Coquille River Basin Stream Temperature Assessment

Tim Mayer, Supervisory Hydrologist,
US Fish and Wildlife Service,
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This is an analysis of geology, climate, hydrology, and stream temperature information in the Coquille River basin. The purpose of this report is to provide some background information on stream temperature for the climate change vulnerability assessment of the Coquille River. This analysis uses historical summer stream temperature data in an attempt to identify factors controlling summer stream temperatures, now and in the future. In my recent study of stream temperatures across the Pacific Northwest (Mayer, 2012), I identified air temperature, baseflow index, stream length, and stream slope as four major regional factors determining summer stream temperatures in the Pacific Northwest. In this study, I focus on these same four factors. I examine longitudinal stream temperature patterns in the mainstem and the three main tributaries; summarize air temperature, baseflow indices, stream lengths, and stream slopes; summarize averages and maximum temperatures in these rivers; and describe the summer thermal sensitivity of the three tributaries (the regression slopes of the summer 7-day average stream temperature to air temperature relationships). The information on summer thermal sensitivities may be used to assess stream temperature increases that can be expected given future increases in air temperatures.

Basic Hydrology Information

The Coquille River drains an area of 1,058 square miles and extends almost 100 miles in length. It is the third largest watershed draining the Oregon Coast Range. Most of the upper watershed is steep and forested. Agricultural lands, pasture and small urban areas occur in the valleys and floodplains of the lower watershed. Approximately three miles from the mouth, the river widens and empties into the Coquille estuary before entering the Pacific Ocean. The 763-acre estuary is long, narrow, and fresh-water dominated because of its small size. The lower river, from the mouth upstream to the North Fork confluence at river mile (RM) 37, is considered tidally influenced (river miles are a measure of the distance upstream from the mouth of a river). Head of tide has been observed as far upstream as river mile (RM) 41, at the confluence of the Middle Fork and South Fork Coquille.

The mainstem Coquille is wide and very low gradient (0.01% stream slope), as well as tidally influenced. These characteristics have an important influence on water temperatures in this reach. The large width of the channel means that riparian shading is less effective at preventing solar loading to the river waters. The low gradient allows time for water temperatures to equilibrate with the surrounding atmospheric conditions. The tidal influence affects both water temperature and salinity, especially in the lower section of the mainstem. Salt-water intrusion has been noted as far upstream as RM 21, near the city of Coquille. During the summer, cold ocean waters enter and cool the lower section of the mainstem on incoming tidal cycles.

There are three major tributaries to the mainstem of the Coquille: the South Fork, Middle Fork, and North Fork (which includes the East Fork). The confluence of the South Fork and North Fork is at RM 37. The mainstem Coquille begins downstream of this confluence. The Middle Fork joins the South Fork four miles upstream of this confluence, at RM 41. The area upstream of the North Fork and South Fork confluence, which includes all three major tributaries, is 882 square miles. Statistics for all three major tributaries are shown in Table 1. The three main tributary forks are narrower and steeper gradient than the mainstem. These characteristics mean that riparian vegetation can be more effective at shading water and reducing solar loading. It also means higher velocities in streams and less time for stream temperatures to equilibrate with the surrounding atmosphere.

Table 1. Basin Statistics from USGS StreamStats or NWIS Web Pages for Three Major Coquille Tributaries.

Basin	Area (sq mi)	Mean Basin Elev (msl)	Stream Slope (%)	Annual Precip (in)	Baseflow Index*	Forest Cover (%)	Average Annual Flow (cfs)**
North Fork (includes East Fk)	289	1070	0.6	74	0.40	76	949
East Fork	134	1440	1.3	77	NA	84	NA
Middle Fork	308	676	0.6	73	0.33	80	748
South Fork (at RM 41, Middle Fk confluence)	246	1700	1.0	81	0.37	73	742

*from Wollock et al. 2003

**average of monthly flows from the overlapping period of record for all three gages: water years 1931-1946.

Climate, Geology, and Flow Regimes

The Coquille River basin is a coastal, rainfall-dominated watershed. The basin receives 70 inches of precipitation annually, with >95% of that falling between October and June. Summers are dry and warm, particularly in the interior of the basin. Air temperatures are mild year round because of the maritime influence but become more variable further inland away from the coast. The average January minimum daily air temperature in the basin is above freezing (1.8˚C) and there is little snowfall or snow accumulation in the watershed.

River flows in the Coquille reflect this seasonal distribution of precipitation and the lack of snowpack. There are no stream gages on the mainstem Coquille but there are, or have been historically, three USGS streamflow gages at the mouths of each of the main tributaries: the North Fork Coquille, Middle Fork Coquille, and South Fork Coquille. All three tributaries are fairly similar in terms of average annual flow (see Table 1). The South Fork gage is the only site still in operation. Average monthly flow, expressed as a faction of the total annual flow, for all three sites is shown in Figure 1. The seasonal distribution of flow is very similar in all three tributaries. Summer baseflows are very low, with close to 99% of the total annual flow in all three tributaries occurring October through June. Because streamflows are inversely correlated with stream temperature, the low summer baseflows are part of the reason for higher stream temperatures in the Coquille River.

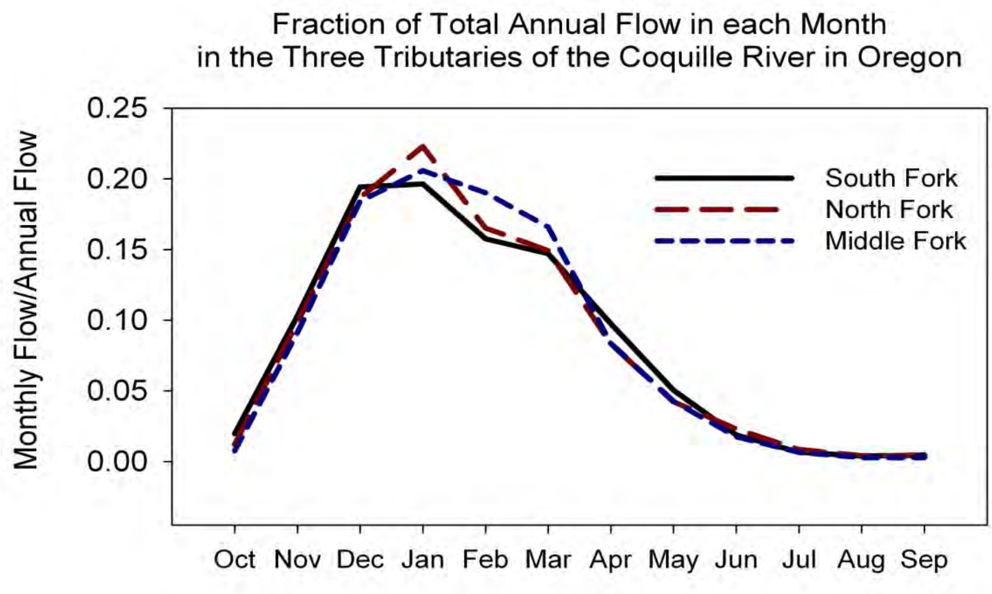

Figure 1. Average monthly flow as a fraction of total annual flow in the South Fork, North Fork, and Middle Fork Coquille River.

The low summer baseflows are due to the geology of the basin, which is dominated by marine sedimentary rocks. This material is not very permeable and this limits groundwater in the basin. As a result, the groundwater contribution to the Coquille River is very small. The baseflow indices (Table 1), which are a measure of groundwater influence, are within the lowest 10th percentile for all rivers in Oregon. Groundwater discharge to rivers can be an important regulator of summer water temperature, particularly during the summer baseflow season, so the lack of groundwater baseflow is another reason to expect higher summer stream temperatures in the Coquille River.

In most watersheds in the Pacific Northwest, summer air temperatures decrease with distance upstream because of higher elevations that occur upstream. The Coquille and other coastal basins are unique in that summer air temperatures are often warmer upstream in the watershed, away from the coast. Regressions of stream temperatures and air temperatures from a number of stream temperature sites on the Coquille show that the correlation is much stronger with air temperatures from interior climate stations (like Roseburg or Riddle, Oregon) compared to coastal stations (like North Bend). I have found similar relationships with other coastal basins (Mayer 2012). This means stream temperatures measured in the Coquille are more responsive to air temperatures in the upper watershed, as represented by interior climate stations, compared to air temperatures in the lower watershed.

Water-Quality Limited Reaches (Water Temperature)

In legal terms, a water quality standard consists of a designated beneficial use for a water body or stream segment and the water quality criterion necessary to protect the beneficial use. Waters can have several beneficial uses but the standard usually protects the most sensitive use. In the case of water temperature, the most sensitive beneficial use is typically cold-water aquatic communities and ecosystems. The designated beneficial uses in cold-water rivers are related to aquatic species and depend on the fish species and life stages present and their temperature needs.

For the Coquille River Basin, the designated fish uses are variable. The first several miles of the lower mainstem Coquille is designated a salmon and steelhead migration corridor, meaning the "waters are primarily used for salmon and steelhead migration during the summer and have little or no rearing during summer." The temperature criterion is 20˚C. The upper mainstem Coquille, along with the lower reaches of the main tributaries, are designated salmon and trout rearing and migration, which means "waters thermally suitable for rearing salmon, steelhead, rainbow trout, or cutthroat trout." The temperature criterion is either 17.8˚C or 18˚C. The upper reaches of the main tributaries are designated core cold-water habitat, which means "temperatures within the range generally considered optimal for salmon and trout rearing." The temperature criterion is 16˚C. The metric for all of these temperature criteria is the 7-day average of the daily maximum temperature or the 7-day average maximum.

A review of the temperature standards and beneficial uses in the Coquille basin shows that most of the basin is out of compliance with temperature standards. The lower section of the mainstem Coquille River, from the mouth to RM 21, is likely influenced by cooler ocean waters. This reach is considered estuarine, according to the ODEQ database, and is not listed for temperature currently because the rearing criterion does not apply to estuarine waters (ODEQ, 2010). The upper section of the mainstem Coquille River, from RM 21 to RM 35.3, is 303(d)-listed for temperature and a TMDL is needed. ODEQ (2010) states that 71% of the samples exceeded the 17.8˚C criterion for rearing.

The ODEQ database states that the lower reach of the North Fork Coquille River, from RM 0.0 to 27.9, exceeds the rearing criterion of 18˚C and is 303(d)-listed and needs a TMDL. The upper North Fork Coquille River, from RM 27.9 to 52.3, exceeds the core cold water habitat criterion of 16˚C and is 303(d)-listed and needs a TMDL. The lower reach of the East Fork, tributary to the North Fork, from RM 0.0 to 26.2 is 303(d) listed for exceeding the rearing criterion of 17.8˚C but the upper reach, from RM 26.2 to 33 (headwaters), meets this standard.

The database says that the Middle Fork Coquille River, from RM 11.2 to 39.6, exceeds the core cold water habitat criterion, and is 303(d)-listed and needs a TMDL. The upper South Fork Coquille River, from RM 42 to 61.9 (headwaters), has an approved TMDL for salmonid fish rearing and anadromous fish passage. A longer reach of the South Fork Coquille River, from RM 18.1 to 61.9 (headwaters), is reported in the DEQ database as 303(d)-listed and needing a TMDL for exceeding the core cold habitat temperature criterion of 16˚C. It's not clear why there are two criteria for overlapping river segments.

Stream Temperature Information

All of the historical stream temperature information in this report was downloaded from the Oregon DEQ LASAR web application at http://deq12.deq.state.or.us/lasar2/default.aspx . Most of the stream temperature monitoring in the basin has been focused on the main tributaries rather than the mainstem. The lack of temperature data in the mainstem Coquille may be a reflection of the fact that mainstem temperatures are going to be determined largely by the tributaries at the upstream end and the ocean at the downstream end. Therefore, what is of interest, and can be influenced, are the conditions affecting stream temperatures in the tributaries. Hence, the focus on the tributaries rather than the mainstem. There are numerous stream temperature sites on the main tributaries. Unfortunately, there are no comprehensive, synoptic monitoring efforts that would allow comparison of stream temperatures across all three tributaries at the same time.

Mainstem Coquille

There are only two stream temperature sites available from the ODEQ LASAR web site on the lower mainstem Coquille. They are located at RM 23 and RM 30 and both had only four days of data from September 11-14, 2007. Daily average temperature for the period was 19.9˚C at RM 30 and 20.2˚C at RM 23. The Coquille River & Estuary Water Quality Report (ODEQ, 1994) reports that instantaneous stream temperatures in September 1989 and September 1991 were about 20˚C in the "free-flowing part of the estuary." The same report states that "temperatures were reduced below 20˚C from about RM 12 to the estuary," likely because of the influence of incoming ocean waters.

Stream temperatures in the upper mainstem Coquille are determined by the contributions from the three main tributaries. Generally, summer stream temperatures in the three main tributaries increase fairly uniformly in a downstream direction as one travels from the headwaters to the confluence with the mainstem Coquille. This is a commonly observed pattern in rivers and streams (Caissie, 2006; Mayer, 2012). Rivers usually warm with distance downstream. Cool water sources, such as springs or tributaries, or warm water sources, such as reservoirs or thermal springs, can alter this pattern. For example, a reservoir on the Middle Fork Coquille appears to warm temperatures temporarily, as described below.

North Fork Coquille

For the North Fork, including the East Fork, I utilized data from monitoring conducted June 28-July 25, 2000, although one site at the mouth was monitored from June 28-September 8, 2000. Note that while the total river length is 54.1 miles, the furthest temperature site upstream is at RM 36.8, which is 17 miles from the headwaters (see Figure 2). Undoubtedly there is some unmeasured increase in stream temperature from the headwaters to the first monitoring site. All of the temperature monitoring has been done on the lower part of the North Fork in the lower gradient section of the stream, as seen in Figure 2. The boxplot of daily stream temperatures at each site shows that the range of daily temperatures is fairly similar at all sites in the lower reach (Figure 3). There is a general increase in temperature with distance downstream and the river warms more rapidly at the upstream end than at the downstream end. This is very typical of streams in the Northwest. Although not shown in the graph, the daily stream temperatures at all the sites behave very similarly and are highly correlated, suggesting they are all mainly responding to the same factor (atmospheric conditions) rather than local factors at each site. The rate of warming between RM 36.8 and the mouth is 0.11˚C/mile.

The average daily temperature for the monitoring period at the mouth is 20.2˚C. The 7-day average maximum at the mouth is 22˚C. The average daily temperature at the mouth of the East Fork is 19.2˚C, which is equal to the daily average (19.3˚C) for the North Fork upstream of the confluence. So the East Fork doesn't appear to influence temperatures in the North Fork to any degree. The 7-day average maximums at the downstream sites mostly exceed the temperature standard of 18˚C.

The slope of the 7-day average stream temperature versus 7-day average air temperature at the mouth in July and August is 0.46, meaning that for every 1 degree increase in summer air temperatures at the site, the stream temperature will increase 0.46 degrees. In a similar analysis of summer thermal sensitivity to increasing air temperatures at 104 sites across the Pacific Northwest (Mayer, 2012), I reported an average slope of 0.47, so the value here is about average.

Middle Fork Coquille

For the Middle Fork, I mainly utilized data from monitoring conducted from June 6-September 8, 2003 at 6 stream temperature sites, although at the furthest upstream site, the Upper Middle Fork at RM 38.9, I used data for the same dates but different years, 1999 and 2000. The total river length is 40.8 miles so furthest upstream site at RM 38.9 is very close to the headwaters (Figure 4). Stream temperatures at this site are very cool for this reason. The July monthly averages in 1999 and 2000 were 15˚C and 15.5˚C, respectively, and in August were 15.9˚C and 15.6˚C, respectively.

As with the North Fork, there is a general increase in temperature with distance downstream and the river warms more rapidly at the upstream end than at the downstream end (Figure 5). The one exception is the temperature at RM 33.3, which is much warmer than the adjacent sites. The higher stream temperatures at this site may be due to a fairly sizeable reservoir (Kinnan Lake) located just upstream of the RM 33.3 temperature site. Temperatures may warm in the reservoir and in the downstream reach. The area around the site is a low gradient, open valley (Camas Valley) that extends for about 10 miles. The valley appears to be more sparsely vegetated and predominantly agricultural.

Temperatures appear to cool somewhat from RM 37.3 to RM 29.8, possibly from tributary inflow, and then continue to increase fairly uniformly downstream (Figure 5). The rate of warming between RM 29.8 and the mouth is 0.17˚C/mile, which is higher than in the other tributaries. Part of the reason for this higher rate may be because sample sites are closer to the headwaters in this tributary. As in the North Fork, daily stream temperatures behave similarly and are highly correlated, suggesting they are all mainly responding to the regional atmospheric conditions rather than local factors.

In 2003, the mouth of the Middle Fork Coquille had a July average daily temperature of 22.7˚C and a 7-day average maximum temperature of 24.6˚C. In August of that same year, the average daily temperature of 21.7˚C and the 7-day average maximum temperature was 23.4˚C. These are the highest averages observed in any of the main tributaries. However, the temperature at the mouth was monitored again in 2010 and the temperatures were slightly cooler, with a July average of 20.9˚C and a 7-day average maximum of 22.2˚C and an August average of 20.6˚C and a 7-day average maximum of

22.1˚C. The cooler temperatures in 2010 may be as result of the much greater flows that occurred in 2010 versus 2003. All sites in this tributary exceed the temperature standard of 16˚C for most of the monitoring period.

The slope of the 7-day average stream temperature versus 7-day average air temperature at the mouth in July and August was 0.32 in 2003 and 0.35 in 2010, meaning that for every 1 degree increase in summer air temperatures at the site, the stream temperature increases between 0.32 and 0.35 degrees. This is close to, but slightly less than, the average slope of 0.47 that I described in my regional study (Mayer 2012). It may be that since this stream is already fairly warm, it is less sensitive to increasing air temperatures.

<u>South Fork Coquille</u>

For the South Fork, I utilized data from monitoring conducted from July 9 to September 8, 2010 at 10 stream temperature sites. As with the North Fork, the furthest upstream site, at RM 35.6, is still 26 miles downstream from the headwaters (Figure 6). Most of the temperature monitoring has been on the lower gradient section of the river. Undoubtedly there is some warming of stream temperatures before this point. However, there may not be too much since this area of the watershed is all Forest Service land and appears to be heavily forested. The stream temperature modeling for Upper South Fork Coquille TMDL (ODEQ 2001) states that the upper reach “is remarkable in that there are no permitted water diversions along the study area. Summer base flows in the modeled reach are as close to natural as exist in the Oregon Coast range.”

The boxplot of daily stream temperatures at each site shows that the range of temperatures is fairly similar at all sites (Figure 3). There is a general increase in temperature with distance downstream. The river warms more rapidly at the upstream end than at the downstream end, where it appears to level out or even cool somewhat. The rate of warming between RM 35.6 and the mouth is 0.11˚C/mile.

The average daily temperature for the period at the mouth of the South Fork was 21.1˚C. The 7-day average daily maximum temperature at this same site was 23.3˚C. All sites exceed the temperature standard of 16˚C for most of the monitoring period. The mouth of the Middle Fork was monitored during the same period. Averages at that site were cooler than at the mouth of the South Fork, with an average daily temperature of 20.6˚C and a 7-day average maximum temperature of 22.2˚C. So while the data from 2003 indicated that the Middle Fork was very warm, the data from 2010 do not indicate this. (This is part of the reason it is helpful to have synoptic samples where everything is measured at the same time).

The flow data from the USGS South Fork at Powers, OR gage (the only flow data available) indicates that June, July and August monthly flows were in the 90th percentile in 2010 while they were in the 20th percentile in 2003. The higher flows in 2010 resulted from a very wet spring, especially June, which was the seventh wettest June since 1895 at the North Bend OR USHCN station. Summer air temperatures were a little cooler in 2010 versus 2003 but the cooler stream temperatures in the Middle Fork in 2010 were also likely related to higher summer flows.

The slope of the 7-day average stream temperature versus 7-day average air temperature at the mouth in July and August is 0.31, meaning that for every 1 degree increase in summer air temperatures at the site, the stream temperature increases 0.31 degrees. This is similar to the value for the Middle Fork and is less than the average slope of 0.47 that I described in my regional study. As with the Middle Fork, it may be that this stream is less sensitive to increasing air temperatures because it is fairly warm already. One observes a decrease in the sensitivity of streams to air temperature increases at high air temperatures in the Pacific Northwest (Mayer, 2012).

August Stream Temperature/Air Temperature Ratios

I computed the August stream temperature to air temperature ratio at the mouths of all three tributaries, using the same method as described in Mayer (2012). The ratios were 1.17 at the mouth of the North Fork, 1.06 at the mouth of the Middle Fork, and 1.10 at the mouth of the South Fork. Ratios greater than one mean that the 7-day average stream temperature exceeds the local 7-day average air temperature at the site. All seven coastal basins that I examined in Mayer (2012) had stream T/air T ratios greater than one so the Coquille river basins are similar to other coastal basins in this respect. The fact that all of these ratios are greater than one means that these rivers are likely at equilibrium with current atmospheric conditions and will not warm further unless there is a change in these conditions (like future air temperature increases).

To meet the temperature criteria in the standard, the stream temperature/air temperature ratios would have to be much less than one (probably around 0.7 to 0.8 although it is difficult to say with certainty since the ratio here involves the average daily temperature but the standard is based on an average 7-day maximum). In Mayer (2012), the only streams I found with ratios in that range were high baseflow streams or headwater streams. The temperature criteria for these streams may be very difficult to attain.

Illinois River – Reference Site

For comparison, I downloaded and evaluated stream temperature data from the mouth of the Illinois river for the 2000 and 2003 summer season (all the data available). The Illinois is another large watershed (990 square miles) located to the south of the Coquille River in southwest Oregon. The site at the mouth is about the same distance inland as the mouths of the three Coquille tributaries. Like the Coquille, the Illinois has very low summer baseflows and little groundwater influence. Upstream of the mouth, the Illinois runs through 50 miles of forests and steep canyons and is designated a Wild and Scenic river. So the river should serve as a natural reference, although summer flows may be affected by diversions and mining operations as well as agricultural practices upstream of the Wild and Scenic segment. The August daily average stream temperature at the mouth was 21.5˚C in 2000 and 21.7˚C in 2003. The average 7-day maximum was 23˚C in 2000 and 23.2˚C in 2003. The average slope of the August 7-day average stream versus 7-day average air temperature for both years was 0.47 and the August 7-day average stream temperature to air temperature ratio was 0.98. These temperature statistics are all fairly similar to the three Coquille tributaries. The August 2003 average daily stream temperature at the mouth of Illinois River and the mouth of the Middle Fork Coquille were exactly equal, 21.7˚C , and the August 2003 average daily max stream temperature for the same two sites were very close, 23.2˚C and 23.4˚C, respectively.

Future Stream Temperature Warming

Annual air temperatures in the Coquille River basin are projected to increase 1.3°C by the 2040s and 1.8°C by the 2060s, compared to a baseline period of 1970-1999, based on a suite of nine regional climate models using the A2 emissions scenario (Sharp, 2012). Air temperatures increases are slightly greater inland, with distance from the coast. For both the 2040s and the 2060s, the summer period (defined as Jun-Aug) has the largest projected temperature increase (median increase is 1.6-1.8°C by the 2040s and 2.1-2.4°C by the 2060s, depending on the site). Most projections are for drier summers as well, although projections for the overall change in annual precipitation are inconclusive.

The question addressed in this section is "how much warmer will streams get, given the projected increases in summer air temperatures?" At most sites, there is a good correlation between stream temperatures and air temperatures. Air temperature is not a major forcing for stream temperatures but the two variables are governed by the same heat flux and are, therefore, closely correlated. The regression slope of the observed stream-to-air temperature relationship is often used to represent the sensitivity of the stream to future warming (Mayer, 2012).

The value of the regression slope is dependent on the time scale of the data (Caissie, 2006). Studies have shown that as the time scale increases (daily, weekly, monthly and annually), the slope of the regression line of water on air temperature generally increases as well. This is relevant to the effort here because while the air temperature projections developed for this assessment are for 3-month seasons (ex. Jun-Aug), stream temperature data are not available to assess the stream-air temperature relationship at such large time steps. The largest time step employed here in assessing stream-air temperature relationships was a 7-day average temperature. This means that the slopes or sensitivities presented above, based on 7-day time steps, could be low or conservative when applied to a 3-month period.

However, there is generally a decrease in the sensitivity of streams to air temperature increases at higher air temperatures in the Pacific Northwest (Mayer, 2012). As stream and air temperatures increase, evaporative cooling from the water surface becomes more dominant and limits further stream warming. Given that these streams are already as warm as many streams in the region (90^{th} percentile of 104 stream sites across the PNW) and that their August stream/air temperature ratios are very high (Mayer 2012), the estimated increases developed here from 7-day time steps may not be low. One other note is that higher flows can moderate stream temperature sensitivity to increasing air temperatures, particularly in June when flows are variable and sensitive to June precipitation. To the extent that June precipitation decreases, this will mean high maximum summer stream temperatures and a longer period of warm stream temperatures overall during the summer season.

The average regression slope of the stream-air temperature relationships from all mouths at all three tributaries as well as the mouth of the Illinois River is about 0.4. Applying this slope to the projected summer air temperature increases for the inland sites, stream temperatures can be estimated to increase about 0.7°C by the 2040s and 0.9°C by the 2060s.

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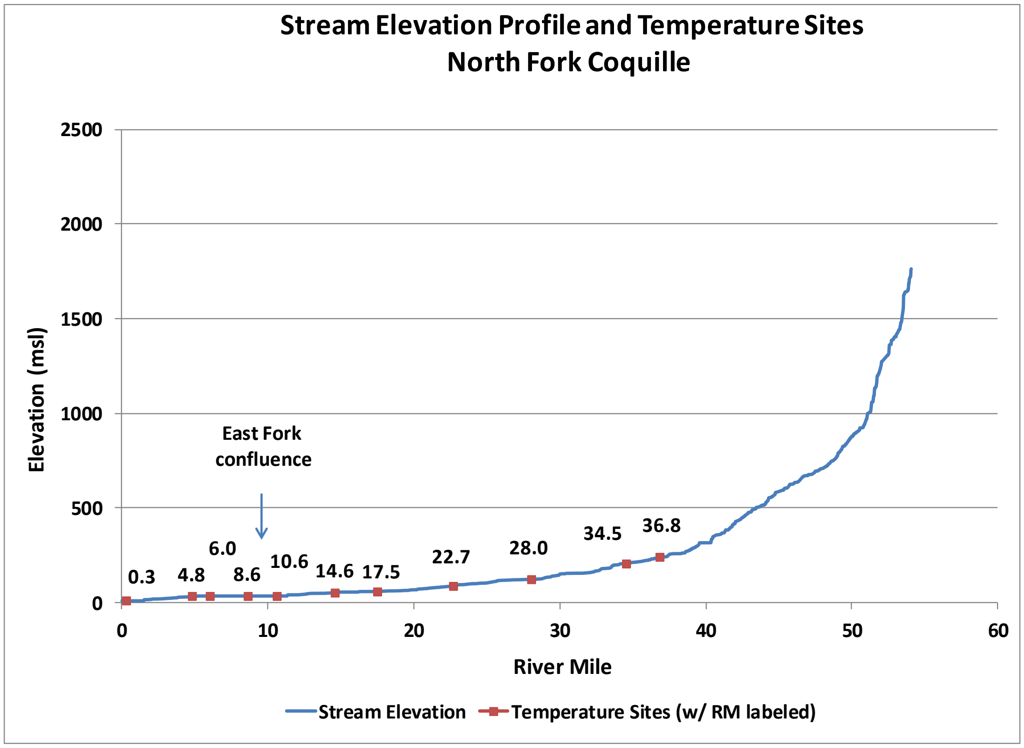

Figure 2. Stream elevation profile for the North Fork Coquille with locations and elevations of stream temperature sites used in this report.

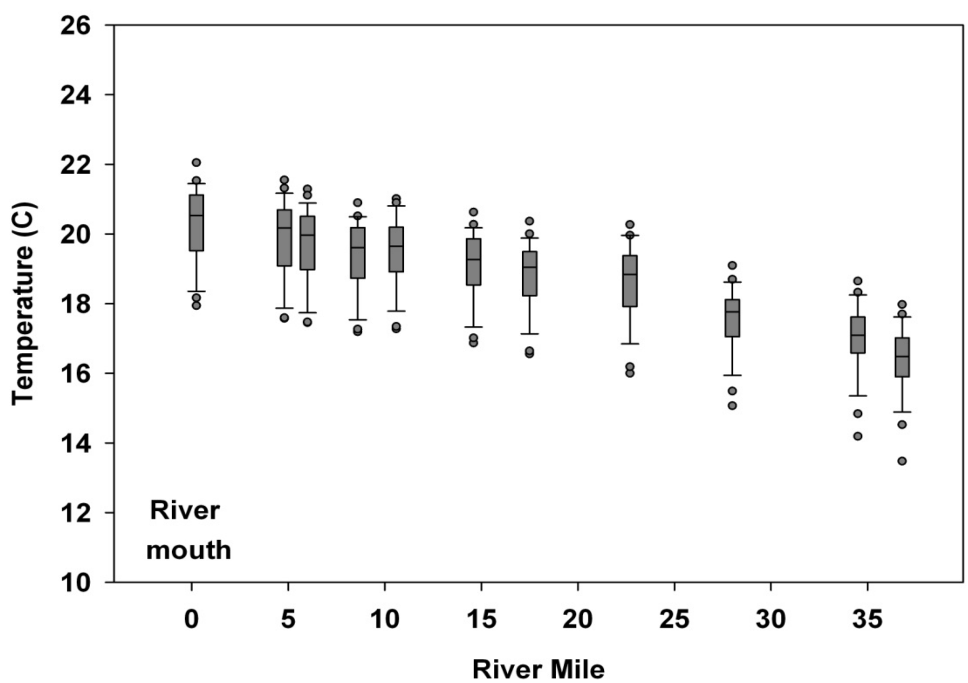

Figure 3. Boxplots showing the distribution of average daily stream temperatures for the period June 28 to July 25, 2000 in the North Fork Coquille.

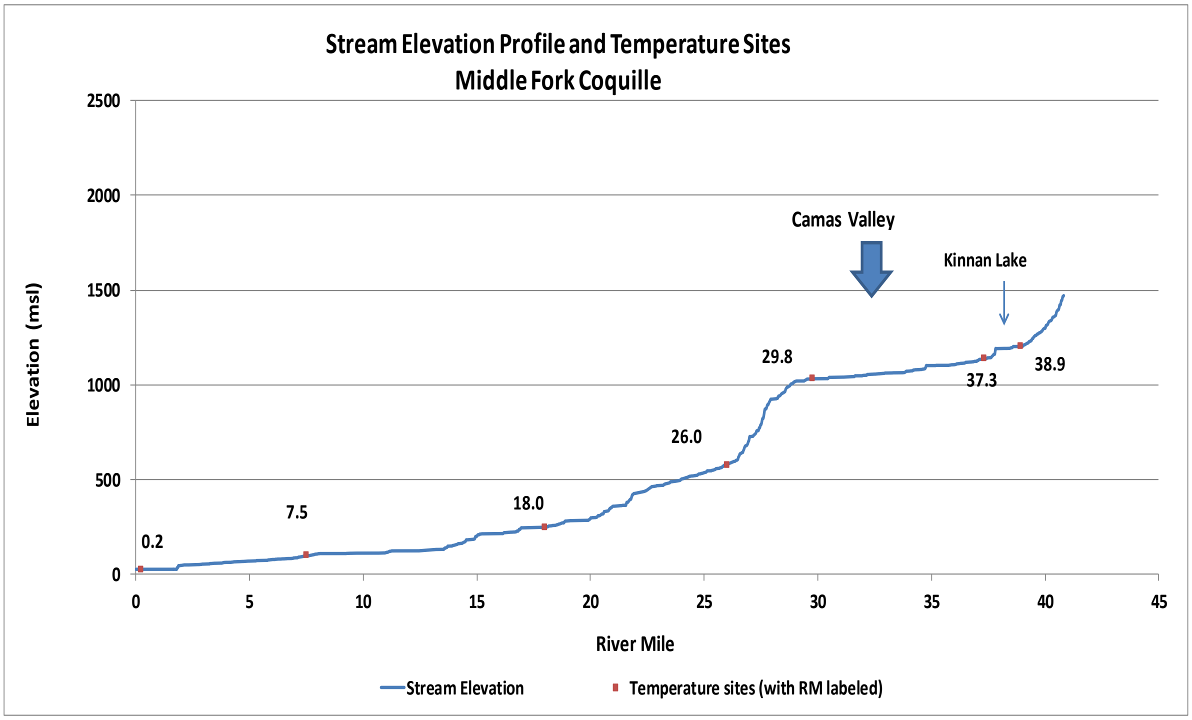

Figure 4. Stream elevation profile for the Middle Fork Coquille with locations and elevations of stream temperature sites used in this report.

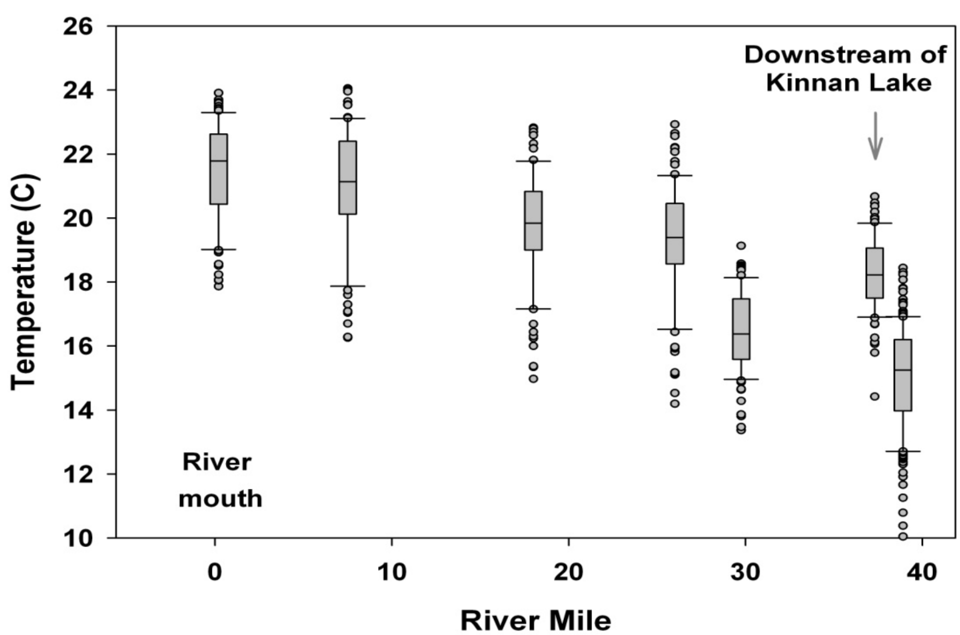

Figure 5. Boxplots showing the distribution of average daily stream temperatures for the period June 6 to September 8, 2003 in the Middle Fork Coquille. (First site upstream – RM 38.9 – uses 1999 and 2000 data for same dates).

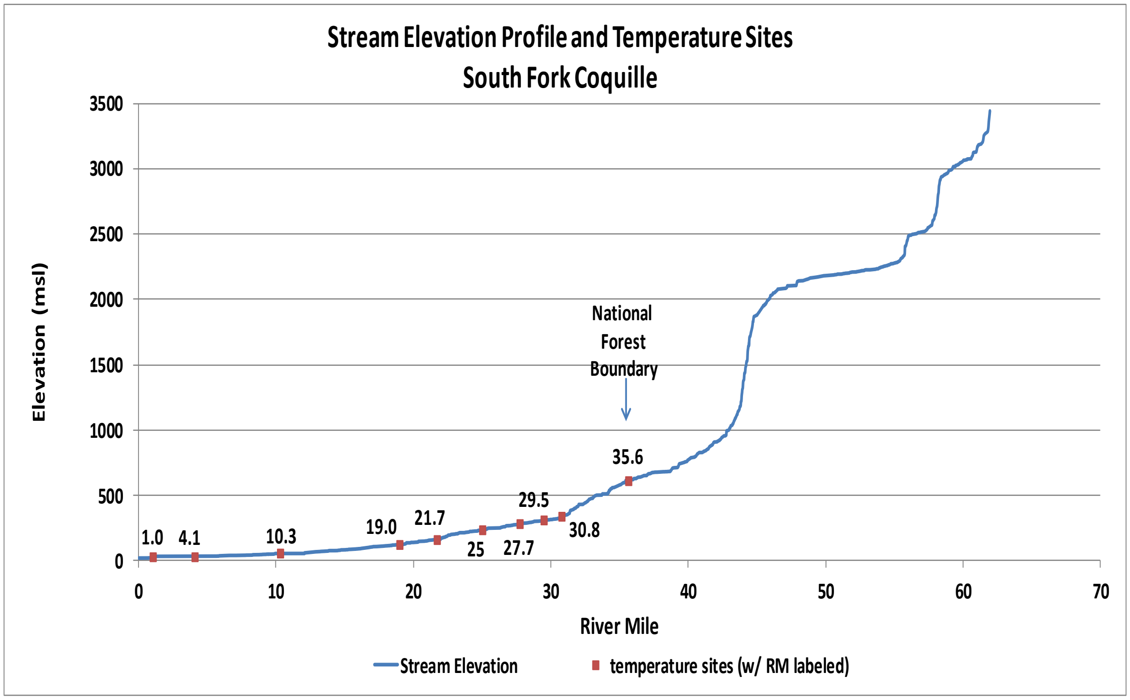

Figure 6. Stream elevation profile for the South Fork Coquille with locations and elevations of stream temperature sites used in this report.

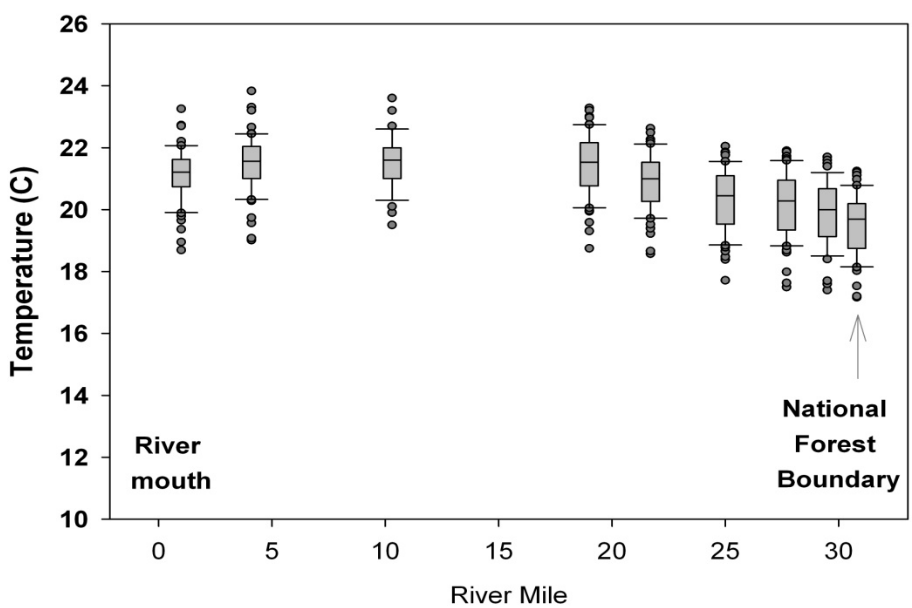

Figure 7. Boxplots showing the distribution of average daily stream temperatures for the period July 9 to September 6, 2010 in the South Fork Coquille.