A Review of Temperature Conditions and Associated Water Quality Standards for the Carson River

A supporting document for the Carson River Report Card

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Carson River at Deer Run Road during extreme flow conditions in 2004

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Introduction

In support of its Clean Water Act responsibilities, the Nevada Division of Environmental Protection (NDEP) – Bureau of Water Quality Planning (BWQP) is developing a Carson River Watershed Assessment or Report Card. Drawing upon numerous studies and monitoring efforts, the Report Card will provide a compilation of current knowledge about the chemical, physical and biological health of the Carson River watershed with a focus on aquatic life uses from the Nevada/California stateline to Lahontan Reservoir. It is hoped that the Report Card will be a valuable tool for educating the public, agencies and decisionmakers on the state of the river (from a Clean Water Act perspective), thereby providing direction for their future actions and decisions. The Report Card will also be a key planning tool for BWQP in possible future steps, such as standards revisions, comprehensive Total Maximum Daily Loads (TMDLs), watershed plan development and restoration projects.

The purpose of this report is to summarize temperature conditions in the Carson River system (Figure 1), physical conditions contributing to the temperature conditions and review the existing temperature water quality standards. Additionally, recommendations on additional work and water quality standard revisions are provided.

Background

Factors Influencing Stream Temperatures

The temperatures found in streams can be highly variable with time and space depending upon cumulative influence of a myriad of upstream factors related to the heat budget. It is well recognized that components of a stream heat budget are related to physical watershed and stream characteristics. An understanding of these factors is helpful in understanding subsequent discussions of Carson River temperatures.

Heat Budget Components

The following discussion provides a general introduction to the components of a waterbody heat budget. Theurer et al. (1984) describes five basic thermal processes that make up the heat balance for a waterbody: 1) radiation; 2) evaporation; 3) convection; 4) conduction; and 5) conversion of energy from other forms of heat (Figure 2).

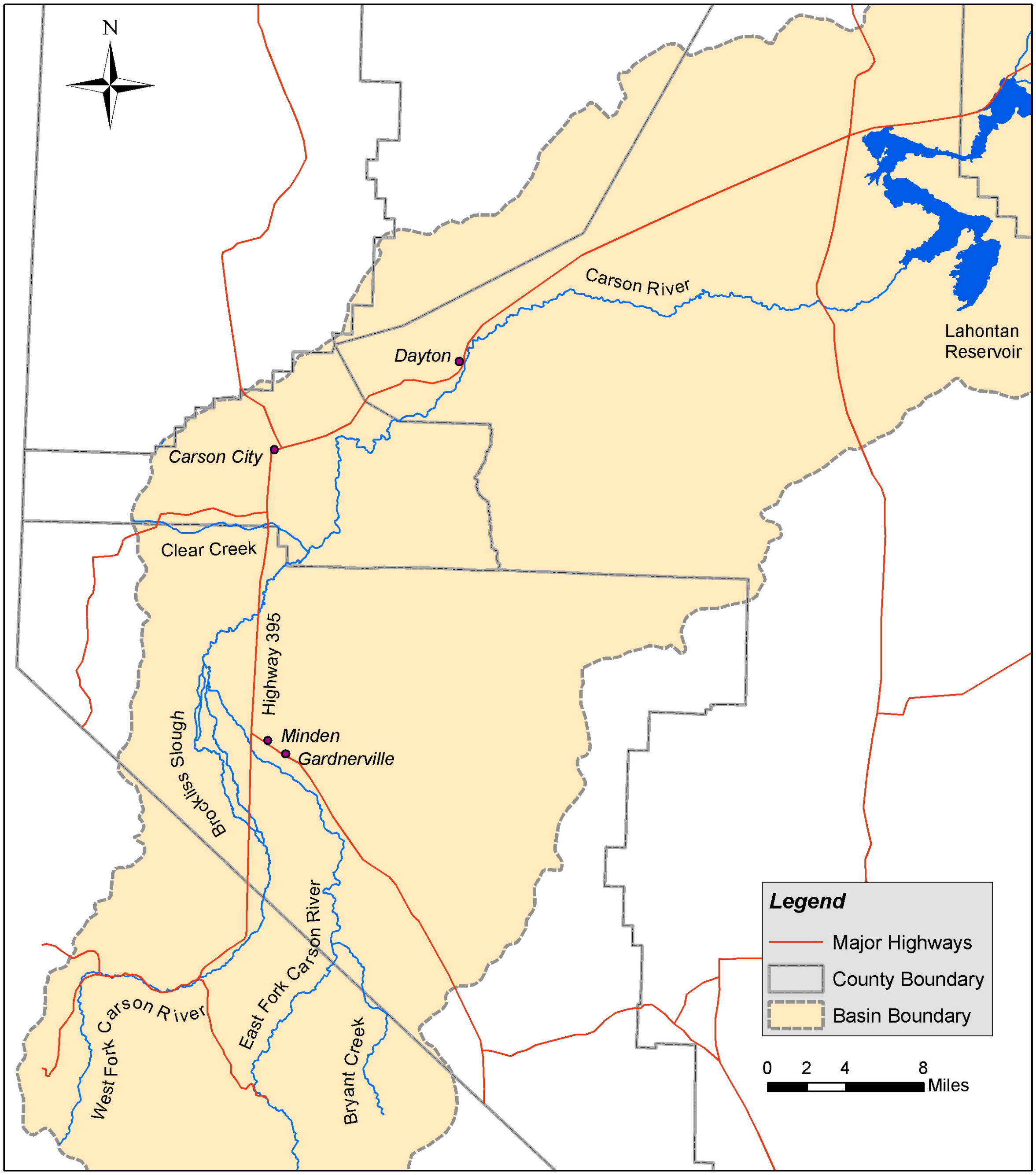

Figure 1. Carson River Study Area

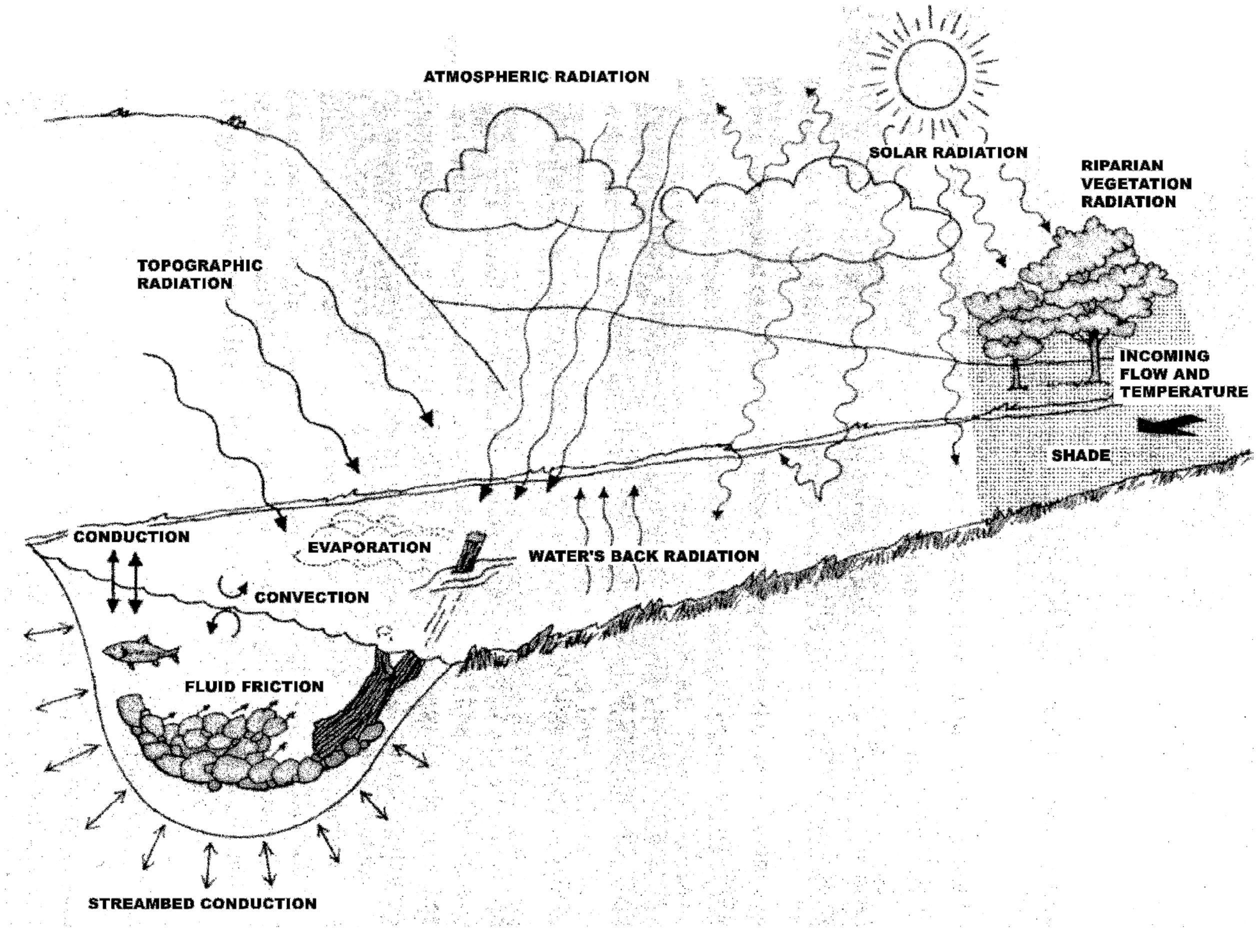

Figure 2. Stream Heat Flux Components (from Bartholow, 2000)

Radiation

Solar Radiation: Radiation from the sun is a major component of a water's overall heat budget. Solar radiation levels that reach the water surface (assuming no topographic or vegetative shading) are a function of latitude, time of year, atmospheric conditions, and cloud cover. A portion of the solar radiation can be reflected off the water surface. The actual solar radiation that penetrates the water can be reduced by topographic and/or riparian vegetation shading. (Theurer et al., 1984).
Atmospheric Radiation: The atmosphere emits longwave radiation. Atmospheric radiation levels are a function of atmospheric moisture; air temperature; and cloud cover (Anderson et al., 1984; Theurer et al., 1984). The amount of atmospheric radiation reaching the waterbody can be reduced through interception by vegetative canopy or shading.
Topographic and Riparian Vegetation Radiation: Riparian shading can totally eliminate a portion of the solar radiation reaching the water. Riparian shading also intercepts longwave sources (atmospheric radiation) and replaces it with its own longwave radiation. The land near the waterbody also emits longwave radiation which may reach the waterbody (Theurer, et al., 1984)
Water Back Radiation: Water emits radiation and this is one factor that prevents the water temperature from increasing without limits (Theurer, et al., 1984).

Evaporation

Stream Evaporation: According to Parker and Krenkel (1969), the evaporative heat flux at the air-water interface is typically the most significant fact in dissipating stream heat. Evaporative cooling is a function of the water temperature, air temperature, relative humidity, and wind speed.

Convection

Convection: At the air-water interface, heat is exchanged in response to a heat energy gradient (difference between temperatures of water and air). The higher the difference in temperature, the higher the rate of heat energy transfer (Boyd and Kasper, 2003). The rate of heat exchange is also a function of relative humidity and wind speed.

There has been significant debate over the role of air temperature in controlling stream temperatures. While a good correlation can exist between air temperature and water temperature, Johnson and Wondzell (2005) have found that direct solar radiation (not air temperature) was the largest contributor to changes in daily temperature. As Johnson and Wondzell concluded "…*just because air and stream temperatures are correlated does not mean that there is a cause-and-effect relationship*".

One reason air temperature can correlate well with stream temperature is that air temperature is well correlated with elevation, basin area (surrogates for time water is exposed to solar radiation, etc. Though the exchange of heat between the air and the water (convection) represents a small portion of the heat budget, air temperature affects other heat flux components such as atmospheric radiation and evaporation.

Conduction

Streambed Conduction: Heat is transferred between the water column and the streambed in response to a heat difference between the water and streambed.

Other

Stream Fiction: Heat is generated by fluid friction as water flows downstream. Typically, fluid friction is the least significant source of heat, but can become noticeable in steep mountain streams (Theurer, 1984).

Stream Characteristics Affecting the Heat Budget

Following is a brief description of some of the key watershed characteristics that affect a stream's heat budget, and thereby determine characteristics of the stream's temperature regime. Many of the discussed characteristics are interrelated.

Latitude

The latitude of a stream affects the angle at which solar radiation strikes the water surface, thereby affecting the solar radiation loading to the water (Theurer, 1984). In general, higher latitude (further north) waters receive less solar radiation than lower latitude waters.

Elevation/Area/Distance from Watershed Divide

Stream temperatures tend to increase with decreasing elevations, increasing watershed area, and increasing distance from the watershed divide (Allan, 1995). In general the farther water has to travel to get to a monitoring point, the longer time there is available for solar radiation, etc. to heat up the water.

Shading (topographic and vegetative)

Shading from the surrounding topography and riparian vegetation can reduce the amount of solar radiation reaches the water surface, resulting in cooler water.

Stream Orientation

Moore (1967) found that east-west oriented streams in Oregon could have temperatures 2 to 4.5º C warmer than similar north-south oriented streams. He concluded that longer exposure to direct solar radiation (to the east-west streams) is the likely explanation for the difference. Available solar radiation modeling confirms Moore's conclusion of increased solar radiation loading to the east-west stream. However for streams with no shading, the solar radiation loads are essentially the same regardless of stream orientation.

Bartholow (2004) developed the SSTEMP model to serve as a simplified tool to calculate the heat flux components for a stream and the resulting stream temperatures. Using SSTEMP to model fictitious streams with varying orientations, it was found that a north-south oriented stream has more vegetative and topographic shading than the same stream oriented east-west, confirming Moore's (1967) findings.

Flow

Flow plays a significant role in observed stream water temperatures. Higher flows lead to higher velocities resulting in less time for heating to occur. Additionally, higher flows provide more water mass that has to be heated. Also, adequate flows are needed to support the riparian vegetation which provides the shading.

Flow can be correlated with elevation, watershed area, distance from watershed divide. The type of water year can have a significant influence upon the magnitude and timing of the maximum temperatures. For a given stream in the arid west, significant amounts of flow may be diverted to support agricultural operations, leading to diminished flows with higher water temperatures.

Stream width

Steeper streams generally are narrower, need less vegetation to provide the same level of shading that a wider stream would have. Stream widths can increase with increased flows, increased basin area (Lewis et al., 2000). Wide shallow channels can be more easily heated and cooled than deep narrow channels (Poole et al., 2001).

Stream gradient

Higher gradient streams can be expected to have lower temperatures for a couple reasons. Streams generally become narrower at higher gradients resulting in more effective riparian vegetation shading

(Lewis et al., 2000). Also, faster flow velocities in higher gradient streams exposes the water to less heating.

Groundwater

Groundwater inflows can be significantly cooler[1] (or hotter in the case of geothermal springs) than surface water and have a significant influence on stream temperatures. Another factor affecting stream temperatures is the exchange of water between the stream and the surrounding hyporheic zone (see Figure 3). Significant hyporheic flow can serve as a buffer against water temperature fluctuations (Poole, et al., 2001; Poole and Berman, in press). As a result of groundwater inflows, stream temperatures can vary significant throughout a river reach.

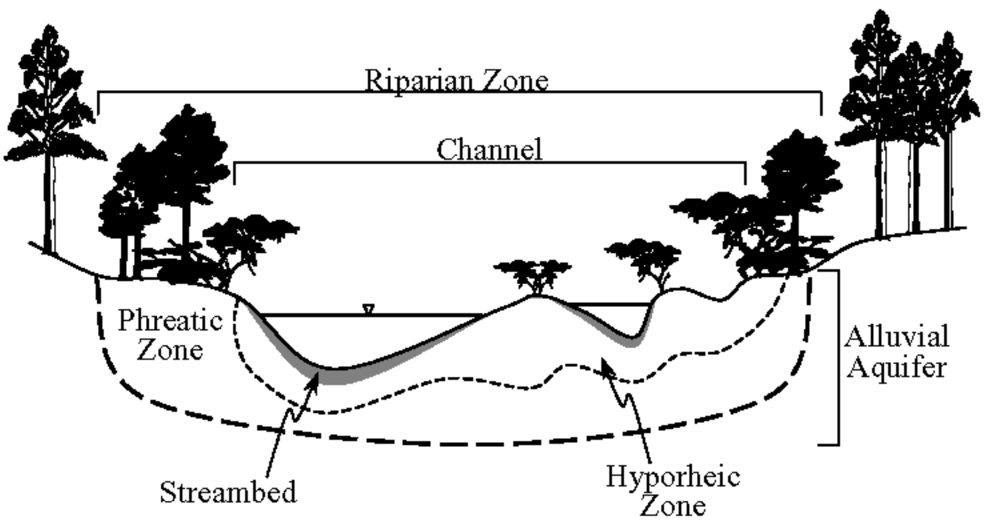

Figure 3. Hyporheic Zone of a Stream System (after Poole and Berman, in press)

Existing Water Quality Standards

Nevada's water quality standards for the East and West Forks, and the Carson River are contained in Nevada Administrative Code (NAC) 445A.146 through 445A.158, and are summarized in Table 1. In general, the temperature criteria recommendations were given for the protection of various fish species of concern for the five main fish life stages: spawning, incubation, nursery-fry, juvenile and adult. For the reaches above New Empire (Deer Run Road), the species of concern are listed as primarily coldwater species (rainbow and brown trout); below New Empire, the species of concern are warmwater species (walleye, channel catfish and white bass). A more detailed discussion of these standards is provided by Pahl (2004).

[1] Groundwater temperatures can vary about ± 3° C around the mean annual air temperature for the region (Adams and Sullivan, 1990). The Carson City mean annual temperature is about 10° C (50° F).

Table 1. Summary of Temperature Water Quality Standards in the Carson River above Lahontan Reservoir (maximum daily temperatures, in °C)

<table>
<tr><th>Water body</th><th>Reach</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">WF Carson</td><td>Stateline</td><td rowspan="9" colspan="4">13</td><td>13</td><td rowspan="9">17</td><td>21</td><td colspan="3">22</td><td rowspan="9" colspan="2">13</td></tr>
<tr><td>Stateline to confluence</td><td>17</td><td colspan="4">23</td></tr>
<tr><td>Bryant Creek</td><td>Stateline to confluence</td><td rowspan="3">13</td><td rowspan="3">21</td><td rowspan="3" colspan="3">22</td></tr>
<tr><td rowspan="3">EF Carson</td><td>Stateline to Hwy 395</td></tr>
<tr><td>Hwy 395 to Muller Lane</td></tr>
<tr><td>Muller Lane to confluence</td><td rowspan="4">17</td><td rowspan="5" colspan="4">23</td></tr>
<tr><td rowspan="6">Carson River</td><td>Confluence to Genoa Lane</td></tr>
<tr><td>Genoa Lane to Cradlebaugh Bridge (Hwy 395)</td></tr>
<tr><td>Cradlebaugh (Hwy 395) Bridge to Mexican Ditch Gage</td></tr>
<tr><td>Mexican Ditch Gage to New Empire</td><td colspan="5">18</td><td>23</td><td colspan="2">18</td></tr>
<tr><td>New Empire to Dayton Bridge</td><td rowspan="2" colspan="3">11</td><td rowspan="2" colspan="3">24</td><td rowspan="2" colspan="4">28</td><td rowspan="2" colspan="2">11</td></tr>
<tr><td>Dayton Bridge to Weeks (Hwy 95)</td></tr>
</table>

Nevada's 303(d) List

Every two years, Nevada is required under the federal Clean Water Act to produce a list (303(d) List) of waters not meeting applicable water quality standards (BUSs only). All of the Carson River and the East/West Forks from the stateline to New Empire are on the 303(d) List for temperature. With limited data for the river below New Empire, the status of these lower stretches is unknown.

Major Past Studies

Limited studies in the Carson basin have focused on stream temperature conditions. Following is a summary of the three main efforts to date.

Airborne Thermal Infrared Remote Sensing: Carson River Basin, NV (Watershed Sciences, 2006)

On August 8, 2006, Watershed Sciences conducted an airborne thermal infrared (TIR) survey for the Carson River and the East/West forks from the stateline to Deer Run Road, including the Brockliss Slough. Project deliverables included TIR survey results in GIS, longitudinal temperature profiles, etc. During the survey, flows were above the median values for that time of year. Data collected by Garner, 2007) show that maximum temperature conditions on August 8, 2006 were generally about 2 to 3°C cooler than during the maximum temperatures for the Summer of 2006.

Key Findings/Conclusions:

- The TIR data showed how surface water temperatures varied over the study area. In some cases, temperature variations were associated with diversion dams and flow diversions.
- Large gravel bars with numerous seeps and side channel are common on the East Fork Carson River. The detected seeps and temperature changes suggest that there are areas of sub-surface exchange within the stream channel.
- The West Fork and Brockliss Slough do not have large gravel bars and resemble canals in some areas. At some sites, the flow conditions led to thermal stratification and algae growth on the water surface.

More detailed discussion on the findings of this study is incorporated into the following ***DISCUSSION*** section.

Modeling the Effect of Riparian Shading on Water Temperature for Portions of the Carson River, Western Nevada, USA (Garner, 2007)

A temperature model was developed for the Carson River from Genoa to Deer Run Road, and was used test how revegetation strategies could improve temperature conditions. In support of the model development, significant temperature, climatological and flow data were generated.

Key Findings/Conclusions:

- A revegetation simulation was performed by applying vegetation attributes from the reaches with substantial riparian coverage (roughly Mexican Gage to Deer Run Road) to the reaches with limited shading (from below Genoa Lake Golf Course to McTarnahan Bridge site). Model results predicted that the assumed revegetation could result in reductions in maximum daily temperatures of up to about 2°C for August 8, 2006. However, the water quality standard of 23°C would still not be met for portions of the study area. Garner notes that August 8, 2006 was selected as the revegetation simulation day as this date was when some of the cooler maximum daily temperatures occurred, and it was reasoned that if the standards could not be met on this day with increased vegetation, then it is unlikely that standards could be met on other hotter summer days.
- An increased flow scenario for August 8, 2006 was simulated under which flows were assumed to increase by 15 m^3/sec (about 530 cfs). The actual average daily flow at USGS Gage 10311000

(Carson River near Carson City) for August 8, 2006 was 87 cfs. This significant increase in flow resulted in predicted maximum temperature drop of about 3°C. The author notes that there is a large degree of uncertainty with these simulations as there was no information available upon which to revise incoming stream water temperature boundary conditions at the start of the study reach. The author also notes that flows of this magnitude are unlikely to be achieved during the summer. However, high flows were evaluated to examine the relative importance of flow to stream temperatures.

- The author noted that the 2005 and 2006 study period experienced median to above-median flows. Temperature conditions would be expected to be worse during other low flows years, and compliance with the standards would be even more difficult.

- The author identifies possible future work to include investigation of the importance of channel width on stream temperatures and the riparian shading characteristics.

Summary of Stream Temperature Metrics for the Carson River (Pahl, 2007)

This report summarizes statistics on daily water temperature data that have been collected for 24 sites on the East and West forks and the Carson River upstream of Deer Run Road. Continuous and/or minimum/maximum temperature data collected by Nevada Department of Wildlife, U.S. Geological Survey, Desert Research Institute and NDEP were used in the report.

Key Findings/Conclusions:

- Information from this report has been incorporated into the DISCUSSION section.

Discussion

Following is a discussion of temperature conditions throughout the study area, including flow effects, spatial and temporal variability, and shading and canopy conditions.

Overall Temperature Conditions and Standards Exceedances

Pahl (2007) presented a summary a temperature metrics for sites throughout the Carson system that warrants repeating (Table 2). All 24 sites in Table 2 have periods during which the water quality standards are exceeded. However, the upper sites tend to have lower temperatures and less frequent standard exceedances. It is important to note that the East Fork Carson River prior to entering Carson Valley has frequent standards exceedances. Limited data suggest that the West Fork Carson River is cooler than the East Fork, where they both enter Carson Valley.

Figure 4 presents a plot of the Maximum Daily Maximum Temperature (MDMT) and Maximum Daily Average Temperature (MDAT) in Table 2 for the East Fork and Mainstem Carson River from stateline to Deer Run Road. These data show that both the maximum daily and maximum average temperatures frequently exceed the standards in this reach. In fact, many sites have experienced over 30 days of standard exceedances in a given year (Figure 5).

Streamflow and Temperature Conditions

As discussed earlier, streamflow can have a significant influence upon temperature, particularly in the Carson River. Pahl (2007) presented data showing strong relationships between flows and temperatures for the East Fork Carson River (USGS Sta. 10309000) above Carson Valley (Figure 6).

Once river flows enter Carson Valley, irrigation diversions represent a significant demand on Carson River flows resulting in significant impacts upon the flow characteristics and the associated temperatures. As part of historic and ongoing irrigation activities, a complex network (particularly in the Carson Valley) of ditches and drains has been created (Figure 7) resulting highly modified flows within the Valley and below.

Note that the West Fork Carson River below Brockliss Slough is depicted as a minor channel for a significant distance (Figure 7). A few miles after entering Carson Valley, the waters of the West Fork Carson River actually “flow into” the Brockliss Slough leaving little to no water in the West Fork Carson River[2] with Brockliss Slough becoming the main carrier of what was West Fork Carson River water. At this split point, some small amount of water is diverted into the historic West Fork channel to meet downstream rights (Pugsley, August 23, 2004). Below this point, the West Fork Carson River channel also serves as a catchment for return flows from land irrigated with East Fork Carson River water (Hess, 1996). Figure 8 provides photographs of the West Fork above/below Brockliss Slough showing the drastic change in the channel and flow.

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[2] Though no definitive historic record can be found, it is likely that in the late 1800s a diversion structure was in place to divert significant water volumes from the West Fork Carson River into Brockliss Slough (an abandoned river channel). As indicated by the Alpine Decree, the water righted acreages associated with the Brockliss Slough are significantly higher than with the West Fork Carson River (below Brockliss Slough). There appears to be evidence that a high flood in the early 1900s took out the diversion structure and the physical conditions were such that the river water began flowing into the Brockliss Slough rather than the West Fork channel. Some time later, a minor diversion structure must have been constructed to divert minimal flows into the West Fork channel below this point as needed to meet the downstream water rights (Pugsley, August 23, 2004).

Table 2. Summary of Temperature Metrics (° C)

Stream	Site	Period of Record	MDMT	MWMT	MDAT	MWAT	Max. Daily Change	Max. WQS
WF Carson River	Paynesville (NDEP)	2001-04	22.1 – 22.9	21.4 – 21.8	18.7 – 19.2	18.0 – 18.7	7.3 – 8.4	22
	Above Confluence	2004	26.5	24.3	22.2	20.4	13.8	23
EF Carson River	Sheep Bridge	2000-01	26.5 – 26.8	24.3 – 25.8	22.0 – 22.2	20.4 – 21.4	10.2 – 10.7	22
	USGS Gage 10309000	1954-65, 1967-72, 1994—1996, 2002-04	18.9 – 29.4	18.0 – 28.6	17.0 – 24.8	16.4 – 23.7	7.2 - 10.6	22
	Washoe Bridge	2004-05	24.5 – 26.9	23.5 – 25.8	20.8 – 22.6	20.1 – 22.0	8.3 – 11.8	22
	USFWS Fish Hatchery	2002-03	26.0 – 26.3	25.0 – 25.3	22.3 – 22.9	21.4 – 21.6	8.8 9.2	22
	Above Lutheran Bridge	2003-05	25.5 – 28.9	25.1 – 27.9	22.0 – 24.3	21.0 – 23.1	9.4 – 11.4	22
	Above Highway 88	2003-05	25.5 – 28.4	24.2 – 26.6	20.4 – 22.6	19.6 – 21.3	10.8 – 13.2	22
	Above Confluence	2003-04	28.7 – 29.1	27.5 – 28.0	22.9 -24.1	21.7 – 23.2	13.4 – 14.6	23
Carson River	Above Genoa Lane	2004	29.9	28.4	22.7	21.7	16.2	23
	Willow Bend	2003	29.4	28.4	24.6	23.8	15.0	23
	Genoa Lakes Golf Course (DRI, Garner)	2005-06	26.9 – 27.3	26.3 – 26.5	23.8 – 24.3	23.5 – 22.8	9.1 – 10.2	23
	Lippencott Ski Ranch	2005-06	28.4 – 29.8	27.1 – 28.4	24.3 – 24.5	23.6 – 23.8	13.0 – 16.0	23
	Cradlebaugh Bridge	2004-05	29.6 - 30.5	28.8 - 29.4	24.0 – 24.8	23.1 – 23.9	13.8 – 13.9	23
	Sunridge Golf Course	2005	29.3	28.2	25.2	23.6	13.6	23
	V&T Railroad Crossing	2005	29.3	28.4	24.3	23.6	13.0	23
	McTarnahan Bridge	2006	29.3	28.3	25.6	24.7	13.6	23
	Mexican Gage	2001-03	32.8 – 33.2	30.8 – 31.4	25.5 – 26.7	24.2 – 25.9	16.3 – 16.6	23
	Foerschler Ranch	2005-06	29.3 – 29.6	28.2 – 28.3	24.6 – 25.5	23.7 – 24.8	10.9 – 11.4	23
	Riverview Park	2005-06	27.9 – 29.8	27.0 – 28.5	25.3 – 25.6	24.4 – 24.7	9.8 – 11.8	23
	Empire Golf Course	2005	29.6	28.5	26.0	24.5	12.0	23
	Morgan Mill Road	2005	30.0	28.5	26.1	24.6	10.8	23
	Deer Run Road (USGS)	1995	26.5	25.0	24.0	22.4	7.0	23
	Deer Run Road (NDOW)	2000	30.2	28.8	26.1	24.7	10.1	23
	Deer Run Road (NDEP)	2003	31.0	29.7	27.4	26.5	10.5	23
	Brunswick Bridge	2005	29.8	28.0	25.6	24.8	9.8	28

MDMT = maximum daily maximum temperature

MWMT = maximum weekly maximum temperature

MDAT = maximum daily average temperature

MWAT = maximum weekly average temperature

Figure 4. MDMT and MDAT Metrics for East Fork and Mainstem Carson River from Stateline to Deer Run Road

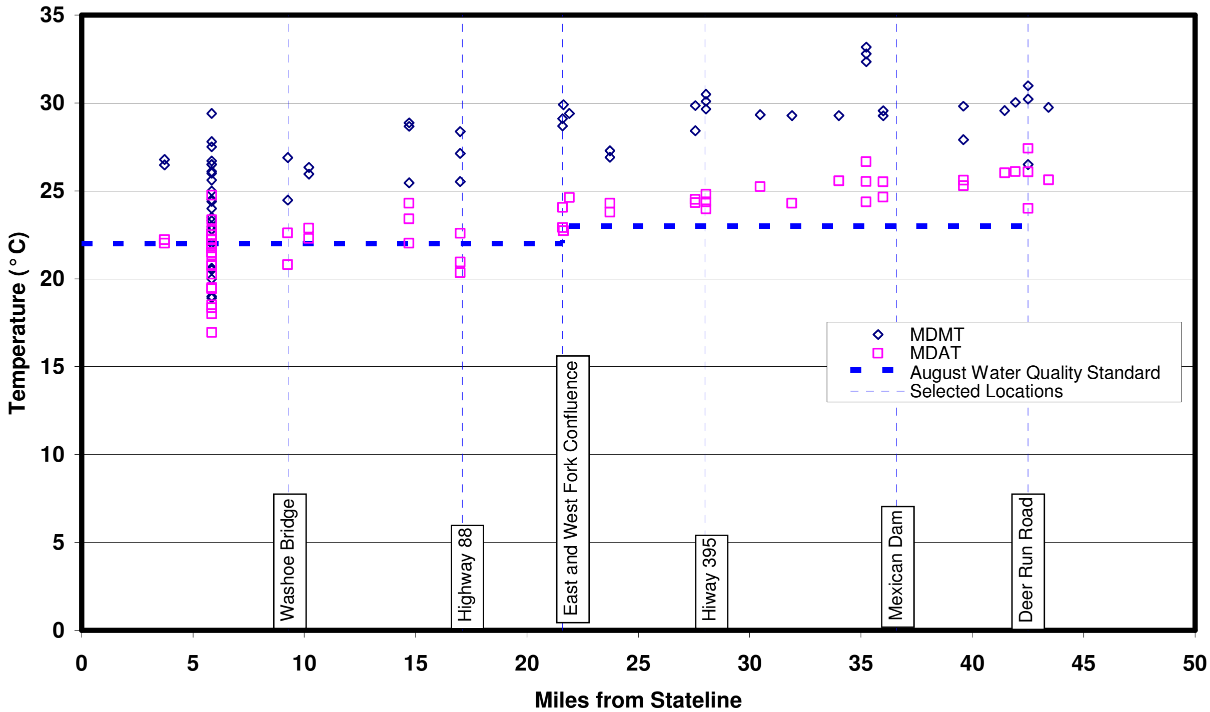


Figure 5. Number of Days Exceeding Standards (July-Sept) - East Fork and Mainstem Carson River from Stateline to Deer Run Road

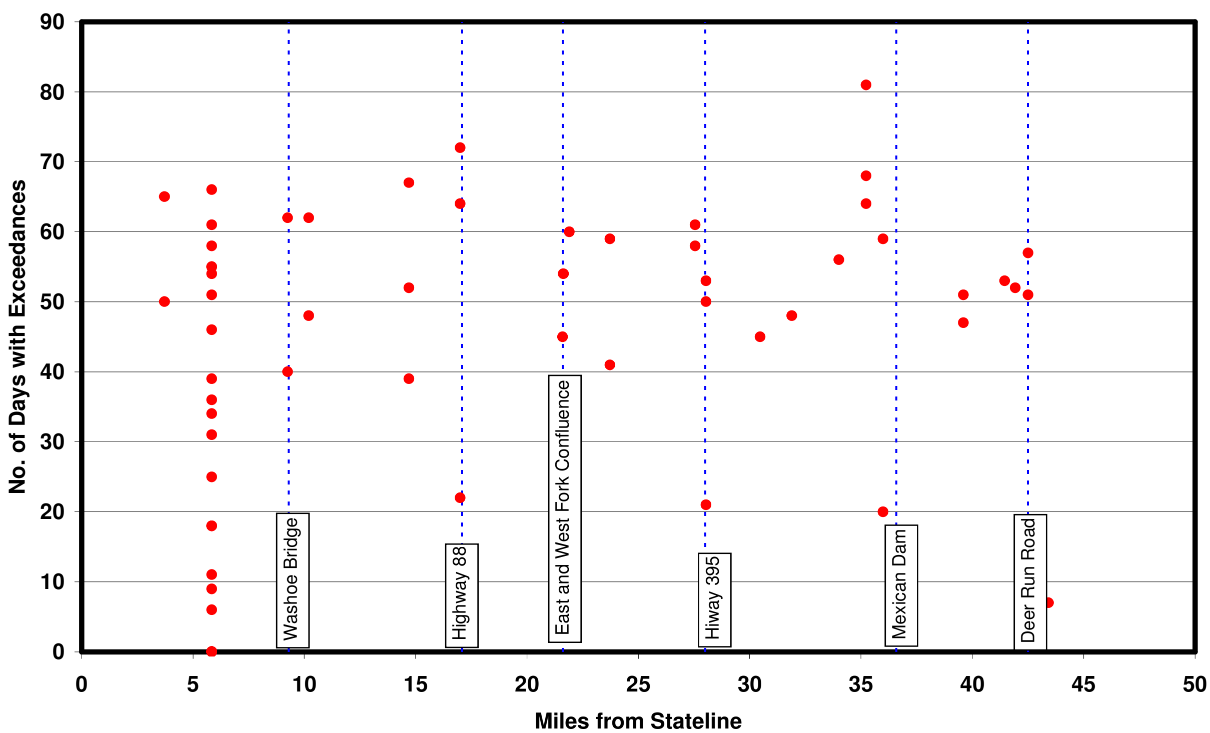
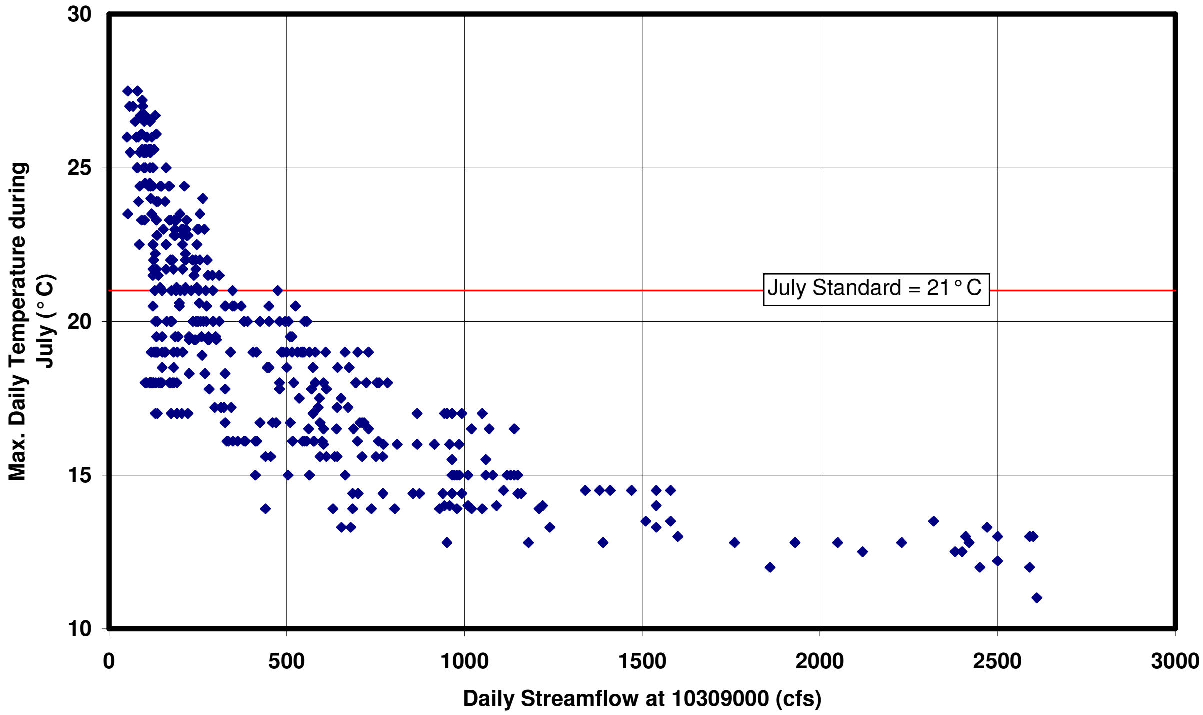


Figure 6. East Fork Carson River (Sta. 10309000): Comparison of Maximum Daily July Temperatures and Streamflow



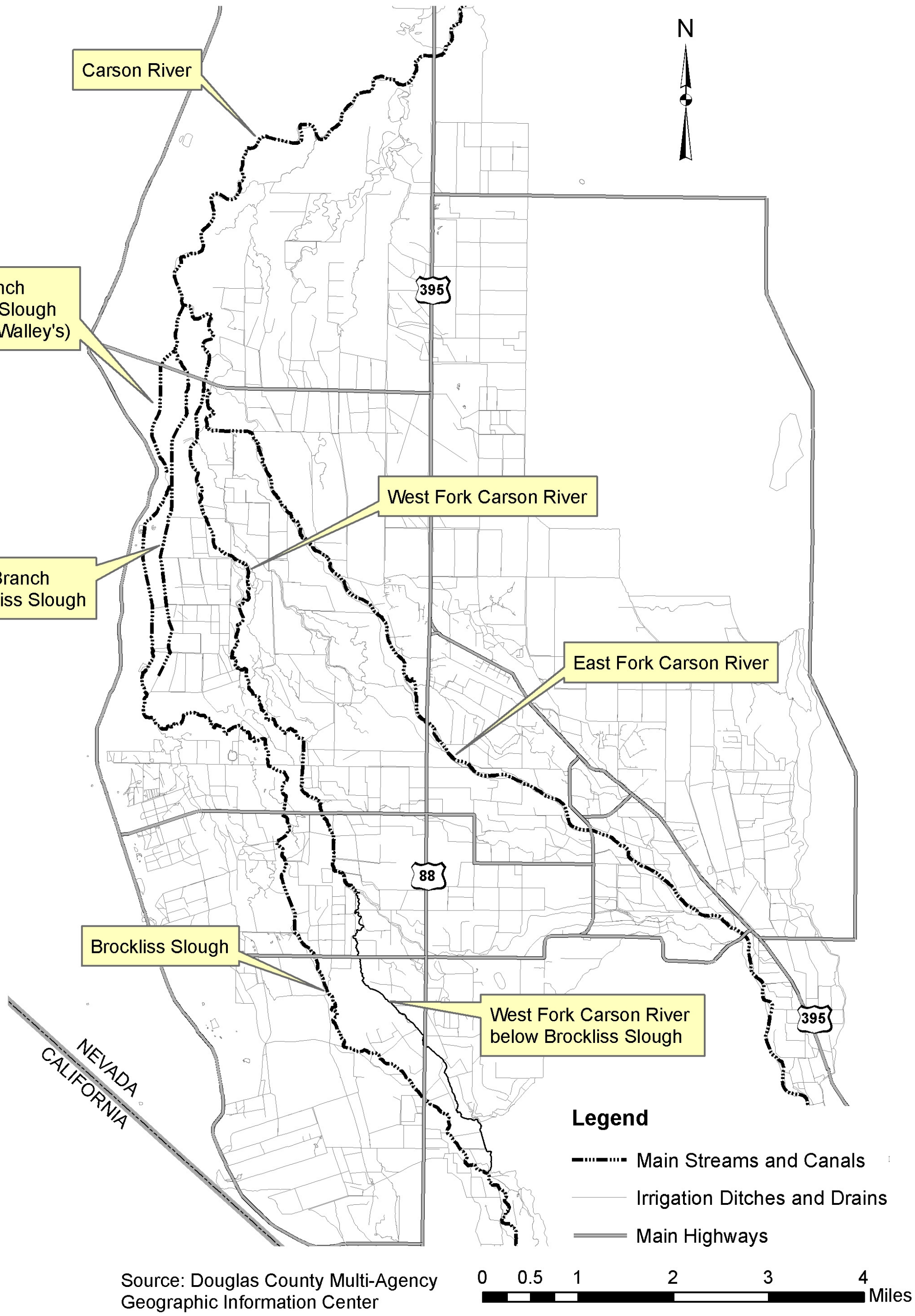


Figure 5. Main Streams, Canals, Ditches and Drains in Carson Valley

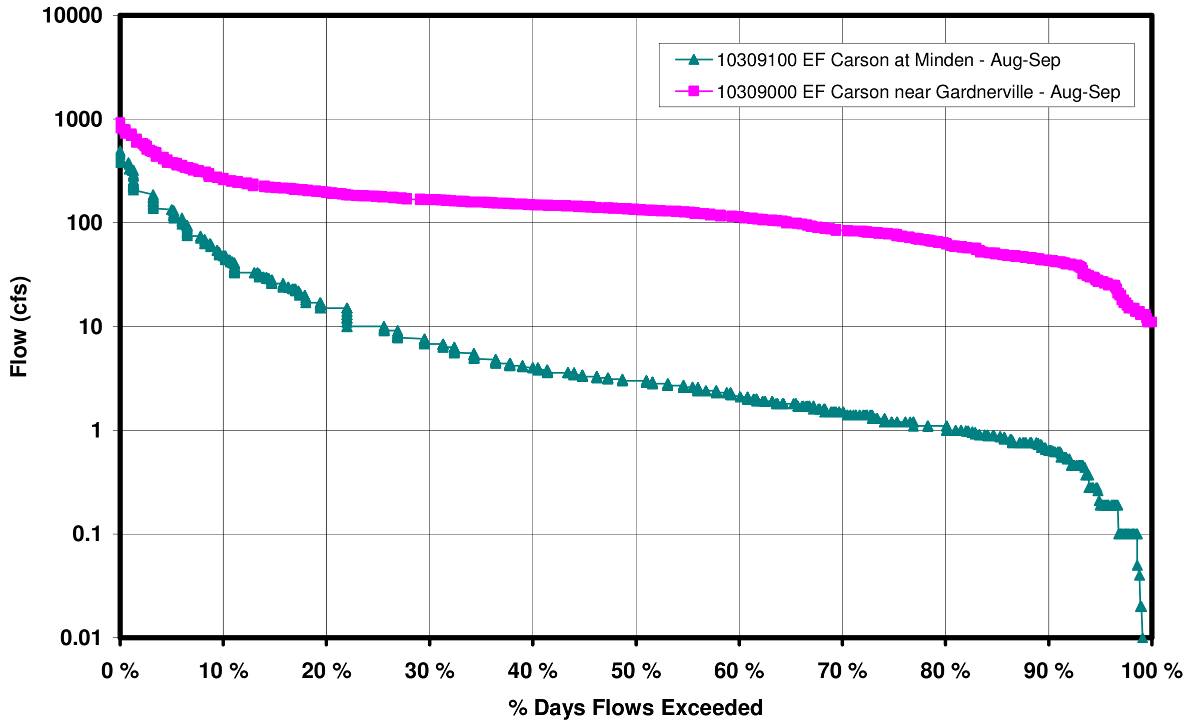
Figure 6a. West Fork Carson River near Stateline (above Brockliss Slough)

Figure 6b. West Fork Carson Channel looking downstream from Highway 88 (below Brockliss Slough)

Of particular interest are the flow conditions at Station 10309100 – East Fork Carson River at Minden, NV (near Highway 88). This site is located within a reach that is currently recognized in the Nevada Administrative Code (NAC 445A.146) as a coldwater fishery, yet the flows are believed to be too low to support such a use in many years. Located below a number of diversions, this site experienced median August-September flows of about 2-4 cfs during the period 1974-84, 1994-98[3]. In comparison, median August-September flows at the upstream East Fork site (Sta. 10309000: East Carson River near Gardnerville, NV) were about 70-450 cfs. The flow duration curves[4] in Figure 9 show the significant difference between the August-September flows at these two USGS stations.

Flows at and near zero are not uncommon on the system, especially from Carson City to Ft. Churchill. During the drought years of 1994, 2001, 2004, August-September flows at Station 10311400 – Carson River at Deer Run Road near Carson City, NV were at 0 cfs for 39% (1994), 72% (2001), 86% (2004) of the days. The river was dry for a time during 2007, however, USGS data were not yet available to provide any details. At Station 10311700 – Carson River at Dayton, NV, August-September flows have been at or below 1 cfs about 30% of the time (for 1994-97, 2002-07). For Station 10312000 - Carson River near Fort Churchill, NV, flows were below 1 cfs about 50% of the time during September (for 1911-2007). The relationships between flow and temperature are unknown for this stretch of the river as little to no temperature data exist.

Figure 9. Flow Duration Curves for East Fork Carson River at Two Locations - August through September (1974-84, 1994-98)

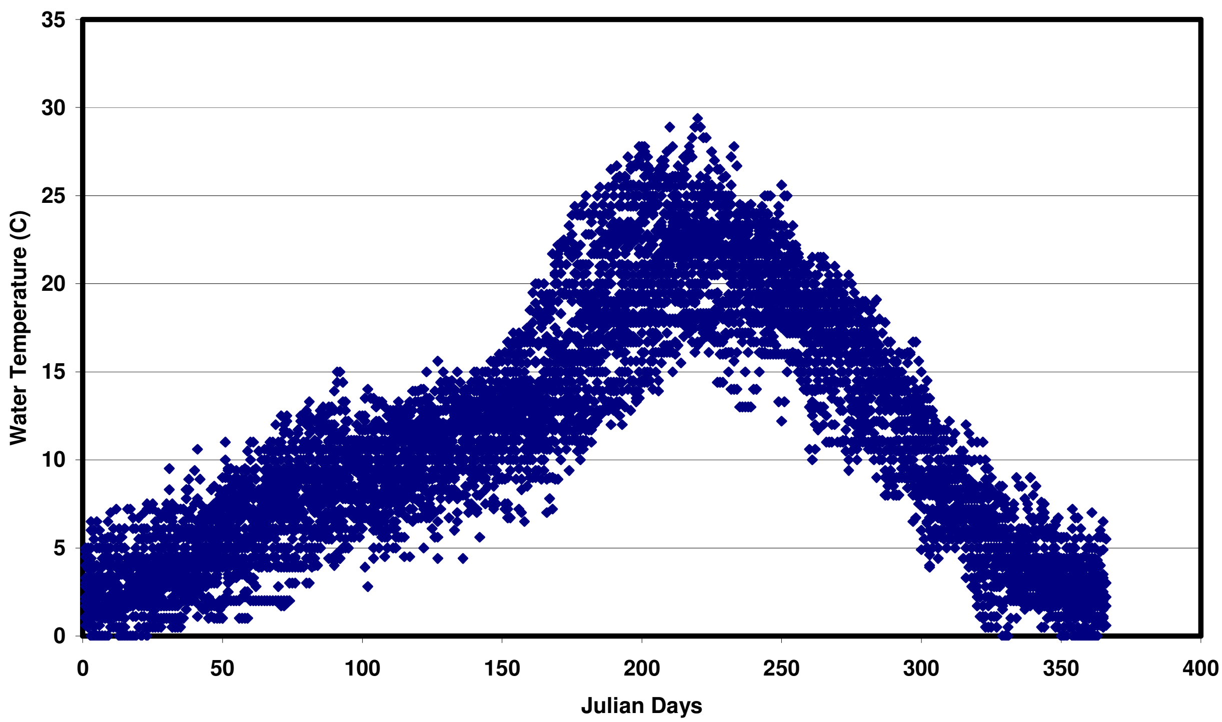


[3] Flows were at or below 2-4 cfs 50% of the time.
[4] A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded

Temporal Variability

Temperature conditions can vary from year to year due to changes in a number of factors affecting the heat budget, such as flow, climatological conditions, etc. However, extensive data are needed to accurately characterize this variability. Figure 10 shows that daily maximum temperatures in the Upper East Fork Carson River can vary by as much as 10° C from one year to another for the same time of the year. As compiled in Pahl (2007) and summarized in Table 2, most other monitoring sites have temperature data for 4 or less years (primarily partial year records). Three years of data at the Carson River at Deer Run Road showed maximum summer temperatures varying by only 4.5° C. It is suspected that annual variability at this site is much greater than 4.5 °C, however more years of data would be needed to more accurately characterize.

Figure 10. EF-2: USGS 10309000 - EF Carson near Gardnerville - Daily Maximum Temperatures (1953-72, 1993-97, 2002-04)



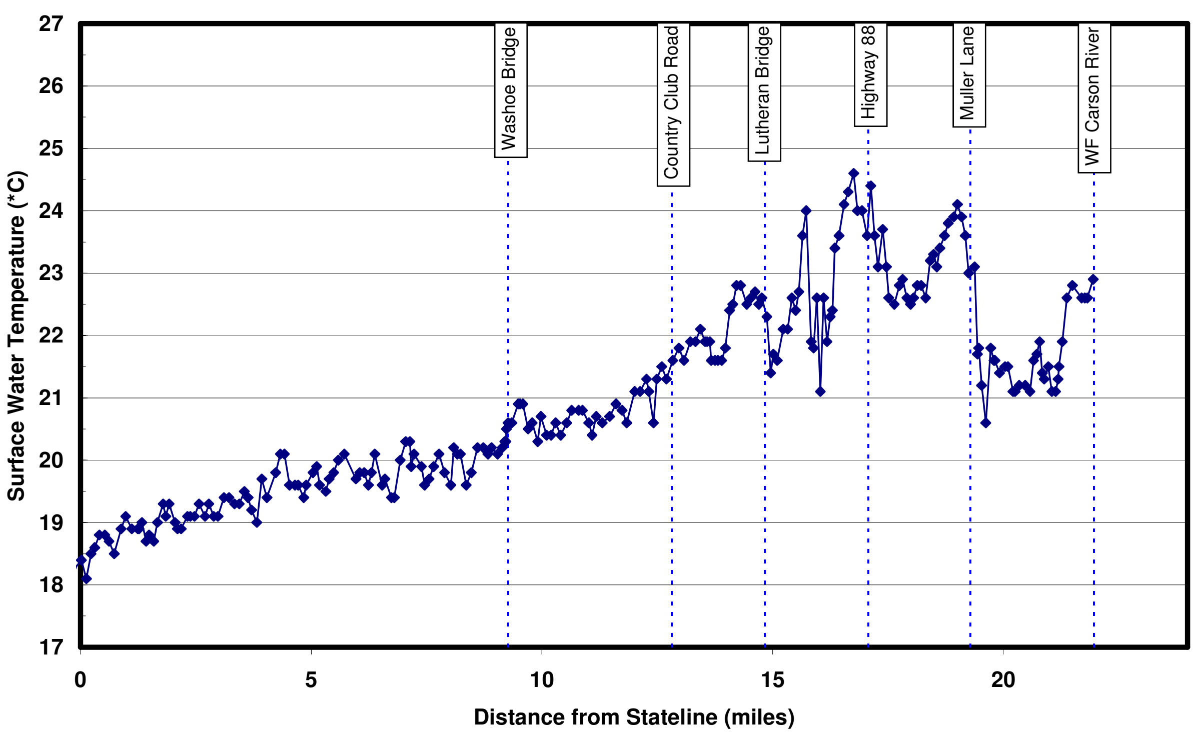
Spatial Variability

Given the significant variability in maximum temperatures from year to year, it is difficult to draw many conclusions from the thermograph data collected to date. Perhaps the best dataset showing the temperature spatial variability was generated by Watershed Science (2007) during their August 8, 2006 thermal infrared survey. This effort showed significant spatial variability in temperatures throughout Carson Valley, thought to be largely due to the extensive network of irrigation dams, diversions and drains. Following is a summary of some key findings from Watershed Science along with additional observations by this author.

East Fork Carson River

During the mid-afternoon on August 8, 2006, the East Fork Carson River temperatures varied from 18.1° C at stateline, to a high of 24.6° C upstream of Highway 88, and 22.9° C at the confluence with the West Fork Carson River (Figure 11). While the data show a rather steady increase in temperatures from the stateline to Country Club Road, temperature changes become more dramatic below Country Club Road. Watershed Sciences (2007) believes that the several diversions in this reach contributed considerably to the temperature variability. Also, Watershed Sciences identified a number of seep areas indicating that groundwater discharges could be a potential cooling source. Flow diversions combined with groundwater inputs likely create the observed variability. These conditions are characteristic of low gradient streams (Watershed Sciences, 2007).

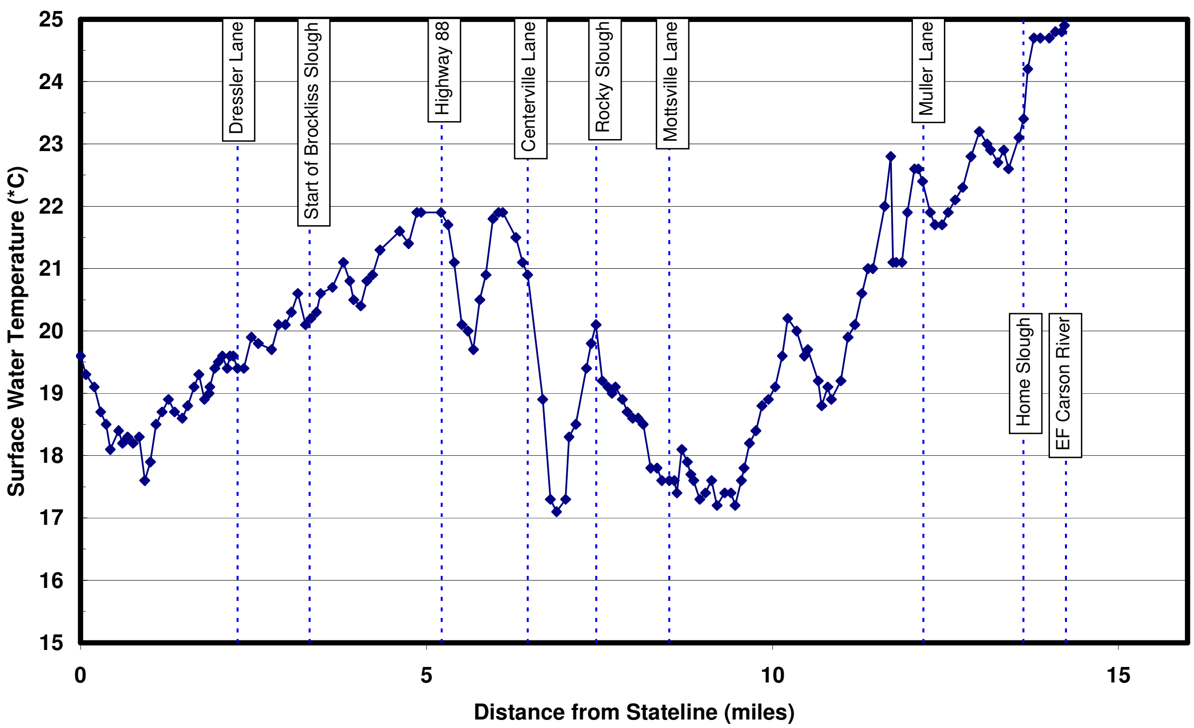
Figure 11. EF Carson River - TIR Water Surface Temperature Profile (8/8/06)



West Fork Carson River

The TIR survey showed that the West Fork Carson River temperatures varied from 19.6° C at stateline to 24.9° C at the confluence with the East Fork Carson River (Figure 12). As described by Watershed Sciences (2006), the West Fork Carson River is influenced by a number of diversions, sloughs, surface inflows, and subsurface inflows, result in dramatic temperature changes. It must be noted that the West Fork Carson River is largely dewatered upstream of Highway 88 with all to most of its flow directed into Brockliss Slough. From that point on, the West Fork primarily conveys East Fork Carson water (diverted and conveyed to the West Fork via Rocky Slough and others), along with return flows and groundwater discharge. It is interesting that the coolest surface water temperatures were identified in the middle of the river in the Centerville Lane and Mottsville Lane area. Subsurface contributions and Rocky Slough inflows are thought to be largely responsible for these low temperatures. From a low temperature of around 17° C below Mottsville Lane, surface temperatures increased to a high of near 25° C (about 2° C warmer than the East Fork) at the confluence with the East Fork Carson River.

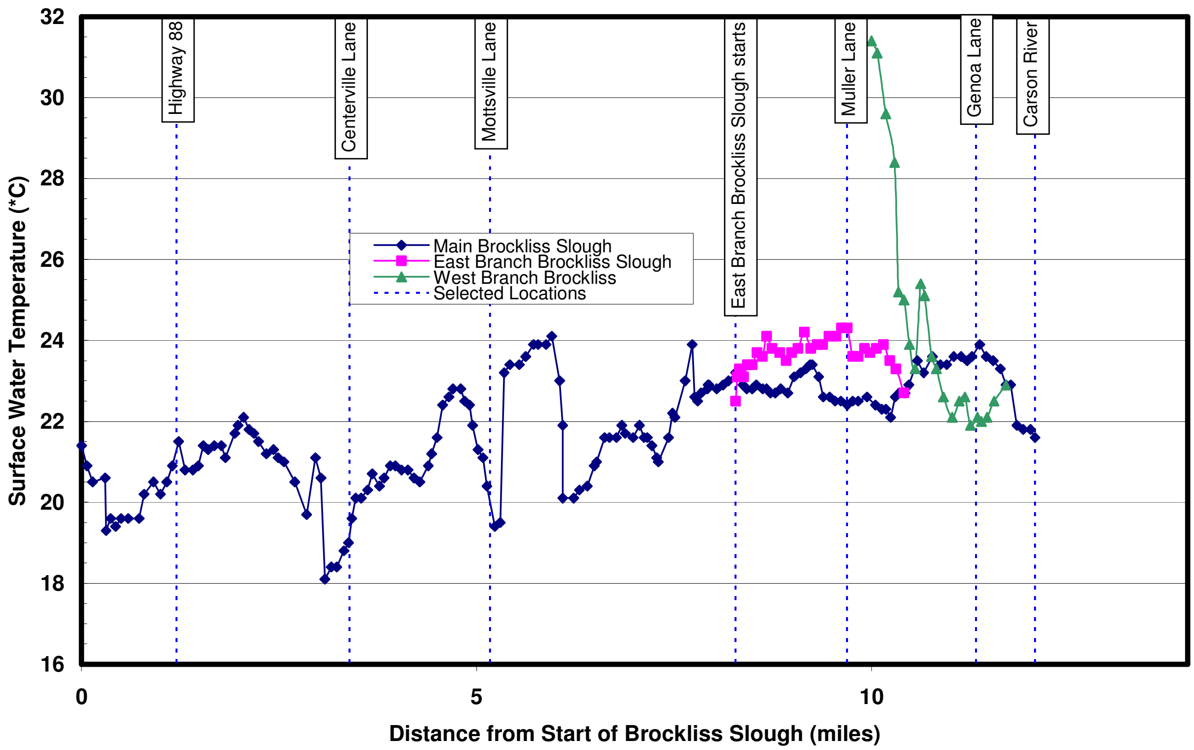
Figure 12. WF Carson River - TIR Surface Water Temperature Profile (8/8/06)



Brockliss Slough

The Brockliss Slough begins between Dressler Lane and Highway 88 at which point the West Fork Carson flow is redirected into the Slough. As a result, the Brockliss Slough is the actual "West Fork Carson River". The TIR survey showed that temperatures varied widely throughout the system, largely due to the influence of several impoundments, diversions, and subsurface inflows (Figure 13). Upstream of Walley's Hot Springs and Muller Lane, the East Branch of the Brockliss Slough begins[5]. About 2 miles downstream, the East Branch combines with the main channel below Muller Lane near Walley's[6]. In the vicinity of Walley's, a west branch begins which then connects with the main channel downstream of Genoa Lane.

Figure 13. Brockliss Slough - TIR Surface Water Temperature Profile (8/8/06)



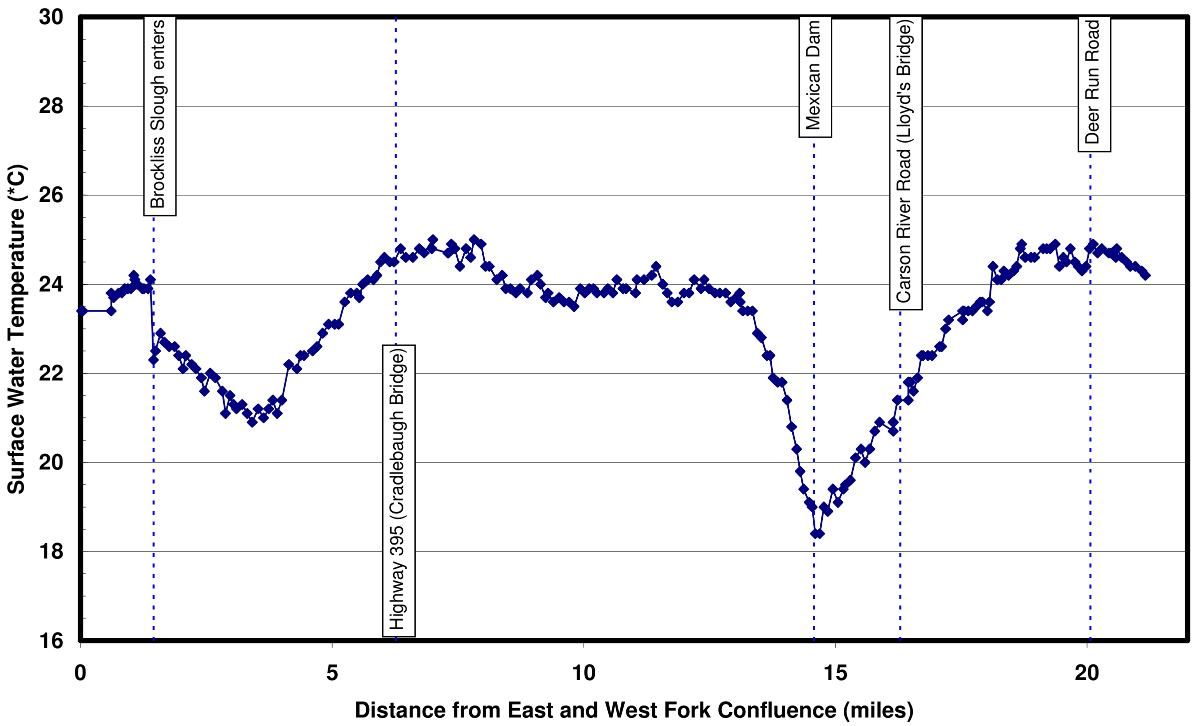
[5] Other maps have shown that the Brockliss Slough actually splits into 2 separate branches, however the TIR images show that head of the East Branch was not connected to the main slough at the time of the TIR survey.
[6] The Brockliss system seems to be somewhat dynamic in this section. Some maps have shown that the 2 branches continue on even farther and reconnect below Genoa Lane. The TIR profiles provided in the Watershed Sciences report was based upon this alignment. A closer examination of the TIR survey images show the branches combining just east of Walley's Hot Springs (upstream of Genoa Lane). Figure * represents NDEP's modification of the TIR profile to reflect a more accurate alignment of the Brockliss Slough and the branches

Carson River

During the TIR survey, Carson River surface temperatures varied from 18.4° C below Mexican Dam to 24.9° C at Riverview Park in Carson City and 25.0° C just below Highway 395 (Figure 14). Carson River did not have the high degree of variability that the lower East Fork, the West Fork and the Brockliss show.

Upstream of Mexican Dam, there was a significant decrease in surface temperatures. It is at this point that the river leaves Carson Valley and enters a canyon area. Watershed Sciences concluded that the valley groundwater may be entering the stream in this area thus resulting in lower temperatures.

Figure 14. Carson River - TIR Surface Water Temperature Profile (8/8/06)



General Observations

The TIR data (Watershed Sciences, 2006) show that the West Fork Carson River was slightly warmer at the stateline (19.6° C) than the East Fork Carson River (18.1°C) on the mid-afternoon of August 8, 2006. It is unknown if this general relationship holds for other days during the summer period.

It is important to note that streamflows on the date of the TIR flight (August 8, 2006) were significantly higher than the long-term median flows. For example, median flows at Sta. 10311000 – Carson River near Carson City (aka Mexican Gage) are 31 cfs while flows on August 8, 2006 were almost triple that at 87 cfs. It is most likely that another TIR flight during the summer of a lower flow year would show higher temperatures overall.

Topographic and Vegetative Shading

Radiation from the sun is a major component of a water's overall heat budget. Any shading that occurs as a result of the surrounding topography or the riparian vegetation reduces the solar radiation reaching the river, and can lead to cooler water temperatures (Theurer et al., 1984). Shading is often quantified using the following equation:

$$Effective\ Shade = \frac{Solar\ Radiation\ without\ Shade - Solar\ Radiation\ with\ Shade}{Solar\ Radiation\ without\ Shade} \qquad Eq.\ 1$$

Utilizing the LiDAR and Hyperspectral data generated by BAE Systems along with *HeatSource* (a temperature model developed for Oregon DEQ), McGwire and Garner (2007) calculated effective topographic and total shade (for August 8, 2006) for the East and West Forks Carson rivers from stateline to the confluence and for the mainstem Carson River above Deer Run Road. The data compiled by McGwire and Garner showed extremely variable shading conditions due to the sporadic nature of the higher riparian vegetation in the study area. Effective shading ranges from near 70% in the West Fork Carson near the stateline to about 1-2% in many areas of the West and East Forks and mainstem Carson River. The difficult question to answer is "What level of shading is achievable in the Carson System?" A simple analysis using the SSTEMP model (Bartholow, 2004) was undertaken to provide some possible shading ranges for various channel widths with rather extensive cottonwood galleries (Table 3).

Table 3. Potential Effective Shading Using SSTEMP model

Channel Width (feet)	Channel orientation		
	North-South	Northeast-Southwest OR Northwest-Southeast	East-West
50	60%	58%	50%
100	47%	43%	26%
150	38%	33%	18%

Key Assumptions: 1) Latitude = 39 degrees North; 2) 100 foot cottonwoods located on both sides of the channel up to the edge of the channel at a density of 75%; 3) Date = August 8th; 4) No topographic shading

For comparison, an additional approach was taken to characterize the vegetative conditions along the river. From the LiDAR and Hyperspectral data, the number of acres of vegetation (at various heights) were determined within a buffer area (200 feet on both side of the water edge[7]) for each mile of river. The two are not always comparable as the effective shading is affected by the channel width, distance from vegetation to water, channel orientation[8], time of year, etc. The following describes the shading and canopy conditions in more detail.

[7] A 200-foot buffer was chosen because preliminary analyses showed that riparian vegetation outside of this buffer contribute little to the overall effective shading of the river. Shading calculations using the SSTEMP model shows that effective shading of 100 foot cottonwood (maximum heights shown by the LiDAR and Hyperspectral data) becomes minor (<10%) at a distance of 200 feet from the water edge.

[8] As described earlier, a north-south oriented stream has more vegetative and topographic shading than the same stream oriented east-west

East Fork Carson River

In the upper East Fork above Washoe Bridge, topography contributes significantly to the effective shading (Figure 15). However once the river enters Carson Valley the topographic shading drops to about 1-2%. Total effective shading is highly variable throughout the reach with values ranging from 2% to over 15%. Maximum canopy acreages occur between Country Club Road and Lutheran Bridge (Figures 16 and 17), which corresponds well with the higher effective shade estimates from McGwire and Garner (2007). While the canopy acreage between Washoe Bridge and Country Club Road are near these maximum values, the effective shade in this reach is much lower than the Country Club Road to Lutheran Bridge reach. This difference could be due to a number of factors such as location of vegetation in relation to the water, channel width, etc. Minimum canopy acreages occur at the lowest levels near the confluence of the East and West Forks (Figure 18), matching the low effective shade estimates for this area.

Figure 15. Average Topographic and Total Shading - East Fork Carson River (August 8, 2006)

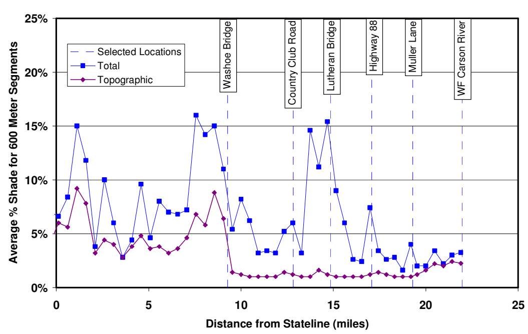
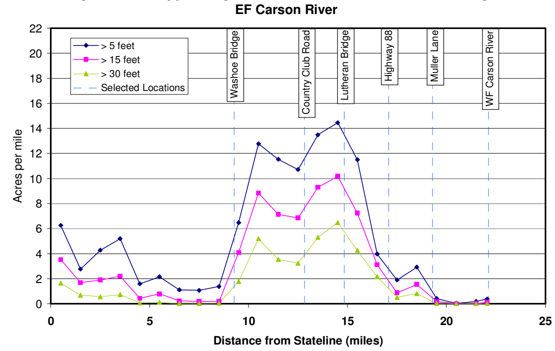


Figure 16. Canopy Acreage within 200 foot Buffer from Water's Edge - EF Carson River



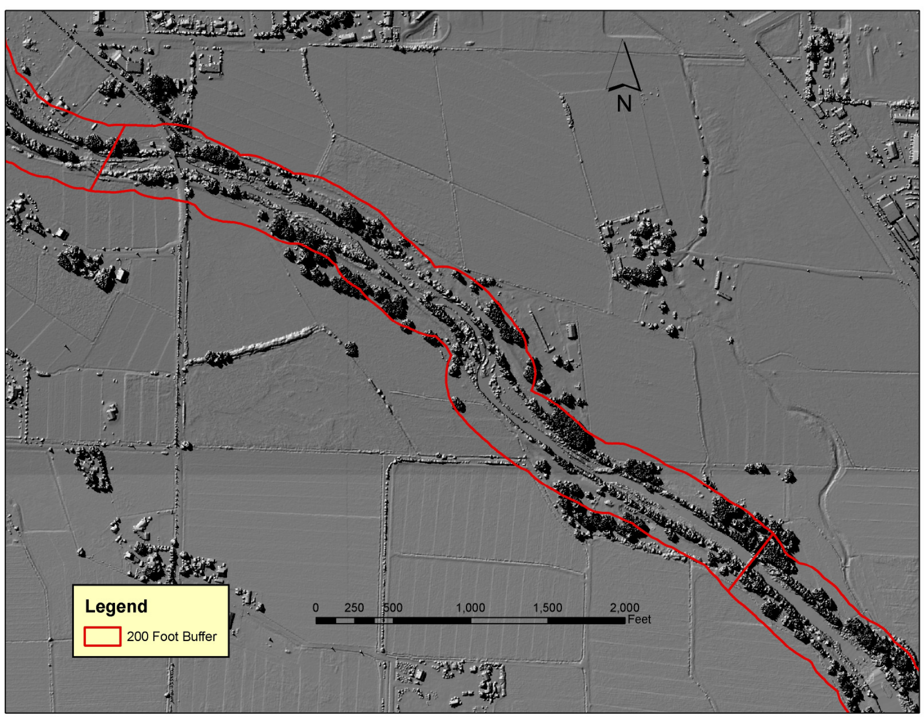


Figure 17. Hillshade View of 1-Mile Long Buffer Area on East Fork Carson River near Lutheran Bridge with Maximum Canopy Acreage (base imagery from BAE, 2004)

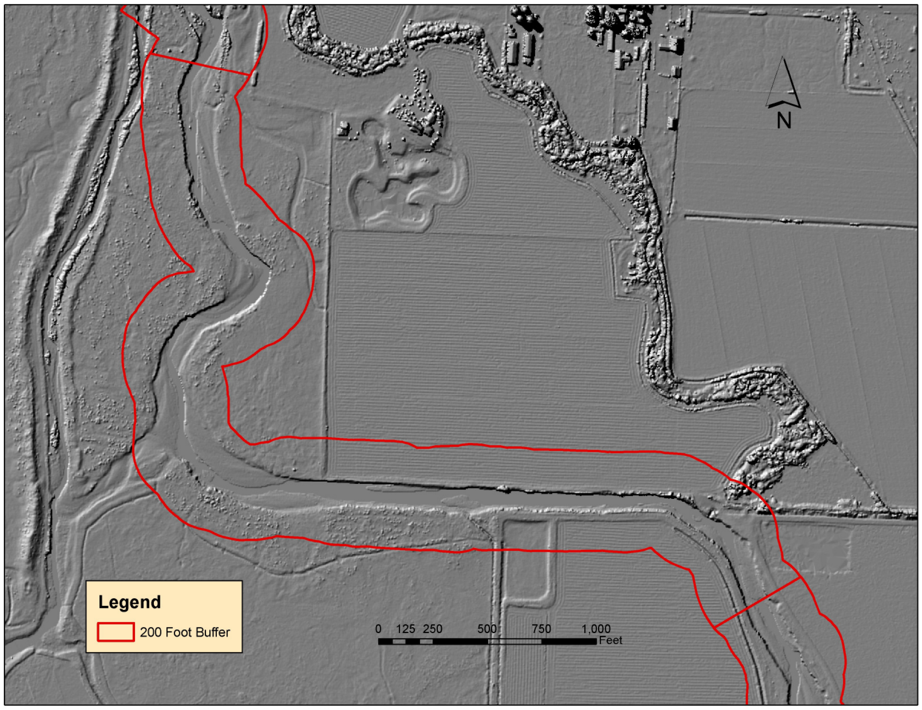


Figure 18. Hillshade View of 1-Mile Long Buffer Area on East Fork Carson River near Confluence with the West Fork with Minimum Canopy Acreage (base imagery from BAE, 2004)

West Fork Carson River

While the West Fork has minor topographic shading (<5%), overall shading due to riparian vegetation is as high as 70% near Diamond Valley (Figure 19), the highest identified by McGwire and Garner (2007). These high levels of shading are not surprising given the health riparian vegetation observed in this area and the narrow channel (compared to the East Fork and mainstem). However below the start of Brockliss Slough, total shading drops to minimum values with some higher values in the Centerville-Mottsville lanes area. A plot of canopy acreage (Figure 20) following a similar relationship with the highest values above Brockliss Slough and very low values below this point with the exception of the Centerville-Mottsville lanes area. Figures 21 and 22 provide aerial depictions of the maximum canopy area near Diamond Valley Road and the minimum canopy area near Muller Lane.

Figure 19. Average Topographic and Total Shading - West Fork Carson River (August 8, 2006)

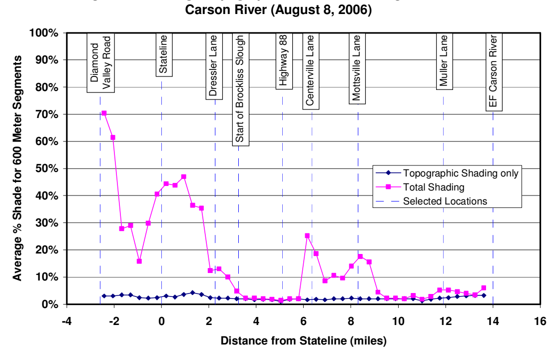
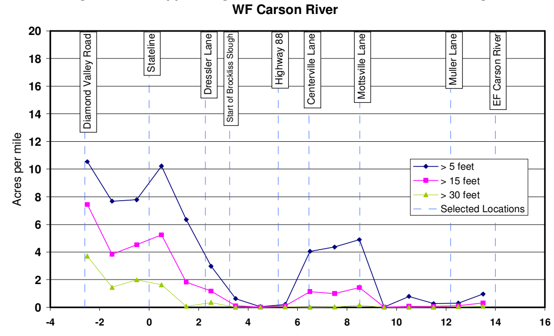


Figure 20. Canopy Acreage within 200 foot Buffer from Water's Edge - WF Carson River



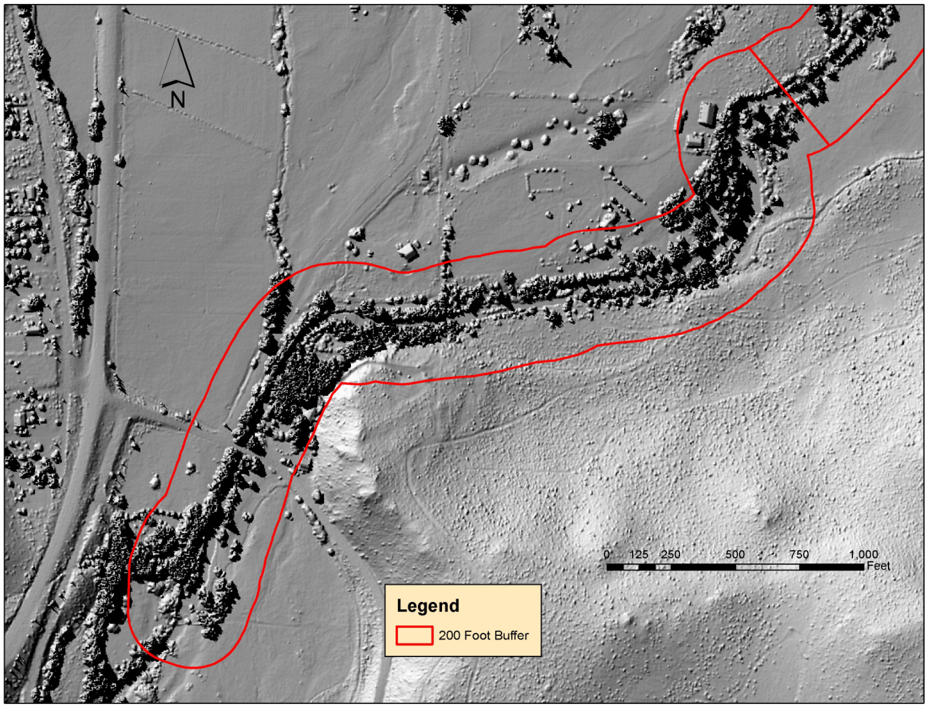


Figure 21. Hillshade View of 1-Mile Long Buffer Area on West Fork Carson River near Diamond Valley Road with Maximum Canopy Acreage (base imagery from BAE, 2004)

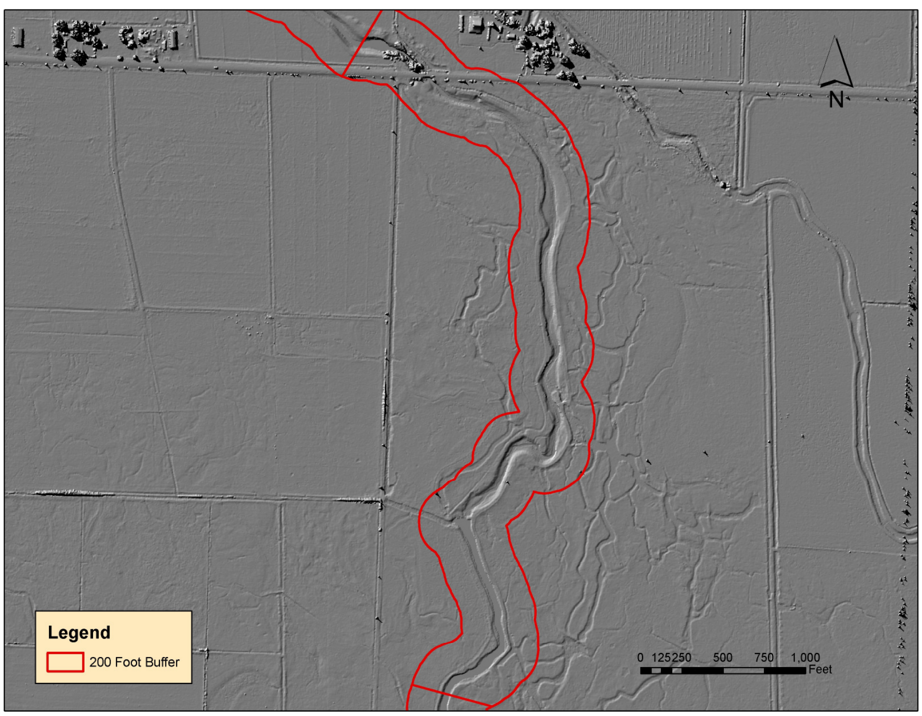


Figure 22. Hillshade View of 1-Mile Long Buffer Area on West Fork Carson River near Diamond Valley Road with Minimum Canopy Acreage (base imagery from BAE, 2004)

Carson River above Deer Run Road

Topography in the Mexican Dam region provide some reduction in solar radiation loads to the river (up to 5%) with the rest of the river having minor topographic shading 1-2% (Figure 23). Riparian vegetation is shown to have increased total shading up to 15% in the Carson River Road area. Both maximum shade and maximum canopy acreage occur in the Carson River Road area (Figures 23 and 24). Figures 25 and 26 provide an aerial view of the maximum canopy area near Carson River Road and the minimum canopy area just above McTarnahan Bridge (abandoned) at the north end of Carson Valley.

Figure 23. Average Topographic and Total Shading - Carson River (Above Deer Run Road (August 8, 2006)

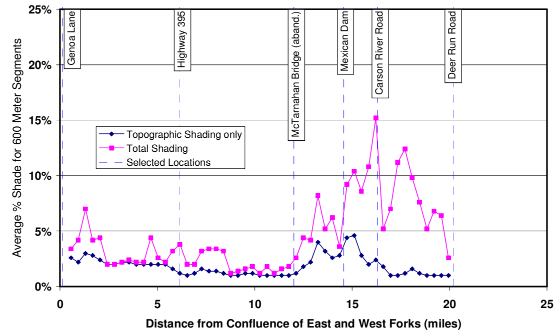
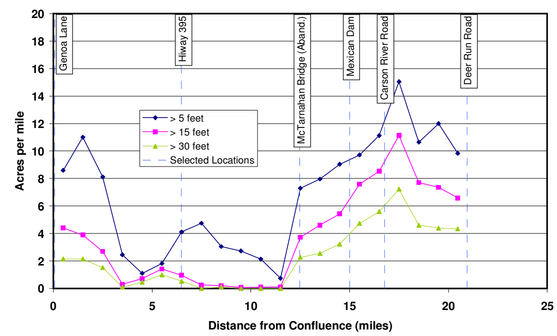


Figure 24. Canopy Acreage within 200 foot Buffer from Water's Edge - Carson River above Deer Run Road



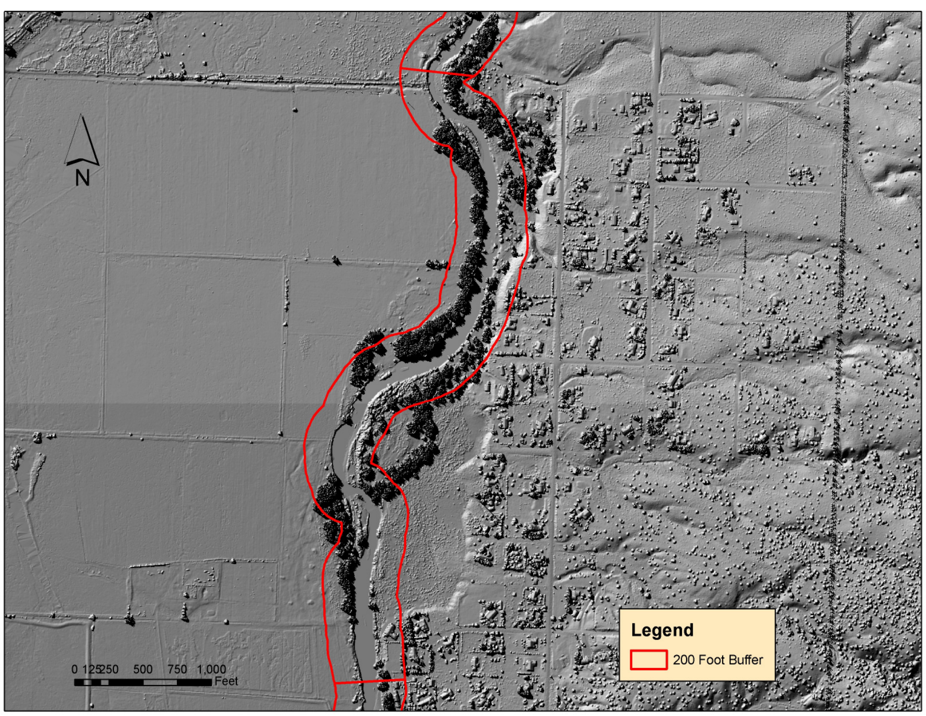


Figure 25. Hillshade View of 1-Mile Long Buffer Area on Carson River just below Carson River Road with Maximum Canopy Acreage (base imagery from BAE, 2004)

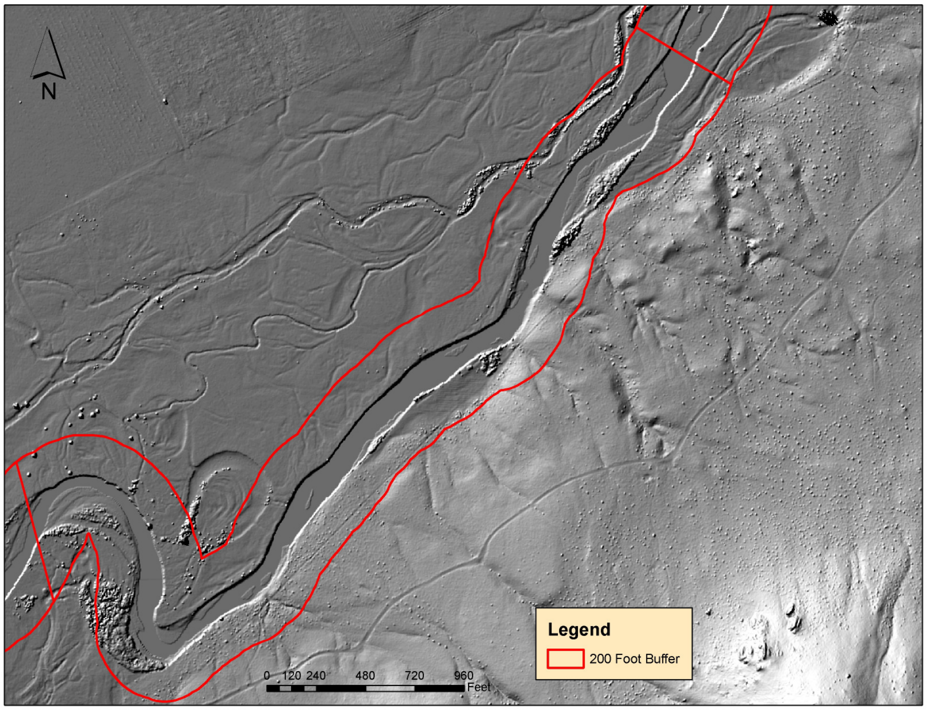
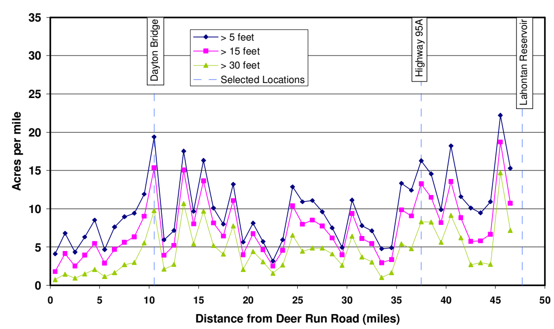


Figure 26. Hillshade View of 1-Mile Long Buffer Area on Carson River just above McTarnahan Bridge (abandoned) at North End of Carson Valley Road with Maximum Canopy Acreage (base imagery from BAE, 2004)

Carson River Below Deer Run Road

Figure 27. Canopy Acreage within 200 foot Buffer from Water's Edge - Carson River below Deer Run Road



Canopy acreages are highly variable throughout this reach with the maximum densities of over 25 acres/mile occurring near Lahontan Reservoir (Figure 27). It is interesting to note that the maximum canopy densities on this reach are higher than on the other reaches discussed above. Even the minimum densities between Deer Run Road and Lahontan Reservoir do not reach the near zero level estimated on the reaches above Deer Run Road. However, the higher canopy densities may not translate into higher effective shade levels given the predominately east-west orientation of the channel and the wide channel conditions. Figures 28 and 29 provide an aerial view of the maximum canopy area between Highway 95A and Lahontan Reservoir and the minimum canopy area above Highway 95A.

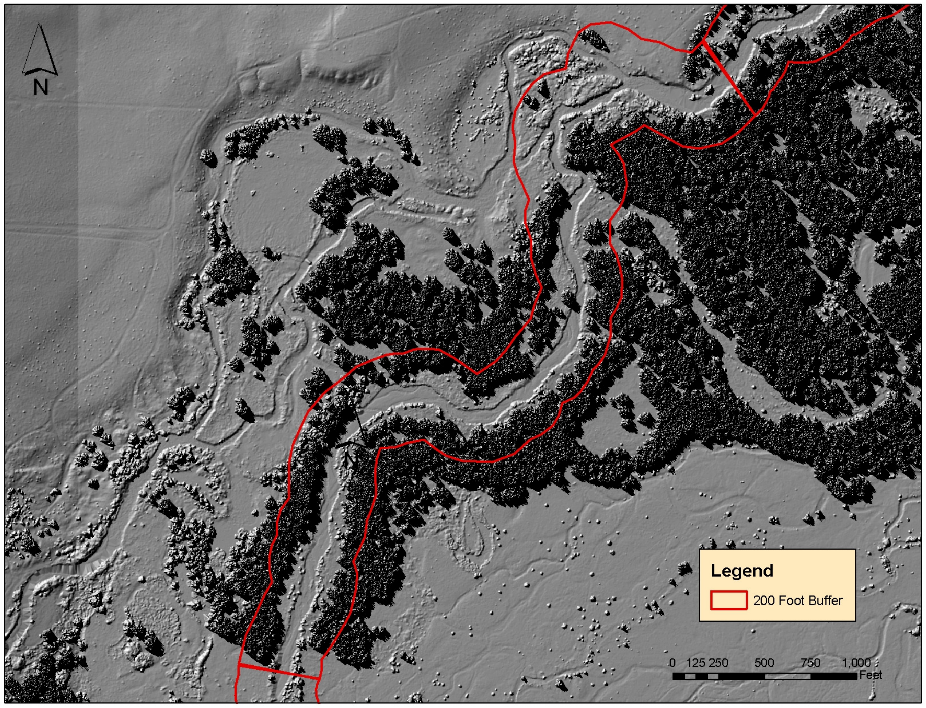


Figure 28. Hillshade View of 1-Mile Long Buffer Area on Carson River about 8 miles below Highway 95A with Maximum Canopy Acreage (base imagery from BAE, 2004)

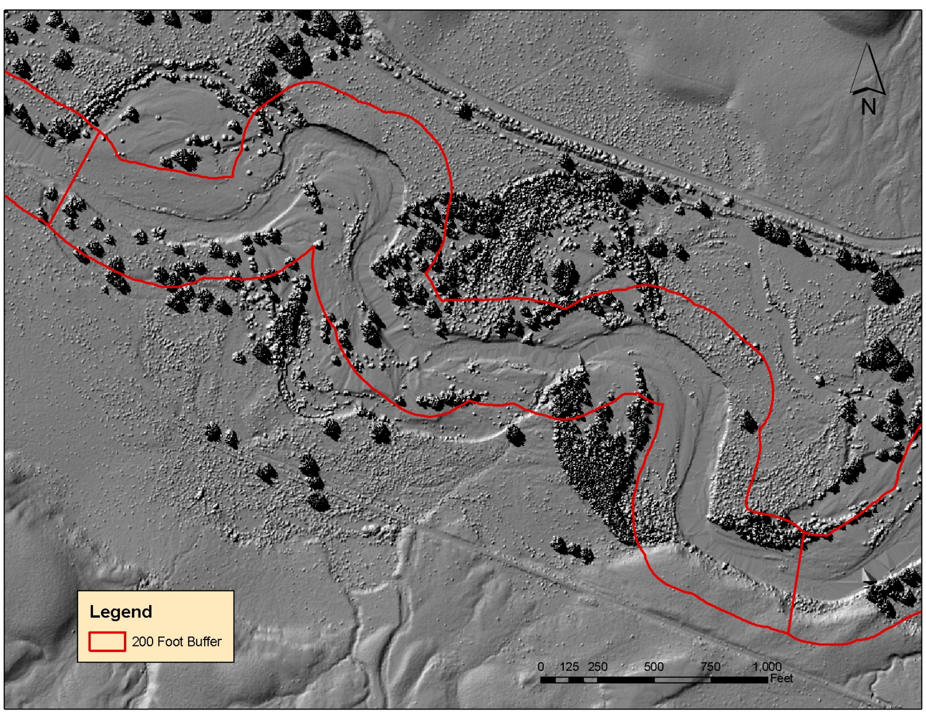


Figure 29. Hillshade View of 1-Mile Long Buffer Area on Carson River 4 miles above Highway 95A with Minimum Canopy Acreage (base imagery from BAE, 2004)

Conditions Affecting Riparian Vegetation Establishment and Growth

Based upon historical accounts and other information, Otis Bay (2007) concluded that mixed-age stands of Fremont cottonwoods were common along the Carson River, and its forks, including the Carson Valley area. Since then, the extent and health of the cottonwood galleries and other riparian vegetation has declined due to a number of factors such as flow modifications, channelization and channel incisement, mining activities, and grazing and other land uses (Interfluve, 1996; Otis Bay, 2007).

Cottonwoods require a variety of certain hydrologic and geomorphic conditions for successful reproduction (Braatne et al., 1996). Deviations from these conditions reduce the likelihood of the long-term survival of cottonwoods. However given a chance, cottonwoods can re-establish after a significant disturbance. Photographs of the Carson River at Brunswick Mills shows the dramatic change in the riparian vegetation from the 1870s to present day (Figures 30 and 31).

Figure 30. Carson River at the Brunswick Mill Downstream of Deer Run Road in 1870s (photograph by C.E. Watkins)

Figure 31. Carson River at the Brunswick Mill Downstream of Deer Run Road in 2005

At this time, there are a number of mature age class cottonwoods at various locations throughout the Carson system. However, Interfluve (1996) concluded that there appears to be a severe under-representation by the intermediate age cottonwoods, likely due to flow modifications and geomorphic conditions. Without the younger classes to take the place of dying older trees, the extent of Fremont cottonwoods could be gradually reduced from the Carson River system (Interfluve, 1996).

The Carson River reach between Highway 395 and McTarnahan Bridge (abandoned) stands out as one of the stretches with the least amount of riparian canopy. It has been surmised that a number of factors could be contributing to this condition such as channel incisement and flow modifications. However, soil and groundwater salinity may also be a limiting factor. Fremont cottonwoods survival is affected by water TDS levels over 1,500 mg/l (Jackson, et al., 1990; Gorley, 2007). Data compiled from NDEP files indicate areas of elevated TDS up to 5,000 mg/l in some areas (Figure 32). Additionally, Stillwater Sciences (2003) examined soil salinity and vegetation along the San Joaquin River and found that cottonwood populations generally occurred on soils having zero to low salinity levels. Carson basin soils maps indicate higher salinity (ranging from low to high salinity) in soils in the area below Highway 395 compared to that upstream of Highway 88 (where higher concentrations of cottonwoods occur).

Review of Standards

Nevada's water quality standards for the East and West Forks, and the Carson River are contained in Nevada Administrative Code (NAC) 445A.146 through 445A.158, and are summarized in Table 3. The current criteria were set in the 1980s based upon recommendations from Nevada Department of Wildlife (NDOW). According to Mark Warren, NDOW (2006), available literature values and field observations were used in developing the NDOW recommendations. However, no other documentation exists to support these criteria.

In general, the temperature criteria recommendations were given for the protection of various fish species of concern for the five main fish life stages: spawning, incubation, nursery-fry, juvenile and adult. For the reaches above New Empire (Deer Run Road), the species of concern are listed as primarily coldwater species (rainbow and brown trout); below New Empire, the species of concern are warmwater species (walleye, channel catfish and white bass).

The current aquatic beneficial uses (propagation[9] of aquatic life with species of concern) were added to the regulations in the 1980s. However, the initial uses being considered were much more detailed and representative of actual aquatic life conditions (Table 4). The recommendations recognized the role of stocking in supporting the coldwater fishery above Deer Run Road. In fact, some reaches were identified as not including any spawning salmonids. However for reasons unknown, the final regulations did not include these uses but incorporated the broader "propagation of aquatic life" use instead (Pahl, 2004).

[9] Propagation of aquatic life is interpreted as including all life stages.

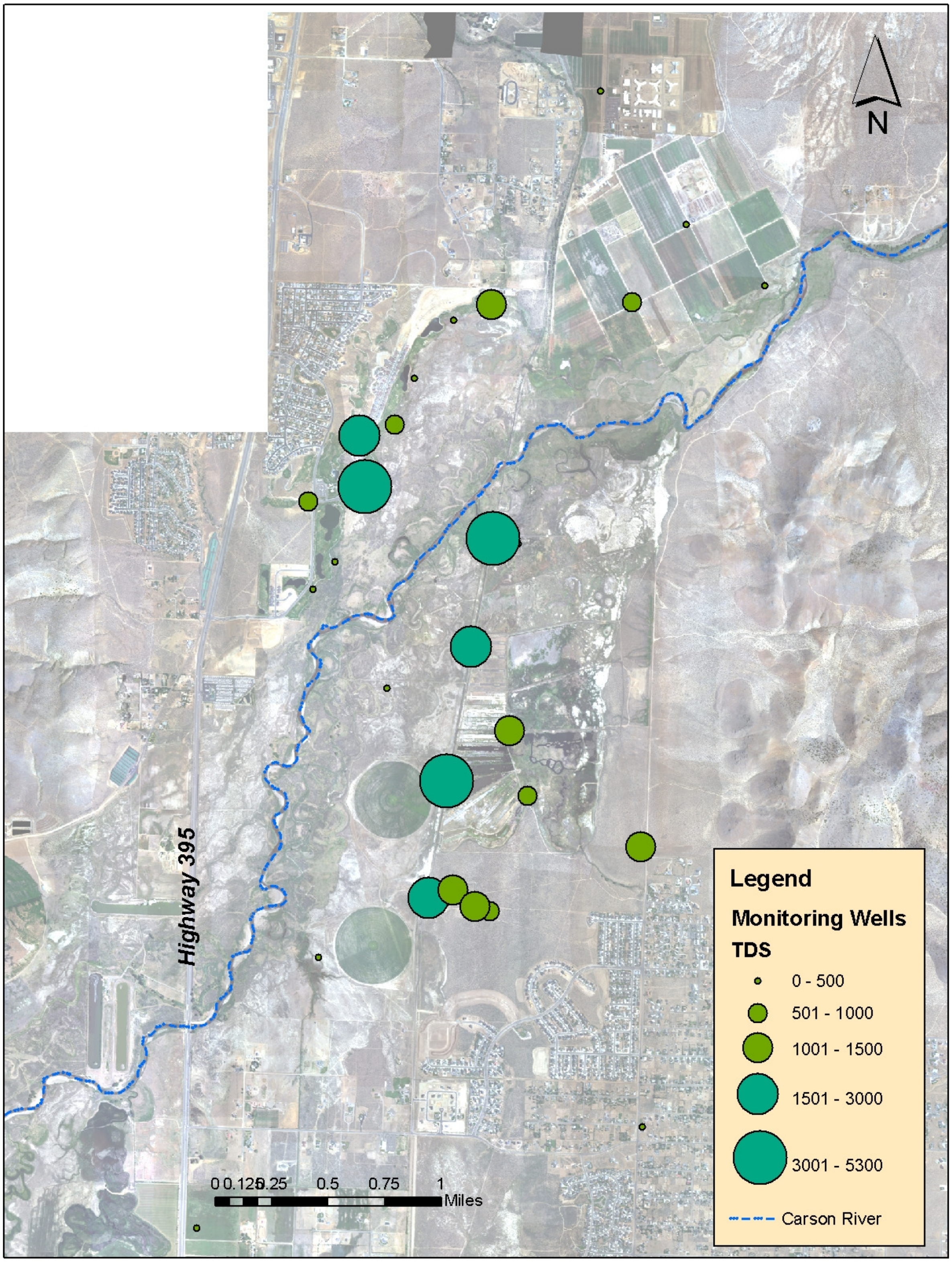


Figure 32. TDS Levels in Groundwater at North End of Carson Valley

Table 3. Summary of Temperature Water Quality Standards in the Carson River above Lahontan Reservoir (maximum daily temperatures, in °C)

<table>
<tr><th>Water body</th><th>Reach</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="2">WF Carson</td><td>Stateline</td><td colspan="4" rowspan="9">13</td><td>13</td><td rowspan="9">17</td><td>21</td><td colspan="3">22</td><td colspan="2" rowspan="9">13</td></tr>
<tr><td>Stateline to confluence</td><td>17</td><td colspan="4">23</td></tr>
<tr><td>Bryant Creek</td><td>Stateline to confluence</td><td rowspan="3">13</td><td rowspan="3">21</td><td colspan="3" rowspan="3">22</td></tr>
<tr><td rowspan="3">EF Carson</td><td>Stateline to Hwy 395</td></tr>
<tr><td>Hwy 395 to Muller Lane</td></tr>
<tr><td>Muller Lane to confluence</td><td rowspan="4">17</td><td colspan="4" rowspan="5">23</td></tr>
<tr><td rowspan="6">Carson River</td><td>Confluence to Genoa Lane</td></tr>
<tr><td>Genoa Lane to Cradlebaugh Bridge (Hwy 395)</td></tr>
<tr><td>Cradlebaugh (Hwy 395) Bridge to Mexican Ditch Gage</td></tr>
<tr><td>Mexican Ditch Gage to New Empire</td><td colspan="5">18</td><td>23</td><td colspan="2">18</td></tr>
<tr><td>New Empire to Dayton Bridge</td><td colspan="3" rowspan="2">11</td><td colspan="3" rowspan="2">24</td><td colspan="4" rowspan="2">28</td><td colspan="2" rowspan="2">11</td></tr>
<tr><td>Dayton Bridge to Weeks (Hwy 95)</td></tr>
</table>

Table 4. Aquatic Beneficial Uses Recommended by NDEP in 1984 (Pahl, 2004)

<table>
<tr><th>Control Point (from upstream to downstream)</th><th>Beneficial Use per NDOW</th><th>Beneficial Use Proposed by NDEP (1984)</th></tr>
<tr><td>Bryant Creek</td><td colspan="2">Not mentioned</td></tr>
<tr><td>West Fork Carson River at stateline</td><td colspan="2">Spring and fall spawning salmonids – rainbow and brown trout. Supplemented by hatchery trout.</td></tr>
<tr><td>West Fork Carson River at confluence</td><td>Not mentioned</td><td>Warmwater fisheries – catfish – year-around. Stocking spring and summer of salmonids</td></tr>
<tr><td>East Fork Carson River at stateline</td><td colspan="2">Spring and fall spawning salmonids – rainbow and brown trout – occasional Lahontan cutthroat. Supplemented by hatchery trout.</td></tr>
<tr><td>East Fork Carson River - 395 south of Gardnerville</td><td colspan="2" rowspan="2">Spring and fall spawning salmonids – rainbow and brown trout. Supplemented by hatchery trout.</td></tr>
<tr><td>East Fork Carson River - Muller Lane</td></tr>
<tr><td>Carson River - Genoa Lane</td><td>Warmwater fisheries – catfish – year-around. Stocking spring and summer of salmonids</td><td rowspan="2">Warmwater fisheries – catfish – year-around. Stocking spring and summer of salmonids</td></tr>
<tr><td>Carson River - Cradlebaugh Bridge (Highway 395)</td><td>Warmwater fisheries – catfish – year-around</td></tr>
<tr><td>Carson River - Mexican Ditch Gage</td><td colspan="2">Spring and fall spawning salmonids (marginal) – rainbow and brown trout. Supplemented by hatchery trout.</td></tr>
<tr><td>Carson River - New Empire</td><td colspan="2">Warmwater fish – smallmouth bass – year-around. Coldwater trout stocked spring and summer</td></tr>
<tr><td>Carson River - Dayton Bridge</td><td colspan="2">Reach not mentioned</td></tr>
<tr><td>Carson River - Weeks</td><td colspan="2" rowspan="2">Warmwater fisheries, year-around. Walleye, channel catfish, white bass.</td></tr>
<tr><td>Lahontan Dam</td></tr>
</table>

Note: Use applies from control point to the next control point upstream

It is this author's opinion that these temperature standards cannot be met consistently, without flow augmentation along with accompanying channel and vegetation restoration. However, the Clean Water Act does not allow for any actions which would supersede, abrogate or impair the State's authority to allocate water quantity. Yet, there is nothing in the Act that prohibits states from establishing flow dependent standards. In fact, temperature standards that change with flow conditions are currently in place on the Truckee River. For the reach from Lockwood to the Pyramid Lake Paiute Tribe Reservation boundary, the April through July temperature standards generally range from 21 to 25°C. However, the following footnote is attached:

> *"When flows are adequate to induce spawning runs of cui-ui and Lahontan cutthroat trout, the standard is….14°C from April through June."*

For this same reach, another footnote is included which recognizes that lower temperatures (21°C) are desired for the protection of juvenile Lahontan cutthroat trout, but are recognized as not being attainable at all times (NAC 445A.187 through 445A.189).

Overall, the current standards do attempt to account for low flow periods. NAC 445A.121(8) (which applies to all surface waters in Nevada) states that the standards "…are not considered violated when the natural conditions of the receiving water are outside the established limits, including periods of extreme high or low flow." While the regulations do not describe how these high/low flows limits are to be established, NDEP generally relies upon 7Q10[10] statistics for these thresholds (Table 5). However, these limits are rather low and temperature standards tend to be exceeded well before these 7Q10 limits are reached.

Table 5. 7Q10 Statistics for Selected Carson River Gaging Stations

ID	Name	7Q10 Low	7Q10 High
10308200	EF Carson River bel. Markleeville	25	3,435
10309000	EF Carson near Gardnerville	29	3,155
10310000	WF Carson River at Woodfords	9.7	1,074
10311000	Carson River near Carson City	4	4,651
10311400	Carson River at Deer Run Road	2.8	5,611
10312000	Carson River near Ft. Churchill	0.3	3,925

NDEP is discussing the possibility of enlisting technical consulting assistance in developing updated recommendations for temperature standards for various fish species for use in setting criteria for waters throughout the state. While it is believed that any new recommendations will be useful for setting appropriate standards for other waters in Nevada, the new criteria would likely not vary much from the current Carson standards. Information suggests that the current maximum summer temperature standards of 21 to 23°C continue to be appropriate for the propagation of rainbow and brown trout. Recently, Colorado, undertook an extensive review of its temperature standards, using a significant level of laboratory-derived temperature tolerance data (Colo. Dept. of PHE, 2006). As a result, Colorado established new coldwater criteria:

For sensitive species (cutthroat trout, brook trout)

- Daily maximum = 21.2° C
- Maximum weekly average = 17° C

For other coldwater species

- Daily maximum = 23.8° C
- Maximum weekly average = 18.2° C

[10] The 7Q10 statistic is the lowest or highest streamflow for 7 consecutive days that occurs on average once every 10 years.

Overall Temperature Standards Options

Following is a discussion of three general options that have been identified for dealing with the current temperature standards.

Option 1: Leave beneficial uses and temperature criteria as is

Under this option, the Carson River will continue to be on the 303(d) list for temperature impairments, and NDEP will continue to be pressured by EPA to develop temperature TMDLs (Total Maximum Daily Loads).

NDEP could develop a TMDL that called for improved shading throughout the system, yet it is unlikely that this alone would result in standards compliance. EPA can only approve TMDLs that demonstrate that implementation will lead to standards compliance. Significant data collection, modeling and analyses would be needed to estimate the level of temperatures that are reasonably attainable with improved channel and vegetative conditions. Even then, it is doubtful that the current standards could be met without flow augmentation.

Idaho Department of Environmental Quality (IDEQ) has been applying the concept of "Potential Natural Vegetation" (PNV) in its temperature TMDLs. In their PNV temperature TMDLs, they have put forth the premise that once a stream is at its PNV levels, then the stream temperatures are at background levels. Due to background provision in Idaho regulations, IDEQ takes the position that once streams are at background shading they meet water quality standards regardless if they don't meet numeric temperature criteria. Currently, EPA Region X has been approving these TMDLs (Shumar, 2007). It is not clear at this time if this type of approach could be taken on the Carson River and approved by Region IX, but may warrant further investigation. This approach could be considerably less expensive than the more traditional approach of using temperature modeling to quantify the linkage between shading and water temperatures.

The PNV approach is similar to the goal of a "Living River" that has come out of the Carson River Coalition. A "Living River" would be expected to have a riparian corridor with vegetation at achievable levels (aka PNV), along with other hydrologic and geomorphic attributes. Once Living River conditions are achieved to the extent reasonable, whatever temperatures that result are what we get.

Option 2: Leave beneficial uses as is and establish flow-variable temperature criteria

This option would not be easy to pursue as it would require significant data collection, modeling and analyses to estimate the temperature levels achievable as various flows and with cost-effective and reasonable restoration activities. Even with revised standards, our hope is to see more of a "Living River" with riparian vegetation conditions greatly improved. Even with flow-variable temperature criteria, the river should remain on the 303(d) list for temperature until riparian and channel conditions have improved. With the Carson River on the 303(d) list for temperature, NDEP would still be pressured to develop temperature TMDLs.

Option 3: Revise beneficial uses and criteria to recognize stocking activities are necessary to maintain coldwater fishery in some reaches

While this option is believed to lead to more realistically achievable uses and criteria, it would not be easy to pursue as it would require an extensive Use Attainability Analysis, and significant data collection, modeling and analyses to estimate the temperature levels achievable with cost-effective and reasonable restoration activities (without flow augmentation).

As with Option 2, completion of this option would not lead to removal from the 303(d) List for temperature, and NDEP will continue to be pressured by EPA to develop temperature TMDLs. However, the UAA and modeling efforts would provide the necessary scientific information to support the TMDL.

Regardless of which option is taken with the standards in the future, the overall goal for the Carson River should not change. A healthier, more stable, "Living River" to the extent reasonable and practicable should be the goal. Under the Clean Water Act, this goal could not account for flow augmentation in evaluating restoration activities. While the current standards have some unrealistic beneficial uses and standards, it may be appropriate to leave them as is given the resources needed to refine.

Some Other Specific Options

Revise West Fork Carson River temperature standards: The West Fork Carson River below Highway 88 has not been a natural stream for about 100 years, due to the redirection of its flow to Brockliss Slough. The current beneficial use of aquatic life (with trout) and the associated temperature standards are not appropriate for this stretch of the West Fork, and should be revised to account for current conditions.

Include Brockliss Slough standards: As discussed above, the Brockliss Slough has in essence become the new "West Fork Carson River", yet no specific standards have been set for the Slough. While Brockliss Slough is far from a coldwater fishery, it may be appropriate to set some level of beneficial uses and standards for this water.

Summary and Recommendations

The available data has shown that temperature standards are commonly exceeded throughout the Carson system from Stateline to Deer Run Road, even where the East Fork Carson River exits the mountains and enters Carson Valley. Given the low flow and wide channel conditions that can exist in the system, it is unlikely that increased shading alone would result in temperature standard compliance. However, extensive study would be needed to identify the appropriate combination of flow, channel, and riparian vegetation improvements needed to achieve compliance with the temperature standards. Nevertheless, the goal of a "Living River" goal (to the extent reasonable and practicable) should be embraced.

It is recommended that the existing beneficial uses and criteria not be changed (with the exception of the West Fork) due to the significant resource demands needed to undertake such an effort. If temperature TMDLs are to be developed in the future, NDEP should initiate discussions with EPA Region regarding the use of the "Potential Natural Vegetation" concept.

It is believed worthwhile to revise the uses/standards on the lower West Fork Carson River. The stretch below Brockliss Slough no longer carries any significant amount of West Fork Carson River and should be recognized as an irrigation drain and delivery canal, rather than any kind of a natural river with a coldwater fishery. It is believed that adequate information exists to support the Use Attainability Analysis needed to support this regulatory change.

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