Planning for Resilience in Oregon’s Coastal Drinking Water Systems

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Contents

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Background

On Oregon's rugged coast, large-scale infrastructure for public utilities is virtually nonexistent, meaning that drinking water must be obtained through small systems, domestic wells, or springs. While a portion of Oregon's coastal population utilizes a domestic or private source, the vast majority of residents rely on small public systems for their drinking water. For example, in Curry County more than 90 percent of residents are served by such systems. Unfortunately, risks associated with small drinking-water systems are not widely documented nor well understood.

For the purpose of this study, "small drinking-water systems" refers to those that serve 10,000 or fewer people. These systems are sourced with either precipitation-derived surface water pulled from small impoundments in the upper reaches of watersheds or shallow aquifers along the coast's limited plains. Nearly all of these systems are constrained in their ability to deliver water of consistent quality and quantity due to technical limitations and deteriorating quality of infrastructure. In its most recent quatra-annual report of state drinking-water infrastructure needs, the federal Environmental Protection Agency (EPA) indicated that systems in Oregon serving fewer than 3,300 people would alone require more than $1 billion to upgrade or repair storage, distribution, and treatment systems (EPA 2009).

Small systems tend to have low storage capacity, and often the treatment components cannot accommodate water with heavy sediment loads, which frequently occurs following exceptionally heavy precipitation events. In a recent study, the Oregon Department of Environmental Quality (ODEQ) (2010) found turbidity to be a common and generally worsening problem in Oregon coastal drinking water systems. The intense storms and consequential flooding in 2006–07 were particularly challenging for coastal systems in this regard.

Uncertainty in climate predictions adds to these concerns, as precipitation patterns are expected to shift both spatially and temporally, but the extent of these changes is yet unknown. This could mean not only a greater likelihood and intensity of flooding and associated turbidity, but potentially an increased incidence of droughts, as well, putting added stress on systems already limited by reservoir storage capacity. These precipitation changes also bring with them new challenges. For example, scientists are beginning to see a relationship between flooding events and episodes of toxic algal blooms, namely in watersheds with high concentrations of phosphorus.[1] Also, current research on native and invasive flora is finding that species distributions will likely change substantially over the next several decades in both spatial patterns and abundance (Helman et al. 2008). These findings could have a wide range of implications for watershed health, local hydrology processes, and, ultimately, for the drinking water systems at the receiving end.

Activities in the upper reaches of these watersheds can exacerbate precipitation-related concerns, especially fertilizer application and riparian timber removal. Unfortunately, much of the western slope of the Coast Range is under different ownership than the water systems that rely upon it. In addition, there are limited regulations on private forest practices as they affect water quality. While purchasing upstream pieces of land is an option for some systems, others lack the resources to do so—which is unfortunate, as this type of source-water protection is often viewed as the most effective step toward achieving optimal water quality at the tap (Freeman, Madsen, and Hart 2008).

Adjacency to the Pacific Ocean makes these systems uniquely vulnerable to changes in—and resulting from changes in—the ocean. Volatile sea floor faults, one of which is located just miles off the Oregon coast, can cause earthquakes and, consequently, tsunamis. While distant tsunamis pose a risk to water quality (e.g., through

Small systems often cannot accommodate water with heavy sediment loads, which frequently occurs following exceptionally heavy precipitation events.

1 Research on this topic is emerging. See, for example, the Lake Champlain Basin Program: http://www.lcbp.org/

surges upstream), a local tsunami event could devastate coastal communities that are not prepared. Coastal storms can also severely damage infrastructure and cause power outages, both of which lead to potential contamination of the water supply. Power outages can cause systems to lose pressure, and without a backup power source the system is at risk for back flow or siphonage. In addition, both sea-level rise and intense coastal storms can cause saltwater to intrude into coastal aquifers, contaminating groundwater supplies.

Physical and political constraints associated with water rights pose additional challenges to small coastal systems. Since the late 1980s, new regulations on both surface and ground water in Oregon have made it more difficult to acquire new water rights, even for community water systems (Achterman et al. 2005). In addition, retaining existing "backup" rights has become more difficult since the Supreme Court decision *Waterwatch of Oregon, Inc. v. Water Resources Commission*. In the past, water rights permit holders could extend the construction date for developing a backup right by filing a request for an extension of time and paying a fee. Now, community systems must justify their need for more time to complete construction and utilize the water (Achterman et al. 2005). Access to undeveloped rights is allowed if written into a Water Management and Conservation Plan (WMCP). While the WMCPs give systems some leeway, limited time, resources, and capacity may impede preparation of satisfactory plans.

The public health of coastal residents will depend upon the ability of Oregon coastal communities to adapt to changing environmental, social, and political conditions as they affect community water supplies. In other words, healthy communities will require resilient public water systems. For example, systems must be able to accommodate fluctuations in the quantity and timing of water and either improve source water quality or enhance treatment technology. Decision makers, such as system managers, must also have political support for prioritizing safe drinking water and taking measures to reduce related risks.

The first course of action in protecting Oregon's coastal drinking water supplies is to identify risks to both water quantity and quality. In its recommendations for follow-up to a recent turbidity study, the DEQ (2010: 42) stated the need to "continue acquiring information about the issues that Public Water Systems face, especially in small communities" as an initial next step. In response, this study, funded by Oregon Sea Grant, began to identify and categorize the current risks, as indicated by a group of experts and as perceived by drinking-water system managers and city staff closely involved with the systems.

Oregon Sea Grant (OSG) has an interest in this topic because of its relevance to OSG's strategic goal of "improving human health and safety related to ocean and coastal use (OSG 2010)" and OSG's long-term commitment to watershed engagement efforts (Hoobyar 2005). The issue of safe and reliable drinking water will likely receive continuing attention by OSG or its partners well into the future. OSG's interest in this study extends to the fact that this study builds upon an earlier OSG-funded study of coastal drinking water systems, which illuminated several social and environmental risks.[2] This white paper is a discussion of findings and recommendations for next steps.

While distant tsunamis pose a risk to water quality, a local tsunami event could devastate coastal communities that are not prepared.

2 See Achterman et al. 2005.

Approach

Case Study Selection

Thirteen drinking water systems in coastal Oregon were assessed for this study. Systems met the following three criteria to be selected: (1) small system (<10,000 population served); (2) municipal/community use; and (3) coastal source (on the west side of the Coast Range). Systems meeting these criteria were identified using the Oregon Health Authority (OHA) system database,[3] and a subset of up to five systems was contacted for interviews in each of the seven coastal counties. The subset for each county was selected by consultation with OHA field personnel, who were able to make recommendations based on system size, severity of relevant issues, and willingness of managers to participate in studies and projects in the past, thus a relatively high potential for responding to interview solicitation. The final individuals selected were a result of response, availability, relative size of system, and geographic location. This type of sample selection is often referred to as "purposive." *It was not a goal of this study to infer results to a larger population or draw general conclusions, but rather to collect preliminary information on a set of criteria to create a knowledge base for future research and engagement efforts.*

For each system, I interviewed a system manager—typically a public works director or city manager—who was very familiar with and worked regularly with the community water system in question. On three occasions, an additional relevant staff member was also present for the interview. Individuals from six of the seven coastal counties were interviewed, ranging from Astoria in the north to Brookings in the south. The systems served populations from 500 to 9,500 individuals, with the majority relying on surface water for the primary source. The map above shows the approximate geographic locations of the systems along the Oregon coast. Table 1 (next page) describes the general characteristics of each community system sampled.

3 Oregon Public Health Drinking Water Data Online allows users to search for basic information on all drinking water systems in Oregon, with an option to search by county: http://170.104.63.9/countyinventory.php

Geographic locations of community drinking water systems represented in interviews. Source: Google Maps 2012.

Data Collection

Risk Defined

The term *risk* can be broadly defined as the potential for an undesirable outcome. In this study, a *risk* pertains to any condition, circumstance or event—natural or human-caused, deliberate or unintentional—that may have a negative effect (temporary or permanent) on the ability of a community drinking water system to deliver safe and reliable drinking water to the population.

Risk Communication Method

The interview methodology was consistent with recommendations by the authors of *Risk Communication: A Mental Models Approach* (Morgan et al. 2002). Others at Oregon Sea Grant have used this method in recent years with favorable results (e.g., Winters 2011). Risk communication, in short, diverges from communications approaches that involve one-way information transfer from expert to lay person in that it seeks to understand perceptions of a target audience before engaging with that audience in a non-persuasive manner (Carnegie Mellon University Center for Risk Perception and Communication 2011). The Mental Models Interview (MMI) approach typically involves five stages, in which the researchers: (1) create an expert model; (2) conduct open-ended MMIs; (3) circulate a follow-up structured survey; (4) draft risk communication materials; and (5) evaluate the communication's effectiveness (Morgan et al. 2002). For

Table 1. Basic System Characteristics

System Name	Population	Primary Source of Water
Astoria, City of	9,500	Surface
Brookings, City of	7,000	Ground
Depoe Bay, City of	1,000	Surface
Garibaldi Water System	1,000	Ground
Gold Beach, City of	3,000	Ground
Heceta Water District	4,500	Surface
Langlois Water District	500	Surface
Port Orford, City of	1,000	Surface
Reedsport, City of	6,000	Surface
Rockaway Beach Water District	2,500	Surface
Seaside Water Department	6,000	Surface
Toledo Water Utilities	3,500	Surface
Waldport, City of	3,000	Surface

Notes: 1. Population has been rounded to the nearest 500 and is based on the number taken from the OHA online database. Interviewees at times reported conflicting estimates, typically higher than the OHA numbers shown here. 2. The ground water use category also includes systems using what is referred to as "ground water directly influenced by surface water."

this study, I implemented the first two steps, as the main objective was to gain understanding (not conduct outreach at this point).

Expert Model

Developing an accurate expert model is a crucial preliminary step to conducting interviews, as it will guide the latter part of the interview and thus affect the breadth and depth of information acquired. To develop the expert model, Morgan et al. (2002) advocate extensive research on the risk(s) and actions that serve to reduce the risk(s), then summarizing the information in an "influence diagram" that illustrates cause-outcome-effect-mitigation processes. The authors suggest developing the model with a panel of experts.

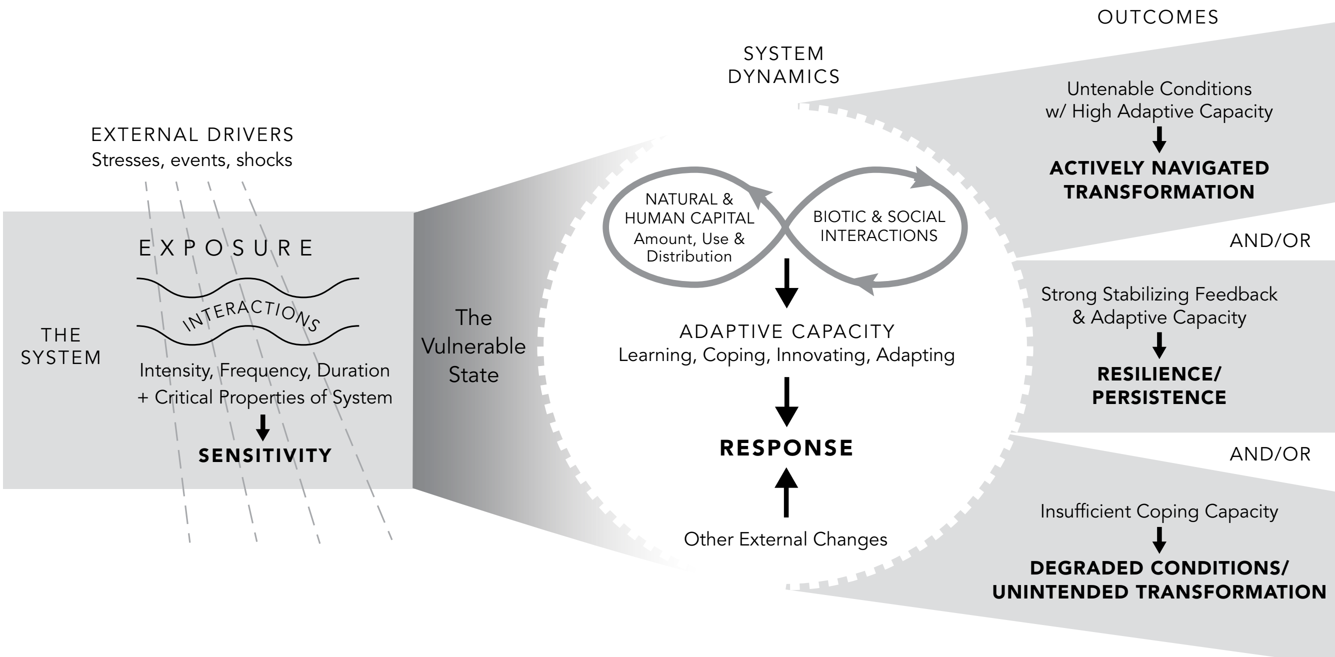
For this study, I collected information for the expert model through literature review and conducted interviews with five key experts on drinking water in Oregon[4] to gather additional information to incorporate into the expert model. The result of this process was not a traditional expert model per Morgan et al., for two reasons: while it was the result of expert input, the preliminary model was not the result of expert deliberations; nor did the preliminary model indicate the relationships among the categories of risks. In addition, rather than an illustrative diagram, the model used to conduct the MMIs in this study was a simplified textual model (Table 2), containing all of the major risks to drinking water systems identified among the literature and experts consulted. Note that interviewees did raise some risks not included in the expert model, such as commercial and residential development; roads; sewage; zoning and lack of access to infrastructure for maintenance and repairs; and algae.

4 Experts interviewed were from the Oregon Department of Environmental Quality (ODEQ), the Oregon Health Authority (OHA), the Oregon Water Resources Department (OWRD), and the United States Geological Survey (USGS) hydrology division.

Table 2. Expert "Model" of Risk

Category	Risk	Effect	Select Mitigation Measures
Climate Risks	Coastal Storms	Damaged infrastructure, and possible loss of pressure; saltwater contamination	Upgraded infrastructure; backup sources; backup power supplies
	Drought	Insufficient quantity; ESA constraints; higher concentration of contaminants	Increase storage capacity; backup sources; improve treatment
	Floods	Turbidity; introduction of contaminants, including phosphorus	Source water protection (buffers, etc.); improve treatment system
Geological Risks	Tsunamis	Damaged infrastructure; saltwater contamination; isolation	Relocation of vulnerable infrastructure; upgraded infrastructure; emergency plans
Infrastructure Risks	Failing or Leaking Pipes	Water loss; higher energy costs; recurrent need for repairs; loss of pressure; introduction of contaminants; boil water advisories; public health effects	Upgraded infrastructure; periodic testing, maintenance and repairs
	Low Storage Capacity	Insufficient quantity during droughts; inability to control flood effects; inability to meet future demands	Upgraded infrastructure; water conservation plans to curtail use
	Poor Treatment or Monitoring Technology	Insufficient quantity; poor quality and possible boil water advisories or public health consequences	Improve treatment system; improve monitoring system; source water protection (buffers, etc.)
Socio-Political Risks	Forest Management Practices	Turbidity; introduction of chemical contaminants; little control over quality of water entering system	Source water protection; land purchases; improved communication with forest owners; stricter regulations on forest management; improved treatment systems
	Agricultural Practices	Introduction of chemical and biological contaminants;	Source water protection; best management practices implementation
	Insufficient Staff	Inability to perform necessary tasks; difficulty handling emergencies	Raise prices of water to fund more positions; collaborate with universities to design apprenticeship programs; form networks with nearby systems
	Regulations	Higher cost of running system; increased paperwork load; changes in withdrawals allowed	Increased adaptability of system to accommodate new rules; water management and conservation plans
	Lack of Community Support	Difficulty for taking any new measures to increase resilience*	Raise awareness; strategic risk communication
	Lack of Funding	Necessary to use own limited funds to meet new regulations; difficulty investing in resilience-building activities	More funding opportunities for small systems; assistance for systems in applying for grants and loans; risk communication

Resilience**, *as used in this document, means* ***the capactiy to recover quickly from difficulties*. See illustration at top of next page.*



A conceptual framework that puts resilience in context shows, from the left, that the System of interest (e.g., household, community) responds to a suite of interacting Drivers (stresses, events) that may put it into a Vulnerable State in which the Adaptive Capacity of the system will determine potential outcomes: (1) actively navigated transformation to a new, potentially more beneficial state; (2) persistence of the existing system through resilience; or (3) unintended transformation to a new state (often degraded) due to vulnerability and the failure to adapt or transform. Graphic and caption adapted from Chapin, Folke, and Cofinas (2009, p. 21). Graphic: Patricia Andersson

Mental Model Interviews

The goal of MMIs is to "get people to talk as much as possible about the risk[s] while imposing as little as possible of other people's ideas, perspectives, and terminology" (Morgan et al. 2002: 63). Thus MMIs follow an open-ended format. The interviewer opens with a rather broad statement or question to gather as much minimally influenced information as possible; then, follow-up questions are asked regarding topics the interviewee has raised; finally, any relevant topics from the expert diagram *not* raised by the interviewee are brought up at the end of the interview by the interviewer (Morgan et al. 2002). The sheet used to guide the MMIs for this study can be found in Appendix 1. Main topics covered are those outlined in the expert model above (Table 2).

All 13 interviews began with the following statement, using prompts to encourage the interviewee to continue expressing his/her thoughts:

> *I'm interested in hearing about your drinking water system and related risks to it or concerns that you have. Please talk about risks related to your system, drinking water, and the wellbeing of your community.*

Interviews were conducted in July and August 2011. They ranged in length from approximately 40 to 65 minutes and were recorded and transcribed for accuracy.

Analysis

An open-source qualitative data analysis program[5] was used to code, sort, and analyze the interview transcripts. Statements were coded by main topics from the expert model and then sorted into sub-topics. Analysis was primarily contextual, though some quantitative assessments (e.g., count of systems perceiving a particular risk) were employed.

5 TAMSAnalyzer (Text Analysis Markup System) for Macintosh OS X, © 2011 Mathew Weinstein. Downloaded from: http://tamsys.sourceforge.net/ September, 2011.

Objectives

This study set out to identify *perceptions* of water system managers, as they relate to climate and other risks and increasing overall resilience of the systems. Results will serve two primary objectives:

- Inform federal, state, and local agencies with a role in community drinking water regulation and planning on *perceived risks* and the *status* of community efforts to increase the resilience of their water systems.
- Inform agencies as well as the OSU Extension Service where research or risk communication strategies are warranted as follow up.

Results and Discussion

The risks identified by system managers can be grouped into three broad categories: (1) risks directly related to climate and climate change; (2) risks not directly related to, but which will likely increase with, climate change; and (3) risks not related to climate change but which affect system resilience nonetheless. Results among these three categories are presented below, followed by results on risk reduction or resilience-improving actions that are underway or proposed and then results on specific research and information needs expressed by system managers.

Risks

Risks Directly Related to Climate or Climate Change

Climate-related risks perceived by system managers were related to the following three topic areas: flooding, drought, and coastal storms.

Flooding. A commonly reported risk was precipitation-derived flooding. Most reported that winter storms typically bring high-volume and high-intensity rains, which result in high water and land or bank slides. Those who rely on surface water were concerned with the slides, as they contribute large amounts of sediment to streams, and also the potentially contaminated runoff entering the streams. Those who pull groundwater as their main source were primarily concerned with well contamination associated with frequent and intense rainfall. Three of the surface water-fed systems did not view flooding as a risk at all.

Drought. Drought was also raised as a risk by about half of the system managers, though the level of concern varied substantially among them. For example, two of the systems expressed familiarity with climate projections that indicate more severe and frequent droughts in coastal Oregon, but as they have not yet experienced those effects, both indicated no concern at this point. Two additional systems were infrequently concerned—when the water levels became low in their impoundments, for example. On the other hand, two of the systems saw drought as a major and very real risk—one pulls surface and the other ground water. The remaining system managers were unconcerned with drought, though two had actually experienced relatively recent and severe droughts.

Coastal storms. A few system managers identified coastal storms, and in particular, storm surges, as a risk. While most did not express concern with sea-level rise, saltwater contamination from storm surges was expressed as a risk. A few of the systems have had to abandon one or more of their sources due to high salinity levels. One system manager discussed how landslides could isolate the community, cutting off emergency access, including backup water supplies. Another saw long-term power loss as a risk, as its distribution pipes traverse varied topography, thus requiring energy to pump it upslope.

Nearly all of the system managers interviewed perceived their drinking water system infrastructure as a major risk.

Risks Indirectly Related to Climate Change

Risks indirectly related to climate change—that is, those risks that will likely be exacerbated by climate change effects but are not directly linked to the climate—were typically the *first risks expressed* and often also those associated with the *greatest level of concern*. These risks fall into three topic areas: infrastructure, land use, and algae.

Infrastructure. *Nearly all of the system managers interviewed perceived their drinking water system infrastructure as a major risk,* including intake, storage, treatment, and distribution infrastructure. The primary cause of the risk is age—several interviewees reported that their system was nearly eighty years old. All but one of the systems identified the age of their infrastructure as problematic. Many also reported that the problem can be exacerbated by natural corrosion processes on Oregon's coast, which actually accelerate aging.

The relatively old age means that many of the pipes were constructed out of asbestos cement (AC). When prompted, most interviewees stressed that no health implications have been associated with consuming water that has traveled through AC pipes. The World Health Organization supports this claim, stating that epidemiological studies have not found asbestos to be a carcinogen when ingested orally (WHO 2003). The major concern managers expressed was the replacement of cracked and leaky pipes; there are strict regulations on AC disposal, and any activity that creates friction against the pipes runs the risk of exposing workers to AC dust, which *has* been proven harmful. Old age also means that many of the treatment systems have to be upgraded to meet new regulatory requirements; storage capacity is low, and water loss is high.

According to the interviewees, water loss is a concern for several reasons. Water wastage affects in-river fish and wildlife. There are financial costs, associated not only with pumping and releasing more water but also with the higher levels of energy required to pump water through pipe systems with leaks, due to loss of pressure inside pipes. One system manager reported an associated public health concern—low pressure coupled with leaks can allow contaminated water to infiltrate the pipes.

About a third of the systems viewed the low storage capacity of their reservoirs as a non-immediate risk. Most were confident in their ability to meet current demands, but storage capacity for fighting fires, other emergency uses, or substantial population growth was questionable. Only one of the systems was completely confident in the storage capacity of its system to meet current, future, and emergency demands.

In addition, two of the system managers believe their treatment system is inadequate to deal with the growing number of regulatory requirements pertaining to turbidity, algae, and emerging issues. Two of the systems expressed concern with local geography and the demands it placed on pumping and piping to residents. One discussed how the regulations on chlorine residue combined with pumping distance put the system at risk for trihalomethanes, a suspected carcinogen. Trihalomethanes and haloacetic acids are byproducts of the drinking-water disinfection process in which chlorine or other disinfectants react with organic or inorganic matter in source water (EPA 2011).

In general, the communities that have upgraded their systems or replaced at least some of their old infrastructure were less urgently concerned with their systems than those that have not.

Land use. Next to infrastructure, interviewees expressed the greatest concern with activities occurring within their source watershed but out of their jurisdiction. These activities primarily relate to forestry and agriculture, but commercial and residential development, roads, and sewage were also mentioned. One of the systems reported no risks whatsoever related to land use.

Forest management practices were by far the most commonly reported risk related to land use.

Forest management practices were by far the most commonly reported risk related to land use. Eleven of the water systems have at least a portion of their watershed—sometimes much more—under private timber company ownership. Though most interviewees reported that they do not currently have problems associated with forest practices, many reported past incidents and most conveyed a general concern with future uncertainty. Four of the systems stated that their current relationship with private timber owners in their watershed was generally positive—and good lines of communication were in place with regard to logging, spraying, or other activities that may contaminate streams. Others reported no working relationship with the timber companies in their watershed. The remaining two systems have either public forest (not currently being managed for timber) or no public or private forest in their watershed.

Agriculture is less common in coastal Oregon than in other parts of the state. However, some exceptions exist and thus some concern was present. Two of the systems pulling surface water perceived fertilizer and herbicide runoff as a risk. One of the systems pulling groundwater was concerned about agricultural practices in the system's wellhead area. One of the systems from time to time experiences dead livestock floating downstream from an upstream farm, which could, if decaying at the system's intake, pose a contamination risk.

The remaining land-use related risks emerged from the interviews and therefore were not part of the expert model. Contamination of supplies from roads was viewed as a risk by two of the systems relying on surface water. Both of these systems are sourced adjacent to a highway, putting them at risk for spray or oil contamination. One explicitly expressed concern with the amount of fuels transported next to its source. The other was more concerned with cars and trucks losing control and entering the water.

Sewage was reported as a risk by two of the systems, one of which has an abundance of residential property in its watershed and the other of which has none. Risks related to development, growth, and land use or ownership changes were identified by four of the systems. Mining and improper disposal of methamphetamines were each raised as a risk by one system.

One system also discussed a risk related not to its source water but to its distribution area: it does not own the land over which its pipes traverse; thus, maintenance and emergency repairs present challenges.

Algae. Finally, an emerging risk that may be indirectly tied to climate change is algal blooms, which are associated with warmer stream temperatures, increased sunlight, and increased runoff and flooding in areas rich in phosphorus (e.g., naturally occurring, agriculture-derived, or septic tank-related). Half of the interviewees mentioned experiencing either seasonal or ongoing occurrences of algae. One system has recently experienced a major jump in blooms, and another recalled 2008 as being particularly bad for algae. The majority of those experiencing problems reported the bloom created a foul taste and odor in the final drinking water product, resulting in complaints from concerned citizens. Algae can cause several complications for drinking water, including taste and odor, reservoir clogging, changes in pH, and the release of toxins from specific species following cell die-off or lysis (Carpenter 2003). This combination of effects makes treating for algae quite complicated and expensive; most systems reported they must either use a bonding substance (which leaves the algae in the water, but removes the associated taste and odor) or a special filter that targets algae (and won't clog). To date, the majority of algae species found in Oregon streams and lakes are not harmful while living, but several recent harmful algal bloom events have been documented (OHA 2012). Obviously a concern is that the incidence of toxic blooms is on the rise and will thus require greater investments to curtail health risks.

Risks Related to General Resilience

A final set of risks are presented here that will affect the resilience of small drinking-water systems but cannot necessarily be directly or indirectly tied to climate change. These primarily relate to tsunamis, human resources capacity, community awareness of and value attributed to drinking water, state and federal regulatory requirements, and the availability of and access to funding for system improvement or source water protection.

Tsunamis. A topic of great concern among interviewees was tsunamis, due in part to the recent distant tsunami event that caused minor damages to some communities on the Oregon coast. The majority of system managers reported that, while the water surges could contaminate water supplies and break water lines, the major risk factor would be the earthquake itself, which would severely damage distribution infrastructure. In one community, some of the main water lines traverse a bridge that is vulnerable to destruction in the event of a local or near-distant tsunami event. Other managers stressed the impact on water quality that would result from storm surges upstream into their water supply.

Staffing. Of the systems interviewed, nine viewed human resources capacity as a risk, namely shortage of qualified staff. All nine reported they have insufficient staff to adequately perform necessary tasks, mainly due to insufficient funds to hire additional personnel. Some are more able to work around this than others. For example, one manager reported that much of the routine system maintenance is left for hourly seasonal hires in the summer.

A related issue is acquiring and retaining skilled staff. Interviewees with three of the systems discussed this concern. One reported reason was the difficulty associated with attracting young, educated people to rural coastal towns. Another reason is the lack of funding to hold onto staff, often lost to bigger municipalities that can afford to pay higher wages. Yet another reason is the discrepancy between the number of retiring staff and the number of newly trained people; one manager pointed out that the nearest college is not graduating enough operators to replace expected retirees.

A final risk related to capacity was reported by one system: in times of crisis, backup assistance is not close at hand. Small, isolated places—a description that fits many of the communities interviewed—have to rely on skilled staff in other towns for help. Bigger cities inherently have higher capacity to deal with emergencies because of the greater number of skilled staff overall.

An emerging risk that may be indirectly tied to climate change is algal blooms.

Community. The majority of managers identified the risk of lacking community support for improving the resilience of their drinking water systems. This relates to: (1) lack of awareness in the community regarding risks to supplies, and (2) reluctance of the community to pay for water and water services. Without community support, efforts to protect source water and upgrade infrastructure are left to the city or system to address independently or with federal/state support, where available.

Most interviewees reported a low level of awareness among community members about the water system and risks. Many also felt their communities had the perception that public works staff were underworked and overpaid. The dilemma is that citizens expect reliable, safe drinking water but lack understanding of the level of effort required to achieve this. Several interviewees attributed the lack of awareness among their communities to the fact that citizens don't see the process; municipal water is expected to come out of the tap when it's turned on, and disappear down the drain or the toilet. Citizens don't have to be concerned with how the water reaches them or how it leaves. One manager termed this the "flush and forget syndrome."

Some communities have demonstrated awareness of risks tied to a certain issue. For example, two managers reported their communities were highly concerned with new regulations that require in-stream flows for fish. Another reported a community concern for development and consequent supply/demand matching challenges. Two managers reported community concerns associated with media coverage of various public health risks—for example, radioactive elements and chromium in drinking water.

One interviewee raised a point about the tendency of people to make decisions reactively rather than proactively. This is an observation shared by many practitioners who engage regularly on the topic of resilience (Cone and Brown 2011). For instance, communities are reluctant to invest time and resources into measures that have not yet proven to pose risks, for fear of compromising resources—time, money, etc.—needed in the present. The real challenge here is that often by the time risks are acutely evident, it's too late to take affordable and effective action. Thus, even with uncertainties looming, planning for likely changes seems wise.

Most systems charge very low rates for municipal water, relative to the costs of supplying that water. Many have recently realized that the only way to fund needed improvements is through adjusting the water pricing structure or raising the overall rates. While some community members understand and support this, many do not, and thus rate adjustments are often voted down. Most system managers reported that their communities either: (1) were satisfied with the current rates but resisted increases; or (2) thought the rates were already too high and should be lowered. However, many interviewees also reported that conservation in their communities is on the rise, meaning the higher rates may be encouraging citizens to use less water. Most of the system managers themselves supported a tiered system and higher rates overall for both cost recovery and system improvement purposes.

> Most interviewees reported a low level of awareness among community members about the water system and risks.

Regulations. While regulations of course are intended to protect public health and the environment, all of the systems interviewed struggle with meeting what seem to be increasingly stringent regulations. Paperwork, testing, and other time-consuming processes consume already limited staff time and system resources, making it a challenge to meet regulations and also manage the day-to-day tasks. The regulations of greatest concern for consuming time and resources were related to water quality, repairs, and renewing water rights, especially dormant (reserved for the future) rights. In addition, regulations such as the Endangered Species Act pose challenges for cities and systems that have designed their system around a particular water right that may now be in question.

Funding. Aging infrastructure, coupled with increasing costs associated with collecting, treating, and delivering drinking water to consumers, has left most systems searching for ways to fund improvements, protect their source water, and increase their human resources capacity—e.g., hire more qualified staff. With community members generally unable or unwilling to bear the cost, securing outside funding is imperative. Unfortunately, one of the most common risks reported by interviewees was a lack of *accessible* outside funding—federal, state, etc.

Most system managers stated that, while funding was "available," it wasn't readily accessible to small, rural communities, because: (1) most funding comes in the form of loans, which must be paid back through taxes, increased water rates, etc., making it a difficult

A Japanese girl despairs after the 2011 tsunami. An earthquake and tsunami in Oregon could damage the water distribution infrastructure and affect water quality.

option to afford; (2) the amounts available aren't enough to make a dent in the needed improvements; and (3) there are too many strings attached and steps involved for capacity-limited systems.

Four of the system managers reported that they did not qualify for most loans and grants, primarily because their rates are too low. The government funding programs essentially require communities to take independent action before seeking assistance. This presents a particular challenge for those communities in which rate increases are repeatedly voted down.

Four of the systems expressed concern that small, rural communities would be at risk for failure in the future unless the state or federal government prioritized small systems for funding. One manager was surprised that aging infrastructure was not recognized as a health hazard, stating that funding should be available on that basis alone.

Of the 13 systems represented in the interviews, only one reported successfully having used federal or state funding. Three of the communities have never gone after outside funding—two because local politics have impeded application processes, and one for lack of need.

Resilience-Increasing Actions

Improving system resilience will require understanding and planning for risks and increasing overall adaptability, so that unforeseen changes can be dealt with if and when needed. Examples of specific resilience-improving actions include preparing management or emergency plans, securing backup water supplies, protecting source water, improving infrastructure, and engaging with the community to enhance political support.

Planning

Under most circumstances, the State of Oregon requires community systems to prepare a Water Management and Conservation Plan (WMCP), which "describes the water system and its needs, identifies its sources of water, and explains how the water supplier will manage and conserve those supplies to meet present and future needs" (EES 2003). One manager reported that the system's WMCP was not currently being used. A drawback of the WMCPs is that, while they do address securing supply and curtailing demand, they do not address adaptation. Another potential issue is that public involvement in the planning process is not required (EES 2003: 17), which could pose a challenge for attaining community support for any related efforts. All but one system interviewed has an active and up-to-date WMCP. However, the interviewees reported varying degrees of usefulness of these plans.

Several interviewees reported they have local emergency planning documents for various situations, but many reported these plans need updating or are in the process of being updated currently. Most interviewees expressed the greatest concern with tsunami emergency response. In addition to planning documents, many interviewees discussed how emergencies are communicated, such as tsunamis and boil water advisories, to the public. The recent tsunami event seems to have served as somewhat of a wakeup call to many of these communities in regards to the efficiency and effectiveness of communication. A boil water advisory in one coastal community in summer 2011 also illuminated the importance of immediately communicating the risk to the public, as several citizens had not been informed and continued to drink potentially contaminated water.

Backup supply

Only 3 of the 13 systems reported having a backup water supply that could be utilized in the event their primary source becomes unusable for any reason or their demand increases beyond the capacity of their main supply(ies). These three systems all reported, as discussed above, a concern with holding onto their backup supply, as the state now requires that dormant rights be documented in a Water Management and Conservation Plan. They also conveyed concern that developing backup supply rights would be challenging, due to pressure from environmental interest groups to take

To better protect their drinking water, some communities in coastal Oregon have embarked upon various source-water protection initiatives, such as fencing alongside streams to prevent fecal contamination.

away unused rights to leave more water in streams for aquatic life. One additional system did have a backup supply but has already tapped into it.

Six systems do not have a backup supply. Two of these systems have multiple supplies but currently rotate among them by season; both are concerned there will not be ample supply for future needs, especially given development pressures. Another has a source that was polluted and will therefore not be of use if needed. One system has acquired some nearby groundwater rights but they may be too small in quantity and may require too much effort to develop. The remaining two of the six have not been able to identify any feasible backup supply. These two rely on surface water where rights have been maxed out and no local groundwater supplies show potential for development.

The remaining three systems did not indicate whether they had a backup supply.

Source water protection

One of the strongest defenses against poor drinking water quality is source water protection (Freeman, Madsen, and Hart 2008). However, state and federal mandates for riparian setbacks and buffers are inadequate in many cases. For example, there are no such mandated protections in place for non-fish streams. Such buffers would provide a great deal of protection against many contaminants originating from managed forests and agricultural lands (ODEQ 2012). This means that surface water sources are potentially at risk for contamination from adjacent or nearby land-use practices. To better protect their drinking water, some communities in coastal Oregon have embarked upon various source-water protection initiatives—for instance, purchasing land in the upper reaches of their watershed or working with private landowners to decommission old forestry roads or fence animals out of streams. The Oregon Health Authority (OHA) and Oregon DEQ completed source-water assessments for all surface water systems—and some of the groundwater systems—throughout the state, to highlight geographic areas most susceptible to contamination and potential sources of contamination (ODEQ 2012c). Oregon DEQ, OHA, and the Oregon Association of Water Utilities (OAWU) regularly provide grants or technical assistance to help water systems develop and implement source-water protection strategies (ODEQ 2012b). As an example of how this assistance can be used, one community acquired a grant from the state to solicit protection assistance directly from landowners, by going door-to-door.

Of the study systems reliant on surface water, five systems were taking action to protect their source water; the remaining surface-water-fed systems rely on periodic communication with landowners. Three of the five protecting their source water had delineated protection zones in their watersheds, one of which had acquired land through recent purchase and easements. One system had recently received OHA funding for enhancing its source water assessment. And one system had a formal agreement in place on management practices with the private timber company that owned much of the watershed. It should be noted that it is unclear whether or not these actions were the result of initiatives on behalf of the systems themselves or the recent ODEQ source water assessments—a major outcome of the source-water assessments was delineated protection areas.

Systems relying on groundwater consider activities taking place in the wellhead area—that is, the area above ground from which water and other substances can enter directly into the aquifer supplying a well. Activities in wellhead areas can potentially affect groundwater quality. Federal regulations, namely the Safe Drinking Water Act and the Groundwater Act, help protect groundwater supplies, with both wellhead protection areas (100 feet) and sewage/hazardous waste disposal site setbacks (50–500 feet) required (ODEQ 2012). However, depending on the type and intensity of land-use practices, these regulations may or may not be enough to prevent all forms of contamination. For example, federal law stipulates that public water supply wells be placed a minimum of 50 feet from confined-animal feeding operations (ODEQ 2012), but no animal number or operation size is associated with this setback minimum.

Representatives of three groundwater-fed systems were interviewed. One reported having a wellhead protection area and one not. Another reported a federal protection mechanism in the wellhead area, but did not specify whether the protection zones extended to the greater watershed.

Infrastructure Improvements

In line with the findings of Achterman et al. (2005), system managers reported they are doing everything within their financial means to make necessary infrastructure improvements. While three of the systems are fiscally capable of routine, preventive upgrades, the majority reported they must prioritize system needs and are very much limited financially.

Six of the systems have either recently upgraded or are in the process of upgrading their storage tanks or reservoirs to store more water, allow sediment to settle prior to treatment, or improve the general function of the system. Three systems have invested in replacing old or leaky pipes. Three others have upgraded their treatment systems to improve filtration or treatment capacity, or to adapt to the increasing need to treat for algae. One additional system recently invested in covers for the reservoirs, to improve the quality of raw water entering the treatment system.

Communication

Widespread community support can: (1) help ensure that planning efforts are seen through to fruition; (2) enable investments in infrastructure and land acquisitions; (3) improve conservation by individuals and commercial industries; and (4) put effective pressure on private landowners to use best management practices. Virtually all the interviewees expressed discontent with the level of awareness of citizens in their communities, as discussed above; yet very few are currently taking action to build awareness. The system managers interviewed who *were* working to raise community awareness were both adamant there was a need and confident in the results of their efforts.

A few systems reported providing printed educational materials to citizens to raise awareness of various issues related to water. The most comprehensive of these efforts involved a variety of approaches, including presentations, YouTube videos, and the local newspaper. The manager of this system stated, "I have spent the last four years [giving] presentations to this community to raise the awareness and the need to protect our water source to provide for the future water needs, and more importantly, to complete the infrastructure projects that need to happen in order to continue to use the system." This manager reported he consistently receives positive feedback from local citizens via phone calls and e-mails, as well as increasing support from voting residents for making financial investments in upgrades and protection efforts.

> System managers reported they are doing everything within their financial means to make necessary infrastructure improvements.

Networks

With the limited capacity that so many of these small community systems face, forming reliable networks with nearby systems may be critical. Some of the coastal systems in Oregon use one another for technical support. Others share equipment. Some have even considered system consolidation, though political support for this from communities has been low and funding has been difficult to secure. However, only two of the managers interviewed reported they have a formal agreement with a nearby system for emergency purposes. This means the remaining systems must devise solutions for themselves in the event their supply becomes contaminated or affected by a drought, fire, or other hazard.

Research and Information Needs

In addition to risks, interviewees were asked what their research and information needs were in respect to protecting and enhancing the resilience of their drinking-water systems. The majority reported that they had no pressing needs, or at least could not think of any at that time. However, a few interviewees did identify specific needs.

Three mentioned that GIS mapping of their systems would be very useful, but it was also mentioned that this carries with it a security risk (as of now, intake sites and distribution lines are not public knowledge; mapping could inadvertently expose the locations).

Three noted that risk assessment guidelines would be useful. For example, one manager requested a checklist of risks accompanied by risk mitigation measures for each risk. Another pointed to a need for water quality assessments, particularly of source water.

A few of the systems, though not reporting current pressing needs, did mention how useful recent research and information has been to their systems. For instance, one recently had university research assistance conducting water chemistry panels; another recently undertook a watershed assessment; yet another had assistance mapping the watershed with GIS.

Expert Model versus Perceived Risk

The unique approach of the MMI method allows for interesting comparisons between risks identified by the experts (in the expert model) and those identified by interviewees. While this paper is not intended as an in-depth discussion of knowledge versus beliefs, a few observations along these lines are noted. Following are four general observations relating to differences observed between the expert model and analysis results.

First, experts and interviewees conceptualized "risk" quite differently. Experts from the state and federal government primarily spoke of risks that affected source water, such as flooding and upstream land-use practices, while interviewees in almost every case were primarily concerned with failing infrastructure, regulations, and lack of funding to address either. State and federal agencies working with small systems should therefore be aware that as long as system managers are facing immediate threats to the survival of their system, it will be difficult for them to focus on longer-term goals, such as source water protection. Furthermore, while these imminent risks will most certainly have to be addressed to increase system resilience, long term planning and adaptation initiatives should be implemented in concert with short-term efforts to reduce the need for recurring crisis management.

This relates closely to the second observation—experts spoke of risk-reduction responsibility as being primarily at the community level, while interviewees generally agreed that the federal and state governments should provide a substantial and accessible stream of funding to reduce risks to small community water systems. There was a general consensus, however, in how experts and interviewees viewed opportunities for small systems to acquire funding for infrastructure and watershed improvements: most agreed that funding is limited and difficult to acquire.

Third, most interviewees were relatively unconcerned with effects that could be attributed to changes in climate, even when they had experienced those changes. For example, two communities had experienced severe droughts in the past 20 years but remained unconcerned about planning for drought in the future. Some systems that did not have backup supplies or large storage capacity (e.g., enough to hold water from the winter to use into the summer) remained unconcerned about future shortages. One interviewee who discussed coastal storms at length opined that climate change would not be an issue in the area. This general lack of concern is in contrast to the 2010 OCAR, which stated:

> Coastal infrastructure will come under increased risk to damage and inundation under a changing climate with impacted sectors including transportation and navigation, coastal engineering structures (seawalls, riprap, jetties, etc.) and flood control and prevention structures, water supply and waste/storm water systems, and recreation, travel and hospitality. (Ruggiero et al., 2010)

A few of the interviewees did express concern with climate change; those tended to be the systems taking action on backup supplies, WMCPs, and source water protection.

Finally, interviewees raised risks not included in the expert model, but that the author was able to find verification for upon further review of the pertinent literature. These risks included algae, sewage, asbestos, contamination from roads, and lack of internal and external backup assistance.

Evaluating and Revising the Expert Model

Discrepancies between the expert model and system managers' perceptions can not only indicate a misperception of risk but also suggest shortcomings in the expert model itself. The interviewees themselves should be considered experts on many of the topics—namely infrastructure, costs, local politics, etc. Thus, some points raised by interviewees could, upon further evaluation, be added to an updated expert model.

Reevaluating the expert model is further justified in that the number of state and federal agency personnel consulted in developing the model was extremely limited. In addition, interviews to collect information for the model were brief, meaning that not all critical information was necessarily conveyed. Already, a few shortcomings have been identified by the experts themselves. For example, one suggestion was for the "climate risks" category to include wildfires; another was for the "geologic risks" category to include earthquakes, landslides, and saltwater intrusion. It is quite likely that, upon vetting with experts outside the original group, further revisions would be suggested.

Conclusions and Recommendations

One of the first recommendations for future research includes workshops with the public, water-supply officials and planners, and local climate-change experts to exchange information and communicate risk.

This study was intended as a preliminary investigation to identify future research and outreach opportunities, given Oregon Sea Grant's interest in and commitment to improving human health and safety in Oregon's coastal communities. This preliminary study has found that community drinking water systems may be unprepared to deal with a variety of both potential and real risks that may threaten the health of residents.

All risks in the expert model were identified by at least one interviewee, and some new risks emerged from the interviews, as well. New risks could potentially be added to a revised expert model by including additional experts and also considering the interviewees (or a new group of system managers) as broadening the expert perspective. Evaluating and revising the expert model is encouraged to ensure its accuracy in going forward with the recommendations that follow.

The first recommendation for future research is thus to gain a better understanding of risks to coastal community water supplies, which could be achieved through three steps: (1) a follow-up survey of a broader representation of the same population, as Morgan et al. (2005) recommend for the risk communication method; (2) interviews or surveys of coastal planners who are responsible for devising community adaptation plans; (3) surveys with the general public in coastal communities to better gauge their understanding of risks; and (4) workshops with the public, water-supply officials and planners, and local climate-change experts to exchange information and communicate risk.

An additional recommendation of this study is for Oregon Sea Grant to partner with state and federal agencies responsible for water rights administration and regulation, with Oregon's source-water protection technical assistance staff, and with coastal communities of interest. Such partnerships are recommended because of the resulting unique combination of expertise and experience of Oregon Sea Grant and state and federal personnel, coupled with the interest, need, and willingness to take action on the part of select coastal communities.

Some risk mitigation measures that could be pursued based on the findings of this study include: (1) source water protection in watersheds with the majority of source water originating from lands outside ownership of the community or system in question; and (2) formulation of more networks among communities (based on geography) for both information exchange and emergency assistance. While the Oregon Association of Water Utilities (OAWU) was discussed as a valuable resource for information by some of the interviewees, tighter and more localized networks would have the added value of providing immediate assistance following a disaster or in times of severe water shortage. Currently, some coastal communities are involved in such networks, but the majority the author spoke with were not.

While lack of funding is a real impediment to action, Oregon Sea Grant is not in a position to make policy recommendations. Thus, its future related efforts will focus on actionable items within its realm of expertise and authority—namely, research and outreach.

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Appendix

Interview Checklist

[Check box on the left if interviewee raises topic; check right if interviewer raises it.]

Sources of Risk

___|___ **Climate / Geological**

- ___ Coastal Storms
- ___ Droughts
- ___ Floods
- ___ Tsunamis
- ___ Other
- ___ Other

___|___ **Infrastructure**

- ___ Failing or Leaking Pipes
- ___ Low Storage Capacity
- ___ Poor Treatment Technology
- ___ Other
- ___ Other

___|___ **Socio-political**

- ___ Forest Management Practices
- ___ Agricultural Practices
- ___ Insufficient Staff
- ___ Regulations
- ___ Lack of Community Support
- ___ Lack of Funding
- ___ Other
- ___ Other

Risk Effects

___|___ **Public Health**

___|___ **Infrastructure**

___|___ **Community Government**

___|___ **Environment**

___|___ **Economy**

Risk Assessment, Management, and Comparison

___|___ **Assessment**

- ___ Programs/financial assistance for evaluating risks
- ___ Independent evaluations
- ___ Responsibility of evaluations (e.g., system, local, state, federal)
- ___ Information needs prior to risk evaluation
- ___ Research/evaluation needs

___|___ **Management**

- ___ Upgraded Infrastructure/Storage/Treatment
- ___ Backup Supply
- ___ Source Water Protection
- ___ Emergency Plans
- ___ Adaptation Plans
- ___ Water Management and Conservation Plans
- ___ Communication
- ___ Water Pricing
- ___ Networks
- ___ Funding and Technical Assistance

___|___ **Comparison**

- ___ Importance relative to other risks in this community—system manager perspective
- ___ Importance relative to other risks in this community—opinion on community perspective

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