ASSESSMENT OF FRESHWATER WITHDRAWALS AND AVAILABILITY FOR MARCELLUS SHALE NATURAL GAS DEVELOPMENT: A CASE STUDY IN PENNSYLVANIA

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Abstract.—To evaluate surface water withdrawals used for Marcellus shale natural gas development and to assess potential impacts on water yield, a regional water balance model was developed for the Pine Creek watershed, located primarily in Lycoming County, Pennsylvania. Marcellus shale development has increased rapidly in Lycoming County since 2007. We used precipitation, potential evapotranspiration, and streamflow from a long-term U.S. Geological Survey station to estimate surface water availability and characterize seasonal changes over a 50-year period. We compared water availability and demand before Marcellus exploration to conservative projections of future water withdrawals for Lycoming County. Results show an increase in total surface water withdrawals related to mining use in Lycoming County. We thus were able to estimate current surface water reserves in the area.

INTRODUCTION

With the development of new horizontal drilling technologies and the ever-increasing demand for energy, the economic feasibility of unconventional natural gas development in the Marcellus shale regions of New York, Pennsylvania, Ohio, and West Virginia is greater than ever before. The U.S. Department of Energy's National Energy Technology Laboratory estimates recoverable natural gas reserves to be as high as 489 trillion cubic feet although these numbers are revised frequently (Arthur et al. 2010).

Several factors have contributed to interest in unconventional natural gas reservoirs such as those present in the Marcellus shale formation. These factors include advancements in horizontal drilling technology and hydraulic fracturing, along with the increase in natural gas prices (Ground Water Protection Council and ALL Consulting 2009). Natural gas is gaining momentum in the United States' energy portfolio and accounted for 25 percent of all energy consumption by fuel type in 2009 (U.S. Energy Information Administration 2010). Much of the increased production of natural gas is due to new techniques in capturing natural gas from unconventional sources (U.S. Energy Information Administration 2010). Unconventional reserves are located in tight, low-porosity formations and differ from conventional reservoirs, which have greater porosity and allow the oil or gas to move within the pore space more naturally.

Marcellus shale exhibits these "tight" formation features, which often consist of sandstone but also take the form of organic rich material, as with coalbed methane and shale gas. The Marcellus formation lies between 4,000 and 8,000 feet below ground level, which are typical drilling depths in Pennsylvania (Blauvelt 2010). Due to the nature of Marcellus shale, hydraulic fracturing techniques

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are used to increase porosity and to facilitate movement of the trapped gas. In this process large volumes of water are mixed with sand and chemicals that are pumped under high pressure down the well column. This pressure creates fissures in the shale which are held open by the sand particles. Gas is then able to flow from the formation up the well. Horizontal drilling also plays an integral role in the process. By allowing for increased exposure to the shale, horizontal drilling has greatly reduced the number of well pads needed for development and has vastly increased the production of wells (Blauvelt 2010).

The process of hydraulic fracturing typically uses between 3 and 5 million gallons (Mgal) of water per well per year, but usage can vary significantly (Abdalla and Drohan 2010). Although much of this water is lost to the Marcellus formation, recovered water known as produced water, is treated as a waste product and is reused many times. To put these numbers in perspective, these volumes are significantly less than consumption for other energy sources and for public use. However, water usage for Marcellus shale hydraulic fracturing operations is consumptive, meaning that water sources removed from the ground or surface water are not directly returned to the same basin for future use. Volumes of water are withdrawn in a short amount of time, which could pose problems for smaller watersheds during droughts. The focus of our study was the Pine Creek watershed in north-central Pennsylvania. This watershed is primarily located in Lycoming County, where surface water withdrawals have recently increased.

Pine Creek watershed is located in one of the six primary sub-basins of the Susquehanna River Basin (SRB), which lies in sections of New York, Pennsylvania, and Maryland. The SRB encompasses more than 27,500 mi^2 and makes up 43 percent of the Chesapeake Bay watershed. The four sub-basins located in Pennsylvania are the Middle Susquehanna, West Branch, Juniata, and Lower Susquehanna. Pine Creek is located in the West Branch of the Susquehanna sub-basin, which covers 6,992 mi^2 of central Pennsylvania and is the largest sub-basin in the SRB. Approximately 72 percent of this area is underlain with Marcellus shale (Susquehanna River Basin Commission 2010).

A multi-state jurisdictional commission called the Susquehanna River Basin Commission (SRBC) has established 12 priority watersheds, of which 5 priority watersheds are located in the West Branch of the Susquehanna. The SRBC has the authority to create and enforce regulations within the SRB (Arthur et al. 2010). All activities pertaining to surface or groundwater withdrawals in the SRB must be approved by the SRBC. A new SRBC ruling went into effect on January 15, 2009, which allowed for increased efficiency in the regulatory permitting process and aided in stream protection through monitoring, reporting, and mitigation (SRBC 2009). In assessing the withdrawals in rivers and streams, the SRBC uses passby flow, which it defines as "a prescribed quantity of flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal is occurring." This passby flow requirement is based on estimates of 7Q-10, defined as follows: "the lowest average, consecutive 7-day flow that would occur with a frequency or recurrence interval of one in ten years. A 10-year low flow event has a 10 percent chance of occurring in any one year. Accepted hydrologic practices must be used to determine the 7Q-10 flow" (SRBC 2009). The 7Q-10 requirements must be included in the water management plan that is completed by each company in the permitting process. Also included in the low-flow analysis is the average daily flow at the point of withdrawal, along with the drainage area.

The sustainability of water withdrawals at the county level across the United States was evaluated by Roy et al. (2005). This study provided a summary of the nation's large-scale use of freshwater and included projected findings to the year 2025. The report outlined three key areas that required further investigation. These key areas were in-stream use requirements to maintain optimal habitat and beneficial uses, water storage and withdrawal capacity available, and more temporally detailed patterns of water use (Roy et al. 2005). Applying methods outlined in this report to address withdrawals at a more localized level would help to identify issues relevant to the Pine Creek Valley. This approach will allow use of local water consumption data as opposed to national estimates provided in the report by Roy et al. (2005). These data should allow for a more accurate analysis of water use and subsequent availability in Lycoming County. The objectives of our research are to evaluate surface water withdrawals in Lycoming County used for Marcellus shale natural gas development and to assess potential impacts on water yield. This research will estimate conservatively future water withdrawals and compare demand and availability pre- and post-Marcellus exploration.

METHODS

A regional water balance model was developed for the Pine Creek watershed. The drainage area of the Pine Creek watershed at the U.S. Geological Survey (USGS) station in Waterville, PA is approximately 950 mi^2. To characterize seasonal changes in discharge of the Pine Creek watershed, 50 years worth of streamflow data, collected by USGS stream gauges near Waterville, Pennsylvania, were evaluated (USGS 2011). Precipitation was collected from several stations in the watershed and combined to approximate average annual and monthly precipitation (National Climatic Data Center 2011).

By using the long-term annual water budget analysis produced from Roy et al. (2005), estimates of surface water availability were evaluated for Lycoming County. County-level water use estimates from USGS were updated to account for the recent increase in Marcellus shale exploration. Current estimates of Marcellus shale drilling activity were obtained from the Pennsylvania Department of Environmental Protection (DEP), which reported the drilling of 106 horizontal Marcellus wells in Lycoming County in 2010. Under the assumption that water withdrawals for Marcellus shale development occur in the same county where the drilling occurred, a conservative estimate of average water consumption per well (2.8 Mgal yr^{-1}) was added to water use in the mining category for 2010. We assumed that water use remained constant in all categories with the exception of mining. Total surface water withdrawals were then compared to all withdrawals for mining use, including shale gas production. The amount of renewable water for the region, determined by subtracting potential evapotranspiration from precipitation summed for all months in which precipitation exceeds evapotranspiration, as outlined by Roy et al. (2005), was then compared to the updated USGS data.

RESULTS AND DISCUSSION

Average annual monthly discharge, expressed as a depth measurement, is approximately 42 mm. Showing seasonal variability, monthly discharge in June through November is below this average; the average August level is approximately 13.5 mm. These individual monthly low flows relative to the average most likely reflect the annual cove hardwood growing season and the corresponding water uptake. Between December and the middle of May, a surplus of water, relative to the average, is observed, peaking in April with approximately 93 mm of discharge. During this time, frozen or saturated soils facilitate runoff of precipitation. Runoff and lack of interception of precipitation by deciduous trees translate into increased water levels. Figure 1 shows monthly discharge and precipitation averages from 1958 through 2010. By outlining the seasonal variability of the Pine Creek watershed, it can easily be determined which months are most susceptible to potential biological, recreational, and other impacts from surface water withdrawals. In 2010, drilling activity occurred more frequently in these months (June through September), as summarized in Table 1.

Average annual discharge and precipitation were evaluated for the Pine Creek watershed from 1958 through 2008 (Fig. 2) to distinguish between high-flow and low-flow years. Although no trends can be determined based on this snapshot in time, we can see that average annual discharge is

Table 1.—Marcellus wells completed in Lycoming County, Pennsylvania, in 2010

Number of wells drilled by month in 2010											
Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
5	12	1	5	9	17	13	7	13	4	14	7

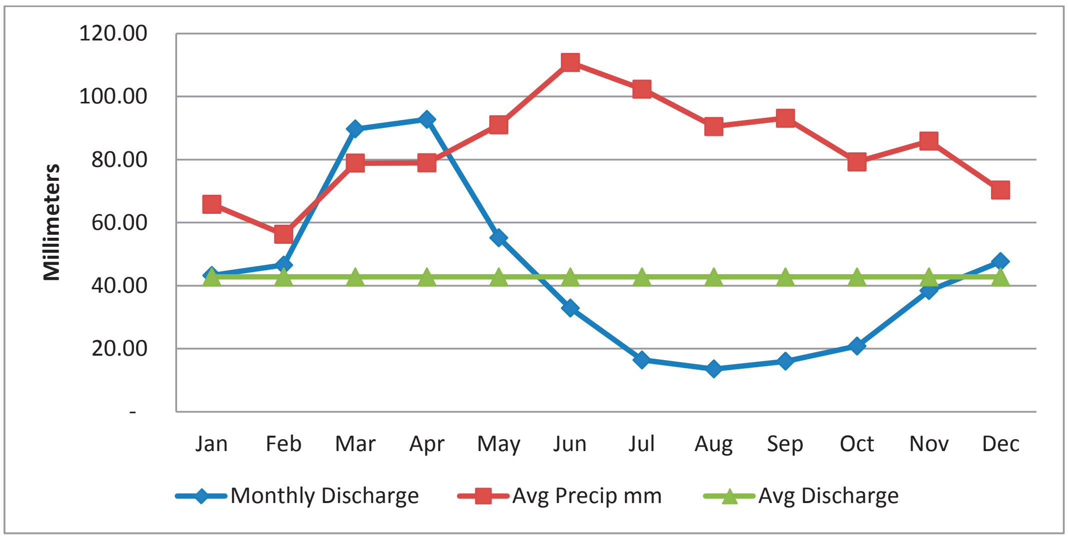

Figure 1.—Average monthly discharge and precipitation in the Pine Creek watershed, 1958 through 2010.

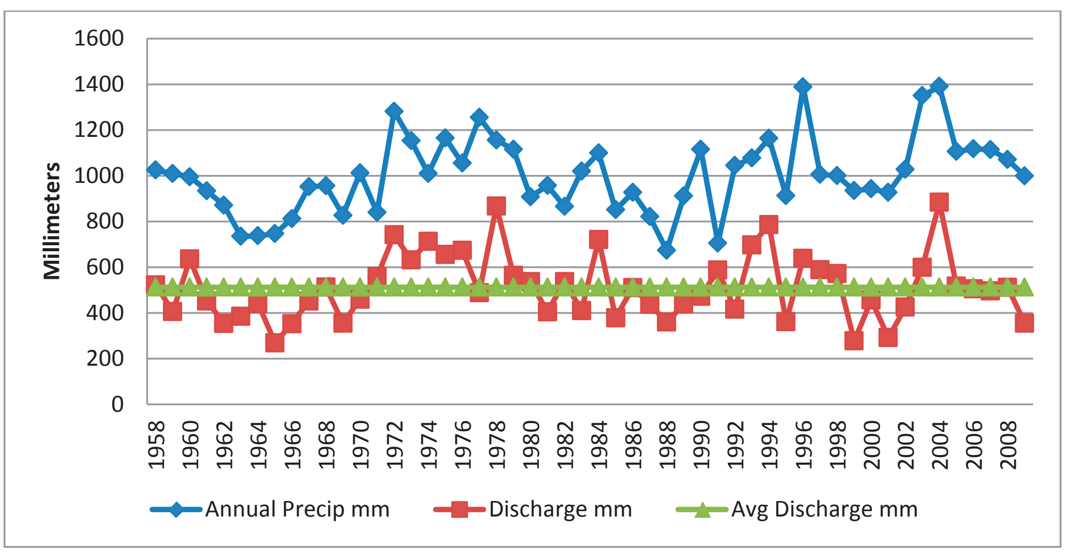

Figure 2.—Average annual discharge and precipitation in the Pine Creek watershed, 1958 through 2008.

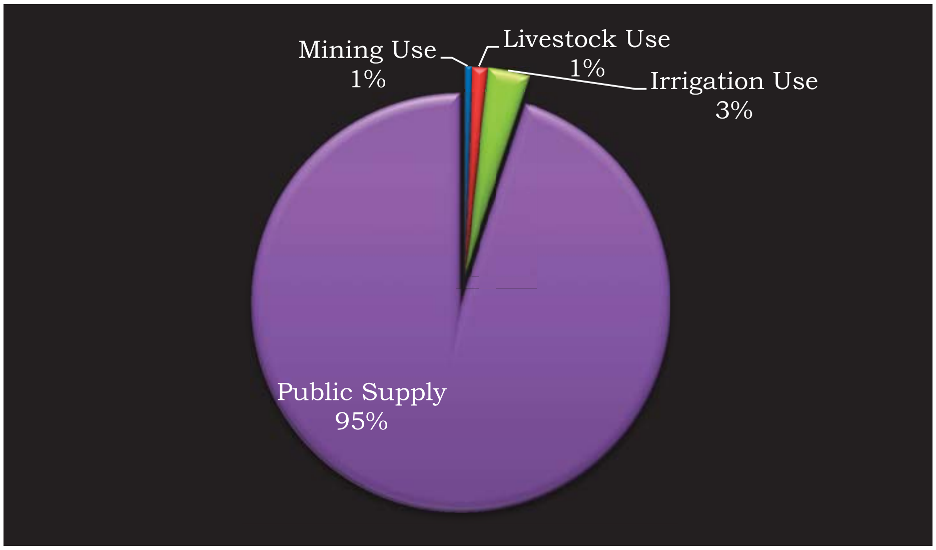

Figure 3.—Surface water withdrawals by category, Lycoming County, Pennsylvania, 2005.

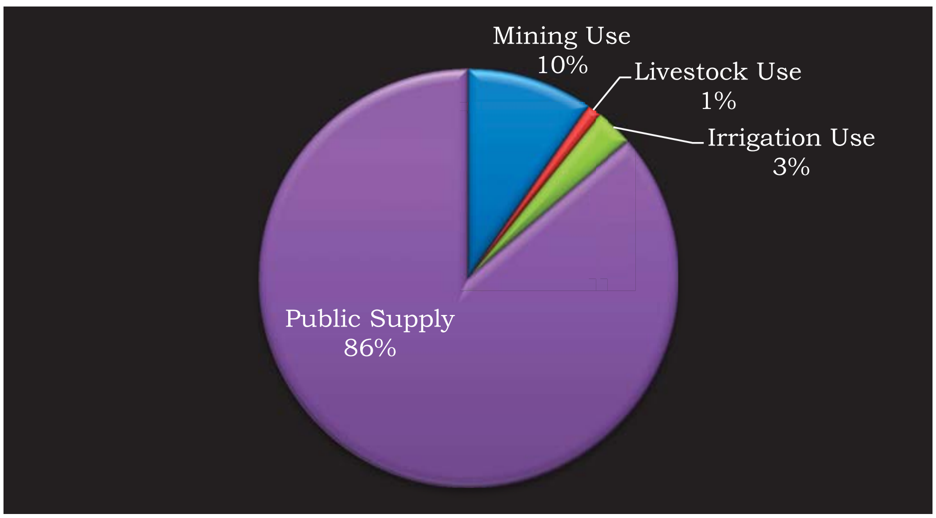

Figure 4.—Surface water withdrawals by category, Lycoming County, Pennsylvania, 2010.

approximately 512 mm, expressed as a depth measurement. Approximately 30 years of data recorded since 1958 have shown below-average flows; the lowest years on record were 1965 and 2001. The highest discharge years were 1978 and 2004, averaging almost 900 mm. In general, high and low precipitation years correspond to high and low average discharge (Fig. 2) although high or low discharges do not necessarily result in flooding or drought events. For example, one of the worst flooding events of this period occurred in 1972, which is not shown as the highest discharge year. Flooding is a response to several factors and usually is caused by the rate at which precipitation or other inputs occur.

In 2005, Lycoming County had four primary categories of surface water consumption: irrigation, livestock, mining, and public supply (Fig. 3). Approximately 95 percent of all surface water withdrawals in the county were used for the public water supply, and less than 1 percent was consumed by mining operations. We estimated use rates for the mining category under the conservative assumption of 0.0077 Mgal day^{-1} per well. Under this assumption, freshwater withdrawals used for mining purposes increased twentyfold between 2005 and 2010, from 0.04 Mgal day^{-1} in 2005 to 0.86 Mgal day^{-1}. Figure 4 shows the updated proportions of surface water withdrawals by category for 2010.

CONCLUSIONS

Natural gas extraction will undoubtedly have an enormous economic impact by creating jobs and increasing state revenue while boosting local economies. With this opportunity comes increased concern from local residents and environmental organizations over potential adverse impacts. Assessments of water withdrawals used for developing the Marcellus shale are necessary to properly evaluate potential effects on forested watersheds. Research on water availability in these catchments and cumulative effects of natural gas extraction on discharge could provide insight into the broader impacts of regional gas development on future water withdrawals.

Assuming development of the Marcellus shale formation continues in Pennsylvania and water withdrawals in the West Branch of the Susquehanna sub-basin remain necessary for this development, an increased value will be placed on water resources in Lycoming County and the Pine Creek watershed. Cumulative effects on discharge will become increasingly important knowledge to protect the ecological integrity of the area.

With freshwater vital to this exploration, increased importance should be placed on analyzing and characterizing the sourcing areas such as the Pine Creek watershed. Although water volumes consumed are not large relative to other uses, the rate at which water is needed and withdrawn could potentially affect watersheds. Smaller watersheds are most susceptible to these impacts, especially in summer low-flow conditions. As Marcellus shale gas production increases, so will mining operations' proportion of surface water withdrawals in the area. Currently water management plans, required by the Pennsylvania DEP, require gas well operators to compare their own surface water withdrawals to the 7Q-10. This impact study also requires operators to outline stream uses and conduct a natural diversity inventory.

Although Pennsylvania has relatively abundant water resources, which are much greater than in other shale natural gas extraction areas, Marcellus shale development potentially still could negatively affect water availability. One option to reduce the potential impact of surface water withdrawals is to store water in months with above-average discharge. This action would reduce the impact of large withdrawals over a short period of time and take water when a relative excess is available. A deeper understanding of surface water availability at the county level would help resource managers to reduce the impact of Marcellus exploration on watersheds.

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