Health of the Casperkill, Dutchess County, New York

February 2009

Vassar College Environmental Research Institute

Cornell Cooperative Extension (CCEDC) Environment Program

Casperkill Watershed Alliance

Photo taken at the site where Rt. 9 crosses the Casperkill

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Prepared by the Vassar College Environmental Research Institute

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Preface: Our Lovely Casperkill

By Dr. A. Scott Warthin, Jr., Prof. of Geology, Vassar College

Once upon a time a little stream began, clear and sweet, in a swamp where the green herons perched in the buttonbushes, and the marsh wrens nested in the long cattails. What this stream may have been called by the Wappinger Indians we do not know, but early Dutch settlers called it the Casperkill. Along its banks the mink and otter hunted and played, while the deer came through the forest to quench their thirst.

The Indians, never of great number, used the stream in small ways; but these ways were in truth so small that they had no visible effect. Some four thousand years of habitation by Indians left the stream and its denizens as little changed as the forests along its banks.

But when the land was granted in patents and sold to settlers the great change began. Forests fell to clear fields, and to furnish lumber and fuel. The Casperkill suffered its first conspicuous indignity in the construction of a mill in its lower reach. Less obvious changes also occurred. Spring rains washed soil from the bare wheat fields, muddying at times the once clear spate. The hot rays of the summer sun warmed the waters that had been sheltered by trees along the banks. And other misfortunes came, at first slowly but at last in a crescendo of disaster. Beneath the headwater swamp lay beds of clay; this was used for the bricks that built much of old Poughkeepsie and the early buildings of Vassar College. When the brick plant closed in 1932 nearly half the swamp had been replaced by a pit, soon full of water. That phase of history remains today only in the name of Brickyard Hill, east of the swamp.

But that hole full of water? What a marvelous place to dump garbage! So a citizen with foresight bought the worthless hole and leased it to the Town of Poughkeepsie for a dump, and the waters that flowed from the swamp down the Casperkill became rich with the organic material of the decaying garbage and charged with iron from the rusting cans. The decay process used up the oxygen normally dissolved in the water; many kinds of life that had swarmed in the stream were drowned in the waters that once nourished them. Some life, however, survived and found that the waters, though fetid, were richer than ever with the decaying organic matter; these things flourished. So the Elodea and waterlilies that once grew in Sunset Lake on Vassar College campus, were replaced by ugly mats of algae. The coliform count of the water grew so high that the Vassar girls had to give up the kayaks in which they once sported. As the sunfish and bass that swam in the lake were replaced by goldfish and carp, so the water loving plants around its edge gave way to Yellow Flags and Sagittaria. And for years, when the

Town burned its dump thrice weekly, a north wind brought a snow of burnt paper ashes on the water.

A few atrocities were corrected; a gravel miner was required to settle the mud from his wash water before returning it to the stream. Vassar College ceased to use Sunset Lake as a cooler for condenser water from the power plant. And in time more people protested the Monday-Wednesday-Friday smog from the burning dump, so dumping at that spot ceased. Of course, it was coincidence that the dumping space had by then all been filled up well above water level, and was now valuable land. So we come to the era of industry and the supermarket, surrounded by acres of parking lots, where rainfall must be drained away at once or business suffers. And where can the storm sewers most cheaply discharge? Poor Casperkill! Today, even a modest rain promptly produces a brown turbid fluid discharge, courtesy of Shoprite and the Great Atlantic and Pacific Tea Company. It is not, however, tea, and it is (slowly, we hope) filling Sunset Lake, which is the first settling basin in its path. And nestling in this unlovely mud are other artifacts – item, two auto tires; item, an estimated 300 beer cans and assorted bottles. How the few surviving Painted Turtles can find a place to burrow for the winter it is hard to imagine. Snug indeed, between Schlitz and Rheingold, in mud spiced with fuel oil released into the Lake by mistake. Why is it that nearly all mistakes made with water are detrimental?

The New York State Water Resources Commission, in effect, has declared the situation hopeless above the Sunset Lake dam, giving that portion a "D" classification. On the theory that running water will gradually cleanse itself, and with the septic tank action in Sunset Lake as an assist, the Commission placed a rating of "C" on the Casperkill below Sunset Lake. This would permit fishing, except for trout, which require more dissolved oxygen than the panfish. This is hardly realistic today, but may come to pass when the organic debris in the Town dump has wasted away.

But will the Casperkill ever return to its early state? No, my friend, the marsh wren can never replace the supermarket, so let us have a care for what is left to us before it is too late.

Published in Wings Over Dutchess, newsletter of the Ralph T. Waterman Bird Club, Dec. 1965, Vol. 6, No. 2

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Executive Summary

The 12 square mile Casperkill watershed lies entirely within the boundaries of the Town (80%) and City (20%) of Poughkeepsie in Dutchess County, New York. Draining the watershed, the Casperkill stream flows for 11 miles from its headwaters at the base of Peach Hill Park to the Hudson River at the Tilcon Quarry and provides a unifying element to the Town.

Along its length, the Casperkill flows through a wide variety of land uses and land covers, ranging from forested wetlands to commercial districts, the Vassar College campus, and both low- and high-density residential neighborhoods (Fig. 1). Water quality indicators reflect changes in land use, and the stream is rated Class C by the New York State Department of Environmental Conservation, indicating that it is not suitable for swimming or other contact activities but is able to support fish populations. Sources of impairment include stormwater runoff from paved surfaces like roads and parking lots, bacterial contamination from leaking sewer lines, lawn chemical applications, leachate from landfills, and unnatural channel dimensions due to a history of straightening and diversion of the stream to make way for development. Despite its degradation, the Casperkill is important to study and to protect: the stream provides an urban refuge for wildlife, remains a scenic amenity in many of its reaches, and discharges accumulated contaminants into the Hudson, the drinking water supply for most of the watershed. In addition, without protection, the rate of property damaging floods and bank erosion may increase.

This study reports on nearly two years of monthly analyses conducted at 21 sampling sites along the Casperkill. Sampling was designed to determine the current health of the stream. Analyses include levels of the nutrients nitrogen and phosphorus, bacteria, and road salt. In addition, overall health of the aquatic ecosystem was assessed at 12 sites through the identification and counting of benthic macroinvertebrates - aquatic insect larvae, worms, crustaceans, and molluscs that have varying sensitivities to pollution. Stream flow and flooding potential were also studied.

The Casperkill is most impaired in the Dutchess and 44 Plaza shopping district of the Arlington neighborhood where it has been diverted into an unnaturally straight channel and underground pipes. Fast food wrappers, plastic bags, shopping carts and other detritus litter the stream and its banks, and parking lots drain directly into it. Benthic macroinvertebrates (BMIs) assign a "poor" rating of water quality to this stretch of the stream, which also suffers from a lack of shade trees (Fig. 1). The Casperkill is healthiest on the Vassar College Farm and Ecological Preserve where it meanders freely across a forested floodplain far from sources of garbage and chemical inputs. Here BMIs

indicate "good" to "very good" water quality, and downed trees in the channel provide habitat for fish. The suburban neighborhoods downstream of the Preserve also show "good" water quality.

While BMIs show that water quality improves somewhat downstream of the commercial district, road salt contamination persists, and the Casperkill is the saltiest stream in Dutchess County, with salinities reaching values the EPA defines as not potable for human consumption and damaging to many aquatic species (Burns, 2006). Additional problems include bacterial contamination and flooding. Monitoring of stream flow over the last year indicates that parts of the Casperkill overflow the stream's banks at a rate much higher than normal (15 times in a 14-month interval as opposed to once every 1.5-2 years), and some homeowners have reported problems with bank stability and erosion.

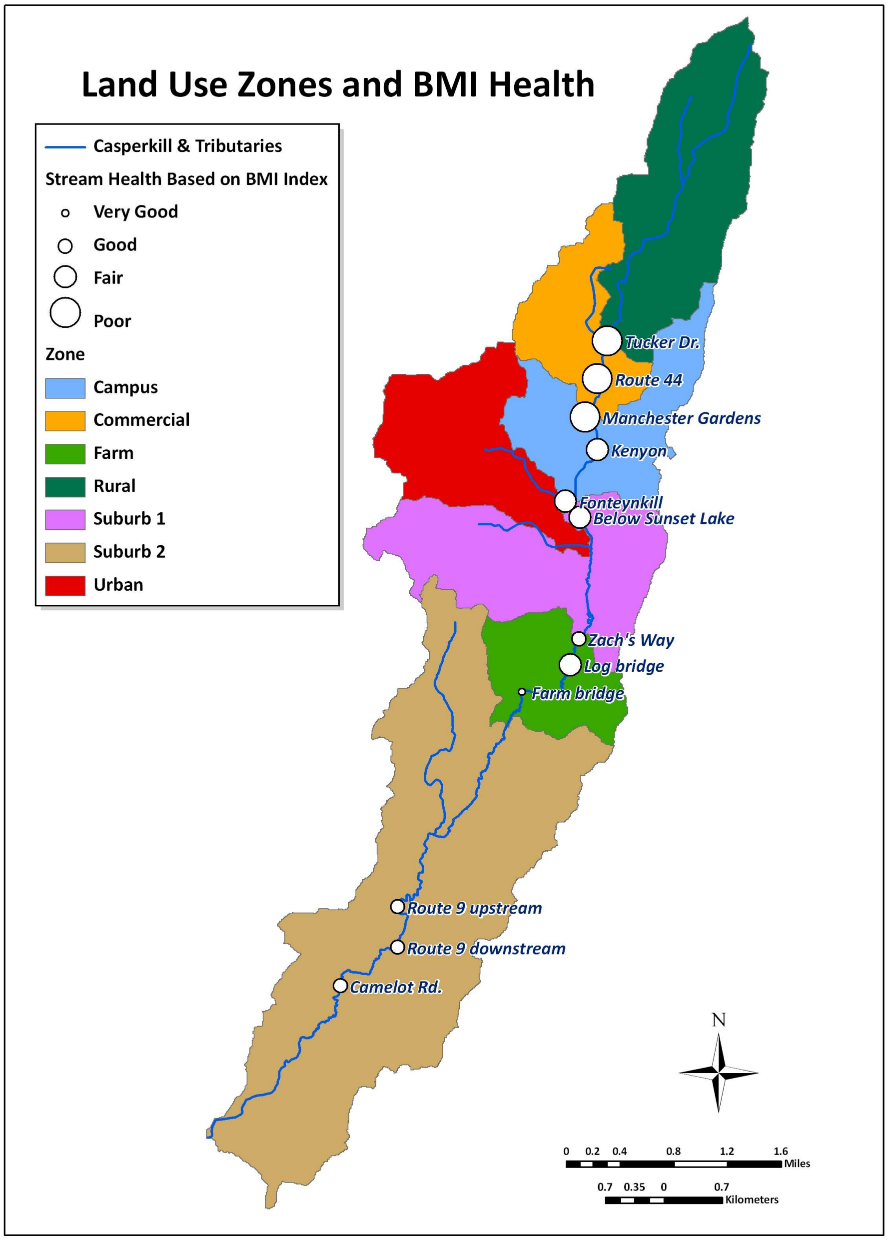

Fig. 1: Land Use/Land Cover zones described in this study and assessment of aquatic ecosystem health based upon the assemblages of benthic macroinvertebrates found at 12 sites along the stream. The commercial district shows the greatest impairment, with water quality improving downstream as the Casperkill flows through suburban developments and the Vassar Farm and Ecological Preserve.

The findings in this study reveal that the overall health of the stream is fair to poor, with high variability between different sections of the stream. This has led us to provide several recommendations that could help improve the health of the Casperkill and possibly restore impaired segments. These include recommendations for homeowners and other watershed property owners, as well as enforcement and corrective recommendations for municipalities. Furthermore our recommendations have general application to streams throughout the Hudson Valley. To improve the health of the Casperkill and other local streams, property owners in the watershed (both residential and commercial) are encouraged to:

1) maintain, or where absent, replant native vegetation along the stream to stabilize its banks, prevent erosion, and ensure a buffer sufficiently wide to minimize nutrient and sediment inputs to the stream
2) minimize the use of lawn chemicals to reduce nutrient inputs
3) use rain barrels or create rain gardens to collect rainwater from rooftops and driveways and give water the opportunity to infiltrate slowly into the ground instead of running off and contributing to flooding hazards
4) avoid removing large woody debris and gravel bars from streambeds that provide habitat for fish and aquatic invertebrates
5) properly maintain septic systems to reduce nutrient and bacterial inputs into the stream
6) minimize the use of salt on driveways, walks, and parking lots during the winter
7) prevent litter from entering the stream

Further protection and restoration of the stream will require action on the part of municipal and county governments. We therefore recommend that the Town of Poughkeepsie:

1) avoid granting variances to its Aquatic Resources Protection Law in order to allow the buffer zone to help remediate the impacts of runoff into the stream
2) strengthen the Aquatic Resources Protection Law to make riparian buffer zones at least 100 feet in width in order to maintain habitat for wildlife and improve aquatic ecosystem health
3) require "Better Site Design" principles that allow on-site infiltration of stormwater to help remediate the impacts of runoff into the stream
4) implement changes in zoning to require clustered development on remaining open space, which would reduce the amount of impervious surface in the watershed and minimize salt and other road related contaminants
5) prevent construction on stream floodplains in order to reduce downstream flooding and potential property damage
6) recognize the importance of small wetlands in storing rainwater and protect them from infilling
7) work toward replacing the Town's antiquated sewer lines to reduce nutrient and bacterial inputs into the stream

8) develop recreational amenities along the stream to strengthen human, environment, and community relationships

Any work to restore the stream will have to involve elected officials, businesses and landowners, whose individual land use decisions affect the watershed. As such, this project also included a pilot analysis of stakeholder values about the watershed, outreach to elected officials with jurisdiction in the watershed, and initiation of a volunteer watershed organization (the Casperkill Watershed Alliance) to protect and restore the Casperkill. Over the course of the project, numerous public education events have been organized to raise awareness about the health of the watershed, and the volunteer organization has been meeting regularly, communicating through a list serve, and beginning to provide input on watershed events and on a county wide watershed website.

History and Purpose of this Document

For two years, students and faculty affiliated with Vassar College's Environmental Research Institute (ERI) conducted research on the health of the Casperkill creek and its watershed. The Casperkill runs through the Vassar campus where it is dammed to form Sunset Lake. The stream is a wonderful educational resource, where students from local schools have learned about environmental science for many years. After witnessing multiple algal blooms on Sunset Lake and learning of raw sewage spills into the creek in the Poughkeepsie Journal, members of the ERI became concerned about the health of the aquatic communities dependent on the stream and embarked on a research project to determine the impacts of urban and suburban development.

Beginning in the spring of 2006 and lasting 22 months, students and faculty conducted water quality monitoring on a monthly basis, assessing such parameters as the amount of road salt in the stream; dissolved oxygen, nutrient, bacteria, and heavy metal levels; stream water pH; the extent and type of streamside vegetation; and the state of aquatic organisms. Most samples were taken at times of low flow, between rainfall events. The goal of the project was to determine what the overall health of the stream is, to identify sources of pollution, and to work with local residents and government officials to improve water quality.

Outreach to the public has been an important component of the work. Casperkill Assessment Project (CAP) members presented their findings at public forums in September of 2006 and 2007 during which streamside residents expressed concerns about pollution, flooding, and loss of biodiversity. These forums led to further presentations before the Town of Poughkeepsie town board and at local Hudson Valley watershed conferences. In addition, over the summer of 2007, CAP members distributed a survey to residents and business owners in the watershed to determine how residents viewed and used the stream and whether sufficient interest existed to create a watershed protection group. The goal of the CAP is to build a collaborative project involving residents of Poughkeepsie and students and faculty at Vassar College to help make the Casperkill the best and healthiest possible community resource.

This report summarizes the research and makes recommendations designed to protect the stream from further degradation and, if possible, to restore the most impaired segments. The intended audience is homeowners who live along the stream, and who therefore have the greatest opportunity to beneficially impact its health, along with Vassar College officials, the Town and City of Poughkeepsie governments, the Dutchess County legislature, local planners and developers. The structure of this report is based in part on the excellent Watershed Management Plan for the Fall Kill written by Patrick Bean and Thomas Lynch at Marist College and David Burns at the Dutchess County Environmental Management Council and the Natural Resource Management Plan for the Fishkill Creek Watershed written by David Burns and Lisa Vasilakos of the Dutchess County Environmental Management Council and Rick Oestrike of the Fishkill Creek Watershed Committee. Background information on streams and watersheds and specific results of the CAP work are discussed at the beginning of the report, with a detailed methods section included in an appendix for those who are interested in learning more about how analyses were conducted. Data tables of water chemistry, bacteria, and benthic macroinvertebrate analyses are available from the authors upon request.

Characteristics of Healthy and Unhealthy Watersheds

Watersheds are tracts of land that drain rainfall to a particular point on a waterbody. Their boundaries are determined by the locations of drainage divides, high points in landscapes that separate waters flowing in adjacent stream networks (Fig. 2), and each contains an infinite number of smaller subwatersheds (Ritter, Kochel and Miller, 2002). For example, the Ohio River watershed is nested within the larger Mississippi River watershed, and actions taken within the Ohio watershed can affect the lower reaches of the stream network. The fundamental components of watersheds are hillslopes and stream channels, and in a typical healthy watershed in the northeastern United States, hillslopes are forested.

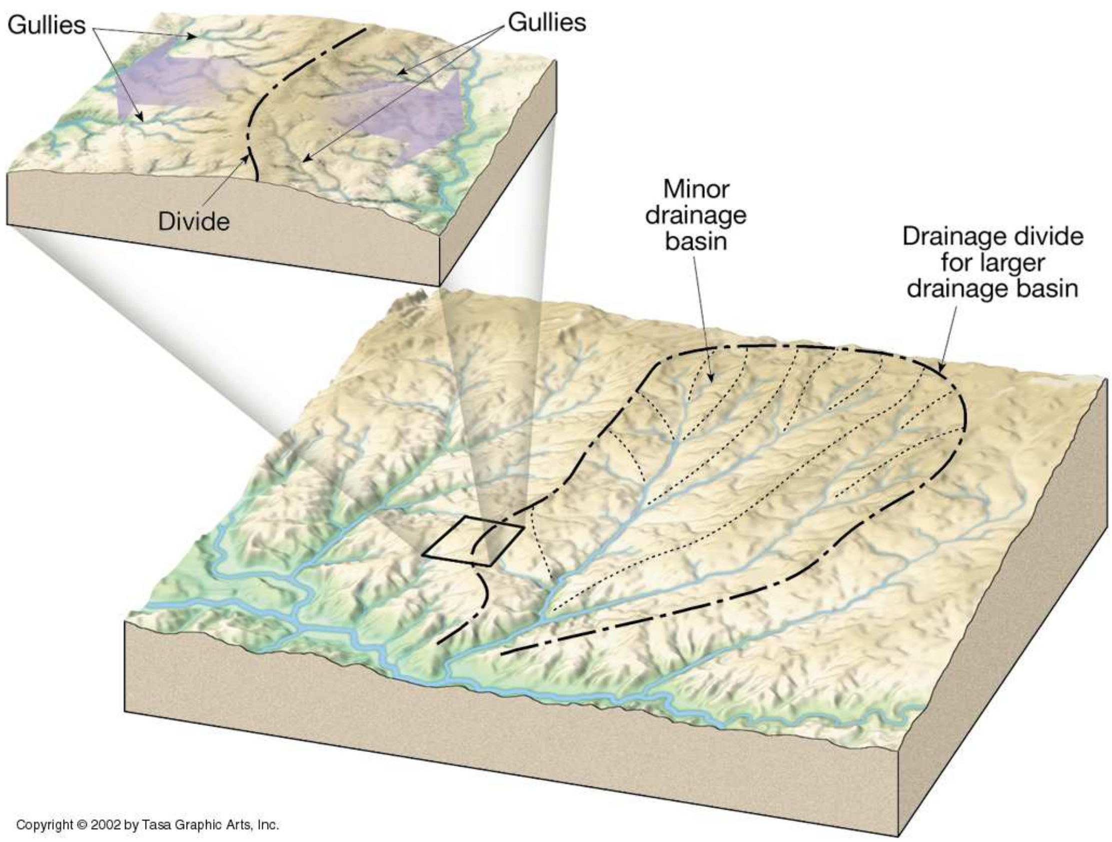

Fig. 2: Watersheds (also called drainage basins) are tracts of land that drain to a particular point in the landscape and are separated from one another by topographic divides. Smaller subwatersheds are nested in larger watersheds.

Trees shade the stream channel from the sun's heat during the summer months, keeping the water cool for fish, and fallen logs provide habitat for these and other aquatic animals (Allan and Castillo, 2007, p. 90, 97). Leaves and twigs drop into the channel and supply food for insect larvae, mollusks, and other invertebrates living in the stream. The presence of vegetation along the channel serves to stabilize the stream's banks and to reduce the erosive power of rain. Each tree, with it's thousands of square feet of leaf surface area, intercepts rainwater and slows or even prevents its descent to the forest floor (Fig. 3). Thus slowed, rainfall has a greater chance to percolate into the pore spaces in soil, allowing for groundwater recharge and decreasing the amount of runoff to stream channels (Federal Interagency Stream Restoration Working Group, 2001). Storm events may cause stream levels to rise, but the rise is small and occurs only after leaves begin to drip water onto the forest floor and pore spaces in the soil become saturated. During periods of drought, infiltrated groundwater gradually migrates toward stream channels and provides life-sustaining flow (Charlton, 2008, p. 26).

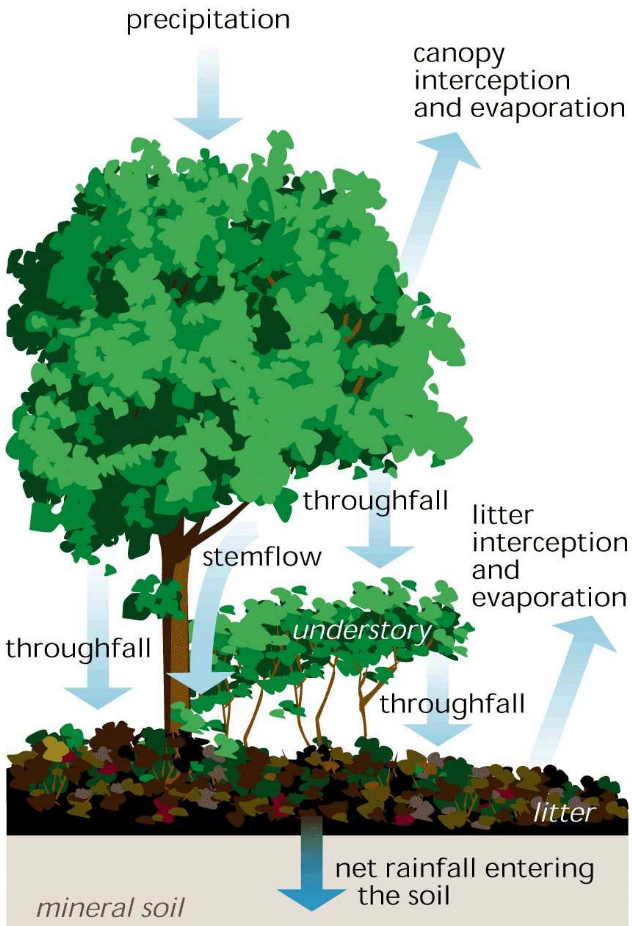

Fig. 3: Trees intercept rainwater falling to the forest floor, decreasing the total amount of water and the rate at which it is delivered. From the Federal Interagency Stream Restoration Working Group, 2001, <http://www.nrcs.usda.gov/technical/stream_restoration/Images/scrhimage/chap2/fig2-03.jpg>

A healthy watershed supports thriving aquatic and terrestrial ecosystems. Nutrients like nitrogen and phosphorus are continuously cycled between soils, vegetation, stream water and animals, and the wastes produced by one organism become food for the next (Mankin et al., 2007; Allan and Castillo, 2008, p. 7). Vegetation, along with underlying bedrock and soils, affects the chemistry of stream water, determining its acidity or alkalinity and the amount of dissolved nutrients available to aquatic organisms. Vegetated hillslopes reduce the amount of sediment washing into streams (Allan and Castillo, 2008, p. 332), and soil organic matter traps heavy metal pollutants before they can enter the water (Chen et al., 2004).

Stream channels in healthy watersheds display a variety of habitats for aquatic organisms (Allan and Castillo, 2008, p. 75). Shallow, fast-flowing riffles contain gravel and cobble-sized rocks that provide shelter for fish, crayfish, and insect larvae. Bacterial slimes and algae growing on these rocks are food for higher organisms. These bacteria and algae are also critical for capturing nutrients from stream water and making them available to the aquatic food web. Deeper, slower flowing pools have floors of silt and sand and support burrowing worms and molluscs. Additional flow regimes, such as glides and runs (intermediate in water depth and speed) may also exist (Vermont Agency of Natural Resources, 2004). Not only do stream channels provide habitat, floodplain wetlands provide essential spawning grounds for fish and amphibians and foraging habitat for birds. These wetlands also store and infiltrate storm water to the underlying groundwater system, reducing runoff and flooding hazards (Federal Interagency Stream Restoration Working Group, 2001).

In unhealthy watersheds, forested slopes have been replaced by pavement, lawns or unprotected bare soil. Impervious surfaces, such as driveways, buildings, sidewalks, and parking lots, prevent rainwater from soaking into the ground and storm sewers carry rainfall directly to streams. A lack of trees to intercept rainwater and impervious surfaces increases the total amount of runoff and the speed with which it reaches channels, and filling in of floodplains and small wetlands for development reduces the ability of the landscape to store storm water (Federal Interagency Stream Restoration Working Group, 2001). Streams in urbanized environments thus exhibit higher peak flows and more rapid rises and falls of water level, a condition known as "flashy" behavior (Fig. 4). Increased peak discharge leads to a greater frequency of flooding, and increased velocity gives the stream greater erosive power.

Clearing of land for construction or agriculture causes destabilization of soils on hillslopes and consequent sediment movement into stream channels (Wolman, 1967). Filled with sediments, streams lose their capacity to carry storm flow and overflow their banks with greater frequency, and fish and other aquatic organisms lose the diversity of habitats they depend on for their survival and reproductive success (Borchardt and Statzner, 1990; Paul and Meyer, 2001). Once their watersheds are developed and pavement replaces bare ground, streams become flashier and begin to erode, both deepening and widening their channels. Homeowners living along the stream may notice the channel begin to change as the stream strives for a new equilibrium (Riley, 1998, p. 136).

In addition to sedimentation, aquatic ecosystems in developed watersheds have to contend with urban toxins (Paul and Meyer, 2001; Walsh et al., 2005). Motor oil, antifreeze, road salt, and other automotive chemicals washing off of paved surfaces shock sensitive aquatic organisms, and fertilizer runoff from lawns along with sewage from failed septic systems promotes the overgrowth of algae that then decays and consumes dissolved oxygen. The lack of trees to shade the stream and runoff from hot parking lots in the warmer months warms the water beyond the capacity of some species to survive and prevents the essential uptake of excess nutrients supplied by fertilizer applications (Galli, 1990; Thompson et al., 2008). The result is an impoverished ecosystem.

Fortunately, scientific studies published in the last two decades have pointed the way toward minimizing the impact of development on streams (Coffman, 1999; Hood et al., 2007; Booth et al., 2002). From the construction of rain gardens that allow runoff from impervious surfaces to infiltrate into soils to clustered development and the maintenance of healthy vegetative buffers along streams, there are many steps we can take to reduce or even avoid the unhealthy watershed scenario, several of which will be detailed later in this report.

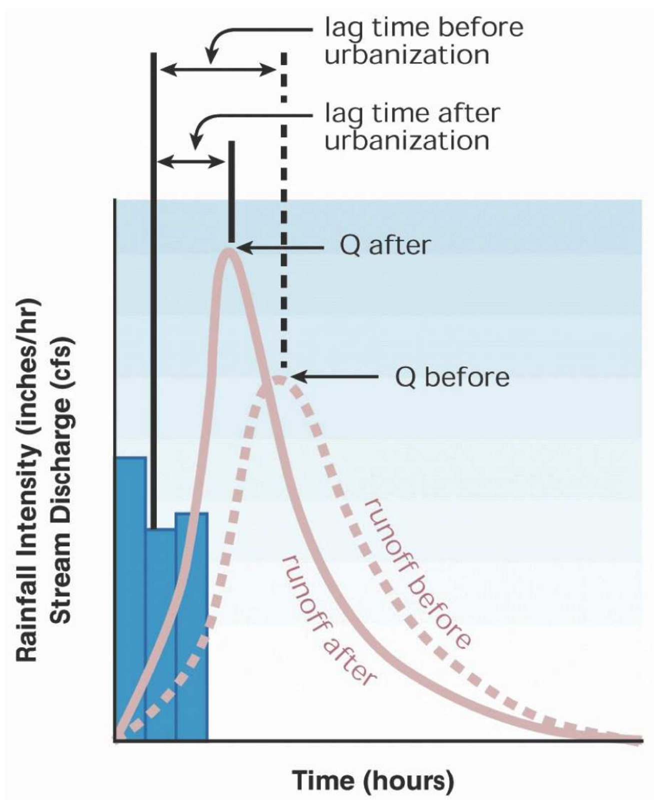

Fig. 4: Stream flow (Q) for the same size storm before and after urbanization. Note that the peak flow is higher and occurs earlier in the urbanized watershed (runoff after) than in the unurbanized watershed (runoff before). From the Federal Interagency Stream Restoration Working Group, 2001. <http://www.nrcs.usda.gov/technical/stream_restoration/Images/scrhimage/chap1/fig1-15.jpg>

The Casperkill and its Watershed

General Setting

The Casperkill flows entirely within the Town of Poughkeepsie, in Dutchess County, NY (Fig. 5). The 11 mile (18 km) long stream begins in a wetland at the base of Peach Hill Park on the north side of Bedell Rd. and empties into the Hudson River southwest of the Poughkeepsie Galleria (Fig. 6). It is joined by a major tributary, the Fonteynkill, on the Vassar College campus just south of the Sunset Lake dam. Together, these streams and several smaller tributaries occupy a 12 square mile (31 km^2) watershed that includes areas of both the City and Town of Poughkeepsie.

For the purposes of understanding trends in water quality, the Casperkill Assessment Project identified seven zones of contrasting land use along the length of the stream (Fig. 1). The uppermost zone ("rural") comprises woodlands and wetlands, with limited residential and commercial development. The Casperkill then crosses a zone of shopping centers, parking lots (Dutchess and 44 Plazas on Rt. 44), and government offices (Town of Poughkeepsie Police and Court Facility on Tucker Dr., Eleanor Roosevelt state office building on Burnett Blvd.), some of which are built atop unlined landfills, a landscape hereafter referred to as the "commercial" zone (Fig. 1). In this zone, segments of the stream are diverted into subterranean pipes, and the remainder is confined to a steeply banked, narrow channel lined with rock cobbles. Parking lots drain directly into the channel, and no tree canopy exists. A salt storage shed and associated truck loading area operated by the New York State Department of Transportation and the Dutchess County Public Works Highway Department also lie within 65 ft of the stream in this zone. Due to the poor quality of the stream-side buffer and the commercial nature of this zone, the Casperkill is littered with trash, ranging from rusting shopping carts and bicycles to plastic bags, soda bottles, and fast-food wrappers (Fig. 7).

Downstream of the commercial zone lies the Vassar College campus ("campus", Fig. 1), where some of the channel resumes a more normal form and a narrow (10-130 ft) band of shrubs and trees lines most of the stream. A campus road occupies part of the floodplain just north of Sunset Lake, coming within 10 ft of the channel. Within the campus zone, the Casperkill is joined by a major perennial tributary, the Fonteynkill, which surfaces from underground culverts about 3,300 ft upstream of the confluence. The Fonteynkill drainage composes a separate "urban" zone (Fig. 1), which represents a residential portion of the City of Poughkeepsie, with impervious surface cover (roads, driveways, rooftops, parking lots) greater than 60 percent. Despite the high level of impervious cover, the stream channel is bordered by residential lots and a 13-230 ft wide band of trees. The scent of raw sewage and high bacterial counts at the point where the Fonteynkill emerges from the underground pipe system to which it has been confined (at Park Ave.) suggests some sort of leak of the sanitary sewer system.

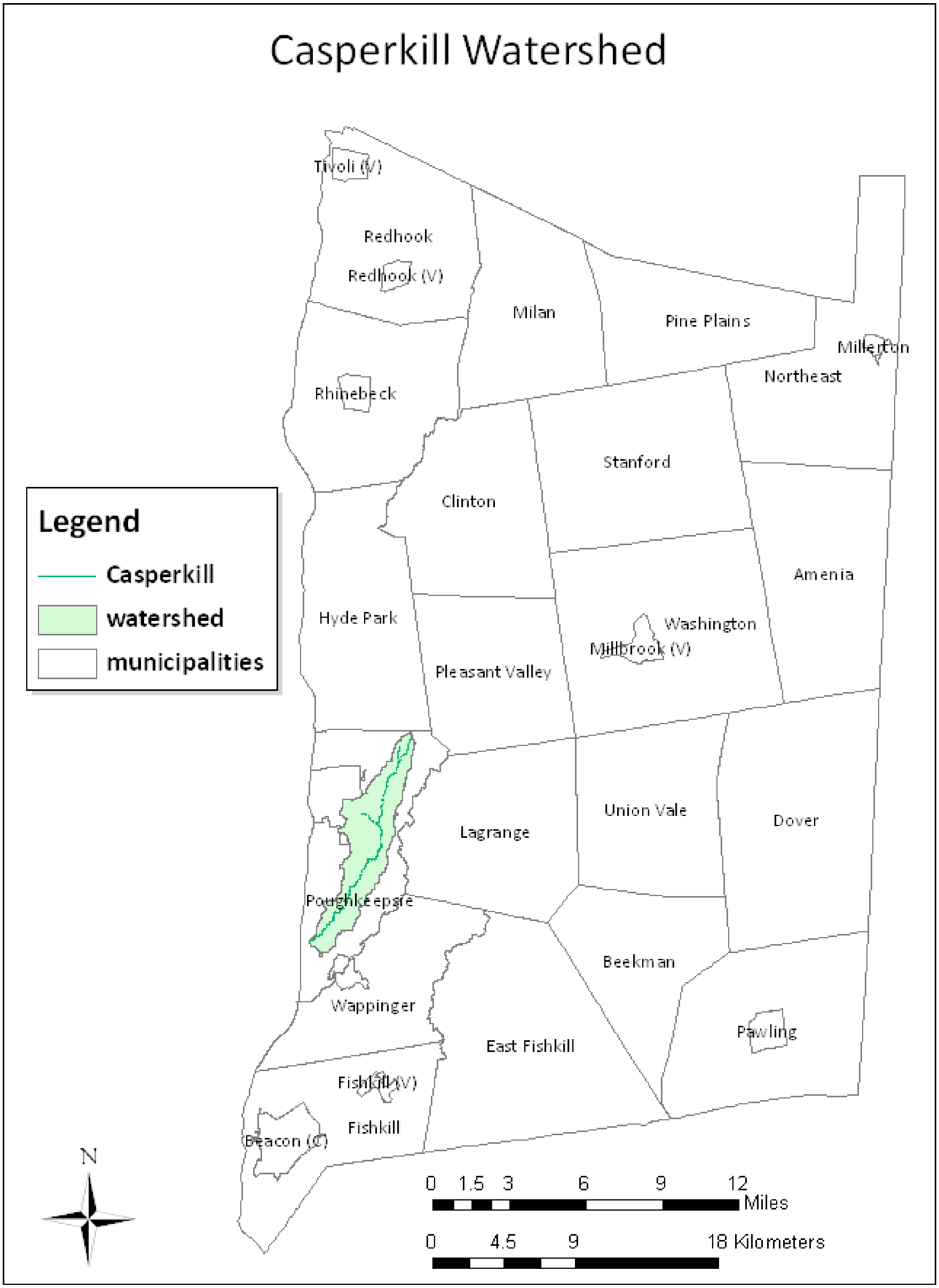

Fig. 5: Location of the Casperkill watershed in Dutchess County, New York.

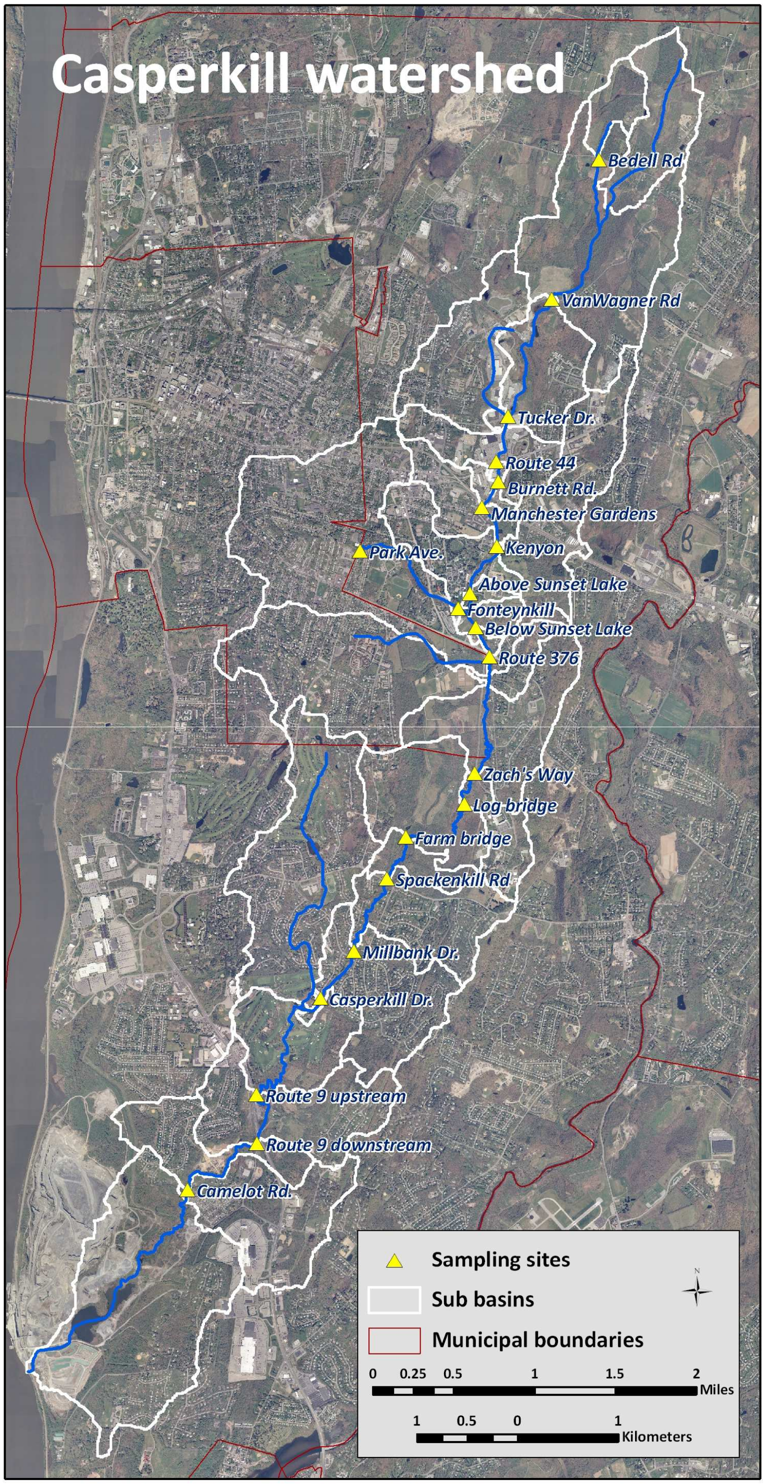

Fig. 6: Aerial photograph of the Town and City of Poughkeepsie showing the location of the Casperkill, its watershed boundary, and the 21 sampling sites used in the study. Channel location between Tucker Dr. and Manchester Gardens sites is approximated due to the fact

that much of it is underground in pipes. The Fonteynkill tributary flows between the Park Ave. and Fonteynkill sampling sites.

Fig. 7: Photos of the Casperkill channel in the Dutchess and 44 Plaza area. The stream has been artificially straightened and deepened and lined with rock cobble rip-rap. Trash, including shopping carts, plastic bags, fast-food wrappers, and soda bottles, litters the site.

Below the confluence of the two streams is an area of suburban residential development between Zach's Way and Boardman Rd. where back yards of homes abut the stream, and in which a forested buffer of 65-165 ft width has been maintained by most residents ("suburb 1", Fig. 1). The stream next enters the 110-ha, largely forested Vassar College Farm and Ecological Preserve ("green space", Fig. 1) in which it meanders freely across a forested flood plain with a vegetated buffer 300 to 2000 ft in width, and another zone of suburban residential neighborhoods with characteristics nearly identical to the first suburban area ("suburb 2, Fig. 1). Within this second suburban zone, the Casperkill passes through the Casperkill Golf Club, where the channel is bordered by lawn. Before entering the Hudson River, the stream crosses a limestone quarry operated by the Tilcon Corporation.

A number of dams on the stream and its tributary the Fonteynkill form small reservoirs. Notable among these are Vassar and Sunset Lakes on the Vassar College campus and two smaller ponds, one on the Casperkill golf course and the other at the Best Western motel on Rt. 9. The extent to which these dams act as barriers to fish migration from the Hudson River has not been assessed in this study. It should be noted that numerous smaller barriers may also present problems for migratory fish. These include culverts and other types of bridge crossings.

Wildlife Resources

The stream and its associated buffer areas host a variety of wildlife including mammals, reptiles, fish, amphibians, and birds. Coyotes, rabbits, deer, mice, foxes, skunks, opossums, muskrats, and raccoons are among a few of the mammals that find refuge in the streamside habitat. Additionally, a variety of fish, painted turtles, box turtles, snapping turtles, green frogs, wood frogs, benthic macroinvertebrates and spring peepers use the waters of the Casperkill for their homes. Birds that utilize the stream and/or surrounding buffer include robins, chickadees, titmice, scarlet tanagers, blue jays, downy and hairy woodpeckers, Carolina wrens, nuthatches, juncos, eastern bluebirds, sparrows, pileated woodpeckers, red-tailed hawks, swans, ducks, Canada geese and even great-blue herons (Ralph Waterman bird club listing; CAP observations).

Fish species diversity in Sunset Lake was last determined in 1992 prior to a sewage overflow into the Casperkill just upstream of the lake that killed off nearly all of the biota as dissolved oxygen levels in the stream and lake plummeted (John Long, Vassar College Biology Department, personal communication). At the time of the census, the lake was home to largemouth bass, black crappies, red-breasted sunfish, pumpkinseed sunfish, redfin pickerels, mosquito fish, white suckers, yellow bullheads, and goldfish. After the dissolved oxygen crisis abated, Vassar Buildings and Grounds staff hired Northeastern Aquatics to restock the lake with golden shiners, brown and yellow bullheads, bluegills, pumpkinseeds, largemouth bass, and redfin pickerels, but it is unknown which species currently occupy the stream.

The Casperkill also provides valuable habitat for regionally and globally threatened freshwater mussels. Four species of the Unionidae family reside in the Casperkill, including the *Pyganodon cataracta*, *Utterbackia imbecillis*, *Elliptio complanata*, and *Strophitus undulates* (Gillikin, unpublished data). Casperkill researchers studied four other regional streams for the presence of freshwater mussels and found that the Casperkill is the only stream to have four species of Unionidae; the other streams (Fall Kill, Crum Elbow, Landsmankill, and Saw Kill) have only one each (Gillikin, unpublished data).

Land Cover

The distribution of different land covers in the Casperkill watershed is variable, with some areas highly urbanized and others more natural (Fig. 8). In the watershed as a whole, 43% of the land is forested, 33% is covered in impervious surfaces, and another 19% is classified as grass. The latter category includes open fields, lawns, and golf courses. The remaining 5% of the landscape consists either of water bodies (small ponds and lakes) or of fallow areas. The Tilcon quarry site is classified as impervious surface inasmuch as the runoff potential of bare stone is similar to that of paved surfaces.

The most urbanized part of the watershed surrounds the Fonteynkill tributary, which drains a portion of the City of Poughkeepsie. Here impervious surfaces constitute as much as 70% of the total landscape. The least urbanized stretches include the northernmost part of the watershed between Van Wagner Rd. and Peach Hill Park, the Vassar Farm and Ecological Preserve, and lands surrounding the Casperkill Golf Club. These areas have vegetative buffers along the stream channel that are largely intact.

In our study, we examined the response of water quality parameters to three different land cover scales, the "subwatershed," "riparian buffer," and "site" scales (Fig. 9). For subwatershed, we used Landsat satellite imagery to determine the percentage of the total watershed area upstream of each of our 21 sampling sites that was impervious surface. For the riparian buffer scale, we determined what percentage of the landscape in a 100 m (328 ft) wide by 200 m (656 ft) long swath surrounding the sampling site was forested or impervious. For the site scale, we determined the total length of vegetated surface in a 50 m (164 ft) transect perpendicular to each side of the stream channel at each sampling site. Landsat imagery may overestimate the actual percentage of impervious cover, because these satellite photos are made up of pixels with a resolution of 30 x 30 m. This means that if more than 50% of an individual 30 x 30 m area was made up of impervious surface, the entire pixel is reported as impervious. Despite this limitation, Landsat images are useful in illustrating different levels of development within watersheds.

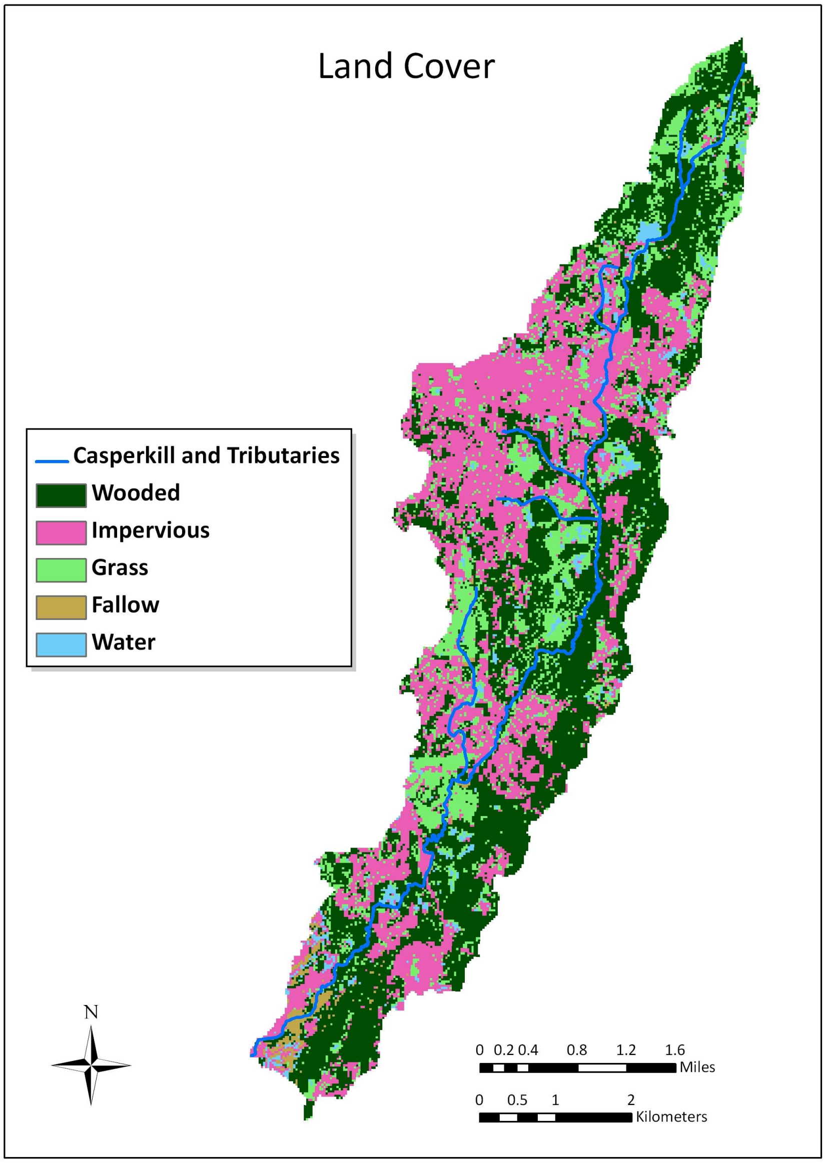

Fig. 8: Landcover in the Casperkill watershed is highly variable. The Fonteynkill subwatershed contains the highest amount of impervious surface at nearly 70%. The northernmost part of the watershed and the area of the Vassar Farm Ecological Preserve contain the most intact riparian buffer.

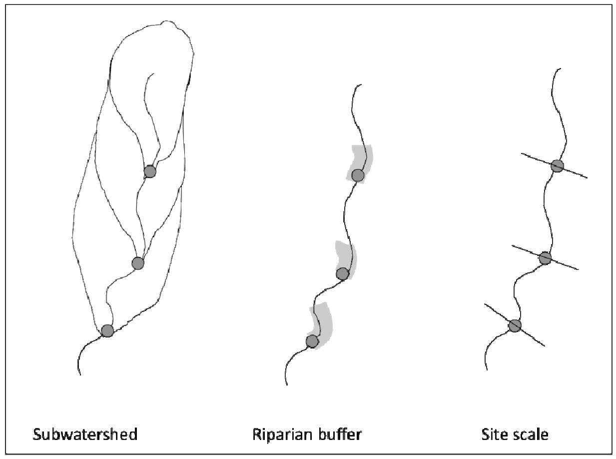

Fig. 9: The three ways land cover is analyzed in this study: the subwatershed scale considers the entire subwatershed that drains to a sample site; the riparian buffer scale considers a 100-m-wide by 200-m-long area upstream of the site; the site scale method considers a 50 m transect perpendicular to each side of the channel.

We found that the percentage of impervious cover varied dramatically between the three scales of measurement even within the same land use zone. For example, suburb and green space zones had low riparian buffer and site scale impervious cover while the amount of impervious cover at the subwatershed-scale was as high as 35 percent (Fig. 10). The commercial zone had low subwatershed impervious cover but 100 percent impervious cover at the riparian buffer and site scales.

Numerous studies (Kaushal et al. 2005, Paul and Meyer 2001, Feminella and Walsh 2005) have shown a link between land cover and the health of aquatic ecosystems, and different land covers can determine whether a watershed is characterized as “healthy” or “unhealthy.” The Casperkill Assessment Project (CAP) analyses presented below show that the Casperkill is in general “unhealthy,” and suffers from all of the components of the “urban stream syndrome” (Walsh et. al 2005a). The data also show that different sources of impairment respond to different scales of land cover change.

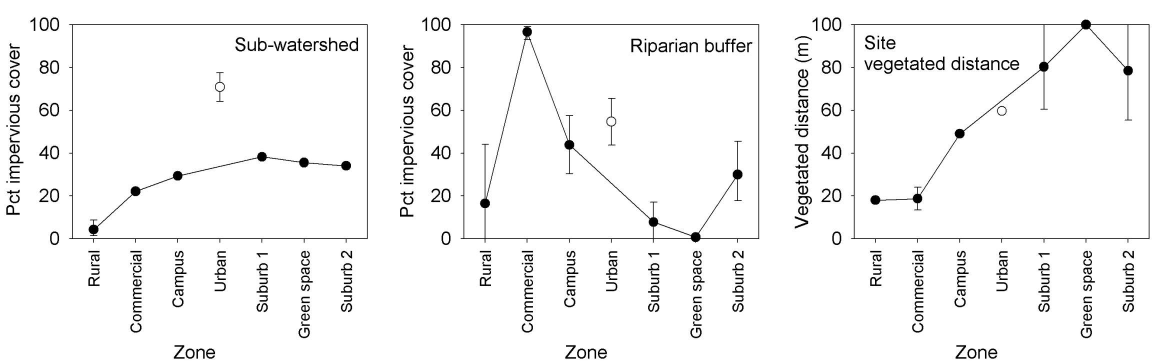

Fig. 10: Land cover information for the three different scales of analysis by land-use zone (zones shown in Fig. 1). Note that the subwatershed and riparian buffer graphs show percentage of impervious surface on the y-axis whereas the site scale graph shows the total length of vegetative cover along a 100-m transect straddling the stream.

Geology and Soils

Bedrock underlying the Casperkill watershed consists primarily of sedimentary rocks from two formations, the Cambro-Ordovician age (540-443 million year old) Wappinger Group dolomite (calcium-magnesium carbonate) and the Ordovician age (490-443 million year old) Normanskill group (shales and sandstones cemented by calcium carbonate) (Fig. 11). These rocks are overlain by sediments left behind by an ice sheet that covered this area until ~18,000 years ago (reported as ~15,300 years radiocarbon in Bloom, 2008, and converted to calendar age here). These sediments consist of unsorted mixtures of large rocks and finer silt and clay known as glacial till, produced as the ice sheet ground over the underlying bedrock, along with lesser quantities of sediments deposited by streams issuing from the melting ice (Connally and Sirkin, 1986). The latter sediments include stream, delta, and lake sediments (Fig. 12) and tend to be better sorted and finer grained than the glacial till. The fact that the Casperkill flows through rocks and sediments containing abundant calcium carbonate means that the stream water is well buffered from acid rain inputs, and our measurements place the pH of the stream between 6.5 and 8 on a scale of 1 (acidic) to 14 (alkaline), where 7 is considered neutral.

Soils in the watershed are typically loamy (containing mixtures of sand, silt, and clay), with silt loams developed on glacial lake deposits and gravelly loams on till (Fig. 13, Table 1). Soils are assigned a drainage class value that reflects the rate at which rainwater percolates through them (Rawls et al., 1993). Class A soils transmit water quickly, leading to soils that are well to excessively well drained and to high amounts of groundwater recharge that maintain stream flows during dry spells. Class B soils are considered moderately well drained, class C poorly drained, and class D very poorly drained. Classes C and D commonly generate runoff during heavy rains as pore spaces in these soils fill with water and the slow infiltration rate inhibits downward movement of water. The Chazen Companies have determined groundwater recharge rates in Dutchess County for these different drainage classes, finding rates of 17.3-20.2 inches/yr for class A, 12.6-14.7 inches/yr for class B, 6.5-7.6 inches/yr for class C, and 3.6-4.2 inches/yr for class D (Urban-Mead, 2006). Given the importance of groundwater recharge in maintaining healthy stream flows between precipitation events, it is important to identify critical recharge areas and minimize impervious surfaces on class A and B soils. In places where impervious surfaces are necessary, rain gardens, bioretention swales, and other retention devices can be used to capture storm water and allow it to recharge aquifers.

In the Casperkill watershed, nearly 40% of soils are class C or D, with 50% better drained (~10% of soils have unspecified drainage characteristics). Since poorly drained soils make up nearly half the watershed, drainage management during storms is a nontrivial affair for both the watershed as a whole and for individual households. Soils developed on the Casperkill floodplain tend to be among the most poorly drained. Residents of the first suburban zone (around Zach's Way and Boardman Rd.) have reported difficulties with their septic systems associated with high rainfall and stream flow events. Saturation of soils leads to rising water tables that force septic effluent to the ground surface, resulting in unpleasant odors and occasionally backwash of septic effluent into homes through household plumbing systems.

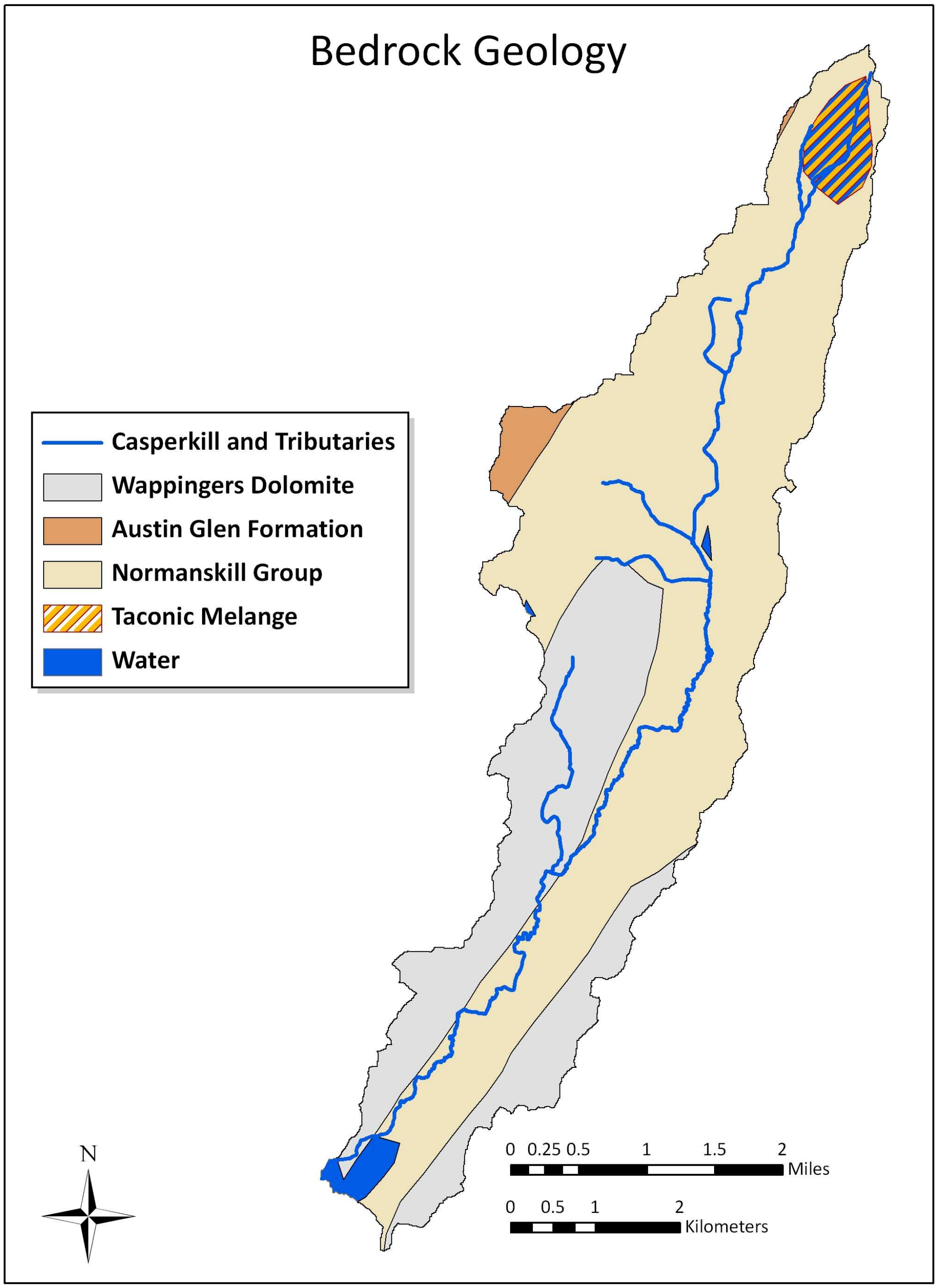

Fig. 11: Bedrock geology of the Casperkill watershed (from New York State Museum, 1999a).

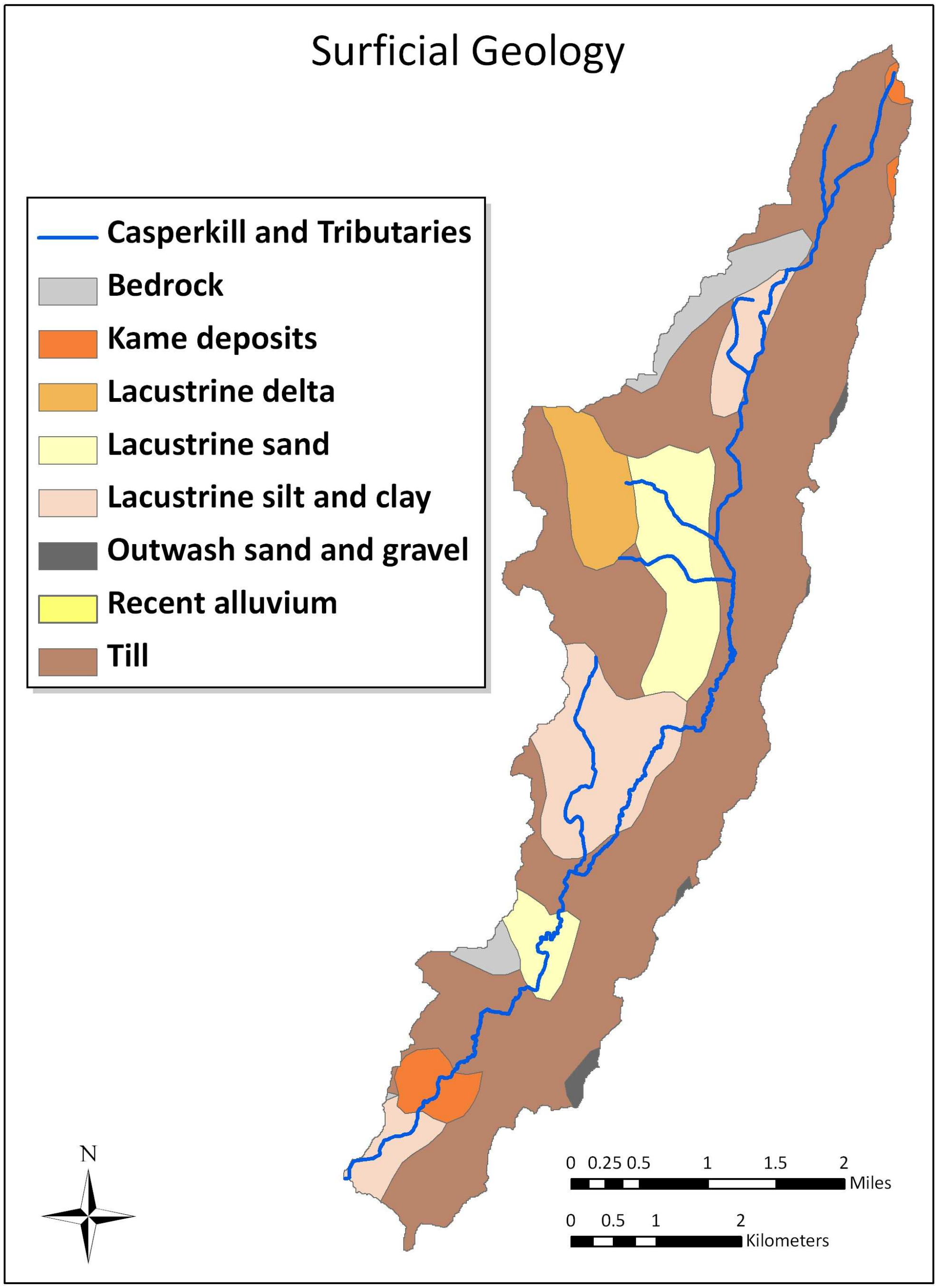

Fig. 12: Surficial geology of the Casperkill watershed (from New York State Museum, 1999b).

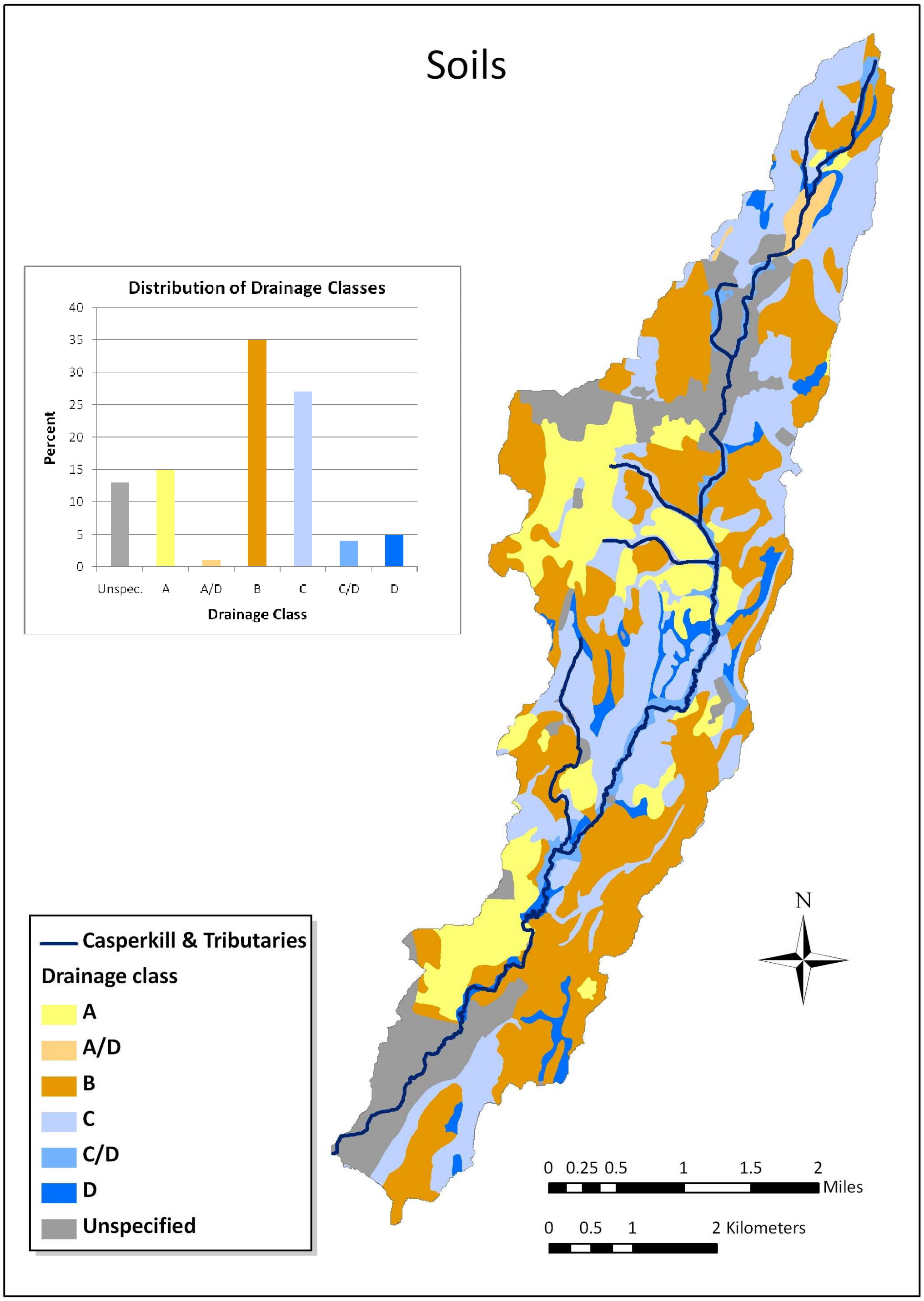

Fig. 13: Drainage class of soils in the Casperkill watershed. Poorly (class C) to very poorly (class D) drained soils make up about 40% of the watershed (from Soil Survey Staff, 2008).

Table 1: Drainage characteristics of Casperkill watershed soils.

Soil type	Area (acres)	Drainage class
Knickerbocker fine sandy loam	786	A
Hoosic gravelly loam	352	A
Dutchess – Cardigan complex	1391	B
Galway – Farmington complex	940	B
Haven loam	192	B
Copake gravelly silt loam	168	B
Dutchess silt loam	8	B
Linlithgo silt loam	2	B
Bernardston silt loam	627	C
Nassau-Cardigan complex	309	C
Hudson and Vergennes soils	231	C
Stockbridge–Farmington comp.	196	C
Fredon silt loam	174	C
Pittstown silt loam	93	C
Farmington with rock outcrops	87	C
Farmington – Galway complex	79	C
Stockbridge silt loam	76	C
Punsit silt loam	71	C
Massena silt loam	65	C
Georgia silt loam	39	C
Raynham silt loam	19	C
Palms muck	74	A/D
Wayland silt loam	219	C/D
Halsey mucky silt loam	50	C/D
Canandaigua silt loam	236	D
Livingston silt clay loam	60	D
Fluvaquents	46	D

Kingsbury and Rhinebeck soils	7	D
Quarry Pit	344	Unspecified
Urban Land	318	Unspecified
Udorthents	316	Unspecified
Water	47	Not Applicable

Stream Flow, Flooding, and Erosion

Daily stream flow on the Casperkill was measured by the U.S. Geological Survey (USGS) between March 1969 and October 1975. The gauging station was located on Camelot Rd. at the north end of the Tilcon Quarry. In the six years of record, flow varied between 1.5 and 340 cubic feet per second (cfs), with an average of 17.9 cfs. Stream flow showed highest values during the spring snowmelt period, and flow was generally lowest in the summer and early fall months, exceptions being 1971 and 1972 when summers were particularly wet. No information exists on the flooding threshold for the stream at the location of the stream gauge, which makes these data difficult to interpret.

As part of the current study, we installed a stream gauge on the segment of the Casperkill that lies in the "suburb 1" zone between Rt. 376 and Spackenkill Rd. The gauge measures water pressure variations related to changes in stream surface elevation, and it has been calibrated to provide flow (Fig. 14; Charlton, 2008, p. 26). In operation since July of 2007, this gauge shows similar patterns to the USGS data, with flow highest during the spring snowmelt period and lower during summer months (Fig. 15). Due to differences in drainage area between the two sites, the two records are not directly comparable, and flows measured at the modern gauge vary between 2 and 90 cfs. At the CAP site, the stream overflows its banks after reaching a discharge of approximately 56 cfs, a flow that was exceeded 15 times in the period from July 10, 2007 to Oct. 30, 2008.

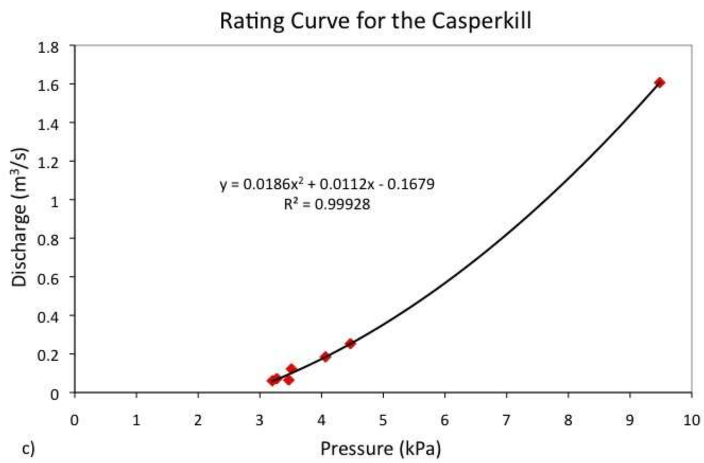

Fig. 14: a) Hobo water pressure sensor used to gauge stream discharge. b) Perforated pipe holding the Hobo sensor. c) Relationship between water pressure and discharge measured using a propeller flow meter.

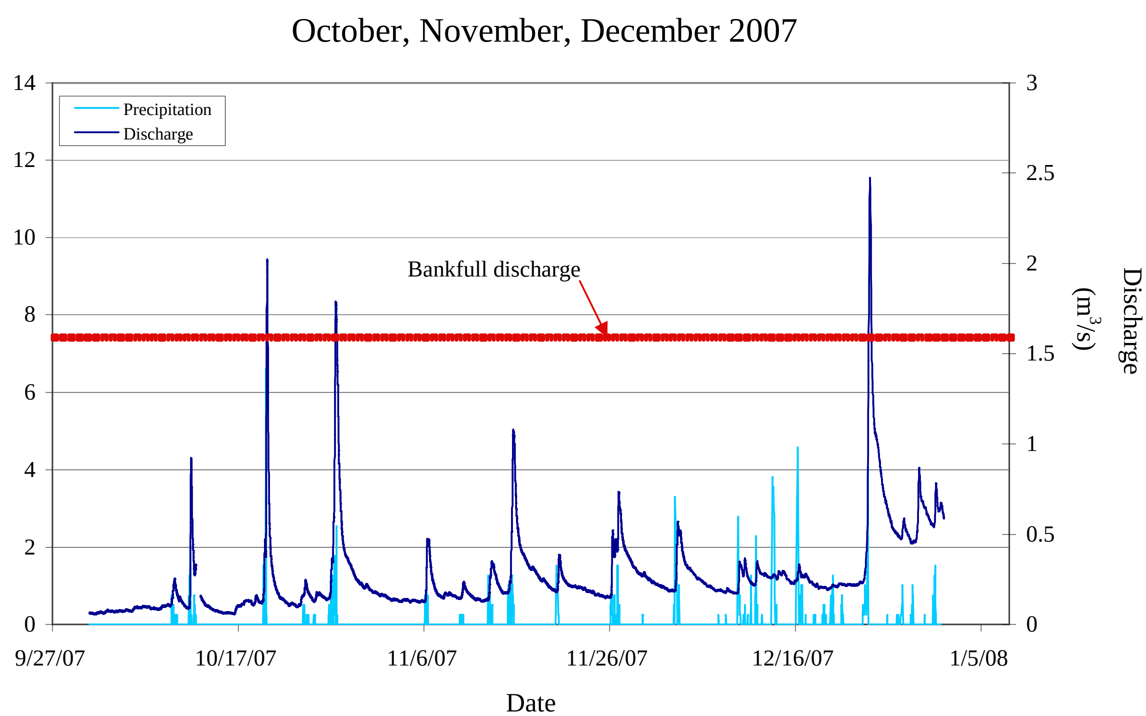

Fig. 15: Stream flow (discharge) and precipitation. Flow rises quickly during rainfall events. Note that dates later in the year (centered around 12/16/07) often show a more subdued change in flow for the same or greater amount of precipitation as fell earlier in the year. These subdued responses reflect precipitation that fell in the form of snow, which less readily enters the stream channel than that which fell as rain. The large increase in discharge at the

end of December reflects a rain on snow event, which resulted in a high amount of snowmelt. Bank full discharge (red line) measures 1.6 m^3/s (56 cfs).

In undisturbed watersheds, streams fill to their banks (called bank full level) only once every 1-2 years (Charlton, 2008, p. 32), so the fact that the Casperkill so frequently overflows suggests that the channel is not in equilibrium with the amount of water it is trying to convey. Potential causes of disequilibrium include a change in climate toward wetter conditions, an increase in the amount of impervious surface in the watershed that speeds runoff into the stream channel, a localized constriction in the channel that backs up water upstream, loss of wetland and floodplain water storage, or some combination of these factors. The fact that the Casperkill overflows its banks during even relatively small storms suggests that impervious surface and loss of storm water storage capacity through wetland infilling is the likely cause. Anecdotal evidence from the homeowners who host the Casperkill Assessment Project stream gauge suggests that construction of a housing development upstream of the site a decade ago may have increased the amount of runoff entering the stream. A box culvert draining the impervious surfaces from that neighborhood lies ~120 m upstream of the gauging station, and these homeowners have noted an increase in high flow events on their property since its installation.

Responses of streams to disequilibrium typically take the form of increased erosion as the stream deepens and widens its channel to accommodate higher flows (Riley, 1998, p. 132). Residents along the Casperkill have reported erosion problems, which may be further exacerbated by poor stream bank management. A stream walk conducted by CAP members revealed that many homeowners have lawns leading directly to the stream edge and are apparently unaware of the importance of stabilizing shrubby vegetation. Even locations with proper stream bank management can suffer from improper management upstream of their site. Poughkeepsie Journal articles from April of 2007 report numerous accounts of stream erosion in nearby watersheds caused by unusually high floodwaters. In one instance, a resident of the Ten Mile watershed invested $50,000 in stream bank mitigation on her property only to have severe flooding destroy the work and part of her property Woyton, 2007).

While problems on the Casperkill are not as severe, erosion still constitutes a problem for some property owners, who have witnessed channel migration that threatens loss of land. It is also a problem for aquatic ecosystems, which suffer when sediments are washed into streams, smothering filter feeders and changing the grain size of materials on the channel bottom. Nooks and crannies between gravel and cobble-sized rocks that are used as shelter by stream-bottom organisms may fill in with eroded sediment and destroy habitat (Fig. 16). In addition, some fish species require a particular grain size of sediment to shelter their eggs. As erosion proceeds, their spawning grounds may disappear. Channel bottom cobble embeddedness data suggest that the Casperkill may suffer somewhat from sedimentation issues. At sites sampled for benthic macroinvertebrates (see Aquatic Community Health section below), cobbles were sometimes deeply buried in finer grained materials (Fig. 17). In addition, several sites could not be sampled because cobbles could not be found. It is unclear whether these sections of the stream simply lacked an input of coarse debris or if cobbles were 100% buried.

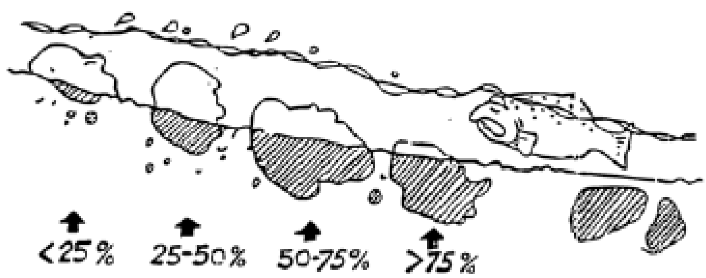

Fig. 16: The more deeply buried cobbles (rocks intermediate in size between gravel and boulders) are, the less habitat they provide for benthic macroinvertebrates and fish. From Behar and Cheo (2004 , pg. 42).

Flooding and erosion issues are often addressed through various "hard stabilization" engineering practices. These include dredging the channel to deepen or widen it so that it will convey more water and armoring channel banks with rip-rap (small boulders), gabions (cobbles contained within wire baskets), or concrete. While temporarily effective, all of these practices ultimately fail and require repeated costly interventions in the channel (Riley, 1998). Furthermore, they can also propagate problems up- and down-stream of the "stabilized" reach, causing problems for adjacent landowners.

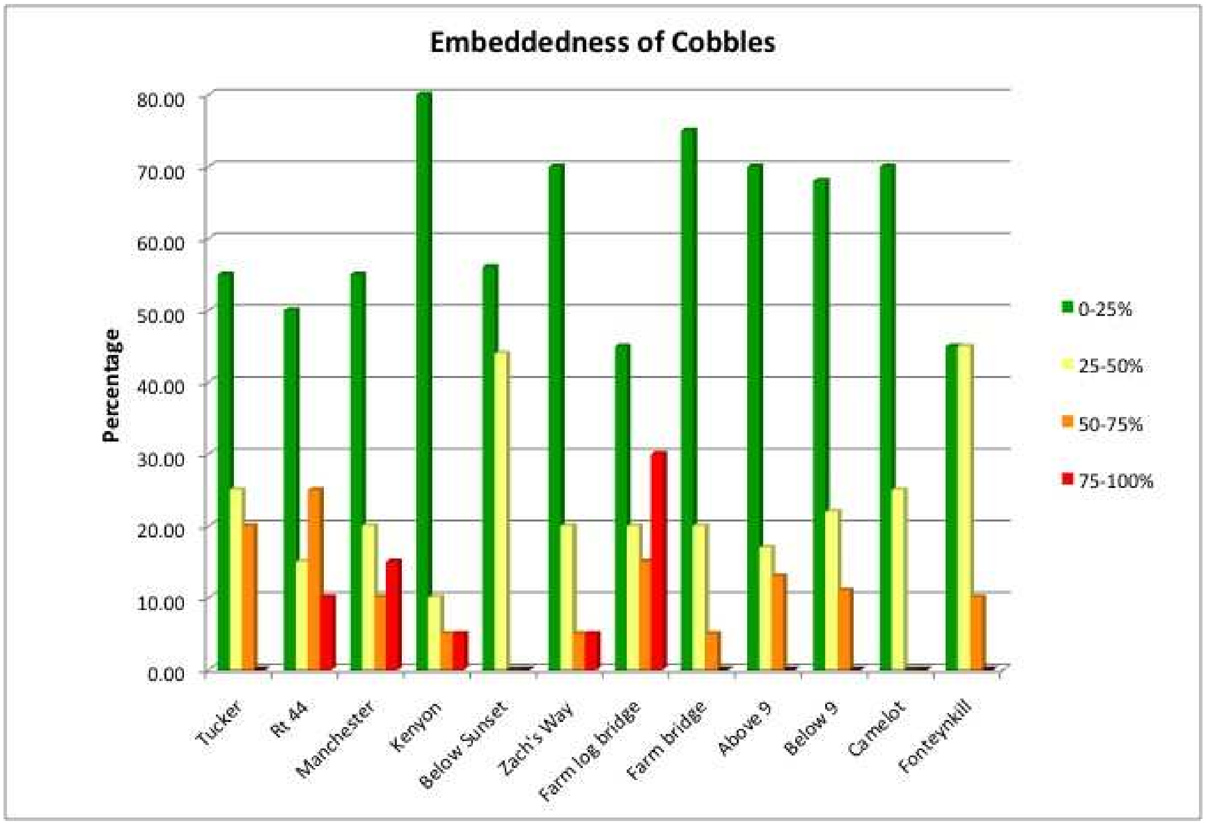

Fig. 17: Percentage of cobbles in each embeddedness class at the benthic macroinvertebrate sampling sites.

Better solutions to flooding and erosion problems come with changes in land management practices. Proper protection of wetlands and avoiding development on floodplains are the first steps towards preventing the causes of stream disequilibrium. Reforestation of expansive lawns and use of rain gardens to allow storm water from rooftops to infiltrate soils can dramatically decrease runoff into stream channels (Buttle, 1994; Dietz and Clausen, 2005). In addition, "Better Site Design" principles (Hood et al., 2007) allow storm water to infiltrate on site by reducing the amount of impervious cover. To adhere to these principles, which will help the Casperkill and other streams in the area, the Town could require residential streets be built to the minimum required width depending on traffic volume, require new development to have shorter streets while maximizing the number of homes along each street, limit the number of residential cul-de-sacs, provide incentives for shared parking spaces, and minimize parking space dimensions in parking lots (Center for Watershed Protection, 1998). The Town could also mandate on-site stormwater management, including use of bioretention areas in parking lots where runoff can slowly infiltrate into the ground. Bioretention areas offer a unique opportunity to increase the aesthetic appeal of parking while offering a low cost, easy maintenance option for reducing impervious surface runoff and ensuring groundwater recharge. Other options to reduce the rate of stormwater runoff and reduce pollutants include dry swales, perimeter sand filters, and filter strips (Center for Watershed Protection, 1998). Furthermore the Town and other local governments can work collaboratively with property owners to restore floodplains or wetlands that were developed to a more natural state.

Additional steps can be taken to deal with erosion problems. The New York State Department of Environmental Conservation's (NYSDEC) Hudson River Estuary Program promotes replanting of Hudson Valley stream corridors through their "Trees for Tribs" Initiative. The "Trees for Tribs" program offers free native trees, shrubs and planting materials as well as technical assistance to project partners, including town governments, watershed groups, and private institutions. The non-profit group Trout Unlimited has also provided shrubs for riparian buffer restoration. Native plantings of vegetation such as willows have a proven superiority over hard stabilization techniques (Riley, 1998), and homeowners (through watershed or non-profit groups) and town governments alike are encouraged to take advantage of the "Trees for Tribs" initiative to stabilize the banks of the Casperkill and other streams in the area.

Aquatic Community Health

A biological assessment of the Casperkill was conducted to determine the ability of the creek to support aquatic life. The assessment included collection and analysis of benthic macroinvertebrates (BMIs are insects with an aquatic larval phase along with aquatic worms, crustaceans, and molluscs) at 12 sites along the creek (data grouped by land use zone are shown in Table 2). BMIs live in the sediments of streambeds for part or all of their life cycles. Some types are capable of tolerating high water pollution and disturbance levels, while others are highly sensitive and tend to die off when water quality is less than optimal (Hilsenhoff, 1987, 1988). Both the abundance of organisms and the diversity of species found provide insight into the general health of the creek and can be used to calculate a biotic index of water quality. Since BMIs depend on environmental conditions similar to those required by trout and other fish, a study of BMI health shows the potential for the health of fish in the creek. This information is especially important given that the Class C rating for the Casperkill designates the creek as suitable for fishing.

The BMI data reveal that aquatic ecosystem health varies along the stream, with some areas in poor condition and a few (particularly in the Vassar Farm Ecological Preserve) in good health. The BMI community is apparently most strongly influenced by the amount of vegetation in the buffer surrounding the stream (Fig. 18), and is relatively insensitive to the overall watershed condition. Low values of biotic index are associated with stream organisms that are extremely sensitive to pollution, whereas high values reflect animals that can tolerate much more degraded conditions. Figure 18 clearly shows that the greater the amount of vegetated cover in a buffer zone surrounding the sampling site, the lower the biotic index value, and by inference, the cleaner the water. The lowest biotic index value (3.5, on the dividing line between "good" and "excellent" conditions) was found on the Vassar College Ecological Preserve (Green space zone), whereas the highest values (7.6, "very poor") were found in the Dutchess and 44 Plaza area (Commercial zone). Based on the benthic macroinvertebrate study, no part of the Casperkill is in "excellent" health. The data also clearly show that the Town of Poughkeepsie's Aquatic Resources Protection Law, which mandates a minimum buffer size of 25 feet (7.6 m) along stream corridors, is insufficient for protecting stream health. This width of buffer falls within the poor water quality range.

Table 2: BMI community composition by land use zone (see Fig. 1 for a map of the zones), shown as percentage of total counts. Zones are listed from upstream to downstream (left to right). The commercial district has the greatest proportion of BMIs with low sensitivity to pollution, whereas the green space zone contains the greatest proportion of organisms with high sensitivity.

Pollution Sensitivity	Family	Rural	Commercial	Campus	Urban	Suburb 1	Green space	Suburb 2
High	Caddisfly larvae	2.4	3.0	25.0	6.0	25.5	47.7	17.4
	Hellgramites (Corydalidae)							
	Mayfly nymphs		0.2					0.5
	Gilled snails (right spiral)		0.3					0.1
	Riffle beetles (Elmidae)	1.2	0.5	2.7		8.7	10.3	7.3
	Stonefly nymphs (Plecoptera)							
	Water penny (Psephenidae)					0.2		2.3
	Other		0.2					0.1
Moderate	Other beetle larvae	0.2	0.2			1.6		0.1
	Clams/mussels	2.0	0.2	10.4	4.3	4.1	2.6	2.9
	Crane fly larvae (Tipulidae)		0.2			1.1	1.9	2.4
	Crayfish (Astacidae)			3.1	0.8	0.2		0.1
	Dragonfly nymphs (Odonata)							
	Damselfly nymphs				0.2			
	Amphipods (Gammaridae)	18.8	6.7	29.2	8.9	9.8	12.6	10.1
	Isopods (Asellidae)	19.5	5.0	0.8	0.2	5.0	2.4	6.7
	Fishfly larvae (Corydalidae)						0.2	
	Alderfly larvae (Sialidae)							
	Watersnipe fly larvae (Athericidae)							
	Other					0.5	0.3	0.4
Low	Oligochaete worms	23.9	47.5	5.0	7.5	7.1	0.3	1.6
	Black fly larvae (Simuliidae)	2.4	2.7		26.9	2.7	5.5	5.5
	Leeches (Hirudinea)	19.0	2.1	2.3	1.0	1.6	0.3	1.6
	Midge larvae (Chironomidae)	10.2	31.0	20.0	42.7	31.4	15.0	39.7
	Left-spiral pouch snails (Physidae)		0.2	0.8	1.4	0.5	0.7	1.3
	Other snails (flattened)	0.2	0.2	0.8	0.2			0.1
	Other						0.2	0.1
	Total number of individuals counted	410	623	260	517	439	585	1224

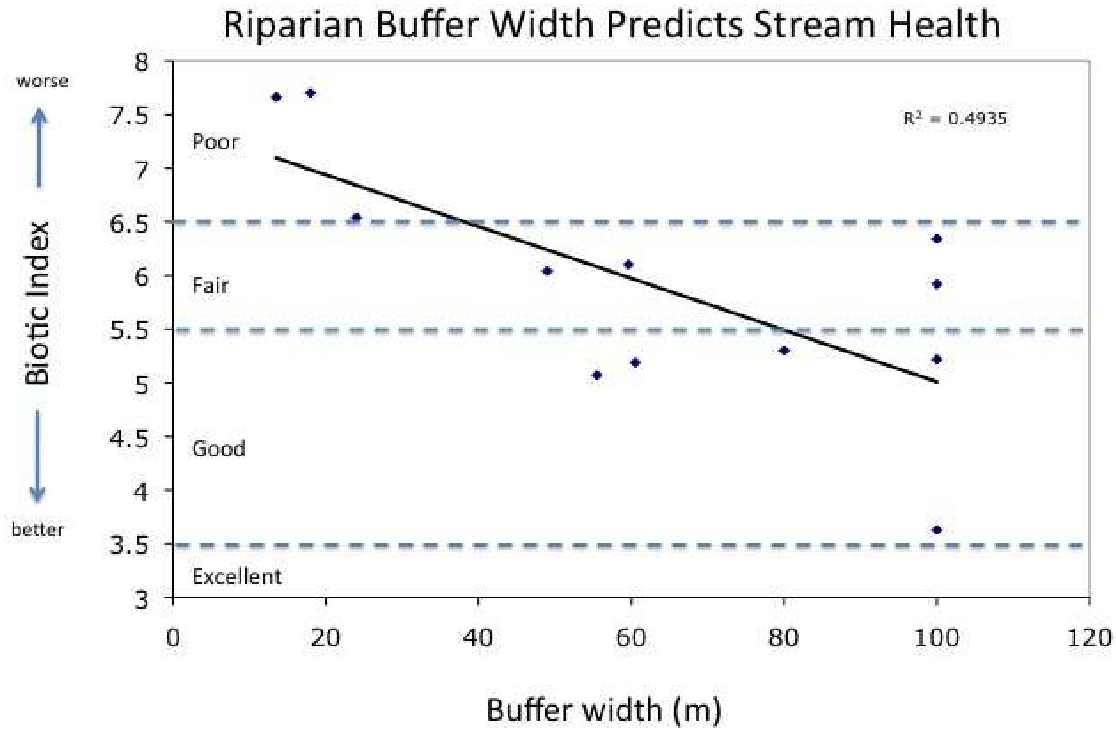

Fig. 18: Biotic index values calculated from benthic macroinvertebrate diversity and abundance indicate that the aquatic ecosystem is healthier in areas with wider forested riparian buffer than in locations with little buffering vegetation. Data from June 2006 sampling. Data for June 2007 display a nearly identical trend and are available upon request.

Water Quality Challenges

Although a 1996 New York State Department of Environmental Conservation (NYSDEC) report refers to the Casperkill as a Class D stream, the NYSDEC final draft of the Lower Hudson River Basin Waterbody Inventory/Priority Waterbodies List Report issued in August 2008 lists the Casperkill, including all of its tributaries, as a Class C stream (NYSDEC, 2008). The more recent classification is based primarily on a 2002 benthic macroinvertebrate sample taken at one downstream site (Camelot Road). The assessment attributes possible pollutants to "nutrient enrichment from nonpoint sources" but acknowledges poor BMI habitat conditions also play a role in the Class C status of the stream. The NY state assessment of the health of the Casperkill reflects the conditions at only one point on the stream. Our research indicates that health varies dramatically between stream segments, and our BMI data qualifies the Camelot Rd. area stream health as "good," a qualification that is much better than some areas farther upstream.

Landfills

As an urban stream, the Casperkill experiences a number of water quality challenges along its length. Approximately 2.2 miles below its headwaters, the stream flows past the FICA landfill on Van Wagner Road (Fig. 19). This landfill was in operation from 1977 to 1985 before being capped (Lubasch, 1987). A Federal civil lawsuit brought in 1987 against the operators of the site alleged that industrial chemical waste had been dumped there, and while the suit did not claim that the dumping had been illegal, it did claim harm to the wetlands surrounding the Casperkill and demanded cleanup (Lubasch, 1987). Anecdotal evidence from residents of Dutchess County confirms that silt fences were placed along side the stream to trap sediment runoff during the addition of a capping and venting system at the site. Unfortunately CAP researchers were unable to find documentable evidence at the Federal or State level that cleanup of the site had been completed. The site remains listed as a "Critical Environmental Area" according to the New York State Department of Environmental Conservation (NYSDEC, 2008a).

Continuing southward from the FICA landfill, the stream flows through the Dutchess and 44 Plaza shopping district in the Arlington neighborhood. The commercial history of this site is lengthy, starting with its use as a clay mine and brick-manufacturing area throughout the 1800s and early 1900s (Hutton, 2003). Beginning in 1948, then owners John and Robert Van De Water leased the land to the Town and City of Poughkeepsie as a municipal landfill site for disposal of construction and yard debris. There is some evidence that the operation of the landfill was occasionally in violation of local and state health codes (NYSDEC, 1996). For example, the NYSDEC found evidence that between 1963 and 1971, a local dry cleaning establishment illegally dumped 50 pounds per year of tetrachloroethene (PCE) residue into the landfill, a probable carcinogen (World Health Organization, 2003).

Once the municipal landfill closed in 1971, the property was developed into two shopping centers – the Dutchess Center Plaza and the 44 Plaza. Construction on the 22-acre plot required the excavation of 25% of the landfill debris, and several Poughkeepsie Journal articles document the complaints of local residents as odors emanated from the area of construction (Duncan, 1971a, 1971b). The excavated trash was relocated to the northern-most portion of the Van De Water Property where, according to the Journal article, it was "buried in alternate layers of earth and refuse, according to proper landfill procedure." However, further investigation in the 1980s and 1990s by the NYSDEC revealed that the actual process of excavation and re-burial of the trash violated a number of regulations, including insufficient trash cover.

The insufficient cover may have resulted in some of the odor-issues. However, the odor was probably caused primarily because part of the Casperkill was re-routed during construction to flow directly through a portion of the excavated trash (NYSDEC, 1996). In addition, at the start of construction, Eberhard Builders were accused of draining seepage from construction and excavation directly into the stream. In July 1971, Cesare J. Manfredi, assistant sanitary engineer for the state of New York, commissioned an ecological analysis of the Casperkill in order to determine the extent of damage resulting from the construction at the old landfill site. Results came back indicating such low levels of dissolved oxygen that Manfredi "doubted if even algae are capable of living in the Casper Kill."

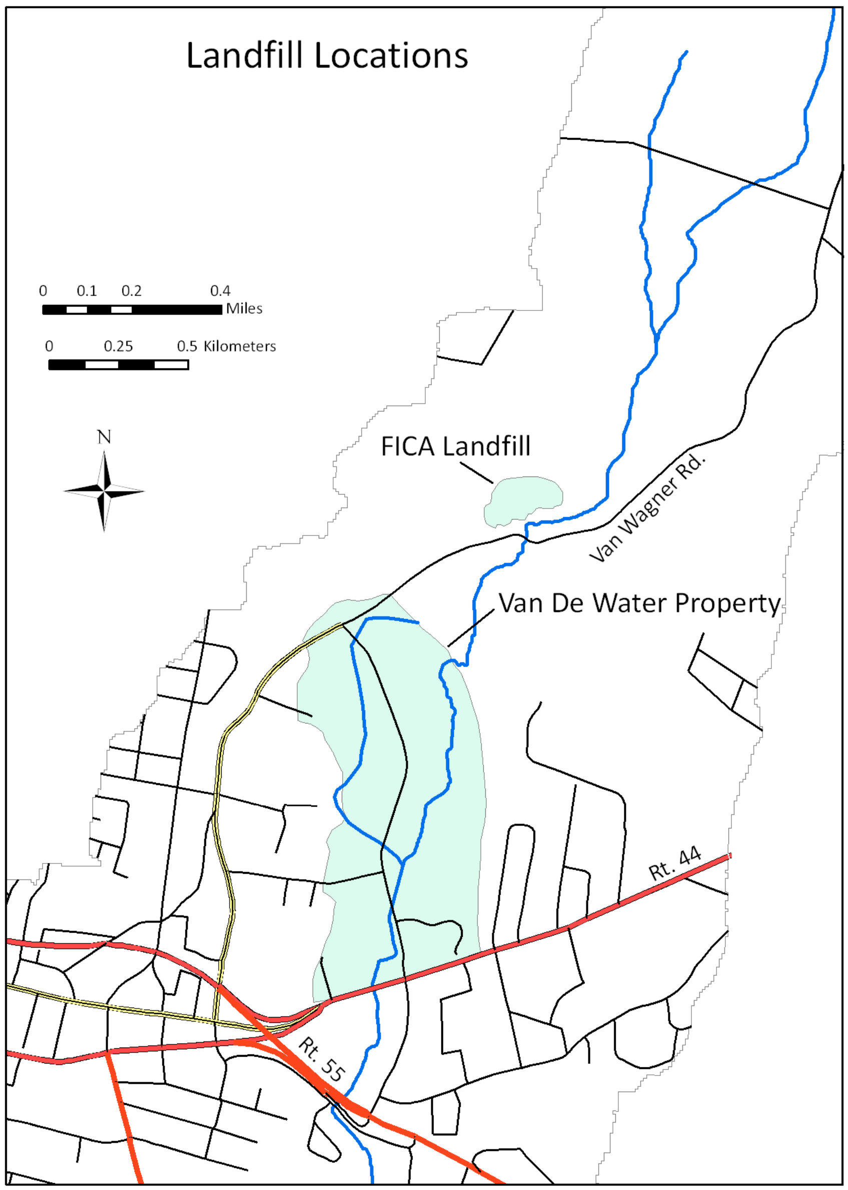

Fig. 19: Location of the FICA and Van De Water landfills in relation to the Casperkill. Landfill outlines from Belk (1995).

In response to the observed pollution and unhealthy characteristics of the creek, the New York State Department of Health and the Town of Poughkeepsie commissioned the installation of a 54-inch diameter galvanized pipe to run through the entire landfill and contain the Casperkill (Duncan, 1971c). Although plans for the pipe were extensive in a December 1971 Poughkeepsie Journal article, it was never constructed. The Casperkill continued to flow through the landfill until construction of the 44 Plaza was completed, and the creek was re-routed through a ditch at the edge of the shopping center.

A 1996 study of the Casperkill conducted by the NYSDEC designates the Van De Water portion of the stream as Class D, a New York State freshwater classification that indicates water best used for fishing, but that will "not support fish propagation." As part of its ecological analysis, the NYSDEC assessed surface water, ground water, sediment, and soil for presence of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), pesticides, PCBs, and metals. Elevated levels of benzene, trichloroethene, dibenzofuran, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, ideno (1,2,3-cd)pyrene, the pesticide gamma-BHC, the PCB Aroclor-1254, and the metals barium, beryllium, cadmium, chromium, cobalt, copper, cyanide, iron, lead, manganese, mercury, nickel, sodium, and zinc were found in soil, groundwater and/or sediment samples throughout the site, though the stream surface waters were found to contain low concentrations of these compounds (NYSDEC, 1996). The NYSDEC study also found that subsurface soils at the site (predominantly clay) act as a semi-impermeable barrier to off-site migration of more toxic compounds into the surface water of the stream – except when water levels are particularly high. This explains a lack of VOCs and pesticides in the surface water, in addition to low levels of SVOCs and metal contaminants. Still, hazardous compounds exist in stream water, indicating that the Casperkill continues to experience some impact from the landfill.

During the Summer of 2007, a qualitative survey of pollution in the Casperkill conducted by the Casperkill Assessment Project detected a pollutant known as dioctyl phthalate (also known as DOP or DEHP – diethylhexyl phthalate) in the Dutchess/44 Plaza area, a plasticizer used in a wide variety of plastic products, including polyvinyl chloride. DOP is known to leach from plastic products during their use and after disposal and is one of the most common organic pollutants in streams of the United States (Wams 1978). The presence of DOP could reflect a number of sources, including landfill leachate into the stream and plastic bag litter breaking down in the channel. DOP is known to be an endocrine disruptor and is toxic to aquatic organisms (Howdeshell et al., 2007; Lundberg et al., 1992). A scientific literature search conducted by members of the CAP found that DOP might also impact the development and behavior of aquatic organisms (Daniel 1978).

Carbon isotope and nutrient research further indicates that the landfills are leaching contaminants into the Casperkill. The CAP found elevated levels of light carbon isotopes in aquatic algae rooted on the streambed in the Dutchess and 44 Plaza area (Fig. 20). These isotopes indicate an input of methane, a product of landfill decomposition. In addition, this reach of the stream contains elevated concentrations of ammonium (NH_4^+), a byproduct of organic matter decay in low oxygen environments, also suggesting that the Casperkill is receiving groundwater that has flowed through the landfill (Fig. 21).

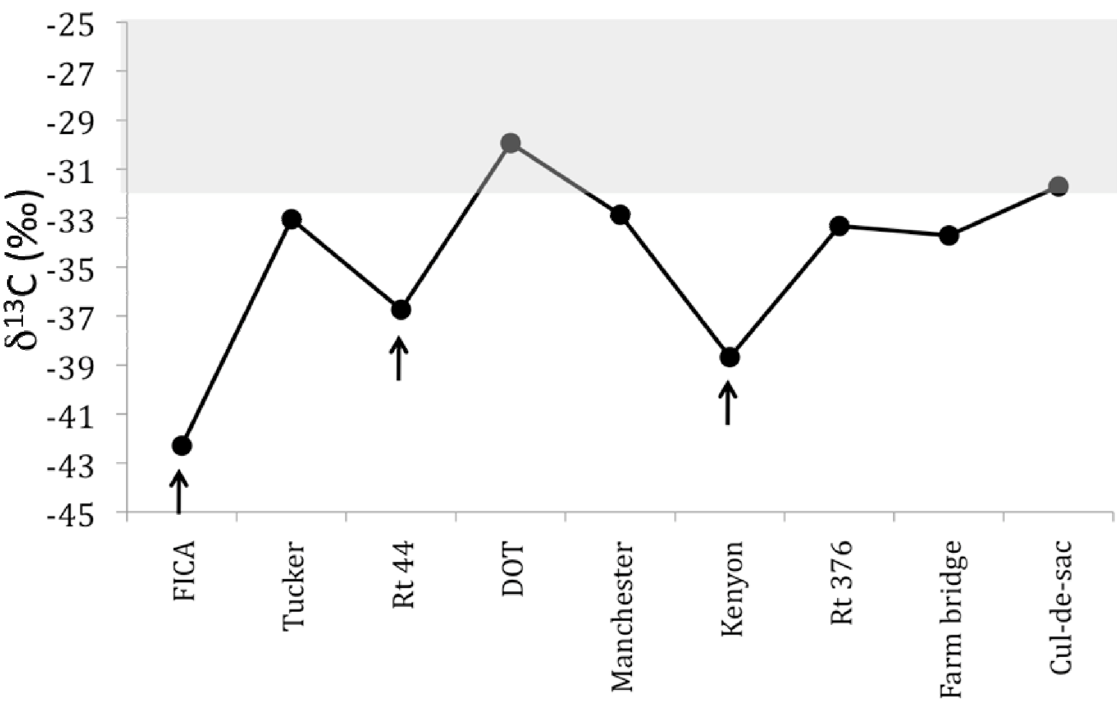

Fig. 20: Stable carbon isotopes of filamentous algae collected along the Casperkill in June 2007. Grey box indicates expected values based on carbon isotopic signature of the stream water. The arrows denote extreme negative values at the FICA landfill, the Van De Water landfill and at the Kenyon site on the Vassar campus. The negative values at the landfill sites suggest that methane leaking from the landfills is entering the stream, possibly with other pollutants from the landfills. The negative value at Kenyon probably is caused by natural methane being produced by organic matter decay in the stagnant ice-skating pond located on a small Casperkill tributary on the Vassar College campus.

Casperkill researchers have also found an iron oxide deposit in the stream near Tucker Drive (Fig. 22). Here, water leaving a drainage pipe buried under the 44 Plaza parking lot enters the stream. Reduced iron contained in the effluent changes oxidation state as the water is exposed to the air, leading to the orange-colored precipitate of iron oxide. Heavy metals and chemical pollutants can accumulate in such iron oxide deposits, and arsenic has been detected that occasionally surpasses the EPA's extreme biological harm threshold of 33 mg/kg. The elevated levels of arsenic seem to be limited to these deposits. Concentrations in the pipe effluent and in the stream itself are below detection levels. This suggests that arsenic sorbs onto the precipitate, gradually increasing in concentration. A few meters downstream of the orange ooze neither the water nor the stream bottom sediment show elevated arsenic levels. Because arsenic levels are below detection in the water, it is unclear if their source in the precipitate is the effluent from under the parking lot, which is most likely groundwater that has traveled through the Van De Water landfill, or the stream itself. The orange iron oxide deposit and elevated arsenic levels are also found at Bedell Rd. where the source of arsenic may be pesticide residues from the old Peach Hill orchard.

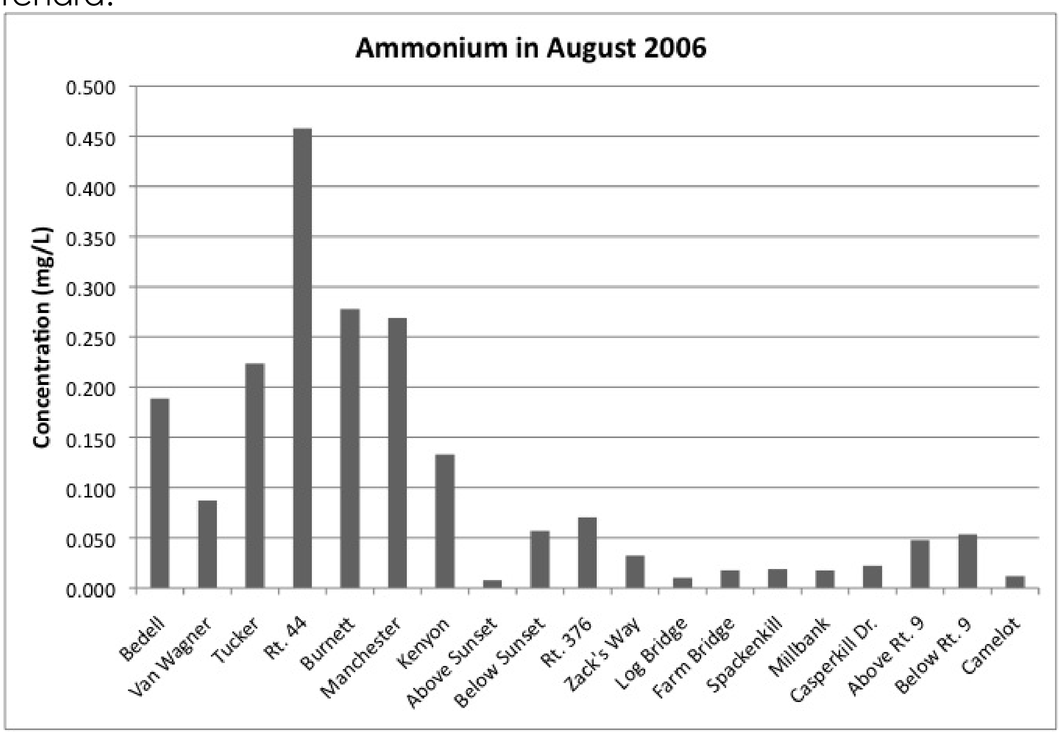

Fig. 21: Ammonium concentration with distance downstream. The highest concentration is at the Dutchess/44 Plaza site (labeled Rt. 44), which suggests that groundwater moving through the Van De Water landfill may be entering the Casperkill. Other months show a similar pattern (data available upon request).

Fig. 22: Iron oxide (orange ooze) precipitates when groundwater from under the Rt. 44 Plaza discharges to the surface. This precipitate contains high levels of arsenic.

Fecal contamination

Many households along the Casperkill have children who may play in the stream, and contamination of stream water by fecal bacteria constitutes a potential hazard to their health. Fecal coliform bacteria are a sign of sewage contamination or fecal matter from animals (New Hampshire Department of Environmental Services, 2003). While they aren't necessarily harmful in and of themselves there is the possibility of gastrointestinal illness resulting from the kinds of pathogens often associated with these bacteria. When associated with sewage inputs, fecal contamination also results in nutrient loading, which promotes algal blooms (Mallin et al., 2007).

The network of sanitary sewers that services homes and businesses throughout the Casperkill watershed is a potential source of fecal contamination in the stream. A sewer collection line belonging to the Arlington sewer district parallels the Casperkill along much of its length north of Spackenkill Road. This line was constructed in the 1950s, and parts of it have fallen into disrepair. Prior to 2008, an access vault on the Vassar College campus south of Sunset Lake had open holes in its masonry (Fig. 23) from which raw sewage entered the stream during the heavy rains and floods of April 2007. Additionally, a Poughkeepsie Journal article dating from October 2005 reports that a manhole on Old Mill Drive in the Town of Poughkeepsie repeatedly overflows sewage into residents' yards and the Casperkill during periods of heavy rainfall (Shapley, 2005). The article also noted that the Old Mill Drive sewer overflow was only one of four sewer overflows that occurred during the October 2005 rains. Whether related to holes in the sanitary sewer line that allow groundwater to infiltrate or to sump pumps tied to the sewer line, it appears that the Arlington sanitary sewer overflows frequently during storm events and should be replaced to avoid public health problems.

Fig. 23: Decaying sewage infrastructure is a source of fecal contamination to the stream. This vault on the Vassar College campus was replaced in spring 2008.

Additional sources of fecal contamination to the stream include dog and cat waste washed into storm drains, wildlife feces, and improperly functioning septic systems. Geese and other waterfowl as well as deer are two of the most probable sources of wildlife feces in the Casperkill. Waterfowl are particularly attracted to open bodies of water such as Vassar Lake (formed by damming the Fonteynkill tributary) and Sunset Lake. Septic system contamination is another possible contributor to the degradation of the stream. For example, many of the homes along Boardman road do not have access to the town sewer system, and as already mentioned, homeowners have reported foul odors from septic system backwash during high rainfall events.

Coliform bacteria counts can be used to determine whether fecal contamination is high enough to pose risks to human health. Two frequently used coliform indicators are *Escherichia coli* (*E. coli*), a type of fecal coliform, and total coliform; a combination of both fecal and nonfecal coliforms. The Casperkill Assessment Project found bacteria levels exceeding NYSDEC limits (NYSDEC, 2008c) for bathing at the majority of sample sites in July of 2007 (other sampling was conducted in June of 2006 and 2007, July 2006 and

November 2006 and also found elevated coliform levels, but the data for these other months were not analyzed in a manner directly comparable to the NYSDEC standards). Coliform levels were highest immediately following rainstorms on the 19th and 23rd of July 2007. During the month of July 2007 bacteria counts exceeded NYSDEC water quality standards of 2400 CFU's/100 mL (CFU's refers to Colony Forming Units) total coliform (median for 5 sample dates) and 200 CFU's/100 mL *E.coli* (geometric mean for 5 sample dates) (Fig. 24). In some samples, total coliform levels taken after rainstorms reached as high as 9740 CFU's/100 mL. At 2060 CFU's/100 mL, the average total coliform levels for all samples in all months sampled was below the NYSDEC standard of 2400 CFU's/100 mL.

Although we do not know whether human contributions of fecal contamination to the Casperkill are primarily due to septic tanks or eroding sewer infrastructure, we can presume at some level that they arise from a combination of both. Therefore both individual homeowners and the Town and City of Poughkeepsie governments are responsible for making changes to limit the amount of fecal contamination in the stream. Homeowners with septic systems should be sure to have their septic systems regularly pumped and checked for proper function (approximately every 2-5 years depending on tank and family size, <http://www.aceseptictankservice.com/Howoften.nxg>). The evidence described above demonstrates that the sewer system has leaks, and we encourage the City and Town to conduct dye or other tests to further investigate and repair any leaks.

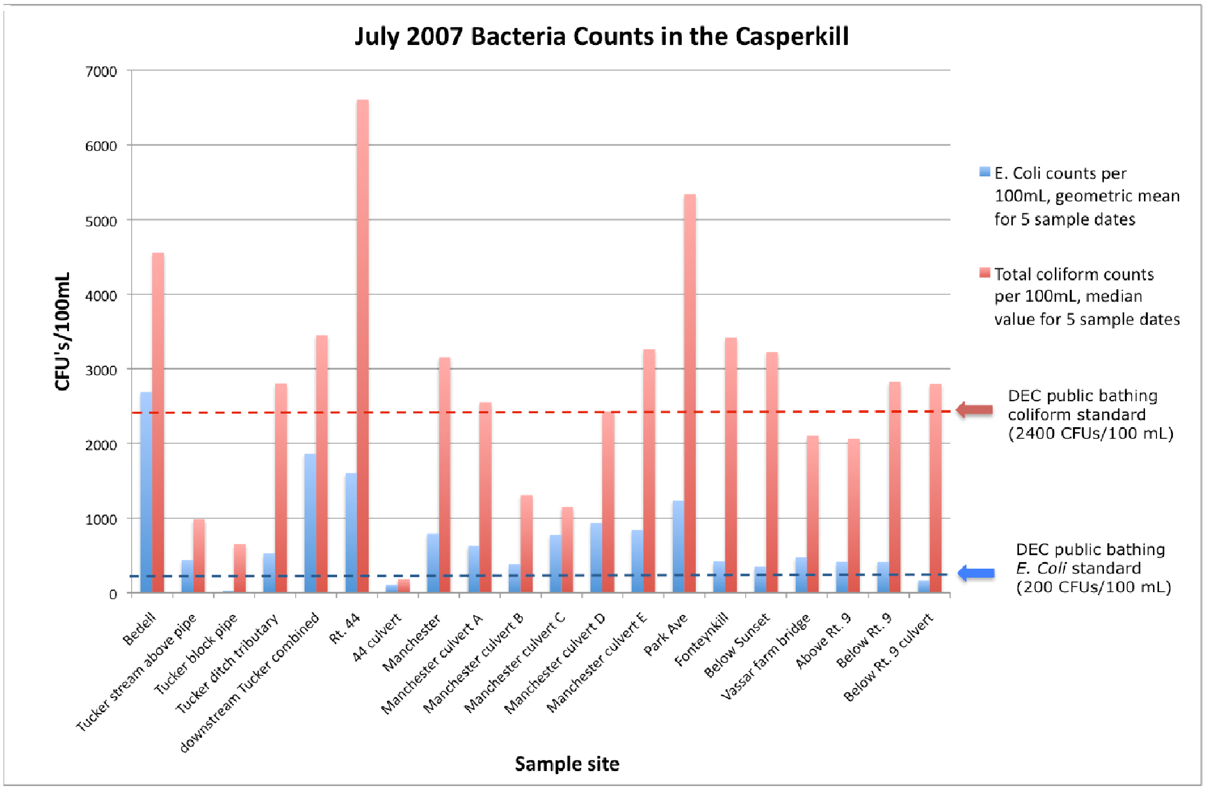

Fig. 24: Total and fecal coliforms in the Casperkill exceed New York State Department of Environmental Conservation limits for bathing in the stream. Values are averages (*E. Coli*) or medians (total coliform) of five measurements made over the month of July 2007. The sites measured in July 2007 include some of the 21 Casperkill sampling sites as well as other sites along the stream. CFU's refers to Colony Forming Units.

Nutrients

Nitrogen (N) and phosphorus (P) are necessary components of ecosystems. When added to crops in fertilizer, they accelerate growth and yield larger harvests. While essential, an overabundance of these nutrients in an aquatic ecosystem can cause environmental harm because they stimulate an overgrowth of algae and/or plants rooted on the floors of streams and lakes (Vitousek et al., 1997). When these aquatic plants die, they fall to bottom of water bodies and begin to decompose, consuming dissolved oxygen (DO). In the most extreme cases, DO may become so depleted that other aquatic organisms perish. Fish generally migrate away from low DO areas, but mollusks, worms, and other more stationary organisms may suffer chronic impairment or death, thereby affecting species higher in the food chain. In addition, excessive levels of nutrients can also be a human health hazard. The United States Environmental Protection Agency (EPA) has placed a limit of 10 mg/L on Nitrate-N (N in NO_3 form; USEPA, 1996) in drinking water supplies due to its ability to bind to the oxygen carrying compound hemoglobin in the bloodstream. Infants are particularly susceptible to this problem, which has been given the name "Blue Baby Syndrome" for the characteristic color infants acquire when their blood contains low levels of oxygen (Laws, 2000, p. 151).

Repeated algal blooms in Sunset Lake on the Vassar College campus suggest that nutrient pollution is a problem in the Casperkill. To assess the degree of pollution, we measured levels of Nitrate-N, Ammonium-N (NH_4), and phosphate (PO_4) in stream water. Sources of these nutrients in urbanized watersheds include fertilizers in runoff from lawns, effluent from septic tanks and leaking sewer lines, leaves and grass clippings that wind up in storm drains, soil erosion at construction sites, and pet waste (Paul and Meyer, 2001; Valiela and Bowen, 2002).

Average monthly Nitrate-N levels in the Casperkill were in the range of 0.313 mg/L to 2.523 mg/L. While these concentrations are well below the EPA drinking water standard of 10 mg/L, they aren't necessarily acceptable for a healthy stream. The New Jersey Pollution Discharge Elimination System (NJPDES) criteria for stream water in the Pinelands Protection and Preservation Areas limits Nitrate-N levels to 2 mg/L (NJAC 2008). Of our twenty-two sample months, eleven had sample sites with maximum levels of Nitrate-N over 2 mg/L and four months had average levels of Nitrate-N over 2 mg/L.

Ammonium-N concentrations were converted to ammonia (NH_3) in order to compare Casperkill values to existing surface water regulatory levels. Most researchers and government agencies base surface water quality standards on ammonia rather than on ammonium because ammonia is more toxic, and both species may be present in water bodies (U.S. EPA, 1999). Ammonia standards are based upon varying temperature and pH. In general, the higher water temperature and pH are, the higher the allowable ammonia limits (New York State Department of Environmental Conservation, 2008). Our research found average monthly ammonia concentrations in the Casperkill ranged between 0.000 μg/L and 19.470 μg/L. All monthly averages fell significantly below the NYSDEC limitations on ammonia in freshwater Class C streams.

Phosphate data were converted to phosphorus for comparison with water quality standards; average monthly levels of phosphorus in the Casperkill ranged from levels below detection to 0.979 mg P/L, with an average value of 0.044 mg P/L. Although the EPA has not established a threshold for phosphorus contamination in drinking water and the NYSDEC has no quantitative limit of phosphorus in freshwater streams, the New Jersey Department of Environmental Protection does have a surface water quality standard for phosphorus. The NJPDES rules for fresh water streams state, "phosphorus as total P shall not exceed 0.1 (mg/L) in any stream, unless it can be demonstrated that total P is not a limiting nutrient and will not otherwise render the waters unsuitable for the designated uses" (NJAC, 2008). The phosphorus totals in the Casperkill are not consistently above the NJPDES water quality standard, although ten of the 22 months sampled had maximum values above 0.1 mg P/L and two of the 22 months had average values of phosphorus above 0.1 mg P/L.

To assess the impact of land use on nutrient levels in the Casperkill, Nitrate-N and Ammonium-N were summed to determine total inorganic nitrogen (TIN) in each land use/land cover zone (Fig. 25), and TIN values were plotted against percentage of forest in the riparian buffer or percentage of impervious surface at the subwatershed scale (Fig. 26). These analyses reveal that nitrogen levels are most sensitive to the local conditions around the stream, with more forested riparian buffers showing lower TIN values than those with higher amounts of impervious surface. This finding is consistent with other studies (Mayer et al., 2005), which show that vegetative buffer width strongly influences nitrogen uptake capacity and points to an important role for landowners along the stream in improving the health of the aquatic ecosystem, primarily through enhancing the buffer with native plantings that could remove nutrient inputs and limit fertilizer runoff into the stream.

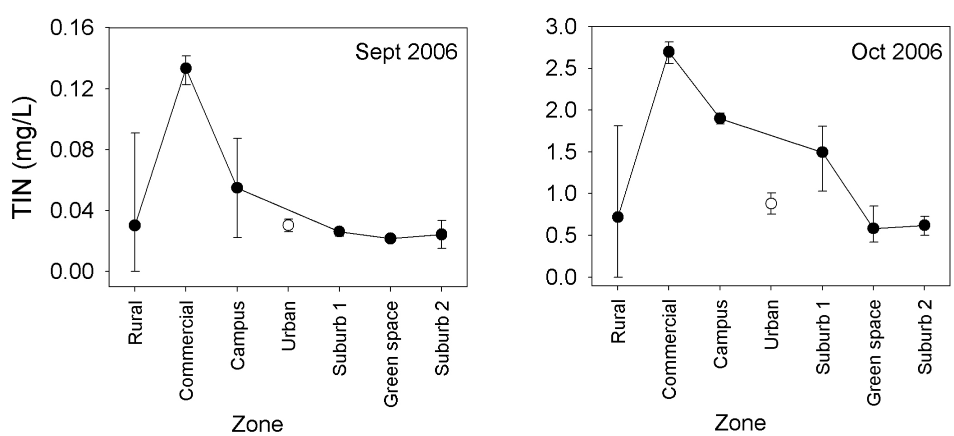

Fig. 25: Total inorganic nitrogen (TIN) by land use zone. Values are highest in the commercial zone, where the nitrogen is primarily found in ammonium form. White circle is the Fonteynkill tributary. Y-axis values vary due to differences in stream flow, but the pattern is largely the same and is nearly identical in all other months (data available upon request).

Although nutrient levels in the Casperkill are mildly elevated, they are not beyond repair: there are ways to reduce the amount of pollution in the stream. Fixing leaky sewer lines, faulty septic systems, and properly cleaning up pet waste, especially that deposited on impervious surfaces, not only decreases the amount of fecal contamination but also reduces nitrate input into the stream. Additionally, researchers estimate that 53% of nitrogen inputs can be attributed to the application of fertilizers in primarily residential mixed urban/open space watersheds (Law et al., 2004). Fall or winter applications of fertilizers are particularly harmful to stream health because of the high rate of fertilizer runoff during this time of year (Mangiafico and Guillard, 2006). If fall fertilizer application occurs, it should be limited to the early fall months when grass is still growing and should be low-input. Proper education on alternative turf management and educating watershed residents on the most appropriate times to apply fertilizer could reduce nutrient overloading in the Casperkill and other local streams. Government regulations and restrictions on the amount of or types of lawn fertilizers might go the furthest in preventing nitrate and phosphorus water pollution. Westchester County in New York State already has proposed legislation to ban the use of fertilizers with phosphates in an effort to protect water quality (Charkes, 2008).

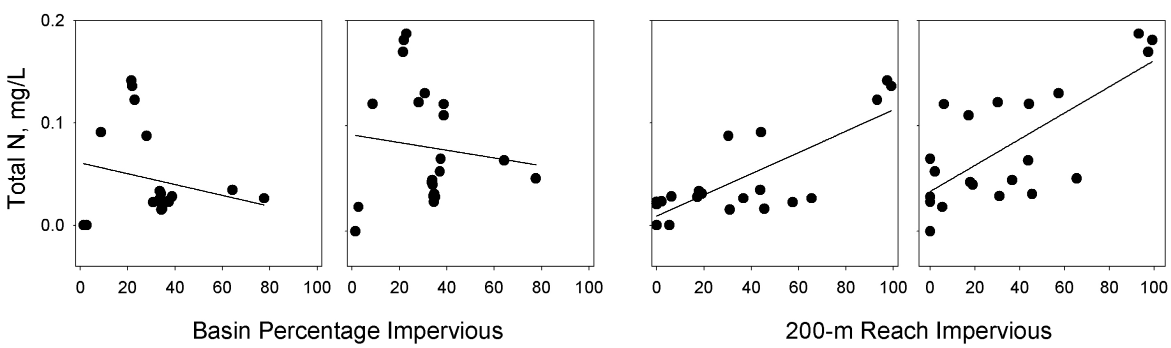

Fig. 26: TIN is most strongly influenced by the riparian buffer scale (right two plots), and the greater the percentage of impervious surface, the higher the TIN value. Graphs are from September and October of 2006 for each analysis scale.

Chloride and Conductivity

Chloride is a dissolved ion found in streams that causes water to conduct electricity. Increased levels of chloride and conductivity in freshwater streams can negatively impact aquatic ecosystems. Chloride concentrations of less than 100 mg/L affect populations of some benthic macroinvertebrates and can lower or stop the rate of growth of some species of algae, affecting the aquatic food web (Benoit, 1988; Benbow and Merritt, 2004). While chloride may be introduced into streams through natural dissolution of bedrock or through sewage and septic effluent, previous work has shown that chloride in Northeastern streams is attributable mainly to road de-icing salt and that salt levels have increased steadily over the past several decades (Peters and Turk 1981, Jackson and Jobagy 2005, Kaushal et al. 2005, Kelly et al. 2008). In winter, salt-laden runoff from paved surfaces flows into storm sewers and directly into streams. In addition, soils accumulate salts that are pushed or kicked off of roadways by snowplows and automobile tires. These salts are then introduced into the groundwater supply as they are washed through the soil by rainfall events and migrate toward streams throughout the year (Howard and Haynes, 1993).

To protect stream health, the NJPDES's and the EPA's criteria for fresh water streams limits chronic levels of chloride to 230 mg/L and state that acute levels of chloride in freshwater streams should not exceed 830 mg/L. Furthermore, chloride concentrations of 250 mg/L exceed the level that is appropriate for human consumption (NJAC, 2008; Benoit, 1988). The Casperkill is known to have among the highest chloride concentrations of all streams in Dutchess County (Burns, 2006). Winter concentrations can exceed 1050 mg/L (K. Menking, unpub. data), a number well above the NJPDES criteria. During any particular sampling period analyzed, chloride concentrations increase with distance downstream, leveling off in the suburban and green space zones (Fig. 27). Plotting conductivity values against percentage of forest in the riparian buffer zone and percentage impervious in the subwatershed above the sampling point shows unequivocally that chloride in the Casperkill reflects watershed-scale salt inputs related to road de-icing (Fig. 28). While conductivity is highest during the active road-salting months of winter, it remains elevated throughout the summer and fall months, reflecting salt released gradually through groundwater and soils (Howard and Haynes, 1993). The role of groundwater transport of road salt is even more apparent in measurements made at the site of the CAP stream gauge. There, a Yellowsprings Instruments Sonde measures chloride and conductivity every 20 minutes for comparison to stream flow. In the spring, summer, and fall, increases in stream flow associated with rainfall events coincide with declines in chloride and conductivity as stream baseflow from groundwater is diluted by runoff (Fig. 29). In winter, the relationship between flow and conductivity/chloride becomes much more direct as melting snow washes road salt into streams after precipitation events.

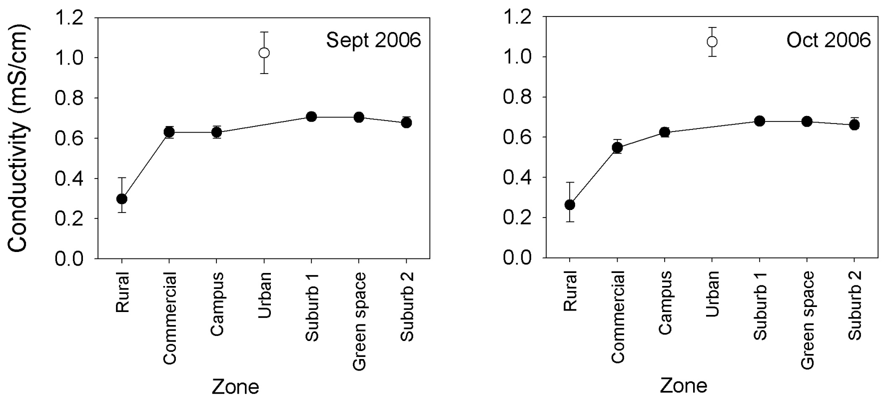

Fig. 27: Conductivity of the Casperkill by land use zone. The white circle represents the Fonteynkill subwatershed. As with TIN, only two months are shown, but all other months show a nearly identical pattern (data available upon request).

Road salt inputs are difficult to reduce, as drivers from both urban and rural areas have come to expect clear and safe roads in all seasons, thus chloride and conductivity are likely to be a persistent problem for the Casperkill and other streams in the area. The presence of rural-dwelling urban workers increases the importance of keeping roads clear in winter, since commuting requires daily travel on a strict time schedule. Commuting is important for many residents in the area because residential development in the past half century has emphasized widely distributed housing without public transportation, while urban areas have been subject to policies of neglect that encouraged out-migration. Reducing road salt impacts on watersheds may require attention to attitudes about planning policies, as much as changes in salt use *per se* (Cunningham et al., in revision). The Casperkill results support recommendations in the Town of Poughkeepsie master plan that call for zoning changes to allow for cluster-style development and maintenance of greenspace parcels. Such development reduces the overall length of roadways necessary to access neighborhoods, thereby decreasing the amount of impervious surface required and associated construction and maintenance costs. Inasmuch as road salt in the Casperkill watershed directly reflects the amount of impervious surface above each sampling point, such cluster-style development has great potential to reduce harm to aquatic ecosystems as development continues.

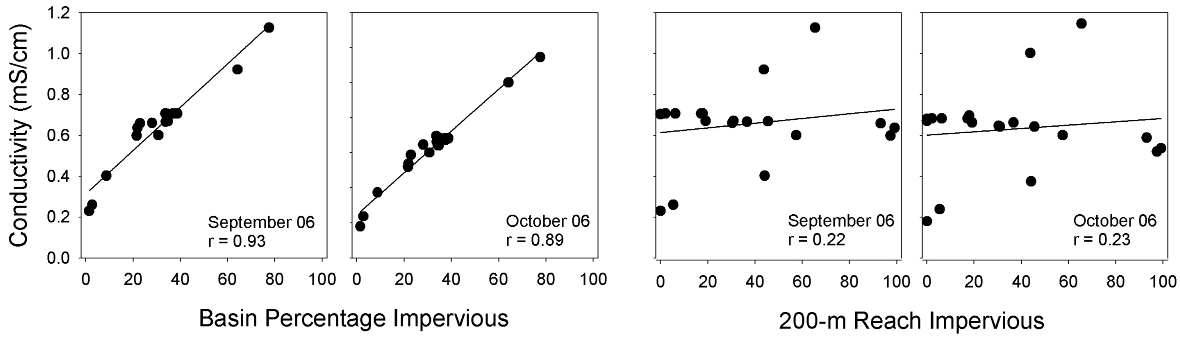

Fig. 28: Conductivity is most strongly affected by land use at the subwatershed scale (left two plots), showing little sensitivity to conditions at the riparian buffer or reach scales (right two plots).

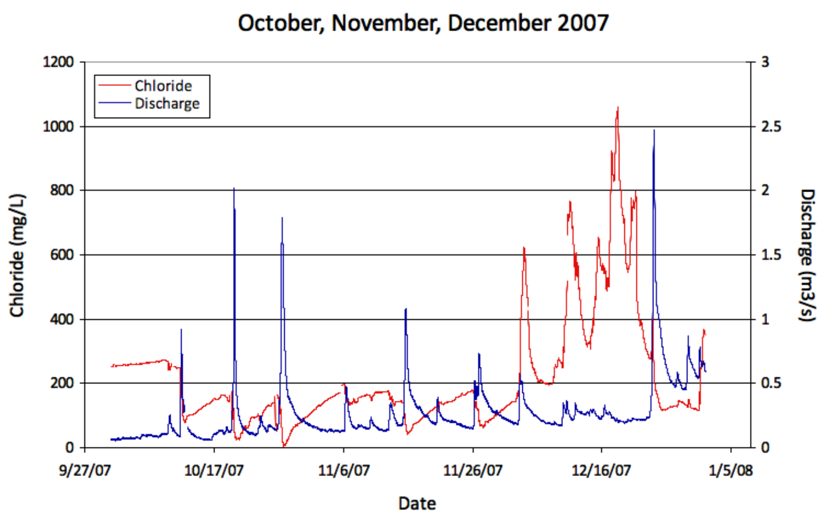

Fig. 29: Chloride concentrations behave inversely to discharge during spring, summer, and fall, when chloride in introduced to the stream through groundwater inflow. In winter, chloride levels more directly reflect stream flow levels as road deicers are applied to paved surfaces and runoff from these salty surfaces enters the stream.

Other steps that can be taken to reduce road salt impacts include following NYSDOT guidelines for the application of snow and ice control materials, using salting trucks fitted with salt distributers that are tied to vehicle speed to avoid excessive amounts of salt being distributed at stop signs and red lights and to allow for more uniform application, using alternative de-icers with lower toxicity, spraying salt water on roads rather than salt crystals to prevent the bonding of ice to pavement, and using sand to provide traction (NYSDOT, 2006; AASHTO, 2009). Some of these solutions are already in use by local highway departments, but more work should be done to implement them region-wide.

Vassar College's application of deicing salts is particularly high, and is a special cause for concern. The campus uses approximately 31 to 37 tons of salt/lane km per year as opposed to the average 12.2 tons salt/lane km per year on Dutchess County roads and 19.6 tons of salt/lane km per year on New York State roads (Cunningham 2008). Unfortunately the desire of private institutions to avoid lawsuits causes the excessive use of deicing salts on campus. Despite the legal barriers to reducing application rates of salt, Vassar College and other private institutions should seriously consider reducing total salt application. As Kaushal et al. (2005) and Godwin et al. (2003) have shown, salt levels in streams have increased over the past five decades, and if they continue to increase along the same trajectory, groundwater resources that humans depend on will inevitably become threatened. Already groundwater in some parts of Dutchess County has become undrinkable due to excessive salt levels, posing a health threat to persons on low-salt diets (Shapley, 2005b).

Other Challenges

Multiple dams along the Casperkill change the nature of the stream in ways that this study has not thoroughly assessed, however the dam that forms Sunset Lake has perhaps the largest impact on the stream. First, Sunset Lake acts as a sink for nutrients; the water immediately downstream of the lake tends to have lower levels of nitrogen and phosphorus than the stream immediately upstream of the lake. The lake also provides habitat for turtles, fish and a variety of other aquatic organisms. As a measure to reduce the buildup of submerged aquatic plants, every one to two years Vassar College takes down the Sunset Lake dam for three to five months during the winter. By draining the water, the lake floor can freeze, killing the roots of these plants, which have historically been considered an aesthetic nuisance.

The immediate result of the dam opening is a small flood that causes sediments, nutrient loaded water, streamside debris, garbage and even wildlife (either already in the water or caught up in the flood) to flow downstream. Residents of Sunset Lake are often stranded in puddles on the lake floor, as the lake once again becomes a stream. Vassar faculty from the Biology department have been known to rescue dying fish from these puddles, capturing and throwing them back into the stream, yet many individuals do not survive this catastrophic change to their environment. On the other hand, since there is no fish ladder on the Sunset Lake dam, its removal allows fish and other aquatic organisms to travel to the upper reaches of the stream. The Sunset Lake dam certainly changes the character of the Casperkill. Whether those changes are beneficial for ecosystem health is a matter of debate, and we encourage College officials to work with Vassar's newly hired landscape architecture firm, Matthew Van

Valkenberg and Associates, to come up with a plan for the lake that enhances environmental stewardship.

Additional challenges to stream health on the Vassar College campus include the use of the stream floodplain as a staging area for construction activities, which may increase siltation in the stream, and as a site for campus roadways, which minimize the width of the riparian buffer, in some cases to as little as 10 feet. Student housing also contributes garbage to the stream and its floodplain. In some cases, this litter may result from careless behavior. However, wildlife dispersal of garbage is also a problem. The dumpsters used to collect household trash from the campus' Terrace Apartments do not close properly, allowing squirrels and possibly raccoons to access the contents inside and pull them out onto the ground. In addition, dumpster service is insufficient during various parts of the year, such as at the end of the school year when students empty out their apartments and move away for the summer. The College's SWAPR program, which accepts household goods and donates them to charity or sets them aside for reuse the following year, minimizes the amount of waste produced at this time, but there is still more garbage produced than the dumpsters can handle, and trash placed in plastic bags in front of the dumpsters attracts wildlife, which then disperse it. These problems could be solved easily by ensuring that dumpsters close properly and by increasing the frequency of garbage pickup during critical times of the year. More active engagement in recycling of paper, soda bottles, and cans should also be promoted. Redirection of campus roadways and restoration of riparian habitat will require a more long-term campus master planning approach.

Stakeholder Involvement

To gauge the level of interest and knowledge about the Casperkill among watershed residents, we conducted a Casperkill watershed survey (see appendix). Our survey was designed to answer the following questions: what are stakeholders' concerns regarding the creek/watershed? Who do stakeholders believe is responsible for ensuring the health of the creek/watershed? What are stakeholders' attitudes regarding threats to the creek/watershed? How are citizens using the creek and surrounding natural areas? And what is the desire of stakeholders to become involved in creek and watershed protection? We sent out 400 mailings, primarily to streamside landowners, and received 30 responses for an 8% response rate.

In general, most respondents believe the Casperkill is an environmentally degraded ecosystem. Approximately 56% of survey respondents perceive the overall environmental health of the Casperkill as fair to poor. Half of the survey respondents think runoff (47%) and leaking sewer/septic systems (50%) are a serious problem for the creek. Additionally, the majority of survey respondents (57%) think that the loss of natural land to development is a serious problem for the creek. Respondents were most concerned about flooding and erosion, sewage contamination, runoff, and over-development in the stream and its watershed.

We found that the majority of survey respondents supported initiatives to protect and restore natural areas. Approximately 60% of survey respondents would like to see more river floodplains maintained or restored to their natural state and would like to see less development of urban areas. Nearly three-quarters of survey respondents (70%) would like to see more wildlife habitat protection/restoration.

Over half of survey respondents (67%) believe that government is the primary responsible party for addressing their concerns regarding the creek. Forty-four percent of the respondents believe either the town or county are responsible for addressing their concerns, while 10% believe it is the responsibility of New York State government, and 13% believe it falls in the jurisdiction of the Federal government.

Despite the environmentally degraded status of the Casperkill, our survey found that respondents use the stream as an environmental and aesthetic resource. Respondents enjoy viewing the stream and its associated wildlife, and some respondents even reported that their children play in or around the stream.

Though the Casperkill is not drinkable or swimmable, it is an amenity that watershed residents utilize for ecosystem services as well as less tangible benefits. The Casperkill offers the opportunity for watershed residents to engage with the natural environment and to enjoy the creek aesthetically and recreationally. The Casperkill has a place in the Poughkeepsie community that extends beyond its role as a drainage ditch for road and parking lot runoff. Furthermore, our survey indicates that respondents are aware of the threats impacting stream health and desire government action to be taken to protect the stream. They are willing to take action on their own lands, but also admit to a lack of knowledge of what to do. Furthermore, some are concerned about the cost of improving their riparian buffers. These concerns could easily be addressed through educational outreach about such programs as "Trees for Tribs."

The Casperkill survey and the community forums on the health of the stream held at Vassar College in September of 2006 and 2007 led to the creation of the Casperkill Watershed Alliance (CWA) in the late fall of 2007. Constituted of concerned watershed residents, streamside landowners, Vassar College faculty and staff, and staff of the Cornell Cooperative Extension (CCEDC) Environment Program, the group meets monthly to plan events and educational outreach to the community. CWA members have thus far conducted riparian buffer plantings at the home of two members, worked with local community groups to do stream cleanups, presented an educational display at the Town of Poughkeepsie Town Day in Bowdoin Park, written an article about the stream for the Valley Views segment of the Poughkeepsie Journal, and contributed to the editing of this document to ensure its readability. Future projects include participation in Dutchess County Creek Weeks in summer 2009, including demonstrations of how to construct rain barrels, and educational displays at Town day and the Dutchess County Fair.

Public Access

Public access to the Casperkill currently exists in four areas along the creek, the Dutchess and 44 Plaza shopping area, the Vassar College campus, the Vassar College Farm and Ecological Preserve, and the Casperkill Golf Club. None of these locations are protected town or county resources, thus future public access is not ensured. On the other hand, it seems unlikely that the landowners will restrict access. While the stream is accessible from parking lots in the Dutchess and 44 Plaza area, the lack of shade trees and benches and the ubiquity of garbage on the stream banks and in the channel make this site unattractive, and most residents don't even know that the perceived drainage ditch along the edge of the shopping area is a stream. The overly steep channel banks lined with rip-rap also make getting down to the water hazardous.

On the Vassar College campus, a campus roadway on the western bank of the Casperkill parallels the stream north of Sunset Lake, and a gravel footpath follows the stream along its eastern bank. Gravel trails ring the lake, and another gravel trail on the floodplain follows the stream southward toward Rt. 376. Families from the local community are often seen around the shores of Sunset Lake, picnicking, fishing, and catching butterflies and tadpoles. Benches and lawns provide seating areas.

At the Vassar College Farm and Ecological Preserve, walking, biking, and running trails follow the stream. An expansive area of mowed fields and woodlands provides educational opportunities for Vassar students in courses in Environmental Studies, Earth Science, Biology, and Art, to name a few, and to local elementary school children participating in the Vassar Farm science program. Bird watching is another favored activity on the Ecological

Preserve. Local high school cross-country running teams make use of the trails, and the College provides public access to the site free of charge.

The Casperkill Golf Club is an 18-hole golf course and driving range area designed by Robert Trent Jones, Sr. The stream features prominently as an aesthetic amenity in the Golf Club's description of the course, however greens fees and the danger of golfing activities may limit public access to this site.

Part of the Dutchess Plaza shopping mall has been vacant for many years, and general upkeep of the parking lot and building facades is poor. As mentioned in the Town of Poughkeepsie master plan, this site could be redeveloped, with the Casperkill restored to a more normal channel form and with native plantings used to make a more attractive environment. The Town of Poughkeepsie has another opportunity to improve public access to the stream with the anticipated development of the Casperkill Golf Club area. Clustered development would allow for the creation of a public park that would protect wildlife habitat, minimize runoff, and provide recreational opportunities for watershed residents. The master plan states clearly that neighborhood access to public parks improves property values. Therefore it is in the best interest of the Town to mandate clustered development, preserve green space, and in so doing, increase public access to the Casperkill.

Casperkill Vision Statement

"Restoring Casper Creek as a natural system along its entire length should be one of the long-term goals and benefits of protecting major greenspace parcels in the Town."

Town of Poughkeepsie Master Plan, 2007, pg. 58

As of 2000, 31,842 people lived in the Casperkill watershed (U.S. census data), including 400 households whose property lies directly adjacent to the stream or to its major tributary, the Fonteynkill. Our survey of homeowners revealed that streamside residents value the creek as an aesthetic amenity and source of recreation and education for their children. At the same time, residents expressed concerns over flooding, pollution, and a perceived decline in wildlife over the years they have lived along the stream.

As mentioned in the Town of Poughkeepsie master plan adopted in 2008, the Casperkill is an element that ties greenspace areas of the town together (Town of Poughkeepsie, 2007). The master plan further suggests that the town should work toward acquiring land along the stream for the purpose of creating public access to a Greenway network that would link larger open space parcels. The importance of such a network for wildlife habitat, groundwater protection, floodwater storage, and recreational opportunities is clearly articulated in the plan, which further calls for the restoration of the Casperkill in the Dutchess and 44 Plaza district of the Arlington neighborhood (pg. 63) and for cluster style development in the remaining open space parcels that would protect and promote the integrity of the stream ecosystem. The results of the Casperkill Assessment Project (CAP) discussed in this report support all of these recommendations, and we therefore strongly endorse these provisions.

We further encourage the Town to take a more active role in upholding its current Aquatic Resources Protection Law and in upgrading the sewer infrastructure, both of which will help every stream within the law's jurisdiction. We encourage the City of Poughkeepsie to adopt a similar local law. In order to protect the stream and adjacent landowner property, we urge the Town not to permit variances to the buffer provision and to work with partnering organizations to maintain and restore the vegetation along the stream in order to reduce runoff, avoid erosion, and decrease the intensity of flood events. The Town should limit construction and development in flood plains as much as possible and should protect small wetlands from development, both of which play pivotal roles in mitigating the impacts of flooding. By maintaining and replacing antiquated sewer infrastructure, particularly in areas where sewer lines are in close proximity to the stream, the Town can decrease the amount of stream pollution.

Furthermore, we acknowledge the roles that streamside landowners and individual watershed residents have in protecting the Casperkill. There is a critical need for educational outreach about the importance of watershed protection, and such outreach can involve partnering organizations like the Casperkill Watershed Alliance, Town and City governments, and local landowners. Educational outreach should focus on ways streamside property owners can increase the width and effectiveness of the vegetated buffer and caution against the use of rip-rap for erosion control. Watershed-wide education should also include information on what rain gardens and rain barrels are, what they do, and how to build them. Further education can include information about the importance of keeping lawn waste out of the stream, and using appropriate amounts of lawn chemicals and fertilizers.

We include a number of watershed protection and restoration objectives for the Casperkill below:

1) Improve stream water quality in order to fulfill NYSDEC requirements necessary to upgrade the stream to Class B from Class C by upgrading sewer infrastructure and fixing all sewer lines that regularly leak. Class B streams contain bacteria levels low enough to allow for wading and swimming.

2) Maintain a vegetated buffer of 25 feet width throughout the length of the creek to comply with the Town of Poughkeepsie's Aquatic Resources Protection Law. For example, homeowners, businesses, governments and private institutions like Vassar College can improve stream bank vegetated buffers and prevent erosion by making use of resources available through the NYSDEC "Trees for Tribs" program. As a secondary goal we encourage the Town to strengthen the Aquatic Resources Protection Law to make riparian buffer zones at least 100 feet wide in order to maintain habitat for wildlife and improve aquatic ecosystem health (Federal Interagency Stream Working Group, 2001).

3) Encourage the retrofitting of existing parking lots and driveways to incorporate rain gardens, bioretention swales, or sand buffer strips when repaving occurs to allow infiltration and reduce storm water runoff and flooding.

4) Identify infrastructure such as bridges, culverts, and dams that are causing local flooding and upgrade them to accommodate the stream.

5) Create at least one park or prominent public access area along the creek to increase public use of the creek and watershed, therefore strengthening human, environment, and community relationships. The Dutchess and Route 44 plazas could be redesigned to include such a park, with the stream channel restored to a more natural form, an enhanced stream corridor planted with native trees and shrubs, and a plan to infiltrate all stormwater using "Better Site Design" principles. Another potential site for a public park is the area surrounding the Casperkill Golf Club.

6) Develop and implement regular educational programs and campaigns about the historical, cultural, and ecological significance of the Casperkill for watershed residents, policy makers, and local schools and about how to best protect the stream. Raising awareness about the role the Casperkill has played in Poughkeepsie's history and currently plays in the lives of residents will provide a common thread linking residents to one another and their local environment and will promote citizen involvement in watershed protection.

This document is the first step toward achieving the above objectives. It is only through citizen involvement, government action, private and public support, and cooperation between all interested parties that we can create a healthier Casperkill and stronger human and ecological communities.

Appendix: Methods

Bacteria

Duplicate water samples were taken ten times (February, June, July and November of 2006, June of 2007 and five times during July of 2007) at 21 sites along the Casperkill and the Fonteynkill tributary when the stream was at base flow. Sample volumes were 25 ml and 100 ml for June 2006 and 25 ml and 10 ml for July 2006, for all other months, sample volumes were 10 ml and then calculated for number of coliforms per 100 ml. Analysis of the samples was carried out using the Coliscan MF method (Micrology Labs, http://www.micrologylabs.com/Home/Our_Methods/Coliscan-MF). Water samples were filtered on-site and the filter papers immediately placed in a Petri dish pre-treated with a growth medium. The dishes were incubated in the lab at 35 ± 5°C for 24 hours after collection until bacterial colonies grew sufficiently large to be counted. Colonies of a blue/purple color were counted as *E. coli* (Fig. 30); pink colonies were counted as other coliform. Total coliform was the sum of *E. coli* and other coliform.

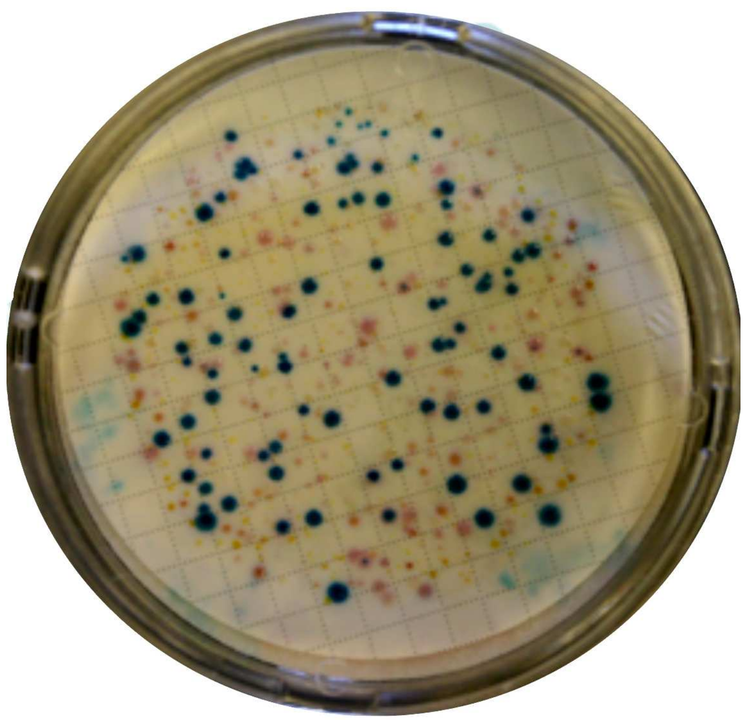

Fig. 30: *E. coli* (blue/purple) and other coliform (pink) bacterial colonies growing on filter papers inoculated with stream water.

Specific Conductance, Temperature, pH

In-stream specific conductance (conductivity), temperature, and pH were measured using a YSI 556 probe (YSI Inc., www.ysi.com) placed into the stream at each sampling location and allowed to equilibrate for several minutes before readings were taken.

Nutrients

Nutrient concentrations were determined by reacting water samples with different compounds to produce colored solutions in which the depth of color was a direct function of concentration. A spectrophotometer was used to measure the percentage of light absorbed by each sample and the results compared to absorbances of solutions of known concentration. In all cases, triplicate samples were collected at each site in 100-ml opaque, high-density polyethylene bottles. Samples were stored at 4 °C and were analyzed unfiltered within 1 to 3 days.

Ammonium

Ammonium concentrations were determined by the phenol-hypochlorite method (Solorzano, 1969) in which ammonium is complexed with phenol under alkaline conditions using sodium nitroprusside as a catalyst. The amount of blue indophenol formed is read with a spectrophotometer and calibrated against a standard curve.

Two samples each of five standard concentrations (0, 5, 10, 25, 35, and 50 µM) of ammonium were prepared by diluting a 5 mM stock solution of ammonium chloride with deionized water. Four mL each of these standards and of the triplicate samples collected from each sampling location were pipetted into test tubes to which were added 0.2 ml of phenol solution (20 grams of crystalline phenol dissolved in 200 ml of 95% ethyl alcohol), 0.2 ml of sodium nitroprusside solution (1.0 gram of sodium nitroprusside dissolved in 200 ml of deionized water), and 0.5 ml of oxidizing reagent (100 grams of sodium citrate and 5 grams of sodium hydroxide dissolved in 500 ml of deionized water). Samples were mixed using a vortex mixer and the color allowed to develop over a 30-minute period. A Spec20 spectrophotometer was used to measure absorbance of light at 640 nm (Abs_{640}) after zeroing against distilled water. Abs_{640} was plotted as a function of ammonium concentration for the 10 standards (five concentrations in duplicate) to create a standard curve that could be used with the measured absorbances of the unknown samples to determine their concentrations.

Nitrite

Nitrite levels were measured using the sulfanilamide-naphthyl ethylene diamine method (Strickland and Parsons, 1972), which produces a pink-colored solution.

Two samples each of five standard concentrations (0, 1, 2.5, 5, 7.5, and 10 μM) of nitrite were prepared by diluting a 5 mM stock solution of sodium nitrite with deionized water. Four mL each of these standards and of the triplicate samples collected from each sampling location were pipetted into test tubes to which were added 0.1 ml of sulfanilamide reagent (12.5 grams sulfanilamide dissolved in 250 ml of 1 N hydrochloric acid) and 0.1 ml of naphthyl ethylene diamine solution (0.25 grams naphthyl ethylene diamine dissolved in 250 ml of 1 N hydrochloric acid). Samples were mixed using a vortex mixer and the color allowed to develop over a 30-minute period. A Spec20 spectrophotometer was used to measure absorbance of light at 540 nm (Abs_{540}) after zeroing against distilled water. Abs_{540} was plotted as a function of nitrite concentration for the 10 standards (five concentrations in duplicate) to create a standard curve that could be used with the measured absorbances of the unknown samples to determine their concentrations.

Nitrate

Nitrate levels were analyzed using the copper-hydrazine reduction method (Strickland and Parsons, 1960). In this method, nitrate is first reduced to nitrite using a catalyst, and the nitrite then measured via the method mentioned in the previous section.

Two samples each of five standard concentrations (0, 5, 10, 25, 35, and 50 μM) of nitrate were prepared by diluting a 5 mM stock solution of sodium nitrate with deionized water. Four mL each of these standards and of the triplicate samples collected from each sampling location were pipetted into test tubes to which were added 0.2 ml of nitrate buffer (equal volumes of phenol solution - 9.2 grams of dry phenol dissolved in 200 ml distilled water - and sodium hydroxide solution - 2.90 grams of sodium hydroxide pellets dissolved in 200 ml of distilled water) and 0.1 ml of nitrate reducer (equal volumes of copper sulfate solution - 0.020 grams of copper sulfate dissolved in 200 ml of distilled water - and hydrazine solution - 1.45 grams of hydrazine sulfate dissolved in 200 ml distilled water). Samples were mixed using a vortex mixer and allowed to sit for 30 minutes. Thereafter, 0.2 ml of acetone were added to each sample and the samples mixed. Then 0.1 ml of sulfanilamide reagent and 0.1 ml of naphthyl ethylene diamine solution were added and the contents mixed by vortexing. The samples were then allowed to sit for another 30 minutes for the color to form fully. A Spec20 spectrophotometer was used to measure absorbance of light at 540 nm (Abs_{540}) after zeroing against distilled water. Abs_{540} was plotted as a function of nitrate concentration for the 10 standards (five concentrations in duplicate) to create a standard curve that could be used with the measured absorbances of the unknown samples to determine their concentrations.

Reactive phosphate

Phosphate concentrations were determined by mixing samples with molybdic acid to form phosphomolybdate, a strongly blue colored compound (Strickland and Parsons, 1972).

Two samples each of five standard concentrations (0, 1, 2.5, 5, 10, and 20 µM) of phosphate were prepared by diluting a 5 mM stock solution of potassium phosphate with deionized water. Four mL each of these standards and of the triplicate samples collected from each sampling location were pipetted into test tubes to which were added 0.5 ml of mixed reagent (2 volumes ammonium molybdate solution - 15 grams of ammonium paramolybdate dissolved in 500 ml deionized water, 5 volumes of sulfuric acid - 70 ml of concentrated analytical grade sulfuric acid added to 450 ml distilled water, 2 volumes of thawed ascorbic acid solution - 27 grams of ascorbic acid dissolved in 500 ml of distilled water, and 1 volume of potassium antimonyl-tartrate solution - 0.34 grams of potassium antimonyl-tartrate dissolved in 250 ml of distilled water). Samples were mixed using a vortex mixer and allowed to sit for at least 15 minutes, but no more than 2 hours. A Spec20 spectrophotometer was used to measure absorbance of light at 885 nm (Abs_{885}) after zeroing against distilled water. Abs_{885} was plotted as a function of phosphate concentration for the 10 standards (five concentrations in duplicate) to create a standard curve that could be used with the measured absorbances of the unknown samples to determine their concentrations.

ANC

Acid neutralizing capacity (ANC) was determined by acid titration. Duplicate 250-ml samples were taken at each site. From these, 100 ml of unfiltered sample were placed in a 125 mL flask to which sulfuric acid (0.1600 or 1.600 N strength) was added incrementally using either a burette or a Hach digital titrator. A stir bar placed in the flask ensured full mixing of each aliquot of acid, and a pH meter was used to measure pH after each acid addition. Acid was added until three readings under pH 4 were made. ANC values were calculated via the Gran function using the web-based U.S. Geological Survey alkalinity calculator at http://or.water.usgs.gov/alk/.

Benthic Macroinvertebrates

Kick-net sampling and multi-plate collectors were used to produce an index of biotic integrity (IBI) for benthic macroinvertebrates (BMIs). Kick-net sampling is done at riffles, where rocky streambeds provide suitable habitat for stream-dwelling invertebrates; thus these samples could only be taken where riffles were present. Sampling is conducted by one person shuffling across the stream bottom for five-minutes to dislodge BMIs while another person holds a net on the stream bottom. Duplicate kick-net samples of macroinvertebrates were taken at 12 of the 21 sampling sites in June of 2006 and in June 2007. In addition, kick-net samples were conducted at four sites in March and October of 2006; multi-plate collectors were placed at 16 sites in summer 2007 and allowed to colonize for six weeks prior to collection. All methods for data collection and analysis followed Tier 3 guidelines outlined in the Hudson Basin River Watch Guidance Document (Behar and Cheo, 2004) for freshwater stream monitoring.

For each sample (kick-net and multi-plate), all invertebrates were identified to the family level. If the number of individuals collected exceeded 100, then 100 individual invertebrates were selected randomly for identification. Each family was assigned a value from 0 to 9 reflecting its tolerance for high temperature, low oxygen, or contaminants (Hilsenhoff, 1987, 1988), with high values representing high tolerance of degraded conditions. The IBI was calculated by multiplying the number of individuals in each family by the tolerance level, summing the products, and dividing the sum by the total number of individuals. The resulting biotic index had high values (8-10) where highly tolerant families dominated the benthic macroinvertebrate community; low values (0-3) indicated dominance of families intolerant of stream degradation, and thus nearly pristine stream conditions (Hilsenhoff, 1988). We used the mean IBI from duplicate samples for each site in our analysis.

Sensitive BMIs include Stoneflies (Order: Plecoptera, Family: Nemouridae), Dobsonflies (Order: Megaloptera, Family: Corydalidae), Riffle Beetles (Order: Coleoptera, Family: Elmidae), and Mussels (Order: Pelecypoda, Family: Sphaeriidae).

Moderately Tolerant BMIs include Sowbugs (also known as pillbugs, Order: Isopoda, Family: Asellidae), Scuds (Order: Amphipoda, Family: Gammaridae), Caddisflies (Order: Trichoptera, Family: Hydropsychidae, Philopotamidae, and Psychomyiidae), and True flies: Crane Fly and Black Fly (Order: Diptera, Family: Tipulidae and Simuliidae).

Pollution Tolerant BMIs include Aquatic Worms (Class: Oligochaeta, Order and Family vary), Pouch Snails (Order: Gastropoda, Family: Physidae), and Midge Fly (Order: Diptera, Family: Chironomidae).

Stream substrate

To test whether increasing availability of hard substrate habitat in the stream (gravel, cobbles, or boulders) influenced benthic macroinvertebrate assemblage, we conducted a simplified Wolman pebble count (Wolman,

1954) on stream bottom sediments by walking back and forth across the stream and recording substrate types (silt/clay, sand, gravel, cobbles, or boulders) at each foot fall (Behar and Cheo, 2004). Transects of the stream moved from upstream to downstream within the riffle zone until a minimum of 50 measurements were made, from which we calculated relative abundance of the different substrates. No sites had exposed bedrock in the substrate. For the analysis presented in this report we used percentage cobbles to represent substrate because of correlations among size classes.

Land use/land cover analysis

Land cover at multiple scales can influence water quality (Wang et al., 2001; Strayer et al., 2003; Roy et al., 2007). Therefore we calculated the percentage of impervious cover at two scales, the sub-basin and riparian zones. Sub-basins were calculated as follows: we used the ArcView 3.2 interface for the Soil and Water Assessment Tool (AvSWAT; Di Luzio et al., 2002) to delineate sub-basins, or the drainage basin upstream of each sampling location, using a U.S. Geological Survey 10-m resolution digital elevation model. Sub-basins were nested: the catchment above the first sample point was included in the catchment above the second sample point, and so on. The last sample point contained the cumulative area of all upstream sub-basins.

Within the sub-basin and riparian zone above each sample point, we calculated the amount of impervious surface cover using land cover data classified from Landsat imagery (date 23 September 1999). Image classification was done with ENVI software (www.ittvis.com/envi/). Classified data had a resolution of 30 m and a classification accuracy of 84 percent for impervious cover, based on an error assessment using a stratified sample of 100 points in the study area.

For the local riparian area, we calculated percentage impervious cover within a 100-m buffer on either side of the stream, for a distance of 200 m upstream of each sample site. For both sub-basins and riparian zones, we calculated the percentage impervious cover contributing to each sampling site using the Tabulate Area utility in ArcGIS (ESRI 2004, www.esri.com).

Vassar College
Environmental
Research Institute

Cornell University
Cooperative Extension
Dutchess County

Casperkill Creek Watershed Survey

Hello! Please fill out one survey per household/business. If you'd prefer, you can fill out the survey on-line at:

http://ws.cit.cornell.edu/ss/wsb.dll/287/CasperkillWatershedSurvey.htm.

30 households completed the survey. Their responses are shown in italics below.

1) Do you live or work in the Casperkill Creek Watershed? See map on the back of this page and please check the box or boxes relevant to you.

	Alongside the creek	*Within 1/2 mile of the stream*	*In the watershed*
Rent house/apt.	*0%*	*0%*	*0%*
Own house/apt.	*53%*	*27%*	*17%*
Work	*0%*	*3%*	*7%*
Own business	*0%*	*3%*	*0%*

2) How many years have you lived or worked in the watershed? Please circle.

☐ 0-2 *0%* ☐ 3-5 *17%* ☐ 6-15 *27%* ☐ 16-30 *30%* ☐ 30 + *27%* ☐Not applicable *0%*

3) Do you make decisions about a property that borders the Casperkill Creek?

Yes - *43%* No – *50%* Not sure – *7%*

4) If you answered yes to question 3, to what extent would you be interested in adapting your landscaping to protect the creek?

Interested – *37%* Not interested – *0%* Not sure – *7%* Not applicable – *20%*
No response – 36%

5) What factors would prevent you from changing your landscaping?

Cost – *20%* Lack of time – *3%* Lack of knowledge – *10%* Other – *27%*
No response – 40%

6) If you use the creek for any purpose, please list your use (e.g. fishing, kids play in creek, enjoy the view, etc.).
Sample answers - view wildlife, children play in creek, dogs play in the creek, boating, camping, fishing, enjoy the view, enjoy the sound of the water

7) Are there particular environmental, social or economic values that you see in the stream?
Sample answers – educational, wildlife habitat, water quality, raises property values, beauty, nesting and hatching area for turtles, waterfowl, frogs, salamanders, was once a trout stream

8) What's your perception of the overall environmental health of the stream and its banks?
Excellent – *0%* Good – *20%* Fair – *33%* Poor – *23%* Not Sure – *13%*
No response – 10%

9) Are you aware of any issues related to the Casperkill Creek?
Sample answers – stormwater runoff, flooding, erosion, too many nitrates and phosphates causing vegetation overgrowth in Wappingers Lake, raw sewage overflow from pump station on Casperkill drive, dumping, non-point source pollution, loss of open space-development, leaking sewage, fertilizer, erosion of bank, not aware of any because stream here appears clean and vital

10) In your opinion, what should be done to address the watershed issues that you identified?
Answers - property owners need to be made aware of good stewardship practices and their potential impact on the watershed. If they live on the stream they need to understand what positive things they can do to support the stream's health. Treat stormwater runoff before it enters the creek, fix streambank erosion & watershed erosion, create a riparian corridor that buffers the creek, reduction of fertilizers. I have kept the stream clean on my property, e.g. removing debris, road standards, fuel oil, tree trunks, etc. Sewage problem is a bureaucracy problem-state jurisdiction. No action from town or state. No one responsible. Publicity to shame officials to action. Flooding is a tough one. Residents say that water levels seen today are unprecedented. More info, knowledge, grants to property owners. Restrictions on impervious coverage. Education on sources of pollution (animal waste, etc.). Set up a watershed association to purchase easements and property, and fee to protect open space. Separate sanitary sewer from runoff drains. New and larger sewage pipes should be put into place. 90 degree angle should be eliminated and much larger pumping station should be built. Help from any agency that is willing to preserve this wonderful and natural waterway. Deny permitting for large-scale housing developments in the watershed. Sanitary sewers along Boardman Rd. Education of landowners who poison their lawns, hence the creek. Better planning of town and DOT projects. Assure that this watershed is addressed in the town's Master Plan. Keep the creek free of leaves, grass cuttings, garbage, etc. Have the Town do more to protect them and change zoning issues.

11) Please estimate how much of a problem you think each of the following issues will be in the Casperkill Creek Watershed within the next 5 to 10 years. Please <u>circle one number</u> for <u>each issue.</u>

Issue	Not a Problem	Slight Problem	Moderate Problem	Serious Problem	Don't Know	No Response
a. Eroding banks along the creek	*3%*	*13%*	*27%*	*40%*	*7%*	*10%*
b. Non-native/Invasive weed growth	*10%*	*3%*	*17%*	*37%*	*20%*	*13%*
c. Runoff from parking lots and streets	*3%*	*10%*	*17%*	*47%*	*10%*	*13%*
d. Seepage from septic tanks/sewer lines	*7%*	*10%*	*7%*	*50%*	*13%*	*13%*
e. Frequency of flooding	*7%*	*13%*	*30%*	*33%*	*7%*	*10%*
f. Economic losses due to flooding	*13%*	*27%*	*30%*	*13%*	*7%*	*10%*
g. Drinking water quality	*17%*	*20%*	*10%*	*13%*	*27%*	*13%*
h. Smells, noise, or dust from	*13%*	*23%*	*17%*	*7%*	*27%*	*13%*

businesses/industry						
i. Property damage from wildlife	*20%*	*20%*	*20%*	*13%*	*17%*	*10%*
j. Solid waste disposal	*3%*	*27%*	*17%*	*10%*	*30%*	*13%*
k. Economic costs of complying with land-use regulations	*7%*	*20%*	*10%*	*17%*	*33%*	*13%*
l. Loss of wetlands	*0%*	*17%*	*17%*	*37%*	*17%*	*13%*
m. Loss of forested or wooded areas	*0%*	*10%*	*23%*	*43%*	*13%*	*10%*
n. Loss of wildlife	*3%*	*10%*	*20%*	*40%*	*17%*	*10%*
o. Loss of natural land to development	*3%*	*10%*	*10%*	*57%*	*10%*	*10%*
p. Nutrient levels in the creek (e.g. nitrate,phosphate)	*3%*	*10%*	*27%*	*27%*	*20%*	*13%*
q. Pesticide/herbicide levels in the creek	*0%*	*7%*	*20%*	*33%*	*27%*	*13%*
r. Soil deposition in the creek	*3%*	*10%*	*23%*	*23%*	*27%*	*13%*

12) Please indicate for each land use listed below whether you would like to see more, about the same, or less, of each in the Casperkill watershed. Please <u>circle one number</u> for <u>each land use.</u>

Land Use	***More***	***About the same***	***Less***	***Don't know***	***No Response***
a. Forest or woodland	*50%*	*37%*	*0%*	*3%*	*10%*
b. Fields	*23%*	*50%*	*7%*	*10%*	*10%*
c. Wetlands	*50%*	*33%*	*0%*	*7%*	*10%*
d. River floodplains that have been maintained or restored to their natural state	*60%*	*23%*	*0%*	*7%*	*10%*
e. Rivers or streams that have been straightened or channeled	*17%*	*10%*	*47%*	*17%*	*10%*
f. Parks	*43%*	*33%*	*3%*	*10%*	*10%*
g. Wildlife Habitat	*70%*	*17%*	*0%*	*3%*	*10%*
h. Farmland or gardens	*30%*	*40%*	*10%*	*10%*	*10%*
i. Developed urban areas	*3%*	*20%*	*60%*	*7%*	*10%*

13) In your opinion, who should be most responsible for addressing the Casperkill watershed issues that you identified in questions 8? <u>Please circle only one.</u>

Federal Government – *13%*
NY State Government – *10%*
Dutchess County Government – *17%*
Town of Poughkeepsie – *27%*
Local Landowners – *7%*
No Response – 16%

Environmental Groups – *3%*
Industry/Business – *0%*
A Local Citizen Group – *7%*
Other – *0%*
Don't know – *0%*

14) Please indicate your rate of involvement in the following activities. <u>Please check the boxes that apply.</u>

Activity	**0**	**1-4**	**Over 4**	**No Response**
a. Approximately how many hours per week have you dedicated to community activities in the past year?	*23%*	*23%*	*47%*	*7%*
b. Approximately how many local governmental meetings have you attended in the past year?	*43%*	*27%*	*23%*	*7%*
c. How many times in the past 5 years have you participated with a local group either as a volunteer or to see out a project?	*27%*	*30%*	*37%*	*7%*

d. In the past 5 years, how many times have you talked with public officials in your community about your natural resource concerns?	*30%*	*43%*	*20%*	*7%*

15) How do you obtain information about your community? <u>Please circle all that apply.</u>

Local radio program (please indicate which program) – *23% (Joel Tyner's radio show on WVKR, WRWV, WHUD, WEOK, WKIP)*
Local television program (please indicate which program) – *20% (Cablevision News)*
Local newspaper (please indicate which newspaper) – *83% (Poughkeepsie Journal, Weekly Beat, Southern Dutchess News, Hudson Valley magazine)*
Direct mail newsletter – *43% (Scenic Hudson)*
Email – *33%*
Web Site – *20%*
Personal communication with family or friends – *47%*
Public meetings – *23%*
Local Extension Offices – *3%*
Meetings of local groups and organizations – *27%*
Other (please specify) – *<1% (Library, Vassar College)*

16) Would you like research about the health of the creek to continue?
Yes – *87%* No – *0%* Not sure – *7%* *No response – 7%*

17) Would you like to be kept informed of research and/or activities regarding the creek?
Yes – *87%* No – *3%* Not sure – *3%* *No response – 7%*

If so, please fill out the contact information sheet.

THANK YOU FOR YOUR INPUT!

Please return the survey in the provided stamped return envelope to:

Kirsten Menking, Box 59, 124 Raymond Ave., Vassar College, Poughkeepsie, NY 12604

References

Allan, J.D., and Castillo, M.M., 2007, Stream Ecology: Structure and Function of Running Waters, Second Edition, Dordrecht, Netherlands: Springer, 436 p.

American Association of State Highway and Transportation Officials, 2009, Compendium of Environmental Stewardship Practices in Construction and Maintenance, Chp. 8 - Winter Operations and Salt, Sand, and Chemical Management, Available at < http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/8_0.aspx> Accessed January 10, 2009.

Behar, S., and Cheo, M., 2004, Hudson Basin River Watch Guidance Document, River Network, 138 p. <http://www.hudsonbasin.org/HBRWGD04.pdf> Accessed January 2009.

Belk, E., 1995, Metal contamination and distribution in Casper Creek, Poughkeepsie, New York: Chromium concentrations near the FICA landfill, B.A. Thesis, 37 p.

Benoit, D.A., 1988, Ambient water quality criteria for chloride – 1988, U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory, Duluth, Minnesota.

Benbow, M.E., and Merritt, R.W., 2004, Road-salt toxicity of select Michigan wetland macroinvertebrates under different testing conditions, Wetlands, v. 24, p. 68-76.

Bloom, A.L., 2008, The late Pleistocene glacial history and environment of New York state mastodons, in Allmon, W.D. and Nester, P.L. (eds.), Mastodon Paleobiology, Taphonomy, and Paleoenvironment in the Late Pleistocene of New York state: Studies on the Hyde Park, Chemung, and North Java sites, Palaeontographica Americana, v. 61, p. 13-23.

Booth, D.B., Hartley, D., and Jackson, R., 2002, Forest cover, impervious-surface area, and the mitigation of stormwater impacts, Journal of the American Water Resources Association, v. 38, p. 835-845.

Borchardt, D., and Statzner, B., 1990, Ecological impact of urban stormwater runoff studied in experimental flumes: population loss by drift and availability of refugial space, Aquatic Science, v. 52, p. 299–314.

Burns, D., 2006 Assessment of In-Stream Water Quality of Hudson River Tributaries in the Rural to Urban Landscapes of Dutchess County, NY. M.A. Thesis, State University of New York, New Paltz.

Buttle, J.M., 1994, Hydrological response to reforestation in the Ganaraska River basin, southern Ontario, Canadian Geographer, v. 38, p. 240-253.

Center for Watershed Protection, 1998, Better Site Design: A Handbook for Changing Development Rules in Your Community. Center for Watershed Protection.

Charkes, J.S., 2008, Healthy Lawns vs. Clean Water? *New York Times*, Oct. 17, 2008, <http://www.nytimes.com/2008/10/19/nyregion/westchester/19lawnwe.html>

Charlton, R., 2008, Fundamentals of Fluvial Geomorphology, New York: Routledge, 234 p.

Chen, Y., De Nobili, M., and Aviad, T., 2004, Stimulatory of Humic Substances on Plant Growth, in Magdoff, F., and Weil, R.R. (eds.), Soil Organic Matter in Sustainable Agriculture, Chp. 4, CRC Press.

Clausen, J.C., 2007. Jordan Cover Watershed Project Final Report, Storrs, Connecticut: Department of Natural Resources Management and Engineering, College of Agriculture and Natural Resources, University of Connecticut.

Connally, G.G., and Sirkin, L.A., 1986, Woodfordian Ice Margins, Recessional Events, and Pollen Stratigraphy of the Mid-Hudson Valley. In Cadwell, D.H., ed., The Wisconsinan Stage of the First Geological District, Eastern New York, p. 50-72, New York State Museum Bulletin 455.

Coffman, L., 2000, Low-Impact Development Design Strategies, an Integrated Design Approach, EPA 841-B-00-003, Department of Environmental Resources, Programs and Planning Division, Prince George's County, Maryland. Available at < http://www.epa.gov/owow/nps/lid/lidnatl.pdf>, Accessed January 2009.

Cunningham, M.A., Snyder, E., Yonkin, D., Ross, M., and Elsen, T., 2008, Accumulation of deicing salts in soils in an urban environment, Urban Ecosystems, v. 11, p. 17-31.

Cunningham, M.A., Menking, K.M., Gillikin, D.P., Belli, S.L., Freimuth, C.P., Smith, K.C., Pregnall, A.M., Schlessman, M.A., and Batur, P., in revision, Can urban stream water quality recover longitudinally? Submitted to Urban Ecosystems.

Daniel, J.W., 1978, Toxicity and metabolism of phthalate esters, Clinical Toxicology, v. 13, p. 257- 268

Dietz, M.E., and Clausen, J.C., 2005, A field evaluation of rain garden flow and pollution treatment, Water, Air and Soil Pollution, v. 167, p. 123-138.

Dietz, M.E., 2007, Low impact development practices: a review of current research and recommendations for future directions, Water, Air, and Soil Pollution, v. 186, p. 351-363.

Di Luzio, M., Srinivasan, R., and Arnold, J.G., 2002, Integration of watershed tools and SWAT model into BASINS, Joural of the American Water Resources Association, v. 38, p. 1127-1141.

Duncan, T., 1971a, Town Grants Developers 5 Days to Control Odors, Poughkeepsie Journal, May 20, 1971.

Duncan, T., 1971b, Excavation to be Completed at Town Dump Site, Poughkeepsie Journal, May 28, 1971.

Duncan, T., 1971c, State Asked to Consider Plan to Reduce Casper Kill Pollution, Poughkeepsie Journal, December 14, 1971.

Federal Interagency Stream Restoration Working Group, 2001, Stream Corridor Restoration: Principles, Processes, and Practices, National Engineering Handbook, Part 653, USDA – Natural Resources Conservation Service.

Feminella, J.W., and Walsh, C.J., 2005, Urbanization and stream ecology: An introduction to the series, Journal of the North American Benthological Society, v. 24, p. 585-587.

Galli, J., 1990, Thermal Impacts Associated With Urbanization and Stormwater Management Best Management Practices, Metropolitan Washington Council of Governments, Maryland Department of Environment, Washington D.C., 188 pp.

Godwin, K.S., Hafner, S.D., and Buff, M.F., 2003, Long-term trends in sodium and chloride in the Mohawk River, New York: The effect of fifty years of road-salt application, Environmental Pollution, v. 124, p. 273-281.

Hilsenhoff, W.L., 1987, An improved biotic index of organic stream pollution, Great Lakes Entomologist, v. 20, p. 31-40.

Hilsenhoff, W.L., 1988, Rapid field assessment of organic pollution with a family-level biotic index, Journal of the North American Benthological Society, v. 7, p. 65-68.

Hood, M.J., Clausen, J.C., and Warner, G.S., 2007, Comparison of stormwater lag times for low impact and traditional residential development, Journal of the American Water Resources Association, v. 43, p. 1036-1046.

Howard, K.W.F., and Haynes, J., 1993, Groundwater contamination due to road de-icing chemicals — salt balance implications, Geoscience Canada, v. 20, p. 1–8.

Howdeshell, K.,L., Furr, J., Lambright, C.R., Rider, C.V., Wilson, V.S., Gray, L.E. Jr., 2007, Cumulative effects of dibutyl phthalate and diethyhexyl phthalate on male rate reproductive tract development: altered fetal steroid hormones and genes, Toxicological Sciences, v. 99, p. 190-202

Hutton, G.V., 2003, The Great Hudson River Brick Industry: Commemorating Three and a Half Centuries of Brickmaking. Purple Mountain Press. Fleischmanns, New York.

Jackson, R.B., and Jobbágy, E.G., 2005, From icy roads to salty streams, Proceedings of the National Academies of Science, v. 102, p. 14487-14488.

Kaushal, S.S., Groffman, P.M., Likens, G.E., Belt, K.T., Stack, W.P., Kelly, V.R., Band, L.E., and Fisher, G.T., 2005, Increased salinization of fresh water in the Northeastern United States, Proceedings of the National Academies of Science, v. 102, p. 13517-13520.

Kelly, V.R., Lovett, G.M., Weathers, K.C., Findlay, S.G., Strayer, D.L., Burns, D.J., and Likens, G.E., 2008, Long-term sodium chloride retention in a rural watershed: Legacy effects of road salt on stream water concentration, Environmental Science and Technology, v. 42, p. 410-415.

Law, N.L., Band, L.E., and Grove, J.M., 2004, Nitrogen Input from Residential Lawn Care Practices in Suburban Watersheds in Baltimore County, MD, Journal of Environmental Planning and Management, v. 47, p. 737-755.

Laws, E., 2000, Aquatic Pollution, 3rd ed., New York, John Wiley and Sons, 639 p.

Lubasch, A.H., 1987, New York sues reputed mobster to force cleanup of landfill, New York Times, Oct. 6, 1987.

Lundberg, P., Hogberg, J., Garberg, P., Lundberg, I., Dobson, S., Howe, P., 1992, Diethylhexyl Phthalate, Environmental Health Criteria 131, Internaional Programme on Chemical Safety, Geneva: United Nations Environment Programme, International Labour Organisation, and World Health Organization. <

http://www.inchem.org/documents/ehc/ehc/ehc131.htm> Accessed January 2009.

Mallin, M.A., Cahoon, L.B., Toothman, B.R., Parsons, D.C., McIver, M.R., Ortwine, M.L., and Harrington, R.N., 2007, Impacts of a raw sewage spill on water and sediment quality in an urbanized estuary, Marine Pollution Bulletin, v. 54, p. 81–88.

Mangiafico, S.S., and Guillard, K., 2006, Fall Fertilization Timing Effects on Nitrate Leaching and Turfgrass Color and Growth, Journal of Environmental Quality, v. 35, p. 163-171.

Mankin, K.R., Ngandu, D.M., Barden, C.J., Hutchinson, S.L., and Geyer, W.A., 2007, Grass-shrub riparian buffer removal of sediment, phosphorus, and nitrogen from simulated runoff, Journal of the American Water Resources Association, v. 43, p. 1108-1116.

Mayer, P.M., Reynolds, S.K., and Canfield, T.J., 2005, Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: A review of current science and regulations. EPA/600/R-05/118:1-40.

New Hampshire Department of Environmental Services, 2003, Fecal Coliform as an Indicator Organism, Environmental Fact Sheet WD-WEB-18, available at < http://des.nh.gov/organization/commissioner/pip/factsheets/wwt/documents/web-18.pdf>, Accessed January 2009.

New Jersey Administrative Code, 2008, Surface Water Quality Standards: 7:9B. <http://www.state.nj.us/dep/wms/bwqsa/swqsdocs.html>

New York State Department of Environmental Conservation, 1996, Final Preliminary Site Assessment: Van De Water Property Site No. 314040, Poughkeepsie (T), Dutchess, (C), report prepared by YEC, Inc. (Valley Cottage, NY) under contract to URS Consultants, Inc. (Buffalo, NY).

New York State Department of Environmental Conservation, 2008a, Critical Environmental Areas in Dutchess County – NYS Dept. of Environmental Conservation, <http://www.dec.ny.gov/public/25113.html> Accessed Dec. 31, 2008.

New York State Department of Environmental Conservation, 2008b, Lower Hudson WI/PWL – NYS Dept. of Conservation, Priority Waterbodies List, <http://www.dec.ny.gov/docs/water_pdf/pwllhudlist.pdf> Accessed Dec. 31, 2008.

New York State Department of Environmental Conservation, 2008c, Part 703: Surface Water and Groundwater Quality Standards and Groundwater

Effluent Limitations – NYS Dept. of Environmental Conservation, <http://www.dec.ny.gov/regs/4590.html#16131> Accessed January 10, 2009.

New York State Department of Transportation, October 2006, Equipment Operator Snow & Ice Manual, Highway Maintenance Division

New York State Museum, 1999a, Statewide Bedrock Geology, 1:250,000 scale map digitized for GIS. Data available at < http://www.nysm.nysed.gov/gis/#state>

New York State Museum, 1999b, Surficial Geology, Lower Hudson Sheet, 1:250,000 scale map digitized for GIS. Data available at < http://www.nysm.nysed.gov/gis/#state>

Paul, M.J., and Meyer, J.L., 2001, Streams in the urban landscape, Annual Review of Ecology and Systematics, v. 32, p. 333-365.

Peters, N.E., and Turk, J.T., 1981, Increases in sodium and chloride in the Mohawk River, New York, from the 1950's to the 1970's attributed to road salt, Journal of the American Water Resources Association, v. 17, p. 586–598.

Rawls, W.J., Ahuja, L.R., Brakensiek, D.L., and Shirmohammadi, A., 1993, Infiltration and soil water movement, in Maidment, D.R. (ed.), Handbook of Hydrology, New York: McGraw-Hill Inc.

Riley, A., 1998, Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens, Washington D.C., Island Press, 423 p.

Ritter, D.F., Kochel, R.C., and Miller, J.R., 2002, Process Geomorphology, 4th edition, New York: McGraw-Hill.

Roy, A.H., Freeman, B.J., and Freeman, M.C., 2007, Riparian influences on stream fish assemblage structure in urbanizing streams, Landscape Ecology, v. 22, p. 385-402.

Shapley, D., 2005a, Pipes belch sewage into yards, Poughkeepsie Journal, Oct. 15th, 2005, A01.

Shapley, D. 2005b, Road salting threatens freshwater life, Poughkeepsie Journal, Sep. 6th, 2005, B01.

Soil Survey Staff, 2008, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for [Dutchess County, NY]. Data available at <http://soildatamart.nrcs.usda.gov> Accessed January 2009.

Solorzano, L., 1969, Determination of ammonia in natural waters by the phenolhypochlorite method, Limnology and Oceanography, v. 14, p. 799-801.

Strayer, D.L., Beighley, R.E., Thompson, L.C., Brooks, S., Nilsson, C., Pinay, G., and Naiman, R.J., 2003, Effects of land cover on stream ecosystems: Roles of empirical models and scaling issues, Ecosystems, v. 6, p. 407-423.

Strickland, J.D.H., and Parsons, T.R., 1960, A manual of sea water analysis, Bulletin of the Fisheries Research Board of Canada, v. 125, 185 pp.

Strickland, J.D.H., and Parsons, T.R., 1972, A practical handbook of seawater analysis, 2nd ed., Bulletin of the Fisheries Research Board of Canada, v. 167, 311 pp.

Thompson, A.M., Kim, K., and Vandermuss, A.J., 2008, Thermal Characteristics of Stormwater Runoff from Asphalt and Sod, Journal of the American Water Resources Association, v. 44, p. 1325-1336.

Town of Poughkeepsie, 2007, Poughkeepsie Town Plan and Final Generic Environmental Impact Statement <http://www.townofpoughkeepsie.com/supervisor/PoughkeepsieTownPlanAdopted092607.pdf>

United States Environmental Protection Agency, 1996, Environmental Indicators of Water Quality in the United States, EPA report # 841-F-96-001.

United States Environmental Protection Agency, 1999, 1999 Update of Ambient Water Quality Criteria for Ammonia, Office of Water, EPA report # 822-R-99-014.

Urban-Mead, R., 2006, Dutchess County Aquifer Recharge Rates and Sustainable Septic System Density Recommendations, report by the Chazen Companies for the Dutchess County Water and Wastewater Authority, Dutchess County, New York.

Valiela, I., and Bowen, J.L., 2002, Nitrogen sources to watersheds and estuaries: Role of land cover mosaics and losses within watersheds, Environmental Pollution, v. 118, p. 239-248.

Vermont Agency of Natural Resources, 2004. Vermont Stream Geomorphic Assessment, Appendix M: Delineation of Stream Bed Features. < http://www.anr.state.vt.us/dec//waterq/rivers/docs/assessmenthandbooks/rv_apxmdelineationbedfeatures.pdf>.

Vitousek, P.M., Aber, J., Howarth, R.W., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., and Tilman, G.D., 1997, Human alteration of the global nitrogen cycle: causes and consequences, Issues in Ecology, v. 1.

Walsh, C.J., Fletcher, T.D., Ladson, A.R., 2005b, Stream restoration in urban catchments through redesigning stormwater systems: Looking to the catchment to save the stream, Journal of the North American Benthological Society, v. 24, p. 690-705.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., and Morgan II, R.P., 2005a, The urban stream syndrome: Current knowledge and the search for a cure, Journal of the North American Benthological Society, v. 24, p. 706-723.

Wams, T.J., 1978, Diethylhexyl Phthalate as an environmental contaminant - a review. Marine Pollution Bulletin, v. 9, p. 249-251.

Wang, L., Lyons, J., Kanehl, P., and Bannerman, R., 2001, Impacts of urbanization on stream habitat and fish across multiple spatial scales, Environmental Management, v. 28, p. 255-266.

Wolman, M.G., 1954, A method of sampling coarse river-bed material, Transactions of the American Geophysical Union, v. 35, p. 951-956.

Wolman, M.G., 1967, A cycle of sedimentation and erosion in urban river channels, Geografiska Annaler, v. 49, p. 385-395.

World Health Organization, 2003, Tetrachloroethene in Drinking-water, < http://www.who.int/water_sanitation_health/dwq/chemicals/tetrachloroethene.pdf> Accessed Dec. 31, 2008.

Woyton, M., 2007, Woman admits defeat in battle with erosion, Poughkeepsie Journal, Apr. 19th, 2007, 3A.