Discharge, source areas, and water ages of spring-fed streams and implications for water management in the McKenzie River Basin

Report to EWEB
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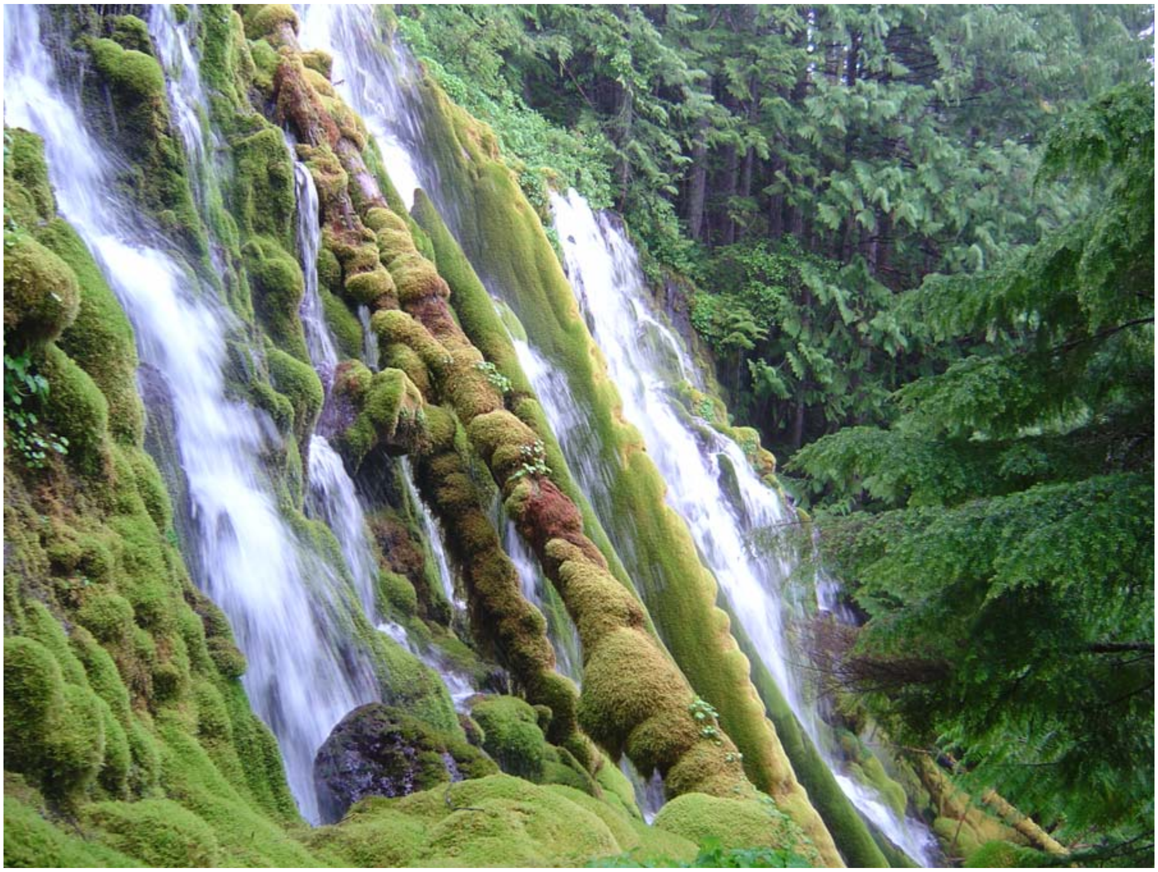

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Abstract:

Long-term sustainable management of the McKenzie River watershed requires an understanding of water sources and discharge patterns from tributary streams, particularly those sourced in large-volume cold springs of the High Cascades. This project combined field measurements of discharge and stream temperature with laboratory analysis of spring water isotopes to improve our understanding of spatial and temporal recharge and discharge patterns of spring-fed streams. Summer streamflow in the McKenzie is dominated by water from approximately 10 spring-fed streams, which maintain 4-7˚C spring water temperatures and relatively steady flow throughout the summer. In winter months, Western Cascades streams respond rapidly to rain and rain-on-snow events and become the major water source to the McKenzie River. Spring-fed streams also respond to precipitation events, but show muted and delayed hydrograph peaks. Summer flow behavior varies between springs, even between those that are located near each other. Isotopic data reveal that recharge to large springs occurs between 1300-1800 m in elevation, which is coincident with geologically young lava between McKenzie and Santiam Passes. Recharge elevations also suggest some disagreement between recharge areas and topographic watersheds of the springs. Mean residence time of water in the groundwater system is on the order of 5-10 years. Because of their importance to summer streamflow, water quality, and habitat in the McKenzie River basin, water resources decision-making must differentiate between spring-fed and runoff-dominated streams.

Problem and Research Objectives:

The McKenzie River basin provides habitat for endangered and threatened fish species, contains federal and private dams for flood control and hydroelectric power generation, and supplies drinking water to Eugene, Oregon's second largest city. In low flow periods, the McKenzie provides a disproportionate share of water to the Willamette Valley, where 70% of the Oregon's population lives (PNWERC, 2002). Recently released climate modeling (Service, 2004) suggests that declining Cascades snowpacks over the next 50 years will exacerbate demand for limited water resources.

Despite the importance of the McKenzie River's water to the region's quality of life, geologic and climatic controls on patterns of streamflow have been poorly understood. The watershed of the McKenzie River, which is tributary to the Willamette River (Figure 1), lies primarily within two distinct geologic provinces: the High and Western Cascades. Preliminary hydrograph analyses indicated that High Cascades streams show much more uniform flow and temperature through time compared to Western Cascades streams (Tague and Grant, 2004). Many High Cascades streams are also sourced in springs, while Western Cascades streams are dominated by water from shallow-subsurface flow through the soil. These differences have significant implications for water quantity and quality in headwater streams and for larger rivers, such as the McKenzie and Willamette, where both High and Western Cascades streams contribute to flow.

This project represents a systematic attempt to quantify volumes, sources, and ages of streamflow in the McKenzie River basin. The overall goal of the project was to provide a more complete picture of flow contributions to the McKenzie River, for use in planning the sustainable long-term water management of the basin. The work was focused around four objectives:

1) Obtain continuous discharge records for large spring-fed streams in the McKenzie River basin
2) Identify, map, and obtain point discharge measurements for additional springs in the basin
3) Use isotopic information to constrain residence times and recharge source areas of the springs
4) Discuss implications of spring-fed streams for management of water resources in the McKenzie basin.

Methods, Procedures, and Facilities:

1) Obtain continuous discharge records for large spring-fed streams in the McKenzie River basin

Trutrack capacitance rod water stage and temperature recorders were installed on 13 streams in the McKenzie River watershed during July 2003, as shown in Figure 2. Stage and temperature measurements were taken at 15 minute to 1 hour intervals, and continue to operate past the ending date of this grant. These streams included 8 spring-fed streams, 4 runoff-dominated streams, and 1 ephemeral spring-fed stream. The selected spring-fed streams included all of the major ungauged springs that are tributary to the McKenzie River. Runoff-dominated streams were selected because they were tributary to or provided a reference site in close proximity to spring-fed streams.

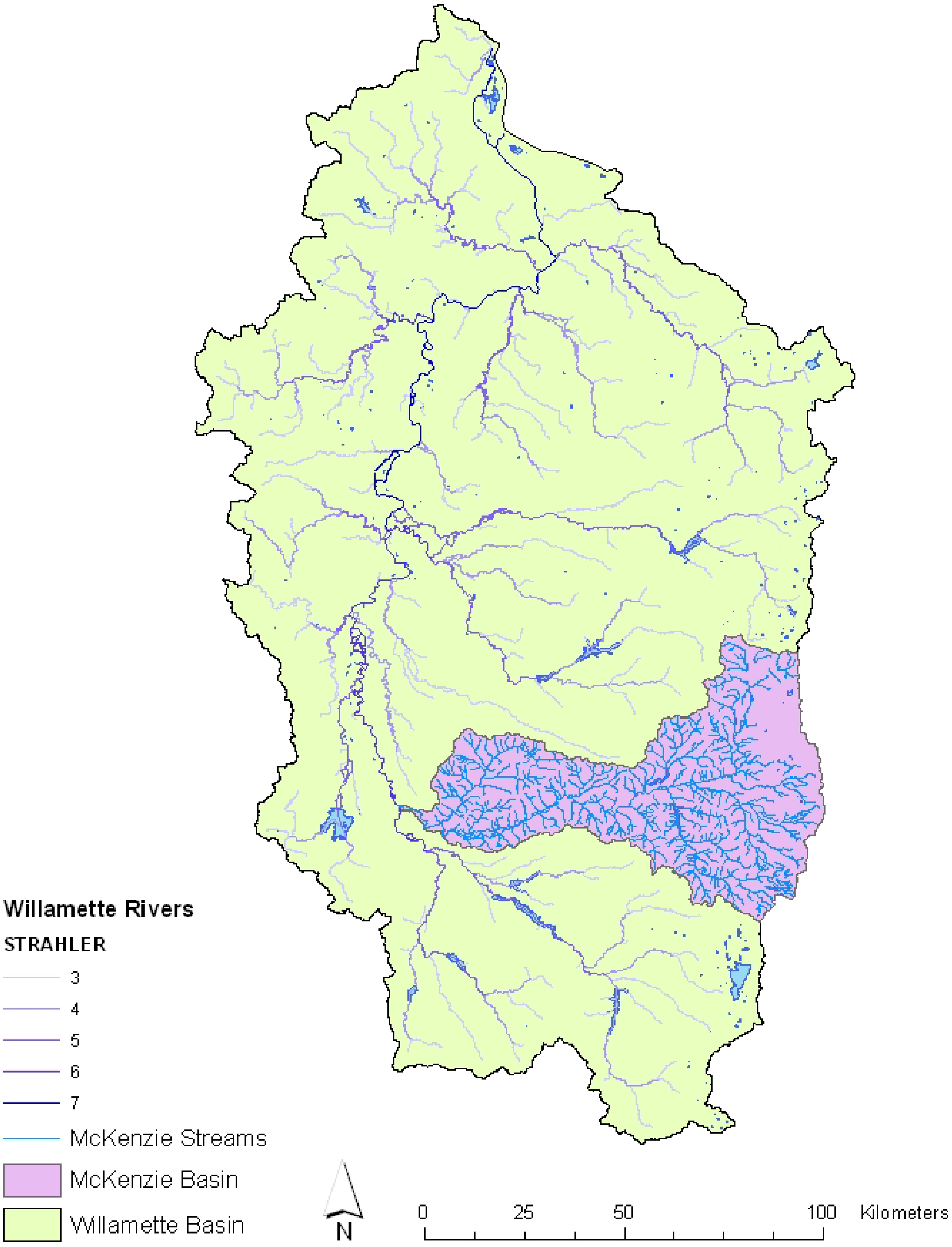

Figure 1. The McKenzie River watershed in the context of Willamette River basin streams and reservoirs.

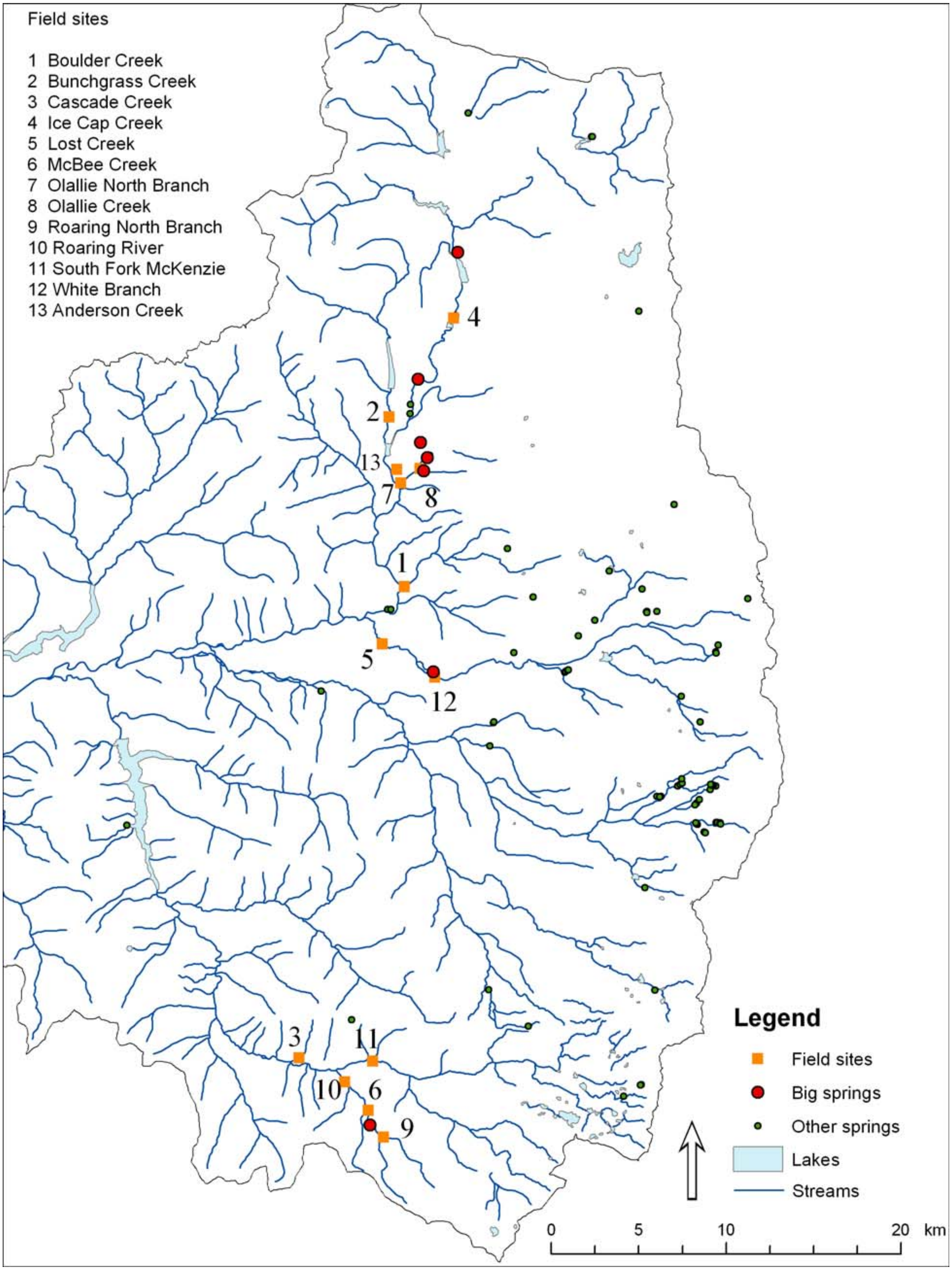

Figure 2. Location map of springs and discharge measurement sites in the McKenzie River basin.

By wading and using a Marsh-McBirney flow meter, discharge measurements were made at a variety of stages in order to develop rating curves for each site, following standard USGS procedures. These curves allow interpolation from stage to discharge and result in daily hydrographs for the streams. Discharge was directly measured between 4 and 18 times at each site, depending on flow variability. Despite repeated measurements, peak flows had to be extrapolated from the rating curve for each site. Where there is not sufficient confidence in such extrapolations, hydrographs are truncated in high flow periods. Rating curve refinement is continuing to date.

2) Identify, map and obtain point discharge measurements for additional springs in the basin

Topographic maps indicated the presence of other springs in the McKenzie River watershed, for which no discharge measurements existed. Several of these springs were visited and one-time discharge measurements were made during the summer of 2003. Additionally, in early and late August, discharge was measured at all tributaries flowing from High Cascades geology between the headwaters of the McKenzie River and the junction with the South Fork of the McKenzie.

3) Use isotopic information to constrain residence time and recharge source areas for springs

In mountainous regions, the isotopic composition of precipitation varies in systematic way with elevation. The isotopic composition of spring water can be projected to the elevation at which precipitation has a comparable composition. Water samples were collected from springs at approximately monthly intervals, and analyzed by Anne Jefferson at Lawrence Livermore National Laboratory under the supervision of Dr. Tim Rose. Isotopic composition of spring water was compared to a published altitude-isotope relationship for the Oregon Cascades (Ingebritsen et al., 1994). In March 2004, after most of the year's snow had fallen, snow cores were collected from sites at 814 to 1729 m elevation for calibration of the altitude-isotope curve to the McKenzie region. These samples are awaiting analysis.

One liter water samples were collected in mid-November 2003 for tritium concentration analysis, from which groundwater age can be estimated. Water samples were taken from Roaring Spring, Lost Spring, Olallie North and South Springs, and Great Spring. Tritium was not analyzed for Tamolitch Spring groundwater, because of possible effects of spilling upstream at Carmen Reservoir during October 2003. Samples were sent to the University of Waterloo (Canada) Environmental Isotope Laboratory for analysis by standard procedures. Data from these samples will be used to guide selection of more refined measures of groundwater age in the summer of 2004.

4) Discuss implications of spring-fed streams for management of water resources in the McKenzie Basin

Patterns of groundwater discharge and recharge have impacts on how flow is regulated at dams along the mainstem and tributaries of the McKenzie River, how stream habitat is monitored and managed, and the quality of water of recreation, habitat, and drinking water uses. Synthesis of objectives 1-3 allows discussion of implications for water resources in the McKenzie basin. Conversations with Forest Service hydrologists from the Willamette, Mount Hood, and Umpqua National Forests also generated examination and discussion of regional-scale significance of spring-fed streams.

Principal Findings and Significance:

1) Obtain continuous discharge records for large spring-fed streams in the McKenzie River basin

Considerable differences were observed between the hydrographs of spring-fed and runoff-dominated streams in the McKenzie River watershed (Figure 3). The difference between peak flow discharges and low flow discharges on spring-fed streams was a factor of 1.5 to 2.7, whereas for runoff-dominated streams peak flows were approximately 30 to 1000 times greater than low flows. Hydrographs of spring-fed streams also showed little recession during the summer, as compared to those of runoff-dominated streams. Comparison of flows from summer 2003 to spot discharge measurements in 2001-2002, and to irregular measurements from the 1910-1926 (Stearns, 1929) suggests that springs have less interannual variability than runoff-dominated streams.

Two major peak flow events are represented in the gauging record: December 13-14, 2003 and January 29, 2004. The spring-fed streams exhibit a delayed peak flow compared to runoff-dominated streams, and this cannot be completely explained by elevation or watershed area. For example, all four runoff-dominated streams had their peak flow on January 29, 2004, but the spring-fed streams reached their peak flows on January 30-31.

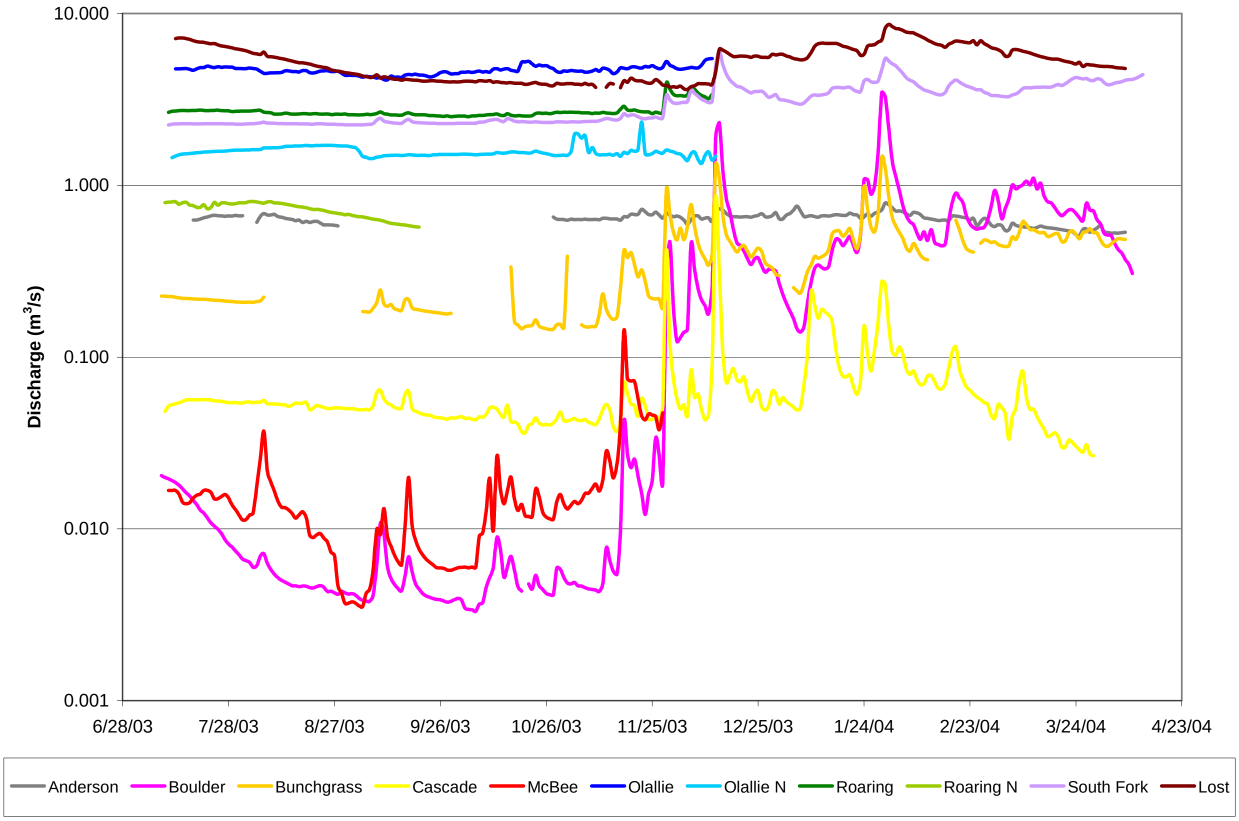

Figure 3. Daily average discharge of spring-fed and runoff-dominated streams between July 9, 2003 and April 12, 2004. Hydrographs are truncated at the last data download date or where there is missing data or low confidence in extrapolated discharge values.

There were also differences in behavior among spring-fed streams (Figure 4). Anderson Creek showed almost no response to rain events, while the bigger spring-fed streams showed some responsiveness. Some of this responsiveness may be due to gauging location, as the Roaring and South Fork sites are downstream of runoff-dominated tributaries. Furthermore, springs feeding the same creek exhibited different dynamics during the summer period, as illustrated below.

Olallie North Branch rises through July and August and drops off in September, while downstream on Olallie Creek, below the confluence of the north and south branches, Olallie Creek exhibits a slight recession throughout the summer. This recession is similar to the stage record at Olallie South Branch (not shown), which contributes most of the flow to Olallie Creek. Thus, although the two branches are sourced in springs less than 1 km apart, they function differently.

Between August 15 and September 15, 2003, the north spring on Roaring River dropped from supplying 29% of the water in the river at Road 19 to providing only 23% of the water. This decrease in relative contribution cannot be explained by increased flow from runoff-dominated streams, because, as exemplified by McBee, their flow decreased by half. Consequently, increased flow from Roaring Spring (south branch) or another unidentified spring must account for the discharge measured at Road 19.

White Branch Creek, as measured near its confluence with Lost Creek, appears to be controlled by an ephemeral spring (Figure 5). It exhibits markedly different discharge dynamics than either spring-fed or runoff-dominated streams, despite its spatial proximity to perennial Lost Spring. The stream had a very steep recession in July-August and again in March, each time resulting in a completely dry channel. The stream did not respond to the December 13-14 peak flow event, and exhibited a 5-day delay in peak flow for the end of January event. Throughout the vagaries in discharge, water temperature remained nearly constant between 6.5 and 6.7˚C, within the range exhibited by Lost Spring. Only when discharge was below ~0.1 m^3/s did significant temperature fluctuations occur.

Water temperature trends also exhibited differences between spring-fed and runoff-dominated streams (Figure 6). Temperature measured directly at springs was nearly constant throughout the year, while streams showed fluctuations due to cooling or heating from the surrounding air mass. However, spring-fed streams showed much smaller variation in temperature both seasonally and daily than did runoff-dominated streams.

2) Identify, map and obtain point discharge measurements for additional springs in the basin

During August 5-7 and again August 26-28, 2003, discharge measurements were made on High Cascades tributaries to the McKenzie River (Figure 7). Discharge of the McKenzie River at Vida was 50.7 m^3/s on August 7, 2003. According to our measurements, 42.3 m^3/s, or 83%, of this flow came from spring-fed streams. By combining locations from this project and the USGS, 49.4 m^3/s, or over 97% of the flow in the McKenzie River was measured, despite ignoring most tributaries flowing from Western Cascades geology. Reservoir supplementation accounted for ~10% of the flow at Vida. Without this supplementation, spring-fed streams would comprise 93% of the flow in the McKenzie River.

These measurements indicated that all major springs discharging into the McKenzie were accounted for in the above gauging scheme. Some small springs discharge water to the surface where it quickly infiltrates back into the ground (e.g., Beeler), while other springs discharge into closed basins (e.g., Linton), where their water either evaporates or recharges the groundwater system. There is also considerable accretion of groundwater along the mainstem of the McKenzie River between Clear Lake and Carmen Reservoir. Discrete springs are found at the base of Koosah Falls and multiple small springs flow into Carmen Reservoir.

3) Use isotopic information to constrain residence time and recharge source areas for springs

Spring water samples plot substantially to the right of the altitude-isotope curve for the west side of the Oregon Cascades (Figure 8). This suggests that groundwater aquifers are recharging at higher elevations (1300 to 1800 m) than they are discharging (600 to 1200m). The recharge elevations for the springs are concordant with the elevation of substantial young lava fields between McKenzie and Santiam Passes. Springs providing flow to tributaries of the South Fork of McKenzie also recharge in this elevation range, despite less aerially extensive young lavas. Recharge elevations estimated by this method represent precipitation-weighted averages and have an error of ±60 m due to analytical uncertainty, plus some uncertainty associated with the meteoric water line.

This analysis also suggests that some springs may derive their water from the same source, while others have unique recharge areas and flow paths. Lost Spring and White Branch have similar isotopic compositions, and thus are likely drawing from the same aquifer or recharging their aquifer in comparable areas. Conversely, Olallie North Spring and Olallie South Spring have dissimilar compositions, indicating

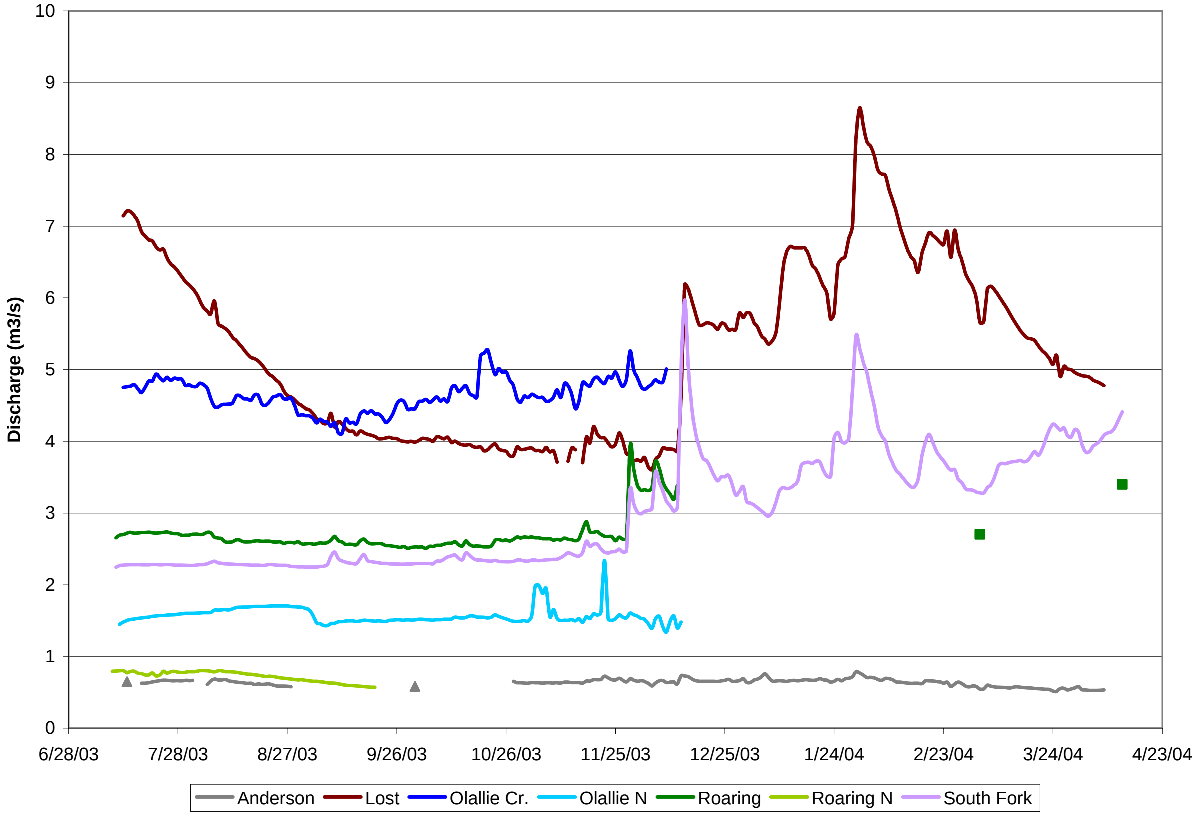

Figure 4. Daily hydrographs of spring-fed streams in the McKenzie River basin. Lines represent daily average flow estimated from stage-discharge relationships, while points represent single discharge measurements.

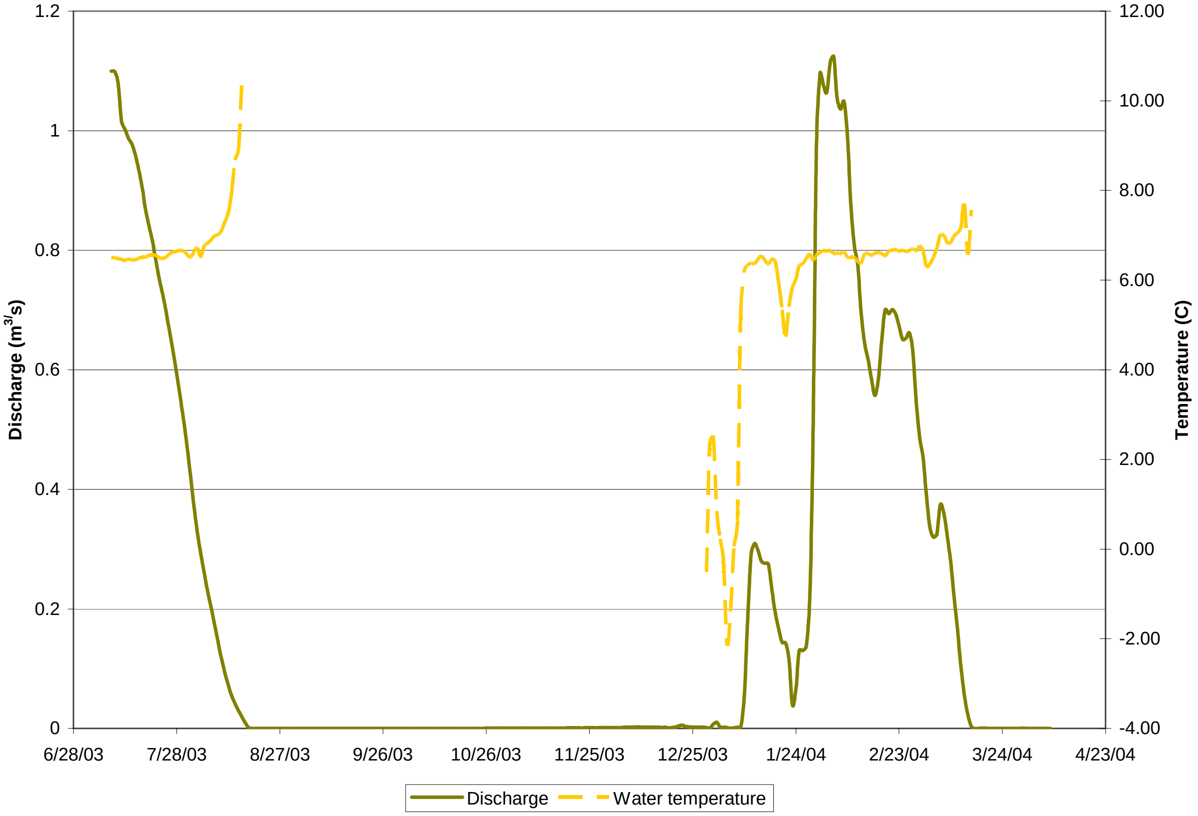

Figure 5. Discharge and water temperature of White Branch Creek near Highway 242. White Branch had no water in its channel from August 19 to October 25, 2003 and from March 16, 2004 until the end of the grant period.

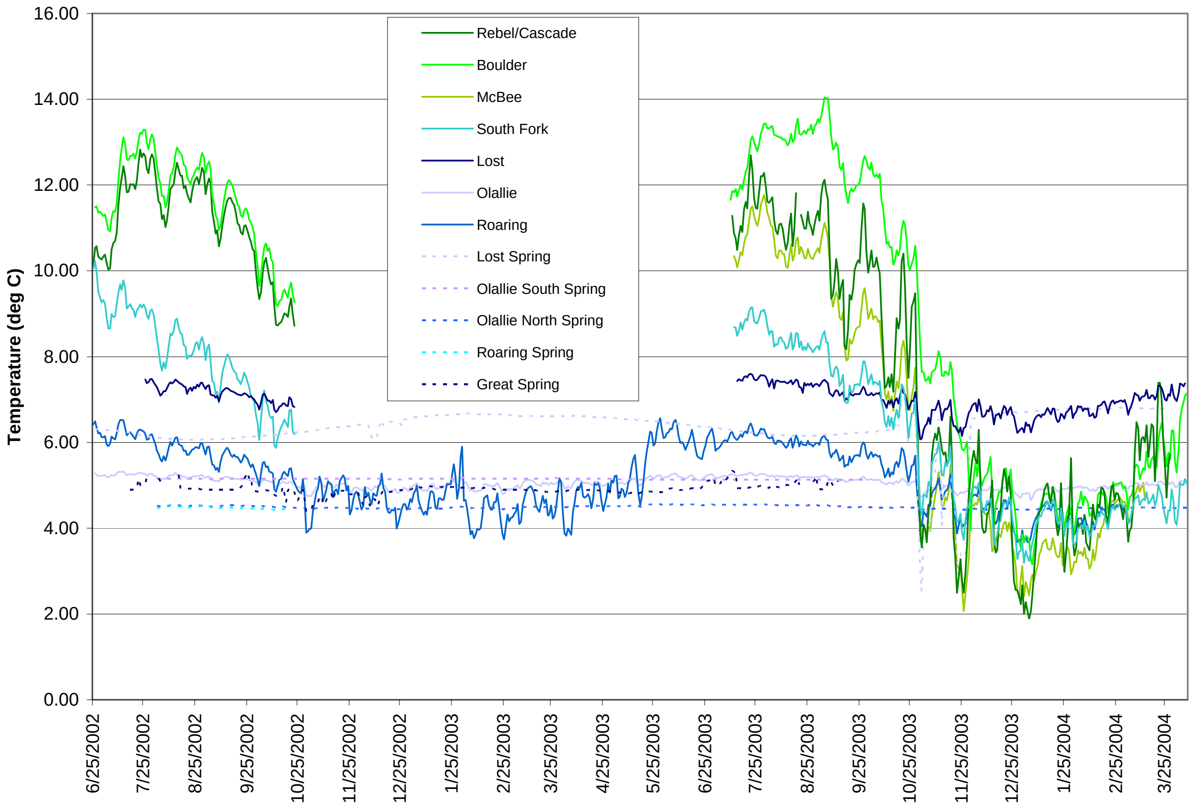

Figure 6. Water temperature histories of springs (dashed lines), spring-fed streams (blue colors), and runoff-dominated streams (green colors). Water temperature at springs measured by Hobo Water Temp Pro sensors, and in streams, temperature was measured using Hobo or Trutrack sensors.

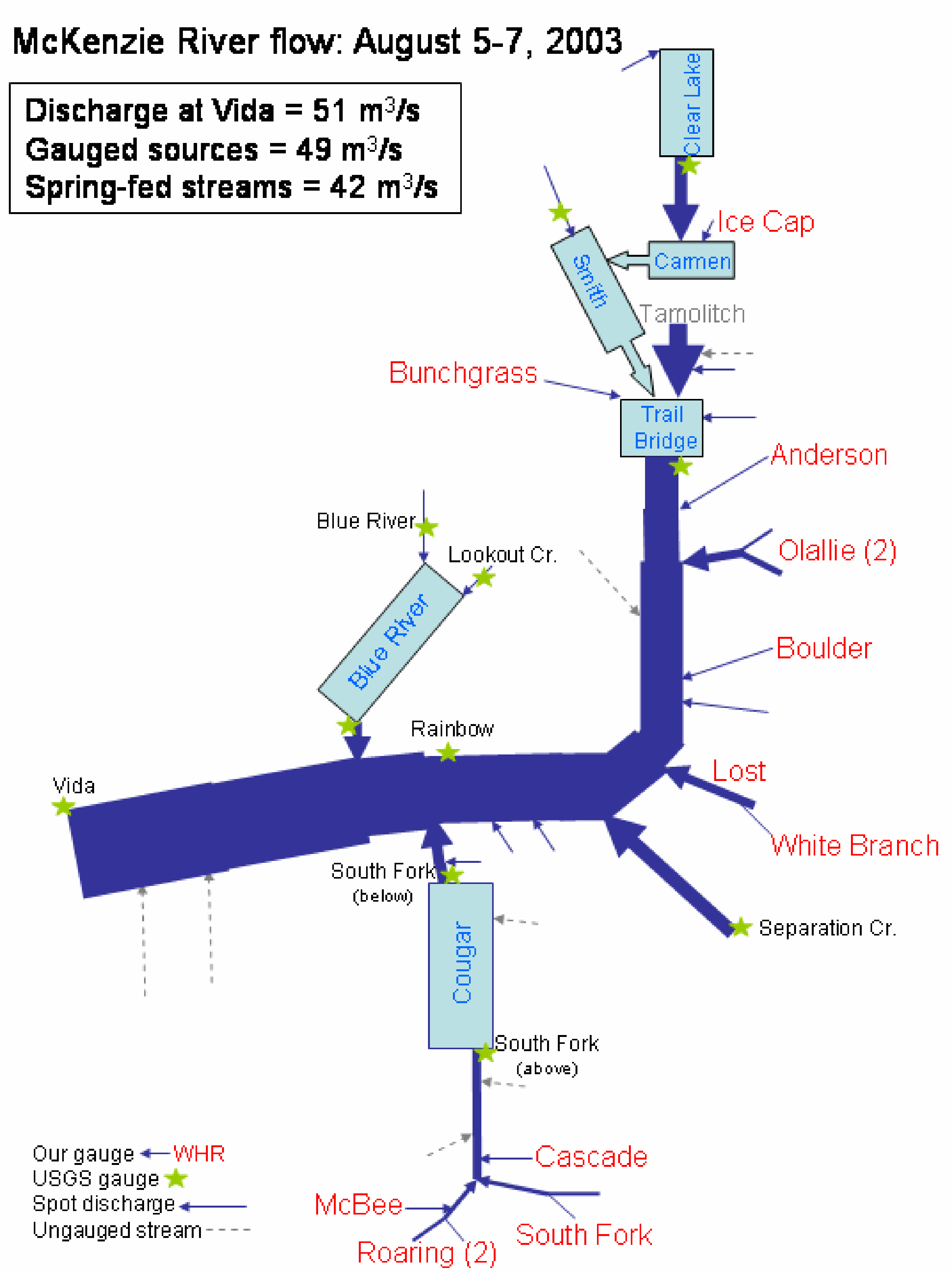

Figure 7. Sources of water to the McKenzie River during low flow (measured August 5-7, 2003).

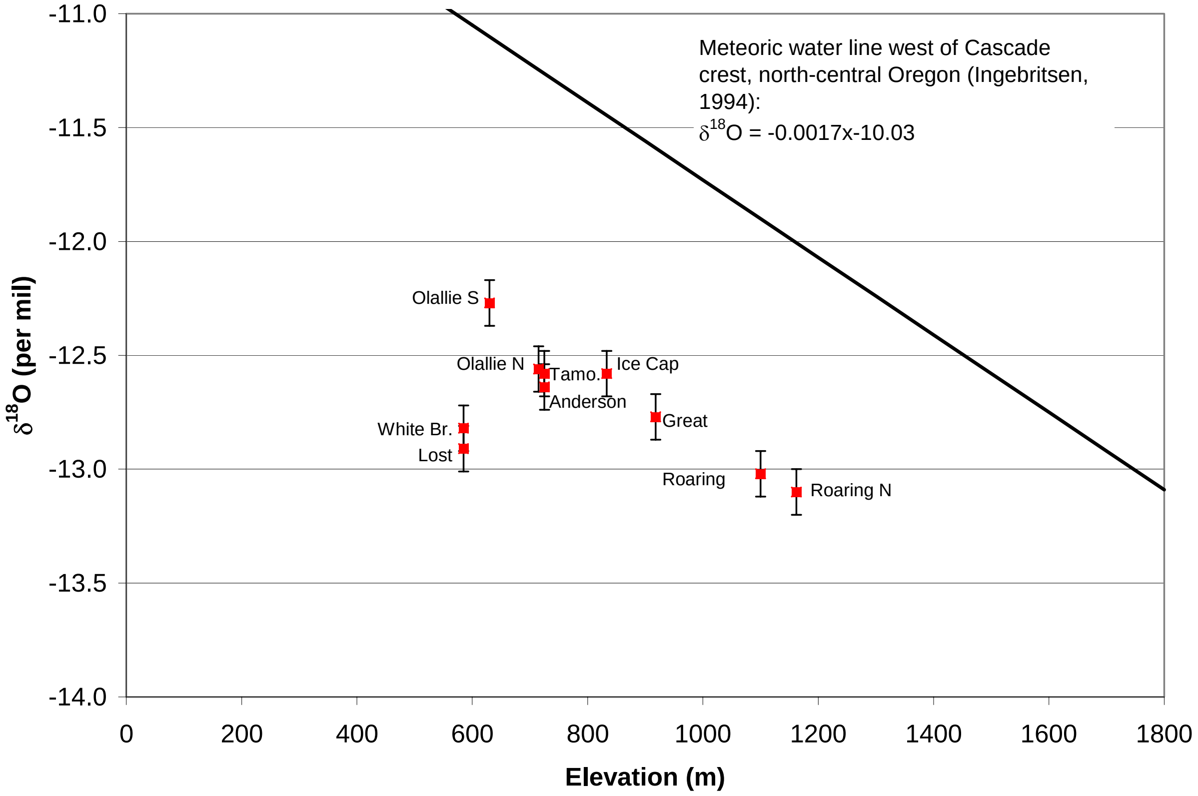

Figure 8. Average isotopic composition of spring water compared to spring elevation. Mean recharge elevation can be determined by projecting isotopic composition onto the meteoric water line.

that their flow paths and recharge areas are distinct. This is supported by the differing flow dynamics of each spring, as discussed earlier. Roaring Spring and Roaring North Spring appear to share similar recharge areas. Furthermore, recharge elevations inferred by isotopic methods infer that topographic watersheds may not be providing evenly distributed recharge to the groundwater system. In at least one case, the inferred average recharge elevation is greater than the maximum elevation in the topographic watershed, requiring significant recharge from outside the topographic watershed.

Mean residence time of groundwater, or groundwater age, can be estimated from tritium (^{3}H) concentrations in the spring water, by comparing the spring tritium levels to a record of atmospheric tritium levels over time. Tritium values for the five sampled springs ranged between 2.9 and 6.1 TU (Table 1). Preliminary analysis indicates that these values correspond to the 5-10 year age range. Based on this method, Great Spring may have a non-unique young residence time solution. Despite their difference in recharge elevations and flow dynamics, Olallie North and South Springs have similar discharge water with similar residence times.

Table 1. Tritium values for spring water samples collected November 15-17, 2003. One tritium unit (TU) is equal to 3.149 picocuries/L or 0.11815 Becquerels/L.

Spring	**TU**
Great	2.9±0.5
Lost	4.5±0.6
Olallie North	4.3±0.6
Olallie South	4.5±0.6
Roaring	6.1±0.7

4) Discuss implications of spring-fed streams for management of water resources in the McKenzie Basin

Spring-fed streams are by far the dominant source of streamflow in the McKenzie River at Vida, and this flow is sourced from less than 10 discrete areas in the watershed. Most of these springs occur on federal land, requiring local and federal water resources agencies to cooperate in their management and protection. The discrete nature of the source areas of water in the McKenzie suggests a number of implications for management:

1) Maintaining the high water quality of the springs and spring-fed streams requires consideration of several distinct environments: a) the springs themselves; b) the extensive but often cryptic or unknown area upstream of the springs contributing flow to the springs; and c) channel and riparian areas bordering spring-fed streams. Each of these environments can potentially have different ownerships (public or private), management allocations, impacts, and consequences for water quality. We are only beginning to understand the interplay of these environments and potential impacts of human and land use activities on each. Specifically, the effects of human activities and natural disturbances in recharge areas on spring water quantity and quality are not well understood. For example, most large springs in the McKenzie drainage are located on National Forest lands, and are included in Riparian Reserves under the Northwest Forest Plan. This affords a relatively high degree of protection against forest harvest and road building activities. However, source areas that contribute to the springs may or may not be included in Riparian or other reserve or protection categories, since groundwater systems are not explicitly included in the Northwest Forest Plan. Whether land use activities, including forest harvest, recreation, and fire suppression and fuels management, affect the flow in springs remains an open question.

Recharge elevations are significantly higher than spring locations and suggest some discordance between recharge areas and topographic watersheds. These findings emphasize the importance of further investigation into recharge area geometry, the question of whether specific portions of the landscape provide a disproportionate share of recharge to the groundwater system, and what effects human activities in source areas may have on streamflow and water quality.

2) It is not clear whether highlighting the location of springs (i.e., on maps or through media) will contribute to their future protection or degradation. Many springs are quite sensitive ecologically, with extensive wetland vegetation, unique habitats, undeveloped access etc., and would probably be degraded by extensive human use. On the other hand, some springs are quite resilient due to presence of bedrock, well-developed trail systems (e.g., Tamolitch). Some degree of heightened awareness of spring location is probably inevitable, but needs to be carefully managed.

3) Despite their importance to water supply during low flow seasons, none of the springs and few of the spring-fed streams have established long-term monitoring facilities (i.e., USGS gages). While spring-fed streams provide more consistent flow than do runoff-dominated streams, they do experience higher flows in response to rain and rain-on-snow events. Thus, adequate gauging of these systems is still important for reservoir management planning. A small number of discharge measurements might be sufficient to characterize summer streamflows in spring-fed streams, but winter flows cannot be assumed to be static. Furthermore, differences in flow dynamics between spring-fed streams, even those in close proximity to each other, preclude generalizing measurements from one spring system to others.

4) Stream temperature, an important habitat criteria for bull trout and other species, is generally lower and more stable in spring-fed than runoff-dominated streams, suggesting that conservation efforts for some species might be concentrated in spring-fed streams. At a minimum, the relationship between ecosystem structure and function in spring- versus non-spring streams should be investigated, as this may have implications of regulatory standards affecting water quality and forest management.

5) Mean residence times in the range of 5-10 years imply that the groundwater system is being actively recharged, probably in balance with the amount discharged at springs annually. This suggests that spring water may be susceptible to contamination by atmospheric deposition or chemical spills in recharge areas. Contamination of spring water may appear several years after a spill and the effects may last several years. Finally, a change in the overall amount of precipitation falling on the Cascades would probably have an impact on spring discharge within a few years, but a change in seasonality or form of precipitation may be less significant for spring-fed streams than for runoff-dominated streams.

Because of their importance to summer streamflow, water quality, and habitat in the McKenzie River basin, water resources decision-making must differentiate between spring-fed and runoff-dominated streams. This will require cooperation between local and federal organizations, continued assessment of long-term behavior of spring-fed streams in light of climate variability and change, and more investigation into how human and natural impacts on recharge areas could affect groundwater quantity and quality.

Publications:

Written materials:

Jefferson, A. and Grant, G.E., 2003. Recharge areas and discharge of groundwater in a young volcanic landscape, McKenzie River, Oregon. Geological Society of America Annual Meeting Abstracts with Programs, 35(6): 151-1.

Tague, C. and Grant, G.E., 2004. A geological framework for interpreting the low flow regimes of Cascade streams, Willamette River Basin, Oregon. Water Resour. Res., 40(4): W04303 10.1029/2003WR002629

US Forest Service Pacific Northwest Research Station, 2002. Geology as destiny: cold waters run deep in Western Oregon. Science Findings, 49.

Video:

Oregon Public Broadcasting Oregon Field Guide segment on McKenzie River springs. Originally aired November 20, 2003.

Invited talks on McKenzie River springs, given by Gordon Grant:

US Forest Service Fish and Wildlife meeting, Eugene, OR 5/1/03
H.J. Andrews Long Term Ecological Research Network Science Hour, Corvallis, 6/6/03
McKenzie Watershed Council, Eugene, OR 6/12/03
Klamath River Watershed Council, Arcata, CA 6/18/03
Middle Fork Willamette Watershed Council, Lowell, OR, 6/18/03
National Council on Air and Stream Improvement Workshop, H.J. Andrews, 7/18/03
Bureau of Land Management National Advisory field trip, Blue River, OR, 7/30/03
Willamette Riverkeeper field trip, Albany, OR 9/9/03
Geological Society of America National Meeting, Seattle, WA 11/3/03
Oregon Public Broadcasting, Oregon Field Guide, 11/20/03, 11/23/03
Willamette Technical Advisory Group, Salem, OR 12/3/03
South Santiam Watershed Council, Lebanon, OR 1/21/04
OSU Science Connection, Portland, 3/11/04
Santiam Fish and Game Commission, Lebanon, OR 4/2/04
National Public Radio, "Earth and Sky", 4/27-28/04

Student Support (# and degree level):

This project involved one Ph.D. student (Anne Jefferson, OSU Geosciences), who oversaw execution of the project, including conducting field and laboratory work and data analysis. An M.S. student (Michael Farrell, SDSU Geography) and a Ph.D. student (Josh Wyrick, OSU Civil Engineering) were supported as field assistants and were involved with stream temperature analysis.

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PNWERC, 2002. Willamette River Basin Planning Atlas: Trajectories of environmental and ecological change. Oregon State University Press, Corvallis, OR, 178 pp.

Service, R.F., 2004. News focus: as the west goes dry. Science, 303: 1124-1127.

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Tague, C. and Grant, G.E., 2004. A geological framework for interpreting the low flow regimes of Cascade streams, Willamette River Basin, Oregon. Water Resources Research, 40(4): W04303 10.1029/2003WR002629.