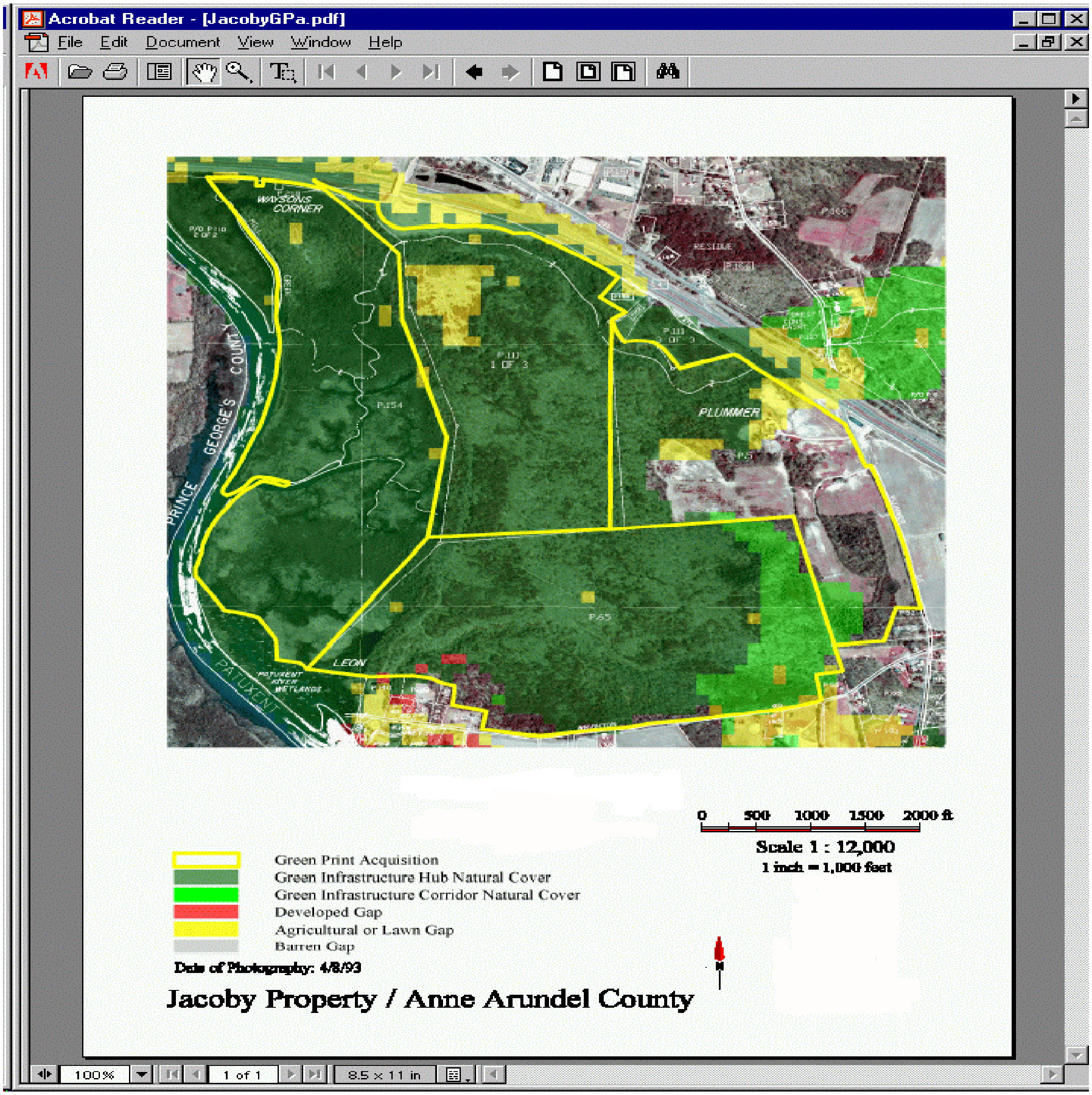
(5) If answer to #4 is yes, please identify potential restoration opportunity

" Row crops adjacent to GI forest
" Unbuffered streams
" Tree plantations
" Ditched waterways
" Other ______________________________

(6) Which of the following vulnerability factors apply to the property?

" Existing or planned water and sewer service
" Close (within one mile) proximity to employment centers, schools, shopping
" Close (within one mile) proximity to increasing level of commercial/residential development activity
" Property is currently on market
" Other ______________________________

Fig. 11-2
Sample site map showing property and green infrastructure



<u>Aerial surveys</u>

We performed helicopter surveys in fall 2001 and spring 2002, acquiring photos and videos of focus areas and parcels. Maryland's Eastern Shore was covered extensively, focusing on potential acquisitions and study areas, and many of the green infrastructure hubs and corridors. We also covered some areas within both Maryland and Delaware, such as the Nanticoke River headwaters, and the major Delmarva bays areas. On the western side of the Chesapeake, we were limited by security issues to Mattawoman Creek, the Potomac-Nanjemoy bend of Charles County, Blossom Point, McIntosh Run watershed, and areas of interest in between. No-fly zones, up to 25 miles in radius, were set up around Washington, Baltimore, and various federal facilities, following the terrorist attacks on the World Trade Center and the Pentagon. These overlapped enough in central Maryland to limit most of our surveys to the Eastern Shore.

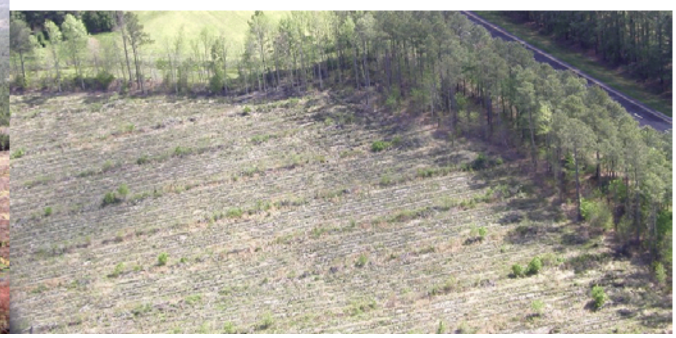
At first, maps were printed with green infrastructure areas of interest, a flight path, and navigation aids like roads, streams, and land cover. Later, this was augmented by the use of a Compaq iPAQ pocket PC with a Trimble Pocket Pathfinder GPS and ArcPad software. This allowed real-time display of our position on digital maps, as well as the ability to query data layers, and add survey data like photo locations. Use of the iPAQ greatly increased the efficiency and accuracy of our navigation.

The surveys were shot on digital video, transcribed to VHS, and made available to DNR staff and cooperating agencies and land trusts. Maps of the flight paths were supplied with the videos. Some video was saved in AVI format, and used in PowerPoint presentations. All video was taken from the left side of the aircraft. Photos were marked with their name and location, and made available in print and digital format. Some sample photos from the helicopter surveys are in Figure 11-3.

Fig. 11-3
Sample photos from helicopter site surveys.

(a) Canter Properties along lower Potomac River, showing unbroken mature deciduous forest and tidal marsh

(b) Jesuit Property at Blossom Point, showing a forest-agriculture mosaic, plus tidal creeks and marsh



(c) pine plantations west of Nassawango Creek, containing both riverine and isolated wetlands

(d) recently replanted pine plantation. The clearcut, although constituting the majority of the parcel, might not have been visible from the road.

<u>Limitations of Tier 3 assessments</u>

While the Tier 3 rapid site visit is a useful, and quite necessary, way to verify the presence of green infrastructure on a property, identify potential restoration needs, and estimate the risk of development, it may give an incomplete picture. If the assessors limit their observations to what can be seen from the road, they may miss many of the natural communities at the site, whether nearly pristine (e.g., old growth), or heavily impacted (e.g., a clear cut). Further, roadside communities may be unrepresentative, having a greater abundance of edge and exotic species.

Another limitation might be the expertise of the reviewer. Traditional property assessors tend to be schooled in real estate appraisal, rather than ecology or botany. A managed pine plantation and a mature oak-hickory forest may not be differentiated in reports, even though their wildlife and other ecological values are greatly different. An optimal natural stream might be equated to a ditch.

Helicopter surveys are better than drive-by visits to view entire properties and the surrounding landscape, but during much of the year, an observer cannot see below the tree canopy. We tried to concentrate most of our aerial surveys in early spring, before trees leafed out, and while standing water was present in wetlands (making them easier to see). Summer is also a bad time for aerial surveys because of haze on hot, humid days. Maryland experienced a severe drought during the 2001-2 survey period, limiting the visibility of wetlands on many flights. The flights themselves were limited by budget, time, and access constraints. It was unfeasible to fly over every property we were interested in, especially ones west of the Chesapeake.

From a management perspective, the completion of Tiers 1-3 is occasionally inconclusive in terms of deciding the most appropriate conservation strategy for a given project. For example, the presence of unique natural features or restoration opportunities may necessitate the involvement of additional resource experts. Also, once the ultimate responsible land management entity is identified, it may be asked to participate "up front" in the land conservation transaction to ensure that resources are protected while other management goals are achieved. An example of this situation would be when DNR is acquiring a property that will then be conveyed to a third party, such as a local government or a private conservation group. In such instances the Department may elect to encumber the property with a conservation easement prior to this conveyance. In an effort to ensure that the easement achieves the resource management objectives of appropriate DNR agencies, a detailed site investigation may be required.

Tier 4 – Detailed Field Assessment

<u>Overview of Tier 4 detailed field assessment</u>

Because it is time-consuming (at least two field ecologists dedicating a day or more to assess the property, plus time for logistics), the Tier 4 detailed field assessment was only done for parcels that passed Tier 1-3 screening. Tier 4 review can take many forms depending on the issues involved and the corresponding expertise required. The approach described here is an overall site assessment which

- maps all natural communities on the site;
- collects data for each community;
- rates the community according to its condition;
- gives the property an overall ecological field rating based on an area-weighted sum of community conditions;
- accounts for high-quality natural communities on site, which may make a property more desirable;
- accounts for impacted or heavily degraded communities on site, which may make a property less desirable;
- identifies restoration needs on the site; and,
- helps identify easement or management requirements.

Logistically, Tier 4 review is accomplished when POS staff invite the participation of other resource experts to provide specific comments regarding conservation, restoration or land management strategies on the property. Upon completion of this detailed site assessment, the agencies involved provide their input to POS/GIS for entry into the database in a Tier 4 "comment" field.

Table 11-1 describes an approach for associating site conditions with conservation potential and potential restoration needs. These rough categories guided the development of our field assessment protocol. The actual protocol was developed by collecting and analyzing data from various sites around Maryland, as well as using hypothetical cases for further calibration.

Table 11-1
Site or Community Categories for Tier 4 Detailed Field Assessment

Overall description of parcel	Grade	Category	Examples
Pristine, or nearly pristine	A	Excellent	Old-growth or mature forest dominated by late-successional species, and with diverse composition and structure. Community could be early successional if subject to repeated natural disturbances (e.g., beach dunes, river scours). No signs of recent human disturbance or exotic species in majority of community or site (>95% undisturbed).
In relatively good condition; little active management required to reach pristine status in time	B	Good	Regenerating forest with natural composition, >30 yrs old. Could be signs of human disturbance, but not recent, and they are not significantly affecting hydrology, species composition, or animal movement. No major ditches, fish blockages, invasive exotics, or roads present.
Minor restoration required, or early successional	C	Fair	Dominated by saplings or early successional native trees (e.g., sweetgum or Virginia pine); or old fields. Restoration needs might include some tree planting, removal of exotic species, burning, fixing minor stream erosion or fish blockages, minor ditch filling, removing trash, culling animal overpopulations (e.g., deer, hogs), etc.
Significant restoration required, but feasible	D	Poor	Dominated by human land uses: pine plantations, row crops, clearcuts, etc. Might contain numerous logging roads or ditches. Might be dominated by exotic species. Streams may be unstable, or major erosion occurring on site. Restoration needs might include clearing and revegetation, road removal, major ditch filling, major road-stream retrofits, or complete stream restoration. Neighboring land uses might require perpetual active management of parcel.
Trashed; restoration difficult or not feasible	F	Very Poor	Areas with minimal ecological potential: e.g., developed, strip-mined, heavily roaded or ditched (including large tax ditches), garbage dumps, etc.

Selection of reference sites

We collected data at sites representing a wide range of abiotic conditions, community types, and disturbance regimes, to develop and calibrate a field assessment system. A much larger sample would have been ideal, but we were limited by time and budget constraints. Natural communities at these sites were evaluated for their plant community structure and composition; wildlife habitat values; hydrology; presence, type, and intensity of human disturbances; and presence and distribution of invasive exotic species. Types of natural communities evaluated included upland forest, high-gradient streams (>3% slope), low-gradient streams (#3% slope), riverine forested wetlands, non-riverine forested wetlands, scrub-shrub tidal and non-tidal wetlands, and herbaceous tidal and non-tidal wetlands. Upland fields were considered forest in an early successional state. Site conditions affecting community parameters, like rocky soils or exposed ridge tops, were noted and considered when rating the community.

Table 11-2 lists the location of reference standard communities, to which other sites were compared. Examples included old growth or mature forest, streams in optimal condition, and unimpacted wetlands. Many were in designated wildlands, with minimal human management. These natural communities were rated as "Excellent" in the assessment protocol. Table 11-3 lists the location of stressed or recovering sites used to calibrate the "Good", "Fair", and "Poor" ratings. More information is available in Appendix C. More sites were visited in the Coastal Plain physiographic province than elsewhere, because of their closer proximity to the DNR offices in Annapolis. Again, a larger sample size would have been ideal. More data are being gathered in the process of evaluating new potential GreenPrint purchases.

Figures 11-4 through 11-6 show examples of some of the ecosystems and conditions we examined: Fig. 11-4 shows some of the reference standard sites; Fig. 11-5 shows examples of communities recovering from past disturbance; and Fig. 11-6 shows examples of current human disturbance.

Table 11-2
Locations of reference standard natural communities (rated as "Excellent" in the assessment protocol).

Site name	Physiographic region	Types of natural communities evaluated
Belt Woods Wildland	Western Coastal Plain	upland forest
Catoctin National Park	Blue Ridge	upland forest
Chapman's Forest	Western Coastal Plain	upland forest, herbaceous wetland
Cunningham Falls State Park	Blue Ridge	upland forest, high-gradient stream
Fishing Bay WMA	Eastern Coastal Plain	herbaceous wetland
Hickory Point Wildland	Eastern Coastal Plain	riverine forested wetland, scrub-shrub wetland
Idylwild WMA	Eastern Coastal Plain	riverine forested wetland, herbaceous wetland, low-gradient stream, upland forest
Jacoby property	Western Coastal Plain	herbaceous wetland, scrub-shrub wetland
Jug Bay	Western Coastal Plain	herbaceous wetland, scrub-shrub wetland
Oregon Ridge Park	Piedmont	upland forest, high-gradient stream
Parker Creek	Western Coastal Plain	herbaceous wetland, riverine forested wetland
Puckham Branch	Eastern Coastal Plain	riverine forested wetland
Savage River State Forest	Appalachian Plateau	upland forest, high-gradient stream, riverine forested wetland
Smithsonian Environmental Research Center	Western Coastal Plain	upland forest
Soapstone Branch	Piedmont	high-gradient stream

Site name	Physiographic region	Types of natural communities evaluated
Quiet Waters Park	Western Coastal Plain	low-gradient stream
Zekiah Swamp headwaters, in Cedarville State Forest	Western Coastal Plain	riverine forested wetland, low-gradient stream

Table 11-3
Locations of stressed or recovering communities used to calibrate the "Good", "Fair", and "Poor" ratings in the assessment protocol.

Site name	Physiographic region	Types of natural communities evaluated
Belt Woods	Western Coastal Plain	upland forest
Chapman's Forest	Western Coastal Plain	upland forest, non-riverine forested wetland, low-gradient stream
Fishing Bay	Eastern Coastal Plain	herbaceous wetland, upland forest
Idylwild WMA	Eastern Coastal Plain	upland forest
Jabez Branch	Western Coastal Plain	low-gradient stream
Jacoby property	Western Coastal Plain	upland forest, riverine forested wetland, low-gradient stream, scrub-shrub wetland
Jug Bay	Western Coastal Plain	riverine forested wetland, upland forest
Parker Creek	Western Coastal Plain	herbaceous wetland
Puckham Branch	Eastern Coastal Plain	riverine forested wetland, low-gradient stream, upland forest
Savage River State Forest	Appalachian Plateau	riverine forested wetland, high-gradient stream, upland forest
Sawmill Creek	Western Coastal Plain	low-gradient stream
Smithsonian Environmental Research Center	Western Coastal Plain	herbaceous wetland, low-gradient stream, riverine forested wetland, upland forest
Wolf Den Branch	Western Coastal Plain	low-gradient stream
Wolf Swamp (Miller property)	Appalachian Plateau	scrub-shrub wetland, upland forest
Zekiah Swamp headwaters, in Cedarville State Forest	Western Coastal Plain	riverine forested wetland, non-riverine forested wetland, low-gradient stream

Fig. 11-4
Some of the reference standard sites used to develop the field assessment protocol

» *(a) Coastal Plain oak-hickory old growth forest in Belt Woods. This is one of the largest remnant stands (although it is only 45 acres) of virgin forest in the Mid-Atlantic Coastal Plain.*

(b) Appalachian Plateau mixed oak old growth forest in Savage River State Forest. This stand was never logged, and the trees are 300-400 years old.

c) Middle Fork, a brook trout stream in Savage River State Forest

d) Spartina patens-*dominated high marsh along Parker Creek*

Fig. 11-5
Examples of communities recovering from past disturbance, used to calibrate the field protocol

(a) Young hardwood forest on abandoned farmland

(b) Young secondary forest undergoing succession: Virginia pine canopy with sweetgum-blackgum understory. In the absence of further disturbance, the Virginia pine will be replaced by the present hardwood understory.

(c) Old field in the early stages of succession, being colonized by red cedar

Fig. 11-6
Examples of current human disturbance

(a) erosion on Galloway Creek from development upstream

(b) Mosquito ditches in Fishing Bay WMA

(c) Shore erosion along lower Potomac River

(d) Microstegium vimineum*, an invasive exotic grass*

Fig. 11-6 (cont.)

(e) logging or access roads (Douglas Point)

(f) selective logging (Catoctin area)

(g) clear cut (wetland converted to pine plantation on eastern shore)

Data collection methodology

Where data were gathered for entire properties, we used the following protocol. First, initial community boundaries were delineated for the site using GIS data (USGS topographic maps, high-altitude aerial photographs–DOQQs, land cover–NLCD, NWI wetlands, GAP vegetation alliances, streams, roads, property boundaries, and the green infrastructure). Of these, topographic maps, aerial photos, and NWI wetlands were the most useful. Steep slopes were unlikely to have been farmed, and less likely than flat areas to have been logged. We marked all large NWI wetlands (>1 ac). Roads and streams were on the topo maps, so this information was redundant. The GAP data were spatially inaccurate at the parcel level. Classification was accurate in some cases, and inaccurate in others. We made no attempt to systematically estimate the spatial and classification accuracy of GAP. Since all the sites were at least partly in the green infrastructure, GI boundaries were usually not helpful at the parcel level, although they were necessary to identify the parcels *a priori*. Because of their finer scale, where parcels were partly outside the GI, the DOQQs helped to more accurately define and digitize GI boundaries. We only considered the portion of parcels within the green infrastructure, after adjusting initial GI boundaries with finer-scale DOQQ's. For example, the Jacoby property contained farmed areas on its eastern edge that were not field analyzed. An example of community boundaries delineated using GIS data is shown in Fig. 11-7.

Where data were collected only for reference standard or impacted communities, we created base maps, but did not digitize community boundaries, or try to evaluate the entire parcel.

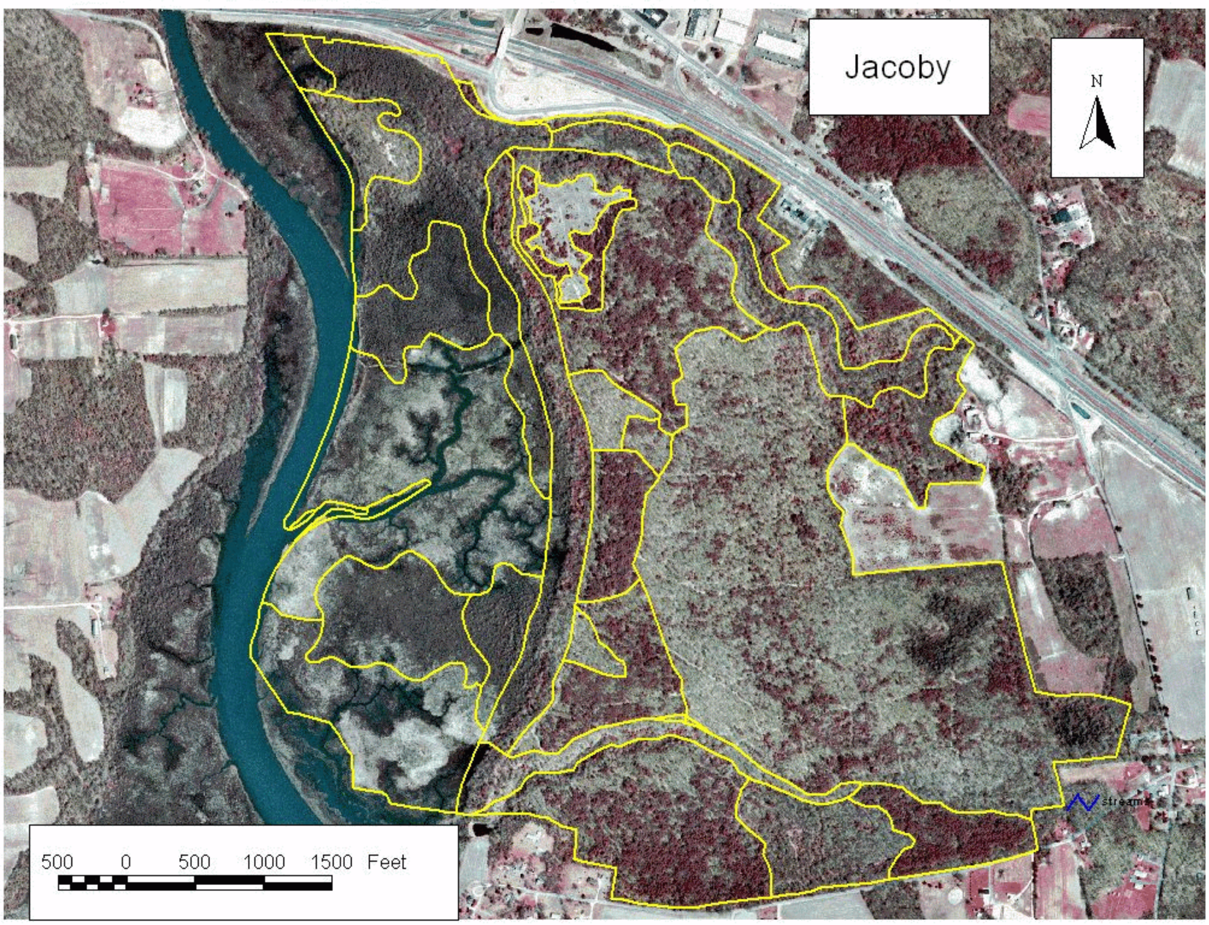
For whole property evaluations, we next defined and digitized transects. These were:
- along streams;
- across roads;
- across topographic gradients;
- into the interior of forest communities; and,
- into wetlands (if small, sample a representative number)

Initially, we created hardcopy maps, and determined our position with a compass and pacing. Our task was later made easier by the purchase of a Compaq iPAQ pocket PC with a Trimble Pocket Pathfinder GPS and ArcPad software (also used during the later helicopter surveys). This allowed real-time display of our position on digital maps, as well as the ability to query data layers, and add the GPS location of our plots. Use of the iPAQ increased the efficiency and accuracy of our navigation. We hope to create data entry forms for the iPAQ to further reduce time.

A sample site map is shown in Fig. 11-7. Data were collected for each community. Community boundaries were adjusted in the field as necessary. For example, forest condition and composition were not always apparent from DOQQ's, and often changed along transects. A community may have changed from its condition during DOQQ acquisition (1995); e.g., forest might have been cleared or an agricultural field abandoned. Or there may be multiple communities within one defined from

DOQQ's (e.g., part of a forest being oak-hickory, and part being pine-sweetgum; or part being mature, and part being newly regenerating). Community boundary adjustments were marked on the site map. We marked only major changes in community type or structure, not minor shifts in species dominance. We suggest a minimum mapping unit of 1 acre to save time. For streams, we walked the entire length within the property, selecting representative sites to survey, and looking for problems, such as fish blockages or bank erosion. We marked the stream reach surveyed on the map. There may be more than one stream reach on a property, in which case a separate form should be filled out for each one.

Fig. 11-7
Site map for Jacoby property, showing community boundaries after field adjustment.



Field teams should contain at least two people: both for safety, and in order to discuss observations and complete the survey in one visit. Ideally, at least one team member should have strong botany skills, and at least one should have strong ecology skills, being familiar with forests, streams and wetlands. There are numerous qualified individuals within and outside DNR. The hardest part of the survey might be defining communities and community boundaries, especially for large properties. Boundaries may have to be approximated, or only marked along transects, and then connected where possible.

Data forms were modified from four different sources. For forest communities, we modified a rapid field assessment from a forest corridor study done by Baltimore County (Baltimore County Department of Environmental Protection and Resource Management, 1996). We modified the wetland rapid field assessments from unpublished (as of this writing) hydrogeomorphic research done during 1999-2000 for non-tidal riverine and flat wetlands in the Nanticoke watershed. We created the stream rapid field assessments from EPA rapid bioassessment protocols for high and low gradient streams (Barbour et al, 1999) and Maryland DNR's stream corridor assessment methodology (DNR-SCA) (Yetman, 2001). These initial data sheets are in Appendix D and include information on community composition, structure, habitat, hydrology, and human disturbances.

Other information collected included the known site history, current site management, indicator species (e.g., forest interior birds, salamanders, brook trout, etc.) observed on the plot or site, and rare species or unique communities observed. Space was left for other notes as well. Ancillary data were used in a qualitative sense. Site history and management, where collected from property owners, managers, or staff, were helpful for explaining current conditions. Absence of indicator or rare species did not decrease a community or site rating, since sampling time was extremely limited. However, presence might add to site scores. Presence of rare species or communities might prompt Natural Heritage biologists to map their occurrence, estimate their long-term viability and potential threats, and make management recommendations. In cases where a property is actually purchased, systematic surveys for rare species should be made by experts.

Field surveyors should take photographs of representative and interesting sites on the parcel, especially if data are collected there. On one of the maps, the photographer can mark the location, direction, and frame number of these photos (an arrow can indicate the faced direction). This can also be done in ArcPad.

In addition to recording data, surveyors rated reference standard or impacted communities using the subjective criteria in Table 11-1. This was done to help identify which parameters were significant predictors of community condition, given varying climate, geology, soils, topography, hydrology, etc.

Analysis of field data

Collected data were analyzed, highly correlated or non-predictive parameters were dropped, weightings were adjusted and calibrated, and some of the community types lumped together. Hypothetical cases (e.g., what we might find at a wetland undergoing various types of stress) were also modeled to calibrate the weightings and scores. This process is described in more detail below.

Upland forest. Data were collected for 90 upland forest communities at 13 sites (see Appendix C). Data were collected for parameters representing species composition, vegetation structure, habitat value, human disturbances, and hydrology (see Table 11-4). The data were grouped into brackets (see data sheets in Appendices D and E) to ease future assessments, although some of the numerical data (e.g., species richness) were also analyzed.

Table 11-4
Parameters measured in upland forest communities (see Appendix D for further details)

Parameter	Rationale
Canopy species composition	Habitat value, plus indicator of successional stage
Number of dominant/co-dominant native canopy species	Tree diversity
Number of indigenous tree, shrub, and vine species	Woody diversity
Evenness of woody species distribution	Woody diversity
Tree seedling recruitment	Future community composition
Crown closure of canopy species	Shading for forest obligate species, and regulation of microclimate
Size class of canopy species	Forest age
Stand stratification	Structural diversity, plus indicator of successional stage
Tree size-class distribution	Structural diversity
Standing dead trees	Woodpecker forage, plus indicator of successional stage
Trees (live or dead) with natural or excavated cavities	Nest sites, plus indicator of successional stage
Downed logs and coarse woody debris on forest floor	Decomposer habitat and nutrient cycling, plus indicator of successional stage
Leaf duff (excluding leaf fall from current year) and humus layer	Decomposer habitat and nutrient cycling, plus indicator of successional stage
Pit and mound structure	Microhabitat, especially wetness differences, plus old growth indicator
Herbaceous ground coverage	Forage and ground cover value
Number of indigenous herbaceous species	Forage value and herb diversity
Evenness of herbaceous species distribution	Forage value and herb diversity
Types of disturbance	Measure of human impact and ecosystem stress
Area affected by human disturbances	Measure of human impact and ecosystem stress

Parameter	Rationale
Presence of exotic invasive species	Measure of human impact and ecosystem stress
Distribution of exotic invasive species	Measure of human impact and ecosystem stress
Extent of exotic invasive species into edges	Measure of human impact and ecosystem stress
Presence and type of streams	Aquatic habitat; water for flora and fauna
Presence of ponds or vernal pools	Aquatic habitat; water for flora and fauna
Presence of headwaters, springs, or seeps	Water for flora and fauna; stream source

Human disturbances in upland forest communities were scored by answering the following questions:

1. How long will it take for the ecosystem to recover from the disturbance, without active restoration?

Recovery time	Score
<1 year	20
1-10 years	10
10-20 years	5
>20 years	0

2. What are the effects on the ecosystem?

Ecosystem effects	Score
Minor	20
Moderate	10
Moderately severe	5
Severe	0

3. How difficult is restoration?

Restoration difficulty	Score
Easy	10
Moderate	5
Difficult	2
Nigh impossible	0

The scores were added together to give the following scores for human disturbances in upland forest (Table 11-5). Scores were calibrated using both collected and hypothetical data. Because we didn't find all possible types of disturbances at our field sites, we supplemented the calibration by considering each type of potential disturbance at a hypothetical site while holding all other variables constant. Disturbances not in Table 11-5 can be scored by similarly considering their effects, persistence, and restoration difficulty.

Table 11-5
Human disturbance scores in upland forest.

Type of disturbance	Recovery time	Ecosyste m effects	Restoration difficulty	Total score
No disturbance, or minor natural disturbances only	20	20	10	50
Roads, power lines, or trails				
Paved road or railroad	0	0	0	0
Power line or other utility corridor (canopy broken)	0	5	0	5
Unpaved road (canopy broken)	0	5	5	10
Unpaved road (canopy unbroken)	0	10	10	20
Paved trail	0	10	5	15
Gravel trail	5	10	5	20
Unimproved trail	10	20	10	40
Vegetation alteration				
Managed for pine production	0	0	5	5
Recent clear cut (<5 years)	0	0	10	10
Logging within 30 years, but not clear cut <5 years	0	10	10	20
Mowing	20	5	10	35
Cattle grazing	20	10	10	40
Understory removal	10	5	10	25
Excessive herbivory (e.g., deer overbrowsing)	20	10	10	40
Microtopography alteration				
Grading	0	10	10	20
Bedding	0	10	10	20
Windrows	0	10	10	20
Skidder tracks	0	20	10	30
Natural disturbances, possibly human-caused				
Fire, flood, landslide, tree disease or pest (minor)	10	20	10	40
Fire, flood, landslide, tree disease or pest (moderate)	5	10	10	25
Fire, flood, landslide, tree disease or pest (severe)	0	0	10	10
Garbage				
Trash dumping	0	20	10	30
Hazardous materials	0	5	2	7

Each community was given a qualitative rating (listed in Table 11-1), and this was used to calibrate the parameter scores. Qualitative ratings were discussed by the field investigators, as were the data collected. We examined the Spearman correlation between each parameter and the overall qualitative rating. Parameters with <25% correlation were dropped, except surface water presence and species richness. The parameter, extent of exotic invasive species into edges, was highly correlated (97%) with the presence and amount of exotic invasives, and was therefore also dropped.

Table 11-6
Upland forest community parameter retention after data analysis.

Parameter	Significant differences between forest conditions and ages?	Keep or Drop?
Canopy species composition	yes	Keep
Number of dominant/co-dominant native canopy species	yes	Keep
Number of indigenous tree, shrub, and vine species	no, but yes if combined with evenness.	Keep, but changed brackets to >12, 6-12, <6
Evenness of woody species distribution	yes	Keep
Tree seedling recruitment	yes	Keep
Crown closure of canopy species	no	Drop
Size class of canopy species	yes (most significant variable)	Keep
Stand stratification	yes	Keep
Tree size-class distribution	no	Drop
Standing dead trees	yes	Keep
Trees (live or dead) with natural or excavated cavities	yes	Keep
Downed logs and coarse woody debris on forest floor	no	Drop
Leaf duff (excluding leaf fall from current year) and humus layer	yes	Keep
Pit and mound structure	yes	Keep
Herbaceous ground coverage	no (least significant variable)	Drop
Number of indigenous herbaceous species	yes	Keep
Evenness of herbaceous species distribution	yes	Keep
Types of disturbance	yes	Keep
Area affected by human disturbances	yes	Keep
Presence of exotic invasive species	yes	Keep
Distribution of exotic invasive species	yes	Keep
Extent of exotic invasive species into edges	yes, but highly correlated (97%) with presence and amount of exotic invasives.	Drop
Presence and type of streams	yes	Keep
Presence of ponds or vernal pools	yes	Keep
Presence of headwaters, springs, or seeps	yes	Keep

The remaining parameters were weighted to maximize the differentiation of sites by total score into categories agreeing with the qualitative ratings. These agreements were not 100%, but were close. The data sheets were amended accordingly (see Appendix E). Appendix F lists the distribution of overall community scores and categories after analyzing data collected during summer-fall 2001. The final scores and categories for upland forest communities were:

Total score	Community category
>390	Excellent
298 - 390	Good
186 - 297	Fair
0 - 185	Poor
<0	Very Poor

Forested wetlands. Data were collected for 26 forested wetland communities at nine sites (see Appendix C). Originally, these were split into riverine and non-riverine forested wetlands, with different parameters and scoring. However, these data sets were too small to analyze, and had to be combined. Hypothetical conditions were also considered to help calibrate disturbance weightings. The original data sheets are in Appendix D. Data were collected for parameters representing hydrology, species composition, vegetation structure, habitat value, and human disturbances (see Table 11-7). As with upland forest, the data were grouped into brackets to ease future assessments, although some of the numerical data (e.g., species richness) were also analyzed. Disturbances were evaluated differently than for upland forest.

Table 11-7
Parameters measured in forested wetland communities (see Appendix D for further details).

Parameter	Rationale
Floodplain condition *(for riverine wetlands) /* Wetland condition *(for non-riverine wetlands)*	Controls wetland hydrology
Stream condition in wetland *(for riverine wetlands only)*	Controls wetland hydrology
Stream condition outside wetland *(for riverine wetlands only)*	Controls wetland hydrology
Near floodplain buffer *(for riverine wetlands)* / Near wetland buffer *(for non-riverine wetlands)*	Wetland buffers perform important functions; see background chapter for details
Far floodplain buffer *(for riverine wetlands)* / Far wetland buffer *(for non-riverine wetlands)*	Wetland buffers perform important functions; see background chapter for details
Forest food, cover and nest site value	Habitat value plus indicator of successional stage. However, many dominant wetland trees (red maple, green ash, bald cypress, etc.) do not have high wildlife value, and/or would be succeeded if not for flooding, but are typical for natural wetlands.
Number of dominant/co-dominant native canopy species	Tree diversity
Number of indigenous tree, shrub, and vine species	Woody diversity
Evenness of woody species distribution	Woody diversity
Tree seedling recruitment	Future community composition

Parameter	Rationale
Crown closure of canopy species	Shading for forest obligate species, and regulation of microclimate
Size class of canopy species	Forest age
Stand stratification	Structural diversity, plus indicator of successional stage
Tree size-class distribution	Structural diversity and stand age
Standing dead trees	Woodpecker forage, plus indicator of successional stage
Trees (live or dead) with natural or excavated cavities	Nest sites, plus indicator of successional stage
Downed logs and coarse woody debris on forest floor	Decomposer habitat and nutrient cycling, plus indicator of successional stage
Leaf duff (excluding leaf fall from current year) and humus layer	Decomposer habitat and nutrient cycling, plus indicator of successional stage
Pit and mound structure	Microhabitat, especially wetness differences, plus old growth indicator
Herbaceous ground coverage	Forage and ground cover value
Number of indigenous herbaceous species	Forage value and herb diversity
Evenness of herbaceous species distribution	Forage value and herb diversity
Types of disturbance	Measure of human impact and ecosystem stress
Area affected by human disturbances	Measure of human impact and ecosystem stress
Presence of exotic invasive species	Measure of human impact and ecosystem stress
Distribution of exotic invasive species	Measure of human impact and ecosystem stress
Extent of exotic invasive species into edges	Measure of human impact and ecosystem stress

Human disturbances in forested wetland communities were scored by answering the following questions:

1. How long will it take for the ecosystem to recover from the disturbance, if the disturbance ceases, but without active restoration?

Recovery time	Score
<1 year	20
1-20 years	10
20-100 years	5
>100 years	0

2. What are the direct effects on hydrology?

Hydrology effects	Score
Minor	20
Moderate	10
Moderately severe	5 to 7
Severe	0
Extremely severe	-5

3. What are the direct effects on the vegetation?

Vegetation effects	Score
Minor	20
Moderate	10
Moderately severe	5 to 7
Severe	0

4. How difficult is restoration?

Restoration difficulty	Score
Easy	10
Moderate	5
Difficult	2
Nigh impossible	0

The scores were added together to give the following scores for human disturbances in forested wetlands (Table 11-8). Scores were calibrated with collected and hypothetical data. The need for supplemental calibration using hypothetical cases was greater for wetlands than upland forest because of fewer field sites and less variable conditions. Disturbances not on this list can be scored by considering their effects on hydrology and vegetation, persistence, and restoration difficulty. The disturbance score for each type of disturbance, used to rate wetland condition, was the total score for that disturbance divided by the score for no disturbance (70). This gave a value between 0 and 1.

Table 11-8
Human disturbance scores in forested wetlands.

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
No disturbance, or minor natural disturbances only	20	20	20	10	70	1.00
Roads, power lines, or trails in wetland or floodplain						
Paved road or railroad	0	5	0	0	5	0.07
Powerline or other utility corridor (canopy broken)	5	5	5	0	15	0.21
Unpaved or logging road (canopy broken)	5	5	5	5	20	0.29
Unpaved or logging road (canopy unbroken)	5	10	10	10	35	0.50
Paved trail	5	10	10	5	30	0.43
Gravel trail	5	10	10	10	35	0.50
Unimproved trail	10	20	20	10	60	0.86

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
Hydrologic modifications in wetland or floodplain						
Ditches or channelized streams that provide effective drainage, and levees present	0	-5	5	5	5	0.07
Ditches or channelized streams that provide effective drainage, but no levees	0	-5	10	5	10	0.14
Unmaintained ditches or prior stream channelization are present in the floodplain, but they are no longer effective, and will in most instances not have the ability to drain water (i.e., ditches have become filled with debris and are not maintained)	5	20	20	5	50	0.71
Tile draining	5	5	10	10	30	0.43
Excavation of substrate or impoundment of water (dams, dikes, weirs, etc.)	0	5	5	10	20	0.29
Deposition of fill or spoil, other than levees	5	10	20	10	45	0.64
Stream or floodplain constricted, but not dammed (bridge, culvert, road bed, etc.)	0	10	20	5	35	0.50
Hydrologic modifications outside wetland or floodplain (within 500m)						
Ditches or channelized streams that provide effective drainage, and levees present	0	5	20	5	30	0.43
Ditches or channelized streams that provide effective drainage, but no levees	5	10	20	5	40	0.57
Unmaintained ditches or prior stream channelization are present in the floodplain, but they are no longer effective, and will in most instances not have the ability to drain water (i.e., ditches have become filled with debris and are not maintained)	5	20	20	5	50	0.71
Tile draining	5	10	20	10	45	0.64
Excavation of substrate or impoundment of water (dams, dikes, weirs, etc.)	0	10	20	10	40	0.57
Deposition of fill or spoil, other than levees	5	15	20	10	50	0.71
Stream or floodplain constricted, but not dammed (bridge, culvert, road bed, etc.)	0	15	20	5	40	0.57
Vegetation alteration by humans in wetland or floodplain						
Managed for pine production	5	5	0	5	15	0.21
Recent clearcut (<5 years)	5	5	0	10	20	0.29
Logging within 30 years, but not clearcut <5 years	5	10	5	10	30	0.43
Mowing	20	5	5	10	40	0.57
Used for livestock grazing	20	10	5	10	45	0.64
Understory removal	10	5	5	10	30	0.43
Burning	10	5	5	10	30	0.43
Microtopography alteration in wetland or floodplain						
Grading	5	10	5	10	30	0.43

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
Bedding	5	10	5	10	30	0.43
Windrows	5	10	5	10	30	0.43
Skidder tracks	5	20	5	10	40	0.57
Pollution of wetland, stream, or floodplain						
Point source pollution (e.g., pipes carrying effluent)	10	10	10	10	40	0.57
Non-point source pollution	10	10	10	5	35	0.50
Stormwater piped in	10	5	10	10	35	0.50
Trash dumping	5	20	10	10	45	0.64
Hazardous materials	5	20	5	2	32	0.46
Diseases, pests, invasive exotic species, or excessive herbivory in wetland or floodplain						
Tree diseases or pests causing significant mortality, multiple species	5	10	0	10	25	0.36
Tree diseases or pests causing significant mortality, one species	5	20	10	10	45	0.64
Tree diseases or pests causing stress	20	20	15	10	65	0.93
Invasive exotic species	10	20	10	5	45	0.64
Excessive herbivory (e.g., deer overbrowsing)	20	20	5	10	55	0.79
Near wetland or floodplain buffer (0-60 ft)						
Forest (either natural or planted)	20	20	20	10	70	1.00
Shrub/scrub or saplings	10	20	15	10	55	0.79
Old field or post-clearcut seedlings	5	15	10	10	40	0.57
Pasture, lawn, or recent clearcut	5	10	7	10	32	0.46
Row crops or bare ground	5	7	7	5	24	0.34
Developed or mined	0	5	7	0	12	0.17
Far wetland or floodplain buffer (60-300 ft)						
Forest (either natural or planted)	20	20	20	10	70	1.00
Shrub/scrub or saplings	10	20	20	10	60	0.86
Old field or post-clear cut seedlings	5	20	10	10	45	0.64
Pasture, lawn, or recent clear cut	5	15	10	10	40	0.57
Row crops or bare ground	5	10	10	5	30	0.43
Developed or mined	0	7	10	0	17	0.24

The disturbance scores were multiplied by an affected area coefficient, which varied between 0 and 1 (Table 11-9). Surveyors recorded the percent area affected by each disturbance; this was converted to a coefficient value and then multiplied by the disturbance value (Table 11-8) subtracted from one. These combinations were then summed to give an overall impact assessment. Combinations closer to 1 were heavily disturbed; values closer to 0 were relatively undisturbed.

Table 11-9
Area affected by disturbances to forested wetlands, and their corresponding coefficient value.

Disturbance area affected	**Coefficient**
None	0.00
Present, but <5% of site	0.20
5-10% of site	0.40
11-25% of site	0.60
26-50% of site	0.80
51-100% of site	1.00
Exotic species area	**Coefficient**
Absent	0.00
Present, but <5% of site	0.40
5-10% of site	0.60
11-30% of site	0.80
>30% of site	1.00
Percent of buffer affected	**Coefficient**
None (all forest)	0.00
Present, but <10% of buffer	0.10
10-25% of buffer	0.25
26-50% of buffer	0.50
51-75% of buffer	0.75
76-100% of buffer	1.00

Each community was given a qualitative rating (listed in Table 11-1), and this was used to calibrate the parameter weightings. Qualitative ratings were discussed by the field investigators, as were the data collected. We examined the Spearman correlation between each parameter and the overall qualitative rating. Parameters with <25% correlation were dropped, except hydrologic parameters with insufficient sampling (Table 11-10). For example, herbaceous cover and composition varied greatly by wetland, and this variation was not related to wetland condition. The parameter, extent of exotic invasive species into edges, was highly correlated (95%) with the presence and amount of exotic invasives, and was therefore also dropped.

Table 11-10
Forested wetland parameter retention after data analysis.

Parameter	**Significant differences between forest conditions and ages?**	**Keep or Drop?**	**Reason for dropping**
Floodplain condition *(for riverine wetlands) /* Wetland condition *(for non-riverine wetlands)*	yes	Keep*	
Stream condition in wetland *(for riverine wetlands only)*	no, but insufficient data for altered wetlands	Keep*	
Stream condition outside wetland *(for riverine wetlands only)*	yes	Keep*	

Parameter	**Significant differences between forest conditions and ages?**	**Keep or Drop?**	**Reason for dropping**
Near floodplain buffer *(for riverine wetlands)* / Near wetland buffer *(for non-riverine wetlands)*	no, but insufficient data for altered wetlands	Keep*	
Far floodplain buffer *(for riverine wetlands)* / Far wetland buffer *(for non-riverine wetlands)*	yes	Keep*	
Forest food, cover and nest site value	no	Drop	Many dominant wetland trees (red maple, green ash, bald cypress, etc.) do not have high wildlife value, and/or would be succeeded if not for flooding, but are typical for natural wetlands. This variable correlated poorly (<20%) with overall rating.
Number of dominant/co-dominant native canopy species	yes	Keep	
Number of indigenous tree, shrub, and vine species	yes	Keep	
Evenness of woody species distribution	yes	Keep	
Tree seedling recruitment	yes	Keep	
Crown closure of canopy species	no	Drop	This variable correlated poorly (<20%) with overall rating.
Size class of canopy species	yes	Keep	
Stand stratification	yes	Keep	
Tree size-class distribution	yes, but insufficient variation overall	Drop	Insufficient variation - all sites but one had uneven tree size
Standing dead trees	yes	Keep	
Trees (live or dead) with natural or excavated cavities	yes	Keep	
Downed logs and coarse woody debris on forest floor	yes, but insufficient variation overall	Drop	Insufficient variation - all sites but two had downed logs >10% of area
Leaf duff (excluding leaf fall from current year) and humus layer	no (dropped before correlation test though)	Drop	varies according to hydrology and wetland position
Pit and mound structure	yes	Keep	
Herbaceous ground coverage	no	Drop	This variable correlated poorly (<5%) with overall rating.
Number of indigenous herbaceous species	no	Drop	This variable correlated poorly (<5%) with overall rating.
Evenness of herbaceous species distribution	no	Drop	This variable correlated poorly (<5%) with overall rating.
Types of disturbance	yes	Keep*	
Area affected by human disturbances	yes	Keep*	
Presence of exotic invasive species	yes	Keep*	
Distribution of exotic invasive species	yes	Keep*	
Extent of exotic invasive species into edges	yes, but highly correlated (97%) with presence and amount of exotic invasives.	Drop	Highly correlated (95%) with presence and amount of exotic invasives.

* combined into composite disturbance assessment

The remaining parameters were scored to maximize the differentiation of sites by total score into categories agreeing with the qualitative ratings. The total disturbance score was derived by adding area-weighted and effect-weighted disturbance scores (Tables 11-8 and 11-9); subtracting this sum from 1.0; if negative, setting to 0.0; and calibrating against the other parameters. The disturbance sum weight was, after calibration, equal to twice the sum of weights of all other parameters (i.e., 544). The data sheets were amended accordingly (see Appendix E). Appendix F lists the distribution of overall community scores and categories after analyzing data collected during summer-fall 2001. The final scores and categories for forested wetland communities are listed as follows:

Total score	Community category
>660	Excellent
525 - 659	Good
365 - 524	Fair
<365	Poor

An inter-agency effort is currently underway to develop a field assessment methodology for various hydrogeomorphic (HGM) classes of wetlands. When complete, these methodologies will replace the GreenPrint wetland assessment discussed here.

Herbaceous and shrub-scrub wetlands. Data were collected for 27 herbaceous and 10 shrub-scrub wetland communities at 9 sites (see Appendix C). Originally, these were split into herbaceous and shrub-scrub wetlands, with different parameters and scoring. The original data sheets are in Appendix D. Data were collected for parameters representing hydrology, species composition, vegetation structure, habitat value, and human disturbances (see Tables 11-11 and 11-12). The data were grouped into brackets to ease future assessments, although some of the numerical data (e.g., species richness) were also analyzed.

Table 11-11
Parameters measured in herbaceous wetland communities (see Appendix D for further details).

Parameter	Rationale
Hydrologic alteration (e.g., impact to exchange of tidal water, input of fresh water)	Controls wetland hydrology
Near wetland buffer	Wetland buffers perform important functions; see background chapter for details
Far wetland buffer	Wetland buffers perform important functions; see background chapter for details
Herbaceous ground coverage	Bare ground is an indicator of unstable substrate
Number of indigenous herbaceous species	Wildlife value and plant diversity
Evenness of herbaceous species distribution	Wildlife value and plant diversity
Types of disturbance	Measure of human impact and ecosystem stress
Area affected by human disturbances	Measure of human impact and ecosystem stress

Parameter	Rationale
Presence of exotic invasive species	Measure of human impact and ecosystem stress
Distribution of exotic invasive species	Measure of human impact and ecosystem stress
Extent of exotic invasive species into edges	Measure of human impact and ecosystem stress

Table 11-12
Parameters measured in shrub-scrub wetland communities (see Appendix D for further details).

Parameter	Rationale
Hydrologic alteration (e.g., impact to exchange of tidal water, input of fresh water)	Controls wetland hydrology
Near wetland buffer	Wetland buffers perform important functions; see background chapter for details
Far wetland buffer	Wetland buffers perform important functions; see background chapter for details
Vegetative ground coverage	Bare ground is an indicator of unstable substrate
Number of indigenous tree, shrub, and herb species	Wildlife value and plant diversity
Evenness of indigenous species distribution	Wildlife value and plant diversity
Types of disturbance	Measure of human impact and ecosystem stress
Area affected by human disturbances	Measure of human impact and ecosystem stress
Presence of exotic invasive species	Measure of human impact and ecosystem stress
Distribution of exotic invasive species	Measure of human impact and ecosystem stress
Extent of exotic invasive species into edges	Measure of human impact and ecosystem stress

Human disturbances in herbaceous and shrub-scrub wetland communities were scored by answering the same questions considered for forested wetlands. The same scores for recovery time, hydrology effects, vegetation effects, and restoration difficulty were used. The scores were added together to give the following scores for human disturbances in herbaceous and shrub-scrub wetlands (Table 11-13). Scores were calibrated with collected and hypothetical data. Disturbances not on this list can be scored by considering their effects on hydrology and vegetation, persistence, and restoration difficulty. The disturbance score for each type of disturbance, used to rate wetland condition, was the total score for that disturbance divided by the score for no disturbance (70). This gave a value between 0 and 1.

Table 11-13
Human disturbance scores in herbaceous and shrub-scrub wetlands.

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
No disturbance, or minor natural disturbances only	20	20	20	10	70	1.00
Roads, powerlines, or trails in wetland						

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
Paved road or railroad	0	5	0	0	5	0.07
Powerline or other utility corridor (canopy broken)	5	5	5	0	15	0.21
Unpaved or logging road (canopy broken)	5	5	5	5	20	0.29
Unpaved or logging road (canopy unbroken)	5	10	10	10	35	0.50
Paved trail	5	10	10	5	30	0.43
Gravel trail	5	10	10	10	35	0.50
Unimproved trail	10	20	20	10	60	0.86
Hydrologic modifications in wetland						
Ditches or channelized streams that provide effective drainage, and levees present	0	-5	5	5	5	0.07
Ditches or channelized streams that provide effective drainage, but no levees	0	-5	10	5	10	0.14
Mosquito ditches	5	5	10	5	25	0.36
Unmaintained ditches or prior stream channelization are present in the floodplain, but they are no longer effective, and will in most instances not have the ability to drain water (i.e., ditches have become filled with debris and are not maintained)	5	20	20	5	50	0.71
Tile draining	5	5	10	10	30	0.43
Excavation of substrate or impoundment of water (dams, dikes, weirs, etc.)	0	5	5	10	20	0.29
Deposition of fill or spoil, other than levees	5	10	20	10	45	0.64
Stream or floodplain constricted, but not dammed (bridge, culvert, road bed, etc.)	0	10	20	5	35	0.50
Erosion (be sure to enter area being affected)	5	10	0	5	20	0.29
Hydrologic modifications outside wetland (within 500m)						
Ditches or channelized streams that provide effective drainage, and levees present	0	5	20	5	30	0.43
Ditches or channelized streams that provide effective drainage, but no levees	5	10	20	5	40	0.57
Mosquito ditches	5	15	20	5	45	0.64
Unmaintained ditches or prior stream channelization are present in the floodplain, but they are no longer effective, and will in most instances not have the ability to drain water (i.e., ditches have become filled with debris and are not maintained)	5	20	20	5	50	0.71
Tile draining	5	15	20	10	50	0.71
Excavation of substrate or impoundment of water (dams, dikes, weirs, etc.)	0	10	20	10	40	0.57
Deposition of fill or spoil, other than levees	5	20	20	10	55	0.79

Type of disturbance	Recovery time	Direct hydrology effects	Direct vegetation effects	Restoration difficulty	Total score	Disturbance value
Stream or floodplain constricted, but not dammed (bridge, culvert, road bed, etc.)	0	20	20	5	45	0.64
Vegetation alteration by humans in wetland						
Mowing	20	20	5	10	55	0.79
Used for livestock grazing	20	20	10	10	60	0.86
Burning	10	20	5	10	45	0.64
Pollution of wetland or stream						
Point source pollution (e.g., pipes carrying effluent)	10	10	10	10	40	0.57
Non-point source pollution	10	10	10	5	35	0.50
Stormwater piped in	10	5	10	10	35	0.50
Trash dumping	5	20	10	10	45	0.64
Hazardous materials	5	20	5	2	32	0.46
Diseases, pests, invasive exotic species, or excessive herbivory in wetland						
Plant diseases or pests causing significant mortality, multiple species	5	10	0	10	25	0.36
Plant diseases or pests causing significant mortality, one species	5	20	10	10	45	0.64
Plant diseases or pests causing stress	20	20	15	10	65	0.93
Invasive exotic species	5	20	0	5	30	0.43
Excessive herbivory (e.g., deer overbrowsing)	20	20	5	10	55	0.79
Near wetland buffer (0-60 ft)						
Forest (either natural or planted)	20	20	20	10	70	1.00
Shrub/scrub or saplings	20	20	20	10	70	1.00
Old field or post-clearcut seedlings	5	15	15	10	45	0.64
Pasture, lawn, or recent clearcut	5	10	10	10	35	0.50
Row crops or bare ground	5	7	10	5	27	0.39
Developed or mined	0	5	10	0	15	0.21
Far wetland buffer (60-300 ft)						
Forest (either natural or planted)	20	20	20	10	70	1.00
Shrub/scrub or saplings	20	20	20	10	70	1.00
Old field or post-clearcut seedlings	5	20	20	10	55	0.79
Pasture, lawn, or recent clearcut	5	15	15	10	45	0.64
Row crops or bare ground	5	10	10	5	30	0.43
Developed or mined	0	7	10	0	17	0.24

As with forested wetlands, the disturbance scores were multiplied by an affected area coefficient (Table 11-9), and these were combined to give an overall impact assessment. Again, each community was given a qualitative rating (listed in Table 11-1), which was used to calibrate the parameter weightings. Qualitative ratings were discussed by the field investigators, as were the data collected. Again, we examined the Spearman correlation between each parameter and the overall qualitative rating. Parameters with <25% correlation were dropped, except buffer conditions, which had insufficient sampling (Table 11-14). The parameter, extent of exotic invasive species into edges, was highly correlated (>90%) with the presence and amount of exotic invasives, and was therefore also dropped.

Table 11-14
Herbaceous and shrub-scrub wetland parameter retention after data analysis

Parameter	Predictive power	Keep or Drop?
Hydrologic alteration	65% correlated with overall rating	Keep*
Near wetland buffer	No variation; all sites had natural buffers	Keep*
Far wetland buffer	No variation; all sites had natural buffers	Keep*
Vegetative ground coverage	No variation; all sites had >75% coverage	Drop
Species richness	No correlation with overall rating	Drop; spp distribution depends on water depth, salinity, etc.
Evenness of species diversity	No correlation with overall rating	Drop; spp distribution depends on water depth, salinity, etc.
Types of other disturbance (if multiple, select lowest score)	65% correlated with overall rating	Keep
Area affected by other human disturbances	69% correlated with overall rating	Keep
Presence of exotic invasive species	74% correlated with overall rating	Keep
Distribution of exotic invasive species	47% correlated with overall rating	Keep*
Extent of exotic invasive species into edges	75% correlated with overall rating, but highly correlated (>90%) with presence of exotic invasive spp	Drop

* combined into composite disturbance assessment

Species composition varied too much by wetland, independently of human disturbance, to predict wetland condition. We therefore retained only measures of disturbance. The total disturbance score was derived by adding area-weighted and effect-weighted disturbance scores (Tables 11-13 and 11-9); subtracting this sum from 1.0; if negative, setting to 0.0; and multiplying by 100. The data sheets were amended accordingly (see Appendix E). Appendix F lists the distribution of overall community scores and categories after analyzing data collected during summer-fall 2001. The final scores and categories for herbaceous and shrub-scrub wetland communities are listed as follows:

Total score	Community category
>75	Excellent
50 - 74	Good
1- 49	Fair
# 0	Poor

High-gradient streams. High-gradient streams were defined as streams with a >3% gradient. Data were collected for just 7 high-gradient streams at 5 sites (see Appendix C). The original data sheets are in Appendix D. Because the sample size was so small, we were heavily dependent on hypothetical situations to define overall stream categories. We retained all the original parameters and scores, trusting that the EPA and DNR-SCA methodologies were sufficient. We used collected data to differentiate between the "Excellent" and "Good" categories. To define the "Fair" and "Poor" categories, we calculated the scores when all EPA stream parameters were set to suboptimal, marginal, and poor, and used the midpoints between these. Exposed pipes, pipe outfalls, fish barriers, streamside construction, and trash dumping were not used to define the categories, but if present, would decrease the stream rating. The final scores and categories for high-gradient streams are as follows:

Total score	Community category
268 - 300	Excellent
227 - 267	Good
174 - 226	Fair
<174	Poor

Low-gradient streams. Low-gradient streams were defined as streams with a gradient #3%. Data were collected for 18 low-gradient streams at 12 sites (see Appendix C). The original data sheets are in Appendix D. We retained all the original parameters and weights, trusting that the EPA and DNR-SCA methodologies were sufficient. We used collected data to differentiate between the "Excellent", "Good", and "Fair" categories. To discriminate between the "Fair" and "Poor" categories, we calculated the scores when all EPA stream parameters were set to marginal and poor, and used the midpoint between these. The final scores and categories for low-gradient streams are:

Total score	Community category
281 - 300	Excellent
250 - 280	Good
174 - 249	Fair
<174	Poor

Property field evaluation

The overall Tier 4 field rating for a property was the area-weighted average of its terrestrial community ratings, after conversion to a number between -1 and 4, plus the length-weighted average of its stream ratings, after conversion to a number between -0.5 and 1.0:

COMMUNITY RATING	COMMUNITY SCORE
Excellent	4
Good	2
Fair	1
Poor	0
Very Poor	-1

STREAM RATING	STREAM SCORE
Excellent	1.0
Good	0.5
Fair	0.0
Poor	-0.5

Overall property score =
mean community score (by area) + mean stream score (by length)

OVERALL PROPERTY SCORE	OVERALL RATING
$3.00	Excellent
1.50 - 2.99	Good
0.50 - 1.49	Fair
0.00 - 0.49	Poor
<0.00	Very Poor

Excellent communities were given special emphasis, since they are rare, and cannot be identified using GIS data.

Appendices G - K contain sample property evaluations, with statistics sampled from the Tier 2 GIS evaluation, a natural community map (after field correction), a Tier 4 field evaluation of the natural communities, an overall site rating, and a short narrative. As mentioned before, this process also creates an ecological map, identifies potential easement and management requirements, and identifies restoration needs on the property.

Future considerations

This field survey methodology can be revised as needed, and is meant more as a guideline than a mandate. For example, the Smithsonian Environmental Research Center (SERC), Maryland DNR, and the Delaware Department of Natural Resources and Environmental Control (DNREC) are working on a hydrogeomorphic (HGM) wetland assessment, which, once completed, could replace the wetland assessment described here.

Site survey for development pressure

A site survey methodology was also created to estimate development pressure (Table 11-15). For this, the surveyors should traverse all roads surrounding the property, as well as a representative sample near the property. For efficiency, this survey should be done during the site visit for ecological condition. This methodology was never used, and is only presented as an example. Development pressure is also addressed in the Tier 3 review (see Fig. 11-1).

Table 11-15
Development pressure field parameters and weightings.
Note: This methodology was never used, and is only included as an example.

Parameter	Parameter value	Risk score
"For sale" sign at site	yes	20
	no	0
Change of zoning sign at site	yes	10
	no	0
New development nearby (within about a mile)	yes, construction in progress	10
	yes, completed in past few years; but no current construction nearby	5
	no	0
Water & sewer available (look for water mains, fire hydrants, etc.)	yes	10
	no	0
	unknown	5
Site developable (i.e., not entirely wetland or steep slopes)	entirely developable	20
	mostly (51-99%) developable	10
	partly (1-50%) developable	5
	not developable at all	0
Site accessible by road	yes, paved	10
	yes, unpaved only	5
	no	0

Chapter 12
RESTORATION AND MANAGEMENT

Restoration of land cover gaps

Although composed primarily of natural ecosystems, the green infrastructure network contains a variety of environmental conditions, including some areas that are heavily degraded. Land cover "gaps" (Fig. 12-1), which are agricultural, mined, cleared, or built-on lands within hubs, corridors, and nodes (see Table 12-1), could be targeted for restoration: converting to wetlands or forests with composition, functions and processes resembling native natural conditions. These human-generated gaps are logical starting points when attempting to identify opportunities for landscape restoration actions. Non-vegetated gaps in the green infrastructure offer a chance to extend or improve the network while at the same time providing water quality or specific habitat improvements. Figure 12-1 depicts Mattawoman Creek, one of the most important anadromous fish spawning streams in the Chesapeake Bay, and its floodplain. On the left are two recent clearings for development that would be classified as barren in NLCD. On the right are a clearcut (would also be classified as barren) and an agricultural field.

Fig. 12-1
Land cover gaps in a green infrastructure hub

Table 12-1
Land cover composition of green Infrastructure (GI) gaps, according to the U.S. Federal Region III Land Cover Data Set (NLCD), version 3.*

NLCD class	Acres in GI gaps	% of GI gaps
Low intensity developed	21,124	5.22
High intensity residential	664	0.16
High intensity commercial or industrial	5,126	1.27
Quarries, strip mines, and gravel pits	4,505	1.11
Transitional barren	16,161	3.99
Hay/pasture	252,684	62.41
Row crops	102,221	25.25
Urban grass	2,386	0.59

*This data set discriminates poorly between hay/pasture and row crops, so we combined the two classes for analysis purposes

Some other forms of restoration are discussed later in this chapter. For example, wetlands impacted by dredging, draining, filling, and other human activities (see Fig. 12-2) could also be targeted for restoration. Structures such as underpasses or bridges can facilitate wildlife movement where roadways and railways cross corridors and hubs. Similarly, stream blockages can be identified for fish ladders, bypasses, or other mitigating structures. Field investigations will reveal additional gaps caused by silvicultural practices, exotic species, etc.

Human-induced gaps should not be confused with gaps created in tree canopies or other vegetation by natural disturbances like storms, fire, or tree falls. Natural gaps are a vital part of healthy ecosystems, as they maintain a suite of species able to respond quickly to disturbances. Natural gaps, unlike human-created gaps, should rarely be targeted for restoration.

Land cover gaps were identified within the county-modified green infrastructure network. Those gaps within Maryland were prioritized for restoration efforts, according to their relative ecological benefits and reclamation ease. The relative benefits of restoring a particular gap were calculated at four different scales: “8-digit” watershed (about 75 mi^2); “12-digit” watershed (delineated for all third-order streams–about 11 mi^2); hub or corridor; and individual gap or site. Table 12-2 lists the potential ecological benefit parameters, analysis scales, and their relative weightings.

Fig. 12-2
Identification of potential riverine wetland restoration sites (gaps with hydric soils and adjacent to streams) and ditch removal in the Green infrastructure.

Table 12-2
Relative weighting of different restoration parameters. Gaps were scored differently if the objective was restoration as forest or as wetland*.

Parameter	Analysis Scale	Importance	Weight as forest	Weight as wetland
8-digit watershed rank (based on Clean Water Action Plan categories, and emphasizing restoration of degraded watersheds, as well as recognizing those that are ecologically significant)	8-digit watershed	High	30	30
12-digit watershed rare fish and mussel rank	12-digit watershed	High	CP=20, other=17	CP=20, other=17
12-digit watershed brook trout presence or connections (N/A for Coastal Plain)	12-digit watershed	Medium	CP=0, other=9	CP=0, other=9

Parameter	Analysis Scale	Importance	Weight as forest	Weight as wetland
12-digit watershed impervious surface	12-digit watershed	High	CP=20, other=17	CP=20, other=17
12-digit watershed % natural cover	12-digit watershed	High	CP=20, other=17	CP=20, other=17
Importance of landscape element	Hub or corridor	High	24	24
Ecological ranking of hub or corridor	Hub or corridor	Medium	48	48
Does the gap break a corridor?	Hub or corridor	High	24	24
Relative gain to landscape element	Hub or corridor	High	32	32
Is the gap in the interior?	Hub or corridor	High	24	24
Area of gap	Individual gap	High	16	13
Gain in interior forest, divided by area of gap	Individual gap	High/ Medium	16	8
Percent of gap area in riparian zone. If this is 0, rank by mean proximity to streams, but rank all of these below those gaps with >0 ac in riparian zones.	Individual gap	High	16	16
Stream order	Individual gap	Very Low, because of skewed data distribution	1	1
Proximity to natural heritage elements (rare or sensitive species, communities, or ecosystems)	Individual gap	High	16	12
Percent of gap area with highly erodible soil	Individual gap	High (lower b/c of data resolution and use of topo param)	12	0
Topographic relief (mean slope). This might be redundant with highly erodible soil, except the data are more extensive, and spatially more accurate.	Individual gap	Low	4	0
Percent of gap area with hydric soils (using SSURGO where available, NSG elsewhere)	Individual gap	None/High	0	24 (note - if 0, gap is unsuitable for wetland creation)
Mean adjacency to intact unmodified wetlands.	Individual gap	Medium	9	16

*Since brook trout do not occur in the Coastal Plain (CP), that physiographic region's weightings were different from the others.

The parameters in Table 12-2 are described in more detail below.

8-digit watershed scale parameter

Watershed rank. Based on watershed condition, the Clean Water Action Plan (CWAP) Technical Workgroup (1998) classified Maryland 8-digit watersheds into the following categories:

- Category 1 - Watersheds not meeting clean water and other natural resource goals and needing restoration
- Category 2 - Watersheds currently meeting goals that need preventive actions to sustain water quality and aquatic resources
- Category 3 - Watersheds containing pristine or unique resources that need an extra level of protection
- Category 4 - Insufficient data

There are 134 of these State-defined "8-digit" watersheds in Maryland, each with an average area of about 75 square miles. Category 1 Priority Watersheds were defined as watersheds that failed to meet at least half of their benchmarks. Watersheds with four or more indicators meeting Category 3 benchmarks were listed as "Selected Category 3 Watersheds." All watersheds had sufficient data to allocate them to Category 1, 2 or 3; thus, there were no Category 4 watersheds. Parameter details are described in Clean Water Action Plan Technical Workgroup (1998).

Because the selection criteria used for Category 1 and Category 3 watersheds were not the same and because land use and related factors may vary considerably within such a large watershed, many of the state's watersheds were identified as both Category 1 and 3 watersheds. These watersheds showed signs of stress or degradation but still contained high quality or sensitive natural resources. For example, a watershed may have contained undisturbed headwaters but be significantly developed at its mouth. Unless watersheds were assessed at a scale where the land use was relatively homogeneous, Category 1 and Category 3 classifications were not mutually exclusive (Clean Water Action Plan Technical Workgroup, 1998).

In the Green Infrastructure Assessment, gaps (all; not just those adjacent to streams or in floodplains) were given the following score according to their 8-digit watershed's CWAP rating:

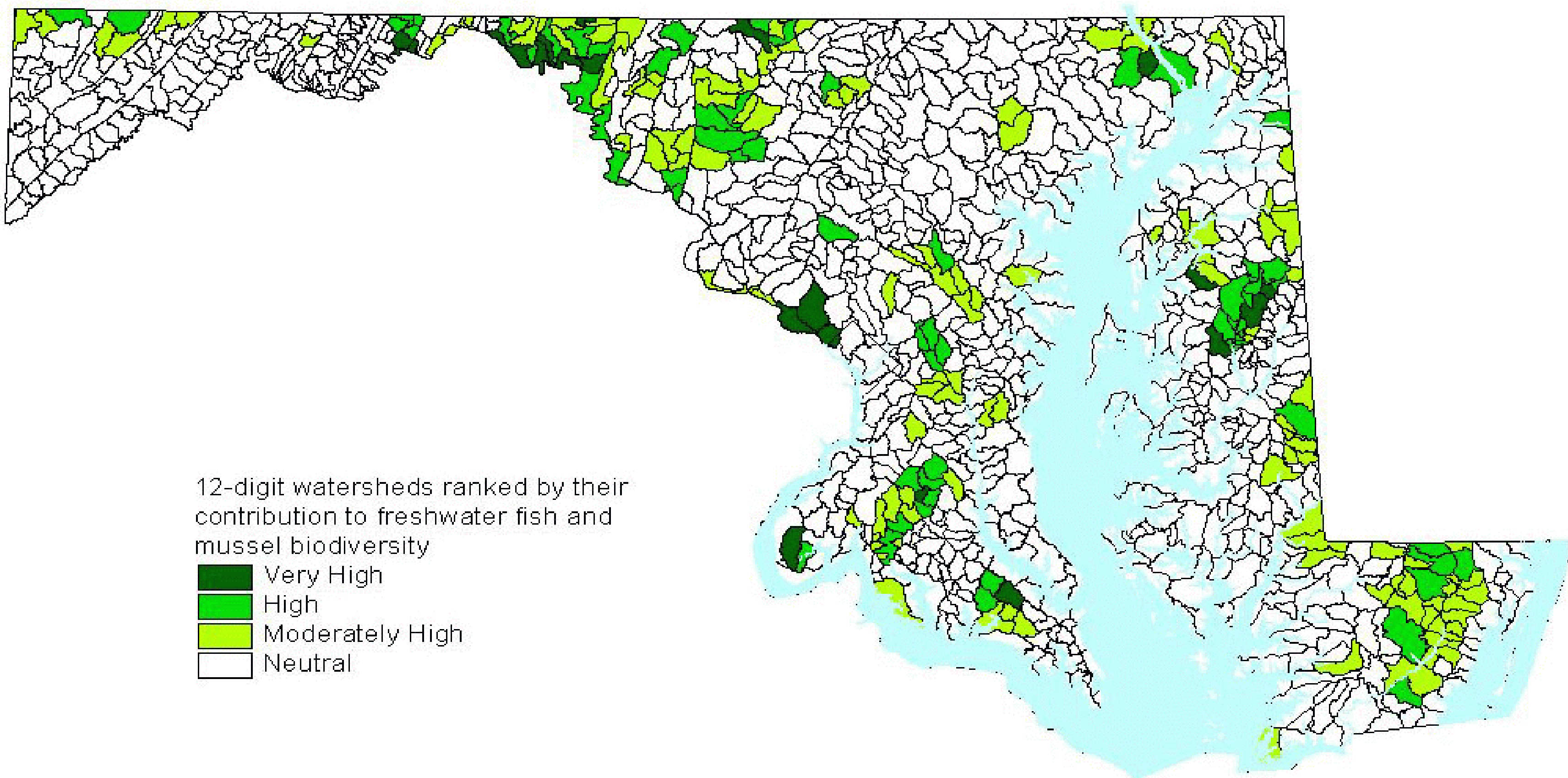
8-digit watershed CWAP categories	Score
Priority Category 1 and Select Category 3	90
Priority Category 1 and Category 3	8
Priority Category 1 only	7
Category 1 and Select Category 3	6
Category 1 and Category 3	5
Category 1 only	4
Select Category 3 only	3
Category 3 only	2
Category 2 only	1

<u>12-digit watershed scale parameters</u>

Maryland 12-digit watersheds were delineated by the state for all third order streams, as defined by Strahler and visible on USGS 7.5 minute quadrangle map sheets. There are about 1100 of these watersheds in Maryland, with a mean area of about 11 square miles (about an order of magnitude smaller than 8-digit watersheds).

Rare fish and mussel rank. This data set (Fig.12-3) categorizes Maryland 12-digit watersheds into four groups according to relatively recent observations (post-1970) of rare freshwater fish and mussels. Presence of these species was weighted by their global and state rarity, and these scores were summed within each watershed. Each species was counted only once per watershed in which it was present; i.e., multiple observations within a watershed did not increase the score. After examining score histograms, watersheds were prioritized as "Very High", "High", "Moderately High", and "Neutral". The last group, "Neutral", does not give a watershed a low priority for conservation or restoration. Rather, it means decisions should be made using other criteria. Lack of rare species observations within a watershed may have resulted from insufficient sampling, not necessarily a true absence. On the other hand, targeting watersheds ranked as "Very High", "High", or "Moderately High" may, with some certainty, benefit biodiversity within Maryland. Watersheds upstream of rare freshwater fish and mussel observations, or connecting disjunct observations of the same species, were also considered important. Generally, their scores were slightly lower than the watershed(s) containing the observation(s). Other aquatic or semi-aquatic taxa like crayfish, amphibians, and reptiles were omitted from this data set, because they are generally less sensitive to stream quality and are able to move overland. More details are available in the metadata. Gaps within these watersheds were assigned the following numeric scores: 4 = "Very High", 3 = "High", 2 = "Moderately High", and 1 = "Neutral".

Fig. 12-3
Third-order watersheds with rare aquatic species (see text for details).



<u>*Brook trout presence or connections*</u>. Brook trout (*Salvelinus fontinalis*) are a native indicator of pristine, or nearly pristine, cold-water streams. They are sensitive to pollution, sediment, and temperature: brook trout are not found in watersheds with >2% impervious surface, or streams with temperatures >22C (Stranko, 1999). They are also under pressure from introduced brown and rainbow trout (Nyman, 1970; Fausch and White, 1981; Larson and Moore, 1985; Nagel, 1991; DeWald and Wilzbach, 1992; Clark and Rose,1997; Early, 1999; Stranko, 1999; Stinefelt,1999). As a result of deforestation and introduced competitors, brook trout in Maryland number just 10% of their historic levels.

12-digit watersheds (see Fig. 12-4) containing brook trout sites were given a score of 2. Watersheds upstream of, or connecting brook trout sites, were given a score of 1. Gaps within these watersheds were given the watershed score.

<u>*Impervious surface.*</u> Impervious surface, which is increased by urban development, has been shown to increase stormwater runoff and peak stream discharges, decrease soil moisture and groundwater recharge, facilitate runoff transport of pollutants, increase erosion and sedimentation, impair aquatic habitat, and cause other negative effects. Blaha et al (date unknown) found that the amount of impervious surface in Montgomery County watersheds was the best predictor of stream quality.

Impervious surface data were classified by Morgan et al at Towson University (see http://chesapeake.towson.edu/impervious/) from March 2001, Landsat 7, 30-meter pixel resolution data for Maryland west of the Chesapeake Bay. October 1999 was used for Maryland east of the Bay due to cloud cover in the 2001 imagery. Percent impervious surface was then calculated within 12-digit watersheds, and classified (see Fig. 12-5) and scored as follows:

Impervious surface (%)	Description	Score
<10	protected (although sensitive streams may be stressed)	2
10-25	impacted - mitigation may be successful	4
>25	degraded - mitigation may be difficult	1

Gaps within these watersheds were given the watershed score.

Fig. 12-4
Third-order watersheds with brook trout, one of the restoration targeting parameters.

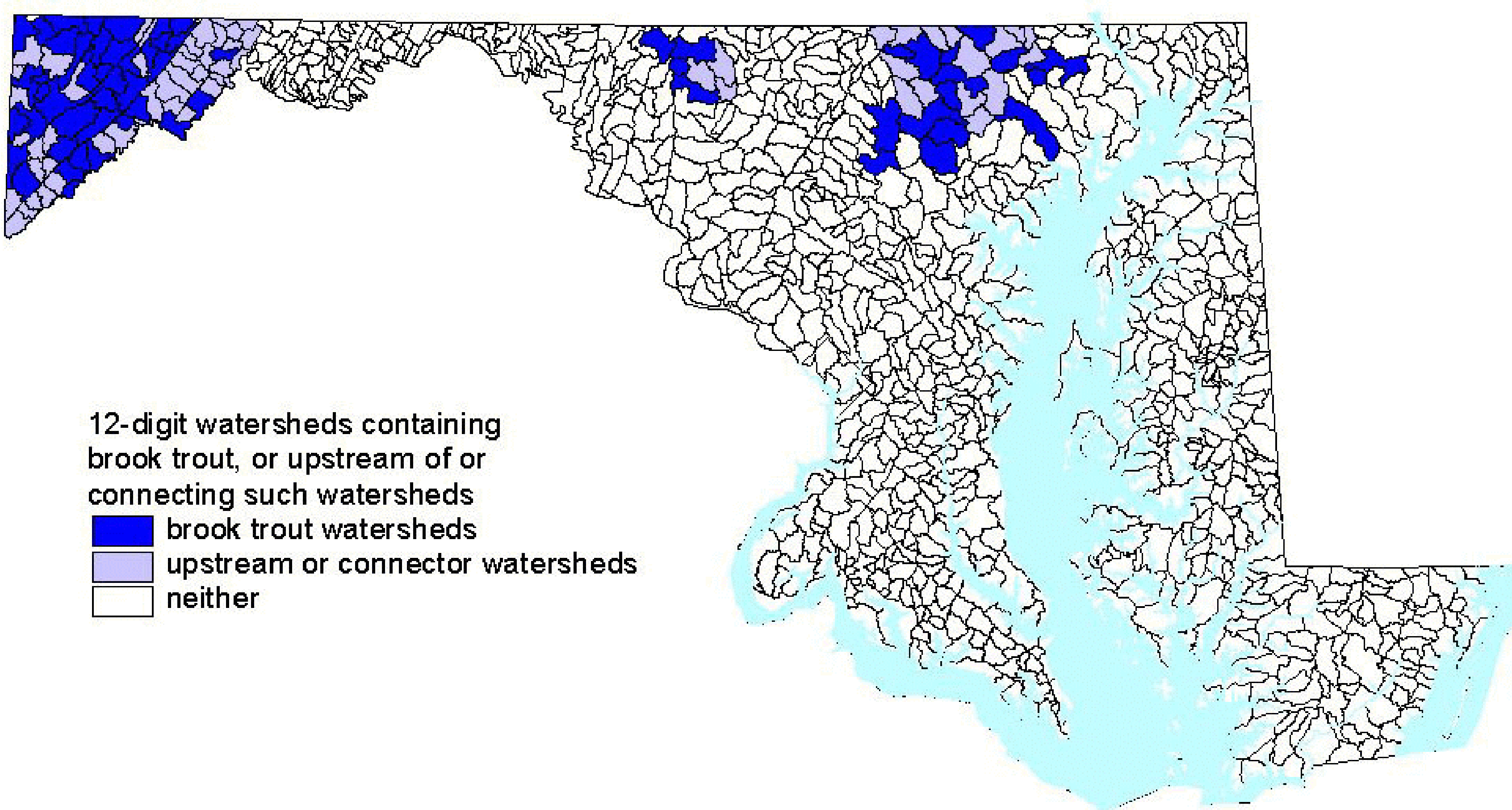
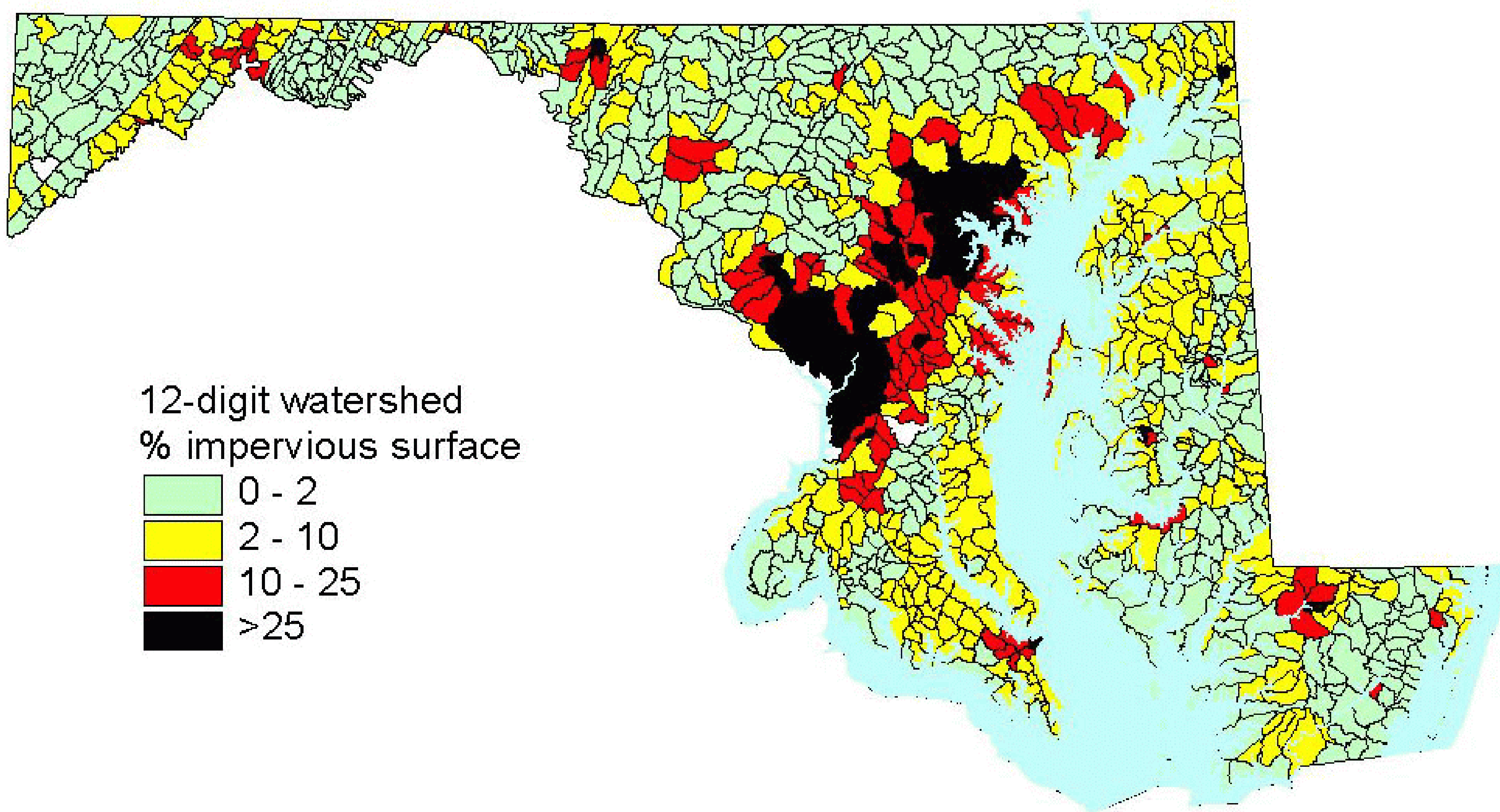


Fig. 12-5
Impervious surface in third-order watersheds.



Land cover. Agricultural runoff has been shown to increase stream nutrient loadings, causing eutrophication problems. Excess nutrients are carried downstream, eventually reaching the impaired Chesapeake Bay. Similarly, development increases the amount of impervious surface, as discussed above. Forested watersheds recharge ground water supplies, stabilize soils, reduce erosion, filter sediments, and moderate flooding. Stream-side trees keep stream water cool, stabilize stream banks, support the aquatic food web with inputs of detritus, and provide coarse woody debris for in-stream habitat. Blaha et al (date unknown) found that benthic invertebrates in Montgomery County first order streams were negatively affected by localized disturbances to surface and subsurface hydrology (from increased imperviousness and decreased wetlands), inputs of sediment (from cropland), and excess nutrients (from cropland and septic systems). Benthic invertebrates in larger (second- and third-order) streams were more affected by in-stream processes and channel hydraulics, which were indirectly affected by imperviousness (Blaha et al, date unknown).

Using NLCD, we calculated:

- forest or wetland (i.e., natural) cover as a percentage of watershed land cover;
- agricultural land as a percentage of watershed land cover;
- developed land as a percentage of watershed land cover; and
- the proportion of stream banks in the watershed with forest or wetland cover.

Land cover metrics were tested for autocorrelation and their correlation with water quality and stream habitat quality data from the Maryland Biological Stream Survey (MBSS). Land cover composition and the extent of unbuffered streams were computed for MBSS catchments (1st-3rd order stream drainages) delineated for field sampling locations. These were then compared to field measurements of nitrate concentrations (NO_3) and a composite metric of stream habitat quality (a composite rank between 1 and 4, with 4 = "good" and 1 = "very poor"; see Roth et al, 1997), using Statistix for Windows.

NO_3 was negatively correlated with percent natural cover in the catchment and percent forest or wetland along stream banks, and positively correlated with percent agriculture in the catchment. These correlations were not strong. Percent natural cover in the catchment, percent forest or wetland along stream banks, and percent agriculture in the catchment were all autocorrelated, implying that only one of these metrics should be used. Percent natural cover in the catchment had the strongest correlation with NO_3. None of the land cover metrics was correlated with stream habitat quality, but this was a categorical rather than a continuous variable and thus may have had insufficient resolution.

We then ran another test for stream habitat quality, the nonparametric Mann-Whitney test. We compared 1995 MBSS stream habitat quality (assigning 1 = "good" or "fair"; and 0 = "poor" or "very poor") with percent natural cover (forest, wetlands) in the catchment (open water discounted) and percent forest or wetland along the stream. The Mann-Whitney rank sum test gave no evidence that the median percent natural cover, percent agriculture, or percent urban differed between stream habitat quality of "good" or "fair", vs. "poor" or "very poor". However, percent natural banks differed ($P = 0.0207$). Aggregating stream quality differently, using 1 = "good"; and 0 = "fair", "poor" or "very poor", none of the metrics differed. Again, the habitat quality metric may have had insufficient resolution.

Next, catchments with low NO_3 (<0.3 mg/l) and stream habitat quality of "good" were defined as optimal. Other catchments were defined as sub-optimal. A nitrate concentration < 0.3 mg/l was used to help identify MBSS reference sites (Roth et al, 1997). 19 of 251 cases met these criteria. Although the sample size was small, all land cover variables were significantly different between optimal and sub-optimal watersheds. Percent natural banks, percent natural cover, and percent agriculture land had $P <= .0001$; percent urban had $P = .0206$. We then ran a logistic regression, but none of the variables was a strong predictor, and no satisfactory model could be built. Percent natural cover was the most significant variable.

Land cover metrics were also tested for autocorrelation and their correlation with observed rare or sensitive fish presence. Rather than using MBSS catchments, we looked at all 12-digit watersheds in Maryland. Percent natural cover, percent agricultural cover, and percent of shorelines in natural cover were all somewhat autocorrelated, although not strongly. Some watersheds, as in central Maryland, were more impacted by urban development than agriculture. Others, as on the Eastern Shore, were more impacted by agriculture. Presence of rare fish or mussels was not strongly correlated with watershed land cover. However, brook trout appeared sensitive to watershed land cover, especially urban cover. Similarly, the Mann-Whitney rank sum test gave no evidence that the median percent with natural banks, percent in natural cover, percent in agriculture, or percent urban use differed between watersheds containing rare fish or mussel observations and watersheds without them. However, all these metrics did differ ($P < .001$) between watersheds containing brook trout and watersheds without brook trout.

Summary of 12-digit watershed parameters. Four parameters were retained. As a measure of biodiversity, the rare fish and mussel score was retained. Similarly, brook trout are very sensitive to watershed condition, and an indicator species for healthy coldwater streams. Thus, this score was retained (although not applicable within the Coastal Plain). Impervious surface classes were retained, because the restoration response was a step function (although presumably smoother in reality). Of the land cover metrics, only percent natural cover in the watershed was retained. This appeared the most significant and inclusive, and adding other land cover metrics appeared redundant. Gaps were given the scores of their watersheds for all of these parameters.

Landscape parameters

Landscape importance (type of green infrastructure element). The position of a gap in the green infrastructure affected its landscape importance (Table 12-4). Percolation models by Tilman et al (1997) showed that a habitat must be more pristine to function as a viable corridor than to serve as a reserve. Tilman et al (1997) explained, "this occurs because it is easier to maintain a species within a highly fragmented habitat than it is to facilitate migration through the same corridor." Gaps in external hub buffers were given greater importance than gaps in corridor nodes, because nodes tended to be intact, and hub buffers appeared especially important where hubs were narrow, or their streams, wetlands, or internal core linkages close to agriculture or development.

Table 12-4
Scoring of gaps by landscape feature

Landscape feature	Score
Corridors linking top tier hubs	12
Top tier hubs	10
Corridors linking lower tier hubs	8
Second tier hubs	7
Third tier hubs	6
External buffers, top tier hubs	5
External buffers, second tier hubs	4
External buffers, third tier hubs	3
Nodes in corridors linking top tier hubs	2
Nodes in corridors linking lower tier hubs	1

Ecological ranking of hub or corridor. This parameter, the composite ecological rank of the gap's hub or corridor (see Chapter 5), is partially redundant with landscape importance. Landscape importance alone had insufficient resolution, though, especially in discriminating between corridors.

Corridor breaks. Top priority gaps should be those that break a corridor, if these gaps are restorable. We gave these a score of 1, and others a score of 0.

Relative gain to landscape element. The more intact a hub or corridor, the better it should function. For each gap, we divided its area by the total gap area within its hub or corridor. Gaps that comprised a large percentage of the total gap area within a hub or corridor were given a higher priority than those comprising a smaller percentage. This could be true either for a large gap in a fragmented hub or corridor, or a small gap in a mostly intact hub or corridor.

Interior or exterior position of gap. Gaps in the interior of hubs and corridors were given a higher priority than those on the exterior. Gaps abutting the edge of hubs or corridors were given a value of 0. Gaps not meeting this criterion were given a value of 1. However, gaps intersecting least-cost paths in corridors were also considered interior, and given a value of 1.

Local scale parameters

Gain in interior forest. Restoring gaps in the center of a forest would create more contiguous interior forest (habitat for many neotropical migrant birds and other species) than reforesting an area near other land cover. For each gap, we calculated the total gain in interior forest if it was reforested, but other gaps unchanged. In other words, each gap was considered separately. We normalized this metric by gap area to give a relative gain.

Riparian length and area. If the gap was adjacent to streams, or in a floodplain, then restoring it would have both habitat and water quality benefits. Riparian zones were defined as 100 year floodplains (from FEMA), wetlands within 200 ft of stream channels, or area 100 feet from the stream bank. (Floodplains were not digitized for all counties or streams.) We calculated the area of each gap within this defined riparian zone.

Proximity to streams. We used distance to nearest stream for gaps beyond the riparian zone.

Stream order. According to stream continuum theory, the lower the stream order, the more important natural riparian cover is. Because most streams are first order, we gave this parameter a very low weighting. A second order stream might have a rank 10,000 below a first order stream, but we didn't want this to be such an overwhelming factor in restoration decisions.

Proximity to heritage elements. We gave gaps that fell mostly inside a heritage polygon (NHA, WSSC, ESA, HPA, or Delmarva Fox Squirrel habitat), or within 750 feet (the positional uncertainty) of a BCD point, a priority of 5 (high). Gaps within 550 ft of a heritage polygon, or between 750 feet and 1/4 mile for BCD points, were given a priority of 2 (medium). Gaps not within a heritage element, but at least partially within an SSPRA, were also given a priority of 2 (medium).

Area of highly erodible soil. Gaps with highly erodible soils are more prone to erosion, and would benefit from perennial vegetative cover, especially woody cover. Highly erodible soils were identified from the Maryland Natural Soils Groups, and tabulated by gap.

Topographic relief *(sum of slopes)*. Topographic relief was used to supplement the previous parameter, to rank gaps without any highly erodible soil data. Also, the Natural Soils Group data set was spatially coarse. We summed the slope percentages within each gap.

Area of hydric soils. Hydric soils are necessary to restore wetlands. Hydric soils were identified from the Soil Survey Geographic (SSURGO) database where available (at the time, Baltimore City, Carroll, Dorchester, Montgomery, Queen Anne's, Washington, and Worcester counties), and from Natural Soils Groups (NSG) elsewhere. According to Maryland Department of State Planning (1973) and comparing these groupings with soil series listed in USDA-NRCS (1995a), hydric soils are classified in the Maryland natural soils groups as F1, F2, F3, G2, and G3. E2 and G1 soils are not listed as NRCS hydric soils. The SSURGO coverages appear to confirm this. Correlation between the Maryland natural soils group data layer and National Wetlands Inventory (NWI) non-tidal wetlands is poor. While many wetlands fall within F2, F3, G2, and G3 polygons, about a quarter fall within B1 polygons (an upland soil). This demonstrates the need for field verification of GIS results. We tabulated the acres of hydric soils within each gap.

Adjacency to unmodified wetlands. As discussed in the background chapter, wetland buffers provide important functions such as sedimentation control, reptile nesting, and protection from invasive species. We calculated the distance of each cell to the nearest unmodified wetlands, and classified and scored this as follows, based on cell size and functions described by Brown et al (1990):

Distance to wetland (ft)	Buffer importance
0-166	10
167-293	4
294-421	2
422-550	1
>550	0

We recorded the mean buffer value within each gap.

<u>Combination of parameters</u>

We ranked green infrastructure gaps within their physiographic regions for each parameter, and converted these to percentiles. A composite ecological benefit rank was derived by summing these percentile rankings multiplied by their parameter importance weights. We examined model outputs from different parameter and weight combinations before choosing those weights listed in Table 12-2.

Two ranks were computed for each gap: one for restoration as forest, and one for restoration as wetland. If the gap scored highly for both, it might be restored as forested wetland. A gap had to contain hydric soils to be considered for wetland restoration. The gap's score for individual parameters could also help guide the type of forest or wetland to create. For example, an agricultural field surrounded by forest, and ranking high for potential gain in interior forest, but containing hydric soils, could be reclaimed as a forested wetland. We summed the wetland and forest ecological benefit scores to rank gaps for their relative ecological benefit as forested wetlands. A floodplain gap could be reclaimed as floodplain forest. Gaps containing streams were ranked for their suitability for riparian forest buffer restoration.

Field investigation will best determine function and community types. Restoration should be done with native plants appropriate for the area and site conditions. They may include species or communities of concern, like Atlantic white cedar, if appropriate for the site.

<u>Gap restoration ease</u>

We also attempted to estimate the ease of restoring each gap, relative to other gaps in its physiographic region. We did not attempt to calculate a dollar figure for each project, since this depends on specific site conditions and effort required, and can vary widely. Rather, this cost comparison is a crude estimate of restoration ease considering the area involved, ownership, ease of access, and land cover–e.g., compared to fields, quarries may require topsoil import and significant re-contouring; and developed areas can be virtually impossible to reclaim.

A composite restoration ease rank for each gap was computed by combining the parameters listed in Table 12-5. After examining model output for different weightings, we used a linear stretch for two parameters, ease of restoration by land cover type, and existing public ownership or existing easement on development. Also, the importance of gap area was increased to "High" from "Medium". We multiplied the gap's parameter rankings by the parameter importance weightings to create a composite ranking within each physiographic region. Gaps outside the state were omitted for lack of data.

Table 12-5
Restoration ease parameters and their relative weights.

Parameter	Importance	Weight
Ease of restoration by land cover type	High	4
Area of gap	High	4
Existing public ownership or existing easement on development.	High	4
Proximity to public lands	Low	1
Proximity to roads	Low	1

Example of gap restoration

In Figure 12-6, a green infrastructure gap is highlighted in Chino Farms, on Maryland's Eastern Shore. The landowner was interested in ecological restoration, but not in reforesting the entire gap. Fig. 12-7 shows how connectivity was restored on site while keeping much of the gap in agricultural use. Interior forest was increased by also reforesting forest-field edge concavities. Several species of native trees were planted (Fig. 12-8).

Fig.12-6
Green infrastructure gap in Chino Farms, with ecological cell scores for context.

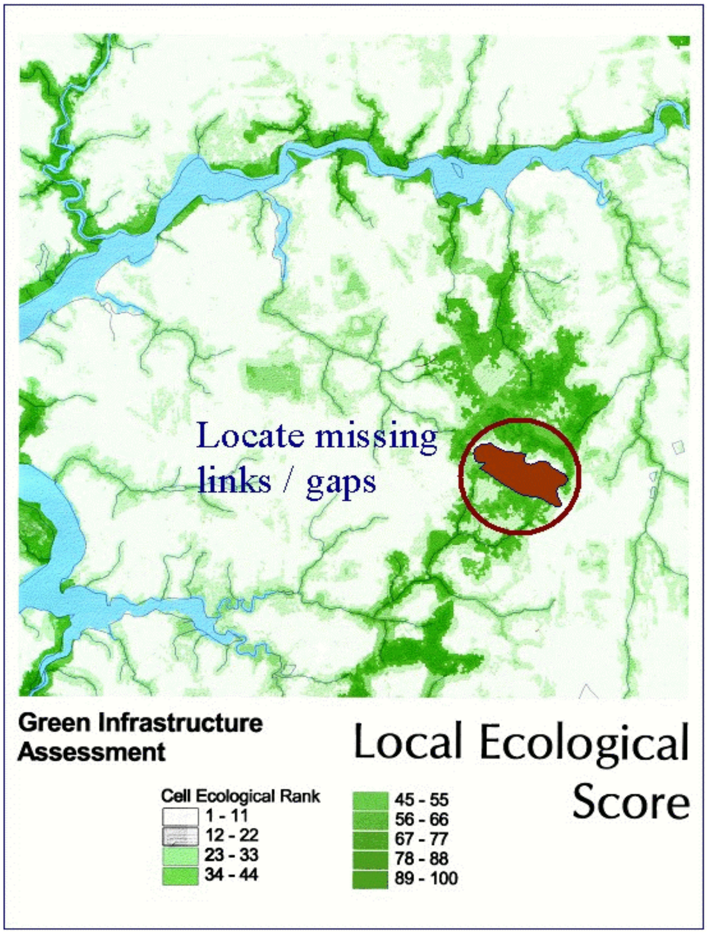


Fig. 12-7
Reforestation plan within green infrastructure gap, showing restoration of connectivity.

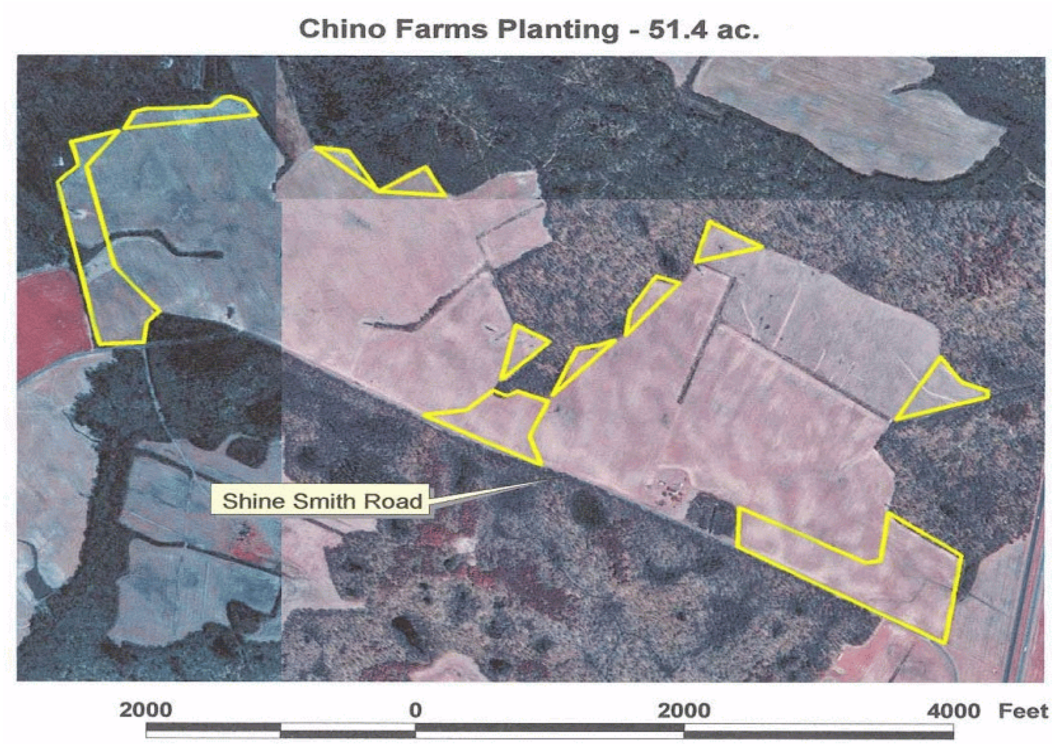


Fig. 12-8
Photo of restoration in Chino Farms gap, the winter after trees were planted.

Wetland restoration

Wetland restoration or creation can utilize green infrastructure targeting where conditions are appropriate (e.g., hydric soils). Wetlands that have been lost entirely (e.g., drained and converted to agriculture) would have to be recreated by restoring the hydrology and possibly contouring and planting. Wetland restoration or creation can be prioritized using gaps containing hydric soils, and the wetland ecological benefit and restoration ease ranks of the gap.

Wetlands that still exist, but have been impacted by draining, dredging, filling, fragmentation, or other impairment, might be restored with less effort. Tiner (2000) identified wetland restoration opportunities in the Nanticoke and Coastal Bays watersheds; this work could be expanded to the rest of the state, and synchronized with green infrastructure and watershed targeting.

The NWI Special Modifier codes are listed below. Many wetlands or deepwater habitats are man-made, and natural ones have been modified to some degree by the activities of man or beaver. Since the nature of these modifications often greatly influences the character of such habitats, special modifying terms have been included to emphasize their importance:

- b = Beaver - Created or modified by the action of a beaver.
- d = Partly Drained - The water level has been artificially lowered, but the area is still classified as wetland because soil moisture is sufficient to produce hydrophytes.
- f = Farmed - The soil surface has been mechanically or physically altered for production of crops, but hydrophytes will become reestablished if farming is discontinued.
- h = Diked/Impounded - Created or modified by a man-made barrier or dam which obstructs the inflow or outflow of water.
- r = Artificial Substrate - Substrates classified as Rock Bottom (RB), Unconsolidated Bottom (UB), Rocky Shore (RS) and Unconsolidated Shore (US) that were emplaced by man using natural or synthetic materials. Jetties and breakwaters are examples of Artificial Rocky Shores.
- s = Spoil - Wetland or deepwater habitat where the substrate is a result of the deposition of spoil materials.
- x = Excavated - Lies within a basin or channel excavated by man. This includes all landcut canals, ditches, dugouts, stock ponds, and farm ponds.

We wanted to concentrate on formerly natural wetlands that had been modified by humans, rather than wetlands that were created by humans. We selected human-modified NWI wetlands within GI, using special modifier “d” (partially drained or ditched). Modifier “b” (beaver) represented natural disturbances. Wetlands with modifier “f” (farmed) would appear as agricultural land cover, and appear as gaps if inside the GI. Wetlands with modifier “h”, “r”, “s”, and “x” were probably created by humans, and excluded from this analysis. None of the parameters were highly correlated. We ranked the wetlands within their physiographic region for each parameter, and multiplied these by the parameter importance weightings to derive a composite ranking.

NWI identified 44,000 ac of wetlands in Maryland as ditched, including about 24,000 ac in the GI. NWI missed many ditched wetlands, such as some of the tidal marsh along Chincoteague Bay and

Fishing Bay. A better wetland inventory was created by Tiner et al (2000) in the Nanticoke and Coastal Bays watersheds, and could be expanded to the rest of the state.

We then prioritized ditched GI wetlands using the parameters in Table 12-6.

Table 12-6
Ecological ranking parameters used to rank ditched wetlands in the GI.

Parameter	Analysis Scale	Weight
8-digit watershed rank	8-digit watershed	15
12-digit watershed rare fish and mussel rank	12-digit watershed	10
12-digit watershed impervious surface	12-digit watershed	10
12-digit watershed % natural cover	12-digit watershed	10
Ecological ranking of hub or corridor	Hub or corridor	30
Area of wetland	Individual wetland	10
Percent of wetland in natural cover	Individual wetland	10
Percent of wetland in riparian zone	Individual wetland	10
Stream order (note: assigned 99 = ditches, river shorelines, and other non-stream order values from the MDP coverage)	Individual wetland	3
Proximity to wetland-dependent rare species (sum of obligate or facultative wetland spp EO weights within 1/4 mile of the ditched wetland)	Individual wetland	10
Area of intact unmodified wetlands within 1/4 mile	Individual wetland	10

Stream restoration

Inadequate stream buffers in the GI are addressed under the gap restoration section. Land cover gaps were ranked for a variety of parameters and parameter combinations, including (where along streams) for restoration to riparian forest. Stream restoration or remediation also includes such actions as restoring stream morphology, restoring in-stream habitat, reducing nutrient and sediment loading, and controlling acid mine drainage and other point source pollution. Ditches and channelized streams were identified by Tiner et al (2000) within the Nanticoke and Coastal Bays watersheds. If completed for the rest of the state, these could be identified for potential restoration to natural stream morphology.

We examined channelized streams in the Nanticoke and Coastal Bays watersheds (see Table12-7) as a pilot study. Tiner et al (2000) attributed streams and ditches in these watersheds as follows. Most of the stream reaches were ditches with seasonal flow, followed in dominance by channelized streams.

Table 12-7
Stream types within the Nanticoke and Coastal Bays watersheds.

NWI code	Stream type	Reach miles in study area
R2UBH	natural nontidal	156.0
R1UBV	natural tidal	60.9
R2UBHx	channelized nontidal	266.5
R1UBVx, R1UBHx	channelized tidal	3.1
R4SBCx	ditches	999.1

Next, we gave each stream reach (regardless of condition) a unique identifier. Here, as we were limited to GIS data, stream reach was defined as the length of stream channel between intersections with other streams or until the stream changed between classes as defined by NWI (e.g., from natural to channelized, intermittent to perennial, or non-tidal to tidal). Table 12-8 lists the parameters we calculated for each reach.

Table 12-8
Parameters used to assess stream reaches in the Nanticoke and Coastal Bays watersheds.

Parameter	Analysis Scale	Weight
8-digit watershed rank	8-digit watershed	15
12-digit watershed rare fish and mussel rank	12-digit watershed	10
12-digit watershed impervious surface	12-digit watershed	10
12-digit watershed % natural cover	12-digit watershed	10
In a hub or corridor?	Hub or corridor	15
Ecological ranking of hub or corridor	Hub or corridor	15
Length of reach within cropland	Individual reach	10
Length of reach within feeding operations	Individual reach	10
Area of wetland within 100 m of perennial streams, or 50 m of intermittent ditches	Individual reach	30
Functional importance of wetland intersected by reach	Individual reach	20
Proximity to wetland-dependent rare species	Individual reach	10

Watershed statistics are described in the gap restoration section. For hub/corridor presence and rankings, we used the hub/corridor that the majority of the stream/ditch fell within. Length of reach within cropland and feeding operations were determined by intersecting the stream/ditch file with MDP 2000 land use. These were potentially major sources of nutrients.

We also computed the area of wetland within 100 m of perennial streams, or 50 m of intermittent or tidal ditches. Actual area of wetland affected by ditch drainage is a function of distance, ditch depth, soil type, etc., and must be determined in the field. This analysis is a rough approximation only.

Wetland functional importance was assessed by Tiner et al (2000), and scored according to Table 12-9. We summed the functional importance scores for each wetland. This sum varied between 0 and 30. We then recorded the mean importance score of wetlands intersecting each stream or ditch reach.

Table 12-9
Wetland functions and scores in the Nanticoke and Coastal Bays watersheds.

Function	Wetland rating	Score
Potential for surface water detention	High	3
	Moderate to High	2
	Some	1
	None	0
Potential for streamflow maintenance	High	3
	Moderate to High	2
	Some	1
	None	0
Nutrient transformation	High	3
	Some	1
	None	0
Retention of sediments and other particulates	High	3
	Some	1
	Local or None	0
Coastal storm surge detention and shoreline stabilization	High	3
	Moderate to High	2
	Some	1
	None	0
Inland shoreline stabilization	High	3
	None	0
Fish and shellfish habitat	High	3
	Moderate to High	2
	Some	1

Function	Wetland rating	Score
	None	0
Waterfowl and waterbird habitat	High	3
	Moderate to High	2
	Wood duck	2
	Some	1
	None	0
Other wildlife habitat	Large	3
	Small	1
Conservation of biodiversity	Uncommon wetland types	6
	Important for forest breeding birds, large wetland complexes, oligohaline wetlands, riverine tidal marshes, estuarine submerged aquatic beds, estuarine fringe wetlands, or interdunal wetlands	3
	None of the above	0

Finally, proximity to wetland-dependent rare species was calculated as the sum of obligate or facultative wetland species' EO scores within 1/4 mile of the stream or ditch reach.

Using the parameters in Table 12-8, we ranked channelized streams for potential restoration to a natural morphology. As with wetlands, none of the parameters were highly correlated. All were in the same physiographic region (eastern Coastal Plain). We ranked channelized stream segments for each parameter, and multiplied these by the parameter importance weightings to derive a composite ranking.

Other stream impairment, such as point source discharges or excessive sedimentation, should be determined in the field. DNR's stream corridor assessment (SCA) surveys (see Yetman, 2001) use Americorps or other volunteers to walk along all streams in a watershed, and record impacts like pipe outfalls, sediment inputs, and fish blockages. Barbour et al (1999) and the Maryland Biological Stream Survey (2000a; 2000b) describe more intensive stream surveys for physical habitat and biological community conditions. Finally, detailed quantitative surveys are described by Rosgen (1996), and provide a geomorphic characterization, assessment of stream stability or trajectory, and suggest engineering approaches to stabilize the stream if necessary. Field surveys can be prioritized using watershed-level targeting data, and then add detailed reach-level information.

Remediation of acid mine drainage

Water that seeps into streams from abandoned coal mines is called acid mine drainage (AMD). These streams have a combination of low pH and high sulfate. They also commonly carry lethal levels of aluminum and high levels of other metals such as iron and manganese. AMD can wipe out a stream's biota for decades. Further details can be found at Earle and Callaghan (2001). Streams impacted by AMD can be remediated by dosing with fine limestone or alkaline coal combustion materials.

EPA identified streams containing AMD as of 1995. We prioritized those within the GI, or draining into aquatic portions of the GI (e.g., the Potomac River). The highest biological priorities for stream remediation should be in 12-digit (third order stream) watersheds important to brook trout or rare fish and mussels (described earlier), or in GI aquatic core areas.

Removal of stream blockages

As described in the background chapter (also, see Kenney et al, 1992), stream blockages prevent fish migration. This decreases fish diversity, abundance, and biomass upstream, and removes vital spawning habitat from anadromous species.

Fish blockage data in the Coastal Plain were available from the Maryland Fish Passage Database, maintained by DNR Fisheries Service. Fish blockages were also obtained from SCA surveys. We also examined road-stream crossings from GIS layers, discounting bridges. We assumed that most non-bridge crossings were culverts. Not all of these may be fish blockages, and conversely, fish blockages may occur away from roads, but verification would have to be determined in the field. Fig. 12-9 shows how not only fish passage, but water movement, can be affected by road crossings.

Each field-identified fish blockage and road-stream crossing was prioritized using the parameters in Table 12-10.

Table 12-10
Fish blockage parameters and weights.

Parameter	Analysis Scale	Weight
12-digit watershed rare fish and mussel rank	12-digit watershed	2
12-digit watershed brook trout presence or connections	12-digit watershed	1
Aquatic core area or linkage value	Hub or corridor	3
Length of stream habitat isolated by blockage	Stream reach	2
Severity of blockage	Individual stream blockage	2

Fig. 12-9
Stream blockage at Riverside Road in Charles County, showing ponding upstream of the road.

Because there were so many potential stream blockages (16,463), we summed parameter scores rather than using nonparametric ranks. Each parameter was given a score from 0 to 10, and then weighted. The ecological ranking parameters for fish blockages are shown in the following tables.

Rare fish and mussels rank

Watershed priority for rare fish and mussels	Parameter Score
Very High	10
High	6
Moderately High	3
Neutral	0

Brook trout

Watershed priority for brook trout	Parameter Score
12-digit watersheds containing brook trout streams	10
12-digit watersheds upstream of, or connecting brook trout streams, unless the streams were far apart	5
Other watersheds	0

Green infrastructure importance

Green infrastructure component	Parameter Score
In aquatic core area in top tier hub	10
In aquatic core area in lower tier hub	6
In top tier corridor with aquatic least cost path	10
In lower tier corridor with aquatic least cost path	6
Elsewhere in green infrastructure	3
Not in green infrastructure	0

Length of habitat isolated by blockage. We were unable to differentiate between upstream and downstream orientations from available GIS data. Instead, we counted the number of stream cells on either side of the blockage, and recorded the minimum of these. Only stream reaches delineated by MDP were included, so many first-order streams may have been excluded. We assigned a parameter value of 10 to entire streams blocked (about 1.5 miles, or 68 cells), and parameter values <10 to subdivisions of this length:

Length of habitat isolated by blockage*	Parameter Score
0	0
1 – 6	1
7 – 12	2
13 - 19	3
20 - 26	4
27 – 33	5
34 – 41	6
42 – 49	7
50 – 58	8
59 – 67	9
$68	10

*Measured as the minimum number of 117 foot stream cells upstream or downstream

<u>Severity of blockage.</u> We assigned values to fish blockages according to their impedance to fish passage. We discounted natural falls, beaver dams, and removed blockages.

Fish blockages identified by SCAs were assigned the following impedance values:

Extent of fish blockage	Impedance value
Total	10
Partial	5
Temporary	2

Fish blockages identified by the Maryland Fish Passage Database were assigned the following impedance values:

Type of fish blockage	Impedance value
Partial blockage	5
Water drop <1 foot and structure height #1 foot	5
No longer a blockage, restoration completed, or action cancelled due to insufficient flow in stream	0
All others	10

Existing fish blockages identified in the Maryland Fish Passage Database as priority sites to undergo fish passage installation were then given a value of 20, because they were a high priority for restoration.

We gave other road-stream crossings from GIS intersections a fish impedance value of 8 (lower than field verified total blockages, but higher than partial blockages). We then created a composite fish blockage score by weighting and summing these parameters (Table 12-10). Field-verified blockages (from SCA or FPD) were identified as such.

Road or railroad underpasses

Roads have numerous negative effects on wildlife and ecosystems, which are discussed in the background chapter. Underpasses beneath roads and railroads can facilitate wildlife passage from one side to the other and partially mitigate the impact of roads on population viability. Underpasses have proven effective at reducing mortality among panthers, black bears, bobcats, foxes, deer, and other wide-ranging mammals, especially when combined with fences elsewhere. Underpasses, bridges, or well-designed culverts also allow hydrologic continuity; Fig.12-9 showed how roads without such features create ponding upstream, and drier conditions downstream.

When I-75 was built in south Florida in 1993, underpasses were constructed to aid the crossing of Florida panthers and other wildlife. These underpasses have been 100% successful at preventing panther mortality while traversing the highway.

More than 50 black bears are killed on Florida roads each year. However, a dirt-floor box culvert built underneath State Route 46 in Lake County may be a model solution. The culvert is 47 feet long by 24 feet wide by 8 feet high, with a clear view across to the other side. Workers also planted rows of pines in the open pasture on one side of the road to guide bears to the culvert entrance. Subsequent monitoring showed that bears and 12 other species, including bobcats, gray foxes, and whitetail deer, crossed through the culvert (U.S. Department of Transportation - Federal Highway Administration, 2000).

To allow wildlife movement across the Trans-Canada Highway, Parks Canada put up 8-foot-high fencing on both sides of the highway, and built 22 underpasses - arched culverts, box culverts, and open-span bridges - and two 164-foot-wide overpasses. The fence has cut ungulate roadkill by 96 percent, and both ungulates and carnivores are using the crossing structures. Locating the underpasses and overpasses near the animals' natural travel corridors was crucial to the project's success. For carnivores, this meant placing the structures close to stream corridors or drainage areas. For ungulates, it involved doing the opposite - placing the structures far from carnivores (their predators) and with a clear view of the structures' entrance (U.S. Department of Transportation - Federal Highway Administration, 2000).

Tunnels under highways have helped reverse the decline of badger populations in the Netherlands. Badgers use the tunnels almost every night, along with foxes, rabbits, and hedgehogs (U.S. Department of Transportation - Federal Highway Administration, 2000).

A study in San Bernardino County, California, found that threatened desert tortoises use storm-drain culverts to cross underneath the otherwise dangerous State Highway 58 (U.S. Department of Transportation - Federal Highway Administration, 2000).

Tunnels built under a street in Massachusetts successfully permitted migrating salamanders to reach vernal pools where they mate and lay their eggs. Two tunnels were placed 200 feet apart at the salamanders' crossing site, and short drift fences were constructed to guide migrating salamanders into the tunnels. Each tunnel had a slotted top to let in light and provide the damp conditions salamanders need. Study results indicated that salamanders at fences farthest from the tunnels were just as successful in reaching the tunnels as those at fences closer to the entrances. The study also revealed that more than three quarters of the animals that reached the tunnels successfully used them to cross the road (U.S. Department of Transportation - Federal Highway Administration, 2000). Scott Jackson, from the University of Massachusetts, offers these tips to those who may be considering salamander tunnels in their communities (U.S. Department of Transportation - Federal Highway Administration, 2000):

- “Design tunnels to accommodate specific site conditions.
- “Avoid single-species designs.
- “Know the biology of the target species.
- “Locate tunnels close to the movement corridors of these species.
- “Monitor the project and make appropriate adjustments.
- “Share the results (positive and negative).”

Converting culverts to bridges, or modifying culverts to eliminate water drops, will allow fish and other aquatic organisms to pass, as well as interfering less with stream morphology. If bridges are constructed wide enough to traverse the floodplain, and perhaps some adjacent upland beyond the slope, they can provide passage for terrestrial organisms along the stream channel. Existing bridges can be widened if they are normally inundated beneath the entire span.

Retrofitting existing roads, culverts, and bridges can be expensive, but fish and wildlife crossings should be considered when building new roads or replacing old structures.

Researchers in the University of Florida's Landscape Ecology Program developed a GIS model to identify future wildlife crossings that captures, manipulates, displays, and combines spatial information such as hydrology, land use, species distribution, and existing roads and greenways. The GIS model will help FDOT integrate the need to improve transportation with the need to counteract increasing habitat fragmentation by roads. Transportation planners can use it to identify and prioritize road kill "hot spots" – habitat corridors where wildlife-vehicle collisions are likely to occur. They can then adapt existing crossing structures or build new ones (like the highly-successful underpasses on I-75 designed for the federally endangered Florida panther). State roads in Florida were prioritized according to overall environmental impact. Primary criteria influencing high rankings included chronic road kill sites, biodiversity hot spots, riparian systems, greenway linkages, and rare habitat types. The project began with a survey of transportation and wildlife experts, who evaluated and ranked criteria for prioritizing projects aimed at reducing road kills and restoring ecological linkages. The project identified 72 "priority 1" road segments and hundreds of lower-priority segments. It also named the highest-priority roads in each of Florida's seven districts - for example, State Route 29 and U.S. 41 in the Everglades - and noted the contributing criteria for each (U.S. Department of Transportation - Federal Highway Administration, 2000).

Road kill data in Maryland were unavailable at the time of this analysis. Maryland roads were obtained from the State Highway Administration (SHA). We identified where roads and railroads cross GI hubs or corridors. We converted these to 30 m cells, and ranked each cell using the parameters in Table 12-11, to identify the best places for potential underpasses. The parameters are described in more detail in Appendix B.

Table 12-11
Parameters and weights used to rank road cells crossing hubs or corridors.

Parameter	Weight
Ecological ranking of hub or corridor	3
Distance from edge of GI	3
Road type (Bridges received the highest priority. If there is a bridge across the hub or corridor, this may already provide suitable crossing, or may do so with modification. Otherwise, the greater the road width and traffic, the higher its score).	2

Parameter	Weight
Does the road cross a stream?	2
Does the road bisect a wetland? (if so, calculate the distance to the wetland's non-road edge)	2
Does the road separate areas of forest? (if so, calculate the distance to the forest's non-road edge)	1
Proximity to rare species	1

We reclassified each parameter to values between 0 and 100, and calculated composite ranks with and without the weights in Table 12-11. We separated out bridges crossing the GI. These should be examined in the field to see how suitable they are for wildlife crossing. We then identified remaining road cells with a composite weighted or unweighted score in the top 1%. After examining the output, we decided to use the weighted sum. The roads corresponding to these cells were selected for later field verification and examination for potential underpasses.

Road closures

Roads have numerous negative effects on wildlife and ecosystems, which are discussed in the background chapter. Non-essential roads in ecologically significant areas, such as GI hubs and corridors, especially highly-ranked (e.g., top tier) ones, could be targeted for closing, and restored to natural conditions. Examples include old or unused logging roads, roads built for development that never took place, and roads associated with abandoned houses or facilities. Insufficient GIS data exist for unused roads, but land managers can consider this option, especially for roads in the interior of hubs or corridors.

Best management practices (BMP's) for road construction and maintenance

New roads, if their construction is deemed necessary, can follow BMP's for placement, including:
- locating outside the GI, especially outside highly sensitive areas;
- following existing transportation or utility corridors wherever possible;
- minimizing forest and wetland fragmentation;
- minimizing hydrologic impact (e.g., ponding, draining, and flow redirection) by constructing culverts and bridges that maintain surface and subsurface flow connectivity;
- constructing bridges over streams, floodplains, and wetlands;
- creating underpasses for wildlife movement, especially where the roads cross corridors, streams, floodplains, or valleys; and
- fencing areas surrounding underpasses, to funnel wildlife through the underpasses rather than across the road

Vickerman (1998) listed the following management recommendations to reduce biodiversity impacts from highways, streets and forest roads:

- “Avoid dredging and filling activities in fish-bearing streams, especially during spawning season.
- “Make sure herbicides and pesticides do not enter the water. A 25-foot buffer is recommended for machine application and a 10-foot buffer for hand application.
- “Install culverts to allow fish passage, and modify existing culverts, as necessary. Culverts that concentrate high-velocity flows and those that cause severe erosion at the outlet end may hamper fish passage. Fish-friendly culverts have a gradual slope, small pools below, and a series of dams to allow fish migration.
- “Avoid removing riparian vegetation; leave large woody debris in and along streams.
- “Be careful when sanding roads. Angular, abrasive gravel that washes into streams can harm spawning fish.
- “Prevent road waste and construction materials from entering the water. Water should be directed through vegetation filters before entering streams.
- “Control erosion so that sediment does not enter the water. Settling ponds and hay bales can be used to control and direct runoff. Planting grass in ditches can help purify water, reduce flow and minimize the need for chemicals. Special varieties, like red fescue, do not require frequent mowing or other maintenance, and are being used on an experimental basis.
- “Maintain beaver dams (unless they directly threaten roads by blocking culverts or other similar structures.) Beaver dams generally enhance overall aquatic ecosystem health.
- “Using native species to revegetate disturbed areas will improve habitat quality and could reduce maintenance costs. Landscaping with "native compatibles" can achieve similar objectives. For example, wildflowers have considerable aesthetic appeal; are low maintenance; and are attractive to butterflies, insects and birds. Avoiding wildflower mixes containing noxious weeds will help control their expansion.”

Power line corridor closures

Power line corridors have both positive and negative effects on flora and fauna. Power line corridors can provide habitat for grassland species or edge species. Some of these grassland species may be rare in Maryland, such as Serpentine Chickweed, Little Bluestem, Indian Grass, and Purplish Three-awn. The Serpentine Aster (*Aster depauperatus*), Sandplain Gerardia (*Agalinis acuta*), Fringed Gentian (*Gentianopsis crinita*), Fameflower (*Talinum teretifolium*), the butterfly Edward's Hairstreak (*Satyrium edwardsii*), and the beetle *Polypleurus perforatus* are found only in serpentine barrens. Grassland birds have declined throughout much of their range, including Maryland. Power line towers and poles can serve as nest sites for hawks.

However, power line corridors are often dominated or co-dominated by exotic weeds, and can host edge predators or parasites (see background chapter for details). Vickerman (1998) writes, “Utility corridors have negative impacts similar to roads, particularly with respect to habitat fragmentation. When located in forested areas, the continuous vegetative community is disrupted, changing the structure and function of wildlife habitat. Utility corridors can cause behavioral changes in species, provide improved access for some species at the expense of others, and facilitate the spread of invasive exotic species.”

Abandoned or unused power line corridors in the GI could be restored, although they may be naturally recolonized from neighboring woods.

Placing new power lines along existing utility or transportation corridors will minimize further habitat loss and ecosystem impact.

Vickerman (1998) summarized management guidelines for utility corridors from Gates (1991):

- "Feather the edges of power line corridors to minimize edge effects. Create successional bands of vegetation in varying heights parallel to the corridor to disperse both predators and prey species. (However, this technique could reduce the amount of interior habitat for locally sensitive species.)
- "Reduce the effective width of corridors. A small change in impermeable edge can produce a major change in the ability of animals to move. Create small lobes or peninsulas of shrubby vegetation extending from the forest edge into the corridor.
- "Establish breaks in the corridor. This can be accomplished by leaving some vegetation along low creeks or draws that traverse the corridor. Alternate spraying to retain some vegetation at all times.
- "Establish shrub communities throughout the corridor. Although initially difficult to establish, shrubs are easy to maintain once established and require less attention than herbaceous cover.
- "Maintain seasonal vegetation in corridors during certain seasons to accommodate the needs of animals during periods of reproduction and dispersal of young (principally, spring and fall)."

We lacked accurate GIS data identifying power line corridors, although many of these may show up as GI gaps. We envisioned prioritizing power line corridors as was done for GI gaps.

Ditch filling

Ditches are constructed for irrigation, mosquito control, or to lower the local water table and dry the land for human uses like agriculture or development. They thereby alter the functioning and biotic composition of nearby wetlands and streams. We examined ditches near wetlands for the potential ecological benefits if they are filled.

Reliable GIS identification of ditches was only available in the Nanticoke and Coastal Bays watersheds, and was mapped by Tiner et al (2000). Almost 1000 miles of ditches were identified in these watersheds alone (Table 12-7), and this is appears to be an underestimate.

Earlier (see the channelized stream section), we gave each stream reach a unique ID, and calculated parameters for each reach (Table 12-8). We ranked ditches for each parameter, multiplied these by the parameter importance weightings, and created a composite ranking. Potential restoration was envisioned generally as filling the ditch, although creating a natural stream morphology might be another option.

We also examined the potential negative impact of stream restoration, namely if urban or agricultural land might be flooded. We tabulated the area of urban and agricultural land (from MDP 2000 land use) within 50 m of ditches. The actual area drained by ditches is a function of distance, ditch depth, soil type, etc., and must be determined in the field. This analysis was a rough approximation only. Managers should consider the potential flooding of urban areas or crop fields if drainage ditches are filled.

Erosion control and restoration

Controlling erosion, especially in high-ranking hubs and corridors of the GI, and/or along streams and wetlands, is important. Highly erodible soils, stream banks, shorelines, and steep slopes should be kept vegetated to minimize erosion. Best management practices should be followed within the GI, as well as many places outside. GI gaps containing highly erodible soils or steep slopes can be examined in the field for reforestation, especially if they are in a riparian zone.

According to the Maryland Department of Natural Resources Forest Service (2000), "there are approximately 4,360 miles of tidal shoreline within the Maryland portion of the Chesapeake Bay watershed alone. 1,341 miles of tidal shoreline have been identified as eroding at various yearly rates. In addition, approximately 14,063 miles of freshwater streams, an integral part of the Chesapeake Bay watershed system, are experiencing intermittent erosion problems. Shoreline and streambank erosion not only result in the loss of land and the reduction of riparian buffer areas and wildlife habitat, but have also been identified as major contributors of sediment to the waters of Maryland. Approximately 5.1 million cubic yards of sediments are delivered annually to the Chesapeake Bay. Sedimentation increases nutrient pollution and degrades water quality."

DNR Shore Erosion Control assists Maryland property owners in resolving shoreline and streambank erosion problems, providing both technical and financial assistance. The preferred method for stabilizing streambanks and shorelines is to plant vegetative buffers, which will also improve water quality and create near-shore habitat for aquatic species and waterfowl. Clean sand fill is placed in the intertidal zone, and stabilized with tidal marsh grasses such as smooth cordgrass and saltmeadow hay. Where erosion rates are high, hardening structures can be added, including bulkheads, walls, revetments, stone reinforcement, breakwaters, jetties and groins. Details are available at http://www.dnr.state.md.us/forests/programapps/sec.html (Maryland Department of Natural Resources Forest Service, 2000).

Land management practices incompatible with ecosystem functioning

Silvicultural or other extractive management practices may interfere with ecosystem and landscape functioning, depending on their intensity, placement, and presence or absence of mitigation measures.

In general, maintaining forests as pine plantations is incompatible with biodiversity protection. Hubs and corridors can benefit from buffers of pine plantations, or even pasture or crop agriculture, if the alternative is industrial, commercial, institutional, or residential development. However, the interior of hubs and corridors should contain predominantly natural ecosystems. Mature temperate forests usually have more biomass, more soil organic matter, better moisture and nutrient retention, greater structural diversity, and higher species diversity than plantation forests. They contain more mast-producing trees, like oaks, hickories, walnut, and beech; which are important for many birds and mammals. While pine plantations provide pulp for human use, and sequester carbon, they do not provide adequate food, shelter, or breeding habitat for many species of concern. Their frequent disturbance regime (<50 years) can permanently exclude those herbaceous plants, lichens, mosses, salamanders, and other organisms that are slow recolonizers. Bedding, ditching, and road building alters the hydrology. Application of herbicides and pesticides can kill native flora and fauna. Logging roads and skidder tracks have numerous negative effects on forest ecosystems, which are discussed in the background chapter and in U.S. Forest Service (1999).

Strip mining can be even more harmful than development, as the vegetation and topsoil are entirely lost, the topography and hydrology are radically altered, and toxic byproducts can result (e.g., acid mine drainage from coal mines). Strip mining is thus counter to protection of natural resources, especially in the green infrastructure.

Less intensive management practices such as selective tree harvesting or the growing of understory crops like ginseng may be best addressed on a case by case basis, taking into account:

- the intensity and impact area of the action,
- the presence, sensitivity, and needs of rare or sensitive species,
- potential introduction of invasive exotic species,
- potential impacts to soil, hydrology, and biota, and
- other ecological effects of the action.

The Forest Stewardship Council (see www.fscus.org and www.certifiedwood.org for more information) is an independent non-profit group that has developed standards for forest management. To be certified by the Forest Stewardship Council (Asato, 2003), forest practices and management plans must :

- "Conserve biological diversity and functioning ecosystems;
- "Ensure sustainable harvests over time;
- "Protect rare, threatened or endangered species; and
- "Advance the economic and social well-being of forest workers, communities and indigenous groups."

Often, active management for some species (e.g., game species like deer and quail that prefer forest-field edges) can conflict with management for other species (e.g., forest interior birds). Ecosystem management is usually preferable to single-species management, although special consideration should be given to rare, sensitive, or declining species. Grumbine (1994) wrote that ecosystem management should have the following goals:

- Maintain viable populations of all native species in their natural habitat.

- Represent, within protected areas, all native ecosystem types across their natural range of variation.
- Maintain evolutionary and ecological processes (i.e., natural disturbance regimes, hydrological processes, nutrient cycles, etc.)
- Manage over a time frame long enough to maintain the evolutionary potential of species and ecosystems.
- Accommodate human use and occupancy within these constraints.

Vickerman (1998) listed the following management recommendations for conservation and recreational lands:

- "Avoid over-developing recreational areas and protect natural areas to help to satisfy a growing interest, especially among urban populations, in nature education and less structured outdoor experiences. Lower capital and maintenance costs are consistent with decreasing resource agency budgets. Fewer paved surfaces may improve habitat value and enhance ecosystem integrity.
- "Manage visitors to minimize adverse impacts. Simply explaining to people why they should avoid certain harmful activities or make a special effort to do positive things may have some impact on behavior. Restricting access to sensitive areas during certain times, like nesting season, may be sufficient.
- "Inventory and protect sensitive areas where rare plants or animals are located. Such areas could be wetlands, riparian areas, bat caves, nesting or roosting sites. Visitor use should be limited, carefully monitored, and in some very sensitive cases, excluded from these areas.
- "Conserve water by relying on native landscaping and only watering those areas where native landscaping is not appropriate, like play fields and picnic areas. Water can also be recycled, and irrigation systems can be designed to reduce loss and to water only when necessary. Some grasses, like fescue, take less water than other types.
- "Minimize use of chemical herbicides, pesticides and fertilizers to save money, protect water quality and avoid harm to non-target organisms. Implementation of integrated pest management strategies is important to biodiversity.
- "Evaluate secondary land uses (e.g., grazing, agriculture, timber harvesting) to determine whether they are causing adverse impacts, and if so, how they can be modified or eliminated.
- "Avoid using exotic plants in landscaping and take steps to control invasive exotics in park and natural area management. Using volunteer labor to help remove unwanted plants, like English ivy in urban parks, can help address the problem while improving the public's understanding of the issue. Allocating more resources to this important task will probably be necessary to the long-term ecological health of parks, natural areas and adjoining properties.
- "Provide a good example and public information. This is one of the most important contributions conservation and recreation land managers can make to overall efforts to protect sustainable ecosystems. Demonstration projects; cooperative agreements with adjacent landowners; high-quality interpretive signing; well-informed staff naturalists and volunteers; and partnerships with schools, scientists, conservation groups and local businesses can all help to meet biodiversity goals.

- "Participate in regional planning to help ensure that park and natural area management fit within the overall watershed or ecoregional strategy, to help avoid inconsistent actions and duplication of effort, and in the long run, to save money."

Removal of invasive exotic species

An invasive exotic species can be defined as "any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem; and whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Douce et al, 2002). Without the natural controls found in their native lands, these species can propagate rapidly throughout a landscape.

The removal of invasive exotic species should be a high priority of land managers. Introduced plants, animals, fungi, and microorganisms can eliminate native species through predation, parasitism, or competition, and often disrupt community structure and organization. The majority of exotic introductions never become established, but when they do, they can have unexpected and negative consequences, sometimes extinctions of native species. Exotic species may reduce native species abundance by outcompeting for common resources, by predation, parasitism, introducing associated pathogens, or a combination of these. Introduced species may have a competitive advantage because they are not held in check by coadapted predators, pathogens, or other mortality agents, because they may be more general in their food or habitat requirements, or because they are more tolerant of degraded habitats (DeWald and Wilzbach, 1992). Invasive species contribute to the decline of 46% of the imperiled or endangered species in the U.S., and are estimated to cost $137 billion annually in losses to agriculture, forestry, fisheries and the maintenance of open waterways in the U.S. (Nature Conservancy, 2002)

There are numerous problem exotic species in Maryland, including mute swans, nutria, *Phragmites sp.*, *Microstegium sp.*, garlic mustard, Japanese honeysuckle, multiflora rose, *Ailanthus sp.*, and European green crabs. Of these, *Microstegium* may be the biggest problem invasive. It is ubiquitous throughout the state, is a rapid invader of both mesic forest and wetlands, is both shade-tolerant and sun-tolerant, and can cover 100% of the forest floor, driving out native herbs and tree seedlings. This upsets the entire forest ecosystem. Garrett county seems to have the fewest invasive species problems so far (although rapid recent development may change this); this may be climate-related, disturbance-related, or a combination of both. Certainly disturbance (especially when human-caused) creates vectors for invasive plants. They are often found in disturbed soil, at forest edges, along roads and trails, etc., and then often invade the interior from these initial disturbed areas.

Lists, descriptions, and control measures for invasive exotic species in Maryland can be found online at:

- http://www.dnr.state.md.us/wildlife/invintro.html (Maryland Department of Natural Resources Wildlife and Heritage Service, 2002);
- http://www.invasive.org/ (Douce et al, 2002);

- http://www.dnr.state.md.us/wildlife/iep.html (Maryland Department of Natural Resources, Wildlife and Heritage Division,1999); and
- http://www.invasivespecies.gov/ (National Agricultural Library for the National Invasive Species Council, 2002).

Areas in the green infrastructure or near sensitive species or communities should be inventoried for invasive exotic plants, animals (including insect pests), and diseases. The more serious outbreaks, or those outbreaks with potential to become serious problems, should be contained as quickly as possible. Invasive exotics must be identified in the field. GIS data may not be helpful, although priority could be given to problems in important hubs and corridors (e.g., top tier), as well as those impacting sensitive species or communities. Exotic plants in forest and wetland interiors may pose a greater threat than those on the edge.

Fisheries and Heritage divisions of DNR already have programs to address exotic species, but more resources are needed. Also, strategically protecting and restoring large natural areas, as well as nipping initial outbreaks in the bud, will be both easier and more effective than trying to remove exotics opportunistically or randomly. A strategy to control exotic plants might include:

- preserving large areas of natural vegetation (e.g., green infrastructure hubs) - the greater the interior to edge ratio, the safer the interior areas are from invasion;
- active removal of invasives, concentrating on forest and wetland interiors, and areas where rare or sensitive plants are threatened;
- closure of roads and trails in sensitive areas (these are often vectors for exotic invasives);
- control of deer, which when they exceed the carrying capacity, wipe out native herbs and woody seedlings, opening up niches for exotic invasives to exploit;
- researching potential native competitors to invasives, and planting these where invasives are removed (e.g., ferns in forest interiors?);
- increasing public awareness of exotic species; and
- creating partnerships with botanical societies, environmental groups, and other sources of volunteers, who, properly trained and/or supervised, can help promote the use of native rather than exotic flora, and help remove invasives.

Exotic species like brown or rainbow trout should not be introduced where they will compete with native species like brook trout, or otherwise impact natural ecosystems. Reintroduction of brook trout into headwater habitats where they are now absent may help arrest their overall decline. Nagel (1991) suggests a network of populations, supported by artificial recolonizations and transfers.

Native species may also pose problems. Top carnivores like cougar and wolves have been extirpated from Maryland. Together with the increasing prevalence of edge habitat, this has led to a significant increase of white-tailed deer from their pre-colonial population. When deer density exceeds 20 per square mile, they overbrowse their habitat, and herbaceous, shrubby, sapling, and seedling vegetation richness and abundance begins to decline. However, hunting can keep deer density below this level. The difference between areas permitting hunting and areas prohibiting hunting can be dramatic. Forest communities surveyed in Catoctin National Park, which does not permit hunting, had herbaceous layers dominated by exotic species like *Microstegium* and garlic mustard, and poor seedling recruitment. Deer were present in large numbers, and appeared unafraid of humans. In contrast, sites in adjacent Cunningham Falls State Park, which does permit deer hunting, had more diverse herbaceous layers, better seedling recruitment, and fewer exotic species.

Adaptive management

Restoration projects do not always succeed. Planted trees may die, hydrology may differ from that expected, exotic weeds may invade the site, or any number of other unexpected problems may occur. Adaptive management is a paradigm that stresses flexibility and learning from mistakes. Restoration or management plans are developed from initial site studies, but are followed by long-term monitoring, assessment of which actions worked and which didn't, and why they succeeded or failed. This process of learning can help avoid repeating mistakes. By sharing this information, furthermore, managers can help keep others from making the same mistakes. Active research can accelerate this process, by experimentally comparing outcomes of different management practices, designed to test alternative hypotheses. For example, a grassland restoration project at Chino Farms on Maryland's eastern shore included plots planted with different species, and long-term monitoring of vegetation and bird species composition and abundance. Salafsky et al (2001) examined adaptive management techniques around the world, and concluded that successful application requires "establishing a clear purpose, developing an explicit model of the project site, selecting actions that maximize results and learning, developing and implementing a monitoring plan to test assumptions, analyzing data, communicating results, and then using these results to adapt and learn."

Coordination with existing restoration programs

The green infrastructure assessment would have little value if it existed in a vacuum. Some restoration programs that can benefit from green infrastructure targeting are listed in Table 12-12. As with conservation, most of these programs were traditionally opportunity-based, but landscape-scale and watershed-scale data and targeting can better integrate efforts and improve overall ecological conditions.

For riparian buffer targeting, the area must be adjacent to a stream or shoreline. Furthermore, the various riparian buffer programs (e.g., Stream ReLeaf, the Conservation Reserve Enhancement Program, the Forest Conservation Act, the Chesapeake Bay Critical Area, and the Buffer Incentive Program) have different eligibility requirements. For example, the Conservation Reserve Enhancement Program (CREP) offers short-term easements and reimbursement of establishment expenses to agricultural landowners to plant buffers within 150 feet of a stream. The Forest Conservation Act requires mitigation of development impact within the same county or watershed. Buffers are a replanting priority. The Chesapeake Bay Critical Area program emphasizes a 1000 foot buffer from the Bay and its tidal tributaries. These programs are intended primarily to reduce aquatic nutrient loading, but by prioritizing projects within the green infrastructure network, multiple ecological benefits can be realized. Agricultural, lawn, or barren gaps with significant riparian area can be further prioritized by considering their watershed, landscape, and local importance (e.g., composite ecological rank).

We identified where land cover gaps overlapped various programmatic focus areas (Table 12-12). These institutional parameters were weighted and summed to approximate the relative programmatic ease of undertaking a restoration project. The higher the number, the more programmatic opportunities for the gap. Gaps were then ranked within their physiographic region, with the lowest (i.e., best) rank representing the gap with the most programmatic opportunities, and with the highest (i.e., worst) rank representing the gap with the fewest programmatic opportunities. Opportunities exist outside those tabulated here, and they change often, so this information should only be used as a rough guide, and not given as much consideration as the potential ecological benefits or potential costs/difficulty.

Much more important than the composite score was the identification of green infrastructure gaps that fell within particular restoration programs. For example, there is a great deal of concern for improving water quality in the Chesapeake Bay, partly by reducing non-point source nutrient loads. Reforesting riparian GI gaps in stressed or impaired watersheds can achieve both water quality and habitat goals. As another example, gaps in state lands are easier for DNR to restore, in that fewer stakeholders are involved. Green infrastructure data were supplied to DNR personnel working in programs like watershed restoration action strategies (WRAS) and the Conservation Reserve Enhancement Program (CREP).

Table 12-12
Partial list of existing forest, wetland, and stream restoration programs

- American Forests: Global Re-Leaf
- Backyard Conservation Program
- Backyard Wildlife Habitat Program
- Bayscapes
- Buffer Incentive Program
- Chesapeake Bay Foundation and Ducks Unlimited
- Chesapeake Bay Initiative
- Chesapeake Bay Trust
- Conservation Reserve Program
- Conservation Reserve Enhancement Program
- Environmental Quality Incentives Program
- Forest Stewardship Program/Stewardship Incentive Program
- Forestry Incentive Program
- Maryland Environmental Trust
- Maryland Forest Conservation Program
- Maryland Agricultural WQ Cost-Share Program
- Maryland Nontidal Wetlands Program
- Native Warm Season Grasses Project
- Non-Structural Shore Erosion Control Program
- Partners for Fish and Wildlife
- Small Creeks and Estuaries Reserve Program
- Tree-mendous Maryland
- Wetlands Reserve Program
- Wild Acres
- Wildlife Habitat Incentives Program
- Woodland Incentive Program

Table12-13
Institutional parameters used to evaluate green infrastructure gaps, and their relative weighting.

Parameter	Importance	Weighting
Existing public ownership	High	8
Forest Legacy Area	High	8
Rural Legacy Area	Low	2
Area zoned for conservation by county	Low	2
CWAP Priority Category 1 watershed	High	8
CWAP Select Category 3 watershed	Low	2
Water supply reservoir property	Medium	4

Parameter	Importance	Weighting
12-digit watershed upstream of drinking water supply, or classified for the Clean Water Act as a public water supply (Use III-P or IV-P).	High	8
12-digit watershed with natural trout waters (Use III)	Medium	4
12-digit watershed with recreational trout waters (Use IV)	Low	2
Scenic or wild river view (500' from bank)	Low	2
Existing or potential greenway	High	8
Near school (educational and volunteer opportunities)	Medium, dependent on distance	0-0.25 mi: 4 0.25-0.5 mi: 3 0.5-0.75 mi: 2 0.75-1.0 mi: 1

Economic costs of restoration

Restoration projects may have associated costs, such as increased flooding if a ditch is removed, or loss of economic return if a corn field is converted to forest or wetland. Such costs can be compared to restoration benefits. Ecological economics and ecosystem valuation offer tools to assess such issues in a consistent framework.

Chapter 13
FUTURE DIRECTIONS

Revision of targeting tools

The Green Infrastructure Assessment is a work in progress. Implementation of conservation and restoration action is preceded by field investigations, which may result in adjustments to the hub-corridor network. For example, about a fifth of the Ankeney property (Appendix G) had not been included in the GIS model because it was in agricultural and residential use. However, field visits determined that these fields and houses had been abandoned, and were afforesting. A study of recent loss to development (Weber and Aviram, 2003) is requiring the identification of alternate connections in places. Regardless of these relatively minor adjustments, the current model has already proved useful for numerous applications.

The green infrastructure data mapped in the Maryland Greenways Commission (2000) represent the product of a collaborative assessment effort between state and local agencies as of 2000. This network was further updated by considering connections with Delaware, wetlands identified as important by Tiner et al (2000), and aerial photographs. The GIS-based modeling approach used to help define the green infrastructure incorporated the best available data that were available statewide at the time. We anticipate that as better data become available, adjustments in the configuration of the network may be appropriate. Specifically, changes in the network could result from the incorporation of:

- updated (i.e., more recent) land cover or other resource data that better account for changes over time;
- higher resolution data that would help to define the hub and corridor network more precisely;
- the final vegetation distribution, predicted distribution of native vertebrate species, and biodiversity hotspots from the Mid-Atlantic Gap Analysis Project (GAP);
- supplemental data that could be used to more accurately define the ecosystem processes at work within the green infrastructure; or
- the results of continued field level verification of the accuracy of the green infrastructure model.

Local green infrastructure applications: opportunities and limitations

While DNR's green infrastructure model is designed for a statewide and regional focus, the concept can be adapted for a smaller scale approach. Smaller hubs, incorporating local parks and open spaces, connected by narrower corridors such as those provided by small, natural stream valleys or planted utility rights-of-way, may not provide all of the ecological benefits sought at the broader statewide or regional scale, but nonetheless can provide important aesthetic, ecological and recreational amenities. Connected to the regional system, they both support the larger system and bring some of its benefits into more urbanized settings.

It should be noted that the GIS-based green infrastructure analysis utilized data that were generally available statewide and at map scales ranging from 1:24,000 to 1:100,000. Therefore, the green infrastructure depictions shown in the atlas should be considered useful for regional planning and assessment purposes only. As an amalgamation of multiple sources of data, the mapped green infrastructure is not intended to be used for confirming the presence or absence of any specific resource feature. Verification of particular features should, at a minimum, be accomplished by consulting the original source data that were used in the green infrastructure assessment. Typically, this information should also be used in conjunction with field or site data before evaluating the merits of specific land or resource conservation and restoration activities. The data also represent a snapshot in time, and will have to be periodically updated.

Multi-state assessments

The green infrastructure analytical model described in this document has been developed and applied in Maryland. As mentioned in the methodology, a multi-state model, the Delmarva Conservation Network, was designed for the entire Delmarva peninsula (see Weber, 2000, for details). This resembles the Maryland model, but was limited to data common to all three states. This ecological network was combined with an agricultural buffer to produce the Delmarva Conservation Corridor, which is being used to help guide cooperative conservation efforts between Maryland, Delaware, and the federal government. Rep. Wayne T. Gilchrest has championed the effort as a prototype for national land preservation.

A similar assessment, the Resource Lands Assessment, is being developed for the entire Chesapeake Bay watershed, except for the portion in New York. The Resource Lands Assessment (RLA) is a multi-agency effort to satisfy the goals and objectives of the Chesapeake 2000 agreement. Although modeled on the Green Infrastructure Assessment, the RLA was developed somewhat differently (see Weber, 2002, for details). Terrestrial core areas were defined as natural interior areas with at least 100 ac, bounded by anthropogenic land cover, all roads or active railroads, or power line corridors, plus a 100 meter edge transition. Terrestrial core areas were classified as upland, wetland, or both, depending on their composition. Aquatic core areas were defined as high quality watersheds, having <10% impervious surface, >66% forest cover, >66% forested stream banks, and no acid mine drainage. These core areas were combined into hubs, ranked for a variety of ecological parameters, divided into tiers, and connected with corridors.

RLA hub rankings were calibrated by EPA Level IV ecoregions (defined in Woods et al, 1996) rather than by physiographic regions. Ecoregions denote areas within which there is general similarity in ecosystems and in the type, quality, and quantity of environmental resources (Woods et al, 1996). The ecoregional map created by Woods et al (1996) depicts revisions and subdivisions of ecoregions originally compiled at a relatively small scale (Omernik, 1987). The purpose of the ecoregional delineation was to assist managers of aquatic and terrestrial resources in understanding the regional patterns of the realistically attainable quality of these resources (Woods et al, 1996). The approach was based on the premise that ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995). Ecoregional delineation was based on climate, elevation, land use/land cover, land form, potential natural vegetation, soil, structural/bedrock geology, and surficial/Quaternary geology (Woods et al, 1999). Expert judgement was applied to these data to form the regions (Woods et al, 1999). Detailed explanations of the methods, materials, rationale, and philosophy of the ecoregion delineation process can be found in Woods et al (1999), Woods et al (1996), Omernik (1995), Omernik and Gallant (1990), and Gallant et al (1989).

Economic valuation of ecosystem services

Finally, it is our hope that the information derived from the Green Infrastructure Assessment will be of value in landscape level conservation and restoration decision-making. To accurately reflect the full range of ecosystem values associated with the green infrastructure, additional assessment work is under way to better measure the socio-economic benefits of the landscape. Maryland's Strategic Forests Lands Assessment (see Maryland Department of Natural Resources, Landscape and Watershed Analysis Division, 2002) includes values to the forest products industry. More comprehensive economic valuation of ecosystem services is being developed for Maryland by Wilson et al (2002). This is based on the work of Costanza et al (1997), which is discussed in the background section of this paper.

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