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WEATHER AND CLIMATE EXTREMES, CLIMATE CHANGE, AND PLANNING
Views of Community Water System Managers in Pennsylvania's Susquehanna River Basin[1]

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ABSTRACT: This research examines the sensitivity and vulnerability of community water systems (CWSs) to weather and climate in the Pennsylvania portion of the Susquehanna River Basin. Three key findings emerge from a survey of 506 CWS managers. First, CWSs are sensitive to extreme weather and climate, but that sensitivity is determined more by type of system than system size. CWSs that rely partly or wholly on surface water face more disruptions than do groundwater systems. Larger systems have more problems with flooding, and size is not a significant determinant of outages from storms or disruptions from droughts. Second, CWS managers are unsure about global warming. Few managers dismiss global warming; most think global warming could be a problem but are unwilling to consider it in their planning activities until greater scientific certainty exists. Third, the nature of the CWS, its sensitivity to weather and climate, and projected risks from weather and climate are insignificant determinants of how managers plan. Experienced, full-time managers are more likely to consider future weather and climate scenarios in their planning, while inexperienced and part-time managers are less likely to do so. Implications of these findings include support for efforts to move away from surface water, for clear communication of climate change information, and for the hiring and retention of full-time professional CWS managers.
(KEY TERMS: community water systems; decision-making and uncertainty; sensitivity, vulnerability, and adaptability; climate variation and change; water management; water resources planning.)

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) (Watson *et al.*, 1996:23-25) uses three terms – *sensitivity, adaptability,* and *vulnerability* – to discuss the potential effects of climate variation and change on human and ecological systems. Sensitivity indicates the degree to which a system responds to weather and climate. Adaptability describes how much practices, processes, or structures of systems may be adjusted to respond to past weather and climate or to anticipate future weather and climate. Vulnerability denotes the extent to which weather and climate may harm a system in the future; it is a function of both current sensitivity and adaptability.

This research examines the current sensitivity of community water systems (CWSs – domestic water supply systems that serve at least 25 residents year round) to weather and climate in the Pennsylvania portion of the Susquehanna River Basin. The paper then relates these sensitivities to how CWS managers plan (i.e., adapt). The goal is to gain an understanding of the vulnerability of CWSs to future climate variation and change.

To reach this goal, we first conducted case studies of CWSs in Centre County, Pennsylvania, and of the Pennsylvania Infrastructure Investment Authority. From what we learned in these case studies, we hypothesized that smaller systems (i.e., those that serve fewer people) and systems relying on surface water will have greater sensitivity to contemporary weather and climate variation than larger systems (i.e., those that serve more people) and systems relying on groundwater. To test this hypothesis, we surveyed CWS managers in the Susquehanna River

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Basin of Pennsylvania, asking them about the current impact of weather and climate on their systems. Then we explored how these water managers perceive climate change and how they think about planning for climate variation and change. Our findings have important implications for CWS management in a varying and changing climate.

CASE STUDIES

Climate variation and change could affect the quantity and quality of water available to CWS customers. Consequently, we undertook two case studies to examine the sensitivity of CWSs to climate variation and change. In the first case study we looked at the effects that changes in regulation – specifically regulations stemming from the Safe Drinking Water Act (SDWA) amendments of 1986 and 1996 – have had on the vulnerability of Pennsylvania CWSs to extreme events such as droughts and floods. We investigated the ability of Pennsylvania CWSs of different sizes to meet current regulations and, through a second case study, the likelihood that they will receive funding to help them comply with those regulations.

Our case study of CWSs in Centre County (Pascale, 1997) suggested that the SDWA has had a significant impact on the operation of those water systems and their vulnerability to weather and climate. The Surface Water Treatment Rule (SWTR), a regulation promulgated under the SDWA, requires filtration of all surface water sources. Further, the SWTR includes provisions for the Surface Water Influence Protocol, which obligates testing to determine whether groundwater sources are under the influence of surface water hydrology. The goal of SWTR is to ensure the filtration of all water drawn from surface sources or from surface-influenced groundwater before delivering it for human consumption. In response to SDWA regulations, by 1997, half of all CWSs in Centre County had switched to groundwater or pursued regionalization of water services, which ultimately reduced their vulnerability to weather and climate. Systems switching to groundwater reduced climate impacts due to the nature of their new source. Systems that chose to regionalize their water services built economies of scale, which helped them to improve their storage and treatment facilities.

Additionally, state policies have reduced drought impacts. Among these, the Pennsylvania drought management plan alerts CWSs of impending droughts. By 1995, the state also required each CWS to develop its own drought management plan.

This combination of indirect and direct measures has reduced the impact of extreme weather and climate variation on CWSs. For instance, during the 1980 drought, seven water systems in Centre County experienced severe water shortages and all had to ration water (Pennsylvania Department of Environmental Resources, 1981). When drought struck in 1995, however, only three systems experienced severe shortages and no system had to ration water.

Our case study of the Pennsylvania Infrastructure Investment Authority (PENNVEST), which funds infrastructural improvements, showed that smaller CWSs are less likely to apply for funding to improve water system facilities (Jocoy, 1998). Although three-quarters of the small systems that do apply receive funding, this proportion is still smaller than that of larger systems that apply for and receive funding (Table 1). Severe events such as flooding, which could change in frequency under climate change (Karl *et al.*, 1996), can destroy infrastructure and can cause changes in water quality. Thus, these funding practices seem to make small systems more sensitive to extreme weather and climate.

TABLE 1. CWS Funding by the Pennsylvania Infrastructure Investment Authority.

	Small (20-3,300)*	**Medium** (3,301-50,000)*	**Large** (over 50,000)*
Number (Total in Pennsylvania))	1986	298	36
Percent of Systems That Applied	12	41	42
Percent of Applicants Funded	75	85	83

*Estimated number of people served by the Community Water System (Jocoy, 2000).

In sum, the findings of these case studies suggest that small CWSs are more vulnerable than their large counterparts to the potential impacts of climate change and are less likely to apply for and receive funding to help mitigate those impacts. Drawing on these results, we hypothesized that smaller systems, systems using surface water, and systems with relatively fewer sources of water would be more sensitive to climate change and variability. In contrast, our survey results below suggest that while surface-base water systems do appear to be more sensitive to climate change and vulnerability, smaller CWSs actually appear to be less sensitive to climate.

THE CWS MANAGERS SURVEY

The Survey Instrument

In the summer of 1998, we conducted individual interviews and focus groups with water managers in central Pennsylvania to learn how they think about the role of climate variation and change in CWS management. We used this information to design and implement a survey of water managers in the Pennsylvania portion of the Susquehanna River Basin. Rather than select a sample, we mailed questionnaires to all water managers in the region. Figure 1 shows the survey area, the CWSs located there, and their sizes.

The methodology for the survey followed a modified Dillman (1978) approach. In Pennsylvania, managers of large systems most often affiliate with the American Water Resources Association, while managers of small systems usually affiliate with the Pennsylvania Rural Water Association. Consequently, in August of 1998, we sent letters from the American Water Resources Association to managers of systems with 10,000 or more users, and from the Pennsylvania Rural Water Association to managers of systems with under 10,000 users, urging them to cooperate. In September, we sent the questionnaire with a stamped, pre-addressed return envelope to 830 CWS managers. One week later, we sent postcards reminding respondents to complete the survey. In October, we mailed a second questionnaire to all respondents who had not had returned the first questionnaire. By the end of fall, we had received 506 completed questionnaires, a 61 percent response rate.

The survey instrument is a booklet with ten pages of questions divided into three sections. The first four pages ask about experiences with and expectations about extreme climate and weather events. The next four pages deal with operating characteristics, and the questionnaire concludes with two pages about finances and planning.

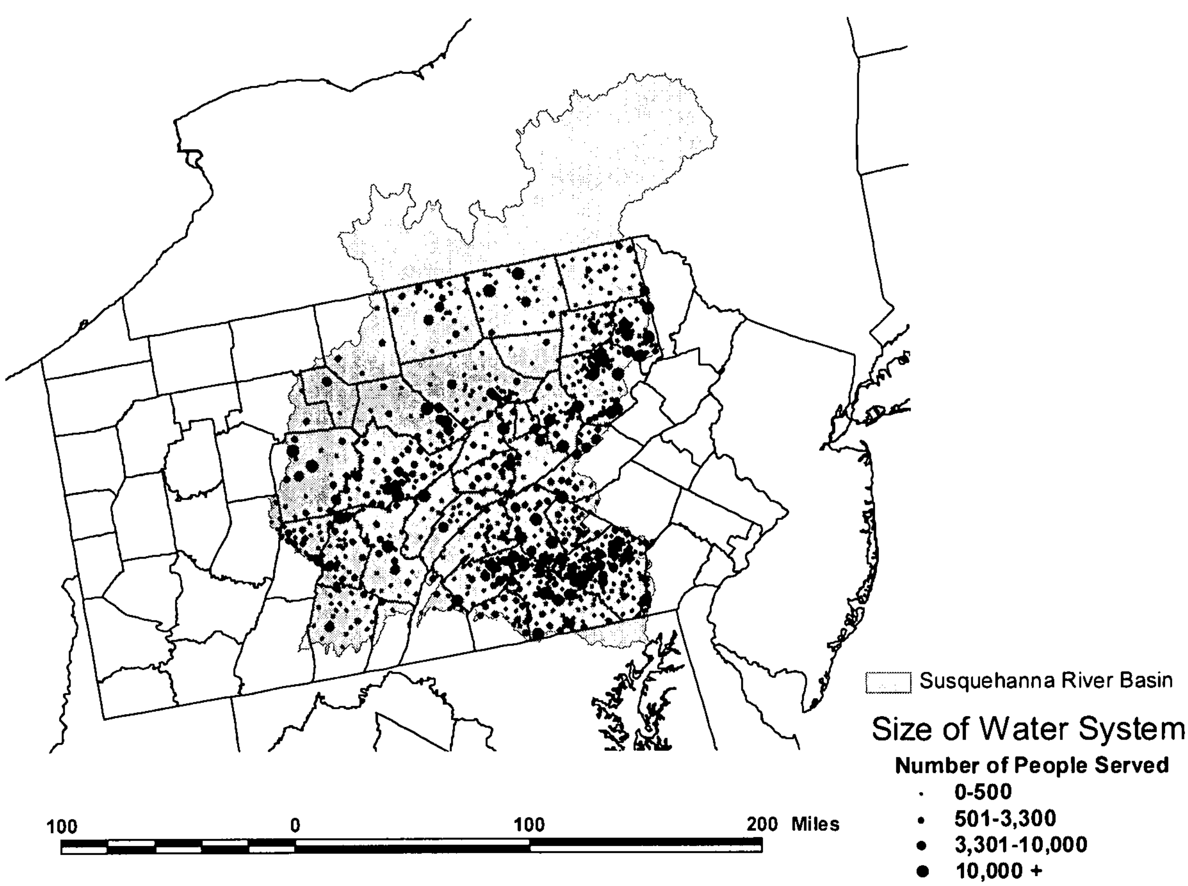


Figure 1. CWSs in Pennsylvania by Size, Highlighting the Systems in the Pennsylvania Portion of the Susquehanna River Basin.

Sensitivity of CWSs to Weather and Climate

The problems that CWS managers say they have from weather and climate events in a typical year are summarized in Table 2. The most common problems (69 percent) involve the inability to pump water because of power outages caused by electrical storms. Problems with pumping water because of wet snows and heavy winds are also common. The next most common type of problem occurs when drought or heat strains the supply of water. Finally, a quarter of the systems – mostly those relying on surface water – experience problems from flash floods. In summary, most CWS managers report problems from weather and climate events in a typical year. Therefore, it is not surprising that most managers say that they expect disruptions caused by weather and climate in daily operations in the next five years (Bord *et al.*, 1999).

Table 3 exhibits three regression equations designed to explore the correlates of sensitivity. These sensitivity measures emerged from a factor analysis of the weather and climate items of Table 2:

- A drought factor combines items a, b, c, and h of Table 2. Cronbach's alpha statistic for these items is 0.77. The measure ranges from 4 (1 on each measure) to 12 (3 on each measure).
- A flooding factor combines items d, e, and f of Table 2. Cronbach's alpha is 0.61. The measure ranges from 3 (1 on each measure) to 9 (3 on each measure).
- An outages factor combines items j, k, and l of Table 2. Cronbach's alpha is 0.79. The measure ranges from 3 (1 on each measure) to 9 (3 on each measure).

The independent variables of Table 3 are straightforward measures. *Population* is the number of people

TABLE 2. CWS Difficulties Resulting from Weather Events.*

		Never (percent)	1-2 Times Per Year (percent)	3 or More Times Per Year (percent)
a.	Drought conditions lowered the supply of water in the system	59	37	5
b.	Drought conditions forced us to seek out another source	88	10	2
c.	Drought conditions led to significant increased demand on our system	58	33	9
d.	(Ground Water Systems) Flash floods have overloaded our recharge area's ability to filter surface water naturally	94	6	1
e.	Flash floods have increased the turbidity in our surface water systems	75	14	12
f.	Storm water runoff has threatened our recharge areas	90	9	2
g.	Extremely high air temperatures have overloaded electrical circuits and knocked out pumping stations	90	9	1
h.	Extremely high air temperatures have increased demand and thus strained our supply of water	72	23	5
i.	Extremely low air temperatures have frozen water in the pipes that expanded and broke water lines	67	28	6
j.	Electrical storms have led to power outages that have affected our ability to pump water	32	58	11
k.	Heavy, wet snows have led to power outages that have affected our ability to pump water	55	42	2
l.	Heavy winds have led to power outages that have affected our ability to pump water	56	42	3

*The question is, "For each of the items below, indicate how many times **in a typical year** your **current system** has suffered some form of difficulty due to the types of events listed below." Ns range from 497 to 459 (for the fourth item).

TABLE 3. Sensitivity Measures Regressed on Size, Number, and Type of Source.

	Drought Factor	Flooding Factor	Outages Factor
Population Served	-.000012 (.00)	.000026* (.00)	.000012 (.00)
Number of Sources	.18* (.05)	-.03 (.03)	.03 (.04)
Surface Water	1.37* (.20)	1.42* (.10)	.11 (.17)
Constant	4.76	3.19	4.68
Adjusted R^2	.14	.40	.00
N	425	383	430

Note: Cell entries are unstandardized regression coefficients, with standard errors in parentheses.
*Significant at .001, all two-tailed tests.

served by the CWS, as reported by the Pennsylvania Department of Environmental Protection. *Number of sources* is the number of different ground water or surface water intakes in the CWS. *Surface water* is a dummy variable for systems that have at least one surface water intake. We would have liked to have included *mixed systems* as another dummy variable in the equations, but could not do so because of multicollinearity with *surface water*. As *surface water* seems a purer measure related to SDWA impact, we use it instead of *mixed systems*.

Contrary to our hypothesis, small systems are not more sensitive than large ones. In none of the three equations are smaller systems more sensitive. In the case of flooding, larger systems have more problems, even after controlling for variance accounted for by the *surface water* dummy variable. Perhaps these larger systems entail greater complexity that makes them more likely to suffer turbidity and recharge problems from flash floods and storm water runoff (Perrow, 1984). In other words, because smaller systems may be simpler, they may have fewer problems. Alternatively, perhaps smaller systems have more excess capacity per capita than larger systems have. Clearly, further research is needed to understand this finding.

The impact of surface water is strong, as expected. Surface water systems are much more sensitive to droughts and floods; flooding rarely causes problems for groundwater systems in the Susquehanna River Basin. Thus, the encouragement of the CWSs by the SDWA to adopt groundwater systems seems to have reduced the impacts from droughts and floods.

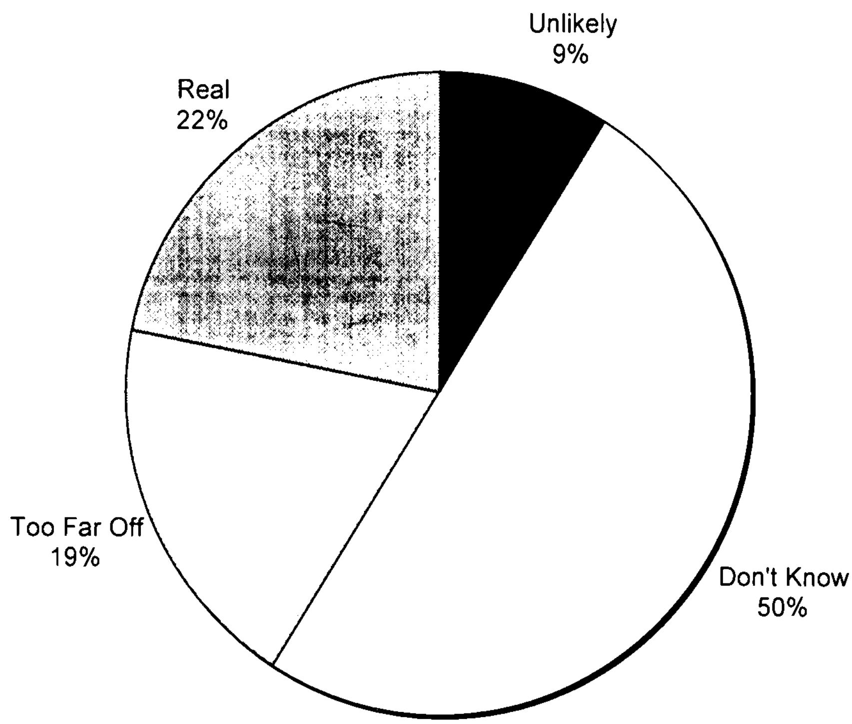
Our data show that CWSs with drought problems have more sources than do systems without drought problems. We suspect that CWSs with drought problems have sought out additional sources to increase their capacity; we doubt that having more sources increases drought impacts.

In summary, droughts are less likely to cause difficulties for systems that rely wholly on ground water. Flooding is primarily a problem in surface water systems, although larger systems also are more likely to have problems with flooding regardless of whether they are surface, ground, or mixed systems. Power outages are the most common problem, but are not related to the system size, the number of sources, or the type of source.

Climate Change and Planning

Forty-one percent of CWS managers report they are "not concerned at all" about global warming influencing their water systems. A more probing question reveals that 50 percent of the sample admits they do not know what to believe about global warming, and 19 percent think global warming may happen but is too far off in the future to warrant worry now. Of the remaining 31 percent, managers who think "global warming is real" (22 percent) outnumber managers who think that global warming is unlikely (9 percent). Overall, managers are mostly ambivalent about global warming, not certain whether it is a hoax or a serious concern to their water systems (Figure 2).

Uncertainty about global warming does not imply that CWS managers in the Susquehanna River Basin think that planning should be based entirely on past events. We asked *to estimate budgetary needs, some*



Unlikely – "Global warming is unlikely to happen and therefore I am not concerned about its potential effects."
Don't Know – "I have heard evidence for and against the case of global warming and I do not know which to believe."
Too Far Off – "Global warming may actually happen but its effects are too far off in the future for me to worry about them now."
Real – "Global warming is real and I am concerned about its potential effects."

Figure 2. Opinions on Global Warming Among CWS Managers (N = 501).

individuals prefer to look ahead and consider all possible difficulties of what could happen to their system, while others look to the past at what events have actually happened to their system. On the [sliding] *scale* [ranging from 1 to 5] *below, please estimate how your system estimates its future improvements needs.* The modal categorical response, with 47 percent of respondents, is 3, falling in the middle between "always plan based on past actual events" and "always plan ahead for possible events." Fifteen percent of the CWS managers fall on the "actual" side of the continuum (scores of 1 or 2) and 38 percent are on the "possible" side (scores of 4 or 5). Most CWS managers take into account possible events as well as actual events.

Table 4 reports regression equations that may account for why some system managers estimate future improvement needs based more on actual events while others pay more attention to possible events. The first equation incorporates the CWS characteristics of size, number of sources, and type of source – all of which have no relationship to the planning emphasis or to possible or actual events. The data do not bear out notions that managers of larger CWSs are more professional and therefore would be more willing to model future events.

The second equation, however, shows that the experience of the manager does matter. CWS managers who have worked more years for their current employer and who work more hours per week are more likely to use possible events in their improvement estimates. New or part-time managers are more likely to depend on actual events in their planning. This is consistent with water managers' judgments reported for Colorado communities by Howe and Smith (1993).

The third equation shows that present sensitivity to weather and climate events (e.g., floods, droughts, and power outages) has no impact on the manager's approach to planning.

The fourth equation has two factors drawn from a question that asked CWS managers to look forward: *In your judgment, how likely is it that in the next five years your water system will suffer disruptions in its daily operations from the following events?* One factor (Cronbach's alpha = 0.83) combines drought, flash flood, long periods of increased precipitation, increased surface runoff contaminating ground and surface water, extremely high air temperatures, and extremely low air temperatures. The second factor (Cronbach's alpha = 0.84) combines electrical storms

TABLE 4. Planning Based on Possible Events Regressed on CWS Characteristics, Management, Sensitivity, and Risk Projections.

	1	2	3	4	5
Population Served	.000003 (.000)				.0000002 (.000)
Number of Sources	.049 (.028)				.023 (.029)
Surface Water	.060 (.121)				-.16 (.15)
Manager (years in position)		.014** (.005)			.013* (.005)
Manager (hours worked per week)		.013*** (.003)			.013*** (.003)
Drought Factor			-.016 (.031)		-.03 (.03)
Flooding Factor			.096 (.051)		.100 (.058)
Outages Factor			.056 (.035)		.04 (.04)
Risk Factor from Droughts, Floods, Temperature Extremes				.004 (.01)	-.006 (.01)
Risk Factor from Electrical Storms and High Winds				.03 (.03)	-.00006 (.03)
Constant	3.18	2.923	2.81	3.13	2.61
Adjusted R^2	.01	.06	.01	.00	.05

Note: Cell entries are unstandardized regression coefficients, with standard errors in parentheses. N = 481 in each equation because we substituted means for missing data, except for the dependent variable.
*Significant at .05
**Significant at .01
***Significant at .001, all two-tailed tests.

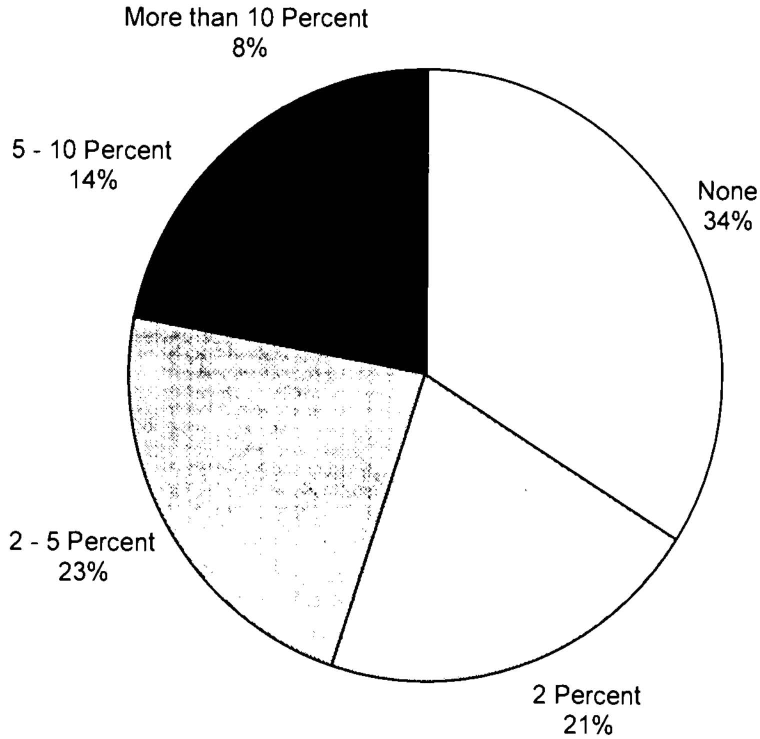
with high winds. We hypothesized that CWS managers who think their systems are vulnerable would be more likely to use possible events in their estimates of future improvement needs. As Table 4 shows, these vulnerability measures have no impact on how managers base their future needs.

The fifth equation of Table 4 demonstrates that the predictive capabilities of the managers' attributes hold up when we add all the other variables to the equation. The nature of the CWS, the sensitivity of the CWS to weather and climate events, and the projected risks to the CWS from weather and climate are immaterial in accounting for the basis of needs estimates. In fact, adding these variables reduces the adjusted R^2. In short, experienced, full-time managers are more likely to plan using possible events as well as actual experience.

The final question in the instrument asks: *Ideally, if you could protect your system from all weather and climate vulnerabilities, what percentage increase in your quarterly service rates would your customers likely tolerate to do so?* Two-thirds of the CWS managers perceive that their customers are willing to pay higher rates for a reliable CWS (Figure 3).

CONCLUSIONS

Many CWSs in the Susquehanna River Basin of Pennsylvania are sensitive to extreme weather and climate. Initial case studies suggested that smaller systems may be more sensitive and vulnerable to



"Ideally, if you could protect your system from all weather and climate vulnerabilities, what percentage increase in your quarterly service rates would your customer likely tolerate to do so?."

Figure 3. Perceptions of CWS Managers of Customer Willingness to Tolerate Higher Rates to Protect CWS from Weather and Climate Vulnerabilities.

weather and climate than larger systems. A subsequent survey of the region's CWS managers indicated, however, that larger systems have more problems with flooding and that size is not a significant determinant of outages from storms or disruptions from droughts. Instead, the source of the system's water is important for disruptions from both droughts and flooding. CWSs that rely on groundwater have lower sensitivity, while systems that rely partly or wholly on surface water face more disruptions from weather and climate.

Although weather and climate extremes influence operations, CWS managers are unsure about global warming. Importantly, few managers dismiss global warming as an irrelevant concern; most think global warming could be a problem, but are unwilling to consider it in their planning activities until greater scientific certainty emerges. This finding agrees with the conclusions of Lins and Stakhiv (1998:1260).

Still, planning is an important element of CWS management. Surprisingly, the way that managers plan for future weather and climate does not appear to be determined or influenced by the nature of the CWS, by its sensitivity to weather and climate, or by the projected risks from weather and climate. Instead, weather-related and climate-related planning is a function of the experience and time devoted to the job by the manager. Long-time, full-time managers are more likely to consider future weather and climate scenarios that go beyond their experience than are less experienced or part-time CWS managers.

Each of the three foci of this study – sensitivity to weather and climate, perceptions of global warming, and use of weather and climate in planning – has an important policy implication. First, CWSs are less sensitive to weather and climate extremes when they rely on ground water. Thus, the move away from surface water and towards ground water, catalyzed by the SDWA, made some systems less sensitive to weather and climate extremes. Decision makers at all levels should encourage compliance with SDWA to continue the reduction of weather and climate sensitivity.

Second, CWS managers want more certainty regarding global warming, so continued research with an emphasis on detecting climate change and on demonstrating climate impacts is essential, especially at the local level. As signs of global warming mount, clear communication of this evidence to CWS managers is necessary. It is essential to note that not everyone agrees that threats from climate change call for special planning. For instance, Stakhiv (1996), Frederick *et al.* (1997), and Lins and Stakhiv (1998) argue, in the context of large federal water projects, that current planning strategies provide sufficient flexibility to accommodate climate change impacts. It is important to note that their work does not address the thousands of smaller systems that may not be able to cope with a changing climate because they have much less absolute capacity and operating flexibility.

Finally, experience and time on the job produce skilled professional managers who are more likely to plan for weather and climate extremes. Within their fiscal constraints, local governments and citizens boards should consider creating full-time positions to reduce risks to their community water systems from the uncertainties of weather, climate variation, and climate change.

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