



The Review of Regional Studies

The Official Journal of the Southern Regional Science Association



Drought Status, Price, and the Effectiveness of Water Use Restrictions in Pennsylvania*

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Abstract: During droughts, governments and water suppliers typically implement non-price policies to encourage water conservation. The state of Pennsylvania requests voluntary reductions in residential water use during moderate droughts and imposes mandatory restrictions during drought emergencies. This study utilizes data on household water consumption to measure the effectiveness of the water use restrictions in Pennsylvania during the moderate drought years 2015-2017. Results suggest that voluntary water use restrictions have smaller than desired effects and that the effects are larger the higher the marginal price of water, perhaps reflecting a trade-off between non-monetary benefits and the welfare loss from reducing water usage. The effectiveness of voluntary water use restrictions also is found to increase with the length of the drought.

Keywords: drought, water conservation, conservation policy

JEL Codes: Q25, Q28

1. INTRODUCTION

It is widely expected that freshwater scarcity will become more common in regions around the world due to population growth, rising consumer demand for water-intensive products and services, environmental demands, pollution, and climate change. During droughts, government agencies and municipal water suppliers typically implement non-price policies to encourage water conservation. The non-price conservation policies include water use restrictions, information campaigns, social comparisons, and financial incentives for installing water-saving devices (Wichman et al., 1992).

Although the state of Pennsylvania typically receives ample precipitation, drought conditions sometimes occur. The state requests voluntary reductions in water use during moderate droughts and imposes mandatory restrictions during more serious droughts. Little is known,

*The author thanks Chris Magee and the participants in the Department of Economics Research Seminar at Bucknell University for helpful comments, Kyle Adams for research assistance, Janine Glather for map creation, and the water companies which supplied data for the study.

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however, about the effectiveness of these Pennsylvania policies. If projections of increased frequency and intensity of drought bear out, knowledge of the effectiveness of existing policies could enhanced drought management.

Studies of droughts in other regions have shown varying results from water use restrictions depending on the location, the policies adopted, and the type of data analyzed. The present study contributes to this literature by analyzing data on household water consumption in Pennsylvania to measure the effectiveness of water use restriction in counties experiencing moderate drought conditions during the years 2015-2017. Another contribution is the theoretical and empirical examination of the conjecture that the higher the price of water, the more responsive residential water users are to requests for voluntary reductions in water use. Results suggest that the voluntary water use restrictions have a smaller than desired effect and that the effects are larger the higher the marginal price of water. Furthermore, the findings show that the effectiveness of voluntary water use restrictions increases with the length of the drought.

The following section discusses how droughts are managed in Pennsylvania. Section 3 reviews the literature on the effectiveness of water use restrictions. Section 4 considers various non-monetary motivations for complying with voluntary water use restrictions. It also examines how the welfare loss from a percentage reduction in water usage varies with the price of water. Section 5 describes the data used in the study, and Section 6 presents the empirical model and discusses the estimation method and results. Section 7 concludes.

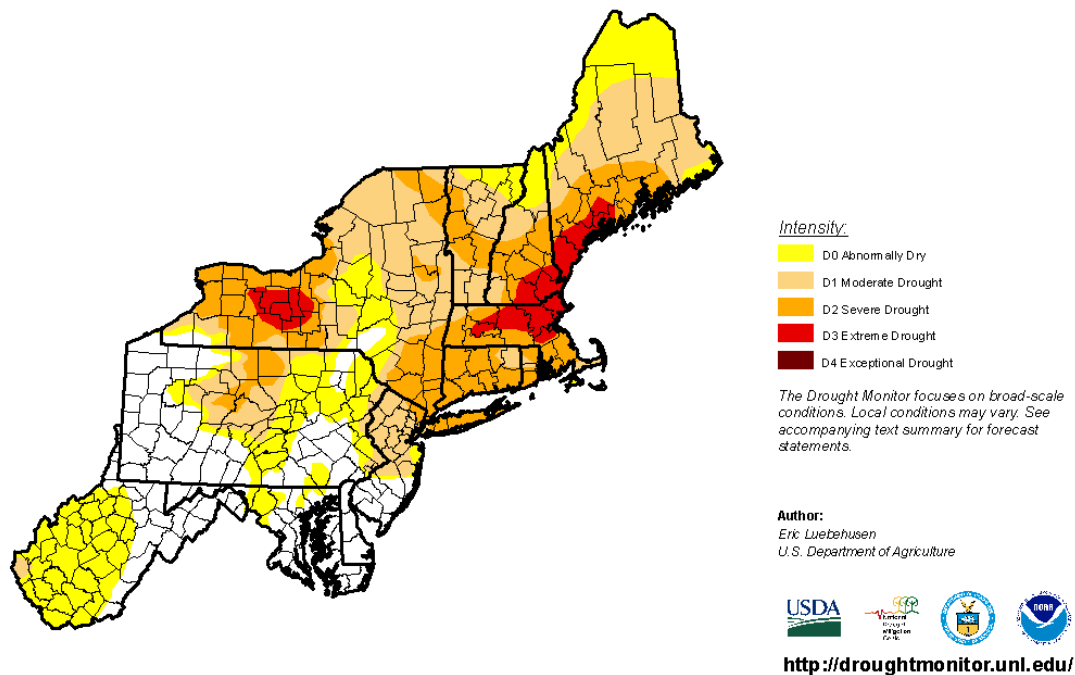
2. DROUGHT MANAGEMENT IN PENNSYLVANIA

There is no single, universally accepted definition of drought. Wilhite and Pulwarty (2018) define drought as a “natural hazard that results from a deficiency of precipitation from average or ‘normal’ that, when extended over a season or longer, results in water supplies that are insufficient to meet the demands of human activities and the environment.” All droughts begin with a deficiency of precipitation (meteorological drought) that can be aggravated by high temperatures, low humidity, and wind. When the deficiency of precipitation continues, it affects agricultural production through reductions in soil moisture (agricultural drought). Persistent drought conditions reduce stream flow, reservoir and lake levels, snowpack, and groundwater levels (hydrological drought), with significant impacts on ecosystems. Socioeconomic drought associates human activity with elements of meteorological, agricultural, and hydrological drought. This type of drought may result from factors affecting goods dependent on precipitation, such as hydroelectric power. Socioeconomic drought may also result from the differential impact of drought on groups of people. The impacts of drought depend on the timing, intensity, duration, and spatial extent of drought (Wilhite and Pulwarty, 2018).

The Northeast region of the United States experienced a serious drought in 2016. In October, most of New England and New York experienced moderate or severe drought, and some areas experienced extreme drought (Figure 1). Portions of Pennsylvania also were affected.

In the state of Pennsylvania (PA), managing water resources during droughts is the re-

**Figure 1: U.S. Drought Monitor: Northeast,
October 18, 2016**



sponsibility of the Pennsylvania Emergency Management Agency (PEMA), with support from the Pennsylvania Department of Environmental Protection (PA DEP). The PA DEP regularly monitors precipitation, stream flow, groundwater level, soil moisture, and reservoir levels, generally on a county basis. Every month, the PA DEP assigns a drought status (normal, watch, warning, or emergency) to each of the drought indicators. Precipitation deficits are the earliest indicators of a potential drought, because precipitation provides the basis for both surface water and groundwater resources. Precipitation levels over the past three months that are 25 percent below normal indicate a drought watch; 35 percent below normal indicate a drought warning; and 45 percent below normal indicate a drought emergency (Commonwealth of Pennsylvania, Department of Environmental Protection, 2016). The Appendix describes in detail how each of the drought indicators (precipitation deficits, stream flow, groundwater level, and soil moisture) is computed and assigned a drought status.

Generally, when three or more of the indicators are signaling a drought watch for a county or a group of counties, PA DEP will inform PEMA of the developing conditions and ask PEMA to convene a meeting of the Commonwealth Drought Task Force. The Commonwealth Drought Task Force includes membership from state, federal, and interstate agencies who may be impacted by drought or drought management operations. Upon recommendation of the Task Force and direction from the Governor, the PA DEP issues a drought watch. Press releases are issued to the media and letters are sent to all public water suppliers in the affected area, notifying them to follow their drought contingency plans. The general goal is to reduce water use by 5-10 percent through voluntary water conservation (Commonwealth

of Pennsylvania, Department of Environmental Protection, 2016).

A similar process is followed when three or more of the indicators signal a drought warning. In this case, citizens are asked to reduce water use voluntarily by 10-15 percent. When three or more of the indicators signal a drought emergency, and upon recommendation of the Commonwealth Drought Task Force, PEMA convenes a meeting of the Emergency Management Council. Upon recommendation of the Council, the Governor may issue a proclamation of drought emergency, imposing mandatory restrictions on nonessential uses of water designed to achieve a reduction in overall water use of up to 25 percent. These restrictions generally apply to watering of lawns, gardens, and shrubs; washing vehicles or paved surfaces; filling swimming pools; and use of water for ornamental purposes (Commonwealth of Pennsylvania, Department of Environmental Protection, 2016).

A public water supplier's drought contingency plan describes stages of drought for its particular sources of water. The water supplier may request voluntary or mandatory water use restrictions in advance of any state announcements or declarations. In some cases, water use restrictions may be insufficient to protect the supplies of an individual public water supplier. When depleted supplies threaten health and safety, the state may approve the water supplier's request to ration water within its service area. Rationing water is a more severe measure than banning nonessential uses, and generally involves allotting a given amount of water based on a percentage of previous usage or a specific quantity per household.

In extreme droughts, large industrial and commercial water users may be required to submit drought contingency plans, which identify actions that can be taken to reduce water use by various percentages. The Commonwealth Drought Coordinator will order such cutbacks only if conditions become so severe that health and safety are threatened. Pennsylvania has never experienced a drought so severe as to require industrial and commercial cutbacks (Commonwealth of Pennsylvania, Department of Environmental Protection, 2016).

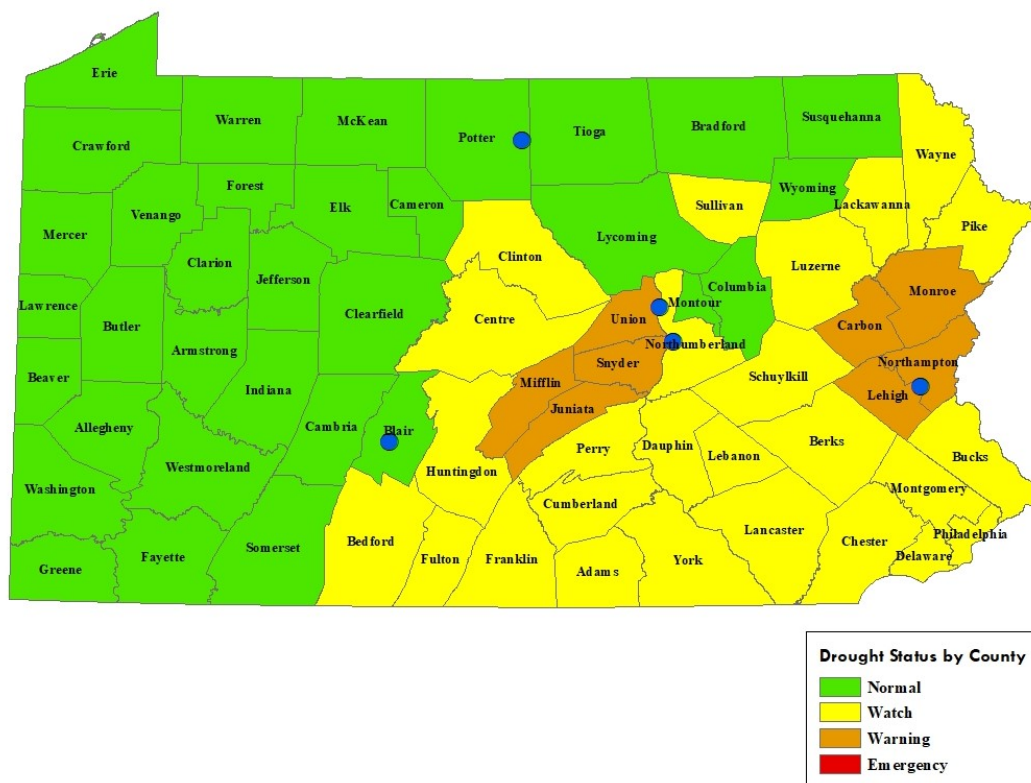
The last drought emergency declared in Pennsylvania was in 2002 (Schweiker, 2002), which followed the previous drought emergency in 1999 (Ridge, 1999). More recently, at the end of 2016 and into 2017, nearly one-half of Pennsylvania counties were under drought watches or warnings (Figure 2). Some counties experienced drought watches in 2015 as well. The effectiveness of water use restrictions in Pennsylvania over the period 2015-2017 is the focus of the present study.

3. PREVIOUS LITERATURE

A number of previous studies evaluate water use restrictions and other non-price demand management policies. The studies vary in their location (many are in the southwest U.S.), time period, measure of water use (daily, weekly, monthly, or quarterly observations on household, city per capita, or city per household water use), type of data (time series, cross section, or panel data), demand management policies considered, functional form of the water demand equation, and estimation methods. Considering just water use restrictions, the range of estimates is wide, but mandatory water use restrictions generally have larger effects than voluntary ones.

The estimated effects of voluntary water use restrictions on average water consumption

**Figure 2: Drought Status by Pennsylvania County,
December 22, 2016**



Source: Pennsylvania Department of Environmental Protection and Janine Glather. Note: Dots indicate locations of water companies supplying data for the study.

typically fall in the range of -12 percent to 0 (Moncur, 1987; Shaw and Maidment, 1987, 1988; Nieswiadomy, 1992; Kenney et al., 2004; Coleman, 2009), although Shaw et al. (1992) found that voluntary water use restrictions in San Diego, California reduced water consumption by 27 percent in the summer of 1991. Two studies from the eastern U.S. are worth highlighting for comparison with the present study. Halich and Stephenson (2009) studied 21 locales in Virginia around the time of the 2002 drought. They found that the effects of the voluntary water use restrictions vary between -7 percent and 0, the magnitudes of the reductions varying directly with the intensity of the public information campaigns conducted. Wichman et al. (1992) found that voluntary water use restrictions adopted in 6 North Carolina cities in 2007 and 2008 reduced water consumption on average by 8.5 percent.

In a study of Cobb County, Georgia, Ferraro and Price (2013) considered the effects of technical advice, prosocial appeals, and social comparisons on water conservation. Prosocial appeals ask households, for example, to conserve water in order to protect wildlife and human health. The social comparisons inform consumers of the percentage of similar households that they consumed more water than, an approach that has been tried with some effect in electricity markets (Alcott, 2011). Ferraro and Price (2013) found that technical advice (“tip

sheets”) reduce water use by less than 1 percent, prosocial appeals combined with technical advice reduce water use by 2.7 percent, and social comparisons combined with the other two approaches reduce water consumption by 4.8 percent on average. Brent et al. (2015) found similar effects of social comparisons in two of three California water utilities studied; there is an insignificant effect in the third company.

Mandatory water use restrictions typically apply to outdoor water use, such as day of use restrictions, hand-watering only, or outright prohibitions. The range of estimates of the effects of mandatory water use restrictions, -56 percent to -4 percent, is even wider than that of voluntary restrictions (Renwick and Archibald, 1998; Renwick and Green, 2000; Grafton and Ward, 2008; Castledine et al., 2014). It is notable that Halich and Stephenson (2009) found that the effects of mandatory water use restrictions are larger in absolute value the greater the penalties for noncompliance and the stronger the enforcement efforts.

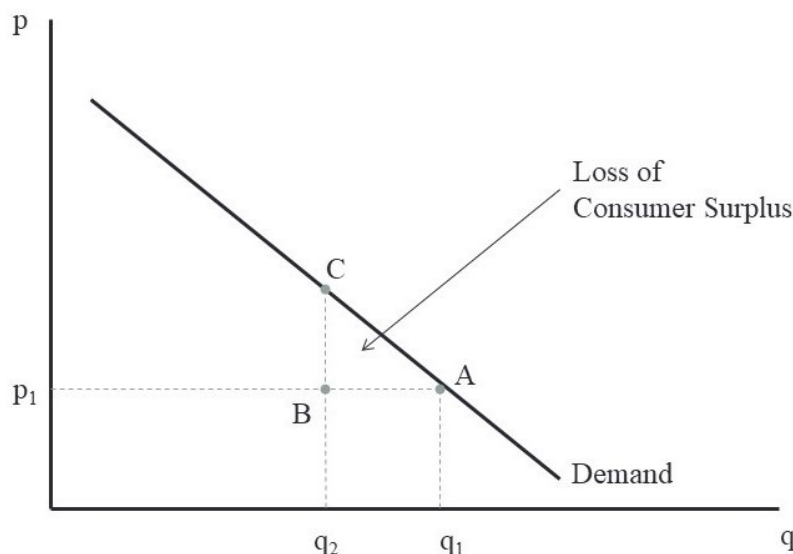
4. NON-MONETARY MOTIVATIONS OF BEHAVIOR

The findings that voluntary and mandatory water use restrictions affect water use raise the question as to why. In standard consumer theory, demands for goods and services such as water depend on relative prices and income. If these factors and consumer preferences do not change, demands would not change. Alternatively, non-monetary motives of behavior could help explain why households comply with voluntary water use restrictions or mandatory restrictions with small penalties and weak enforcement mechanisms.

In the context of recycling, Abbott et al. (2013) provide an informative summary of non-monetary motives of behavior found in the psychology, economics, sociology, and other literatures. They identify “warm glow” and social norms as the primary non-monetary motives of pro-environmental behavior. Warm glow can be defined as the enjoyment derived from an activity independent of its outcome (Deci, 1971; Andreoni, 1990). It is an intrinsic motivation that reflects self-interest.

Social norms are “shared understandings about actions that are obligatory, permitted, or forbidden” (Ostrom, 2000). Compliance with social norms depends on beliefs about the degree of conformity among the population (descriptive norms) and what other people expect (injunctive norms). Injunctive norms can influence behavior because of sanctions, such as shaming, which others can exert in the event of noncompliance. However, sanctions are not required for compliance if the social norms have become internalized (Abbott et al., 2013). Some writers link social norms and warm glow together. For example, Brekke et al. (2003), identify warm glow with an individual’s positive self-image, which depends on the degree to which their behavior is socially responsible.

In light of these non-monetary motivations of behavior, households might comply with water use restrictions because of the warm glow they receive from doing so or because of a social norm they internalize or feel compelled to follow because of external sanctions. A tradeoff is the conventional loss of welfare from reducing consumption of water in the absence of a change in price. For example, Ferraro and Price (2013) incorporate this tradeoff between consumption utility and the nonpecuniary payoff in their model of the channels through which technical information, prosocial messages, and social nudges might influence

Figure 3: Welfare Loss from Water Use Restrictions

water consumption. Binder and Blankenberg (2017) note on page 307, “it is well-known from the environmental literature that people have problems with following through on certain behaviors if they are associated with additional costs (however small).” In the present context, the greater the welfare loss from reducing the consumption of water relative to the non-monetary benefits, the lesser the extent of compliance with water use restrictions.

Furthermore, the welfare loss from a given percentage reduction in water use might depend on the price of water. If so, then the price could affect the extent to which consumers comply with voluntary water use restrictions expressed as a percentage of water use. This possibility does not appear to have been discussed in the literature.

Consider the case of a linear demand function for water:

$$q = a - bp + cy \quad (1)$$

where q is the quantity of water, p is the marginal price of water, y is income, and a , b , and c are positive parameters. Both p and y are deflated by an appropriate index of other prices. The initial price of water is denoted by p_1 and the associated initial quantity of water by q_1 . Suppose that there is a voluntary $100r$ percent reduction of in the quantity of water consumed ($0 < r < 1$), so that $q_2 = (1 - r)q_1$. Using Marshallian consumer’s surplus as the measure of consumer welfare, the loss in welfare from the water restrictions (L) is given by:

$$L = \left(\frac{1}{2b}\right)(q_1 q_2)^2 = \left(\frac{1}{2b}\right)r^2 q_1^2. \quad (2)$$

The Marshallian deadweight loss is shown by area ABC in Figure 3.

The Marshallian deadweight loss from a percentage reduction in water use is a decreasing function of the price:

$$\frac{\delta L}{\delta p_1} = -r^2 q_1 < 0. \quad (3)$$

This suggests that the higher the price of water, the smaller the welfare loss from a given percentage water use restriction, and the more likely a consumer is to comply with the restrictions, given the tradeoff between the welfare loss and the non-monetary benefits of complying.

Under certain conditions, Marshallian consumer's surplus can be a good approximation of Hicksian compensating variation, an accurate measure of consumer welfare. Hausman (1981) shows, however, that the Marshallian measure of deadweight loss can be a poor approximation of the compensated measure of deadweight loss. Nevertheless, with a linear demand function, the Hicksian measure of deadweight loss from water use restrictions decreases with the initial price, just as the Marshallian measure does.

Following Hausman (1981), the linear demand function in Equation (1) has the following Hicksian compensated demand function:

$$h(p, u_1) = cu_1 e^{cp} + \frac{b}{c} \quad (4)$$

where u_1 is the initial utility level and $u_1 < 0$ is necessary to satisfy the Slutsky condition in consumer theory. Let p_2 denote the shadow price of water following the imposition of water use restrictions, such that $q(p_2) = q_2$ (point C in Figure 3). With $q_2 = (1 - r)q_1$ under the water restrictions, the compensating variation (CV) is given by:

$$CV(p_1, p_2, y_1) = \int_{p_1}^{p_2} h(p, u_1) dp = \frac{1}{c} [e^{c(p_2 - p_1)} - (1 - r)] q_1 - \frac{b}{c^2} [e^{c(p_2 - p_1)}]. \quad (5)$$

The compensated deadweight loss (CL) is:

$$CL = CV - (p_2 - p_1)h(p_2, u_1). \quad (6)$$

Substituting Equations (4) and (5) into Equation (6), it can be shown that the Hicksian compensated deadweight loss decreases with the initial price:

$$\frac{\delta CL}{\delta p_1} < 0. \quad (7)$$

In light of these theoretical results, one hypothesis tested in the empirical analysis below is that compliance with voluntary water use restrictions by consumers is greater the higher the price of water.

5. DATA

The PA DEP defines a Community Water System (CWS) as a Public Water System which provides water to the same population year-round (Commonwealth of Pennsylvania, Department of Environmental Protection, 2017). There were 1,951 CWSs in Pennsylvania in 2016,

Table 1: Community Water Systems in Pennsylvania

Size	Number	Percent	Pop Served	Percent Served
Small	1,619	83	950,753	8
Medium	299	14	3,935,318	35
Large	33	2	6,491,628	57
Total	1,951	100	11,377,699	100

serving 11.4 million of the state's population of 12.8 million, but most of these systems are small, serving 3,300 or fewer people each. The 332 medium and large CWSs provided water to 92 percent of the population served (Table 1). Most of the systems are owned by municipalities or regional authorities, but some are owned by private companies that operate one or more systems throughout the state.

To obtain the data used in the present study, requests were sent in October 2017 to 34 medium and large community water systems and to one small system that were identified as billing monthly and charging a uniform consumption rate (price) for water in addition to a fixed (base) charge. The small system (Galeton Borough Water Authority) was selected because it was identified by in PA DEP drought reports as imposing water restrictions during 2016. Many Pennsylvania water companies bill only quarterly or bi-monthly. Companies that charge uniform rates for water were chosen because the price is administratively set and individuals take it as given and decide how much water to consume. Under increasing or decreasing block rate pricing structures, the marginal price of water depends on the amount consumed, making the price endogenous and creating econometric complexities. The 35 companies are located throughout Pennsylvania in counties with differing histories of drought status over the years 2015-2017.

Companies were requested to provide monthly water use data for each residential account from January 2015 to the most recent month in 2017, water rates charged over this period, and a description of measures taken to reduce water use during droughts. The request was supported by the Commonwealth Drought Coordinator and was accompanied by a letter of support from a Pennsylvania Representative. In the end, monthly account level data were provided by five water systems: the Milton facility of Pennsylvania American Water serving parts of Northumberland and Union Counties, the Borough of Hollidaysburg in Blair County, the Sunbury Municipal Authority in Northumberland County, the City of Bethlehem serving parts of Lehigh and Northampton Counties, and the Galeton Borough Authority in Potter County (see Figure 2). The primary source of water for each company is surface water (purchased surface water for Hollidaysburg). For the City of Bethlehem, less than 5 percent of the residential customers are billed monthly and included in the data provided, and many of those are in low-income housing and rental units, including multi-unit dwellings.

In managing the data received, customers were dropped if there was information that identified them as institutions or commercial establishments. Observations were dropped if water use was missing or less than or equal to zero. Then observations were dropped if water use was greater than the mean plus four standard deviations by company in order to account for leaks or large, unidentified institutions. Finally, customers were dropped from

Table 2: Summary Statistics by Water Company

	Milton	Hollidbrg	Sunbury	Bethlhm	Galeton
Residential units	7,700	2,172	2,012	519	266
Observations	276,688	75,044	66,241	17,180	9,523
Mean water use (1000 gal/month)	3.3	3.3	4.4	10.0	3.0
Mean price (1000 gal, 2015\$)	10.1	7.6	4.2	3.9	10.7
Mean base charge (2015\$)	14.8	14.8	11.3	8.3	33.6

the sample if they were missing two or more observations.

Table 2 presents summary statistics for data used in the empirical analysis by water company. The number of residential units varies from a low of 266 in Galeton to a high of 7,700 in Milton. Mean monthly water use per residential unit in thousands of gallons over 2015-2017 ranges from 3.0 to 4.4 in Galeton, Milton, Hollidaysburg, and Sunbury, with Bethlehem averaging 10.0 per account. The latter value reflects the presence of multi-unit dwellings in Bethlehem's small sample. The mean marginal price per thousand gallons, adjusted for inflation to 2015 dollars of purchasing power, varies from a low of \$3.9 in Bethlehem to a high of \$10.7 in Galeton. Galeton's base charge of \$33.6 also is relatively high, but it includes an allowance of 2,000 gallons of water. For 2,000 gallons or more of water used, a Galeton customer would pay an amount similar to a Milton customer.

The pattern of average monthly water use by residential units over the years 2015 to 2017 for each of the five water companies is shown in Figure 4. There is noticeable variability month-to-month in average water use. This likely reflects variation in meter reading dates and the number of days of water use billed per month. In fact, the spike in average water use late in 2016 in Hollidaysburg can be traced to a substantial change in meter reading dates for a number of customers. The other noticeable outlier is the relatively low value of average water use in January 2015 in Bethlehem. There were many missing values for this month in the Bethlehem data, and apparently many of these were multi-unit dwellings.

Although there is sizeable variation in the marginal price of water across water companies, there is less variation in the price over time within companies. As shown in Figure 5, there were slight step increases in the real price of water in Sunbury and Hollidaysburg, and a relatively large increase in 2017 in Galeton. The nominal price of water was unchanged over 2015-2017 in Milton, so the real price declines slightly due to the small rate of overall price inflation. Unusually, the marginal price of water took a sharp dip of over 1 dollar per 1000 gallons in 2017 in Bethlehem, only partially offset by an increase of \$0.61 in the base rate.

Figure 6 shows the drought status of the counties that the water companies operated in. Over the 36-month period 2015-2017, Blair County was in drought watch status three months, Northampton and Northumberland Counties were in drought watch or warning status 10 months, and Union County was in drought watch or warning status 13 months. Potter County was in a drought watch for four months in 2015, and Galeton Borough was under mandatory water use restrictions for six months beginning in August 2016.

Halich and Stephenson (2009) found that the effects of the voluntary water use restrictions depend on the intensity of the public information campaigns that accompanies them. In light

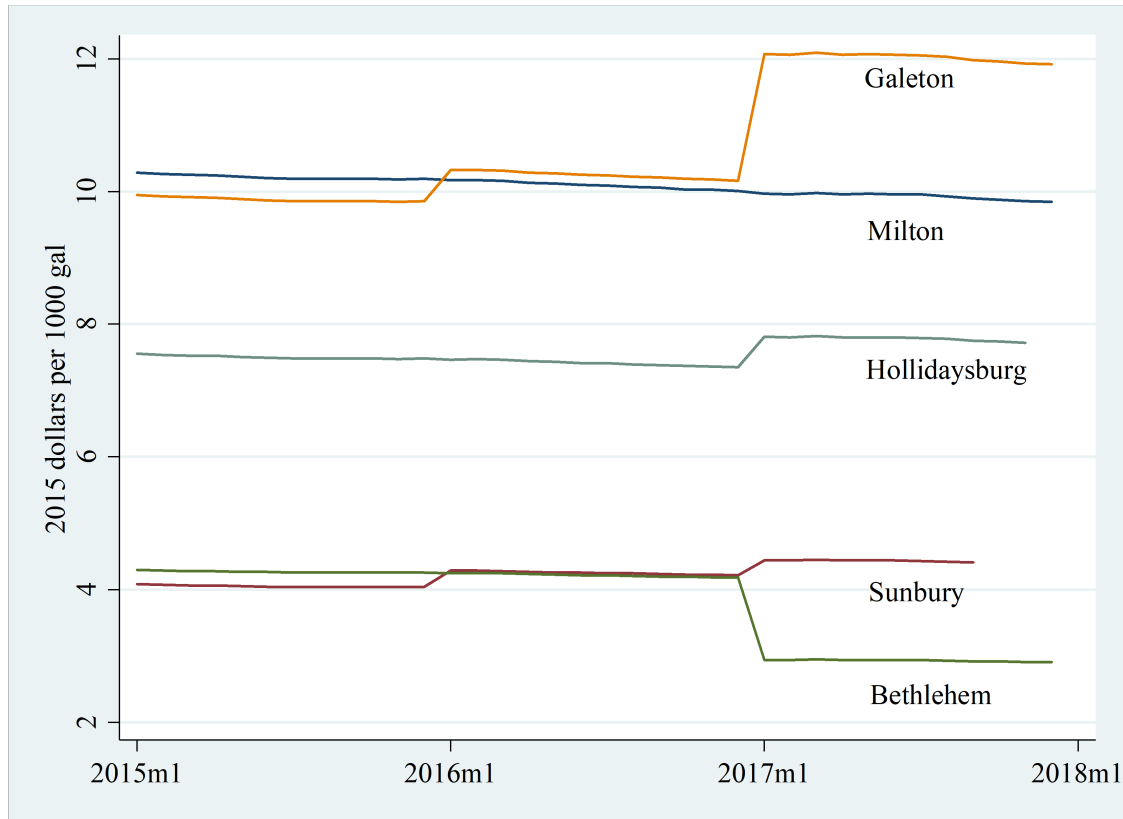
Figure 4: Average Water Use

of this, is worth noting what the water companies in the sample do when their county is under a drought watch or warning, and the PA DEP requests voluntary reductions in water use. The drought contingency plans and practices of the five companies are summarized in Table 3. Based on information provided by the companies, when voluntary reductions in water use are called for, the company provides notices to customers and, perhaps, information to local news media. It is difficult to judge the intensity of these efforts from the descriptions provided, but the efforts do not in general appear to be very vigorous in the event of a drought watch or warning.

6. EMPIRICAL MODEL AND RESULTS

6.1. Empirical Model

Empirical models of residential water demand commonly include as explanatory variables some measure of the price of water, household income, household characteristics such as number of residents, lot size, and landscape irrigation system, indicators of the season, weather variables, and policy variables such as voluntary and mandatory water use restrictions, and water technology rebates and subsidies (Olmstead, 2010). For the present study, however, data on household income or characteristics were not available, although an unobserved fixed effect represents them in the model.

Figure 5: The Marginal Price of Water

The empirical model estimated is as follows:

$$\begin{aligned}
 \ln(\text{water}_{gmt}) = & b_0 + b_1\text{price}_{gt} + b_2\text{watch}_{gt} + b_3\text{warning}_{gt} + b_4\text{mandatory}_{gt} \\
 & + b_5\text{watch}_{gt} * \text{price}_{gt} + b_6\text{warning}_{gt} * \text{price}_{gt} \\
 & + b_7\text{watch}_{gt} * \text{duration}_{gt} + b_8\text{warning}_{gt} * \text{duration}_{gt} \\
 & + b_9\text{precip}_{gt} + b_{10}\text{temp}_{gt} + \mathbf{T}_t b_{11} + h_g + c_{gm} + u_{gmt},
 \end{aligned} \tag{8}$$

where subscripts g , m , and t denote water company, residential unit, and time period, respectively; $\ln(\text{water})$ is the natural logarithm of monthly water use in 1000 gallons, price is the marginal price per 1000 gallons of water in 2015 dollars, watch is a (0, 1) indicator variable for PA DEP drought watch status in the county, warning is an indicator variable for drought warning status in the county, mandatory is an indicator variable for mandatory water restrictions in Galeton, duration gives the number of consecutive months in a drought (watch, warning, or mandatory restrictions), precip is monthly precipitation in inches recorded at the weather station nearest to the primary facility of the water company, temp is the monthly average of daily maximum temperature, \mathbf{T} is a vector of period fixed effects, and h_g , c_{gm} , and u_{gmt} are the unobserved group fixed effect, residential unit fixed effect, and idiosyncratic error, respectively. The semilogarithmic functional form for water demand is adopted because with it, the percentage effects of drought status are independent

Figure 6: Draught Status

	Blair County (Hollidaysburg)	Northampton County (Bethlehem)	Northumberland County (Milton and Sunbury)	Potter County (Galeton)	Union County (Milton)
2015					
Jan	1	1	1	1	1
Feb	1	1	1	1	1
Mar	1	1	1	1	1
Apr	1	1	2	2	2
May	1	1	2	2	2
Jun	1	1	2	2	2
Jul	1	1	1	2	1
Aug	1	1	1	1	1
Sep	1	1	1	1	1
Oct	1	1	1	1	1
Nov	1	1	1	1	1
Dec	1	1	1	1	1
2016					
Jan	1	1	1	1	1
Feb	1	1	1	1	1
Mar	1	1	1	1	1
Apr	1	1	1	1	1
May	1	1	1	1	1
Jun	1	1	1	1	1
Jul	1	1	1	1	1
Aug	2	2	1	4	2
Sep	2	2	1	4	2
Oct	2	2	1	4	2
Nov	1	3	2	4	2
Dec	1	3	2	4	2
2017					
Jan	1	3	2	4	3
Feb	1	2	2	1	3
Mar	1	2	2	1	3
Apr	1	2	2	1	2
May	1	2	2	1	2
Jun	1	1	1	1	1
Jul	1	1	1	1	1
Aug	1	1	1	1	1
Sep	1	1	1	1	1
Oct	1	1	1	1	1
Nov	1	1	1	1	1
Dec	1	1	1	1	1

1	Normal
2	Watch
3	Warning
4	Mandatory (Galeton)

Source: Consumer Expenditure Survey 2015.

of water use, and the price elasticity of demand varies with the price.

If the voluntary water use restrictions during drought watches and warnings are effective, then the coefficients on *watch* and *warning* will be negative. Similarly, if the effectiveness of the voluntary restrictions rises with the price of water, then the coefficients on the drought status interacted with *price* will be negative. If the effectiveness of the voluntary restrictions increases the longer the drought lasts, then the coefficients on the drought status interacted with duration will be negative as well.

The marginal price of water in Galeton is zero up to 2000 gallons due to an allowance included with the base charge. This makes the marginal price endogenous, and results in a biased estimator of the coefficient on the Galeton price variable. To address this issue, the instrumental variables technique is applied. The marginal price of water for Galeton households is estimated, with the base rate and the marginal price in excess of 2000 gallons

Table 3: Drought Contingency Plans and Practices

Milton	Following PA DEP's guidance for issuing conservation notices, a press release is sent to local media outlets and is posted on the company's website and social media outlets. In the event of a declared drought emergency, mandatory restrictions on nonessential uses of water are imposed, and the company is authorized to collect fines for noncompliance.
Hollidaysburg	When the Blair County EMA issues a drought watch or a warning, notices are sent out to the affected areas and water usage by customers is monitored.
Sunbury	Each year, a link is provided to our residential and commercial customers for the PA DEP's Water Conservation Fact Sheet, which provides tips for conserving water and protecting water resources. The link is also posted on the company's web site. In the event of a drought watch or warning in our local area, customers are informed of such on their monthly bills and are reminded to be conscious of their water usage, and to take steps to minimize it where they can.
Bethlehem	Following the PA DEP's declaration of a drought watch or warning, information is provided to news media. In the event of a drought warning, the public is informed about the potential for mandatory restrictions on water use. Water conservation measures and use of water saving devices are promoted. In the event of a drought emergency, regulations on the nonessential uses of water are publicized and enforced in conjunction with local law enforcement agencies.
Galeton	In the event that the Galeton Borough Council declares a stage one drought, voluntary restrictions of nonessential are encouraged. In the event of the declaration of a stage two drought, mandatory restrictions of nonessential water use are implemented and the PA DEP is notified. In the event of a stage three drought, the local water rationing plan is implemented in addition to the ban on nonessential water use. Penalties for violations include a fine not to exceed \$1,000 and/or imprisonment for a term not to exceed 30 days.

Source: Information provided by the water companies.

used as instruments. The fitted values from this equation are used as the water price variable for Galeton.

Equation (8) is estimated by the fixed effects method using Stata, version 13.1. The fixed effects transformation, which subtracts the mean over time from each variable, eliminates the group and residential unit fixed effects as well as the cross section variation of the averages of the other variables such as the price. Note, however, that the fixed effects method will not eliminate all of the cross section variation in the interaction terms between price and drought status. For example, if a drought watch were in effect in 25 percent of the months, then fixed effects estimation would leave about 75 percent of the price in the transformed interaction term between the price and the drought watch indicator.

Table 4: Regression Results by Water Company

Variable	Coefficient (standard error)				
	Milton (1)	Hollidaysbrg (2)	Sunbury (3)	Bethlehem (4)	Galeton (5)
price	a	1.3223 (1.0211)	a	1.8442*** (0.0509)	-0.0312*** (0.0072)
watch	-0.0074 (0.0047)	-0.0631** (0.0308)	-0.0262*** (0.0102)	-2.0870*** (0.0058)	-0.0605** (0.0288)
warning	-0.0023 (0.0076)		1.6167*** (0.0459)		
mandatory					-0.0485 (0.0309)
precip	-0.0145*** (0.0008)	-0.0016 (0.0029)	-0.0073*** (0.0003)	0.5473*** (0.0003)	-0.0312** (0.0072)
temp	0.0013*** (0.0001)	0.0012* (0.0006)	0.0023*** (.0001)	0.0480*** (.0012)	0.0010* (.0006)
Observations	276,668	75,044	66,241	17,180	9,523
R ²	0.011	0.007	0.006	0.013	0.023

Notes: Dependent variable is $\ln(\text{water})$. Fixed effects model with robust standard errors clustered at the residential unit level. *, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively. The letter “a” indicates omitted due to collinearity.

6.2. Regression Results

Results from estimating Equation (8) without interaction terms separately for each water company are reported in Table 4. Two observations are noteworthy. First, the price variable is eliminated in the Milton and Sunbury regressions due to collinearity. The collinearity is with the period fixed effects, and reflects the small extent of variation over time of the prices of water for these two companies in the sample. Second, the coefficient estimates for Bethlehem are highly implausible. The data for the City of Bethlehem are unrepresentative, coming from less than 5 percent of its residences, mostly low-income housing and rental units, including multi-unit dwellings. In view of this, Bethlehem is excluded from the remainder of the analysis.

Table 5 reports summary statistics for variables in the combined sample excluding Bethlehem. Note that the average monthly water use in the sample is 3,460 gallons, the average marginal price per 1000 gallons of water in 2015 dollars is 8.7, drought watch status is present in 25 percent of the observations, but only 2 percent of the observations have a drought warning and less than 1 percent have mandatory restrictions. The sample mean of *duration* is 1.0 months, but conditional on there being a drought, the mean duration is 5.1 months (see Figure 6).

Results from estimating Equation (8) with the combined sample are presented in Table 6. Column (1) shows coefficient estimates when the interactive terms involving drought status are excluded. The coefficient on *price* is negative and significant, and implies a price

Table 5: Summary Statistics

Variable	Definition	Mean (Std. Dev.)
<i>water</i>	Monthly water use per residential unit (1000 gallons)	3.46 (2.18)
<i>price</i>	Marginal price per 1000 gallons of water in 2015 dollars	8.68 (2.15)
<i>watch</i>	=1 if county drought status "Watch" for 1/2month	0.25 (0.43)
<i>warning</i>	=1 if county drought status "Warning" for 1/2month	0.02 (0.14)
<i>mandatory</i>	=1 if mandatory water restrictions in place (Galeton)	0.004 (0.066)
<i>duration</i>	Consecutive months under a drought (0, 1, 2, ...)	1.00 (2.07)
<i>precip</i>	Monthly precipitation in inches	3.28 (1.82)
<i>temp</i>	Monthly average of daily maximum temperature (F)	61.2 (17.7)

Note: Bethlehem is excluded.

elasticity of water demand of -0.23 at the sample mean. The coefficients on *watch* and *warning* are negative but statistically insignificant. The coefficient on the mandatory water restrictions in Galeton, however, is negative and significant. The weather coefficients have the anticipated signs and are statistically significant.

Column (2) of Table 6 shows the estimates when the interaction term *watch * price* is included. Interaction terms involving *warning* and *mandatory* are excluded because there is no cross section variability, there are relatively few observations on them, and when included the estimated coefficients (not shown) are implausible. Noteworthy is the negative and significant coefficient on *watch * price*. This result is consistent with the notion that the higher the price of water, the more likely is compliance with voluntary water use restrictions.

The estimates when *watch * duration* is included are reported in column (3) of Table 6. With this specification, all of the coefficients have the anticipated signs and are statistically significant, including the coefficients on the drought warning indicator and the interaction terms. The higher the price of water and the longer a drought lasts, the greater the voluntary reduction in water use during a drought watch. The estimated price elasticity of demand evaluated at the sample mean is -0.33 during a normal period. This elasticity estimate is similar to the mean price elasticity of -0.41 in the meta-analysis of Dalhuisen et al. (2003), although it is sensitive to the inclusion of the *watch * duration* interaction term.

Halversen and Palmquist (1980) showed that the coefficient on a dummy variable in a semilogarithmic regression equation, multiplied by 100, does not give the percentage effect of that variable on the variable being explained. This is because the dummy variable is a discrete variable, rather than a continuous one. In the present setting, the relative effect on monthly residential water use (*g*) of being in a drought watch is given by:

$$g = \exp(b_2 + b_5 \text{price} + b_7 \text{duration}) - 1, \quad (9)$$

Table 6: Regression Results

Variable	Coefficient (standard error)		
	(1)	(2)	(3)
<i>price</i>	-0.0263*** (0.0085)	-0.0283*** (0.0085)	-0.0384*** (0.0087)
<i>watch</i>	-0.0037 (0.0027)	0.0289*** (0.0061)	0.0459*** (0.0063)
<i>warning</i>	-0.0070 (0.0060)	-0.0089 (0.0060)	-0.0200*** (0.0069)
<i>mandatory</i>	-0.0498*** (0.0158)	-0.0498*** (0.0158)	-0.0482*** (0.0158)
<i>watch*price</i>		-0.0038*** (0.0006)	-0.0035*** (0.0006)
<i>watch*duration</i>			-0.0072*** (0.0010)
<i>precip</i>	-0.0048*** (0.0007)	-0.0047*** (0.0007)	-0.0046*** (0.0007)
<i>temp</i>	0.0017*** (0.0005)	0.0019*** (0.0005)	0.0019*** (.0005)
Observations	424,700	424,700	424,700
R ²	0.025	0.025	0.025

Notes: Dependent variable is $\ln(\text{water})$. Bethlehem is excluded.

Fixed effects model with robust standard errors clustered at the residential unit level. *, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively.

and the percentage effect on water use is 100g. The relative effect of being in a drought watch is evaluated at particular values of *price* and *duration* because of the interaction terms. Similar expressions without the interaction terms can be given for the relative effects of a drought warning or mandatory water restrictions. Replacing the coefficients in Equation (9) with consistent estimates of them will provide a consistent estimate of g (Kennedy, 1981).

Estimates of the relative effects of drought status on water use are reported in Table 7. These effects are based on the results in column (3) of Table 6. The first section shows that the estimated relative effect of being in a drought watch is -0.0204, or -2.0 percent, when evaluated at the sample mean price (8.7) and the average duration of a drought episode (5). The estimated relative effect of being in a drought warning is essentially the same (-0.0198, or -2.0 percent). Both of these estimated effects are smaller than the effects of drought watches and warnings desired by the PA DEP (5-10 percent and 10-15 percent, respectively), but are within the range Halich and Stephenson (2009) found in Virginia. The relative effect of the mandatory water use restrictions in Galetton is found to be -0.0471, or -4.7 percent. This falls near the bottom of the range of estimates in previous studies, but indicates that mandatory water use restrictions reduce residential water use more than voluntary restrictions.

The quantitative importance of the marginal price of water to the effects of voluntary

Table 7: Relative Effects of Drought Status on Water Use

Variable	Coefficient (standard error)			
Price	Duration	Watch	Warning	Mandatory
Mean (8.7)	5 months	-0.0204** (0.0037)	-0.0198*** (0.0068)	-0.0471*** (0.0151)
Mean+ (10.9)	5 months	-0.0277*** (0.0038)		
Mean- (6.5)	5 months	-0.0128*** (0.0041)		
Mean (8.7)	3 months	-0.0063** (0.0027)		
Mean (8.7)	7 months	-0.0343*** (0.0052)		

Notes: Calculated from estimates in Table 6, column (3). Standard errors are in parentheses. *, **, and *** indicate statistical significance at the 10, 5 and 1 percent levels, respectively.

water use restrictions during a drought watch is shown in the middle section of Table 7. When the price is one standard deviation below the mean (6.5), the relative effect of being in a drought watch is -0.0128, or -1.3 percent. At one standard deviation above the mean (10.9), the relative effect of being in a drought watch is -0.0277, or -2.8 percent. In other words, increasing the marginal price of water by 50 percent more than doubles the response to a drought watch, although the impact is only 1.5 percentage points of water use.

The longer a drought lasts, the greater the estimated reduction in water use under a drought watch is. In the third month of a drought watch, the relative change in water use is estimated to be -0.0063, or -0.6 percent (Table 7, bottom section). By the seventh month, the relative change in water use is -0.0343, or -3.4 percent. In light of the limited lengths of the moderate droughts in the sample, however, care should be taken when extrapolating the effects of drought duration.

The estimates of the effects of water use restrictions are conditional on the weather variables. Water use is found to decrease with precipitation and to increase with temperature. Periods of droughts are drier and perhaps hotter than normal, so water use would be higher during droughts absent any policy actions. The estimated effects of voluntary and mandatory water use restrictions are relative to what water use would have been under drought conditions without such restrictions. Any reduction in water use relative to normal water use would be smaller than the estimated effects.

7. CONCLUSION

This study analyzes data on monthly household water use from four Pennsylvania water suppliers to assess the effectiveness of water use restrictions over the period 2015-2017. Voluntary water use restrictions during drought watches are found to have significant effects,

but smaller than desired by regulators. The reduction in water use during drought watches is found to be greater the higher the price of water. This is consistent with the notion that the higher the price of water, the smaller the welfare loss from some percentage reduction in water use, and the more likely is compliance with water use restrictions. Another finding is that the effectiveness of voluntary water restrictions during drought watches increases with the length of the drought. There is some evidence that residential water use declines during drought warnings, but this result is sensitive to the specification of the model, and the sparse number of time periods with drought warnings make any conclusions about them tenuous. The mandatory water use restrictions implemented by one small water supplier are found to reduce residential water demand by a slightly larger percentage than voluntary water use restrictions, consistent with the findings of previous studies.

Based on the results of the present study, water suppliers in Pennsylvania may wish to reconsider the publicity that accompanies drought watches and warnings in order to increase their effectiveness. For their part, state officials may wish to reconsider the importance of their goals for reductions in water use during drought watches and warnings and how to help water suppliers meet those goals. One problem is the revenue lost by water suppliers when water use restrictions are effective. Lost revenue weakens the incentives water suppliers have to reduce water use during droughts. Addressing this problem satisfactorily might increase the effectiveness of water use restrictions.

Given the limitations of the data available for the present study, further investigation of the effectiveness of water use restrictions during droughts in Pennsylvania and the impact of the price of water is warranted. Researchers, water suppliers, and state officials may wish to plan for a thorough randomized study of Pennsylvania households following the next period of widespread moderate and severe drought to inform and guide drought management policies and practices.

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APPENDIX: PENNSYLVANIA DROUGHT INDICATORS

Precipitation Deficits

Every month in each county, total cumulative precipitation over periods ranging from three to 12 months are compared with the normal (average) values. Totals that are less than the normal values represent deficits, which are converted to percentages of the normal values. Drought conditions are indicated by various precipitation deficit percentages in relation to the duration of the deficits.

Table 8: Precipitation Deficit Percentages

Duration (months)	Drought Watch	Drought Warning	Drought Emergency
3	25	35	45
4-6	20	30	40
7	18.5	28.5	38.5
8	17.5	27.5	37.5
9	16.5	26.5	36.5
10-12	15	25	35

Stream Flows

Every day, the average stream flow of the preceding 30 days is computed from the United States Geological Survey (USGS) stream-gage records. This stream flow statistic is compared with a flow percentile that indicates the percent of the time on that date throughout the historical record that the flow has been equal to or below that value. An average stream flow over the last 30 days falling into a percentile range of 10 to 25 indicates a drought watch; a percentile range of 5 to 10 indicates a drought warning; and a percentile range of 0 to 5 indicates a drought emergency.

Groundwater Levels

Every day, an average groundwater level in USGS observation wells over the preceding 30 days is computed. This groundwater statistic is compared with a groundwater percentile that indicates the percent of the time on that date throughout the historical record that the groundwater level has been equal to or below that value. As with stream flows, an average groundwater level over the last 30 days falling into a percentile range of 10 to 25 indicates a drought watch; a percentile range of 5 to 10 indicates a drought warning; and a percentile range of 0 to 5 indicates a drought emergency.

Soil Moisture

Soil moisture is measured by the Palmer Drought Severity Index, computed weekly by the National Weather Service for the 10 Palmer regions of the state. Palmer index values of -2.00 to -2.99 indicate a drought watch; values of -3.00 to 3.99 indicate a drought warning; and values of -4.00 and less indicate a drought emergency.

Source: Pennsylvania Department of Environmental Protection, 2016.