Cannonsville Reservoir and Town Brook watersheds: Documenting conservation efforts to protect New York City's drinking water

R.B. Bryant, T.L. Veith, P.J.A. Kleinman, and W.J. Gburek

Abstract: The Cannonsville Reservoir watershed is a major component of the unfiltered New York City water supply system. The voluntary, incentive-based Watershed Agricultural Program is a collaborative effort among producers, federal, state, and local organizations to address the problem of phosphorus loading effects on water quality through implementation of whole-farm plans. The effectiveness of selected conservation practices, including streambank fencing, precision feeding, and the use of cover crops with silage corn (Zea mays L.) are being evaluated. Simulation models have been developed and improved to evaluate the effectiveness of individual conservation practices and better assess animal agriculture and manure management practices. Conservation practices implemented through the Watershed Agricultural Program are resulting in lower phosphorus loading from nonpoint sources in the watershed. Future efforts need to identify the most cost-effective conservation practices and extend our knowledge of watershed quality protection beyond the boundaries of the Cannonsville Reservoir watershed.

Key words: best management practices (BMPs)—Cannonsville Reservoir—Conservation Effects Assessment Project (CEAP)—water quality—watershed management

The Cannonsville Reservoir watershed (CRW)—a Conservation Effects Assessment Project (CEAP) benchmark watershed—is a major component of the unfiltered New York City (NYC) water supply system. The CRW has a 15-year history of focused attention on water-quality management through conservation. At times, it has been designated as phosphorus (P)-restricted due to algal blooms that interfere with the less costly, no-filtration approach to water treatment desired by NYC. Dairy agriculture—the dominant agricultural land use within the CRW—is thought to be a major contributor to P loading in the reservoir. To address the problem, the Watershed Agricultural Council—a nonprofit organization funded by NYC, USDA Forest Service, and other federal and foundation sources—is working in conjunction with the USDA Natural Resources Conservation Service (NRCS), the Delaware County (New York) Soil and Water Conservation District, and Cornell University Cooperative Extension of Delaware County to implement the Watershed Agricultural Program (WAP). The mission of the WAP is to "assist the agricultural community in adopting operational management techniques that protect water quality as well as enhance economic competitiveness and viability."

In general terms, the WAP consists of a comprehensive whole-farm planning process applied to farms participating on a voluntary basis and the implementation of resulting conservation or best management practices (BMPs). The planning and implementation processes involve coordinated education, extension, and technical assistance components, with the technical assistance component consisting of BMP design and installation under a 100% cost-support program where funding comes from NYC, the direct beneficiary of improved water quality. Thus, there are quantifiable consequences related to the success or failure of the BMP design and implementation program—costs of installing and maintaining the conservation practices versus costs associated with building and maintaining a new water filtration plant for NYC.

Collaborative efforts by USDA Agricultural Research Service scientists and Cornell University scientists conducting USDA Cooperative State Research, Education, and Extension Service-funded CEAP-related research are documenting the effectiveness of selected conservation practices. The overall research objectives of these groups are to quantify P loss from dairy farms, evaluate the effectiveness of current BMPs in reducing P loss, and develop new or improved BMPs and conservation practice strategies. Research involves a combination of field experimentation, monitoring, and modeling focused primarily within the 37 km² (14 mi²) Cannonsville Reservoir watershed (TBW), a subwatershed representative of CRW conditions. Our purpose is to summarize research results to date, which have helped determine the effectiveness of selected conservation practices. We also identify limitations that need to be addressed for better conservation monitoring and decision making in this region.

Methods and Materials

The CRW is located in the Catskills Mountains, approximately 160 km (100 mi) northwest of NYC (figure 1). The physiography is characterized by narrow valleys that have steep walls and smooth floors (USDA NRCS 2006a); the elevation ranges from 350 m to over 1,100 m (1,150 ft to over 3,600 ft). The mean temperature is 8°C (46°F). The average annual precipitation of 115 cm (45 in) is characterized by intense summer thunderstorms, but most of the precipitation occurs as snow. The bedrock includes alternating shale and sandstone beds of Devonian age. The mountains are mantled by dense, compact glacial till of Wisconsinan age, and deposits of glacial outwash consisting of unconsolidated sand and gravel fill the valley floors. Dystrudepts (Arnott, Lordstown, and Oquaga series) are on landforms where bedrock is within 1 m...
New York City's water supply system with locations of Cannonsville Reservoir watershed and Town Brook watershed identified (adapted from New York City 2007).

Figure 1

Catskill/Delaware Watersheds

DEP

Catskill/Delaware watershed area
Croton watershed area
Rivers and reservoirs
Catskill aqueduct and tunnels
Croton aqueduct
Delaware aqueduct and tunnels
County borders
State borders

www.ny.gov/dep

(40 in) of the surface (USDA NRCS 2006b). Fragiudepts (Bath, Lakawanna, Lewbeach, Onteora, and Wellsboro series) formed in the dense tills on hills and mountain slopes. Dystrudepts (Chenango, Tunkhannock, and Deposit series) formed in the glacial outwash on valley floors. The West Branch of the Delaware River flows approximately 80 km (50 mi) to the Cannonsville Reservoir and has an annual discharge of 16.4 m$^3$ s$^{-1}$ (580 cfs). The reservoir, completed in 1965, has a surface area of about 2,020 ha (5,000 ac) and a total capacity of about $3.8 \times 10^{11}$ L ($1.0 \times 10^{12}$ gal).

Agriculture first came to the area over 200 years ago following the Revolutionary War, and the oldest farms have celebrated their bicentennial. Land use within the 917 km$^2$ (355 mi$^2$) CRW consists of cropland ($2\%$ corn [Zea mays L.] and alfalfa [Medicago sativa L.]), pasture ($48\%$ pasture and hay), agroforestry ($49\%$), and other ($1\%$ farmsteads, roads, etc.). There are approximately 200 active large farms and about 50 active small farms ($<$10,000 annual income) within the watershed; roughly $70\%$ dairy, $15\%$ beef, and $15\%$ other (sheep and goats, greenhouses, etc.). The farms represent about 11,000 dairy cows and 1,300 beef cattle. Most of the dairy farms operate as confined or semi-confined operations, with minimal emphasis currently on intensively managed grazing. There are 45 inactive large farms, reflecting a decline in agricultural operations over the last decade. Approximately 150 landowners are enrolled in the Conservation Reserve Enhancement Program (CREP), and about 40 farms participated in the Environmental Quality Incentives Program for nutrient management credit; both programs are natural resource conservation efforts managed by NRCS. The New York State Department of Environmental Protection provides funding to the WAP to continue a nutrient management credit program, and 65 farms are currently enrolled. Management practices generally employed are those most typically recommended by NRCS for the region, including but not limited to barnyard improvements, nutrient management plans, precision feeding, conservation crop rotation, contour buffer strips, filter strips, forage harvest management, grassed waterways, streambank fencing, and wooded riparian buffers.

Water-quality monitoring in the CRW is a cooperative effort by the New York State Department of Environmental Protection and the US Geological Survey. From 1992 to 2006, data for flow, dissolved P, and total P were recorded at the station near Beerston, New York, where the West Branch of the Delaware River flows into the Cannonsville Reservoir. In June 2006, this station was destroyed by a flood. Data are also available for a station at the mouth of Trout Creek, which feeds the northern branch of the Cannonsville Reservoir. The total maximum daily load for the Cannonsville Reservoir is $20 \mu g$ P L$^{-1}$ (20 ppb), measured in the suspended water column of the reservoir.

Results and Discussion

Specific research emphases are related to the following: effectiveness of streambank fencing implemented through the CREP program in reducing impacts of cattle in the streams, reduction of the P imbalance at the farm scale by precision feeding and increased use of homegrown forage, reduction of erosion from land in corn silage to
reduce sediment-sorbed P loss, development of techniques for cost-effective targeting of BMPs at farm and watershed scales to derive maximum benefit at minimum cost, and improvement of models for simulating and assessing management practice effectiveness. A recent project is directed toward assisting and quantifying the economic decision-making process at farm and watershed levels by linking production costs and commodity prices to BMP costs and conservation program incentives.

Streambank Fencing. Pastures in the CRW are characterized by low-intensity management, with seasonal grazing providing a secondary source of forage for milking cattle and primary source of forage for heifers and dry cows. Allowing cattle access to streams has historically been one means of providing pastured cattle with drinking water and comfort during hot weather but is now recognized as a poor management practice from the standpoint of streambank erosion, nutrient loss, stream health, and cattle health (James et al. 2005). Streambank fencing initiatives such as CREP have been implemented by the WAP with special provisions for CRW producers such as sign-up bonuses, 100% cost support, and other incentives. James (2005) conducted a mail survey of dairy farms enrolled in the WAP, documenting resistance to the adoption of streambank fencing by many farmers for reasons ranging from historical (stream setbacks had been one of the first measures proposed for CRW before the implementation of the WAP and were opposed by farmers seeking to gain input into management decisions) to aesthetic (the growth of riparian vegetation was seen as wild or as blocking scenic views) to economic (cost of maintaining and repairing fencing) and to political (privacy rights).

To better understand the water-quality implications of farmer resistance to installation of streambank fencing, James et al. (2007) conducted a study quantifying dung P loadings to streams and near-stream areas by pastured dairy cattle. They observed cattle use and defecation patterns within the pastures of four dairy farms, finding high concentrations of dung in pasture streams and within near-stream areas. Based upon their observations, they developed a model to estimate dung P distribution in pastures across the CRW. Dung P spatial distribution was modeled as a function of several stocking variables (intensity, duration) and lactation stage of dairy cow (heifers and dry cows versus milk cows), as well as the specific characteristics of individual pastures within the watershed (obtained from the WAP’s spatial database). Using readily available information on characteristics of dairy farms participating in the WAP, James et al. (2007) estimated that 2,800 kg (6,170 lb) of P was defecated directly into pasture streams by pastured cattle every year and that an additional 5,600 kg (12,350 lb) P was deposited within a 10 m (33 ft) riparian area. Across the CRW, direct deposition of dung P into streams was estimated equivalent to 10% of annual P loadings attributed to all agricultural sources.

Precision Feeding. A precision feed management (PFM) project involving controlled dietary P and increased production and utilization of high-quality homegrown forage in cattle ration was conducted on CRW pilot farms by personnel from Cornell University Cooperative Extension of Delaware County, New York. A goal of the project was to reduce P imbalance at the farm scale by limiting P inputs. In conjunction, comprehensive whole-farm assessments were needed to determine the impacts of PFM strategies on feed nutrient imports, manure nutrient excretions, nutrient losses, and profitability of farms. For two farms in the CRW, PFM was seen to reduce whole-farm mass P surpluses by 49% and manure P content by 33% while maintaining milk production levels (Ceresaletti et al. 2004). Using the Integrated Farm System Model (IFSM) (Rotz and Coiner 2006), farm-specific PFM strategies that balance farm P inflows and outflows with minimum P losses and increased profitability were successfully identified (Ghebremichael et al. 2007). Simulation of more accurate feeding of P (based on P in animal diets) integrated with increased productivity of high-quality grass-forage and increased proportion of forage in the diet resulted in reductions of surplus farm P inflows ranging from 78% to 100% and reductions of manure P concentrations and soluble P loss in runoff of 25% and 18%, respectively. Feed supplement purchases declined by 7.5 kg cow⁻¹ yr⁻¹ (16.5 lb cow⁻¹ yr⁻¹) for dietary mineral P and by 1.02 to 1.35 Mg cow⁻¹ yr⁻¹ (1.1 to 1.5 tn cow⁻¹ yr⁻¹) for protein concentrates through adoption of the improved system. Moreover, when a land use management practice of converting corn to grass was coupled with the precision feeding of P and improved forage management, IFSM predicted a reduction of 7.5 kg sediment-bound P ha⁻¹ (6.7 lb P ac⁻¹) in erosion on average each year for each hectare (acre) of corn converted to grass. The model also predicted slight increases in grain purchases to offset the reduction in corn silage but no appreciable change in the farm P balance due to land use conversion. The location-specific data and strategies simulated in this study provided robust whole-farm assessments of the impacts of pre- and post-PFM efforts on milk production, farm profitability, and farm-level P balances and losses for New York dairy farms.

Cover Crops. The adoption of cover crops by farmers in the northeastern United States has been limited due to short growing seasons and narrow planting windows for fall seeded cover crops (Johnson et al. 1998; Hively and Cox 2001). A novel system for establishing cover crops in silage corn at time of planting was developed by NRCS for dairy farms in the northeastern United States (Squire 1997; Salon and van der Grinten 1999). The Simultaneous Corn and Cover Crop (SCCC) system uses post-emergence herbicides to allow for simultaneous seeding of various cover crops with silage corn.

Kleiman et al. (2005) reported the results of trials conducted at two locations in the TBW, testing the agronomic and water-quality effects of the SCCC system with a variety of cover crops: red clover (Trifolium pratense), perennial ryegrass (Lolium perenne), and alfalfa. Yields of silage corn from plots interseeded with cover crops varied, with red clover comparing most favorably with the conventionally cropped controls, followed by perennial ryegrass. No significant differences in yields were noted between the red clover and the control treatments at either location, whereas the perennial ryegrass was associated with slightly depressed yields.

Kleiman et al. (2005) conducted rain simulations on 1 x 2 m (3.3 x 6.5 ft) runoff plots established within the agronomic trials both before and after surface application of dairy manure at rates of 50 and 100 kg total P ha⁻¹ (45 and 90 lb P ac⁻¹). Losses of P in runoff before manure application were primarily a function of soil erosion. All cover crops significantly increased ground cover in comparison with the control, lowering sediment losses in runoff by an average of 77% less than the control. Total P losses in runoff from cover cropped plots averaged 74% less than from conventionally cropped controls.
Application of manure obscures differences in P runoff losses between treatments due to high concentrations of readily soluble P in the applied dairy manure, with manure application rate controlling P losses in runoff. Therefore, in as much as leguminous cover crops (e.g., clover, alfalfa) can decrease the agronomic requirements for manure nitrogen, the SCCC system may help to reduce manure application rates, lowering the potential of P losses before and after manure application. Results of this study confirm the agronomic and water-quality benefits of the SCCC system, particularly when implemented with red clover.

**Watershed Modeling.** A range of simulation models have been used in the CRW to formulate long-term predictions from experimental data and to assess relative impacts of conservation management changes on water quality. By simulating the spatial distribution of runoff producing areas over the watershed, the Variable Source Loading Function model is capable of delineating target areas for BMP implementation (Schneideman et al. 2007). Currently, the Variable Source Loading Function model is able to predict localized saturated areas in the landscape with surprising accuracy. Explicit knowledge of runoff producing areas is a key to better understanding watershed-scale hydrodynamics, as well as potential P source areas. The Soil and Water Assessment Tool (SWAT)—a more complex model which also simulates sediment and nutrient movement—has been applied to the CRW and calibrated for flow (daily Nash-Sutcliffe of 0.80), sediment, and P (Tolson and Shoemaker 2007). Two customizations were made to SWAT to more accurately represent the soil water and sediment movement under frozen conditions. This work provides a baseline watershed snapshot and a tool for readily assessing the impact of management changes on water quality response.

One farm, encompassing a small headwater catchment in the CRW, has implemented numerous BMPs, including manure management, strip cropping, crop rotations, filter strips, and barnyard paving. Due to this involvement as well as various topographic characteristics and the graciousness of the owners, this farm has been the site of considerable water-quality related research. A paired watershed experiment by Bishop et al. (2005) evaluated BMP effectiveness in reducing streamwater P loads by monitoring pre- and post-BMP conditions. Overall event load reductions of 43% total dissolved P and 29% particulate P were found for the catchment. SWAT was then calibrated for flow, sediment, and P at the catchment outlet and applied to the pre- and post-BMP periods of the farm (Gitau and Ghurek 2005). Although the simultaneous implementation of BMPs precluded individual assessments of effectiveness, SWAT was found to successfully represent the overall impact of BMP implementation on stream flow, sediment load, dissolved P, and total P.

A literature-based quantification of BMP effectiveness was developed for BMPs currently in use throughout the northeastern United States, considering site characteristics, study methods used, scale, and resulting levels of P reduction (Gitau et al. 2005). The information was stored in an Microsoft Access database, which served as the foundation for development of the assessment tool. The tool allows site-specific estimation of BMP effectiveness. It outputs estimates for a number of possible BMPs for a particular site, thus providing a basis for BMP selection. It also offers access to summarized information on various aspects of BMP effectiveness. The tool can be used as a stand-alone application, or it may be linked to a geographic information system-based model. The tool serves as a resource for BMP selection by providing estimates of BMP effectiveness under a variety of site-specific conditions. The accumulation and analyses of BMP effectiveness data from previous studies offers a means of BMP assessment that is widely applicable.

Techniques for quantifying BMP effectiveness have expanded from individual BMPs on experimental hill-slope plots to modeling and model-based approaches and, more recently, to watershed-level optimizations of BMP solutions (Gitau and Veith 2006). It is possible through field studies or simple modeling to estimate the extent to which a specific group of BMPs can improve water quality on a specific farm or watershed. It is more complex to select and place a combination of BMPs on the farm or watershed in a manner that is both inexpensive and minimizes pollution. In solving such a selection and placement problem, it is also important that farming practices be profitable and minimally impact the environment. Gitau et al. (2004, 2006) used an optimization technique to select combinations of BMPs based on P reduction data reported in the literature, accessed by the tool discussed in Gitau et al. (2005), and on results from the SWAT water-quality model. For a New York farm within the CRW, the optimization determined a combination of BMPs that reduced annual P losses by 0.6 kg (1.3 lb) for each dollar spent in implementation and maintenance (Gitau et al. 2004). Optimal scenarios for TP favors nutrient management plans, crop rotations, and contour strip cropping (alone or in combination), and riparian forest buffers, with the BMPs being placed where they offered the greatest benefits in terms of reducing both P losses and costs, as shown in figure 2 (Gitau et al. 2006). With the optimal BMP scenarios, P losses could potentially be reduced by an average of 60% over time, with the most effective scenario having a cost-effectiveness of $24 kg⁻¹ ($11 lb⁻¹) P removed per year, an improvement from the basic scenario, which resulted in $34 kg⁻¹ ($15 lb⁻¹) P removed per year. This study showed that P losses could be reduced substantially when BMPs were applied selectively (that is, to selected high P-loss areas), and demonstrates a means by which alternative scenarios can be evaluated to arrive at a more cost-effective solution.

**Model Improvement.** Manure application on crop and pasture lands is a common form of enriching agricultural soils on beef and dairy farms of the northeastern United States and a necessary means of managing manure storage. Accordingly, it is crucial that water-quality models used to evaluate BMPs in this region adequately simulate nutrient transformation and transport in manure applied to the soil surface as well as after incorporation into the soil. A simple model developed by Walter et al. (2001) to evaluate the impact of various dairy manure spreading techniques on reducing soluble P losses found that timing and location of manure spreading were key factors to controlling loss. However, widely used models do not simulate P in runoff from surface-applied manures. Vadas et al. (2004) and Gerard-Merchant et al. (2005) developed mechanistic, predictive equations for approximating P release from surface-applied manure. Vadas et al. (2005) used box and field-plot experiments to further develop and improve prediction of P transport for manure-amended soils by correlating soluble P losses to soil P levels and water-extractable manure P. These routines were developed into a process-level soil P model including surface and subsurface com-
Figure 2
Optimal scenario for best management practice selection and placement in comparison with basic scenario (adapted from Gitau et al. 2006). Notes: In the basic scenario all fields were required to have a nutrient management plan, all cropland was in rotation, and all barnyards had barnyard runoff management and filter strips (not shown in the figure as these would not be visible at this scale).

Summary and Conclusions
Although CEAP has barely a five-year history, accelerated efforts to improve water quality in the Cannonsville Reservoir, research in support of those efforts, and the associated water-quality monitoring program are entering their 16th year of operation in the CRW. Strong evidence of the effectiveness of conservation practices in aggregate is provided by analysis of a 15-year record of water-quality monitoring data (Longabucco and Rafferty 1998). After accounting for P reductions due to upgrading municipal waste water treatment systems in the CRW that reduced P loads from point sources by an order of magnitude, data from the Beerston station show a 50% reduction in dissolved P and a 17% reduction in total P from nonpoint sources during the five-year period from 2000 to 2004 compared to the period from 1992 to 1999. The magnitude of these reductions is conservative because mean annual flow was 11% greater during the five-year period from 2000 to 2004 compared to the period from 1992 to 1999. The magnitude of these reductions is conservative because mean annual flow was higher than the long-term average. Figure 2 illustrates the use of the model, IFSM simulations were recently performed to evaluate the effects of manure handling and tillage systems on P loss from farms in Pennsylvania (Sedorovich et al. 2007). For a 100-cow dairy farm, a manure-handling strategy that used a six-month storage and application by injection decreased total P loss by 19% compared to daily surface application, but annual farm net return was decreased by $57 cow⁻¹. Compared to conventional tillage with a moldboard plow, use of conservation and no-till systems reduced total P loss by 46% and 57%, respectively, with small increases in farm profitability. Reduced tillage increased soluble P loss, suggesting that conservation and no-till systems should be combined with practices such as manure injection to reduce all forms of P loss. The enhanced IFSM containing the soil P model provides a tool for whole-farm analysis of management effects on P loss along with other environmental and economic considerations.
2000 to 2004 compared to the period from 1992 to 1999 (Bishop 2006). Conservation practices implemented through the WAP in the CRW are lowering P loadings from nonpoint sources, and although costs for the 100% cost-share program regularly exceed $3 million per year, NYC is reaping huge economic benefits by not having to filter their drinking water supply at a cost of billions of dollars. The "champagne of drinking waters" may not be cheap, but it is a bargain. The challenge for CEAP is to lower the costs of water-quality protection so that other watersheds where public resources are limited can also meet reasonable water-quality standards. By identifying those practices that are most cost effective and most acceptable to landowners through CEAP-related research and by strengthening our models so that the knowledge gained from CEAP-related research can be extended beyond the CRW, we will assist conservationists in meeting that challenge.

Acknowledgements

We thank the producers who allowed us to conduct research on their farms. We greatly appreciate the collaboration and assistance provided by the staff and members of the Watershed Agricultural Council, the Delaware County (New York) Soil and Water Conservation District, Cornell University Cooperative Extension of Delaware County, Cornell University, the New York State Department of Environmental Protection, and the USDA Natural Resources Conservation Service.

References


USDA NRCS. 2006b. Soil Survey Geographic (SSURGO) database for Delaware County, NY. Fort Worth, TX: USDA.


