Use Attainability Analysis for Water Temperature for the Jordan River from confluence with Little Cottonwood Creek to Narrows Diversion, Utah and Salt Lake Counties, Utah

APPENDIX 1

WATER TEMPERATURE MODELING

Two-zone Dynamic Temperature Model Development and Calibration for the Jordan River

DRAFT REPORT

Utah Water Research Laboratory,
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for
Utah Department of Environmental Quality
Division of Water Quality

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Introduction

The Jordan River, from the Narrows to its confluence with Little Cottonwood Creek (Segments 5, 6 and 7) is included on the Clean Water Act's 303(d) list for Impaired Waters. These segments do not meet the 20 °C cold water fishery standard for 3A waters in at least ten percent of the samples. Through inflow temperature manipulations and possible increased shading, the goal of this project is to apply an instream temperature model to determine if the Jordan River can realistically meet the water quality standards set for cold water fisheries. Once calibrated, if the model does not show confidence that the river can cool to the degree necessary, then alternative actions such as a site specific standard may be pursued for these segments.

To determine whether the instream water quality standards can be met, a dynamic instream temperature model has been applied to the Jordan River. The model reach starts at the Joint Diversion and ends near the confluence of Little Cottonwood Creek. This model application is based on research by *Neilson et al.* (2010a, 2010b) where a two-zone temperature/solute model was developed and tested that includes the typical surface (e.g., solar radiation, evaporation, conduction), bed and ground conduction, hyporheic, and dead zone fluxes (Figure 1). In this application, only the surface flux and bed conduction components are considered as there was no information regarding transient storage (i.e., hyporheic and dead zone) behavior.

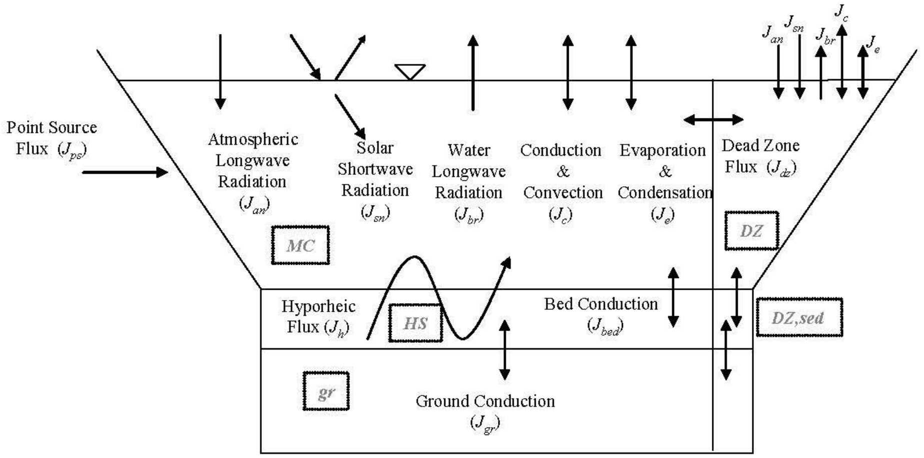

Figure 1. Energy balance components of two-zone temperature and solute model (taken from *Neilson et al. 2010(a)*).

Model Structure

The model structure, as illustrated within Figure 2, consists of a model headwater location, 13 point inflows/outflows, and distributed inflows/outflows (assumed to be primarily groundwater) based on a seepage study in July 2010. For modeling purposes, both flow and temperature values are required for the headwater and all inflows for the modeling time period in order to provide a water balance and track heat exchanges. The quality of these data types significantly impact the accuracy of model predictions.

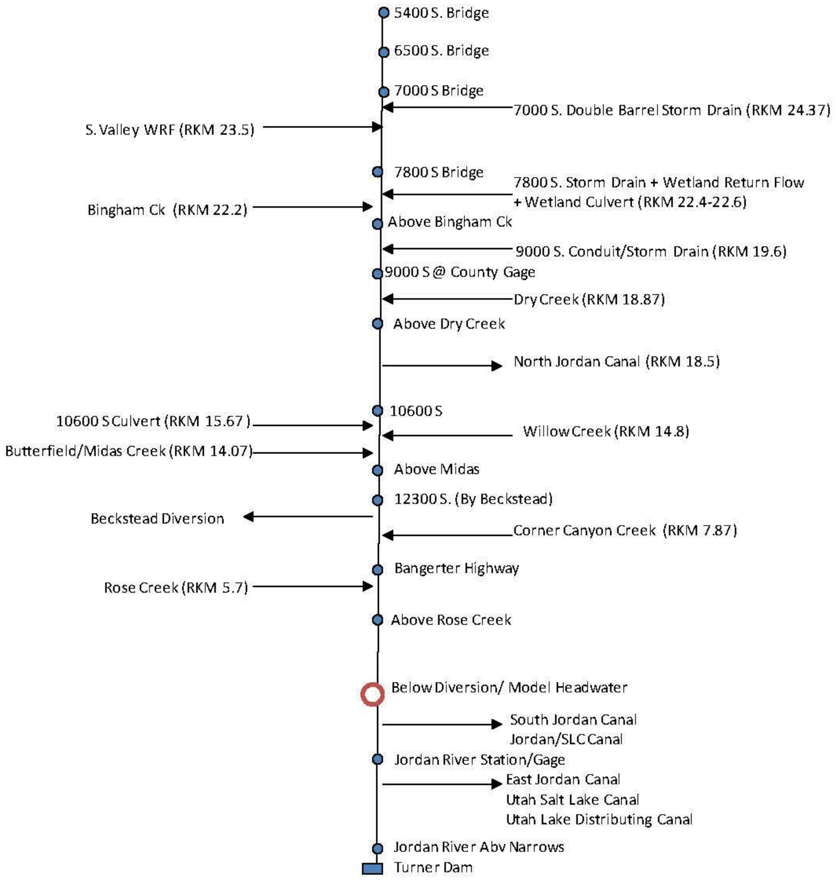

Figure 2. Layout of the portion of Jordan River initially included in the modeling (not to scale) showing inflows and outflows accounted for within the modeling effort. The final model structure did not include the portion of the river spanning Turner Dam to the South Jordan/Jordan/SLC Canal diversion. The beginning of the modeling reach (or model headwater location) is indicated by the red circle at the "Below Diversion" site.

Model Population

Headwater/Boundary Condition

The headwater location for this modeling effort was established as the Jordan River below South Jordan and Jordan/Salt Lake Canals (shown as Below Diversion in Figure 2). Initially, the model reach spanned from Turner Dam to Above Little Cottonwood Creek Confluence; however, the temperature information collected within Turner Dam did not appear to represent the temperatures of the water leaving the dam. This sensor was placed at a location near the bank within the Turner Dam backwater wetland area. Since a key model requirement is an accurate headwater or boundary condition temperature time series, the next temperature time series downstream within the Jordan River was selected as the starting location of the modeling effort. For the model calibration period, the boundary condition flow was set at 98.4 cfs (~2.79 cms) based on measurements made on July 26, 2010 and assumed constant throughout the 7 day model calibration period.

Reach Segmentation/Characteristics

The model reach (~30.3 km) was broken into 902 model subreaches. For consistency with the Jordan River TMDL modeling work (Stantec Consulting, 2010), much of the required information to describe the channel geometry was taken from the August 2009 QUAL2K modeling effort. This included the average bottom slopes (shown in Table 1) and an average Manning's n value based on those spanning from Turner Dam to Little Cottonwood Creek confluence (n=0.0392).

The sediment thermal properties were set based on actual laboratory measurements of stream sediment samples similar to the substrate within the Jordan River. The thermal conductivity (K) was measured as 0.8846 W m^{-1} K^{-1}, the thermal diffusivity (α) was measured as 0.00241 cm s^{-1}. From these values and an assumed density of 1.810 g cm^{-3} (soil, wet value from QUAL2Kw manual (*Pelletier et al. 2006*)) a heat capacity (C_p) of 0.4862 cal g^{-1} k^{-1} was calculated.

Simplifications were made in describing the channel geometry due to the inherent variability in channel widths and geometric properties longitudinally in streams. Additionally, limited information was available for these characteristics during the time period of interest for this modeling effort. This led to setting the side slope of channel to 0 (assuming a rectangular channel) and the reach widths were initially approximated as the top widths estimated from 2009 QUAL2K modeling. These top width estimates incorporated the hydraulic characteristics used within the 2009 QUAL2K modeling (side slope, bottom width, and predicted depths). Past this, these top widths were averaged over larger reaches with similar characteristics to make sure there was numerical stability within the TZTS model. Due to these assumptions and the uncertainty regarding the reach widths, as discussed further below, these values were used within model calibration.

Table 1. River sections, descriptions, and the assigned corresponding bottom slopes.

River Section	*Description*	*Bottom Slope*
RCH 1 – RCH 117	Below Confluence to Below Rose Creek Confluence	0.004

RCH 118 – RCH 327	Below Rose Creek Confluence to 12300 S.	0.0025
RCH 328 – RCH 731	12300 S. to 7000 S.	0.001
RCH 732 – RCH 902	7000 S. to Little Cottonwood Confluence	0.00098

Point Inflows/Outflows

The point inflows/outflows accounted for within the model include Rose Creek, the wetlands below Rose Creek, Corner Canyon Creek, Butterfield/Midas Creek, Willow Creek, 10600 S. Culvert, North Jordan Canal, Dry Creek, 9000 S. storm drain, Bingham Creek, 7800 S. storm drain/wetlands return flows, 7800 S. Culvert, South Valley Water Reclamation Facility, and the 7000 S. double barrel storm drain. At a number of locations, multiple inflows that were located in close proximity to each other (e.g., Murray City wetlands and the 7800 S. storm drain) were lumped and represented as one inflow in the modeling. Temperature time series data were collected at various locations along the Jordan River and within the inflows; however, not all of the inflows had continuous temperature measurements during the time of interest (Figure 3). The primary source of flow information for these point sources was the seepage study conducted on July 25-27, 2010 (Figure 4) through a joint effort between DEQ and Salt Lake County Watershed Planning and Restoration Program staff. Since the data sources used in the model for the inflow temperatures and flows varied, Table 2 describes the data used to represent each of these inflows. It is important to note that many of these inflows are inherently variable, but data limitations resulted in representing these sources as having constant flow and/or temperature during the seven day model calibration period.

Diffuse Inflows/Outflows

One of the primary motivations for conducting the seepage study (Figure 4) was to measure the amount of groundwater inflow or outflow influencing the temperatures within the modeling reach in order to predict if overall river temperatures can realistically meet the 20 °C cold water fishery standard. This resulted in an understanding that there are sections of the river where even after accounting for the point inflows/outflows, significant differences in flow were measured within the channel. Figure 5 shows the net differences in flow (ΔQ, cfs) over specific reaches. In the model, these gains and losses were assumed to be entirely groundwater exchanges. However, we know that there were a number of unidentified inflows that were not subsurface, creating some uncertainty in the associated temperatures. Data collected from various wells by Sharon Steel (*Howes 2009*) during the late summer and early fall periods reported values ranging from 15-20 °C and Midvale Slag Superfund Site (*URS 2010*) reported ranges from 15-23.7 °C for July 2009. Table 3 shows the sections of the river that were assigned distributed inflows and outflows within the model as well as the temperatures assigned to the distributed inflows (assumed primarily to be groundwater) during calibration (see Model Calibration section for more information about this).

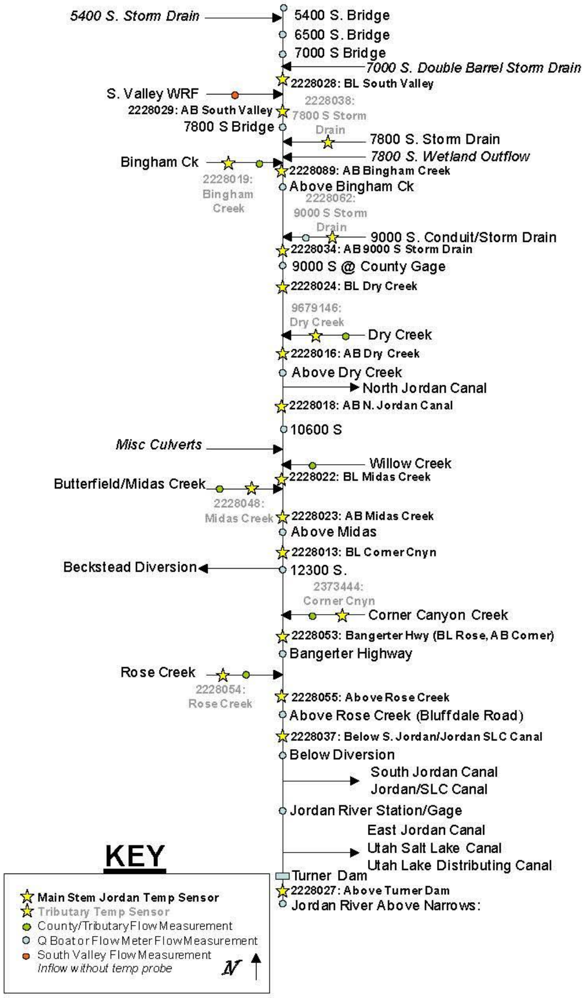

Figure 3. Temperature sensor locations during the modeling period as well as locations where flows were taken during the seepage study.

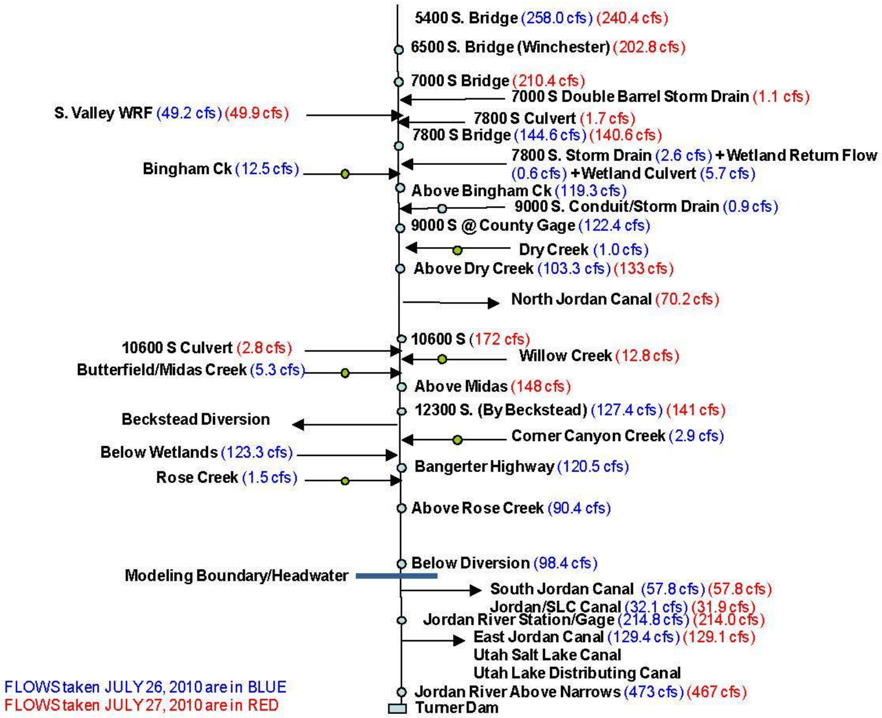

Figure 4. Flow values measured at various locations during the seepage study conducted on July 26-27, 2010. Some locations were measured twice due to precipitation occurring on the afternoon of July 26.

Table 2. Jordan River point inflow/outflow names, locations, and data sources used to represent them within the temperature model.

Inflow Name	*Inflow Reach*	*River Kilometer*	*Data Source*
Rose Creek	172	5.70	Discrete Q (Seepage Study), Temperature Time series (#2228054)
Corner Canyon Creek	237	7.87	Discrete Q (Seepage Study), Temperature Time series (#2373444)
Butterfield/Midas Creek	423	14.07	Discrete Q (Seepage Study), Temperature Time series (#2228048)
Willow Creek	445	14.80	Discrete Q (Seepage Study), Used Temp Time series from Dry Creek (#9679146/ 2228049)
10600 S. Culvert	471	15.67	Discrete Q (Seepage Study), Used Temp Time series from 7800 S. Storm Drain (#2228083/2228074)
North Jordan Canal	556	18.50	Q = Average Value from July 20-27, 2010 from DWR website
Dry Creek	567	18.87	Discrete Q (Seepage Study), Temp Time series (#9679146/ 2228049)
9000 S. storm drain	589	19.60	Discrete Q (Seepage Study), Used Temp Time series from 7800 S. Storm Drain (#2228083/2228074)
Bingham Creek	667	22.20	Discrete Q (Seepage Study), Temp Time series (#2228019/2228086)

Inflow Name	*Inflow Reach*	*River Kilometer*	*Data Source*
7800 S. storm drain/wetlands	673	22.40	Discrete Q (Seepage Study), Discrete Temperature
7800 S. Culvert	679	22.60	Discrete Q (Seepage Study), Temp Time series (#2228083/2228074)
SVWRF	688	23.50	Average Q from SVWRF, Discrete Temperature
7000 S. double barrel storm drain	732	24.37	Discrete Q (Seepage Study), Used Temp Time series from 7800 S. Storm Drain (#2228083/2228074)

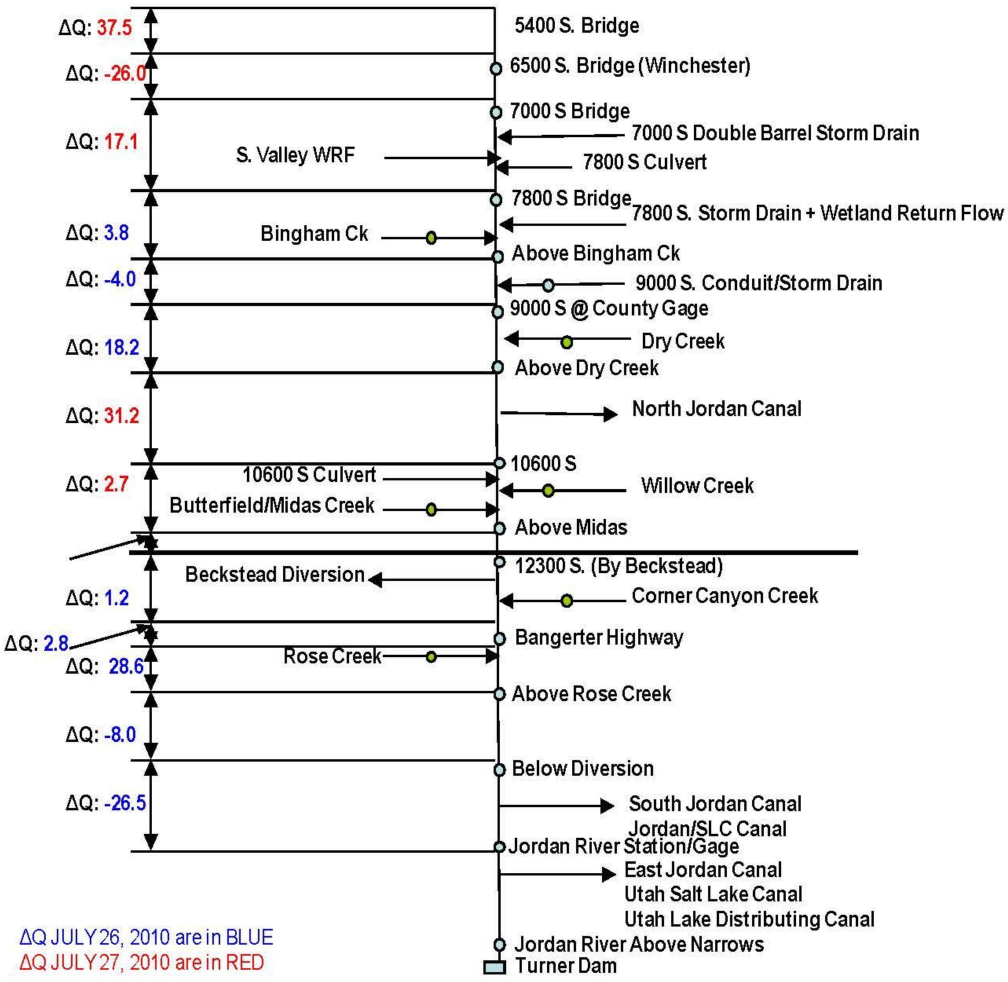

Figure 5. Difference in flows (net gains or losses in cfs) over various reaches after accounting for point inflows and outflows. This information was based on data collected during the seepage study (Figure 4) conducted on July 26-27, 2010.

Table 3. Sections of the river receiving distributed flows and the associated temperature.

Beginning River (km) / Model RCH	Ending River (km) /Model RCH	Distributed Inflow (cms)	Distributed Temperature (C)
0	3.6	-0.2264	
3.61	8	0.598	23
8.1	10.4	0.325	17
10.41	15.7	0.27451	17
15.71	18.83	0.88296	17
18.84	19.63	0.51506	17
19.64	19.8	-0.1132	
19.81	22.6	0.10754	17
22.61	24.37	0.48393	17
24.38	25.2	-0.7358	

Weather Information

Instream temperature modeling requires a number of weather data time series to predict the heat exchanges between the water and the atmosphere. These include air temperature, wind speed, relative humidity, and solar radiation. For this modeling effort air temperature, wind speed, and relative humidity were downloaded from the Mesowest website (http://mesowest.utah.edu) for the Salt Lake International Airport station. Solar radiation data were downloaded from the Integrated Surface Irradiance Study (ISIS) Network (http://www.srrb.noaa.gov/isis/index.html) for the Salt Lake City station. Since these solar radiation values are raw data, all negative numbers that occurred during the night (when shortwave radiation should be 0) were set to 0. For use within the modeling, these data were further scaled to account for shading influences using information from the QUAL2K August 2009 modeling effort. The scaling was completed by taking an average hourly average percent shading for the entire study reach (spatial average) and then adjusting the radiation values used within the temperature model to account for hourly differences in shading.

Model Calibration - July 2010 Simulation

The calibration period of July 20 4:30 pm - July 27 11:00 pm (40379.68785 - 40386.98154) was selected based on the availability of the necessary temperature information (both forcing and calibration). It should be noted that there was some precipitation on July 21 that may have caused inflow from storm drains. While conducting the seepage study on July 26, there was significantly more inflow within the storm drains. Due to continued precipitation from July 27-29 , these days were not included in the calibration period.

For model calibration, instream temperature data were collected at 9 locations within the Jordan River (Figure 3 and Table 4) to be used in model calibration. Unlike instream water quality modeling, there are very few parameters within a temperature model that can be adjusted within calibration. Within this effort those that could be considered are the sediment thermal properties (α, C_p, and ρ) and constants within the surface heat flux estimates (e.g., water emissivity and atmospheric longwave reflection or attenuation coefficients). In very shallow rivers, sediment thermal properties can be important since bed conduction can be a significant driver (*Brown 1969*). However, previous work (e.g., *Neilson et al. 2009*) has illustrated that bed conduction is a relatively insignificant heat flux in larger, deeper rivers. Therefore, thermal properties were not adjusted during calibration in this study. In contrast to this, shortwave solar radiation has been shown to be a dominant source of energy in most systems (e.g., *Neilson et al. 2009, Brown 1970, Johnson 2004*), particularly during the summer months, leaving the other surface fluxes and their coefficients relatively insignificant. The relative values of the surface fluxes in the Jordan River are shown in Figure 6 and show that the dominant heat source during the day is the incoming shortwave radiation (J_{sn}). The incoming longwave (J_{an}) and back radiation (J_{br}) nearly cancel each other out and the conduction term (J_c) is positive during much of the day while the evaporative term (J_e) represents a net heat loss.

Table 4. Calibration data locations, temperature probe IDs, and corresponding reach numbers.

Location	ID	Model Reach #
JR Below S Jordan Canal and SL Canal	**2228031**	1
JR Above Rose Creek (Bluffdale)	**2228055/4994600**	109
JR at Bangerter HWY	**2228053**	181
JR at 12300 S	**2228013/2228060**	328
JR Upstream Midas Creek	**2228023**	421
JR Below Midas Creek	**2228022**	424
JR Above North Jordan Canal Diversion	**2228018**	555
JR Above Dry Creek	**2228017**	566
JR Below Dry Creek	**2228015/2228024***	571
JR Below 9000 S	**2228014/2228034****	590
JR Above Bingham Creek	**2228089**	655
JR Above South Valley WWTP Inflow	**2228010**	705
JR Below South Valley WWTP Inflow	**2228028/2228073**	707

*2228015 was gone when went to retrieve it on 7/20/10. Replaced it with 2228024.

**2228014 was gone when went to retrieve it on 7/20/10. Replaced it with 2228034.

With this information, it is important to consider the information used within the model that influences the amount of incoming shortwave radiation reaching the river. This includes the amount of riparian or topographic shading and the variability of width and channel geometry throughout the reach. Given that the shading during the key portions of the day was estimated to be very small in the 2009 QUAL2K modeling effort (ranging from 2-18% over the entire reach from 9:00 am- 6:00 pm), this left the reach width as a key factor controlling the amount of shortwave radiation passing the water surface. Therefore, the calibration efforts focused on adjusting the top widths by certain percentages (up to a 20% reduction in width).

Past shortwave radiation, other key heat fluxes include inflows and outflows. Since many of the point inflows were measured, we assumed these values were reasonable. However, there was still uncertainty in the temperature of groundwater entering the river, particularly because there are areas that are geothermally influenced. Therefore, varying temperatures within the ranges observed in nearby wells became the other key calibration factor. In the end, discussions with Utah DEQ resulted in reach specific ranges of 20-23 °C between the Joint Diversion and upstream of 123000 S and 15-19 °C down to 5400 S.

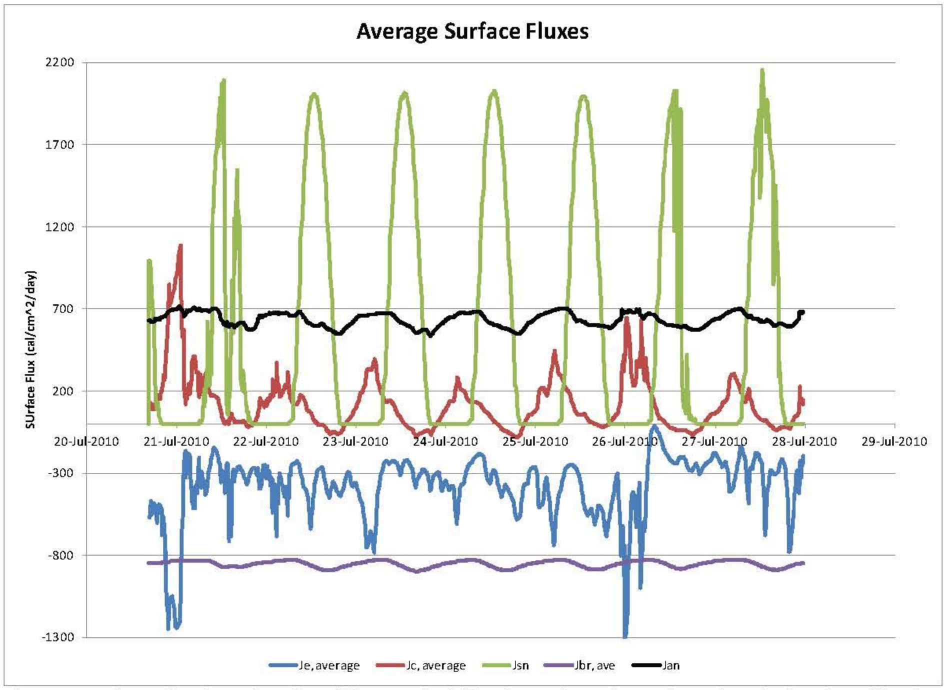

Figure 6. Values of each surface flux (illustrated within Figure 1) on the Jordan River during the calibration time period where $J_{e,average}$ = spatially averaged value of evaporation and condensation, $J_{c,average}$ = spatially averaged value of conduction and convection, J_{sn} = solar shortwave radiation, $J_{br,average}$ = spatially averaged water longwave radiation, and J_{an} = atmospheric longwave radiation.

The resulting approach to calibration was straightforward. First, groundwater temperatures were varied in the upper reach followed by the lower reach until the average temperatures at the various calibration locations were acceptable. Next, the reach widths were scaled by either 80 or 90% to further refine the daily minimum and maximum temperatures since this influences the area over which all surface fluxes occur (e.g., evaporation (cooling) and shortwave radiation (heating)). These simulations resulted in a groundwater temperature of 23 °C in the upper section and 17 °C in the lower reaches. Further simulations resulted in adjusting the top width by 80% throughout all reaches. Figures 7-15 show the resulting temperature predictions at the locations observations were available.

From these figures there are some general trends when comparing the predictions to the observations. First, you can see that the model is underestimating the temperatures from the headwater to above Rose Creek (Figures 7 and 8). After this, the model is generally overestimating maximum and minimum temperatures until the Jordan River below Midas Creek (Figures 9-11). The predictions after this point (Figures 12-15) are more similar to the observations. There is, however, a consistent lag in the observations when compared to the predictions and the cause is not clear. Smaller diel fluctuations and temperature lags like this are commonly associated with hyporheic exchange and river bed processes (*Johnson 2004; Loheide and Gorelick 2006*). In this case, however, while it could be due to in part to bed exchange processes missing in this model application, it could also partially be caused by inaccurately representing the channel geometry, shading, discharge volumes, and/or groundwater exchanges and temperatures.

Besides the potential simplifications and model assumptions already identified, other key influences that have not been accounted for in the modeling and could significantly impact predictions include: the large amount of backwater and adjacent wetlands upstream of the North Jordan Canal diversion that can result in significant warming; localized groundwater influences, some of which are geothermal; and problems associated with diversion quantity measurements. However, even with the assumptions and simplifications, this model still provides good estimates of minimum and maximum instream temperatures at most locations within the Jordan River.

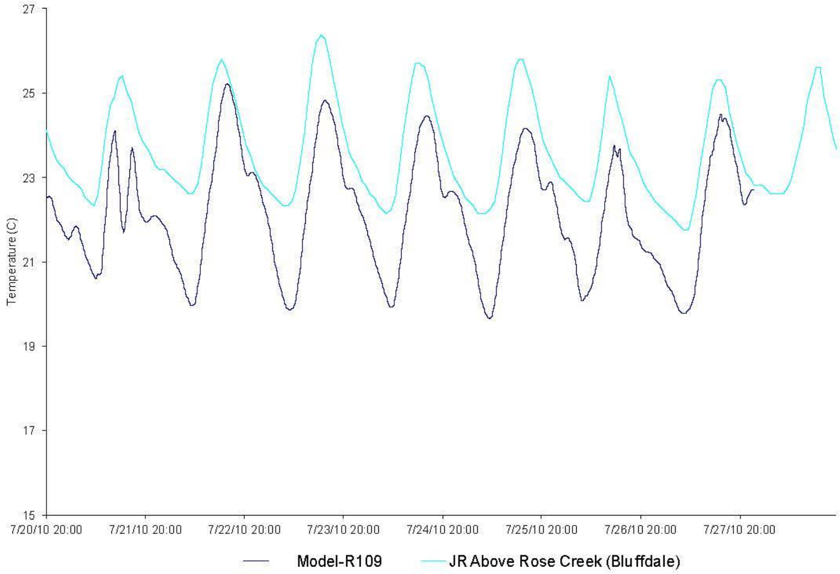

Figure 7. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River above Rose Creek (near Bluffdale).

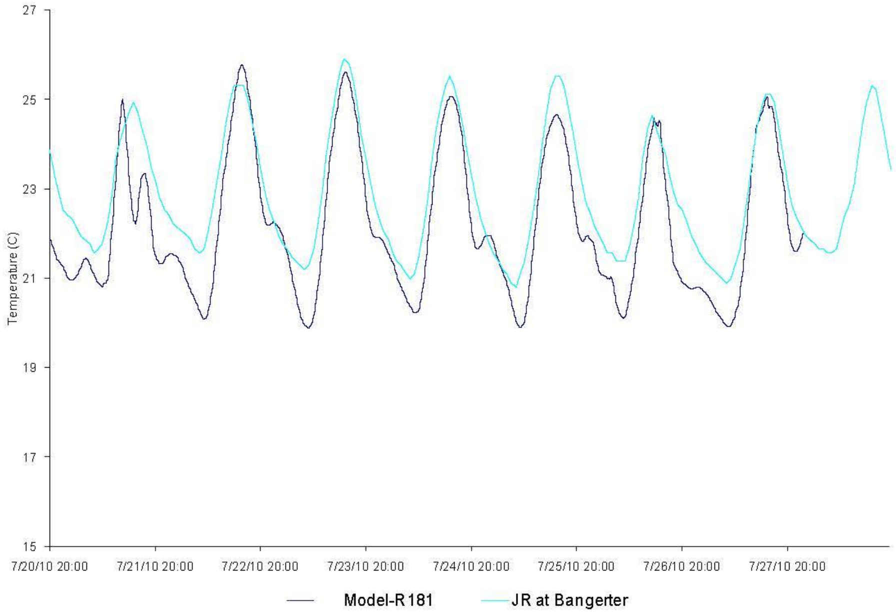

Figure 8. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River at Bangerter Highway.

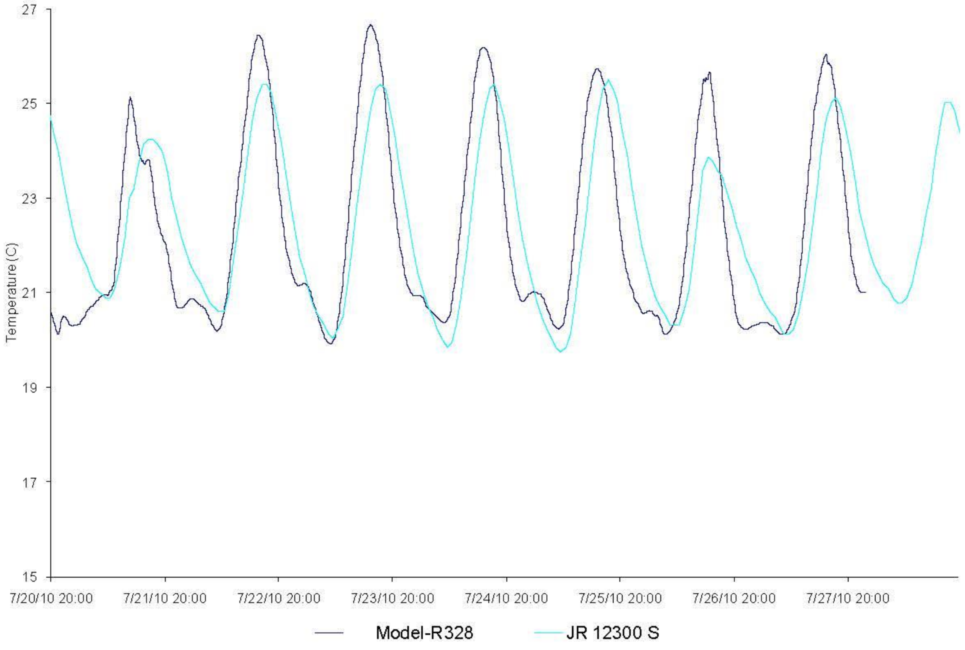

Figure 9. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River at 12300 S.

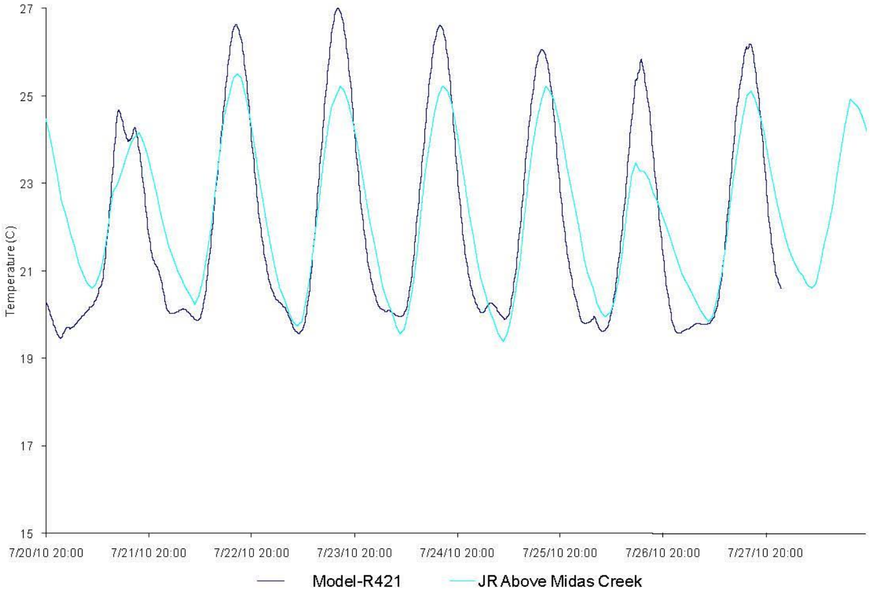

Figure 10. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River at Above Midas Creek.

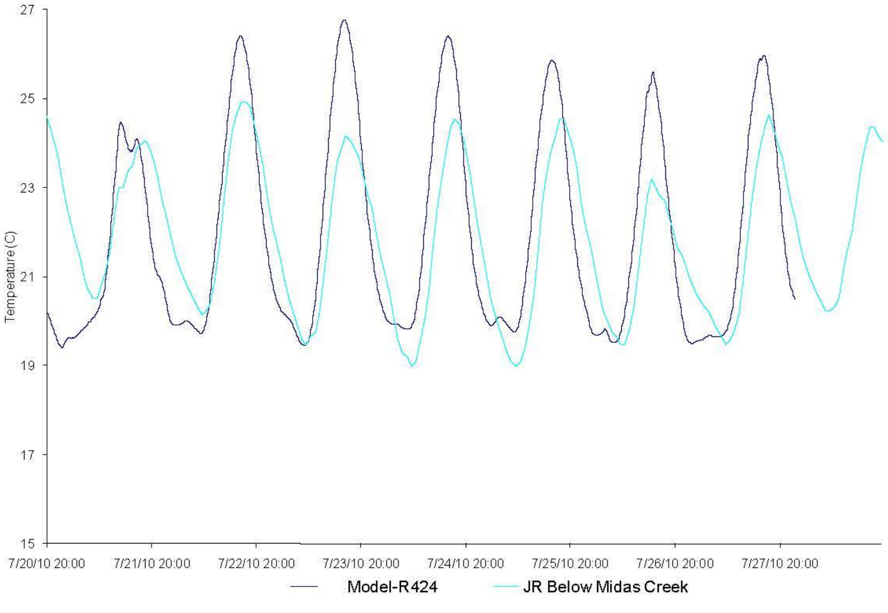

Figure 11. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River below Midas Creek.

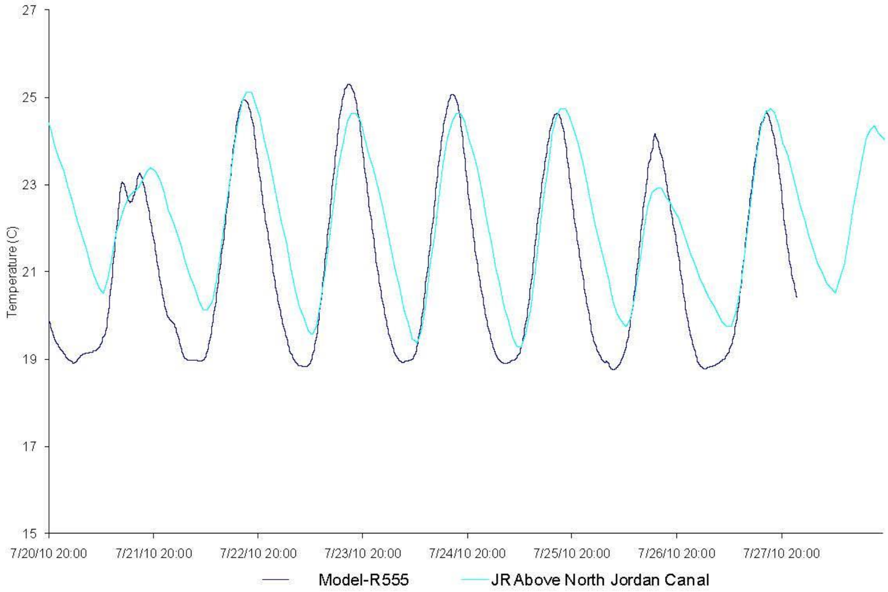

Figure 12. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River above the North Jordan Canal diversion.

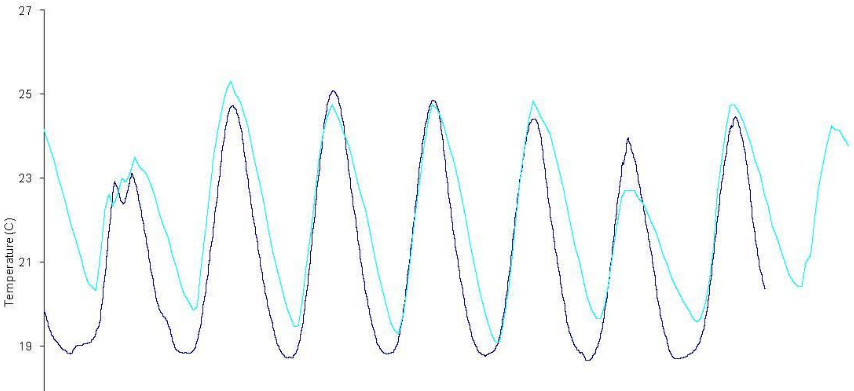

Figure 13. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River above the Dry Creek confluence.

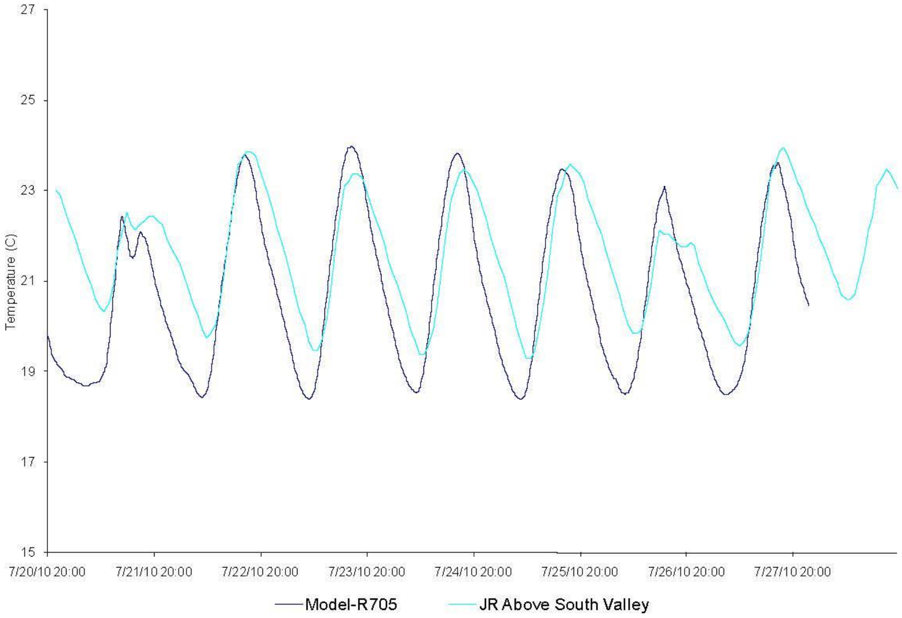

Figure 14. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River above South Valley Water Reclamation Facility.

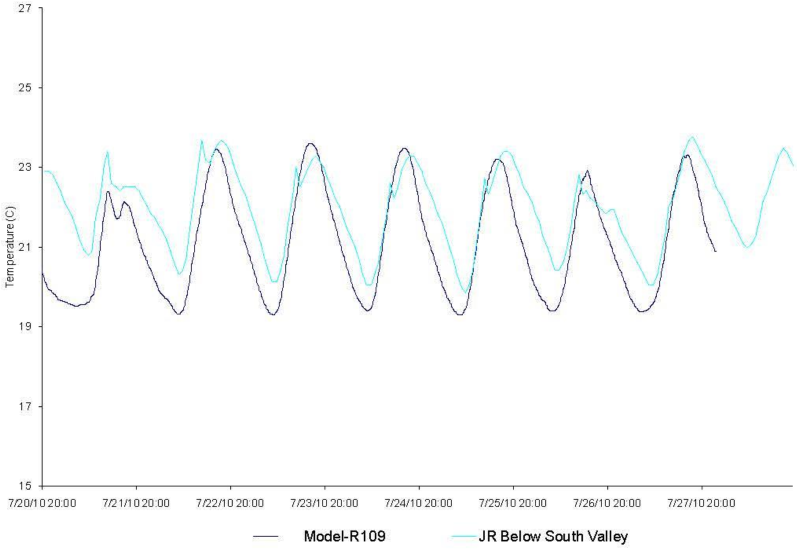

Figure 15. Calibrated model results and observed temperatures for July 20 4:30 pm - July 27 11:00 pm at Jordan River below South Valley Water Reclamation Facility.

Model Corroboration - August 2009 Simulation

To ensure that the dominant heat transfer processes and driving forces are being captured, the model was applied to an independent time period. The time period of August 18-20, 2009 was selected to correspond with the Jordan River QUAL2K August 2009 modeling. For this simulation the headwater location was same as that for the model calibration (Jordan River below South Jordan and Jordan/Salt Lake Canals). The flow assigned at this location was taken from the August 2009 QUAL2K predictions for the Joint Diversion location. Additionally, the temperature data collected below the South Jordan Canal (#2228032) from this time period were assigned as the headwater temperatures. The reach segmentation, channel description, shading percentages all remained identical to those used within the model calibration.

Since the forcing conditions during August 2009 were different than those in July 2010, where possible, inflow information was adjusted to account for these differences based on the QUAL2K modeling information. However, some information collected in 2010 had to be used in the 2009 simulation due to missing information. The details regarding data used and assumptions about the point sources are described in Table 5. A key assumption was that the distributed inflows and outflow remained the same quantity and temperature as those established in the model calibration for 2010. Weather data sources remained the same, however, the information for the 2009 simulation time period were used. Figures 16-20 show the model predictions versus observed temperatures at key locations along the Jordan River.

Table 5. Model corroboration inflow names, reach identification numbers, locations, and sources of data.

Inflow Name	*Inflow Reach*	*River Kilometer*	*Data Source*
Rose Creek	172	5.70	Discrete Q (Seepage Study 2010), Assumed 2010 Temperature Time series (#2228054)
Corner Canyon Creek	237	7.87	Discrete Q (Seepage Study 2010), Assumed 2010 Temperature Time series (#2373444)
Butterfield/Midas Creek	423	14.07	Discrete Q (Seepage Study 2010), 2009 Temperature Time series (#2228084)
Willow Creek	445	14.80	Discrete Q (Seepage Study 2010), Used 2009 Temp Time series from Dry Creek (# 2228049)
10600 S. Culvert	471	15.67	Discrete Q (Seepage Study 2010), Used 2009 Temp Time series from 7800 S. Storm Drain (#2228074)
North Jordan Canal	556	18.50	Q = Value from QUAL2K August 2009 Model
Dry Creek	567	18.87	Discrete Q (Seepage Study 2010), 2009 Temp Time series (# 2228049)
9000 S. storm drain	589	19.60	Discrete Q (Seepage Study 2010), 2009 Temp Time series (#2228062)
Bingham Creek	667	22.20	Discrete Q (Seepage Study 2010), 2009 Temp Time series (#2228086)
7800 S. storm drain/wetlands	673	22.40	Discrete Q (Seepage Study 2010), Discrete 2010 Temperature
7800 S. Culvert	679	22.60	Discrete Q (Seepage Study 2010), 2009 Temp Time series (#2228074)
SVWRF	688	23.50	Q and temperature from QUAL2K Aug 2009
7000 S. double barrel storm drain	732	24.37	Discrete Q (Seepage Study 2010), Used 2009 Temp Time series from 7800 S. Storm Drain (#2228074)

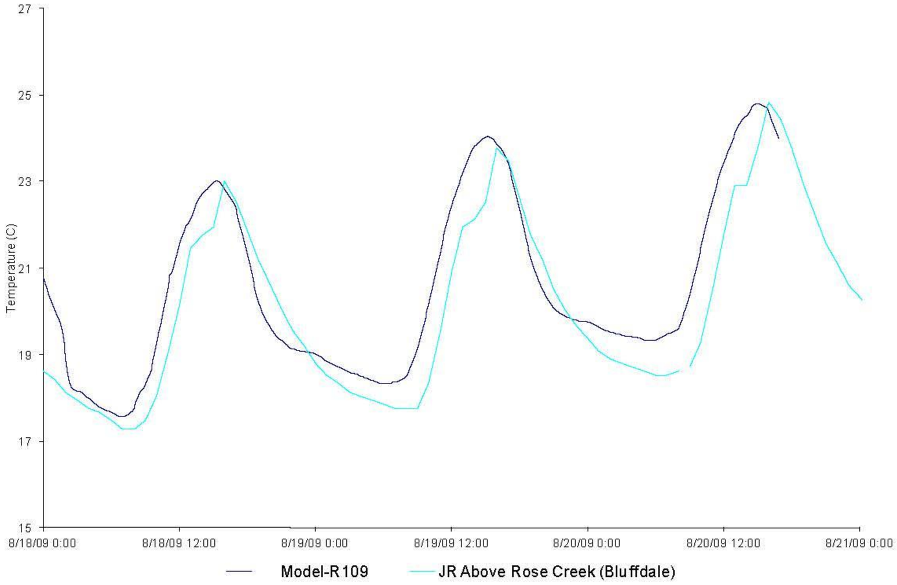

Figure 16. Model corroboration results and observed temperature for August 18- 20, 2009 at Jordan River above Rose Creek (near Bluffdale).

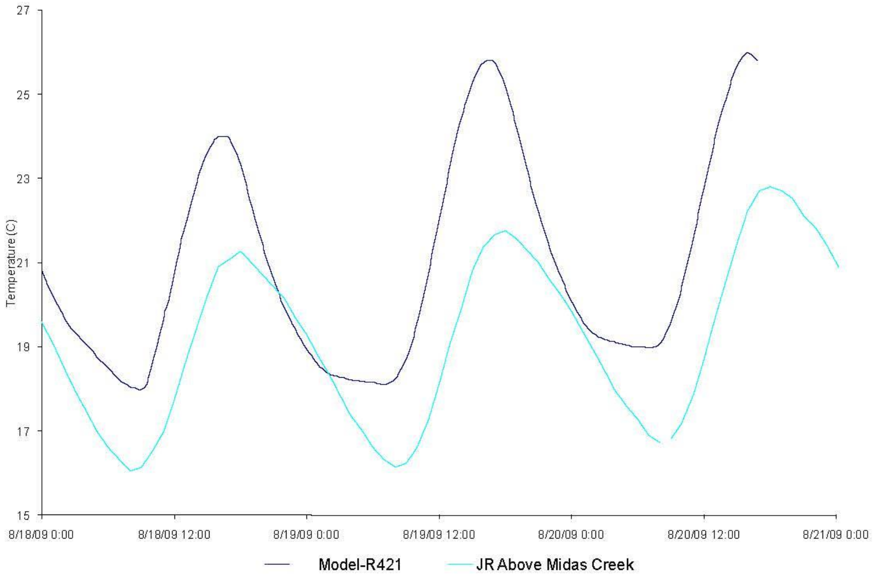

Figure 17. Model corroboration results and observed temperature for August 18- 20, 2009 at the Jordan River above Midas Creek.

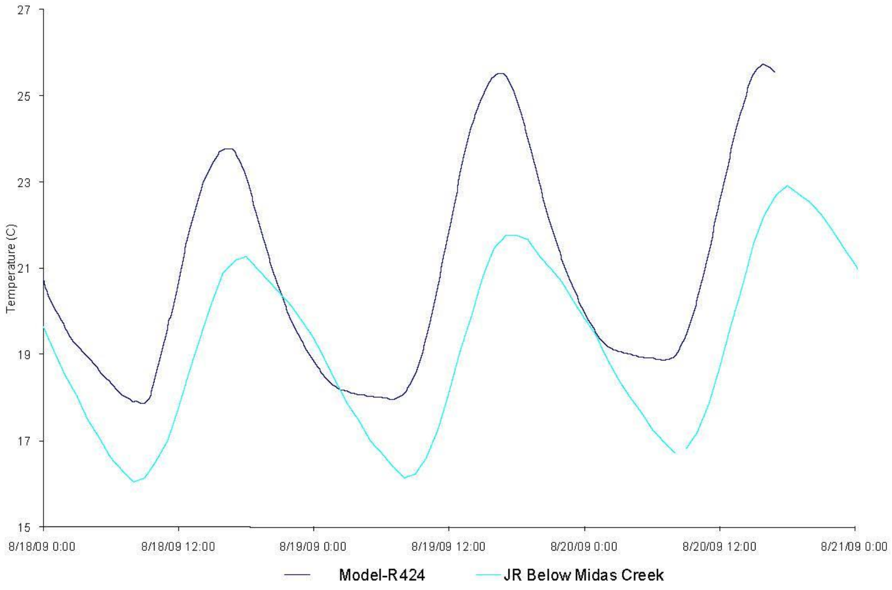

Figure 18. Model corroboration results and observed temperature for August 18- 20, 2009 at the Jordan River below Midas Creek.

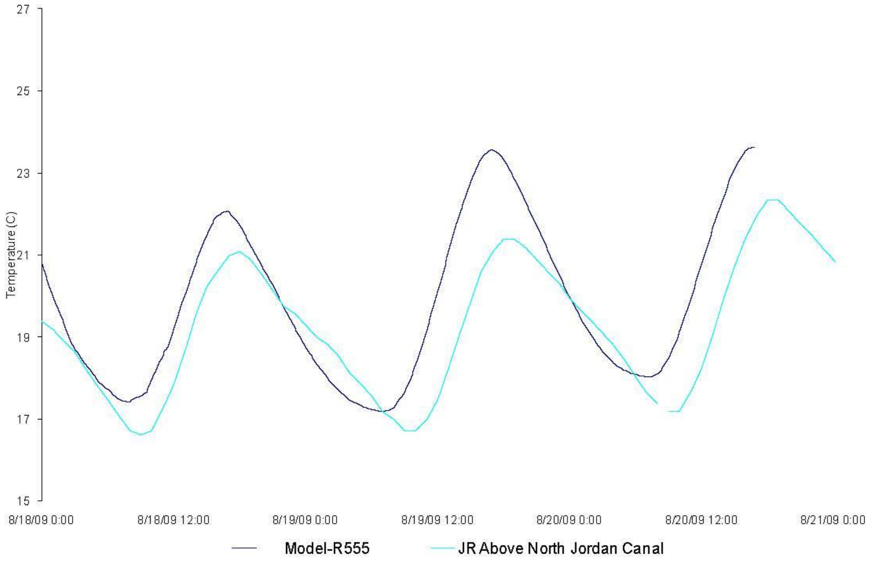

Figure 19. Model corroboration results and observed temperature for August 18- 20, 2009 at the Jordan River above the North Jordan Canal.

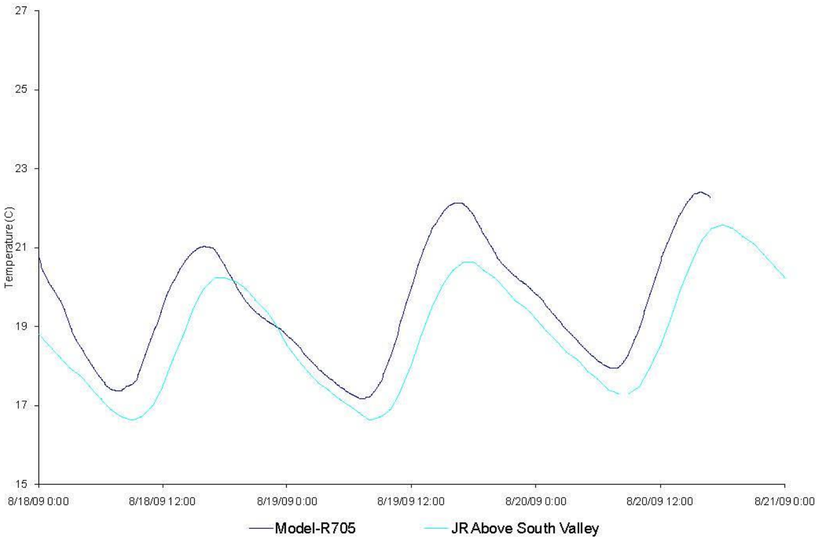

Figure 20. Model corroboration results and observed temperature for August 18- 20, 2009 at the Jordan River above South Valley Water Reclamation Facility.

The 2009 and 2010 models both provide reasonable results, however, the 2009 results are not as representative as those from the 2010 calibration period. This is to be expected since we have very little information about inflows (flows or temperatures) and these significantly influence instream temperatures all along the reach of interest. In general, our ability to predict temperatures above Rose Creek are better than the calibration. However, as with the calibration, the predictions both above and below Midas Creek are not as accurate and suggest something local occurring that is not being accounted for within the model. Temperatures above the North Jordan Canal and above South Valley WRF are consistently overestimated during the corroboration time period. Regardless, these results confirm that we are capturing the key heat sources and sinks that influence this stretch of river.

Scenarios using the July 2010 Simulation Period

In an effort to determine if the current designated use of a coldwater fishery and the associated 20 °C instream temperature standard is achievable, a number of scenarios were developed. These use the 2010 model calibration period and only include possible management options identified by Utah DEQ. According to Utah DEQ, this excludes the possibility of increasing the instream flows throughout these segments of the Jordan River or changing the temperatures coming from Utah Lake.

First, scenarios were run that illustrate the impacts of increasing shading of the river between 40-80% rather than the current minimal shading of the river (Figures 21-26). For these scenarios, the incoming shortwave solar radiation values were scaled by the appropriate percentage. As would be expected, the impacts of up to 80% shading of the river are significant and the effects of channel shading have a larger impact as you go further downstream. The other management option of interest is the effect of shading tributaries and impervious surfaces that collect the urban runoff even during these low flow conditions. To provide realistic temperature values of the anticipated cooler inflow temperatures, the temperature time series from Midas Creek (the coolest of all the tributary inflows (Figure 27)) was applied to all inflows (except the SVWRF) along the Jordan River. The results (Figures 28-33) show that for the upper section of the river (Figure 28-29) the results are identical to the calibration. This is due to no inflows influencing this portion of the study reach. There is some net cooling effect of these inflows as you move downstream (Figures 30-33). Last, combinations of these two scenarios were run to investigate the influences of shading on both the mainstem Jordan River and its tributaries (Figures 34-39). In comparing these results to those of just shading (Figures 21-26), there is no difference in the upper reaches (Figures 34-35), but the combined influence does impact temperatures more significantly further downstream.

Current beneficial use designations within the Jordan River have the upper portions of the river designated as a cold water fishery (above the Little Cottonwood confluence) and the lower section (below the Little Cottonwood confluence) designated as a warm water fishery where the latter requires meeting the instream temperature standard of 27 °C. From all these scenarios, the results of this modeling study suggest that it would take drastic measures to meet the cold water fishery standard at the compliance point for Segments 5-7 of the Jordan River (7800 S. crossing). As shown in Figure 24, upwards of an 80% increase in shading would be required. Another option would be an approximately 60% increase in shading on the Jordan River as well as shading along all tributaries (Figure 37). However, neither of these scenarios is realistic given the difficulty associated with a 60-80% increase in shading of the Jordan River.

To look further at the temperature regimes throughout the Jordan, Figures 40-45 show temperature data collected during the month of August in 2009 from various locations longitudinally. These data illustrate that the cold water standard is not consistently met anywhere during this limiting time of year. However, it is important to note that the locations further downstream of Midas Creek are significantly cooler and are closer to meeting the cold water fishery temperature standard. In fact, the locations within the warm water designation (downstream of the cold water designation) are closer to the cold water standard due to cool tributary inflows (e.g., Little and Big Cottonwood Creeks). Table 6 further illustrates a downstream trend showing a net cooling from Below S. Jordan Canal to Above South Valley. After that point there is a net warming downstream based on monthly averages. However, even at Burnham Dam the temperatures do not reach those at the beginning of the study reach.

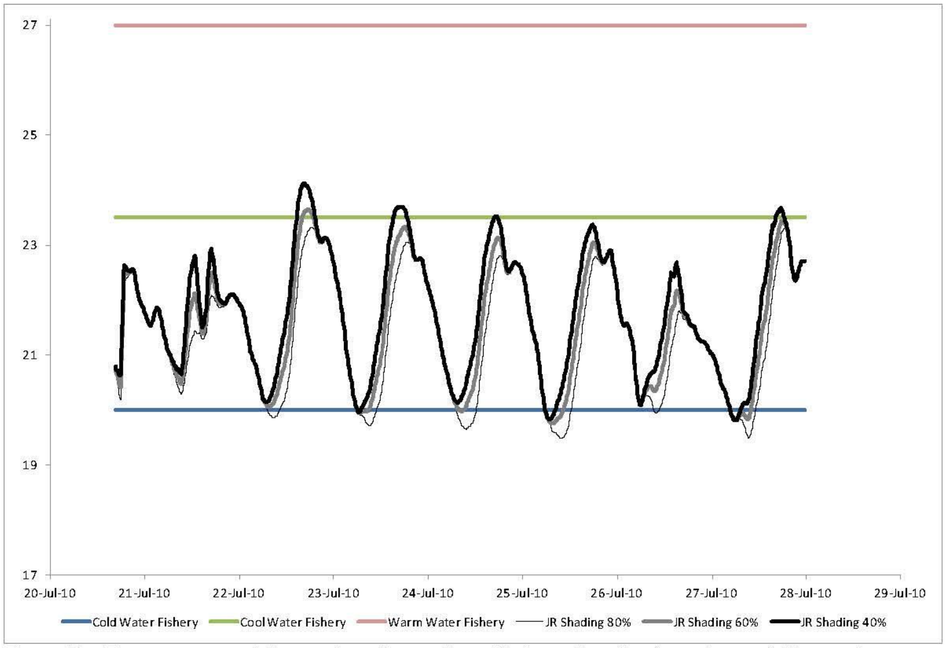

Figure 21. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above Rose Creek (Compliance Point for Segment 7 for TDS).

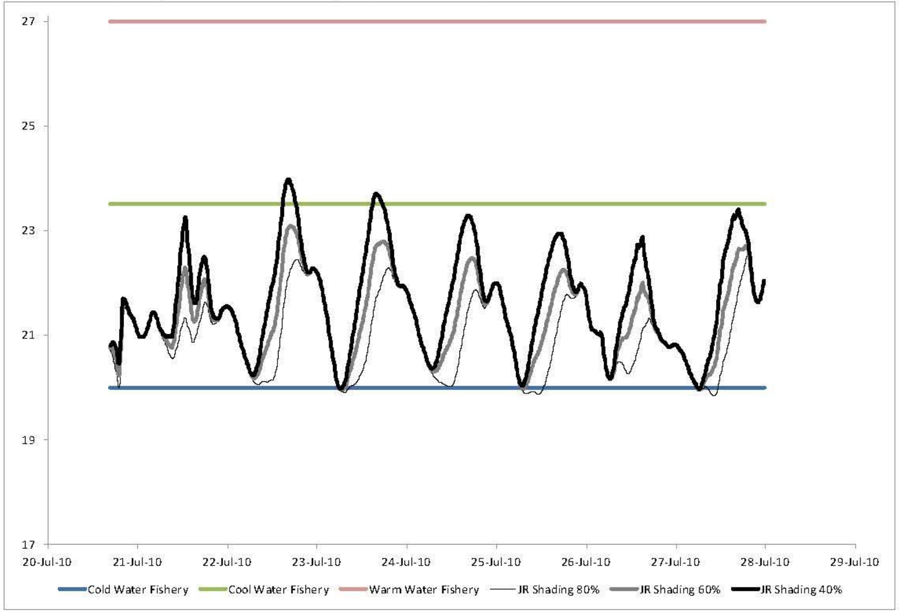

Figure 22. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures near Bangerter Highway.

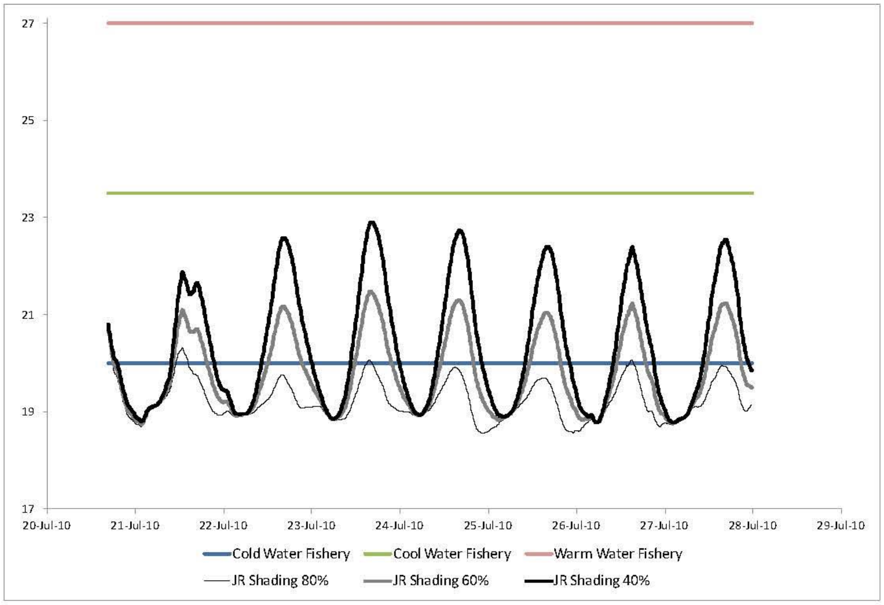

Figure 23. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above the North Jordan Canal diversion.

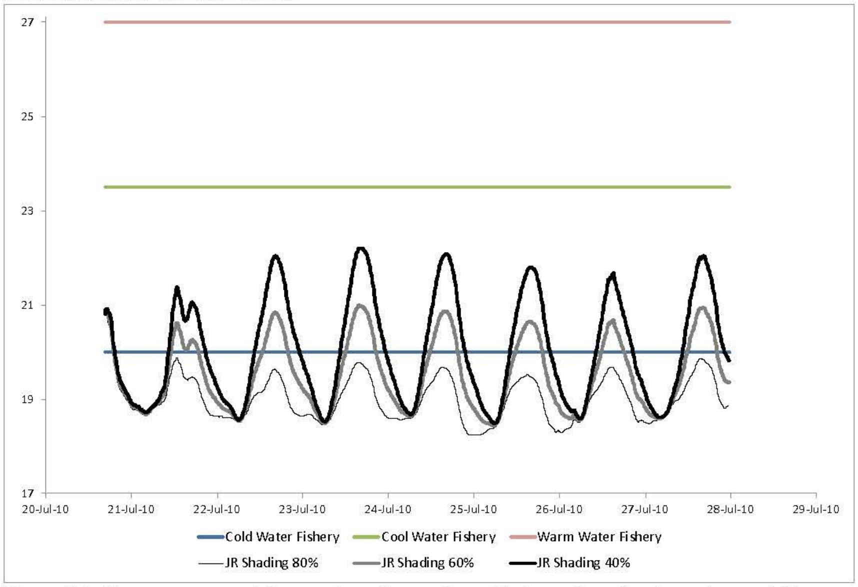

Figure 24. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures at 7800 S. crossing (Compliance point for Segments 5-7 for temperature).

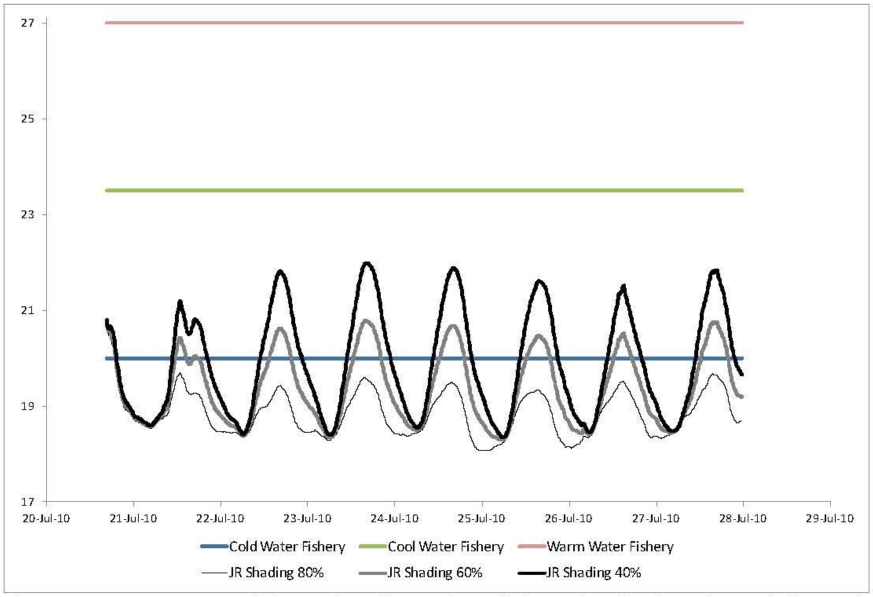

Figure 25. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures below South Valley Water Reclamation Facility.

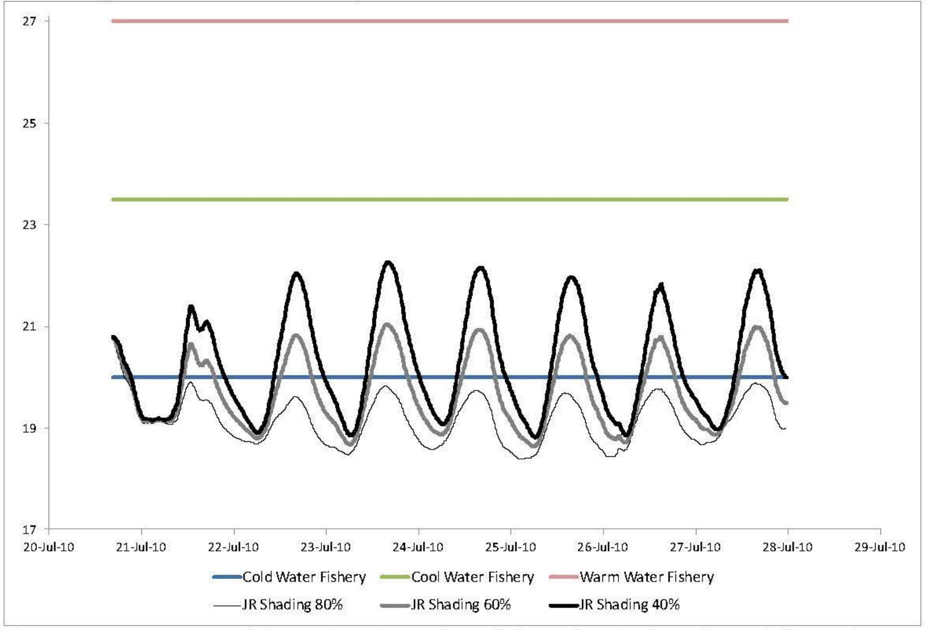

Figure 26. Temperature model scenarios where solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above the Little Cottonwood confluence (end of Segment 5).

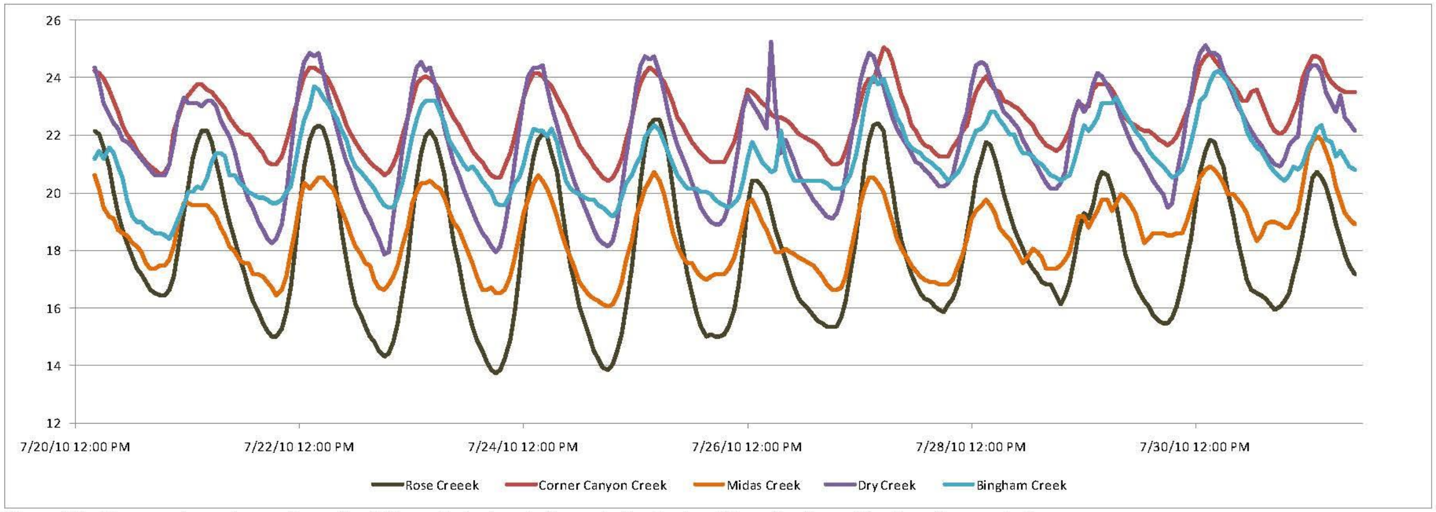

Figure 27. Temperature observations for different tributary inflows to the Jordan River for the calibration time period.

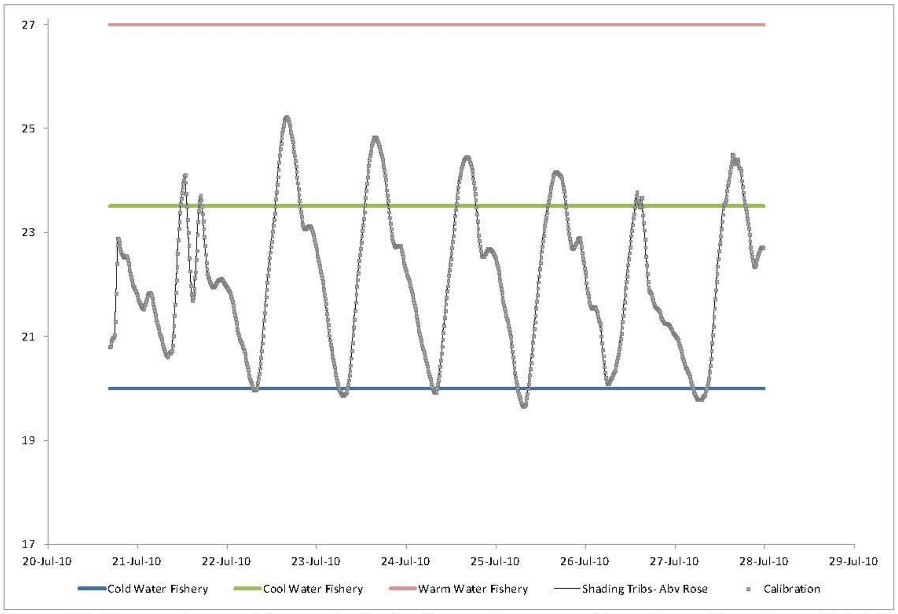

Figure 28. Temperature model scenario for the Jordan River above Rose Creek (Compliance Point Seg 7) where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

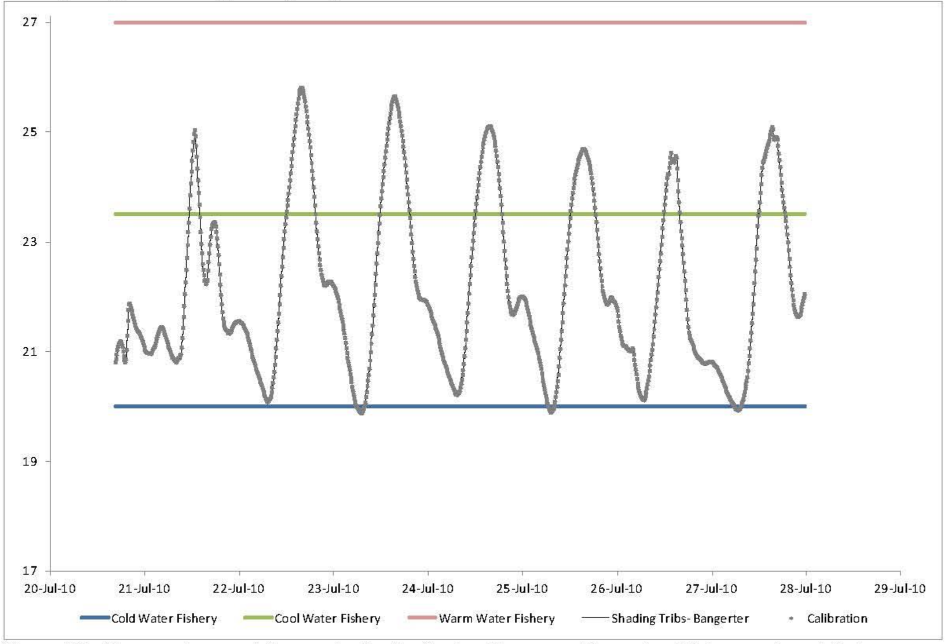

Figure 29. Temperature model scenario for the Jordan River near Bangerter Highway where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

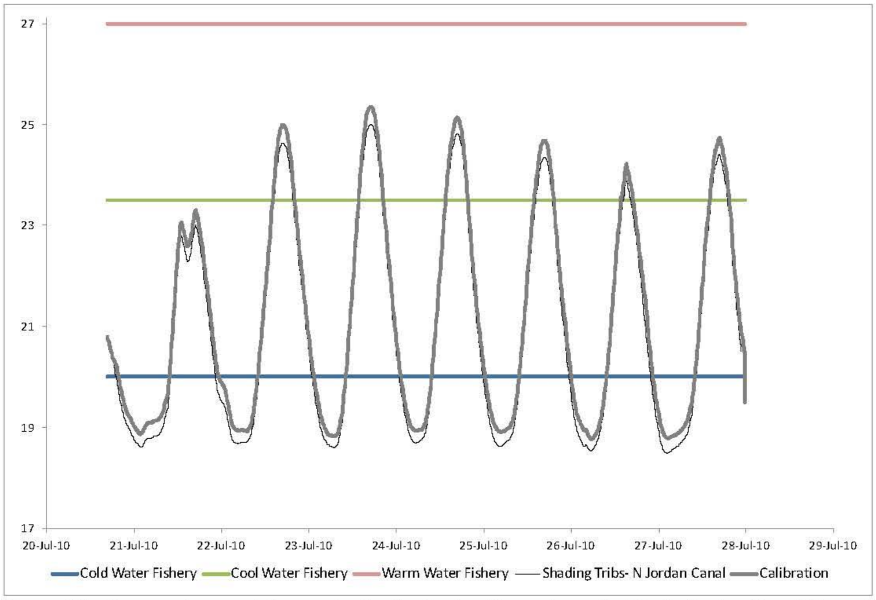

Figure 30. Temperature model scenario for the Jordan River above the North Jordan Canal Diversion where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

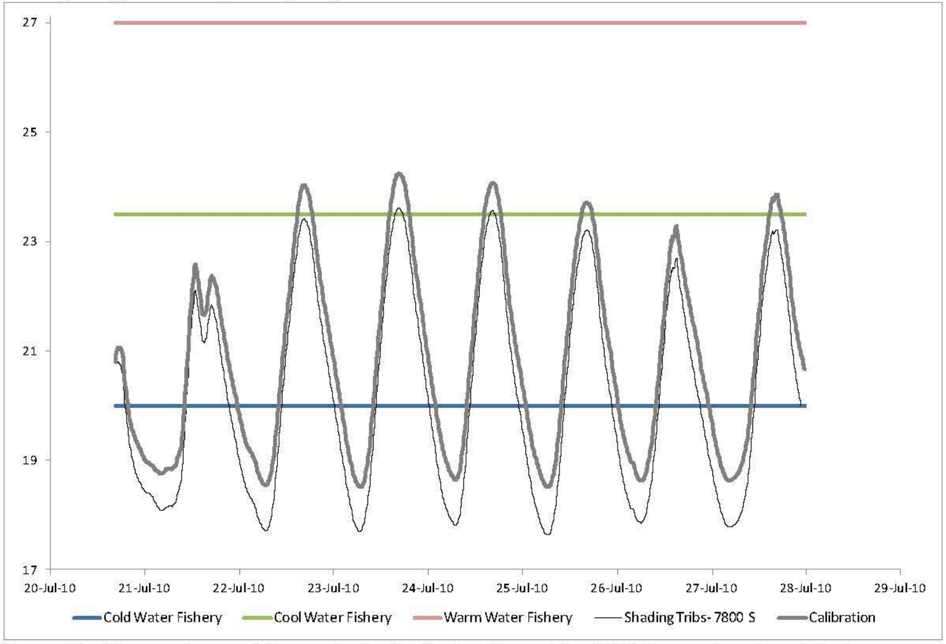

Figure 31. Temperature model scenario for the Jordan River at the 7800 S. crossing where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

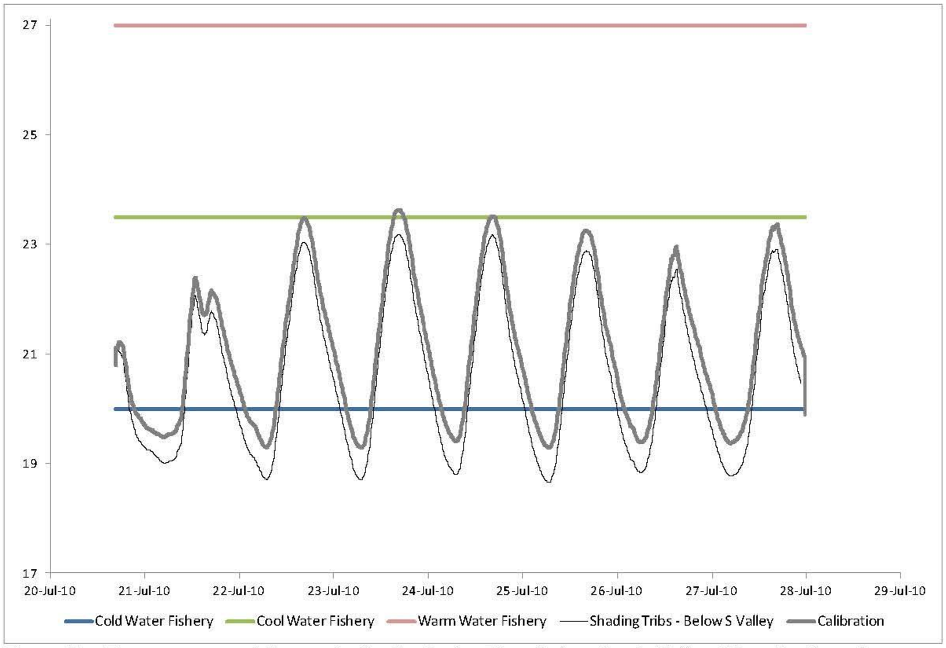

Figure 32. Temperature model scenario for the Jordan River below South Valley Water Reclamation Facility where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

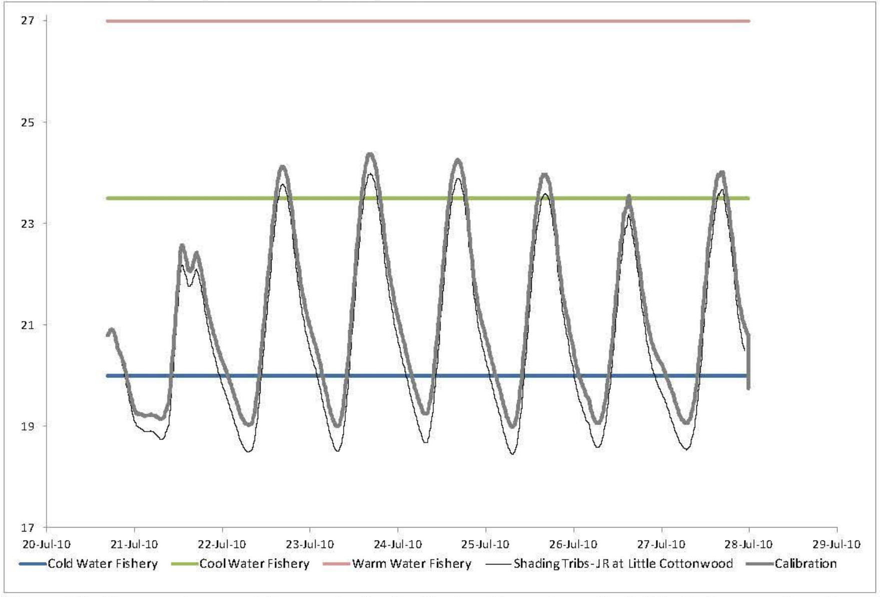

Figure 33. Temperature model scenario for the Jordan River above the Little Cottonwood confluence where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries, parking lots, etc.

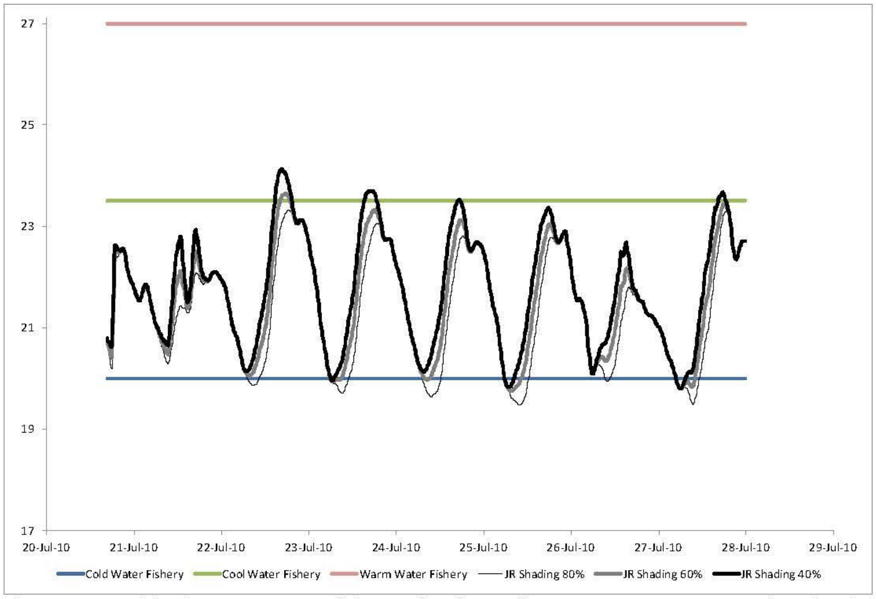

Figure 34. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above Rose Creek.

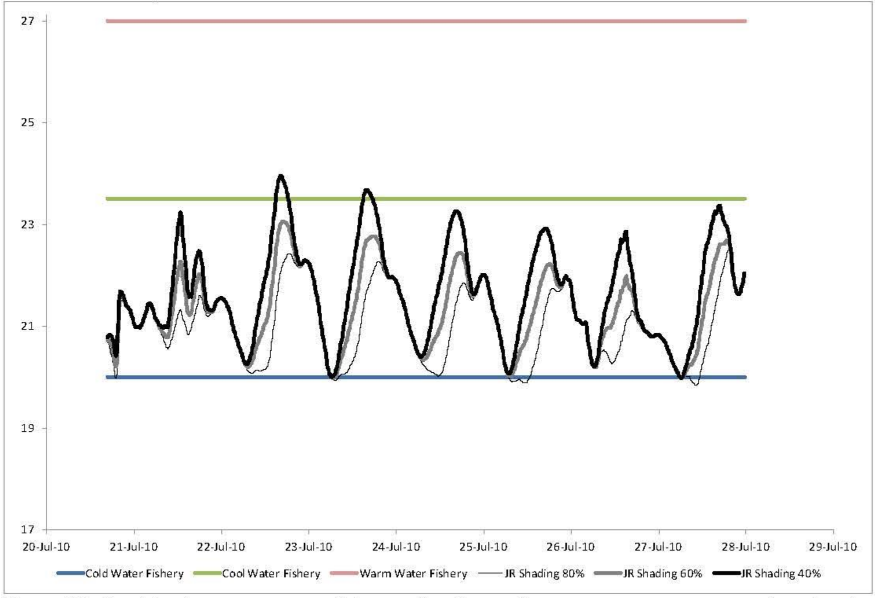

Figure 35. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributary and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures near Bangerter Highway.

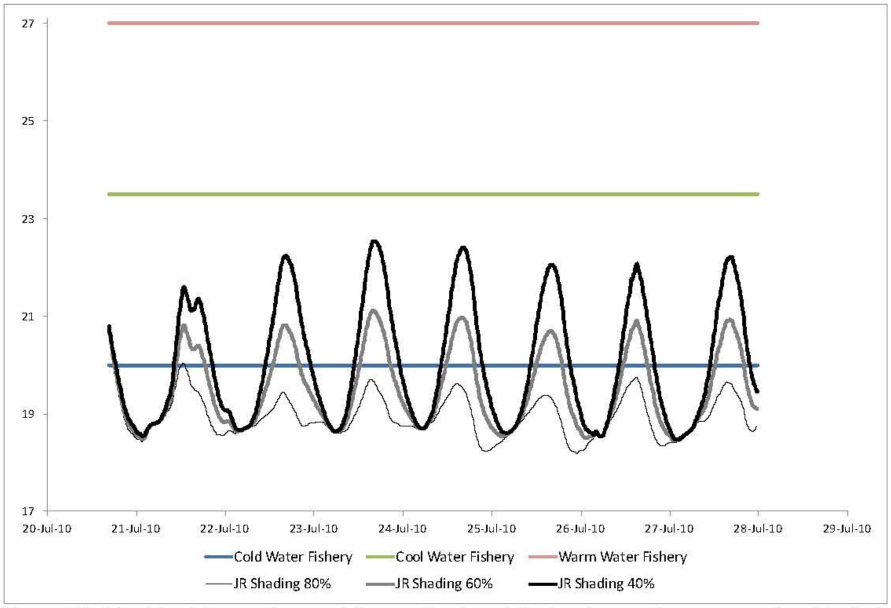

Figure 36. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above the North Jordan Canal diversion.

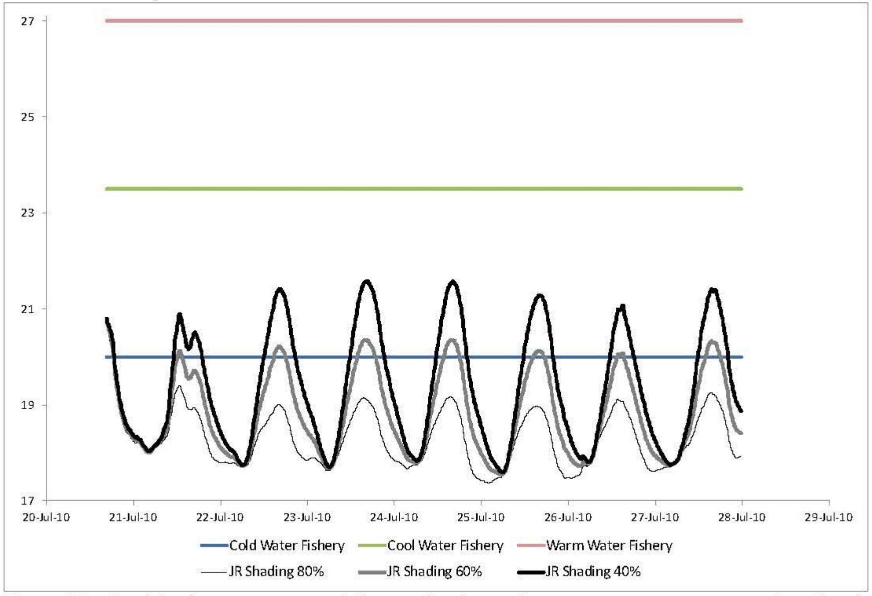

Figure 37. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures at 7800 S. crossing (Compliance point for Segments 5-7 for temperature).

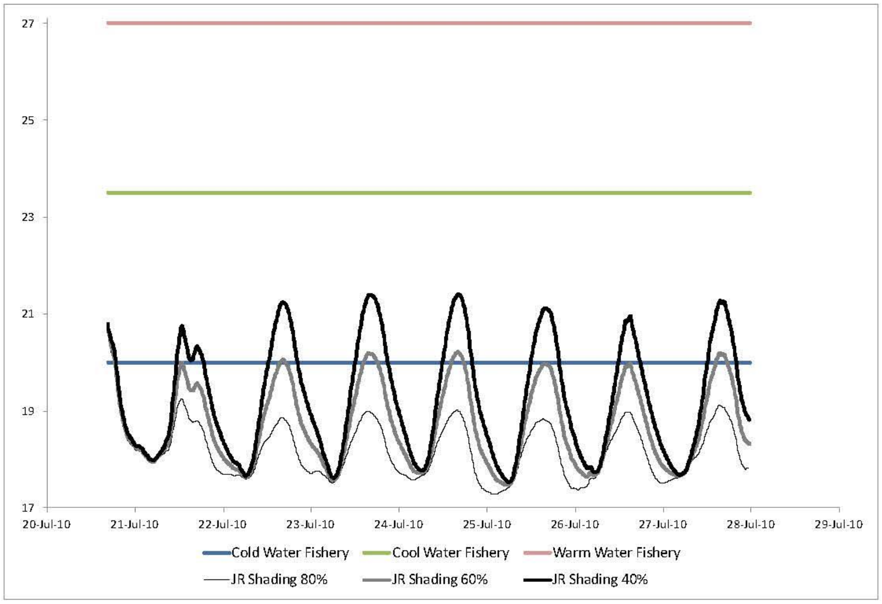

Figure 38. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures below South Valley Water Reclamation Facility.

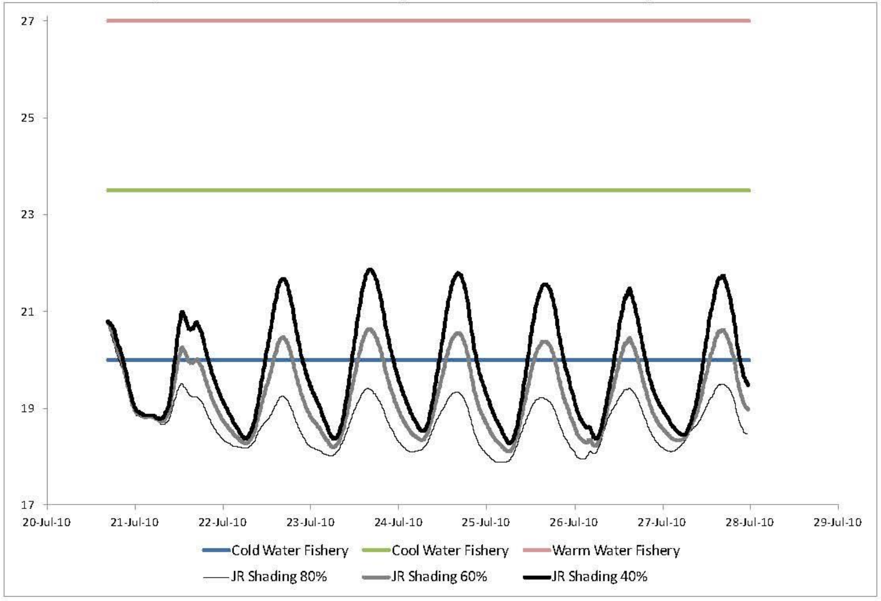

Figure 39. Combined temperature model scenario where tributary temperatures were reduced to that of Midas Creek to account for the possible effects of shading along tributaries and solar radiation values for the entire modeling section were reduced by 40, 60, and 80% to illustrate the possible effects of shading on Jordan River temperatures above the Little Cottonwood confluence (end of Segment 5).

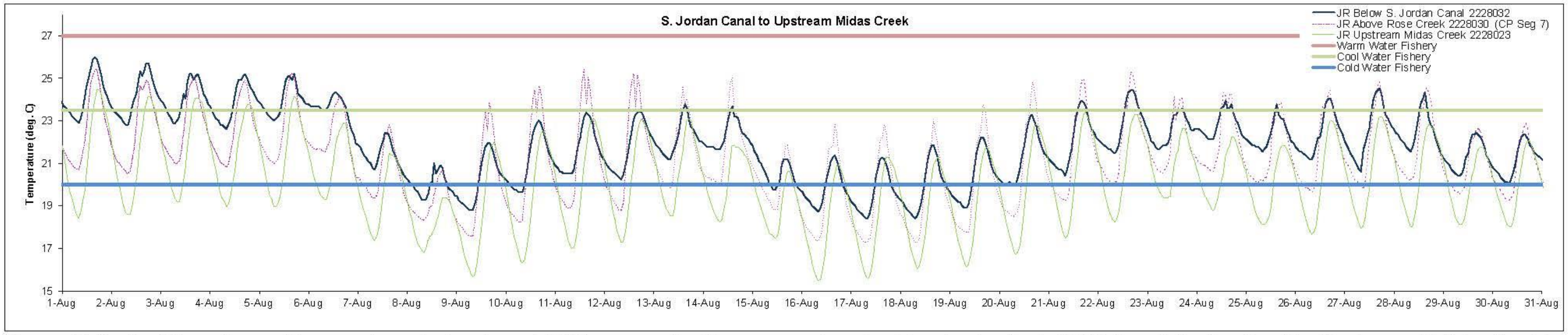

Figure 40. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR Below S. Jordan Canal to Upstream of Midas Creek).

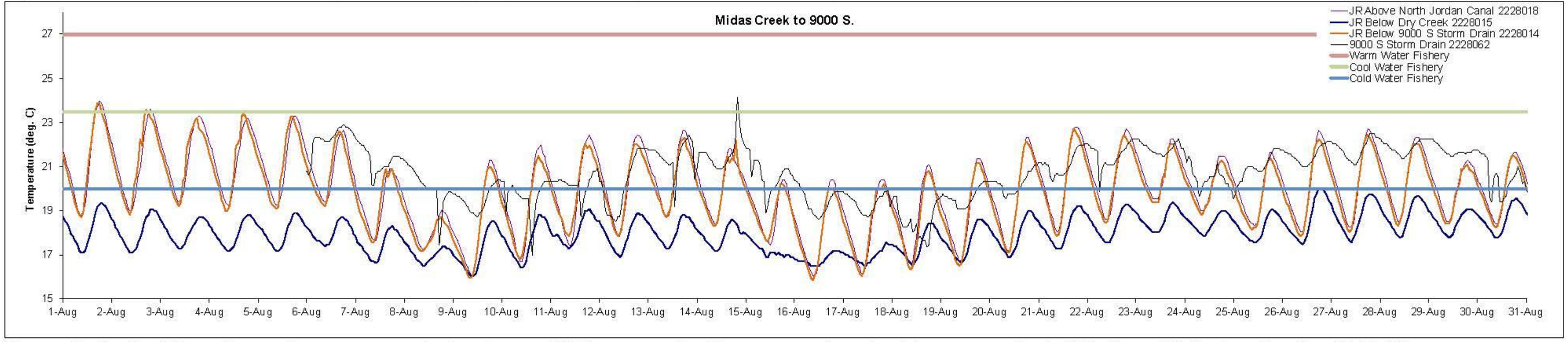

Figure 41. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR Above N. Jordan Canal to 9000 S.).

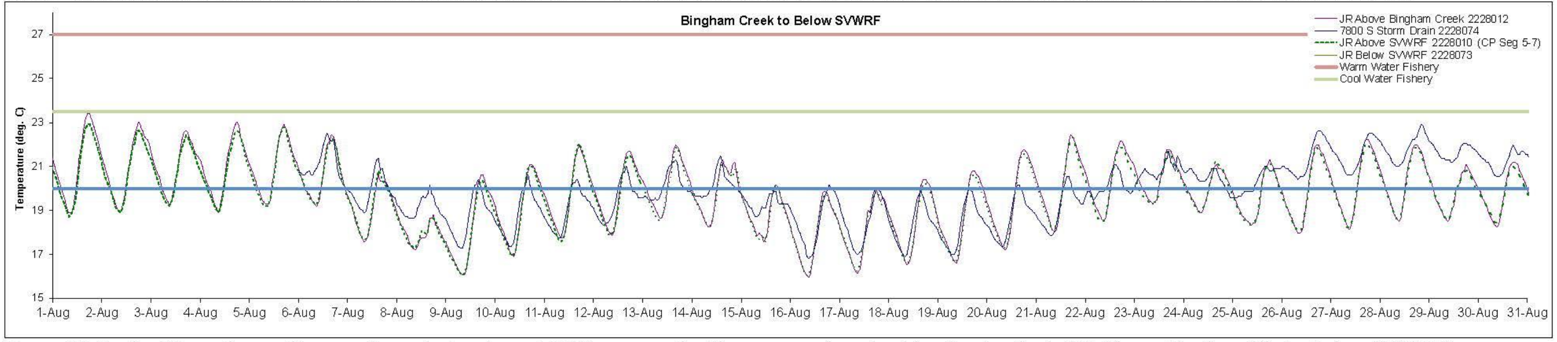

Figure 42. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR Above Bingham Ck. to Below SVWRF).

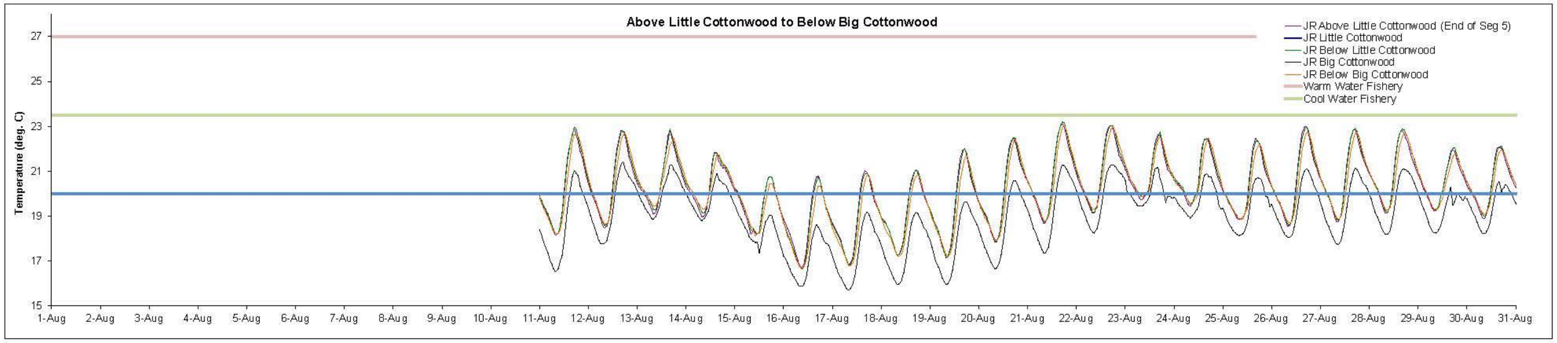

Figure 43. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR Above Little Cottonwood to Below Big Cottonwood).

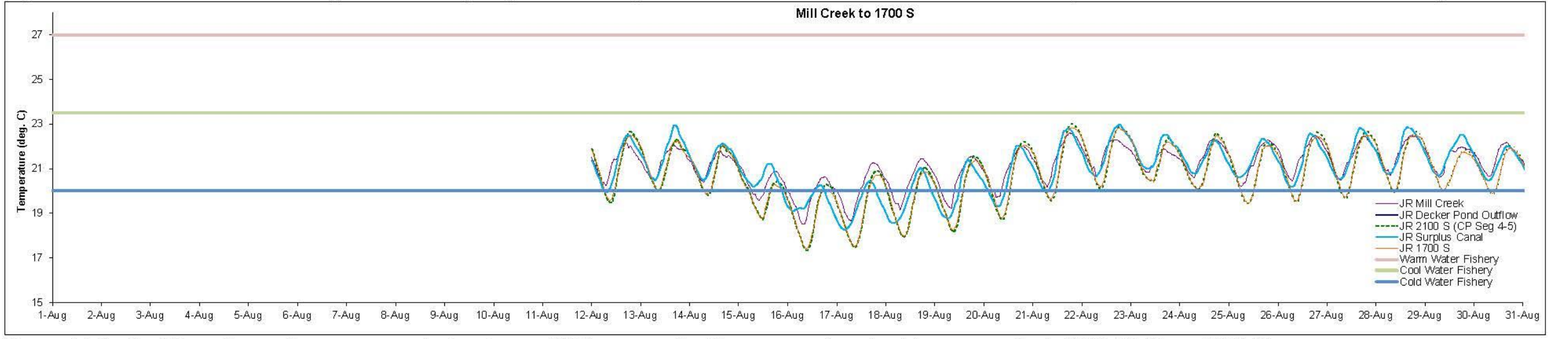

Figure 44. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR Mill Ck. to 1700 S).

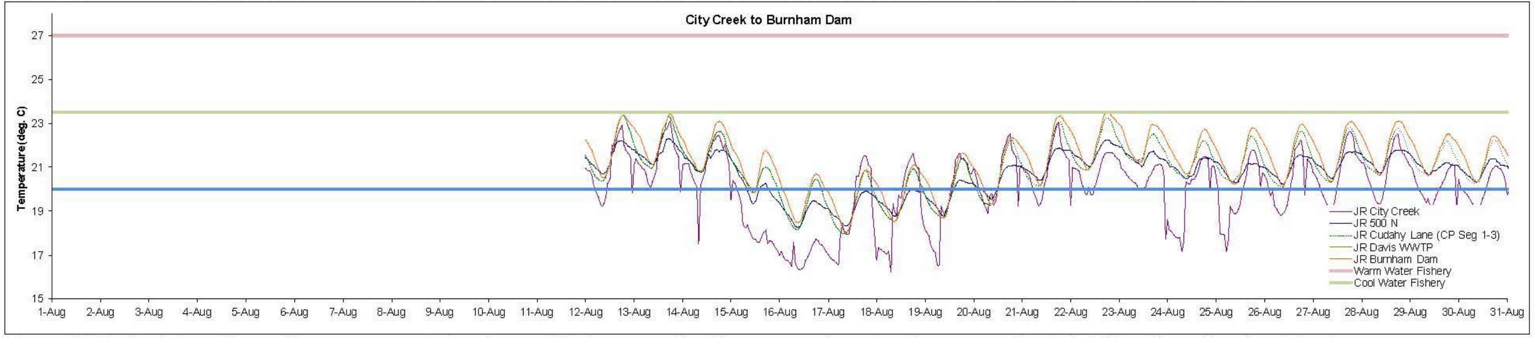

Figure 45. Jordan River observed temperatures during August 2009 compared with warm, cool, and cold water standards (JR City Ck. to Burnham Dam).

Table 6. Average August 2009 temperatures along Jordan River.

Location Along Jordan River	Average August 2009 Temperature (°C)
Below S. Jordan Canal	21.9
Above Rose Creek (CP Seg 7)	21.2
Upstream Midas Creek	20.1
Downstream Midas Creek	20.1
Above North Jordan Canal	20.0
Below Dry Creek	18.0
9000 South	20.8
Below 9000 S Storm Drain	19.9
Above Bingham Creek	19.7
Above South Valley	19.6
7800 South (CP Seg 7,6,5)	20.1
Above Little Cottonwood (End Seg 5)	20.3
Below Little Cottonwood	20.3
Below Big Cottonwood	20.2
2100 South (CP Seg 5, 4)	20.8
1700 South	20.8
500 North	20.8
Cudahy Lane (CP Seg 3-1)	21.1
Burnham Dam	21.5

Since the source of water for this portion of the Jordan River is a shallow and warm lake, the ability to meet a cold water standard at the compliance point for Segments 5-7 is unattainable without implementing impractical management strategies. Essentially, a significant amount of cooling of the water has to occur between Utah Lake and 7800 S. (~2° C based on Table 6, Below S. Jordan Canal to 7800 S). In looking at the monthly average, much of this cooling is occurring, however, as shown by the modeling, it is practically impossible to decrease the daily maximum temperatures. In looking at Figures 40 and 42, the observed maximum temperatures at JR Below S. Jordan Canal on August 1, 2009 was 26 °C and would need to cool to the 20°C standard which is an extra 3°C lower than those temperatures observed above South Valley WRF. Given the constraints associated with water rights, flood control, or influencing the water temperature coming from Utah Lake, these results suggest the need to revisit the beneficial use designation. Some options would include changing the entire river to a warm water fishery designation or establishing a site specific cool water standard at 23.5°C. Under a cool water designation the river would nearly be meeting the standard at the Segment 5-7 compliance point (Figure 31) and at most locations along the river (Figures 41-45). However, some of the upstream locations (JR Below S. Jordan Canal and JR above Rose Creek (the end of Segment 7)) are likely not meeting even the higher standard during the warmer, high irrigation demand months. In general, this type of site specific cool water standard would be more realistic in terms of supporting the Jordan River's potential given the source water and management constraints. If a cool water standard was applied to the entire stretch between Utah Lake and Great Salt Lake, the lower reaches would additionally be more protected since these segments are currently designated a warm water fishery.

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References

Brown, GW (1969), Predicting Temperatures of Small Streams, *Water Resources Research*. 5(1), 68–75.

Brown, GW (1970), Predicting the effect of clearcutting on stream temperature, *Journal of Soil and Water Conservation*, 25, 11–13.

Howes, Tony, (2009), Annual Ground and Surface Water Monitoring Report Sharon Steel OU1 Superfund Site. Utah Department of Environmental Quality Division of Environmental Response and Remediation. Midvale City, Utah.

Johnson, S.L. (2004), Factors influencing stream temperature in small streams: substrate effects and a shading experiment, *Canadian Journal of Fisheries and Aquatic Sciences,* 61: 913–923.

Loheide, S. P., and S. M. Gorelick (2006), Quantifying stream aquifer interactions through the analysis of remotely sensed thermographic profiles in in situ temperature histories, *Environ. Sci. Technol.*, 40(10), 3336–3341, doi:10.1021/es0522074.

Neilson, B. T., D. K. Stevens, S. C. Chapra, and C. Bandaragoda (2009), Data collection methodology for dynamic temperature model testing and corroboration, *Hydrological Processes*, 23, 2902–2914, doi:10.1002/hyp.7381.

Neilson, B.T., S.C. Chapra, D. K. Stevens, C. Bandaragoda. 2010a. "Two-zone Transient Storage Zone Modeling Using Temperature and Solute Data with Multi-Objective Calibration: Part 1 –Temperature" *Water Resources Research*, 46, W12520. doi:10.1029/2009WR008756.

Neilson, B.T., D. K. Stevens, S.C. Chapra, C. Bandaragoda. 2010b. "Two-zone Transient Storage Zone Modeling Using Temperature and Solute Data with Multi-Objective Calibration: Part 2 – Temperature and Solute" *Water Resources Research*, 46, W12521, doi:10.1029/2009WR008759.

Pelletier, G. J., Chapra, S. C., and Tao, H. (2006), QUAL2Kw - A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. *Environmental Modelling & Software*, 21(3), 419-425.

Stantec Consulting (2010), Jordan River TMDL: 2010 QUAL2Kw Model Calibration Technical Memo PUBLIC DRAFT. Utah Department of Environmental Quality, Division of Water Quality. Salt Lake City, UT.

URS Corporation, (2010), Midvale Slag Superfund Site Groundwater Monitoring System Midvale, Utah WA'03: Final Midvale Slag Superfund Site 2009 Annual Monitoring Report. Contract No. 086217. Salt Lake City, UT.