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The potential use of climate forecasts by community water system managers

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Abstract

This study investigates the possible use of climate forecasts by Pennsylvania Community Water System (CWS) managers for planning and decision making. The first phase involves analysis of data from a mail survey to identify managers most likely to use climate forecasts. The second phase uses semi-structured interviews with the managers of large surface-water systems to determine the extent to which they currently use forecasts, the circumstances in which they would be most likely to integrate forecasts into their planning, and the formats that would encourage them to use forecasts. Analysis of the survey data demonstrates that managers of the largest systems are more likely to use forecasts than managers of smaller systems. The interviews reveal that these CWS managers do not currently use climate forecasts for planning, even under extreme drought, but that there are circumstances in which they would consider doing so. In a broader context, the findings suggest that when scientists work with decision-makers, they should be prepared, first, to learn about the decision-making context, then to put the information of concern into that context and, finally, to work closely with the decision-makers to help them gain experience using that information.

Introduction

In summer 2002, community water system (CWS) managers in Pennsylvania's Susquehanna River basin (SRB) experienced a fourth consecutive summer of drought; many of those managers found themselves in a drought emergency. Some of the CWS managers needed to purchase water from other systems to supplement their dwindling supplies. Others had to postpone necessary maintenance, repairs, or improvements because water levels were too low. Although the situation was not desperate, many managers felt constrained by the drought.

Such conditions would seem to call for management innovations for dealing with continued or future episodes of water scarcity. One form of innovation that might be of value to water managers is climate forecasts. Government agencies, such as the National Oceanic and Atmospheric Administration (NOAA), and research groups, such as the International Research Institute for Climate Prediction, issue forecasts of temperature and precipitation from one to 12 months in advance. These forecasts do not yet provide highly accurate predictions at fine spatial and temporal scales, but do provide probabilistic forecasts of modest accuracy over broad regions (Barnston, 1994). Given the

great impacts of seasonal-to-interannual climate variability and the considerable efforts to disseminate climate forecasts, there is growing experience with the communication and use of these forecasts (Glantz, 2001).

The adoption and use of seasonal-to-interannual climate forecasts by decision-makers, however, is complicated. Numerous factors influence the communication, interpretation, and use of climate forecasts (Stern and Easterling, 1999), including users' understanding of forecast accuracy (Barnston *et al.*, 1999) and their ability to interpret probabilistic information (Phillips *et al.*, 2001). Socioeconomic factors constrain decision options (e.g. Barrett, 1998; Broad and Agrawala, 2000; Archer, 2003). Numerous authors have offered suggestions for ways to increase the salience and value of climate forecasts for a wide range of decision-makers and other end-users (e.g. Hartmann *et al.*, 2002; Archer, 2003). For example, Katz and Murphy (1997) proposed forecast quality thresholds for several different socio-economic settings. Pulwarty and Melis (2001) suggested decision calendars that identify crucial decision periods for specific sectors. Patt and Gwata (2002) identified six barriers to climate forecast adoption — credibility, legitimacy, scale, cognitive capacity, procedural and institutional barriers, and available choices — and proposed ways to overcome those barriers. From these works and others, it appears that forecasts need to be targeted to specific decision problems. Certain decision-makers can use relatively low-resolution climate forecasts (e.g. insurance companies), while others need much finer-scale information (e.g. subsistence farmers). Some researchers have argued that sector-specific, custom forecasts can overcome perceptions of low utility and low accuracy that limit the adoption of forecasts (Hammer *et al.*, 2001; Nelson *et al.*, 2002). Perhaps more important is the growing concentration on the end-users and not on the forecasts themselves (Archer, 2003).

Although water management was identified early as a sector that may benefit from climate forecasts (e.g. Glantz, 1982; Changnon and Vonnahme, 1986; Stern and Easterling, 1999), only a modest number of studies have linked water managers and climate forecasts (Callahan *et al.*, 1999; Pagano *et al.*, 2001; Pulwarty and Melis, 2001; Pagano *et al.*, 2002; Changnon and Vonnahme, 2003; Carbone and Dow, 2005; Rayner *et al.*, 2005). In contrast, numerous studies worldwide have coupled agricultural decision making with climate forecasts (e.g. Broad and Agrawala, 2000, in Ethiopia; Phillips *et al.*, 2001, and Patt and Gwata, 2002, in Zimbabwe; Nelson *et al.*, 2002, in Australia; and Archer, 2003, in South Africa). Most of the previous water resource-climate forecast studies focused on the arid western United States or drier parts of the Midwest; only Carbone and Dow (2005) and Rayner *et al.* (2005) have looked at the potential role of climate forecasts in the water management of the humid eastern United States. Outside the United States, work on agriculture and climate forecasts is common, but research linking water resources and climate forecasts are rare (e.g. Lemos *et al.*, 2002). Of all the water resource-climate forecast studies, only Changnon and Vonnahme (2003) and Rayner *et al.* (2005) asked CWS managers about their perceptions of climate forecasts.

In summary, although the literature suggests that climate forecasts might provide water managers — such as the CWS managers of the Pennsylvania SRB — with a tool that helps them plan and manage their systems better, there is

little evidence to support that claim and to show that they are adopting this tool. Moreover, there is limited understanding of the potential role for climate forecasts to play in water resources management more generally. Consequently, this research attempts to help fill gaps in that understanding by probing the CWS managers of the Pennsylvania SRB about their use of climate forecasts.

The purpose of this study is to explore three research questions:

- To what extent do the CWS managers use climate forecasts as a management tool?
- Are there circumstances in which they are more likely to incorporate climate forecasts into their planning and decision making?
- Are there ways that climate forecasts could be presented that would encourage CWS managers to use them?

This research is limited to a small subset of CWS managers located in the Pennsylvania SRB, so the results are not necessarily generalisable to other areas where physical environments, regulations and management cultures differ. Similarly, it is possible that the small subset of CWS managers is not representative of most CWS managers in the Pennsylvania SRB. Nevertheless, a careful exploration of these managers' perceptions of climate forecasts should provide insights into their forecast use, forecast needs and preferred modes of forecast presentation that apply beyond the Pennsylvania SRB to resource managers everywhere.

Methods

To identify the CWS managers in the Pennsylvania SRB most likely to use climate forecasts, the investigators analysed select portions of data from a mail survey. This analysis served as a basis for the interviews to follow.

The source of the data analysed here is a mail survey administered to CWS managers in summer 2000. In preparation for the survey, the investigators conducted focus groups and interviews with key contacts in the SRB during spring and early summer. The focus groups included CWS managers from small rural, large urban, surface- and groundwater systems. Following the focus groups, the investigators developed the survey and pre-tested it with CWS managers and members of professional organisations. The investigators used a modified Dillman (1978) method of survey design. The research team mailed 764 surveys and received 400 returns — a response rate of approximately 52 percent. Two returned surveys served populations smaller than 25 so these were excluded from the analysis because the definition of a CWS is a system that serves more than 25 people.

The survey instrument was a booklet with 11 pages of questions divided into five sections. This article uses responses to questions about actual and potential use of weather and climate forecasts. The remainder of the survey responses contributes to papers on water managers' risk perceptions and views on vulnerability, which are currently 'in press' and 'submitted', respectively.

Before analysing the survey data, it was necessary to define precisely what a 'large' CWS is. The Environmental Protection Agency (EPA) distinguishes CWS size based on

Table 1. Characteristics of the Pennsylvania SRB Community Water System (CWS) dataset using the three-category system developed for this research

<i>CWS Size</i>	<i>Population Served, per CWS</i>	<i>Completed Questionnaires</i>	<i>Total Population Served</i>	<i>Percent of Total Population</i>
Small	25–3 300	317	221 868	13
Medium	3 301–10 000	42	222 778	13
Large	More than 10 000	39	1 234 510	74

population served and has three-tier and five-tier categorisations (U.S. Environmental Protection Agency, 1997a and 1997b). Although the EPA categories reflect typical CWS sizes for the United States, for this study, the investigators manipulated the five-tier categorisation to create a three-tier categorisation that is more useful for a study of the Pennsylvania SRB (Table 1). Using these classes, they cross-tabulated the survey data to search for trends in the system characteristics related to system size. The investigators then used these results to guide the interview phase of the research.

The investigators created and administered a semi-structured interview in fall 2002 that explored four topics: the manager's use of forecasts; the manager's management of the CWS; the potential usefulness of current climate forecasts; and how climate forecasts might be customised for CWS managers in the Pennsylvania SRB. The semi-structured nature of the interviews made it possible to compare the open-ended responses across the managers.

Results

Survey results

The CWS managers contacted in the survey worked for systems that potentially served a total population of 2 092 125 customers in the Pennsylvania SRB (Table 1), or about half of all residents in the SRB (including all New York and Maryland residents of the basin and all Pennsylvania residents of the SRB not receiving water from CWS). Most of the survey respondents were from small systems, but these CWS only represented 13 percent of the total population served by respondents of the survey. The respondents for large systems represented 74 percent of the total population served by respondents.

Table 2 relates the primary water source type to system size. The responses showed that most of the small systems have groundwater sources. Medium-sized systems are almost evenly split between groundwater and surface water sources. Most of the large systems rely on surface water.

The survey posed a series of questions aimed at determining if the use of weather and climate forecasts for planning and infrastructure decisions varies by system size. At this point in the survey, the investigators were interested in knowing whether the managers used either weather or climate forecasts; the distinction between weather and climate forecasts becomes important in subsequent parts of the research. The results (Table 3) show a clear difference among small, medium and large system managers' reliance on weather and climate forecasts. Most managers of large systems (56 percent) indicated that they used weather and

Table 2. "What Is Your Primary Source Type of Water?" Response Rate: 86.9% (352/405)

<i>Source Type</i>	<i>Community Water System size</i>		
	<i>Small</i>	<i>Medium</i>	<i>Large</i>
Groundwater	82.6% (238/288)	45.9% (17/37)	22.2% (6/27)
Surface water	17.4% (50/288)	54.1% (20/37)	77.8% (21/27)

climate forecasts to schedule additional testing for water quality. Nearly 20 percent fewer (37 percent) of the managers of medium-sized systems denoted that they used weather and climate for additional water quality testing. A clear minority (25 percent) of small-system managers said that they used weather and climate forecasts in scheduling additional water quality testing. When asked whether they use weather and climate to adjust existing reservoir levels or plan back-up storage, most managers of large CWS (68 percent) specified that they used forecasts for this type of planning. Only 39 percent of the managers of medium-sized systems indicated that they used forecasts for this purpose. Not surprisingly, only 19 percent of small system managers claimed that they used forecast information for adjusting reservoir levels or back-up storage. When responding to the question asking whether they used weather or climate information to schedule personnel, maintenance or construction, most managers of large CWS (82 percent) and of medium-sized CWS (76 percent) indicated yes. Managers of small CWS were split, with 50 percent revealing that they used forecasts for scheduling. In only the three questions mentioned above did most CWS managers indicate they used forecasts for planning and scheduling. In the remaining five questions, considerably less than half the managers claimed to use forecasts.

The survey also asked a series of questions to see if the managers would find climate forecasts about specific phenomena — e.g. droughts, floods, lightning strikes and damaging winds — useful if the forecast information were perfect. Table 4 demonstrates that regardless of system size, most CWS managers would find accurate climate forecasts of drought 'definitely helpful'. This result might have been related to the fact that the managers were in the second year of a four-year drought at the time of the survey, so drought was important to them at that moment. Apart from that one situation, however, most managers of small CWS did not perceive perfect climate forecasts as especially useful. In contrast, most managers of medium and large

Table 3. Percentage of CWS who use weather and climate forecasts by size

Question	Community Water System size		
	Small	Medium	Large
Plan future water storage needs for finished water	13	17	18
Plan expanded distribution system	7	14	8
Plan when to bring new water supplies on line	14	24	33***
Adjust existing reservoir levels or back-up storage	19	37	64***
Anticipate inventory supply needs or guide purchasing decisions	14	26	36***
Schedule personnel, maintenance, or construction	48	79	80***
Schedule additional testing for water quality	26	31	54***
Help make budget projections	10	7	19
Justify increased infrastructure investments	10	17	18
Start a public information campaign to conserve water	66	64	74

Wording: "Does your water system ever use weather and climate forecasts to:"

N's vary from 297 to 310 for small systems and 41 to 42 for medium systems. The N for large systems is 39.

*** significant at .001, two-tailed test

Table 4. Percentage of CWS Managers who would find perfect forecast information "definitely helpful"

Phenomenon in question	Community Water System size		
	Small	Medium	Large
Drought Emergency	60	62	74*
Several months of above-average temperature	32	46	44*
Flood emergency	35	71	56***
Several months of above-average precipitation	31	55	36***
Intense Rain storms	31	57	51***
Lightning strikes	35	69	49***
Damaging winds	34	55	41***
Hurricanes	39	66	62***
Ice storms	40	71	50***
Several months of below-freezing temperature	40	62	51**

Wording: "Imagine that perfect forecast information is available. Please indicate whether climate forecasts for the next 12 months would not be helpful, might be helpful, or definitely would be helpful in adjusting your system to cope with these weather and climate events."

N's vary from 303 to 311 for small systems, 41 to 42 for medium systems, and 38 to 39 for large systems.

* significant at .05, two-tailed test

** significant at .01, two-tailed test

*** significant at .001, two-tailed test

systems thought accurate climate forecasts of specific phenomena would be helpful. Interestingly, in all but two cases, higher percentages of managers of medium-sized systems than managers of large systems thought that perfect forecasts would be 'definitely helpful'.

To summarise, it is clear that most managers of small CWS did not use weather and climate forecasts at the time of the survey and were unlikely to use climate forecasts in the future. A minority of managers of medium-sized CWS used weather and climate forecasts, but a majority thought climate forecasts would be helpful in ideal circumstances. In four specific questions, managers of large systems indicated that they use weather and climate forecasts today for planning; in all but one question, this group claimed to use forecasts at a rate that was greater than the managers of

small and medium-sized systems. In six of ten categories, at least half of the managers of large CWS claim that they would use accurate climate forecasts.

It appears, therefore, that large system managers would be more likely to use climate forecasts than managers of smaller systems, and possibly more likely to do so than the managers of medium-sized systems. This is an important conclusion because large systems provide household water to 76 percent of the CWS customers in the Pennsylvania SRB (Table 1). Based on this result, the investigators decided to conduct interviews with managers of large CWS.

From a practical standpoint, the relatively small number of Pennsylvania SRB CWS serving more than 25 000 customers — 15 surface water and two groundwater systems

— presented a manageable list of potential interview participants. Because O'Connor *et al.* (1999) found that surface water systems are much more sensitive to adverse weather and climate than are groundwater systems, the investigators decided to interview only the managers of surface water CWS serving more than 25 000 customers.

Interview Results

Between July and September 2002, the investigators interviewed ten of the potential 15 managers. The investigators attempted to contact all 15 managers, but only ten responded to their messages. All ten were willing to be interviewed.

The intense drought conditions during the interview period may have affected their responses. Nine of the ten CWS interviewed by the investigators were in drought watch, warning or emergency conditions. Two participants referred to the drought as '*historic*' and '*hundred-year*'. Each of the managers who made these statements had worked in local water management for at least 20 years, so they had experienced drought conditions in 1988, 1991, 1995 and other years. All of the interviewees had drought on their minds and were anxious to discuss the impacts of drought on their systems, so they probably downplayed the usefulness of forecasts during excessively wet conditions. The themes of time scale, system flushing, tank maintenance, reservoir maintenance and accuracy ran through all of the interviews. The managers also had similar opinions about the ways in which they would like to see forecasts presented to them.

The managers all stated that most of their decision-making relates to processes operating on daily and weekly time scales, thereby suggesting that the monthly to seasonal time scales of climate forecasts have little relevance to CWS decision horizons. Nevertheless, the interviews revealed that there are some crucial maintenance and infrastructure decisions, including flushing, tank maintenance and reservoir maintenance, that are planned several months to a year in advance.

All ten managers oversee the scheduling of system flushing. System flushing typically takes place in spring and fall, entailing the release of water through fire hydrants. Flushing cleanses the system to maintain the clarity and quality of the water to which customers are accustomed. Nine CWS managers stated that they were unsure whether they would perform system flushing during fall 2002 because of the ongoing drought. Five managers noted that they also had skipped the spring flushing, so the outlook for the fall flushing became even more important than usual.

Seven of the ten participants stated that tank maintenance was another operation that they planned several weeks to months in advance. Tank maintenance revolves around the storage of finished water; for tank maintenance to occur, finished water must be lowered, thus reducing the storage of finished water at a facility. The seven managers disclosed that they were not performing both routine and pressing tank maintenance because, with the ongoing drought, the amount of finished water in storage was crucial. Several participants noted that the tank maintenance normally performed before the winter season would have to wait until spring or summer 2003.

Similar to tank maintenance, reservoir maintenance

involves the lowering of water levels to perform upgrades to the reservoir dam. Although reservoir maintenance does not directly relate to amounts of finished water, the lowering of raw water does ultimately influence the overall amount of finished water. One manager had particular problems with dam maintenance and discussed the balancing act between performing critical maintenance and the availability of water to replenish the reservoir. Again, several managers indicated that they were not performing reservoir maintenance due to the intensity of the drought and were putting off this maintenance until spring or summer 2003. After experiencing a fourth summer of drought with falling stream and reservoir levels, a few of the managers divulged that they were purchasing water from other systems and, consequently, searching for a more-reliable groundwater source and seeking approval for well development. They were also considering the expansion of their finished-water storage facilities. The managers thought that forecasts of continued drought might encourage them to place a higher priority on exploring these options.

The CWS managers were concerned with the accuracy of climate forecasts. One of the mail survey questions asked the managers to depict their faith in climate forecasts. Regardless of system size, most CWS managers do not find climate forecasts sufficiently reliable for management purposes. They rely upon weather forecasts to make short-term decisions and are comfortable with their accuracy, but all ten participants questioned the accuracy of forecasts that predict from a month to a year in advance. None of the managers felt that he could trust forecasts of climate more than three months in advance, so they did not think climate forecasts could inform longer-term budget decisions. The managers did not think that the probabilistic information presented in these long-range conditional forecasts would be useful to them.

Despite this skepticism, because of their interaction with the investigators and because of the deferred maintenance and other drought impacts, most of the CWS managers became particularly interested in the climate outlook for the late summer-early fall of 2002 and the implications that forecast had for their systems. For instance, one manager indicated that a forecast for a wet fall and beyond would mean that he could take a risk and do some critical dam maintenance, assuming that the reservoir would be able to fill up quickly afterward.

One of the research questions asked if there are ways to present the climate forecasts that would encourage the CWS managers to use them. The investigators asked all of the participants how the forecasts could be delivered to CWS managers. All of the CWS managers had access to a personal computer; all participants indicated that the Internet was the best option. Several thought that a personal email alert stating that new forecasts were available with an embedded link would be a good way to update managers. *None* of the managers was currently accessing the forecasts available online from NOAA or the International Research Institute for Climate Prediction (IRI).

The CWS managers were asked to comment on the NOAA monthly and seasonal forecast products to find out how they might be modified to suit the needs of CWS managers. In all cases, the managers' first or second preference was to receive the forecasts in map form. In particular, all managers agreed that limited-area maps — for instance, the SRB, Pennsylvania, or the northeastern

United States — would be much more suitable for their purposes than the present maps that cover the United States or North America.

The colour schemes and map key used by NOAA confused several participants. In at least half of the interviews, the investigators had to explain what the key meant and how to use it to interpret the map, thereby suggesting that the map is not easy for non-experts to interpret. From the interactions with the climate forecasts maps and the investigators, it became clear that the CWS managers needed a facilitator to help interpret the maps and to show them how to use the maps effectively.

In the end, the interviews revealed that CWS managers could use climate forecasts for planning long-term maintenance projects. Nevertheless, CWS managers did not recognise at first that these forecasts could be helpful to them. Through interaction with the investigators and the forecast products, the managers appeared to develop an increased willingness to use climate forecasts in the future. Still, the forecast maps were perceived as confusing, as displaying too large a geographical area for the needs of CWS managers, and as inaccurate. It was difficult for the managers to interpret the forecasts for their local system. The managers wanted information with more absolute, spatial, and temporal accuracy than NOAA and IRI supply at this time.

Conclusions and discussion

The aim of this research was to determine if CWS managers in the Pennsylvania SRB use climate forecasts as a management tool, if there are circumstances in which they might be more likely to use climate forecasts in their planning and decision-making, and if there are ways to improve the presentation of climate forecasts that would encourage the managers to use them. Producers of climate forecasts stress their product's potential usefulness, particularly for natural resource management. While most studies have examined the attitudes of water managers in the western United States toward climate forecasts, this study offers a perspective on water managers in the eastern United States, specifically the Pennsylvania SRB.

In answering the first research question, the investigators found that managers of large CWS use weather and climate forecasts for some operations and that most would find perfect climate forecasts helpful. It was inferred, therefore, that this group of managers would be more likely to use climate forecasts than would the managers of smaller systems. Because large CWS supply water to a large proportion of the population of the Pennsylvania SRB, their managers are a significant group to query about the utility of climate forecasts as a potential planning and decision-making tool.

For research question two, the investigators determined that the managers of large CWS do not use climate forecasts for planning, even under extreme drought. Although these managers do use forecasts for certain operations, both the forecasts and operations proved to be short term (i.e. daily to weekly time scales), so their perception is that climate forecasts are not relevant to their decision horizons. The research suggests, however, that through education, these managers are open to the idea of incorporating forecasts into their planning. For example, through interaction with

the investigators, the CWS managers learned that the climate forecast was for continued drought through fall 2002. This information made some rethink their fall tank flushing, possibly delaying it until the following spring or summer. They also thought this forecast could influence vital tank and reservoir maintenance. In addition, forecasts of continued drought could reinforce managers' decisions to explore the possibility of expanding finished water storage facilities and the potential for establishing groundwater sources as a back-up supply during dry periods. By the end of the interviews, it was clear that the CWS managers thought that they could use reliable climate forecasts to help their decision-making. Nevertheless, because of their limited experience accessing, interpreting and applying climate forecasts, they perceived the forecasts as unreliable and confusing and were still unlikely to use them.

In answering research question three, the investigators found that despite the CWS managers' hesitation to use forecasts, they were willing to express their preferences for ways to receive this information. Instead of the large-area maps produced by forecasters, the managers would prefer more detailed maps focused on their immediate region. They found the maps difficult to use and to interpret. The managers were unanimous in their judgment that the Internet is the most appropriate and accessible delivery system.

This research, therefore, made tentative steps toward identifying the ways in which CWS managers of the Pennsylvania SRB could use climate forecasts and the formats in which they could use them. The research also made modest steps toward raising the awareness of CWS managers to the potential utility of climate forecasts in their planning and decision making.

Despite this limited progress, it is clear that advances in the communication of climate forecasts are necessary for these and other resource managers to embrace that information. If the creators of climate forecasts want to see their products used, then trained 'integrators' (Jacobs, 2001; Cash *et al.*, 2003) must work with the potential users to communicate, translate and mediate the development of the information. Support for these 'integrators' could come from government funds or the commercial sector. In either case, only through prolonged interaction will the 'integrators' become sufficiently knowledgeable of the users' needs and the users become suitably aware of how climate forecasts can help them make better-informed plans and decisions.

Although the study had a narrow focus, it is likely that the findings apply beyond climate forecast use by CWS managers in Pennsylvania and, indeed, beyond climate forecasts, water resources management and the United States. It is possible to generalise the three findings to environmental information, resources management and the world:

- Most decision-makers working with resources management find accurate environmental information useful.
- Experience with using specific environmental information is an essential factor in the decision to use that environmental information.
- To be useful, environmental information must relate to the management needs and contexts of decision-makers.

The first of these findings is obvious, but the second two

findings may be helpful to scientists working on issues of integrated land and water resources management (ILWRM). When ILWRM scientists work with decision-makers, they should be prepared to:

- (1) learn from the decision makers about their decision-making context before trying to communicate information on ILWRM;
- (2) put all ILWRM information into the decision-makers' context willingly; and
- (3) work closely with the decision makers to help them gain experience using ILWRM information.

Even when professional 'integrators' mediate between scientists and decision-makers, such steps are essential if scientists want decision-makers to use the information they have to offer.

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