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Gauging the Vulnerability of Local Water Utilities to Extreme Weather Events

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Abstract

Water utilities that rely on surface water may be vulnerable to future droughts and floods, a vulnerability that may be magnified by climate perturbations as well as shorter-term and, in some cases, ongoing changes in the political and regulatory environment in which utilities operate.. Unfortunately, day-to-day responsibilities currently occupy most utility operators, leaving little time to plan for inherently uncertain effects. The record of actual responses to past droughts and floods can be illuminating, however, particularly when placed in the context of plausible hydrologic and institutional disruptions. This paper draws on interviews of water utility operators in the northwestern U.S. to highlight opportunities and constraints that water utilities may face vis-à-vis such disruptions. Key considerations affecting vulnerabilities include water rights, institutional barriers to efficient utility operations, hazards management policy, and the fiscal status of utilities.

Key Words: water utilities, extreme events, environmental planning, climate variability, climate change, adaptation

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Introduction

The recent report from the Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation and Vulnerability* underlines the point that vulnerability to climate change impacts is related not simply to changing average conditions but to increased climate variability and extreme events (Intergovernmental Panel on Climate Change, 2001). Unlike gradual changes in climate which, in certain locations, may have positive impacts for managed resource systems such as agriculture or forestry, extreme events are inherently more disruptive to both natural systems and to the entities and institutions that manage natural resources. Examining the response to extreme events can thus reveal how managed systems may be vulnerable to future climate perturbations. Existing responses to extreme events can also alert us to the way policy measures to reduce risk from these hazards evolve in a context of ongoing patterns of adjustment to climatic and non-climatic stresses and competing private and public initiatives.

In this paper, we examine the current vulnerabilities of drinking water utilities in the Willamette Valley in northwest Oregon to extreme events and consider the institutional pressures that have influenced how these utilities have coped with past floods and droughts. During the 1990s, water utility operators in the Willamette Valley had to deal with notable climate extremes. Drought affected water system operations in the early 1990s and, in the latter part of the decade, severe flooding, accompanied by mudslides and other threats to utility infrastructure, presented a challenge to many operators trying to maintain service to their customers. At the same time,

* Robert Hersh and Kris Wernstedt are Fellows at Resources for the Future. They would like to thank the many water utility managers in the Willamette basin for participating in the study. As always, we remain solely responsible for all opinions and conclusions.

growth pressures in the region, new regulatory demands on water utilities, and institutional changes related to water use complicated the coping efforts of the operators.

Our paper poses what appear to be three simple questions. First, how vulnerable are water utilities to extreme weather events? Second, what range of institutional choices and constraints influence the way water utilities respond to these events? Third, how have water utility operators responded to severe weather events and how should we evaluate the prospects of adaptation to changing climate and institutional conditions in the face of such experience?

To address these questions, and as part of a larger project on the hydrologic response to climate change in the Pacific Northwest,¹ we have studied the operations of both large and small municipal water utilities in the Willamette River watershed in the state of Oregon. A major part of this study rests on detailed interviews of 20 utility operators in the region. Although we view our study largely as an exploratory exercise, we hypothesize that smaller utilities generally are more vulnerable than larger utilities to past extreme events and, because of underlying structural changes, less capable of responding to severe extreme events in the future.

We start the substantive part of the paper below by describing the watershed and several water stresses brought about by changing institutions. We follow this with a discussion of two sources of climate perturbations in the Pacific Northwest. We next review our study methodology and present background information on drinking water utilities in the Willamette basin. After this, we briefly present the results of our interviews. We then discuss the implications of these results, focusing on the institutional features of water utilities in the Willamette and how these features shape the susceptibility of systems to future extreme hydrologic events. In the final section, we summarize our findings and highlight several opportunities for water utilities and other stakeholders in the region to cooperatively address possible future changes in natural and institutional conditions.

¹ This larger project was funded by the Science to Achieve Results (STAR) program of the U.S. Environmental Protection Agency's National Center for Environmental Research and Quality Assurance (Grant Number R824805-01-0). This paper also draws on work supported by the Climate and Global Change Program of the U.S. National Oceanic and Atmospheric Administration (Grant Number NA96GP0251). As always, we remain solely responsible for all opinions and conclusions.

Background: The Willamette Basin

Oregon's Willamette River basin, which drains into the Columbia River near the city of Portland, occupies nearly 30,000 square kilometers between the Cascade Mountains on the east and the coastal range on the west (see Figure 1). Nearly three-quarters of Oregon's residents live in the basin and a similar proportion of the state's economic output, employment, personal income, and value added comes from or flows to the 10 counties that make up the watershed. The climate in the lowland areas of the basin—wet and mild winters and dry and warm summers—has provided favorable conditions for settlement and economic activities.

For much of the last century, agriculture, forestry, and related sectors have undergirded the region's economy, but in the last decade high-technology industries and the service sector have played a major role in the region's economic expansion. Moreover, the area has experienced steady population growth, particularly on the outskirts of the Willamette Valley's major urban areas—Portland, Eugene, Salem, and Corvallis. Between 1970 and 2000, for example, the population of the 10 counties in the basin grew by 50% from 1.5 million to more than 2.4 million, and recent population projections anticipate 2.7 million residents by the year 2010 (Center for Population Research and Census, 1999). This population increase is placing an increasing burden on the basin's water resources even absent possible climate-change induced hydrologic disturbances. In addition, two other additional stresses have appeared.

First, uncertainty about developing existing water rights and obtaining new ones is perhaps the most problematic area for many of the basin's water utility managers vis-à-vis planning for future demand. Like other states in the western U.S., Oregon's water laws are based on the principle of prior appropriation; the first person to obtain a water right on a stream is the last to be shut off in times of low streamflows. Although Oregon's 1909 Water Code stipulates that any portion of a water right not used for five or more consecutive years is subject to cancellation, municipalities historically have been exempt from this provision and many hold significant unused rights (Oregon Water Resources Department and Commission, 1999). These rights have become the focus of regulatory attention and political discussion in the state legislature, with some arguing that the municipal exemption unjustifiably limits opportunities for transferring water among competing users.

Second, in March 1999, the U.S. National Marine Fisheries Service dropped a bombshell on water resources managers in the Willamette basin, when it listed winter steelhead and spring Chinook salmon as threatened under the U.S. Endangered Species Act (16 *U.S.C.* §§1531 *et seq.*). This announcement may have dislodged the issue of future demand from the top spot of many water providers' agenda, since basic operations of water utilities and of reservoirs can affect critical salmon habitat in numerous ways and be unlawfully detrimental to salmon. Within the Upper Willamette basin, for example, existing water diversions and reservoir construction already have limited access to a considerable portion of Chinook salmon spawning and rearing habitat. Moreover, continuing water utility operations may degrade water quality—by increasing sediment loads through construction of new impoundments or diversion structures and flushing chlorine and ammonia into streams as part of regular system maintenance—and impair salmon migration through improper intake screening or reduction of instream flow. In the future, water system managers will have to devise monitoring programs to assess the effects of their actions on salmon populations, secure additional budgetary resources to make necessary changes, and spend a considerable amount of time consulting with the U.S. National Marine Fisheries Service about measures to minimize impacts to listed species. In short, the Endangered Species Act could make it very expensive and disruptive for water utilities to upgrade their facilities and to develop existing water rights.

Natural Variability and Water Utility Management

Against the backdrop of socio-economic stresses in the Willamette basin, the basic hydrology of the watershed also presents complications in the context of climate perturbations. Although generally thought of as well watered, the seasonal pattern of flow in the catchment not surprisingly is uneven and reservoir storage can only accommodate roughly $\frac{1}{4}$ of the basin's annual runoff (U.S. Army Corps of Engineers, 1999). As Figure 2a shows, flows on the Willamette River mainstem are highly variable yet they largely follow the pattern of

precipitation.² The graph represents average monthly natural discharge at the T.W. Sullivan dam site—past which moves roughly 80% of the Willamette basin's runoff—that has been corrected for changes in upstream storage. This discharge corresponds closely to average monthly precipitation, with the highest mean monthly flow (January) roughly 16 times the lowest monthly mean flow (August). In higher elevation catchments within the Willamette a different pattern appears. Figure 2b shows the flows and precipitation in the North Santiam River watershed at a site upstream of all impoundments, the drainage outlet for a 550 square kilometer catchment just west of the Cascade crest. In this latter watershed, discharge is much more evenly spread across the late winter and spring months. The highest mean monthly flow is less than four times the lowest mean monthly flow, a situation that reflects the dual importance of wintertime precipitation and snowmelt in shaping stream discharge.

Seasonal and Long-Term Climate Change

Both of the seasonal patterns of flow depicted in Figure 2 can show large deviations during intermediate term, seasonal climate events and are likely to be significantly altered under most plausible longer-term global climate change scenarios, particularly with respect to the timing of snowmelt. Taking the intermediate-term events first, a large body of research in the Pacific Northwest over more than a decade (Cayan, 1996; Cayan & Peterson, 1989; Clark, et al., 2001; Greenland, 1994; Kahya & Dracup, 1993; McCabe & Dettinger, 1999; Redmond & Koch, 1991; Taylor, 1998; Wolter, et al., 1999) suggests a strong link between the El Niño Southern Oscillation cycle and streamflows in the region.³ El Niño events appear correlated with warmer

² The precipitation estimates in Figure 2 and Figure 3 have been calculated from the PRISM model developed by researchers at Oregon State University and the Oregon Climate Service and funded by the Water and Climate Center of the U.S. Natural Resources Conservation Service Daly, C., Neilson, R. P., & Phillips, D. L. (1994). A Statistical-Topographic Model for Mapping Climatological Precipitation Over Mountainous Terrain. *Journal of Applied Meteorology*, 33, 140-158. The estimates are based on an unpublished and provisional 44-year (1950-1993) time series of monthly precipitation means for nearly 1,950 grid points in the Willamette watershed that have been modeled with the PRISM software (see reference to be provided for further details).

³ El Niño is a naturally occurring change in climate conditions that brings a warming of coastal waters off of Peru and Ecuador, while La Niña brings a cooling of these waters below normal temperatures. They are accompanied by a change in atmospheric circulation known as the Southern Oscillation. The general term ENSO (El Niño Southern Oscillation) refers to the two elements of this cycle.

winter temperatures and reduced precipitation, snowpack, and streamflows, and La Niña events with higher-than-normal wintertime precipitation and streamflow. The correlation between La Niña events and higher streamflows are particularly strong. For example, an examination of daily flow records in December (the highest flow month) over the period of record from 1934-1999 at a gauge site at Salem upstream of the T.W. Sullivan dam site (see Figure 1), shows that a disproportionate number of the highest discharges in the month occur in La Nina years. These constitute little more than one-fifth of the 66-year-record, yet, when we look at the top 1% of daily flows in December over the record, more than two-thirds of these high flows occurred in La Nina years.

There is some evidence that suggests the frequency of these intermediate term climate events may be increasing in response to global climate change (Timmermann, et al., 1999; Trenberth & Hoar, 1996), although the connection is still highly uncertain. Regardless of this possible link, most research suggests that global climate change itself will influence streamflow patterns in the region. No detailed studies of potential climate change specific to the Willamette have appeared in the literature, but a number of studies of both the larger Pacific Northwest region and of smaller subwatersheds within the region provide guidance on the possible effects of such change on the Willamette's hydrology. A recent exercise by the JISAO/SMA Climate Impacts Group at the University of Washington under the U.S. Global Change Research Program has applied the results of seven general circulation model runs to examine the possible impacts of climate change and climate variability on water resources, salmon, forests, and coastal areas in the Pacific Northwest (Mote, 1999). All of the general circulation models suggest significant increases in temperatures in all seasons in the region by the year 2020. While they differ as to whether summers will be wetter or drier—and thus it is uncertain whether summer river flows will decrease even with higher potential evapotranspiration resulting from higher temperatures—the models generally agree that winters will be wetter and warmer.

With higher wintertime precipitation and temperatures in the region, peak flows likely will occur earlier in the water year, at least in smaller, less topographically varied watersheds that are dominated by snowmelt and where groundwater flows are not a significant factor. Modeling by Leung and Wigmosta (1999) of a 200 square kilometer mountain watershed along the crest of the Cascade Mountains in Washington state, for example, suggests a significant

increase in annual average runoff, decrease in snow-water equivalent, and a shifting of peak flow from June (under current conditions) to multiple peaks (November and April). Wintertime flooding may increase and summer and fall flows greatly decrease, even if summer and fall precipitation remains constant.

Utility Planning for Climate Change

The potential impact of changes in climate conditions on water utilities in the Willamette is complicated, in part because base flows in some of the Cascade tributaries and in streams that originate in the lowlands in the Willamette basin are sustained by groundwater discharges (Woodward, et al., 1998). In addition, some hydrosystem managers may have some limited flexibility to alter storage and release rules in upstream impoundments, with regard to balancing the multiple purposes of the impoundments (for example, water supply, flood control, instream flows, recreation) in light of climate-driven changes in expected inflows to the impoundments (see, for example, Wood, et al., 1997). However, much of the Willamette operates on a fixed draft policy (releases are predetermined) and changes to these policies would require extensive and, lengthy consultations with a wide variety of interest groups and formal modifications to regulatory practice (Brooks, 2000).

Ultimately, the vulnerability of water utilities to hydrologic changes will depend on the extent of the hydrologic changes and the external institutional stresses that the utilities face, as well as the adroitness with which managers anticipate problems and adjust. The utilities themselves, however, typically have not developed contingency plans for the longer-term disturbances. Given the daily demands of providing potable water, the apparent lack of interest in the potential impact of hydrologic change on system operations is not surprising. As Russell and co-authors (1970) and Schilling and Stakhiv (1998) have pointed out, water managers tend to be technical pragmatists. As such, they are unlikely to re-evaluate system design parameters on the basis of what models say about changes in mean stream flows or the higher probabilities of more frequent extreme weather events associated with changing climate conditions.

Yet, a number of commentators have viewed this recalcitrance as a constraint on the ability of water utilities to adapt to new hydrological conditions in the coming years (Frederick

& Gleick, 1999; O'Connor, et al., 1999). Indeed, as if to throw down the gauntlet to its members, the American Water Works Association has recommended that water managers should “re-examine engineering design assumptions, operating rules, system optimization and contingency planning for existing and planned water-management systems under a wider range of climatic conditions than traditionally used” and “explore the vulnerability of both structural and non-structural water systems to plausible future climate change, not just past climatic variability.” (American Water Works Association, 1997)

To illuminate possible vulnerabilities and responses, we draw below on detailed structured interviews we have conducted with utility operators from 20 different community water systems in the basin to understand more fully the operators’ experiences with extreme events in the recent past, most notably the 1996 wintertime floods and a drought in the early 1990s. We also have constructed scenarios of increases in the frequency and magnitude of some of these events to help us examine perceptions of vulnerabilities to future events that may lie outside of the operators’ experiences.

Methodology

From October 1998 to December 1999, we conducted telephone interviews with operators of drinking water utilities in the Willamette watershed that rely wholly or in large measure on surface water to produce drinking water. Each of these interviews followed a structured questionnaire.⁴ The first quarter of the interview asked for background information on ownership, staffing, and characteristics of the service population, with the remainder of the questions ranging over an array of topics related to revenue streams and rate schedules, the utility’s experiences with droughts in the early 1990s and with floods from 1996 to 1998, its susceptibility to extreme events, the extent of the utility’s emergency preparedness plan, availability of alternative water supplies, and the barriers to more effective drought and flood

management policies. We also included a number of open-ended questions to give operators the opportunity to express their views at length. Each interview took roughly one hour to complete.

Our population of interest for the interviews was delineated by the Oregon Health Division, which provides a list of water utilities in northwest Oregon that rely wholly or in large measure on surface water to produce drinking water. To be eligible for inclusion in our interviews, utilities on this list had to meet two additional criteria: 1) qualify as a community water system as defined under the U.S. Safe Drinking Water Act (42 *U.S.C.* §§300f *et seq.*), which means the system must provide drinking water to 25 or more permanent residents, or to 15 or more permanent connections; and 2) produce finished water from raw surface water sources located inside the Willamette watershed boundaries, a criterion that excludes many surface water utilities in the basin that purchased but did not produce finished surface water. These conditions narrowed our population to 37 surface water utilities. We contacted the water utility supervisor or operator of each of these utilities and, after explaining our objectives, scheduled an interview time. To those who agreed to participate, we then faxed or mailed our interview questions, and followed this with the interview at the appointed time. This process yielded a sample of completed interviews with 20 water utilities.

While our participation rate is fairly high (54 percent) the actual number of respondents is quite small and thus many of our inferences cannot pass formal statistical tests of significance. Moreover, it is likely that we have some sampling bias. As Table 1 shows, large and very large water utilities (those with service populations greater than 10,001) account for 50% of our sample although they make up slightly less than 33% (12 out of 37) of all surface water systems in the basin. By contrast, only 10 of the 25 smaller and medium-sized surface water systems in our study area participated. This in part reflects the difficulty we had in contacting water providers at many smaller utilities (often small systems are operated by a circuit rider), or

⁴ The questionnaire is available from us upon request. As a prelude to its administration, we collected inspection reports on each utility from the Drinking Water Program in the Oregon Health Division. These reports provide background on each utility's system characteristics, such as its source of water, number of connections, and treatment technology and capacity.

completing a survey after such providers repeatedly had to cancel scheduled interviews due to work demands.

Our sample also is skewed with regard to utility ownership in relation to the country as a whole. According to national-level data from the U.S. Environmental Protection Agency, private sector companies own nearly 75% of utilities with service populations under 500 and nearly 25% of utilities with service populations between 500 and 3,300 (U.S. Environmental Protection Agency, 1997). Yet, both our regional population of interest and our sample are weighted heavily toward publicly owned utilities. In the basin, only three of the 37 surface water utilities are privately-owned. Of the 20 utilities in our sample, 19 are owned by municipalities and one is owned by a homeowner's cooperative. The fundamental difference in objectives between these two ownership types—publicly-owned systems provide drinking water as part of an array of public services whereas investor-owned companies provide drinking water to create returns on capital investment—is likely to influence the ways private and public systems deal with the risk and uncertainty of potential climate impacts. Unfortunately, our sample does not allow us to assess these potential differences.

Results

Our results in this section focus on the personal experiences of water utility operators with droughts and floods. Because a number of operators had limited experience of drought conditions in the early 1990s, we also asked water providers to anticipate how they would respond to reduced stream flows that, in many cases, were outside of the operators' personal experiences. We find overall that recent droughts had affected 37% of water utilities in our sample and recent floods nearly 90% of the utilities.

Droughts

Table 2 shows that drought impacts are evenly distributed among large and small utilities. Nearly two-thirds of the utilities report “no impacts” (which we define as conditions that require minimal or no changes in utility operations to prevent service disruption) from droughts in the 1990s, and nearly one-third report “moderate impacts” (which we define as conditions in which

utility operators implement voluntary or mandatory curtailments to prevent service disruption). The only reported “major impact” occurred at one utility where the level of the source river dropped below the sill of the utility’s intake structure, requiring operators to use a portable pump to draw water from the river channel into the intake. The six utilities reporting moderate impacts were able to manage low flow conditions with a variety of demand reduction measures, ranging from requests for voluntary compliance, prohibitions on selected institutional uses (for example, public park watering restrictions), restrictions on nonessential uses, and staged curtailment plans. These measures, according to the survey respondents, were generally not perceived as difficult, with six of the seven utilities that noted impacts reporting that the measures were “not disruptive at all.”

Table 3 shows how the responses change when we posed scenarios of more prolonged and severe droughts. In a modestly more severe drought (a 20% reduction from the lowest monthly stream flow), 55% of our respondents did not envision disruption to their service provision, anticipating for the most part that the U.S. Army Corps of Engineers would release stored water from reservoirs. For the eight utilities affected by a 20% reduction—and here the number is split evenly between large and small utilities—the impacts fall into three categories: the possibility of reduced releases of stored water if reservoirs upon which utilities rely to supplement summer flows come under fish passage rules of the Endangered Species Act; water quality problems; and, for the larger utilities, insufficient water rights.

When we shift the scenario to a 50% reduction in summer stream flows, we appear to cross a threshold. As the right half of Table 3 shows, only 4 of 18 water providers answering the question believed their systems could manage with minimal disruption. For 70% of the larger systems and virtually all of the smaller systems in our sample (seven out of eight respondents) a 50% reduction in summer flows would raise both technical and regulatory problems, most notably a diminished ability to withdraw water because of the location of their intake structures.

Floods

Utilities generally appear more sensitive to flooding than to droughts, with the lower entries in Table 2 indicating that nearly all utility operators who we interviewed have experienced flood impacts in recent years. In the table, “no impact” refers to conditions in which a utility could maintain service with minimal deviation from routine operations; “moderate impact” refers to conditions that necessitated significant changes to routine operations and maintenance activities, such as more frequent backwashing of filters and adjusting chemical mixes to deal with prolonged turbidity, as well as increased costs associated with additional chemical use and operator over-time; and “major impact” refers to extensive structural damage to components of the water system.

Overall, 8 of the 19 utility operators who responded to our question on flooding experienced major impacts. Most remarkably, 60% of the smaller utilities that responded to the question reported such damage from the 1996 floods. In a number of cases, intake structures and slow sand filters designed to handle fixed volumes were subject to physical failure. In two different instances, a pump house and water treatment plant were damaged by floodwater, even though the facilities were thought to be outside the 100 year floodplain when they were built earlier in the decade. For one small utility, an access road leading to its intake was washed out and a “mountain of mud” crushed a major supply line to one of its two sources. A landslide tore out the intake structure of another small utility located in the foothills of the Coastal Range. In general terms, many of the small systems were susceptible to flooding because of design failures, the location of system infrastructure in the floodplain, and the proximity of their systems to landslide prone areas.

A less severe but more widespread flooding problem evident from our interviews involves elevated suspended sediment levels, or turbidity. During the 1996 floods, many utilities experienced their highest raw water turbidity readings on record. One respondent said the turbidity was so bad at 4,000 NTU “they could stand a pencil in” their test beakers.⁵ Another

⁵ NTU (nephelometric turbidity units) indicate the amount of suspended sediment in the water. Under the U.S. Safe Drinking Water Act, the standard for turbidity is 0.5 NTU for systems that use conventional or direct filtration.

respondent claimed that the turbidity was so high he could not read it, even after diluting it 10 to 1 with water. Despite these high readings, however, 12 of the 14 utilities in our sample that experienced turbidity impacts were able to mitigate the impacts and maintain service through a variety of means. As Table 4 shows, these include turning to storage and alternative water sources, using ample supplies of chemical coagulants, and drawing on the expertise of experienced operators. Only two of the 14 were unable to keep drinking water flowing to their customers. In one instance, high turbidity levels impaired the slow sand filters of a large municipal water treatment system, forcing the system to shut down for a week; the utility had to implement conservation measures and bought water from a utility to which they were connected by an inter-tie. In the second case, a small water utility did not have the treatment capacity to handle the volume of sediment in the stream and was forced to use stored water. It had to request that customers reduce water use voluntarily by 50% for a few weeks to ensure supplies while turbidity levels remained high.

Fiscal Features

In addition to the vulnerability that arises from their direct physical exposure to floods and droughts, our interviewees suggest two important fiscal factors are relevant to understand the range of options available to water utilities to respond to extreme events. The first of these relates to the degree to which water utilities can make fiscal decisions on utility matters independent of the city budgetary process. As Table 5 demonstrates, six out of seven large utilities considered themselves “very independent” from the city’s budgeting process. The least-independent ranking for any large utility was three on a scale from 1 (very independent) to 5 (very dependent). By contrast, only two of seven smaller utility operators ranked their utility as “very independent” while four of the seven are clustered on the scale toward “very dependent.”

The second institutional factor relates to the need for and financing of capital improvements. Few communities could generate sufficient revenue solely from water sales to pay for large capital improvements to make their water systems more resilient to an increase in the prevalence of droughts and floods that might result from climate disturbances. Table 6 shows that utilities in the basin have raised capital through a wide array of financing mechanisms, mechanisms that depend to some degree on the size of the utility. Both size classes

of utilities rely on system development charges, but large utilities also have access to funding from special assessment districts and internal sources (capital reserve funds and cash). Many of the larger publicly owned utilities make frequent use of revenue bonds to fund high cost capital improvements. By contrast, smaller utilities have relied on general obligation bonds to finance system improvements.

Discussion

The overall risk to water utilities of potential hydrologic changes needs to be viewed in the context of institutional features that shape the vulnerability of utilities to extreme events. Here, we are referring to the broadest notion of “institutions,” the set of formal and informal ground rules within which water utilities operate. This encompasses not only those specific entities involved in water provision—regulatory agencies, legislative bodies, health agencies, and the utilities themselves, for example—but also norms of behavior, conventions, the allocation of property rights and the ability of various groups to call upon the power of the state to protect their interests.

In particular, four complicating institutional features stand out. Two of these—water rights and efficiency improvements in water utility practices—relate primarily to droughts, while a third factor—hazard policy—relates to flooding. The final feature picks up on the fiscal themes discussed above and applies to both drought and flood vulnerabilities.

Water Rights

As noted earlier, due to the U.S. Endangered Species Act and mooted changes to municipal water rights, water utility operators believe developing existing water rights and obtaining new ones is likely to be more difficult in the future. Large system operators appear most acutely tuned to this concern, particularly those who, for the past decade, have accommodated increasing demand but are now running up against capacity expansion problems even when they have adequate water rights on paper. One utility located to the south of Portland, for example, has rights to 3.5 times as much water as it currently uses, but to develop these rights, the utility would have to build a new, larger intake structure and add a new pipeline.

These modifications would require lengthy discussions with both federal and state regulatory agencies and attract considerably more scrutiny from environmental groups. According to the utility managers the likely result of such discussions is uncertain. Smaller water utilities, while not immune to these problems, may be less susceptible to increasing demands and low flow conditions and less troubled by water rights concerns because they can supplement their production from surface supplies with well water and springs.

Most utilities in our survey have water rights with priority dates from different years—some quite senior rights, date back nearly one hundred years, and other more junior rights were acquired during the last 25 years. As noted earlier, the time of the claim is the key determinant of allocating water under Oregon water law. Given the historical land use patterns in the Willamette basin, priority rights are often attached to agricultural lands and, in certain instances, municipal water rights may be junior to the historical agricultural usage. Two operators of smaller utilities, both with very junior rights compared to those of the farmers and ranchers in the area, believed they might be hard pressed to serve their customers without imposing severe curtailment conditions during low flow conditions. During prolonged dry spells, water utilities, especially those holding junior rights, also may be vulnerable to more senior instream water rights. For example, under state policy to augment stream flows, water rights transferred to the state become instream rights with the priority date of the original right. Seven water utilities in our sample—three smaller utilities and four larger utilities—claimed that during drought conditions the junior status of one or all of their water rights could limit the amount of water they could divert. However, there was considerable uncertainty on the matter because:

- Oregon law has some statutory flexibility to accommodate municipalities with junior water rights during periods of chronic water shortage. Under Oregon law, if the governor declares a drought the state may grant temporary preference to household consumption purposes, regardless of the priority dates of the other users (*O.R.S.* 536.720 & *O.R.S.* 536.780), and municipalities and other water right holders may apply for a temporary change in place of use or point of diversion (*O.R.S.* 538.410).

- Many utility operators, particularly those at larger utilities, believe they could blunt the problem of junior water rights by negotiating with the U.S. Bureau of Reclamation to purchase additional water supplies from the Corps of Engineers' 13 reservoirs.
- Larger water utilities could obtain additional supplies through adjacent water districts with which they have inter-ties (while two-thirds of the larger systems currently have inter-ties with neighboring water systems, only one of the 10 smaller utilities has such a connection).

Improvements in Water System Efficiencies

In principle, all utilities in the Willamette watershed could increase their resilience or ability to cope with low-flow events through a combination of interties, demand reduction measures, and increases in system efficiency such as through an aggressive leak reduction program to curb system loss. However, well known obstacles can impede the realization of such improvements. Not only has the historic mission of water utilities been to ensure plentiful water supplies rather than promote and implement demand-management programs, but investments in publicly owned water utilities compete for dollars against other public works projects and thus can be hampered by the chronic lack of public funds (especially if rates are set too low to generate sufficient revenue). Moreover, for many towns in the Willamette basin, the efficiency argument for a more regional water supply network, whether this would be implemented through inter-ties or with a combined administration, holds little sway with customers who want to maintain local control of their system (Oregon Association of Water Utilities, 1999).

All the water utilities in our survey have the legal authority to undertake short-term demand side management activities and drought mitigation measures, including water rationing and imposing penalties on customers who do not comply with the restrictions. Indeed, during the droughts in the early 1990s, the majority of larger utilities were able to implement formal staged curtailment plans, beginning with even and odd day lawn watering restrictions and ratcheting up to include restrictions on non-essential uses and cut backs to selected commercial and industrial users. The smaller utilities handled demand reduction on a more voluntary basis,

relying on informal pressure, rather than strict allocation criteria. In the event of low flow conditions, half of the small utility respondents said they knew their customers and could simply ask them to conserve or to be more careful with water.

Increasing efficiency can make a water system less vulnerable to low flow conditions by finding, in effect, hidden sources of water. However, for many of the utilities, and particularly for smaller systems, the more visible attributes of the water system (taste, odor, and pressure) tend to receive the greatest attention in decision-making. In contrast, the less visible components of the system—leaking pipes, deteriorating infrastructure, and the need to plan for unlikely events such as droughts and floods—tend to be under-weighted. The problem of system inefficiency is thus in part a political question, a point we return to below.

Hazard Policy and Planning

The short-term response of utility operators and others whom the utilities depend on undoubtedly has been and will continue to be an important feature in mitigating the impacts of flooding. However, longer-term efforts at flood planning and preparation are also critical for shaping effective responses to flood crises, particularly if climate disturbances increase the frequency or intensity of floods. Unfortunately, such advance preparation often operates in what May and Williams (1986) describe as a world of “apathetic politics”, in which the contours of flood planning are shaped by the most recent extreme event, with disaster assistance, rather than better planning and management, the recurrent “solution” to flooding. Moreover, the “shared governance” of flood planning and management among multiple levels of government has created a long-observed dissonance between federal and local stakeholders (Burby, et al., 1988; Holway & Burby, 1993). Local interests have historically preferred post disaster relief and structural mitigation as a cornerstone of flood policy, while federal parties have offered a mixture of this and longer-term non-structural mitigation and compulsory insurance (Rossi, Wright, and Weber-Burdin as cited by May & Williams, 1986).

Our interviews revealed that the majority of larger utilities have developed longer-term plans to help guide operations during flood conditions. One utility, for example, documented in detail the record of the 1996 flood events—who did what, when, and what chemical dosages were used at what point during the flood—to create a usable record and reference document that

operators could consult if they encounter such peak flow conditions and turbidity again. Communication apparently was a problem for this utility in 1996, but now the city is better able to act in a coordinated fashion. Other large utilities did not document their responses to the flood in such detail, but have devised plans to mobilize staff and coordinate efforts and equipment. Many have formalized agreements with outside agencies to provide water in case of system failure. Clearly, for large utilities we found the main thrust of emergency planning directed toward identifying incremental adjustments to operations, a finding one would expect given the degree to which the larger utilities successfully absorbed the impacts of the flood.

In sharp contrast, not one small utility has plans in place to deal with flooding. One might want to explain this result by way of May's and Williams' notion of apathetic politics—the utilities carry out their operational responsibilities with limited resources and cannot afford or consider it expedient to focus on flood planning. As one small utility operator explained, “We haven't done anything because [flooding] is not a yearly event.” All of the smaller systems have a host of other functions and responsibilities that they must carry out during normal times—and many operators are employed on a very part time basis—and with limited resources can not afford to focus on flood preparations in prospect. As with many other entities involved in flood planning, they often perceive that the political and economic costs of proactive flood management actions are disproportionate to their benefits (Berke, 1998; Wiener, 1996).

Despite these difficulties, we found through our open-ended questions that small utilities have indeed made informal plans to help them mitigate the impacts of future floods. These plans are not written down, but are based rather on informal commitments of resources. Operators of small utilities have access to emergency electricity generators from private contractors, stainless steel tankers from volunteer fire departments to haul potable water, and in-kind support from private companies to help them rebuild and reinforce infrastructure damaged by past floods. For example, after the 1996 flood damaged the intake and above ground pipe going from the creek to the reservoir at one utility, a nearby company provided materials to rebuild the diversion and replace the pipe. The labor was done voluntarily by the system's ratepayers. While these resources are often difficult to quantify and may be too limited and makeshift to help smaller utilities cope with potentially severe effects from climate disturbances, the point worth noting is

that for small utilities they show us how efforts to mitigate flooding can be locally initiated and embedded in social networks.

Fiscal Situation

Compared to smaller systems, larger utilities have access to more diverse sources of funding for capital improvements, an important facet in shaping vulnerability to extreme events. The special assessment districts and capital reserve funds that larger systems rely on presuppose a certain degree of planning expertise, and many of the larger utilities have the resources to employ public relations staff to help build public and political support for revenue bonds to underwrite what may be expensive capital improvement projects. These bonds are issued by the municipality and are repaid with the revenues the water supply system generates and places in an enterprise fund. Usually they do not require voter approval. In contrast, a government entity that issues a general obligation bond has a legal obligation to raise sufficient funds to pay the bondholders. Because this obligation may require local government to increase general tax levies, voters must approve the bond sale. Water utility operators in our sample described instances where such votes have been politically contentious and failed, outcomes that forced them to cancel capital improvement projects. In other cases, water utility managers have decided to delay capital improvement projects—sometimes for a number of years—because they thought it unlikely the community would vote to pass the bond issue to pay for system improvements. Without the resources to explain system needs to local communities, the ability of smaller utilities to plan for and implement projects to mitigate future contingencies is hindered by political uncertainties.

Smaller utilities also appear at a relative disadvantage because of their limited fiscal independence. Having less fiscal independence from municipal budgeting processes has meant that revenues from water rates are not dedicated to routine operations and maintenance—labor, repairs, chemicals, lab tests, electricity—but are allocated to other municipal responsibilities, such as fixing potholes or repairing storm water drains. It also has meant that, for political reasons, a number of water utilities have been unable to convince city councils—usually the rate making authority for publicly-owned utilities—or local citizens to increase rates sufficiently to cover the costs of replacing aging infrastructure, complying with new environmental

requirements, and adding flexibility to the system (for example, buying back-up generators, increasing storage capacity, developing new well-fields) to help utilities cope with disruptions. This problem is compounded by the fact that per capita costs for water service at smaller utilities are often higher than such costs in larger communities where fixed costs are spread over a larger population. Moreover, average incomes in smaller communities may be too low to provide sufficient revenue regardless of the fee structure, and none of the small utilities have institutionalized lifeline programs that soften the impact of higher rates on lower-income customers.

There is some indication that managers of smaller water utilities are taking a harder look at the costs facing their systems. Several are undertaking rate analyses to determine how to meet these costs and putting forward proposals to raise rates to accommodate infrastructure repair, expansion, and new source development. Every water utility in our survey planned to increase rates in the next five years. In the case of many of the smaller water utilities these increases could be significant, from a 78% increase in one year to annual 10% increases over the course of the next five years.

Conclusion: Opportunities for Reducing Vulnerabilities?

The vulnerability of drinking water systems in the Willamette basin to extreme events driven by climate disturbances is by nature uncertain. There is some evidence, albeit limited, that more intense ENSO cycles and global climate change might lead to a higher incidence of extreme events. The operational burdens placed on water utility operators by increases in the frequency or intensity of extreme events may cause little disruption to drinking water provision. However, the combination of hydrologic effects and current institutional stresses—population growth, the added costs of complying with provisions in the Endangered Species Act, the constraints to develop water rights, the political environment of flood policy and planning and fiscal issues—could make some water utilities more susceptible to extreme weather events associated with a changing climate.

Our hypotheses that smaller utilities have been more vulnerable than larger utilities to past extreme events, and less capable of responding to severe extreme events in the future, were

borne out only in part. Both small and large utilities were only moderately vulnerable to drought, but nearly three times (in percentage terms) as many smaller utilities as larger utilities reported major impacts from the 1996 floods. They also appear to have less fiscal independence from municipal budgeting processes and typically lack inter-ties with other utilities that could provide buffering. In terms of future vulnerabilities, a slightly higher percentage of smaller utilities than larger utilities indicated they would be affected by the more severe flow restrictions that we posited under alternative climate scenarios. However, many of these smaller utilities have senior water rights, which provide them with greater security and flexibility in the case of flow disruptions, and have more viable alternative sources of water since they require relatively small volumes of it.

Policies to improve the prospects of water utilities to adapt to extreme events must take into account pressures for institutional change. For both size classes of utilities, trends toward less coercive and more cooperative approaches toward flood and other hazard management (May, et al., 1996) may improve the environment for water utility planning for extreme events. In addition, more efficient water allocations through temporary or permanent water rights transfers (Frederick & Gleick, 1999) and legislative and programmatic changes may attenuate the pressure that hydrologic and institutional stresses bring. Although knotty institutional obstacles still impede the implementation of a water rights market in the Willamette, such a market could shift water from lower-value agricultural uses toward higher-value uses, such as municipal water supply, thus potentially mitigating many of the supply problems that utilities face.

At the national-level, new regulatory guidelines may also enable water utilities, particularly smaller utilities, to more effectively plan for and adapt to extreme events. The 1996 amendments to the U.S. Safe Drinking Water Act and recent implementation guidelines issued by the Environmental Protection Agency (U.S. Environmental Protection Agency, 1998) mean that federal and state regulatory authorities must now consider system capacity—including the seasonal availability of source water, source reliability, infrastructure condition, operator certification, planning, capital improvement plans, revenue sufficiency, fiscal management and controls, and credit worthiness—in their oversight of water utilities. Consequently, states may be able to use the authority and resources of the Safe Drinking Water Act to promote greater

regional water system planning for greater efficiencies and to encourage economies of scale through managerial consolidation and physical interconnections among smaller water systems. Moreover, states can provide technical assistance to system operators and help less viable water systems prepare business plans that identify infrastructure needs and possible sources of financing. Such assistance is a key recommendation of a recent report issued by U.S. EPA's Office of Water on assisting small water systems to meet the requirements of the Safe Drinking Water Act (U.S. Environmental Protection Agency, 2000).

At the state level, Oregon's Drinking Water Program has encouraged water utilities to plan for longer-term capital projects by making available—since 1997—some \$66 million in low interest loans from EPA to water utilities under the Safe Drinking Water Revolving Loan Fund. Each application is rated along a number of criteria including: reducing risk to human health; achieving or maintaining compliance with federal and state drinking water regulations; and community affordability (i.e., costs to residents on a household basis). Bonus points are given for consolidation of two or more systems. These criteria clearly favor loan applications from smaller utilities. Since the inception of the program, some 70% of loans awarded went to utilities with service populations of between 25 to 3,300 people (Oregon Health Division, 2001). While increasing a system's resiliency to climate perturbations is not a specific criteria of the program, one could argue that many of the improvements requested by the smaller utilities—such as upgrading water treatment plants, relocating intakes, replacing leaking water lines, adding additional storage, and drilling new wells to supplement existing sources—could make many of these systems less susceptible to extreme events.

In summary, the lesson that the Willamette offers for other water utilities is that vulnerability to long-term environmental changes is highly specific to individual systems and not necessarily related to the financial resources available to a utility. Even in an area as blessed with natural resources as the Pacific Northwest, some water utilities appear at risk from prospective environmental perturbations that many have ignored or thought unlikely. The ability of water utilities to cope with extreme events is influenced by the ongoing adjustments made by water utilities and local utility boards to meet new regulatory demands, changing environmental preferences, and growth pressures. Clearly, there is no one decision point for water utilities to deal with extreme events. In their deliberations about system upgrades, capital investments, and

revisions to rate structures, water supply managers and other environmental planners in the region would benefit from considering scenarios that suggest a greater range of climate variability. Such information could help water suppliers develop plans that seek to exploit synergies between capacity development and broader policy objectives.

FIGURE 1—Willamette River Watershed



FIGURE 2a—Willamette River Precipitation and River Flow at T.W. Sullivan
(Monthly Average, 1950-1993)

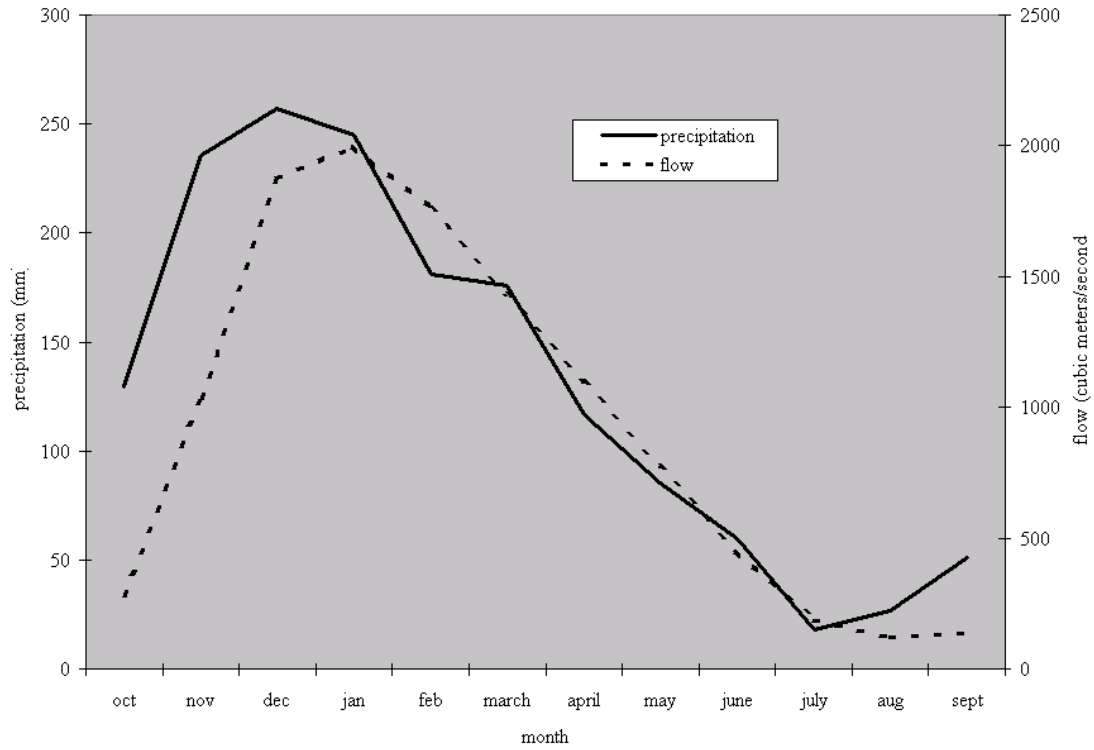


FIGURE 2b—North Santiam River Precipitation and River Flow
(Monthly Average, 1950-1993)

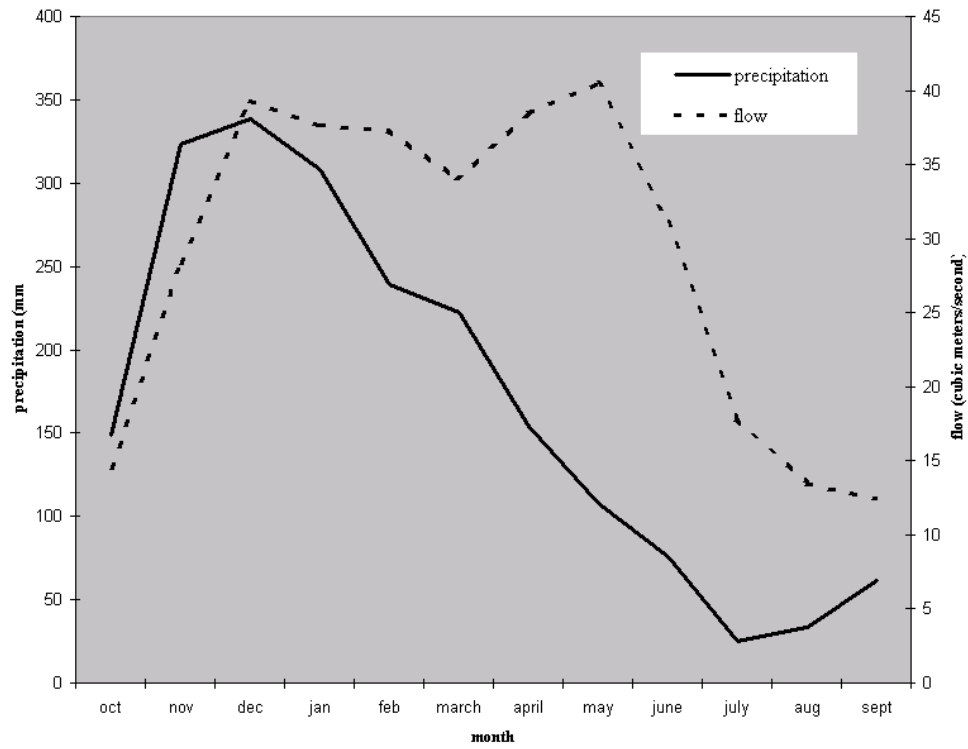


Table 1
Utility Characteristics: Population vs. Sample

	very small	small	medium	large	very large	total
Service population	25-500	501-3,300	3,301-10,000	10,001-100,000	>100,000	
# of utilities	5	14	6	9	3	37
# of respondents	1	4	5	7	3	20

Table 2
Drought and Flood Impact by System Size

System Size	No impact	Moderate impact	Major Impact
DROUGHT			
Large utility (n=9)	6	2	1
Small utility (n=10)	6	4	0
FLOOD			
Large utility (n=9)	2	5	2
Small utility (n=10)	0	4	6

Table 3
Potential Impacts of Reduced Summer Streamflow

	20 % reduction in summer stream flow		50 % reduction in summer stream flow	
	No impact	Impacted	No impact	Impacted
Large Utilities	6	4	3	7
Small Utilities	4	4	1	7

Table 4
Factors Mitigating Turbidity Impacts

	Factors	# responses
Large systems (n=7)	Higher chemical use	7
	Experienced operators	3
	Storage	2
	Use of rapid filters	2
	Voluntary conservation	2
	Alternative water source	1
	Physical barrier	1
Small systems (n=7)	Alternative water source	3
	Experienced operators	2
	Higher chemical use	3
	Storage	1

Table 5
Fiscal Independence of Water Utilities from City Budgeting Process

Ranking	Very independent			Very dependent	
	1	2	3	4	5
Large utilities	6	0	1	0	0
Small utilities	2	0	1	3	1

Table 6
Funds Used to Pay for Capital Improvements

Source of funds	Large Systems	Small Systems
Revenue bonds	4	1
General obligation bonds	0	2
State or Federal subsidized loan	2	2
Capital Reserve Fund	1	0
Special Assessment	1	0
Cash from current revenues	1	0
System development charge	4	6
Grants	0	1

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