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Abstract

Under current trends, municipal demand for water in Oregon's Willamette River Basin will double by 2050. Municipalities will have to develop new sources of water, in competition with agricultural and other established uses, as well as increased demand for water to support ecological values. Municipalities can, to a limited extent, turn to their currently dormant water rights, but executing these rights will displace other currently established uses of water or diminish flows for fish and wildlife. Recent listings of salmon and other fish under the Endangered Species Act greatly diminish the acceptability of making water-use decisions without accounting for their potential impacts on water quantity and quality throughout the basin. This paper adopts a basin-wide perspective to analyze the need for new development of new sources of municipal water in the basin, and the impact of increased municipal water demand on water resource management in the basin as a whole.

The analysis employs a computer model that simulates the regulation of water rights across the basin. We develop scenarios for future demand and supply of water, and use the computer model to determine the resulting allocation of water across water rights in the basin. Results indicate that the state's three largest urban areas have adequate water resources, but many smaller municipalities will have to develop new sources. The analysis here indicates that eliminating summer releases from storage in the basin's federal reservoirs would not affect water availability at current municipal points of diversion.

Subject area classifications: water supply; water resources.

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Caveat: Although EPA supported this study, it has not been subjected to the Agency's required peer and policy review. Therefore the study does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

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I. Introduction

The Willamette River basin occupies only a small proportion of the state of Oregon, but it is home to the majority of the state's population and the three largest urban areas. (Figure 1 shows the location of the basin, and some major landmarks.) Western Oregon is renowned for its wet climate, but the Willamette basin has apparently run out of "easy" water: the Oregon Water Resources Department has put severe limits on where it will issue new water rights in the basin (Bastasch, 1999, p. 68). Demographers expect the basin's population to double by 2050 (Institute for a Sustainable Environment, 1999). Where will the basin's future residents get their water, how much do they need, and what will they sacrifice in the process?

The planning of urban water resources requires assessments of future demand, infrastructure and available water supplies. The natural water supply is the simplest way to represent the available water supply, but this may exaggerate available water since it does not account for consumption of water upstream. Further complications arise because Oregon, like other western states, regulates water use by the "priority" of the water right, and the state can shut off a water user if a superior right downstream is adversely affected. Even municipalities with high priorities are not without some risks. If increasing their water diversions shuts off established users upstream, adverse economic, social, and political impacts could be severe.

Since a single water use can affect other users upstream and downstream, comprehensive and reliable water resource planning must take place from the perspective of an entire basin, where the planning can consider all competing interests. This paper adopts a basin-level perspective to analyze the future of urban water resources in the

Willamette River Basin. The analysis focuses strictly on surface water supply and demand, since the link between surface and ground waters has not yet been clearly established in the basin. We give a spatially-explicit assessment of the future urban demand for water, and discuss the basin-wide implications of using existing sources of water to meet some of those demands. The public, politicians and resource managers often look to the federal reservoirs in the basin as the answer to the basin's water problems. So we also examine the extent to which changes in the reservoirs' operation could affect surface water management in the basin.

The analysis is based on three components: a spatial database of all surface water rights in the basin; a model for natural streamflow; and a computer model that synthesizes the first two components to simulate regulation of water rights across the basin. Section II contains a brief description of water regulation in Oregon, and section III has a detailed description of the water rights data, the model for natural streamflow, and the computer model.

Section IV contains a graphical analysis of two different future scenarios. The first is based on a projection of diversions in the basin in August, 2050, and with natural streamflows and releases from reservoir storage following historical patterns. The second scenario uses the same projected diversions, but water supply includes only natural streamflows (i.e., no summer storage in the reservoirs).

According to this analysis, many small municipal water providers in the basin must undertake major development of their infrastructure to secure water from new sources. The need arises not only from greater demand, but also from anticipated stricter regulation of water rights in the future. If the federal reservoirs operate following historical patterns, the analysis indicates that increased municipal diversions will have little or no impact on other water rights in the basin. Eliminating summer storage from the federal reservoirs has virtually no impact on municipal water rights in a "dry year", but several large hydropower and aquaculture rights may face severe restrictions. The restrictions are concentrated in a relatively small part of the basin, but the affected areas are near the second and third largest urban areas in the basin, so they may have adverse impacts on the basin's economy. We discuss these results further in section V, which concludes the paper.

II. Water regulation in Oregon

The state of Oregon regulates water use by a system of water rights based on the "prior appropriation" doctrine. Under this system, the owner of a water right has permission to use the public's water, subject to various conditions. For the purposes of this paper, the most important conditions are the location of the point of diversion and the "priority".

The prior appropriation system allocates water across those who hold water rights by establishing a queue of users; in essence, water is distributed along the queue until the end of the queue is reached, or until the available supply is exhausted. The priority of a water right establishes its position in the queue. The specified priority of a right is typically a date – in Oregon, the priority is generally the date at which the Oregon Water Resources Department (OWRD) received the application for the water right.

There is one exception to the relationship between priority date and position in the queue. A water right for hydropower generation cannot displace a water right upstream with a junior priority (Oregon Administrative Rules 690-051-380). Hydropower rights are thus always at the end of the queue, where they can compete with each other but not with other water rights.

In practice, the allocation of water along the queue occurs through the recurrent establishment of a "regulation date" at every water source. The state official charged with setting regulation dates is called a "watermaster". For example, a watermaster might determine that, for a particular subbasin there is only enough water in the given month to satisfy water rights up to a priority date of 1950. All water rights with priorities after 1950 may not use any water, and all water rights before 1950 may use the amount that they are legally entitled to; 1950 is therefore the regulation date. Regulation dates generally apply to dry, summer months and can vary over time and across the basin, reflecting local variations in climate. See Bastasch (1998) for more details on water rights and water management in Oregon.

III. The method of analysis

The Willamette River basin contains thousands of surface water rights, with widely varying priorities, uses and points of diversion. There are only a hundred or so applicable municipal water rights, but these rights are distributed throughout the basin, with priorities ranging from 1857 to 1989. Analyzing the impact of increased municipal diversions on the competition for water is a computationally intensive task that would be impossible without a specialized computing tool.

The tool used in this paper is a computer program, called The Watermaster, that simulates the actions of a real watermaster in establishing regulation dates and allocating water. The program requires three basic inputs:

1. a list of points of diversion, and the position of the points in the stream network;
2. the total supply of water at each point of diversion; and
3. a list of all water rights that divert from live flow, along with various characteristics of the rights (discussed below).

The Watermaster synthesizes these three inputs and calculates the regulation date at each point of diversion. It then allocates water to all water rights whose priority dates are below the regulation date, and calculates the net consumption of water (water not returned to the stream) at each point of diversion. Finally, it calculates the resulting flow at each point of diversion, by subtracting consumption from the total water supply. Figure 2 gives a graphical summary of The Watermaster program.

The output of the program is a simulation of water use across the basin, based strictly on the legal mechanisms for allocating water, and the information supplied to the program. We do not regard the output of the program as a prediction or forecast of actual water use, for two reasons. First, actual water use can legally (or illegally) depart from that based on purely legal prescriptions. For example, the owners of competing water rights can voluntarily engage in a "rotational agreement" in which the owners agree to coordinate their diversions. And second, accurate predictions of regulation would require accurate predictions of natural stream flow, diversions and consumption. The best available information on the inputs is still not good enough to expect accurate predictions of the model. See Dole (2000) for more details on The Watermaster program.

The points of diversion

Although a water-right holder must specify the exact location where water is diverted, this spatial detail is not analytically useful because the Oregon Water Resources Department does not have an estimate of streamflow at each point. Instead, it has estimates only for 178 points, distributed throughout the basin. By necessity, these 178 points became the spatial foundation for this analysis. That is, The Watermaster regulates water use as if diversions occurred only at the 178 points where estimates of water supply are available. This is not as limiting it might seem, since regulation in practice also occurs over broad areas, and is not necessarily different at each unique point of diversion.

The program also needs to a know the spatial relationship between the points of diversion. To this end, the program requires a list of the points (if any) that are upstream of each point of diversion.

The drainage area above each of the 178 points in the stream network determines a set of nested watersheds, which culminate at the mouth of the Willamette in the entire Willamette River Basin. Moving downstream between consecutive points, the drainage area increases, while encompassing the previous drainage area. The difference between the drainage areas of consecutive points defines a relatively small area which in this paper we will refer to as a "sub-basin". We derived the sub-basins from the nested basins that the Oregon Water Resources Department calls "Water Availability Basins" (WABs). The WAB is the department's primary spatial unit of management and analysis. The distinction between a WAB and this paper's "sub-basin" is that a WAB is a proper drainage basin, while our "sub-basin" is merely part of a basin: at any one of the given

178 points in the stream network, the collection of all sub-basins upstream equals the WAB defined at that point. Figures 3 through 10 each show the boundaries of the 178 sub-basins.

As discussed above, the location of the point of diversion for each water right is specified only in terms of sub-basins. Hence, the size of the sub-basin determines the spatial resolution of this analysis. The sub-basins vary considerably in area (from 1.18 to 398 square miles), so the spatial resolution of this analysis varies across the basin.

The water supply data

Before The Watermaster can start the process of simulating regulation, the program needs to know the total available supply of water at every point – the flow that would occur in the absence of any human consumption of water upstream. As it starts the regulation process within a sub-basin, it subtracts upstream consumption from the total supply, to get the available supply of water within that sub-basin. In general the total supply of water consists only of the natural stream flow. In some places in the Willamette Basin, though, the natural stream flow is augmented by releases from reservoirs upstream.

The Oregon Water Resources Department issues rights to divert from rivers and streams with respect to natural flow only, and not with respect to releases from reservoirs upstream (rights to divert reservoir water are attached specifically to the reservoirs). In practice, though, water users can divert from both natural flow and reservoir releases. This occurs since the owners of water rights themselves drive regulation. That is, a real watermaster regulates water in response to complaints from the owners of water rights; if releases from a reservoir are not attached to a specific water right, there is no practical mechanism for preventing any water user from diverting the released water. Hence, a water user below a federal reservoir has access to releases from the reservoir, even if it does not have a formal legal right to divert from such water.

We wish to emphasize, though, that even if such diversions may occur in practice, it is contrary to both water rights law in Oregon and the general policies of the Oregon Water Resources Department. We include such illegal diversions in this paper in recognition that such diversions can occur, but we do not endorse it and we especially do not recommend it as a means to obtain water.

We used two different scenarios for total water supply in this analysis: natural streamflow plus the change in reservoir storage, and natural streamflow alone. Comparing the two scenarios will give an indication of the maximum impact of the reservoirs on water regulation in the basin. It will also indicate the maximum impact that changing the management of the reservoirs may have on water regulation, since the Army Corps of Engineers is currently conducting a study of the future management of the basin's reservoirs (see www.wrd.state.or.us for more information). Future management of the reservoirs may differ significantly from previous management, but it cannot (and almost certainly will not) be as severe as the scenario analyzed in this paper.

The Oregon Water Resources Department has developed a statistical model that estimates natural stream flow at the "pour-point" (i.e., lowest point) of each sub-basin; that model provided the estimates of natural stream flow used in this paper. The Oregon Water Resources Department's model does not predict actual streamflows at the pour-point of a sub-basin. Instead, it aims to predict points on the probability distribution of natural flows. For example, the model can predict the 20 percent quantile (or the 80 percent "exceedence level") of the probability distribution of natural flows – natural flow is below this point 20 percent of the time. The model can predict any point on the probability distribution, but we used the 20 percent point here, since that is consistent with Oregon Water Resources Department's water resource management and analysis. We interpret the 20 percent level as a scenario for a relatively dry year (but not drought conditions). See Cooper (1993) and ECONorthwest (1999a) for further details on the model of natural streamflow.

The US Army Corps of Engineers provided data on the daily storage in each of the federal reservoirs in the Basin, for the period 1967 to 1995. Using these data, we calculated the average daily diversion or release from each reservoir, for each month of the year. The analysis reported in this paper is, in this sense, one based on historical management of water resources in the Basin. It is likely that the reservoirs will be managed much differently in the future. The method of analysis here is sufficiently adaptable that it can easily accommodate future changes in reservoir management.

The water rights data

The Oregon Water Resources Department supplied data on all water rights that allow legal diversions from natural stream flow in the Willamette River Basin. A water right is subject to many different conditions, but The Watermaster requires only five pieces of information:

1. the priority date;
2. the location of the point of diversion;
3. whether the water right is an in-stream right;
4. the amount of water diverted; and

5. the amount of water consumed (not returned to the stream).

As discussed above, the points of diversion are consolidated to correspond to the nearest downstream pour-point of a sub-basin. Of course this means that many water rights were piled up at the same point of diversion. In this case, The Watermaster allocates water sequentially through the rights at each point, in order of priority, giving each water right its desired amount, or the available supply, whichever is smaller. The Watermaster assumes that any amount not consumed is returned to the flow, and is available for the junior water rights at that point of diversion, and to all water rights downstream.

The return flow from some municipalities (and probably other types of water rights) occurs downstream from the point of diversion, but the analysis here assumes that the point of diversion and return flow are coincident. The water rights database does not include information on the location of the return flow, so we are attempting to get this information from other sources. Later versions of this paper will allow for the point of diversion and return flow to be different.

The Watermaster treats in-stream water rights in the same manner as all other water rights, with one minor exception. An in-stream water right does not consume any water, and yet the entire flow allocated to the right is not available for the junior water rights at that point of diversion (an in-stream water right does not extend beyond the pour-point of a sub-basin; a different in-stream water right would apply downstream). The Watermaster ensures that whenever an in-stream water right is in force, the streamflow protected by the right is not available to other uses in that sub-basin, but the water is not consumed and so is available to other water rights (including other in-stream rights) downstream.

We modeled the amount of water diverted by each water right as a function of two aspects of the water right: the legal use of the water, and the maximum allowed rate of diversion. This paper focuses on municipal diversions, so we will discuss that type of use separately and in more detail below. For the other types of use, we specified the amount diverted as a percentage of the maximum, allowed rate of diversion. This percentage, which we call the "coefficient of diversion", varied by the type of use.

For irrigation, we used a coefficient of diversion developed by Berger and Bolte (2000), who developed a model of agricultural land use in the Willamette River Basin, with projections of agricultural production (including irrigation water applied) out to 2050. Berger and Bolte developed this coefficient of diversion by modeling, at the level of actual fields in agricultural production, the crops that are grown on those fields, the water requirements of those crops over the irrigation season, and the rate and duty of the water rights attached to the given fields. They then aggregated the diversions of each field over the sub-basins, to given an "average" rate of diversion of irrigation rights per sub-basin.

For the other types of use, we set the coefficient of diversion at 100 percent. This is a reasonable value for at least three types of use: in-stream water rights, hydropower generation, and industrial uses. In-stream water rights would be "executed" at their full capacity at all times. Hydropower rights are always at the end of the queue, and so they get whatever is available; the "diversion" to the hydropower right thus does not affect the calculations. One could expect that existing industrial water rights would be fully executed by 2050 (if not now). The remaining types of use, such as drinking water for livestock, make up only three per cent (by rate of diversion) of the water rights in the basin, so the results would not be especially sensitive to the coefficient of diversion for these other uses.

We modeled the amount of water consumed as a percentage of the amount diverted, as shown in Table I. These percentages, derived from various studies conducted by the USGS, are used by OWRD in its assessments of the availability of water for further allocation. Consistent with the assumption in Berger and Bolte (2000) we assume farmers use water efficiently and, hence, we set the coefficient of consumption for irrigation at 100 percent for all runs of The Watermaster reported in this paper.

Diversions by municipal water providers

Municipal water rights have a unique status among water rights in Oregon: a municipality may hold a water right with a maximum rate of diversion in excess of the municipality's current capacity or intention to divert. Other types of water rights must demonstrate, at different stages in the application process, the potential to divert the requested amount, and (later in the process) that they are actually using the requested amount. If the maximum rate of diversion on the water right exceeds the potential or actual diversion, the OWRD would reduce maximum rate of diversion to whatever is observed at the time of inspection. Hence, for other types of water rights, diversions can be modeled using the maximum allowed rate, but municipalities require special consideration.

For the purposes of this study, the Portland Water Bureau developed scenarios for possible municipal diversions within the Portland Metropolitan area. (The Bureau's scenarios provide a realistic depiction of potential diversions within the Metro area, but the scenarios should not be regarded as more than that.) We used the Bureau's scenarios to model diversions within the Metro area.

A different approach was required for municipal water providers outside the Metro area. Modeling municipal water demand is a complex and data-intensive task. Many studies have been published reporting different approaches to this task, but even the simplest approach can be very difficult and time-consuming. Dziegielewski (1996) describes the state of the art in forecasting municipal water demand. The analysis reported in this paper required a scenario for demand for each of 69 municipal water providers, so we had to use a relatively simple approach: multiplying the total population in the service area by the average rate of diversion.

The Institute for a Sustainable Environment at the University of Oregon provided projections of population within the urban growth boundaries (UGBs) for all urban areas of the Willamette River Basin. An informal analysis of municipal service territories and UGBs indicated that UGBs coincided closely with service territories, so we took population of the UGB as a predictor of the population of the service territory.

The Oregon Water Resources Department provided data on recent diversions associated with all municipal water rights in the Willamette River Basin. From these data we identified the active points of diversion associated with each municipal water right in the Basin, and the amount of water supplied by each. We calculated the total monthly diversions for each municipality, and for each active water right, we estimated the percentage of total diversions supplied under that right, also by month. For example, we calculated the average per capita rate of diversion as 0.268 gallons per minute in August (5.97E-3 cfs), and 0.218 gallons per minute in September (4.85E-3 cfs).

To develop a scenario for future diversions, we spread the total estimated demand for each municipality across its active water rights, in the proportions estimated from their recent diversions. For each water right, we capped the total diversions by the maximum allowed rate of diversion. If the projected diversion for a water right exceeded the maximum allowed rate, we reallocated the excess demand to active rights that had excess capacity.

We allowed for two departures from current infrastructure. First, we assumed the city of Salem would execute a currently dormant water right on the North Santiam River; this allows Salem to meet the demand in September, 2050 that it cannot supply through the water rights that it currently executes. And second, following the recommendations of the Portland Water Bureau, we assumed the Tualatin Valley Water District and the City of Wilsonville would develop infrastructure to establish a new diversion of water from the mainstem of the Willamette River.

IV. Graphical analysis of the future water regulation

Figure 3 shows that municipalities in several sub-basins must undertake significant development of their infrastructure over the next 50 years, or else institute severe conservation measures. The shading in Figure 3 represents the change in "excess demand" for municipal diversions between August, 1990, and August, 2050. We define "excess demand" as the difference between the projected diversions for that municipality, and the maximum rate of diversion for the water rights at points of diversion that were extant in the 1990's. We show the *change* in excess demand in Figure 3, for two reasons. First, some municipalities in the basin are already dealing with excess demand, so showing absolute excess demand would not represent the effect of changes from 1990. And second, we believe the model is much more reliable for measuring changes, rather than predicting levels. All of the analysis that follows is based on changes, for these same two reasons.

The cross-hatching in Figure 3 indicates whether that sub-basin is below a federal reservoir that can supply water to municipalities. Many of the sub-basins that require increased capacity to divert are not below the federal reservoirs. Virtually all of the municipalities with excess demand have undeveloped water rights, so they may have access to other water sources besides the federal reservoirs.

The city of Sandy (northwest of the Clackamas sub-basin) has the single largest change in excess demand (16.4 cfs). Sandy does not have direct access to water in the federal reservoirs. The sub-basin with the largest total excess demand (22.9 cfs) is the one northeast of the North Santiam sub-basin, containing the cities of Newberg, Dundee and Keizer.

Figure 4 shows that increases in "desired" or demanded municipal diversions of surface water will be spread across the basin. The shading in Figure 4 represents the change in municipal diversions of surface water between August, 1990, and August, 2050, relative to the infrastructure extant in the 1990s. Figures 3 and 4 show independent components of the total increase in municipal demand, but the two figures together do not show the total increase in demand; the third component, demand for groundwater, is beyond the scope of this study.

The increased diversions by the three largest urban areas in the Willamette show up clearly in Figure 4. In the scenario analyzed here, an additional 68 cfs would be diverted from the Clackamas River in August, 2050, to serve parts of the Portland metropolitan area. (The City of Portland imports most water used in the metropolitan area from the Bull Run watershed, which lies outside the Willamette River basin.) The City of Salem Public Works Department would divert an additional 60 cfs from the North Santiam River in August, 2050. And the Eugene Water and Electric Board would divert an additional 86 cfs from the McKenzie River.

Figure 5 shows that a few municipalities would face shortages due to regulation of their water rights. The shading in this figure represents the change in "regulated shortfall" between August, 1990, and August, 2050. We measure "regulated shortfall" as the projected diversions under water rights that were exercised in the 1990s, less the actual amount available to those water rights after regulation by The Watermaster. This shortfall is in addition to that which is based on the infrastructure extant in the 1990s (Figure 3). None of the three largest urban areas would face an increase in water scarcity as a result of regulation of their water rights. At least one municipality, McMinville (diverting from the small sub-basin in the northwest), faces a severe increase in water scarcity (23 cfs) resulting from regulation of its current water rights. None of the sub-basins with regulated shortfalls is below a federal reservoir, so the affected municipalities do not have direct access to this source of water.

Figure 6 shows that increased municipal diversions will affect other water rights only in the Clackamas River sub-basin. Figure 6 excludes municipal rights and in-stream rights; the shading in Figure 6 shows the change in the "regulated shortfall" for these rights, between August, 1990 and August, 2050. As in Figure 5, we measured the regulated shortfall as the difference between projected or "desired" diversions and the actual amount available to each water right, after regulation by The Watermaster. The regulated shortfall in the Clackamas sub-basin is fairly large (15.7 cfs), but the entire deficit falls on only one water right, a right associated with a fish hatchery; this water right has a maximum rate of diversion of 45 cfs, and under simulated regulation it still has access to nearly two-thirds of its maximum allowance (29.3 cfs).

Figure 7 shows that, with the increased urban consumption, flows will be reduced across the basin, with the reduction in flows accumulating (of course) in the lower reaches of the Willamette River. The shading in Figure 7 represents the change in simulated flow between August, 1990 and August, 2050. We define the "flow" in both months as the natural streamflow at the pour-point of the sub-basin, plus the flow resulting from any decrease in reservoir levels upstream, less the consumption from all water rights upstream. The absolute changes in flow are fairly small off the mainstem of the Willamette, but the percentage change is as high as 27 percent; in the sub-basins where flow decreases, the average percentage decrease in flow is six percent. Comparing Figure 7 to a measure of the riparian health in 1990 could indicate where increased urban water consumption could intensify ecological stress in the future.

Figure 8 shows that removing the reservoirs completely from the basin's summer water supplies will have virtually no impact on municipal water supplies. The shading in Figure 8 represents the change in the regulated municipal shortfall in August, 2050, with a new water supply scenario that does not include *any* release of stored water from the federal reservoirs. (That is, the change is relative to the regulated shortfall of Figure 5, so the shortfalls shown in that figure would still apply.) Only two sub-basins are adversely affected, but the effect in both is less than 1 cfs.

Figure 9 shows that, in contrast to the municipal rights, other water rights face severe regulation in the absence of reservoir releases. The shading in Figure 9 represents the change in regulated shortfall for other water rights in August, 2050, relative to the changes shown in Figure 6. The scarcity is concentrated in only four sub-basins, but the increase is large.

The largest increase in scarcity (1070 cfs) occurs in the McKenzie River sub-basin. A large number of water rights, covering all types of use, face shortages of less than 0.1 cfs each. The greatest shortage, though, falls on a single hydropower right. Five rights associated with fish hatcheries and aquaculture face shortfalls between eight and fifty cfs.

The distribution of shortages is similar in the North Santiam sub-basin. A large number of rights and a wide variety of types of use face relatively small shortages, but most of the impact falls on a few hydropower and aquaculture rights. One industrial right and one right associated with mining also face substantial increases in scarcity (20 and 70 cfs).

V. Discussion and interpretation of the results

The analysis presented in this paper shows that municipal water providers in the Willamette River Basin must undertake substantial development of their infrastructure over the next 50 years, if population and patterns of water use continue under historical trends. The development could occur by expanding capacity to divert at existing points of diversion, or developing capacity at new points of diversion. Since water users compete both spatially and by the legally-established priorities of their water rights, the analysis of future municipal development must occur from the perspective of a watershed or basin. The analysis here has taken the perspective of the entire Willamette River Basin, but it is probably not necessary (at least in the Willamette) to adopt a perspective as large as this; interactions between sub-basins via regulation of water rights are largely limited to adjacent or nearby sub-basins. This holds in the Willamette basin, since water rights on the Willamette River are largely unregulated; the Willamette River thus provides a buffer zone for competition between sub-basins.

If the supply of surface water in the Willamette River basin continues along historical patterns, then it appears that water supply is sufficient to meet the municipal demand that could occur at existing points of diversion over the next 50 years. Many municipalities, though, must develop new points of diversion to meet increased future demand. Surface water supplies may not be able to provide for all of this increased demand, but municipalities could use the method developed here to analyze availability of surface water at other potential points of diversion.

The analysis here has not considered the impact of future municipal diversions on ecological values across the basin. Ecological concerns are critical in the basin, given the recent listings of fish under the Endangered Species Act. The analysis can project changes in flows, but the evaluation of those changes is beyond the scope of this paper. Further, related research will consider the impact of future economic development in the basin on ecological values in the streams of the Willamette.

Perhaps the biggest source of uncertainty in this analysis is in the supply of water. The federal reservoirs in the basin have a large impact on flows in many parts of the basin. The future management of those reservoirs is currently under review, and it is possible (though unlikely) that, in a dry year, the reservoirs may not have water to release from storage in August. The analysis here shows that existing municipal points of diversion are not at risk from any change in future reservoir management: eliminating all flow augmentation in August does not increase scarcity at existing municipal points of diversion. Other types of water rights are not so fortunate, though. Several large hydropower rights and several rights associated with aquaculture may face a dramatic reduction in available water. This increase in scarcity is limited to only two sub-basins, though, so reducing summer releases from the reservoirs should not affect the quantity of water available to water rights across the basin. Reducing summer releases could reduce water quality, though, and this could increase scarcity for all water rights below the reservoirs – both municipal rights and others.

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Table I shows the coefficient of consumption by type of use. (Source: Oregon Water Resources Department, pers. comm.)

Type of use	Coefficient
Irrigation	1.00
Livestock	0.50
Other agriculture	0.50
Municipal	0.45
Domestic	0.20
Commercial	0.15
Industrial	0.10
In-stream	0.00
Hydropower	0.00
Recreation facilities	0.00
Fish ponds	0.00
Wildlife	0.00
Mining	0.00
Miscellaneous	0.00

Figure 1 shows the location of the Willamette River Basin in the state of Oregon, and the location of the major landmarks within the basin. The municipalities shown on the map are not necessarily the ones with surface water rights. The map has a minor error: Big Cliff should be shown as a re-regulating dam downstream of Detroit (the labels Big Cliff and Detroit should be transposed). (Source: USGS.)

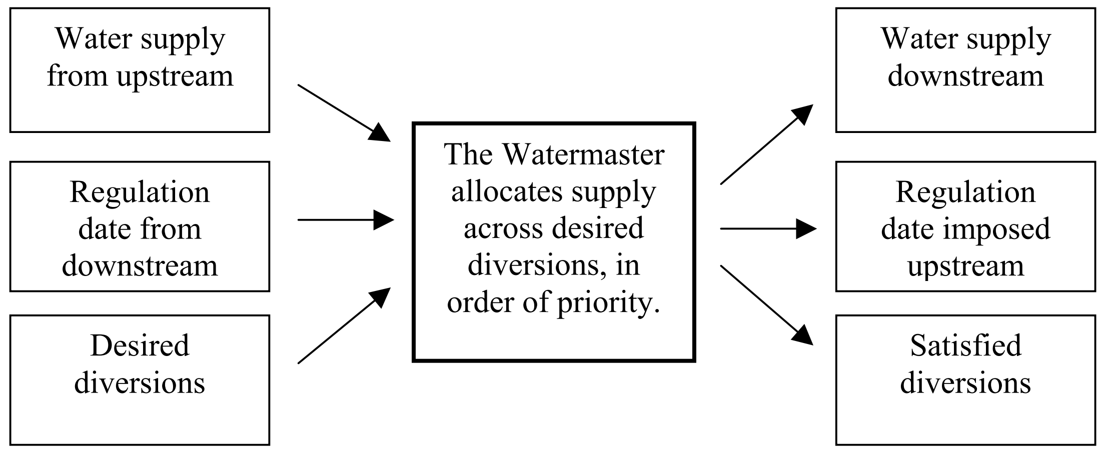

Figure 2 outlines the inputs and output of The Watermaster program, for each sub-basin.

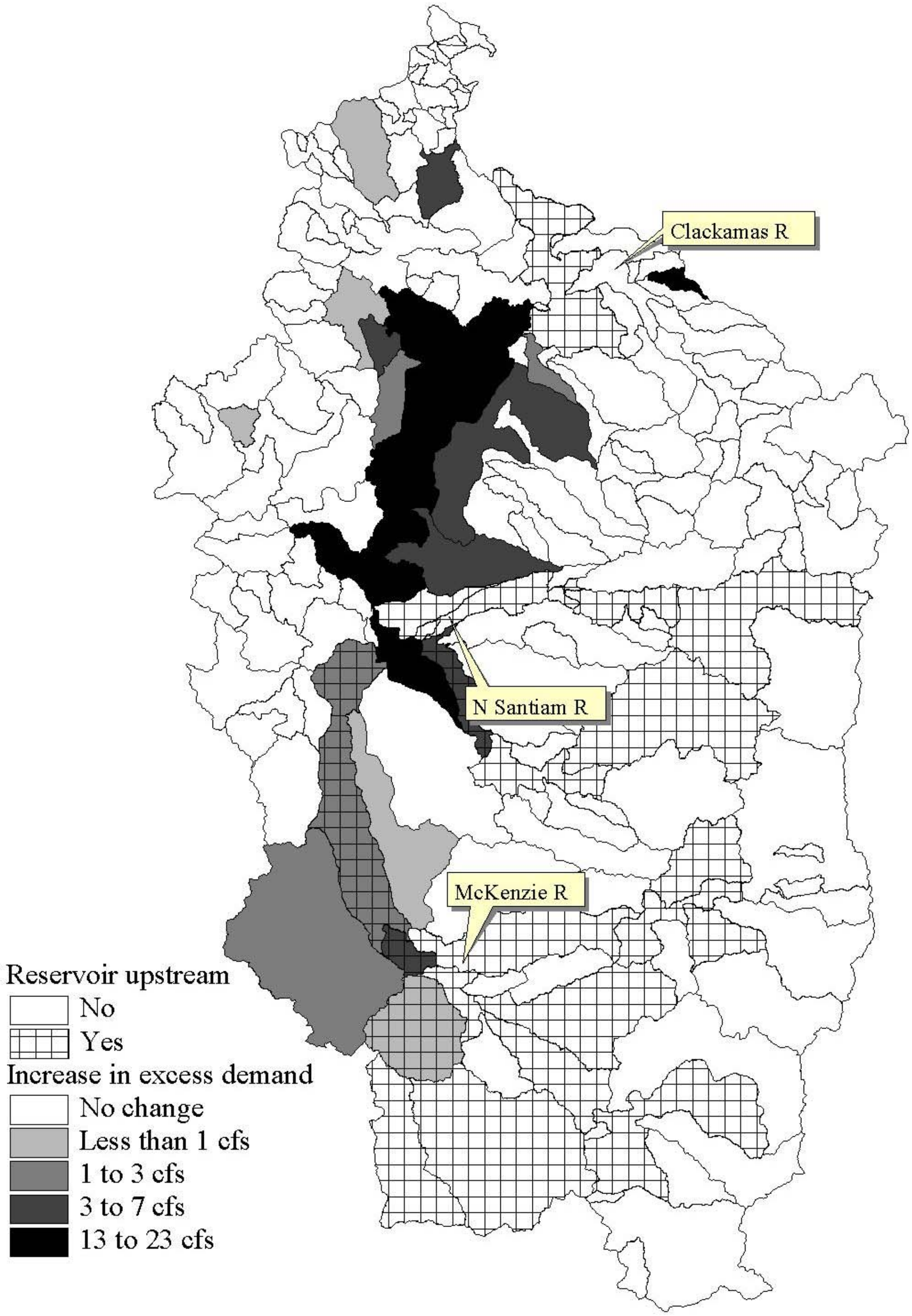

Figure 3 shows the change in excess municipal demand relative to current infrastructure, between August, 1990 and August, 2050. The grid pattern indicates whether the sub-basin is below a federal reservoir that can supply water to downstream uses.

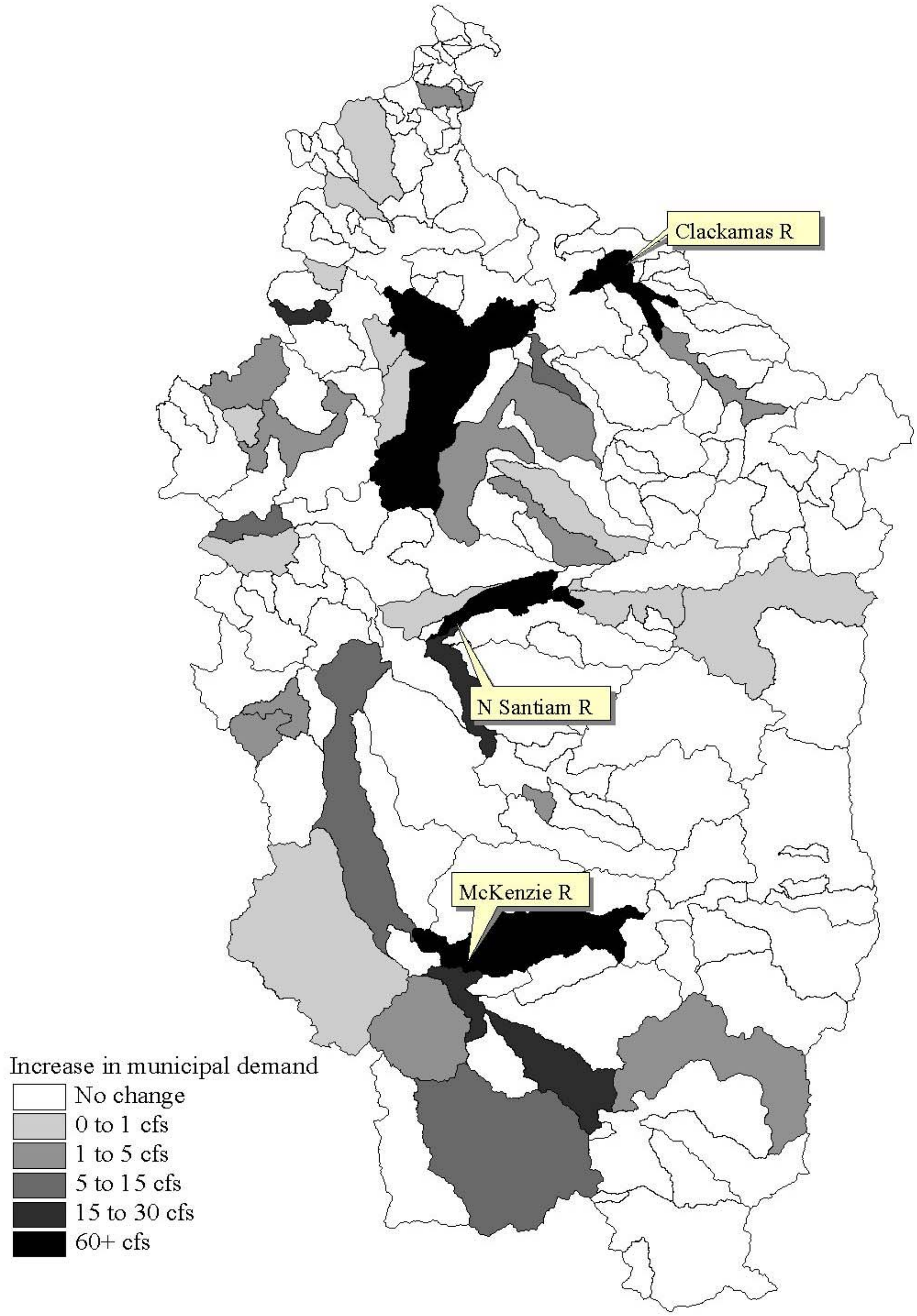

Figure 4 shows the change in municipal diversions of surface water between August, 1990 and August, 2050, at points of diversion extant in the 1990s.

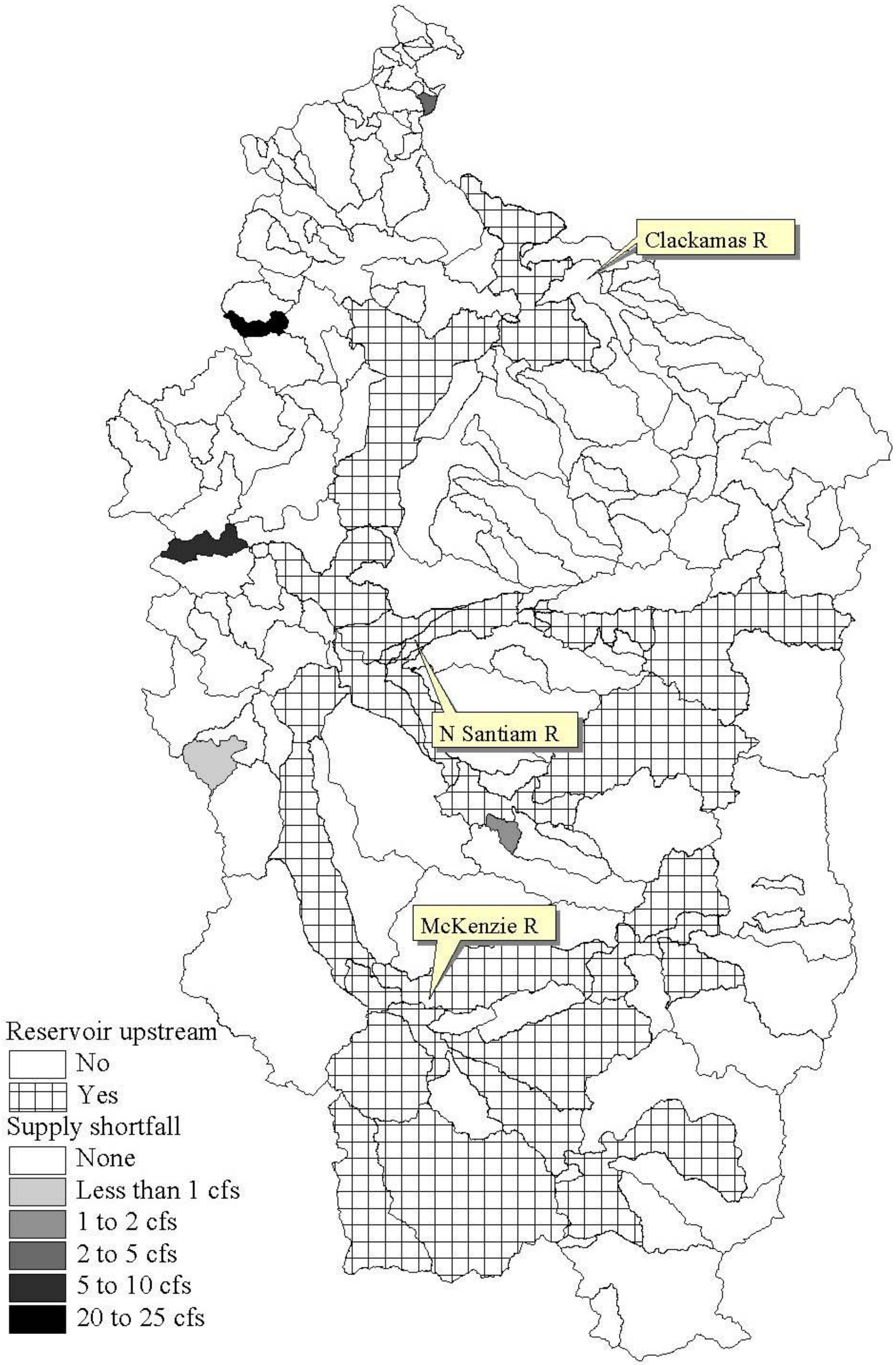

Figure 5 shows the change in the shortfall of municipal supply resulting from regulation of water rights, between August, 1990 and August, 2050.

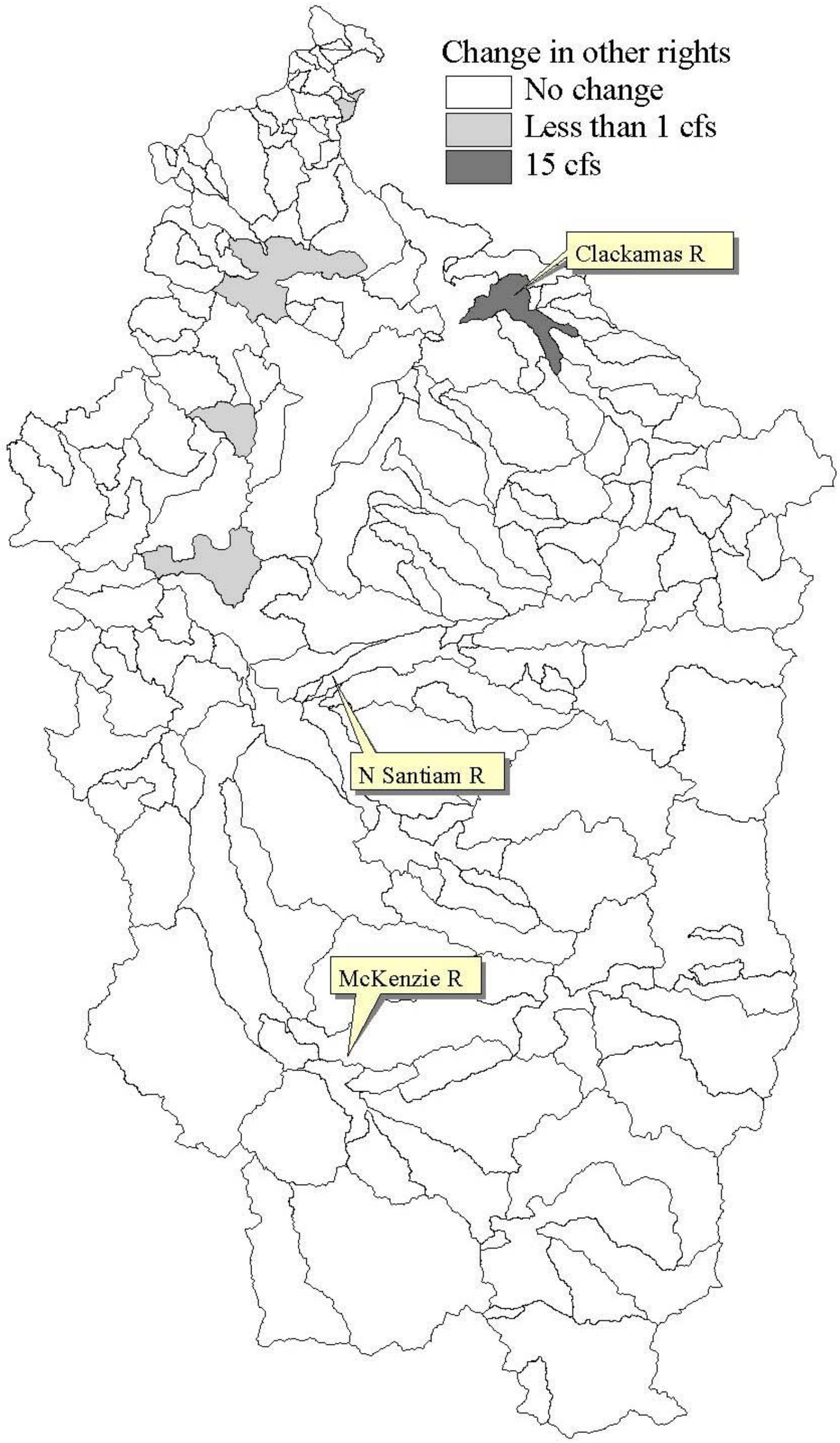

Figure 6 shows the change in the water supply available to non-municipal water rights, and non-in-stream water rights, between August, 1990 and August, 2050.

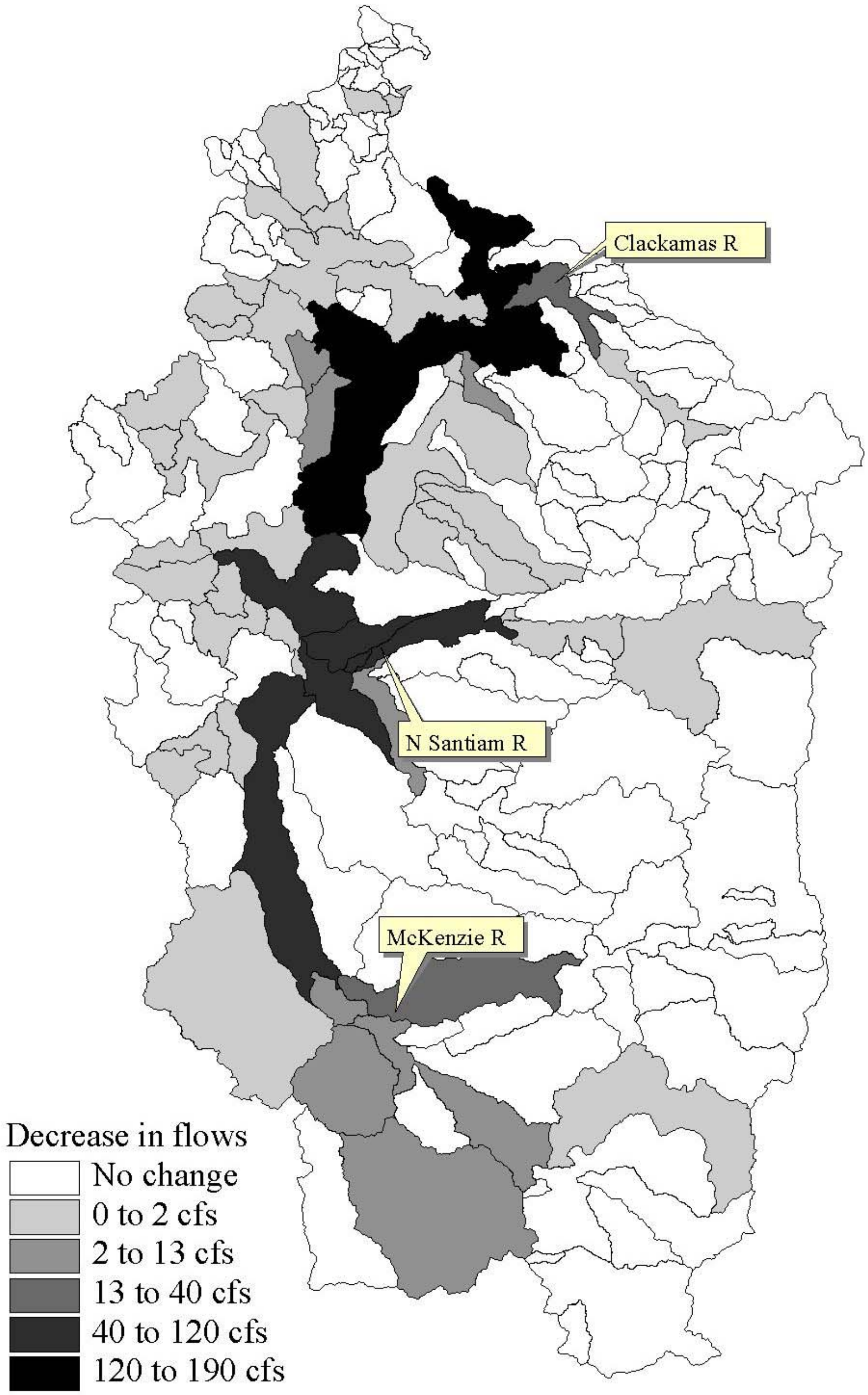

Figure 7 shows the decrease in flows (natural streamflow less consumption) between August, 1990 and August, 2050.

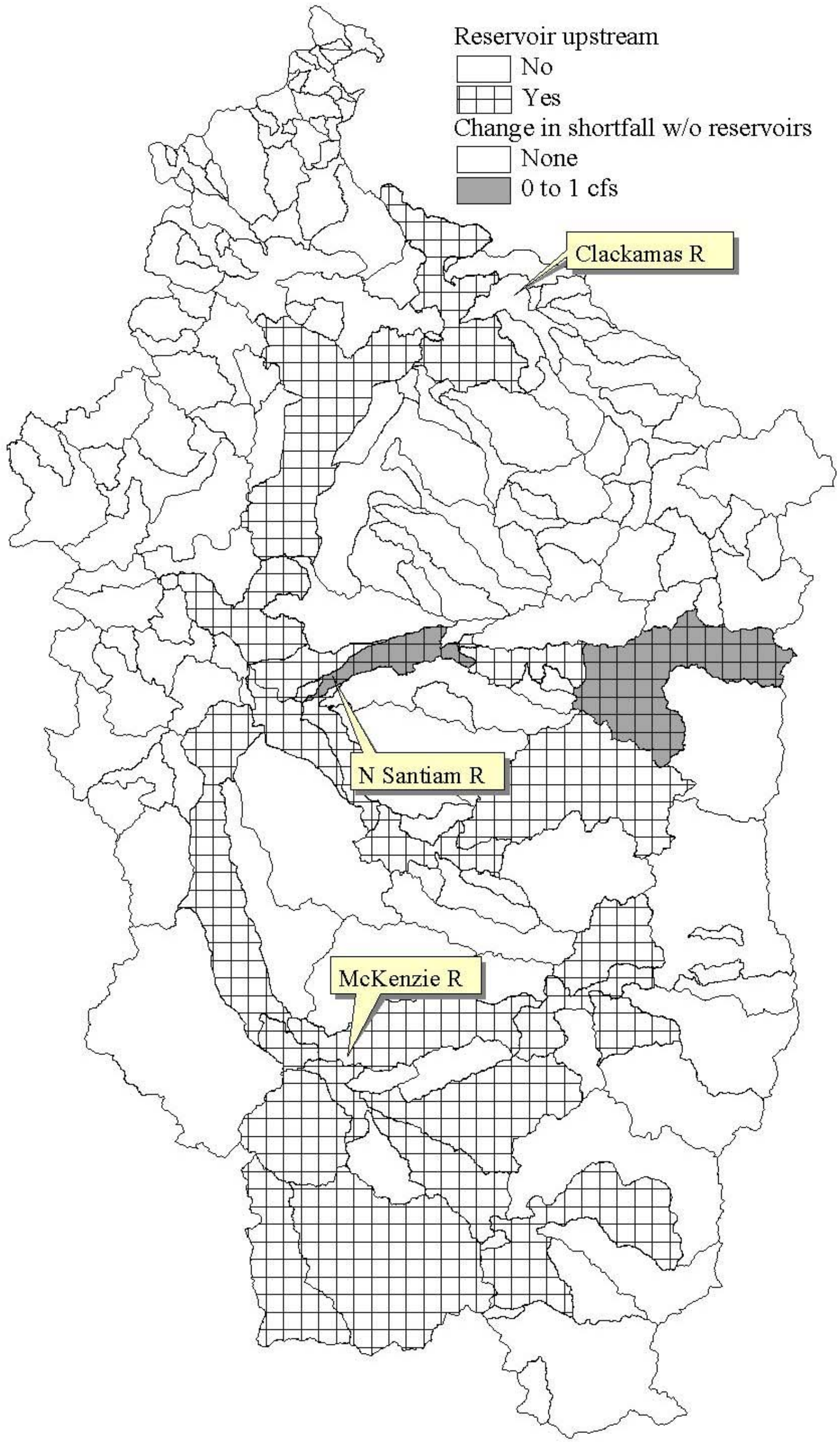

Figure 8 shows the change in the shortfall of municipal supply resulting from regulation in August, 2050, if there are no releases from the federal reservoirs in that month.

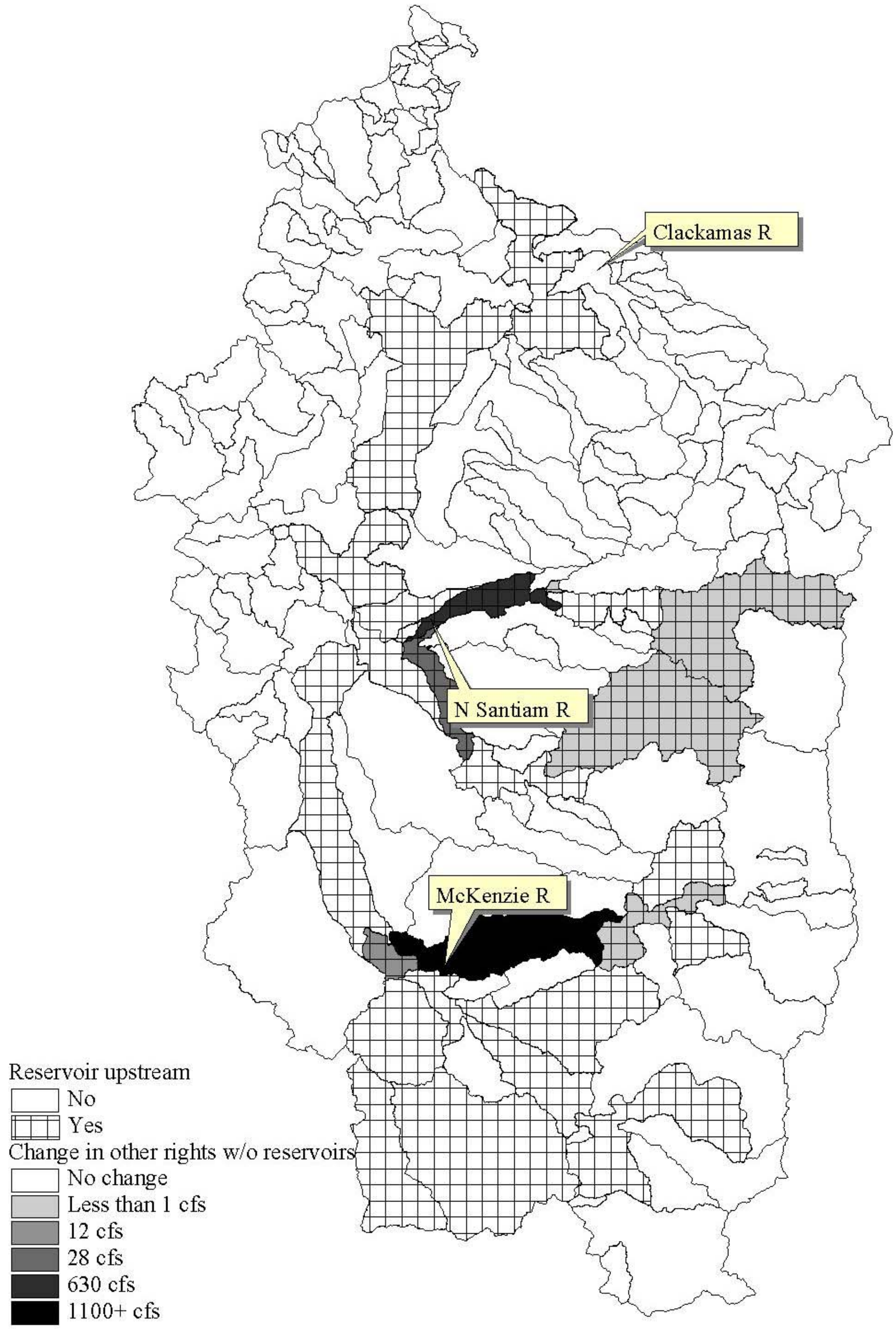

Figure 9 shows the change in the supply available to non-municipal rights and non-in-stream rights in August, 2050, if there are no releases from the federal reservoirs in that month.

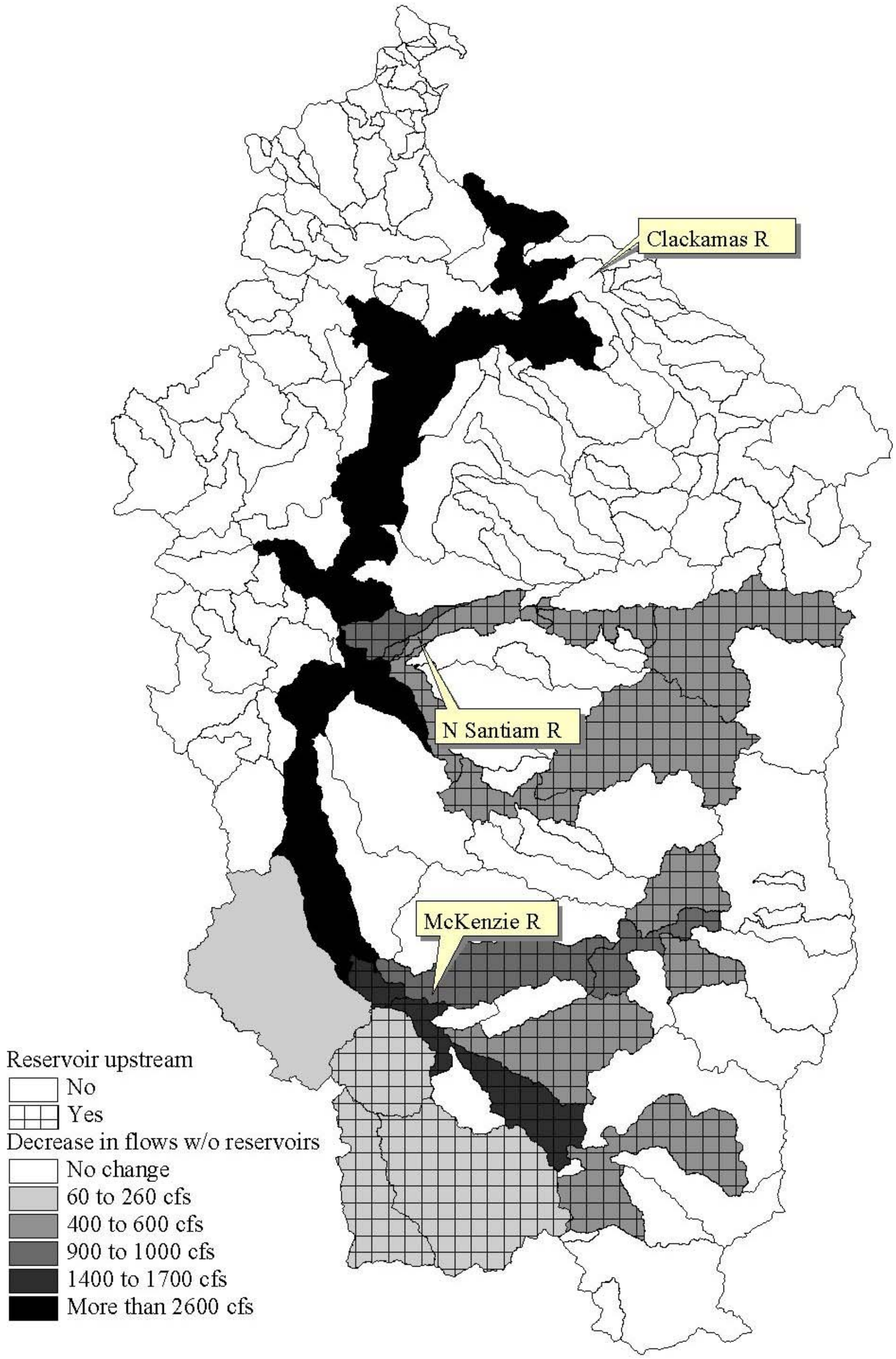

Figure 10 shows the change in flows in August, 2050 if there are no releases from the federal reservoirs in that month.