Chapter 17

Cannonsville Reservoir, New York: National Institute of Food and Agriculture–Conservation Effects Assessment Project

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The overall goal of the New York National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP), Integrating Data and Models from the Cannonsville Reservoir, New York City Watershed, to Assess Short- and Long-term Effects of Phosphorus BMPs in the Northeast, was to use modeling, statistical inference, and extensive data sources to quantify the effectiveness of best management practices (BMPs) in New York and the Northeast (Shoemaker et al. 2005). Specific objectives listed for the project included the following:

1. Assess the relative benefits and costs of alternative BMPs for controlling dissolved and total phosphorus (P) in the context of short- and long-term water quality goals
2. Use both Hortonian and saturation excess runoff and variable source area (VSA) models to evaluate P transport in watersheds where permeable surface zones overlay dense sublayers and to develop an extension of the Soil and Water Assessment Tool variable source area (SWAT–VSA) that incorporates VSA hydrology
3. Develop a computationally feasible procedure for cost-effective ranking of BMPs and develop an understanding of causes of differences among the rankings generated by different models
4. Develop methods to incorporate the most cost-effective BMPs in the whole-farm plan in close cooperation with the New York State Watershed Agricultural Council, Cornell Cooperative Extension, the USDA Natural Resources Conservation Service (NRCS), local Soil and Water Conservation Districts, and county planners

Watershed Information

In 1997, an historic partnership—The New York (NY) City Watershed Protection Program—was signed into law to protect the drinking water resources of NY City. By contributing funds and oversight to protect water quality in the source watersheds for NY City's drinking water, NY City was allowed to avoid the much more expensive control method of building a filtration plant. Although drinking water for NY City comes from watersheds within eight counties,

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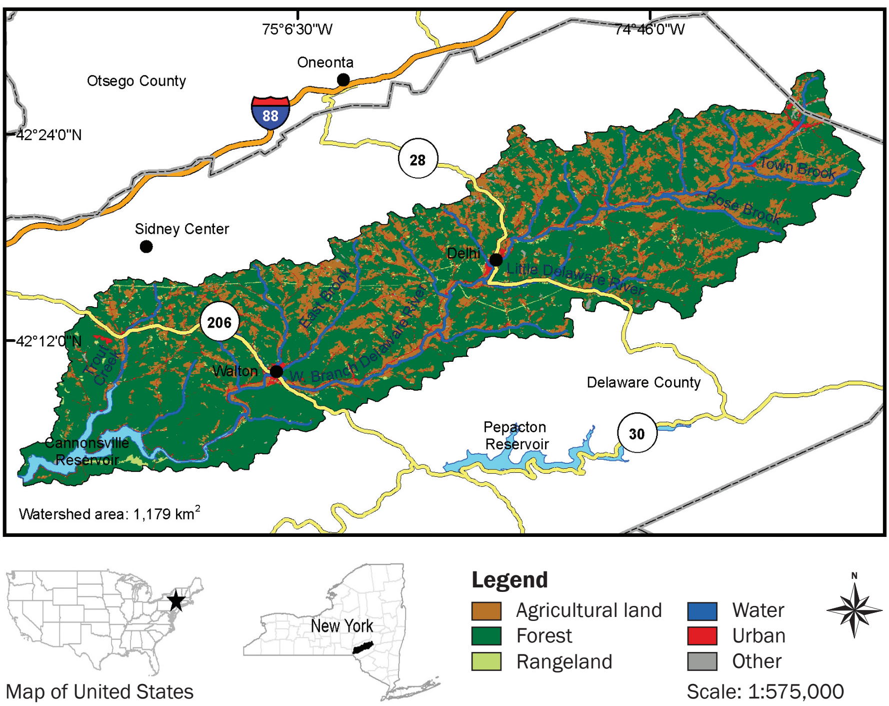
the focus of this project is on the Cannonsville Reservoir, one of the six reservoirs in the West Hudson system that provides drinking water used daily in NY City.

The Cannonsville Basin (National Hydrography Dataset hydrologic unit code #02040101) is on the West Branch of the Upper Delaware River in the Catskills Mountain region of NY State (figure 17.1). The Cannonsville Reservoir is the third largest reservoir in NY City's water supply system; it was constructed by damming the West Branch of the Delaware River in the early 1960s and became part of the reservoir system owned by the City of NY in 1966. Land for the reservoir was condemned and purchased from townspeople and farmers. According to Platt et al. (2000), approximately 1,000 residents were displaced, and land prices were often half the assessed property value. As detailed in Pfeffer and Wagenet (1999), the building of the reservoir along with other activities in the watershed by NY City caused historical tension (Armstrong et al. 2011).

The Cannonsville Watershed is ~1,200 km^2 (463 mi^2) in area, the largest of the water supply watersheds, and can provide as much as 362 million m^3 (95.7 billion gal) of potable water. The watershed is characterized by undulating topography, shallow soils over a less permeable till or bedrock layer, and runoff generation mechanisms dominated by a combination of interflow and saturation excess overland flow. Elevations within the watershed range from 285 to 995 m (935 to

Figure 17.1
The Cannonsville Reservoir Watershed, New York, land use and stream networks.



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3,265 ft) above mean sea level, and slopes range from 0% to over 40%, with an average land-surface slope of 19%. Shallow soils overlie relatively impermeable bedrock or glacial till. The climate of the Cannonsville Basin is humid, with an average annual temperature of about 8°C (46°F) and average annual precipitation of about 1,100 mm (43 in), one third of which falls as snow.

The Cannonsville Reservoir Watershed is predominantly rural. Land use is dominated by forests (66%); agriculture comprises 14% of the watershed (4% silage corn, 5% pasture, 5% hay), with dairy farms accounting for the vast majority of the agricultural land use. The NY City Department of Environmental Protection (NYCDEP) has instituted an extensive water quality management program that emphasizes the use of structural and management-based conservation practices, such as calf sheds, milking parlor drainage, reduced tillage, and nutrient management), and provides 100% cost share for installation or use of these practices (see the Land Treatment section in this chapter).

The NY City Watershed Protection Program includes a watershed protection strategy aimed at protecting the reservoir from pollution, especially nutrients and pathogens, generated from watershed sources, particularly farms located in the watershed. Much of the conservation work and funding has been through the Watershed Agricultural Council, a voluntary partnership between the NY City and producers in the watershed. Funding for the Watershed Agricultural Council has been provided by the NYCDEP; additional funds have been leveraged through the USDA (Farm Service Agency, Natural Resources Conservation Service, the US Forest Service, and Agricultural Research Service), the US Environmental Protection Agency (USEPA), and other agencies.

Much of the information presented in this report is a result of many years of work by many agencies. The NY NIFA–CEAP focused on modeling (see the Modeling Section in this chapter), which was done in conjunction with the NYCDEP. Water quality and land treatment data for modeling were derived from past research efforts conducted by the NYCDEP and Cornell University. All information in this report, except the modeling section, derives from the totality of The NY City Watershed Protection Program.

Water Quality Information

The primary water quality concern is the threat of eutrophication and pathogen loading to Cannonsville Reservoir. The Cannonsville Reservoir is one of the most eutrophic of the 19 water supply reservoirs operated by the NYCDEP. The NY City Watershed Protection Program focuses on prevention in order to protect the quality of NY City's water supply so that filtration is not necessary.

Studies have identified P loads to the reservoir from point and nonpoint sources as the cause of eutrophication. Total dissolved phosphorus (TDP), in particular, plays the most important role in stimulating the growth of algae. The majority of point source loads come from wastewater treatment plant (WWTP) discharges, while the local dairy farms are thought to be responsible for most of the nonpoint source loads. In the last 15 years, all WWTP in the Cannonsville Basin have implemented tertiary treatment for P removal.

The USEPA (2009) uses the following criteria for water sources that are not filtered:

> For a drinking water system to qualify for filtration avoidance under the Surface Water Treatment Rule (SWTR) the system cannot be the source of a waterborne disease outbreak, must meet source water quality limits for coliform and turbidity and meet

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> coliform and total trihalomethane maximum contaminant levels. Disinfectant residual levels and redundant disinfection capability must also be maintained. Filtration avoidance also requires that a watershed control program be implemented to minimize microbial contamination of the source water. This program must characterize the watershed's hydrology, physical features, land use, source water quality and operational capabilities. It must also identify, monitor, and control manmade and naturally occurring activities that are detrimental to water quality. The watershed control program must also be able to control activities through land ownership or written agreements.

Additionally, on July 30, 2007, the USEPA released its NY City Filtration Avoidance Determination for the Catskill/Delaware Water Supply. The USEPA determined that NY City has an adequate long-term watershed protection program for its Catskill/Delaware water supply, which meets the requirements of the Surface Water Treatment Rule and the Interim Enhanced Surface Water Treatment Rule for unfiltered water supply systems. The new NY City Filtration Avoidance Determination included many provisions that are responsive to the numerous public comments received during the public comment period and during the public outreach sessions. The goals, therefore, of the overall NY City Watershed Protection Program were simple; the water had to meet USEPA criteria for drinking water for the citizens of NY City, and farmers had to be able to keep their livelihood.

Stream discharge, along with sediment, and nutrient (P and nitrogen) concentrations have been routinely monitored at seven locations in the watershed. Monitoring in the Cannonsville Reservoir Watershed is a cooperative effort by the NYCDEP, the New York State Department of Environmental Conservation (NYDEC), and the US Geological Survey (USGS). Data collected from the gaging station at Beerston, New York, where the West Branch of the Delaware flows into the Cannonsville Reservoir, include flow from 1950 to the present and 14 years (1992 to 2006) of total P and TDP concentration. Water quality records from at least five years are also available from a station at the mouth of Trout Creek that feeds the northern branch of the Cannonsville Reservoir. Databases are kept by NY City Watershed staff and the watershed councils.

A paired-watershed study conducted by the NYDEC under the USEPA Section 319 National Nonpoint Source Monitoring Program (NNPSMP) from 1993 to 2005 has the most complete dataset. The single-farm paired-watershed study (Bishop et al. 2003, 2005, 2006) is frequently cited, and results are used extensively as representative of the Cannonsville Basin. The control watershed was a nonfarm control; the treatment watershed included a single dairy farm. Particulate phosphorus (PP), TDP, soluble reactive P, nitrate + nitrate-nitrogen (NO_2 + NO_3-N), total ammonium-nitrogen (NH_4-N), total Kjeldahl nitrogen, total organic carbon, total suspended solids (TSS), alkalinity, pH, runoff, and precipitation were measured. Two years of pre-BMP monitoring occurred before conservation practices were implemented (1995 to mid-1996). Monitoring data collected after November of 1996 were considered postconservation.

Land Treatment

The objective of the overall nonpoint source pollution control strategy was to control sediment, nutrient, and pathogen loads so that the NY City Watershed Project would continue to meet USEPA water quality standards required to comply with the NY City Filtration Avoidance Determination.

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The NY City Watershed receives significant amounts of financial resources that fund conservation practices and a very large technical staff. Operationally, whole-farm planning was used in the Cannonsville Reservoir Watershed to select and locate conservation practices. However, all farms are required to have and implement a nutrient management plan (NMP). Other practices were added based on producer preference. Farmers were encouraged to implement practices using 100% cost-share funding through the Watershed Agricultural Council from the NY City Watershed Agriculture Program, reinforced by the threat that agricultural activities would be regulated within the watershed. By 2008, the program had prepared 248 whole-farm plans for large farms and 67 whole-farm plans for a new small-farm program. According to Armstrong et al. (2011), 83% of farmer respondents in the Cannonsville Watershed survey used whole-farm plans. This percentage corresponds well to the 90% of large farms (>US$10,000 gross yearly income) that have whole-farm plans.

Conservation practices include livestock housing improvements, improved management of manure stockpiles and storage, stream fencing and livestock exclusion, protected stream crossings, riparian forest buffers, grazing management, barnyard runoff management, cover crops, the use of NMPs, and precision feeding. As of 2008, 5,703 practices had been implemented, at an average cost of US$83,000 per farm. Under the USDA Conservation Reserve Enhancement Program (CREP), by 2008, 298 km (185 mi) of streambanks were protected (NYCDEP 2009). Enrollment in CREP was strongly dependent on farmer attitudes toward NY City (Armstrong et al. 2011).

Until recently, these practices were not targeted based on effectiveness or pollutant contribution of the farm, and no deliberate scheduling of these practices occurred. Beginning around 2010, the Watershed Agricultural Council decided to start prioritizing conservation practices based on water quality priorities. Farms were also ranked based on pollutant risk. Ranking allowed the Watershed Agricultural Council to determine priorities for conservation practice implementation to protect water quality.

Nutrient management is the cornerstone conservation practice in the project area. Nutrient management plans are rewritten every three years based on crop nitrogen needs and the NY Phosphorus Index. The NMP uses maps to help with implementation. Color and shading denote timing, crops, and no-manure fields. The number of allowed spreader applications for each field is written on the map. A nutrient application calendar is used for record-keeping purposes, and the farmers denote the date and loads of manure by field within the calendar. Nutrient implementation is tracked yearly, as farmers must submit their calendars annually to a peer-review committee composed of agricultural watershed council managers that certifies compliance. Peer review is considered more palatable by locals than agency review. Producers receive US$24 ha^{-1} (US$10 ac^{-1}) + US$4.30 per animal unit, which is adjusted for cost of living, if they adhere to their NMPs. This is not a cash reimbursement; the reimbursement is for nutrient-related costs, such as new manure spreaders or tires for the spreader. Note that while all NY City Watershed farms are required to have a NMP, the incentive program operates in the Cannonsville Basin as a trial program.

The NY City Watershed Agriculture Program has been locally led by farmers, who had a significant voice in the conservation practices that have been adopted. Farmers help design their practices in conjunction with agency personnel from the county Soil and Water Conservation District. Farmers responded to the very real possibility that farming would be regulated in this watershed if practices were not implemented. Conservation practice adoption appeared to favor practices that improved the health of the cattle (e.g., improved calf housing) or reduced eco-

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nomic or land losses (e.g., stream restoration); other practices were less well received, such as CREP buffers (Armstrong et al. 2011).

Land-use data for the NY City Watershed Agriculture Program are held by the Watershed Agricultural Council. The Watershed Agricultural Council and the Soil and Water Conservation District collect conservation practice information spatially. Data include NMPs, field boundaries, contracts, costs, and engineering documents. All of this represents significant amounts of data that have been generated to characterize the watershed, and it represents a relatively rich dataset. As a result, conservation practice data are maintained by a third party so that farmers are assured that regulators do not have access to the data. These data are only released if the farmer gives permission or if the Watershed Agricultural Council confirms that the data for release contains no personally identifiable information, such as operator name or field location. The NIFA–CEAP received detailed data for two farms where research was conducted and researchers worked closely with the farmer and extension personnel. For the remainder of the Cannonsville Watershed, the NIFA–CEAP worked with a lumped dataset that included conservation practices, crop rotations, buffer installation, and drainage used within the 11-digit hydrologic unit code. If there were six or fewer conservation practices within the 11-digit hydrologic unit code, then the conservation practice data were excluded to ensure privacy.

In addition to installing agricultural conservation practices and the 30% decline in the cattle population between 1987 and 2002, the WWTP upgrades likely contributed to lowering P loads during the period of this study. The P concentration in WWTP discharges was 3 to 4 mg L^{-1} before the upgrades but was only ~0.02 mg L^{-1} after the changes. This represents approximately a 200-fold decrease in total P concentration of WWTP discharge, which would significantly reduce P loads from the WWTPs.

The paired-watershed study contributed significantly to the overall watershed effort as a case-study of the water quality effects of implementing conservation practices, primarily because of the concentrated focus on the actual farm, which produced useful water quality results. The objective of the paired-watershed study (NNPSMP) was to test the ability of whole-farm planning to correctly identify the pollutant source and recommend cost-effective conservation practices to reduce pollutant loads (Spooner et al. 2008). Conservation practice objectives for nutrients were to reduce P excreted from cattle and keep the animal waste out of hydrologically sensitive areas. The objectives for pathogens were to separate the calves from the cows, thus removing pathogens from the majority of the animal waste stream and isolating the pathogens in an area where they could be controlled.

The critical area of the single-farm paired-watershed study (Bishop et al. 2003, 2005, 2006) was the entire 165 ha (408 ac) farm. All conservation practices believed to be needed to control P were used on this farm. The original conservation practices applied in the paired-watershed study were installed over the period of one year. These conservation practices were based on a comprehensive NMP; crop rotations; strip cropping; riparian buffers and associated cattle exclusion from the riparian areas; alternative water development using springs; barnyard improvements, including the development of a lagoon; filter areas for barnyard runoff; relocation of the stream and the silage storage area; targeted manure spreading schedule; and interceptor drainage ditches to reduce flow to frequently saturated areas (Bishop et al. 2003). After conservation practices were installed, the milkhouse waste was directed to the manure storage lagoon and was applied to fields along with the manure (Easton et al. 2008b). A targeted manure spreading schedule prioritized spreading to fields and pastures that were deemed least

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likely to generate runoff (i.e., avoiding spreading in hydrologically sensitive areas) as described in the NY Phosphorus Index. The manure-spreading schedule also prioritized spreading to fields with low soil test P levels. The installation of the lagoon allowed storage of waste during high runoff periods. During this time, however, cow numbers were increased by about 30%. About five years later, based on information from water quality monitoring and using adaptive management, additional conservation practices (precision feeding, an additional stream crossing, and streambank restoration) were added to the farm. In addition, it was discovered that additional P losses were coming from a shed, through a cow path that lead to the stream; the path was delivering high amounts of P to the stream. More conservation practices were installed to address these additional sources of P.

For years, landowners and farmers in the Cannonsville Reservoir Watershed were advised to apply manure and other agrochemicals in lowlands along the stream corridor because it was presumed that most of runoff was generated from sloping lands. However, extensive field-scale efforts by the NY CEAP team and other groups prior to the NIFA–CEAP have indicated that the largest portion of runoff is generated by and accumulates within these lowlands. Thus, application of chemicals to these areas likely contributed to the eutrophication of water bodies in the system.

Water Quality Response

To date, NY City has not yet been required to filter its water because there have been improvements in water quality from agricultural practice adoption and WWTP upgrades. A 15-year data record suggested that there has been a 50% reduction in dissolved phosphorus (DP) load (Longabucco and Rafferty 1998).

Water quality monitoring from the NNPSMP Project showed event load from the initial conservation practices increased by 20% for NO_2 + NO_3-N but decreased for PP by 34%, TDP by 41%, TSS by 28%, and NH_4-N by 33%; there was no change in total Kjeldahl nitrogen. After additional conservation practices were added, there were further reductions in loads: TDP by 14%, TSS by 0%, NH_4-N by 43%, and NO_2 + NO_3-N by 26%. There was no change for PP or total Kjeldahl nitrogen (see Spooner et al. 2008 for detailed information.) The researchers were able to show seasonal response of water quality from timing of conservation practices. In addition to event load reductions, there were baseflow concentration reductions of TSS (22%) and NO_2 + NO_3-N (35%) but none for total Kjeldahl nitrogen or total organic carbon. The paired-watershed approach, along with statistical analysis of the data, allowed conservation practice implementation to be associated with changes in water quality.

The conservation practices used in the paired-watershed study were most effective in the summer season. After the first set of practices was installed on the farm, there was no change in nutrient loading from the second set of conservation practices, probably due to fall manure spreading. Winter reductions of P probably were due to manure storage that allowed the elimination of daily manure spreading. Increases of nitrate during the winter were due to transformation of NH_4-N to NO_2 + NO_3-N and to leaching losses. Barnyard conservation practices seemed to reduce TDP. The seasonal effects of nutrient losses were related to timing of manure spreading and barnyard practices.

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Model Application

The Cannonsville Reservoir NIFA–CEAP focused on modeling and statistical inference to quantify conservation practice effectiveness for conditions found in the NY City Watershed area. A number of studies have shown that saturation excess drives runoff generation in the region, and thus, application of agrochemicals and implementation of conservation practices should be targeted accordingly. These studies also indicate that soil properties and slope of fields are key factors in characterizing the spatiotemporal extent of saturation excess areas. During the NIFA–CEAP, models were modified and tested to adequately represent these important considerations in the simulation of hydrologic and water quality processes.

The central operating principle of this project is that runoff (and therefore nonpoint source loads) generation in the watershed is governed by saturation excess overland flow. The extent of runoff-generating saturated areas varies with the extent of saturation over time (i.e., VSA hydrology). Calibration of a model for streamflow at the watershed outlet does not necessarily corroborate the spatial distribution of runoff generation (areas and processes) within the watershed system. It is well documented that different sets of model parameters could yield similarly good fits with observed data, although they underline different processes and areas within the watershed as main contributors to streamflow at the watershed outlet. A procedure to define hydrologically sensitive areas by their probability of generating runoff was developed using a physically based hydrologic model (Agnew et al. 2006). The soil topographic index (Easton et al. 2008b) gave strong, regionally consistent correlations with the probability of runoff generation. Equations correlating the topographic index and probability of runoff generation can be used to estimate hydrological sensitivity in the region surrounding the study watersheds. This analysis was used to identify critical source areas.

Because the main water quality concern in the system is the fate and transport of DP, it is critical to accurately model locations within the watershed that contribute heavily to runoff. There is ample evidence in this particular watershed system that runoff generation for precipitation events with return periods of less than five-years is driven by saturation excess (i.e., infiltration rates prior to full saturation of the soil layer exceed the rainfall intensity). Thus, runoff only occurs when the soil layer is saturated. This behavior is particularly evident for snow events and runoff generated from snowmelt. It is noteworthy that the saturation excess concept does not hold for some precipitation events with very high intensities during summer months.

Simulated total P and soluble reactive P stream concentrations predicted for 10 catchments in the Town Brook Watershed were strongly affected by the assumed runoff mechanism (Lyon et al. 2006). The modeled total P and soluble reactive P concentrations estimated according to the saturation excess processes were on average 31% and 42% higher, respectively, than those estimated by models using the infiltration excess processes. Misrepresentation of the primary runoff mechanism could not only produce erroneous concentrations but also could result in incorrect identification of the landscape position of critical source areas for implementation of conservation practices.

A suite of models and predictive tools were developed and modified to implement the saturation excess processes in the modeling approach and to identify critical areas for implementation of pollution control measures:

1. The SWAT (Soil and Water Assessment Tool) model was used for statistical evaluation of conservation practice effectiveness at the watershed scale was explored by apply-

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ing the original SWAT model with no modifications for VSA hydrology and saturation excess runoff processes. The goal was to extend the lessons learned from the field-scale paired-watershed study to the entire Cannonsville Basin through the use of a pseudocontrol watershed represented by the SWAT model simulations. The distributed hydrologic and water quality response of the watershed to the variability in climate in the absence of conservation practices was represented by SWAT simulations. The response of the watershed with the existing conservation practices was represented by observed data. A multivariate, paired-regression model was used to determine the watershed-scale reduction of P that could be attributed to the implementation of existing conservation practices. The results showed a 44% reduction in P concentration in response to conservation practice implementation. Also, a 42% reduction in TDP loads was documented.

2. The GWLF (Generalized Watershed Loading Function) was used for the following:
   - The GWLF model was modified to incorporate the saturation excess processes in driving runoff and nonpoint source pollutant loads. The project team modified the Soil Conservation Service curve number (SCS–CN) equation in the GWLF model to account for VSAs. The new model was named the Variable Source Loading Function (VSLF) model. The modified model simulates the watershed runoff response to rainfall using the standard SCS–CN equation, but the runoff response is spatially distributed according to the soil topographic wetness index (Schniederman et al. 2007). The spatial distribution of runoff from the VSLF was shown to be more realistic than the estimates from the original GWLF model. This has important consequences for water quality modeling and for the use of models to evaluate and guide watershed management. Accurate prediction of the coincidence of runoff generation and pollutant sources is critical to simulating nonpoint source pollution transported by runoff.
   - The NYCDEP uses a customized GWLF–VSA model (see above), developed with assistance from Cornell researchers, which is linked to a reservoir model. The NYCDEP modeling system includes a weather driver for GWLF–VSA linked to a reservoir hydraulic and nutrient model, which is in turn linked to a chlorophyll a model. This system ties watershed management to measurable outputs that are directly related to the resource use. In conjunction with Cornell, the NYCDEP applied the GWLF–VSA and reservoir model using water quality data for streamflow, DP, and PP. The result of this modeling indicated that TDP decreased by 20% due to changes in land use and by 45% due to the implementation of conservation practices.
   - Easton et al. (2008a) applied the VSLF to the NNPSMP single-farm watershed (Bishop et al. 2005). Four conservation practices were modeled: (1) manure P reduction (e.g., precision feeding), (2) hydrologic alteration (e.g., drainage tiles, stream channel movement), (3) land-use changes (e.g., conversion of near-stream fields to riparian buffers), and (4) redistribution of P application to the landscape (manure spreading schedule). Manure P reduction by precision feeding was represented in the model by altering corresponding model parameters based on actual measurements of manure P before and after precision feeding was initiated. Hydrologic alterations were primarily achieved by recalculating the wetness indices based on the modified surface-flow paths due to, for example, drainage ditches and stream channel modifications. The regrading of the barnyard was similarly implemented in the model by adjusting the slope and aspect of the part of the elevation map corresponding to the

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barnyard to reflect this practice, which directed flow away from the stream. The addition of near-stream exclusionary fencing effectively reduced crop and pasture land uses and subsequently increased the area of riparian buffer, which was simulated in the model by changing the land-use distributions. Redistribution of P applications to the landscape was primarily achieved by adjusting the manure-spreading schedule to prioritize spreading on areas with low soil-test P levels and low hydrological sensitivity. Farmer records on the location, timing, and rate of manure application were used in simulations. The VSLF predictions of DP loads were generally within 3% of observed results and showed a 35% reduction of P after conservation practice implementation. It was also found that prevention of application of P inputs (i.e., manure) in areas prone to generating storm runoff resulted in the most profound reduction in P export to streams. In the modeling study of Easton et al. (2008b), efforts to reduce manure P content had less short-term impacts on P export. However, Ghebremichael et al. (2007) noted that this practice does result in long-term P reductions. Easton et al. (2008b) concluded that exporting excess manure from the watershed would result in more than a 50% reduction of P yield at the watershed outlet. This study concluded that conservation practices implemented in concert could protect riparian areas and streams from direct pollutant loading and provide substantial water quality protection per unit of land taken out of production. The model results showed that if conservation practices are designed and implemented on farms in a spatially explicit manner with regard to VSAs, then DP loss can be decreased.

- Bishop et al. (2005), from the same farm, reported event load reductions of 43% for DP and 29% for PP after conservation practice implementation in a small watershed. Eaton et al. (2008b) demonstrated spatially where these reductions might have been realized. The model results indicated that the most effective conservation practices were those preventing the incidence of high pollutant source inputs in hydrologically active areas (e.g., VSAs). Specifically, protecting riparian areas (buffer), reducing the spreading of manure during hydrologically active periods through NMPs, and excluding livestock from the stream via cattle crossings resulted in the largest DP reductions. Further analysis using a combination of VSLF and geospatial techniques will allow researchers to advise farm planners on optimal placement of conservation practices in VSA watersheds.

3. The SWAT–VSA: NIFA–CEAP researchers have modified SWAT (Easton et al. 2008a) to incorporate saturation excess runoff processes in the model. The SWAT code was modified to simulate overland flow in ways consistent with VSA hydrology by modifying how the SCS–CN and available water content are represented:
   - The SWAT–VSA defines hydrologically sensitive areas as the incidence of saturated areas based on the soil topographic index and land-use factors. The performance of SWAT versus SWAT–VSA was evaluated at the Town Brook and Cannonsville watersheds. The SWAT–VSA model was used to evaluate the water quality impacts of land-use change (mostly pastureland to forest) and conservation practices in the Cannonsville Watershed over the 1990 to 2005 period. Both the original SWAT and SWAT–VSA gave similar simulated discharges at the watershed outlet, but the improved spatial assignment of runoff in SWAT–VSA showed improved DP predictions. Event runoff was predicted similarly well for SWAT and SWAT–VSA.

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However, the distribution of shallow perched water table depths was predicted better by SWAT–VSA. It is this shallow groundwater that governs VSAs. Event-based DP export from the watershed was also predicted better by SWAT–VSA, presumably because the distribution of runoff source areas was better predicted, particularly from areas where manure was applied.

- Another group (USDA Agricultural Research Service Pasture Systems and Watershed Management Research Unit, Pennsylvania) combined SWAT with conservation practice effectiveness and cost data in a genetic algorithm-based optimization study. It was shown that the optimal design of conservation practices would achieve the same water quality effectiveness as a baseline scenario corresponding to the existing conservation practices at a 30% lower cost (Gitau et al. 2006).
- An effort comparing SWAT2005 with SWAT–VSA showed that relocating corn production (and associated nutrient inputs) out of saturated runoff–producing areas makes a significant difference in P runoff losses (Cowan 2008).

4. The Soil and Water Assessment Tool Water Balance (SWAT–WB) model (Easton et al. 2011; White et al. 2011) modified the SWAT code to calculate runoff using available soil water storage based on soil parameters (e.g., porosity, soil moisture) rather than by the curve number method. In this code (SWAT–WB), a new parameter called "Effective Depth Coefficient" is used to adjust the surface runoff-to-baseflow ratio during simulation. In the Town Brook Watershed, the SWAT–WB model performed as well as the original SWAT model for streamflow simulations, suggesting that a physically based water balance approach could replace the less physically based curve number method for runoff computations. Thus, SWAT–WB may simplify and improve simulation of areas in which the water-soil characteristics are well understood but the correct curve number is unclear or highly variable.
5. Remote sensing for identification of variable source areas (de Alwis et al. 2007) was done in the Town Brook Subwatershed, where temporal trends of the topographic wetness index were derived using an unsupervised classification of remotely sensed Landsat Thematic Mapper satellite imagery to identify hydrologically active areas. The derived maps of saturated areas were tested by comparison with two distributed hydrologic models. Results showed the adequacy of remotely sensed data for representing the spatial distribution of saturated areas for most land covers in the watershed.
6. An online tool to conduct real-time identification of sensitive areas has been developed, which exposes the location of hydrologically active areas based on short-term climate forecasts (one to three days) and can be freely accessed by farmers (Dahlke et al. 2009). Based on these forecasts, farmers can decide whether they should apply chemicals, or not, over the next few days. These maps are updated based on climate forecast on a daily basis. These maps are reproduced retrospectively a week after using the observed climate information.
7. A geographical information system–based P-Index tool is being developed by NIFA–CEAP researchers. The tool will use precipitation forecasts with a water balance model to predict the fraction of a watershed likely to act as a VSA. The outputs of the tool are provided at a 10 m (32 ft) spatial resolution, and thus, further components are needed to provide management recommendations for an entire field (Marjerison et al. 2011).

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Although the acreage of treated land over time is known and available in a geographical information system database, the exact locations of existing conservation practices were not available for modeling purposes due to locational censoring of data when released. Data on the location and type of practices were only available as aggregated at the subbasin level. The project team addressed this issue by classifying conservation practices according to the wetness index of subbasins for modeling purposes. In addition, several farms allowed the spatial referencing of conservation practices through data release agreements so that their data could be used in models.

Overall, however, lack of data on exact location, type, and timing of conservation practices increases the uncertainty in evaluation of conservation practices using these or any other modeling approaches. The lack of availability of exact practice locations may skew inferences with regard to water quality benefits of practices because landscape position of hydrologically sensitive areas, and thus conservation practices, need to be paired for the most effective modeling and conservation practice placement.

All data for the models are stored electronically and are georeferenced by participating organizations. Most of the data have already been incorporated into the SWAT–VSA, which also has additional information on manure-spreading practices and on nonagricultural sources of P. Important data used in the models include the following:

- Stream discharge and water quality data are recorded by the USGS. Additional flow, water quality, and groundwater level data are available from other sources. There are 12 gages in Cannonsville (USGS 2012b) representing various periods of record and various constituents. Some gage records go as far back as the 1930s. The NYDEC has monitored water quality in the West Branch of the Delaware River just before it enters the Cannonsville Reservoir from 1992 to 2010. Data from automated stream monitoring stations in three farm and nonfarm watersheds are also available.
- Land-use and land-cover data are available as statewide 30 m (98 ft) resolution 1992 and 2001 National Land Cover Dataset coverages (USGS 2012b) and from 2001 Landsat-7 Thematic Mapper data available from the NYCDEP.
- Soils data are available as a georeferenced digital soil map that includes soil physiochemical attributes (from the USDA NRCS Soil Survey Geographic [SSURGO] database); field-specific soil P data are collected every three years as part of the farm planning process.
- Topographic data are available in digital form from the USGS and the Cornell University Geospatial Information Repository. Higher resolution LiDAR (light detection and ranging) maps are under development by the NYCDEP.
- Long-term precipitation data are available from the National Climate Data Center.

Commonly used error statistics, such as root mean square error, the Nash-Sutcliffe coefficient of efficiency, and relative error were used to evaluate the model performance. Overall, all models performed well for hydrologic and water quality simulations. Sensitivity analyses were conducted on every model that was calibrated. There was an attempt to minimize calibration in all models by incorporating physicality into the processes that were modeled.

The watershed configuration and spatial discretization scheme used in the modeling approach built on the existing approach in ArcSWAT with a major difference in the definition of hydrologic response units in each subwatershed. In the SWAT model available during the NY NIFA–CEAP, a watershed was subdivided into subwatersheds, and subwatersheds were further

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divided into hydrologic response units obtained from the overlay of soil and land-use maps. In the NY NIFA–CEAP, a soil topographic index was used to account for the runoff generation gradient across the watershed. Essentially, hydrologic response units in the NY NIFA–CEAP were distributed by overlaying soil, land use, and soil topographic index. The temporal variability of land-use conditions was captured by using two land-use maps from the National Land Cover Dataset from 1992 and Landsat 7 Thematic Mapper datasets.

A spatially distributed model of TDP loading was developed using raster maps covering a 165 ha (408 ac) dairy farm watershed (Hively et al. 2006). Predicted loads agreed well with loads observed at the watershed outlet when hydrology was modeled accurately. The predicted contribution of TDP from manured soils was overall less than 10% of total loads for the entire simulation period. However, the relative contribution of manured areas varied greatly with time, with almost no contribution during most of the year, to a monthly average of 25% in April and May and maximum contributions up to 90% on some days of these months. This encouraging observation may reflect the efficiency of the manure conservation practices implemented on the farm: no manure was spread from November to April, and there was a reduction of manure on hydrologically sensitive areas.

Combining monitoring on the 165 ha (408 ac) dairy farm watershed (conducted by Bishop et al. 2005) with modeling (Rao et al. 2009) has allowed the Cannonsville Reservoir NIFA–CEAP to develop hypotheses on the most effective conservation practices, including NMPs, riparian buffers, filter strips and fencing, which were all installed to reduce phosphorus loading from the farm. Despite its simplicity, the VSLF predicted the spatial distribution of runoff-producing areas well. Dissolved P reductions were simulated well by using calibrated reduction factors for various conservation practices in the VSLF model. Total P losses decreased only after cattle crossings were installed in the creek. The results demonstrated that conservation practices, when sited with respect to VSAs, reduced P loss from agricultural watersheds, providing useful information for targeted water quality management.

The emphasis of the modeling work has been on targeting the landscape position and timing of management actions using the reconceptualized SWAT and GWLF models and a Web-based mapping tool; optimization for location and timing of practices was not done. The idea is that chemicals and nutrients should not be applied on fields that are hydrologically active. The extent of these areas varies over space and time depending on landscape characteristics and precipitation events and is derived from the reconceptualized models. The critical areas (i.e., landscape locations with high runoff potential and pollutant loadings) were found to be typically at the lowlands along the stream corridor. Thus, fertilizers and pesticides should be applied on the sloping land.

Socioeconomic Analysis

The watershed is comprised of approximately 200 active large farms and approximately 50 active small farms; 70% of farms are dairy with 11,000 dairy cows and 15% are beef with around 1,300 beef cattle. Most dairy farms operate as total or semiconfinement operations with minimal emphasis on managed grazing. Unlike most NIFA–CEAP watershed studies where producers must provide at least 25% of the cost share, these producers were encouraged to implement conservation practices through 100% cost share and fully staffed technical support.

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Because of 100% capital funding of conservation practices and 90% farmer participation, the Watershed Agricultural Council BMP database describes all conservation practices installed in the watershed, including their costs, locations, dates of installation, and uses. The Watershed Agricultural Program personnel evaluates practices coming out of contract for continued effectiveness, and they will reinvest (and restore if necessary) in the practice and seek a new contract with the landowner if the practice is deemed effective. Data are kept private between the farmer and the Watershed Agricultural Council. This security helps encourage farmer participation. However, as a result, no widespread socioeconomic studies have been conducted.

A cost-benefit analysis was conducted on the paired-watershed farm (Bishop et al. 2005) in the Cannonsville Basin (Rao et al. forthcoming). Economic results were compared to variable source loading of P. The study demonstrated that the conservation practices reduced DP loads by 43% and particulate loads by 29%. Monitoring data were used to calibrate a model that was then used to compute loading for different BMP scenarios. One scenario was pre-BMP, a second accounted for the post-BMP condition, and five additional scenarios represented increasing levels of converting wet areas to buffers. The economic analysis included installment cost, maintenance cost, and opportunity cost. No water quality benefits were assumed to accrue for the producer. Benefits were payments from government programs. None of the practices were profitable in a 10-year horizon when barnyard practices were included. Conversion of the two wettest areas to buffers was profitable when barnyard practices were not included. These results should be used cautiously because profit levels are based on benefits from government payments, which is not the same as actual economic benefit.

Outreach

The NY NIFA–CEAP personnel worked closely with the farmers on whose fields they conducted research, but there was no explicit outreach within this project.

The NY City Watershed Program provides extensive outreach to producers, and all outreach is directed through them. Farmers in the NY City Watershed are trained annually (121 farmers in 2006, 199 farmers in 2007, and 337 farmers in 2008) through the Watershed Agricultural Council. Cornell Cooperative Extension provides part of this training. They strive to reach 25% of watershed farmers every year. They do this through field days, classroom training and tours, and other traditional extension methods. They use farmer-to-farmer training, surveys to determine what subject areas farmers are interested in, and some recertification for nutrient management. In addition, collaboration among Watershed Agricultural Council, extension, and the NYCDEP on planning and possible implementation of conservation practices has been shown to be the most cost-effective approach to outreach.

Because the majority of the NY NIFA–CEAP was focused on modeling, the primary stakeholder was the NYCDEP. There was close collaboration between the NY NIFA–CEAP and NYCDEP personnel relative to water quality modeling.

Research papers and conference presentations have been the principal means of communication by NY NIFA–CEAP staff, and many of these documents are cited in the Cannonsville Reservoir NIFA–CEAP Publications list that follows. No annual reports for the NY NIFA–CEAP were produced beyond the very limited reporting required by the USDA NIFA–CEAP. The USEPA 319 NY Project reported annually in the Summary Report: Section 319 National Monitoring Program Projects, National Nonpoint Source Watershed Project Studies (Spooner et al. 2008).

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Cannonsville Reservoir National Institute of Food and Agriculture–Conservation Effects Assessment Project Publications

This project's results have been published in numerous journal articles, and much of the information-sharing has been done through conference proceedings. The list is provided below.

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Project Personnel

Tammo S. Steenhuis (soil and water management and modeler) and Christine Shoemaker (civil and environmental engineer) were the lead project investigators. M. Todd Walter (agricultural and biological engineer), Jerry Stedinger (environmental and water resources systems engineer), and Zeyuan Qiu (associate professor of chemistry and environmental science) were coproject investigators. Many other individuals participated in this project.

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