Assessment of Surface and Ground Water Exchange with a Thermal Infrared Airborne Survey and Streambed Monitoring: Carson River, Nevada

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Table of Contents

Introduction

Groundwater-surface water exchange in streams is of interest from a water budget perspective, as well as because of the influence groundwater can have on surface water quality. Groundwater upwelling can influence nutrient dynamics of a stream bed as well as the surface water thermal regime. The influence of groundwater on stream temperature can vary seasonally: groundwater seepage can cool stream temperature in summer and have a warming influence in winter. The upper reaches of the Carson River in Nevada are designated to support beneficial use as a coldwater fishery despite frequent exceedances during summer of temperature standards for cold water biota (Pahl 2008). This report assesses surface-groundwater interactions of the Carson River to promote a better understanding of how such dynamics may influence the River's thermal regime.

Time-series measurements of surface and bed temperatures can serve as a tool for identifying gaining or losing reaches of streams (Silliman and Booth 1993). Temperature fluctuations over daily and longer time scales have been analyzed with groundwater elevation data to estimate streamflow gains and losses (Constantz and Stonestrom 2003). Thermal measurements when combined with numerical simulation of heat transport can provide the basis for estimates of water flux in systems ranging from simple to complex (Constantz 2008). Although temperature logging in a stream bed involves relatively simple equipment, coverage is typically limited to discrete points, and a broad view of conditions can be equipment and labor intensive.

Airborne thermal surveys provide a synoptic view of stream temperature conditions over distances of tens of kilometers. Airborne thermal sensing typically only records a snapshot in time of conditions. However, the broad spatial coverage of an airborne survey can provide a means to identify areas of stream channel where groundwater influence may be significant (Torgersen et al. 2001). An airborne survey based on thermal infrared (TIR) remote sensing was conducted during August 2006 in the Carson River basin, Nevada. (Watershed Sciences 2006, Brock 2011). The survey covered 79 miles of the mainstem Carson River and tributaries, including the Carson River's East Fork, West Fork, and Brockliss Slough.

Exchange between groundwater and surface water in the Carson River is a source of considerable uncertainty in the Carson River Basin water budget (Maurer et al. 2006). Streambed temperature data were used by Maurer et al. (2006) to identify the distribution of gaining and losing reaches on the Carson as well as to estimate rates of seepage and infiltration (Figure 4). In their conclusions, Maurer et al. emphasize the point nature of their temperature measurements, suggesting that spatial generalizations beyond their specific study sites be made cautiously.

Airborne TIR provides an efficient screening tool for identifying the thermal signature of surface water over a broad geographic area. The objective of the research reported here was to determine the extent to which the remote sensing results can aid in identifying zones of exchange as measured on the ground with thermal profiling probes and piezometers. The study's intent was to assess groundwater exchange using point-based analytical techniques and compare these ground-based findings with apparent zones of groundwater influence identified by means of the airborne imagery.

This report presents results of the temperature monitoring in the streambed of the East and West Forks of the Carson River. Results of measurements of hydraulic gradient collected with mini-piezometers are described elsewhere (Brock, in preparation).

Background on Qualitative Thermal Responses to Direction of Seepage Flux

A stream segment with water flowing from the bed into the surface water is called a "gaining" stream and conversely, a reach that leaks water from its channel into the ground is "losing." Here we use the term "seepage" to indicate flow across the water-sediment interface, with positive seepage flux occurring in gaining stream reaches. Losing reaches have a negative seepage flux and are considered downwelling (Figure 1).

In temperate climates significant thermal gradients can develop over the course of a 24-hr day in a stream bed. The direction and magnitude of seepage flux influences the vertical thermal profile in the bed (Figure 1). During summer, the sediment in gaining reaches can be markedly cooler than in the water column due to strong control by advection from groundwater. Strong positive seepage flux can lead to minimal variation through time (Figure 2). Diel (24-hour) fluctuations of temperature in the surface water are reflected downward into the sediment of streams with negative seepage flux. The diel oscillation of temperature in such losing streams becomes attenuated with depth and can have a lag in phase resulting from travel time from the surface. This phase lag is influenced by the seepage rate. In the case of a neutral reach with zero seepage flux, the temperature in the sediment will be driven by conduction, and will vary as the temperature of the sediment surface varies. Comparison of time series of stream and sediment profile temperatures can identify zones of exchange between groundwater and surface water (Silliman and Booth 1993).

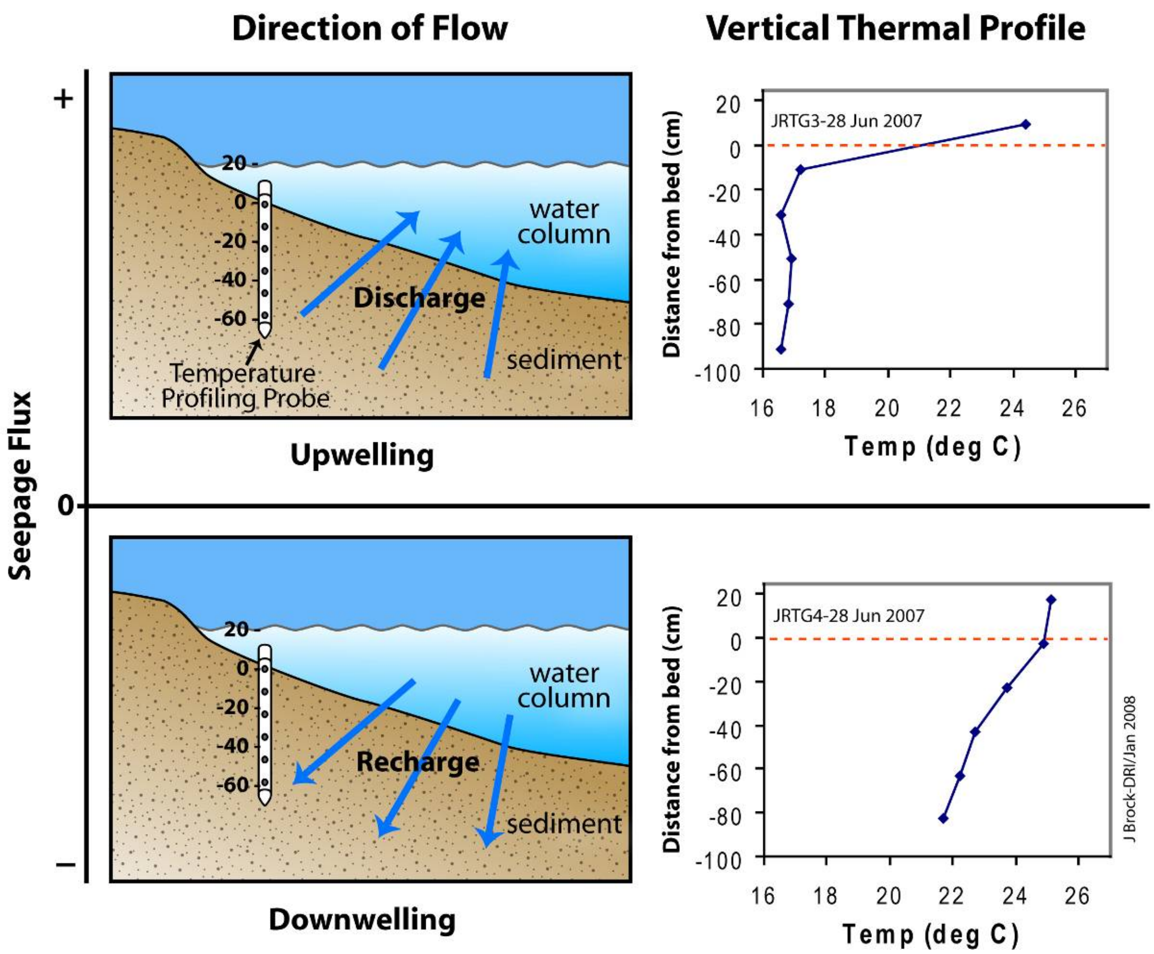


Figure 1. Direction of flow between sediments and water column in a stream and the vertical thermal profile as monitored with a temperature profiling probe. Data from the Truckee River illustrates the thermal signatures with depth of upwelling and downwelling zones. In the lower right panel, there is a gradual reduction in temperature with depth in the bed down to 21.8°C at -82 cm, suggestive of surface water flow downwards into the bed. In the top right panel, the bed temperature at the deepest point measured (93 cm) was 16.8°C. Relatively cool thermal conditions (~17°C) were observed throughout the bed nearly up to the surface, suggesting upwelling conditions.

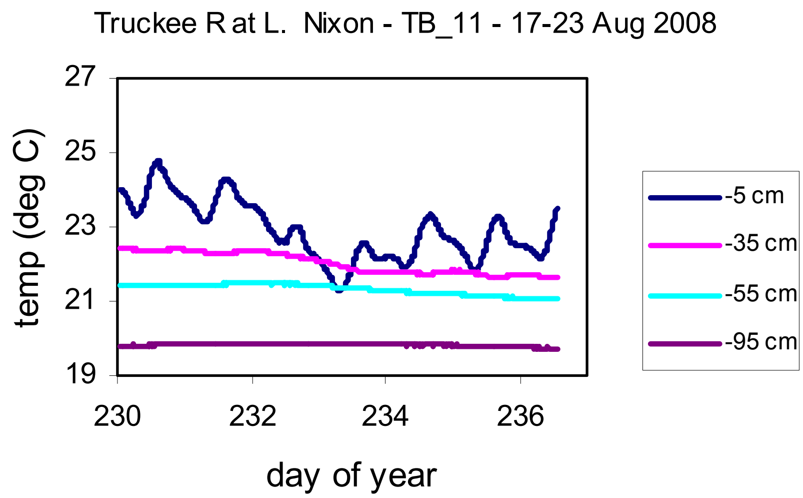


Figure 2. Temperature of Truckee River bed in an area in an upwelling area, as suggested by the relatively constant conditions through time at greater depths. Values in legend represent depth from surface of bed.

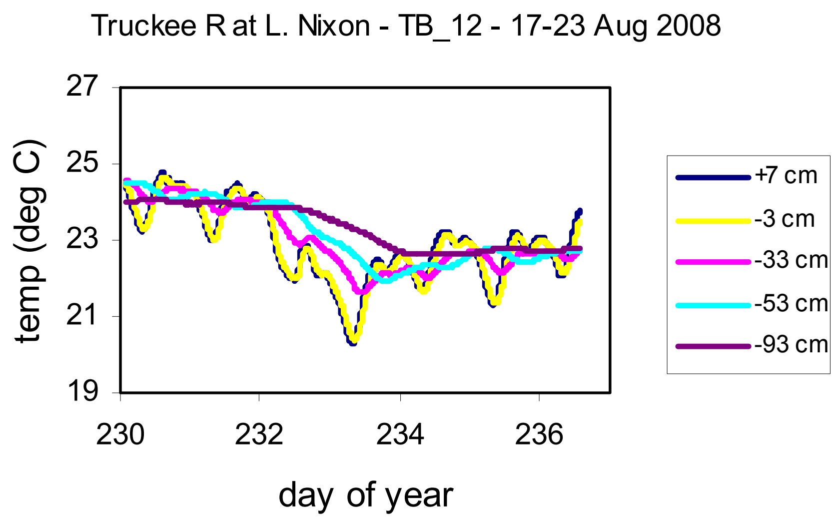


Figure 3. Temperature of Truckee River bed in an area in which surface water is downwelling into the bed. Note how the amplitude of the diel termperature oscillation diminishes with depth and demonstrates a lag in phase.

Thermal Infrared Survey

Study Site and Methods

Sites were selected for this study based on results of the 2006 TIR survey, river geomorphology, interest for resource management/planning, and access. Overall, the TIR survey on the East Fork of the Carson River revealed an increasing trend in water temperature with distance, with 18° C measured on the surface at Stateline and warming to a peak of 24.6° C above Highway 88 (Figure 5). Several segments of the East Fork revealed distinct cooling signatures of 2-

3° C relative to the overall trend of increasing temperature (pink highlighted areas in Figure 5). Such areas of localized cooling on a longitudinal profile during summer can be indicative of groundwater upwelling of cooler water relative to surface. Areas of the East Fork with distinct cooling zones included downstream from Highway 88 and below Muller Lane. Maurer et al. (2005) classified their site below Muller Lane as a gaining stream (Figure 4). Ground-based temperature measurements of the water column during August 2006 in the reach above and below the irrigation diversion downstream from Muller Lane were reported by Brock (2011). Maurer et al. (2005) classified their ST-23 site west of Highway 88 as a neutral stream.

The lower reaches of the West Fork of the Carson River (downstream from Waterloo Lane) are comprised of remnant channels because most of the flow is diverted to the Brockiss Slough. Water flow in the lower portion of the West Fork is primarily surface runoff from precipitation and subsurface return flows from irrigation. The TIR survey revealed a cooling zone on the lower West Fork between 1.2 to -2.0 km from the mouth (Figure 9).

Two reaches were selected for the present study, which was conducted during March-May 2009.

a) East Fork between Highway 88 and confluence with the West Fork: (Figure 5 and Table 1). This 8-km reach of the East Fork Carson River flows through fields irrigated by an extensive gravity flow system with unlined ditch laterals (Figure 4). The pastures were actively grazed by cattle during spring 2009. A residential area of Minden, Nevada (Douglas County) borders the east bank of the Carson River west of Highway 88 between stations T370 and T380 (Figure 5). The airborne thermal survey (August 2009) of the East Fork Carson River between Highway 88 and Muller Lane had suggesting possible influence from groundwater. Observations of deteriorated surface water quality in this reach (low DO levels and high biomass of attached algae) supported the presumption that the reach may be gaining nutrient enriched groundwater (Pahl 2007).

b) West Fork Carson River on the Nature Conservancy's River Fork Ranch: Facilitated access the River Fork Ranch enabled us to monitor thermal conditions in the bed of a 4-km reach of stream channel of the West Fork of the Carson River. During 2009 the River Fork Ranch property between Muller Lane and Genoa Lane was undergoing a restoration design study, thus providing ancillary data on floodplain hydrology **(**Graham Matthews and Associates and McBain and Trush. 2009)

The locations of the transects where temperature gradient measurements were made are shown in Figure 7 and Table 1.

Methods

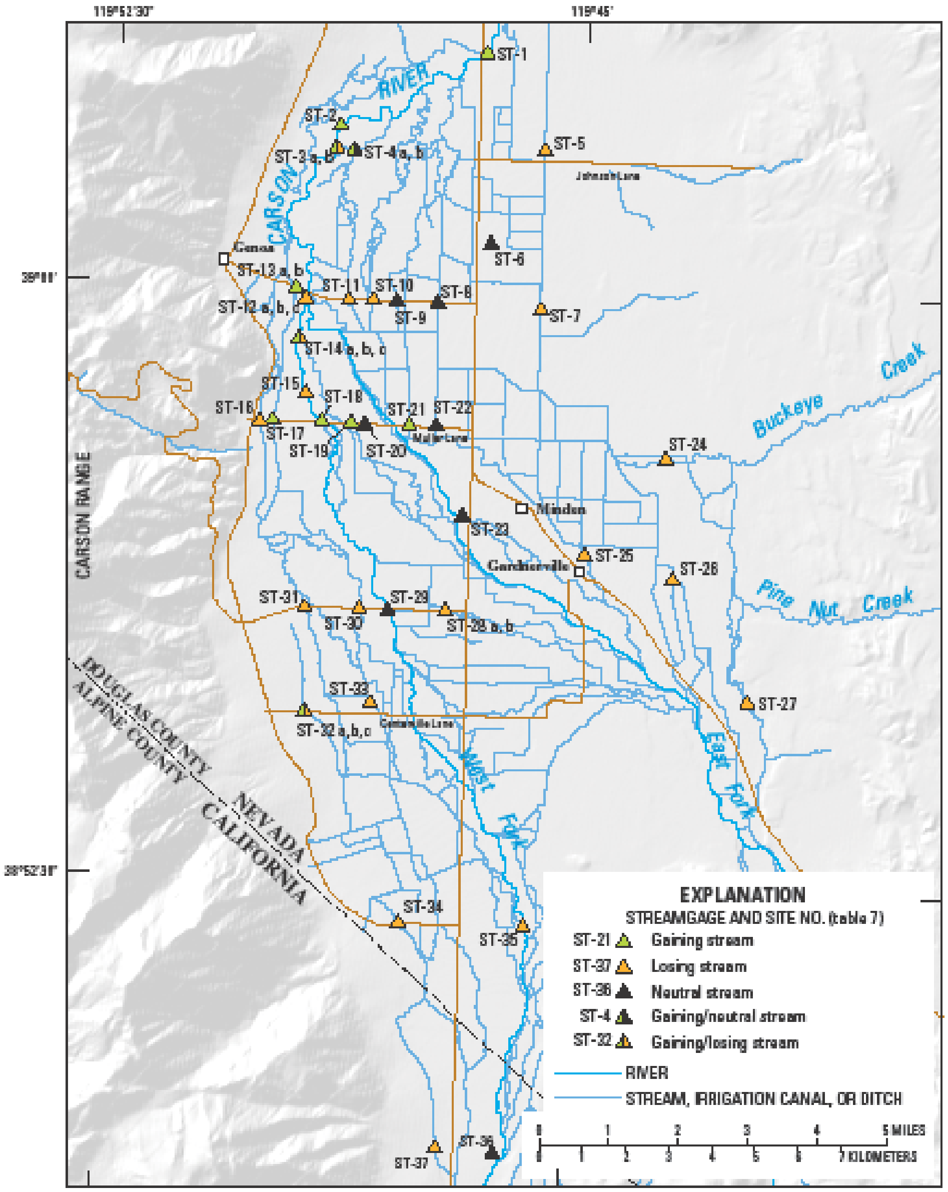
For the West Fork and East Fork reaches, 9-12 transect locations were selected on each for installation of thermal profiling probes. On the West Fork, transects were selected to correspond with staff gages installed for the restoration design study (Graham Matthews and Associates and McBain and Trush. 2009). The profiling probes were of stainless steel construction with a length of 100-cm and a diameter of 1.4 cm (Model L-100; Rapid Creek Research, Boise, ID). Each steel probe contained seven thermistors embedded in thermally-conductive epoxy at 0, 20, 30 40, 60, 80 and 100 cm. The probes were driven into the stream bed using a slide hammer (AMS, American Falls ID). In some cases a pilot hole was created using a hardened steel digging bar and post pounder. The probes were driven into the bed so that the sensor at 0 cm was 2-3 cm above the bed at the time of installation. The probe thermistors were negative temperature coefficient precision thermistors (± 0.1°C accuracy). Data loggers (Campbell CR10x and CR206) recorded temperature at 10-min intervals over 4-7 points in the vertical profile. Due to the mobile bed conditions and channel width on the East Fork, the CR206 data loggers were deployed in submersible enclosures (Model Caretta; Rapid Creek Research, Boise, ID). Coordinates of the locations in the stream bed were determined with a GPS Map 765 (Garmin Instruments, Olathe, KS).

The surface temperature results of the airborne TIR survey were analyzed graphically for anomalies in the longitudinal profile indicative of groundwater influence. As the TIR survey was conducted during mid-summer (August 2006), segments of cooling relative to the generalized warming trend were interpreted to suggest areas with possible groundwater gains, as the groundwater tends to be cooler than surface water during the warm part of the day. A similar thermal profile method to identify potential ground-water discharge areas for long river reaches was employed by Vaccaro and Maloy (2006) in surveys of preferred salmonid habitats. They used a moving boat thermal survey method to locate groundwater discharge areas using deviations (e.g., stabilization, cooling or declining rate of change) of the longitudinal temperature profile.

The time series of temperature in the sediment and water column were examined graphically to evaluate whether the surface water location was gaining, losing, or neutral. Neutral sites with insignificant seepage flux were identified by oscillations over the diel period in the sediments that followed the fluctuations observed in the water column. When the thermal oscillations observed in the bed became attenuated with depth and included a phase lag, the thermal signature was interpreted to indicate downward seepage flux associated with a losing surface water location. Gaining reaches with positive seepage flux were identified with water column and sediment conditions that were markedly different, with sediments at depth relatively constant due to the influence of groundwater that tends to be constant temperature on a day-to-day basis. Although qualitative, this type curve analysis was considered suitable to meet the objectives of the present project, which was to use thermal profiling of the stream bed to identify areas and direction of seepage flux, but not to quantify actual rates of groundwater-surface water exchange.

From Maurer et al. 2005 USGS Scientific Investigations Report 2005-5288

4 ET Rates, Recharge from Precipitation, and Streamflow Gain and Loss, Carson Valley, Nevada and California



Base from U.S. Geological Survey digital data, 1:100,000, 1988
Universal Transverse Mercator projection, zone 11.
North American Datum of 1983 (NAD 83).
Shaded-relief from 30-meter Digital Elevation Model. Datum is NAD 83.
Sun illumination from northwest at 30 degrees above horizon.

Figure 15. Location of streambed temperature sites and gaining, losing, or neutral conditions at 37 sites in Carson Valley, Nevada and California.

Figure 4. Location of stream bed temperature sites in Carson Valley. Figure 15 from Maurer et al 2005.

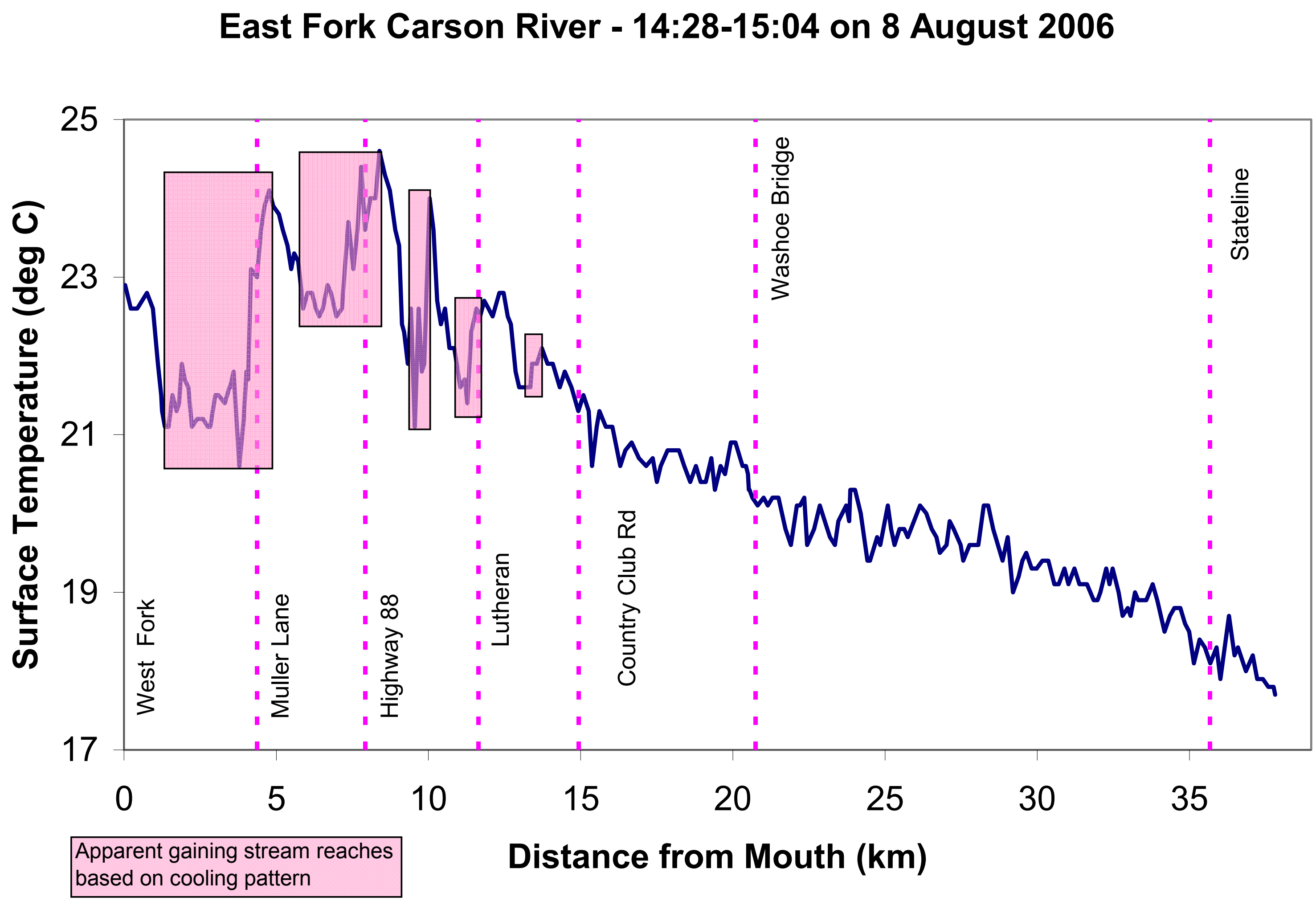


Figure 5. Longitudinal profile of surface temperature for 8 August 2006 on the East Fork of Carson River from the California-Nevada Stateline to confluence with the West Fork Carson River. The apparent gaining stream reaches are highlighted in pink. (Data Source: Watershed Sciences 2006).

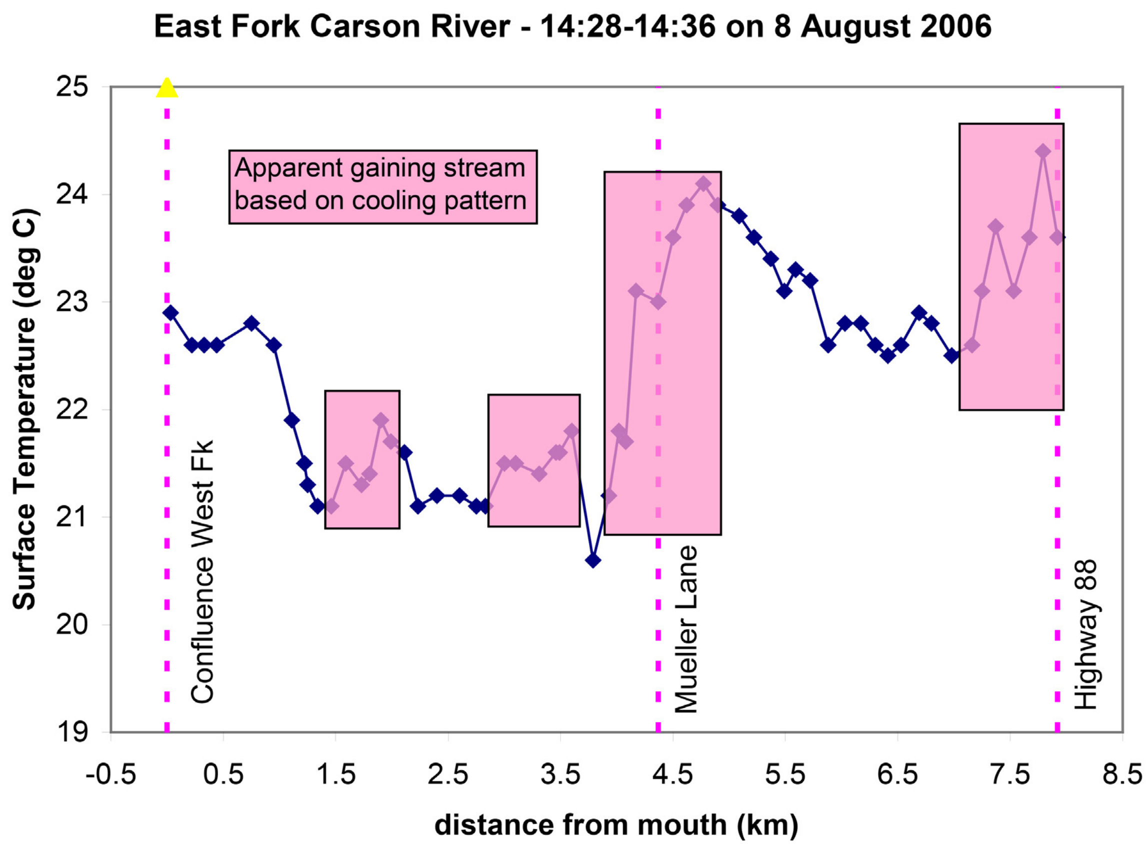


Figure 6. Longitudinal profile of surface temperature for 8 August 2006 on the East Fork of Carson River from Highway 88 to confluence with the West Fork Carson River. The apparent gaining stream reaches are highlighted in pink. (Data Source: Watershed Sciences 2006).

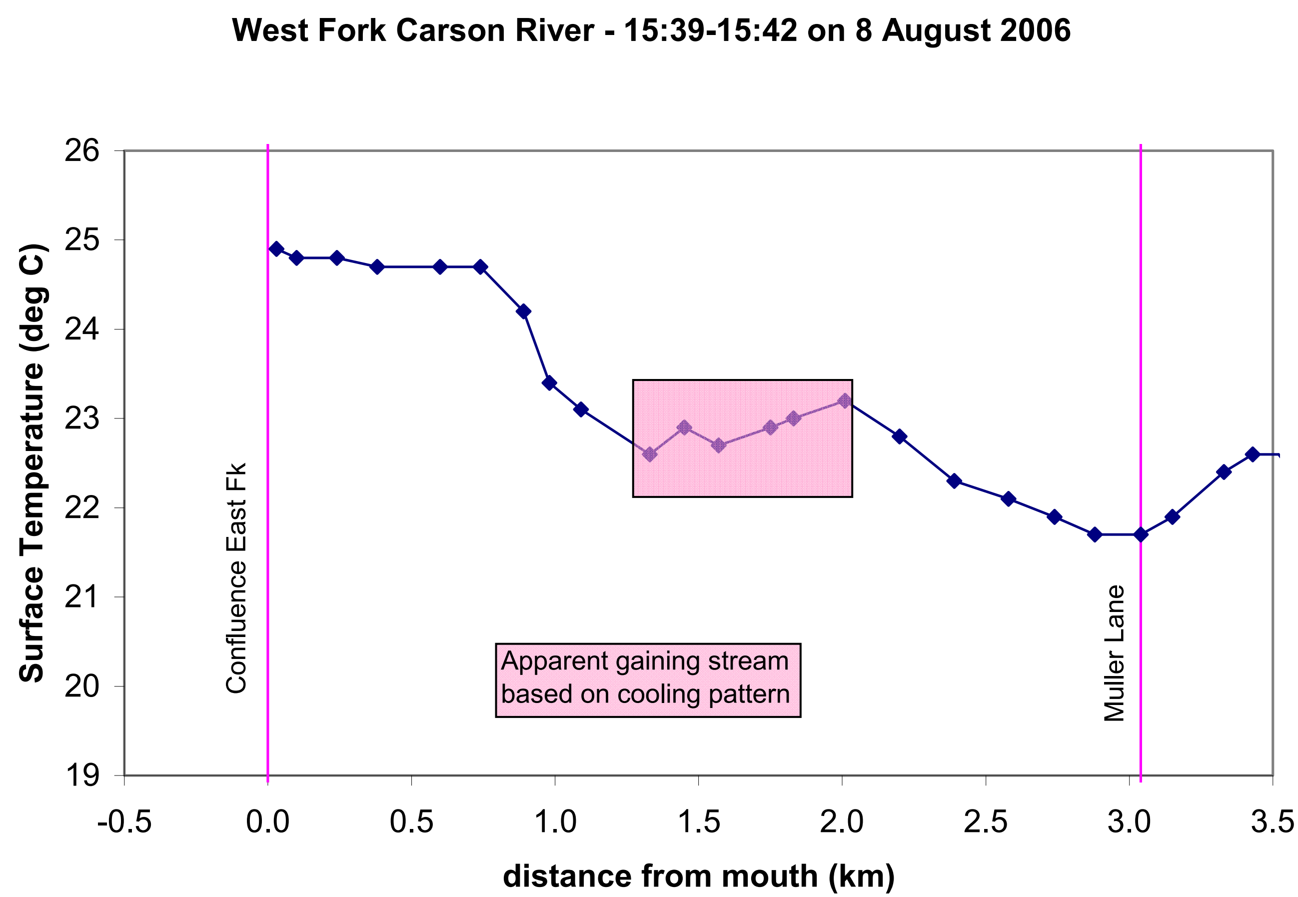


Figure 7. Longitudinal profile of surface temperature for 8 August 2006 on the West Fork of Carson River from Muller Lane to confluence with the East Fork Carson River. The apparent gaining stream reaches are highlighted in pink. (Data Source: Watershed Sciences 2006).

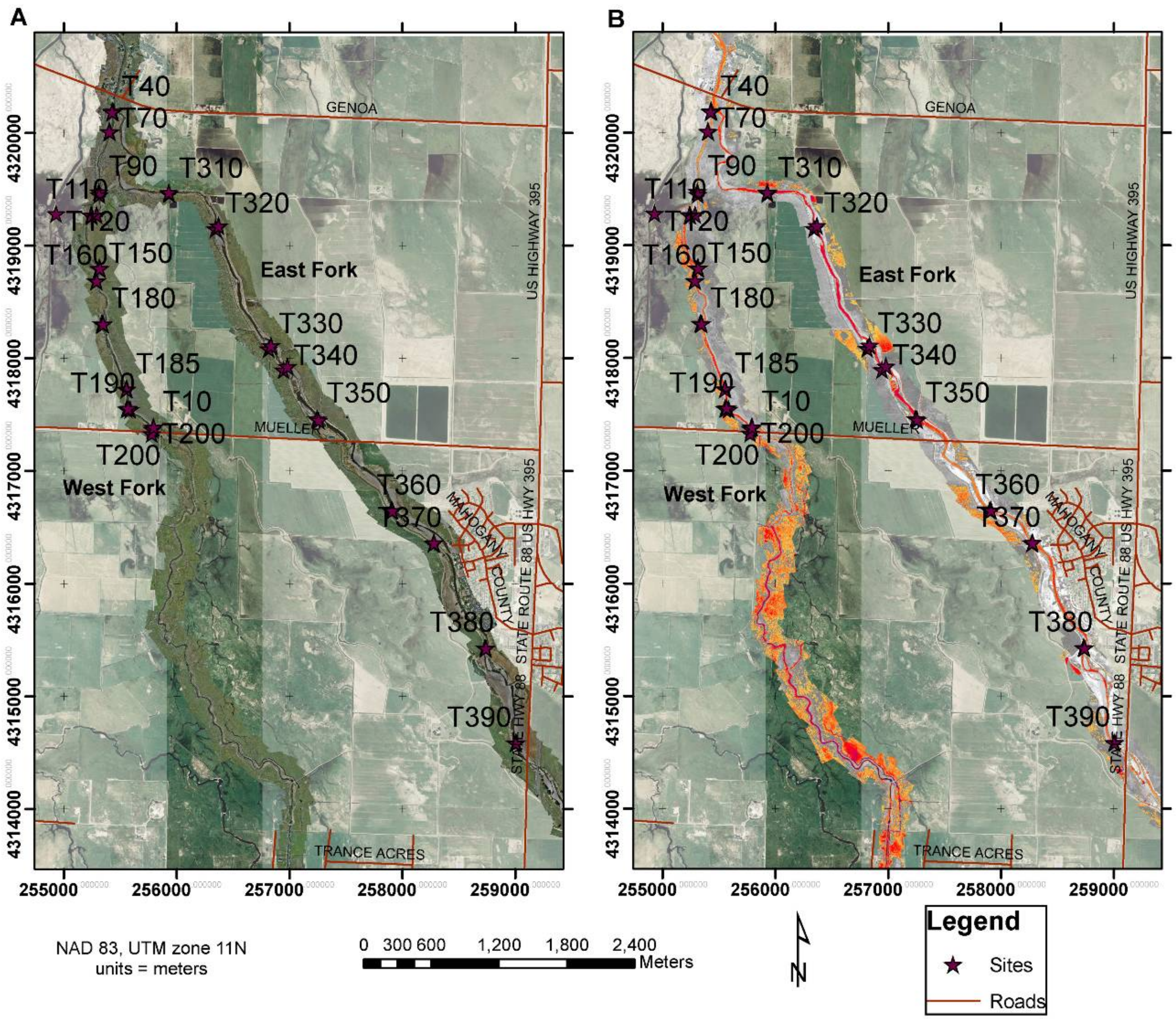


Figure 8. Location of stream bed temperature measurement sites on the East Fork and West Fork of Carson River.

Table 1. Coordinates of transects on East Fork Carson River (EFCR) and West Fork Carson River (WFCR) for bed temperature profile measurements March-June 2009. Coordinates referenced to NAD83. Rkm represents distance from mouth in kilometers.

Location	Date	Transect	Time	Station	N Latitude	W Longitude	Rkm
EFCR	1-Apr-09	T310	16:22	BM	38.99013	-119.81799	1.34
EFCR	1-Apr-09	T320	15:56	BM	38.98745	-119.81313	1.99
EFCR	1-Apr-09	T330	15:35	BM	38.97797	-119.8073	3.31
EFCR	1-Apr-09	T340	15:11	BM	38.97633	-119.80572	3.46
EFCR	1-Apr-09	T350	14:44	BM	38.97252	-119.80216	4.02
EFCR	1-Apr-09	T360	14:16	BM	38.96536	-119.7943	5.09
EFCR	1-Apr-09	T370	13:50	BM	38.96286	-119.78986	5.59
EFCR	1-Apr-09	T380	13:02	BM	38.95463	-119.78427	6.69
EFCR	1-Apr-09	T390	12:10	BM	38.94712	-119.78078	7.67
WFCR	19-Mar-09	T40	12:50	top fence post	38.99655	-119.82397	0.03
WFCR	18-Mar-09	T70	19:10	BM	38.99494	-119.8243	0.24
WFCR	18-Mar-09	T90	18:10	BM 11	38.99012	-119.82518	0.74
WFCR	19-Mar-09	T110	12:00	Bolt at SA12	38.98822	-119.82589	0.98
WFCR	18-Mar-09	T120	16:43	BM	38.98826	-119.8295	1.09
WFCR	18-Mar-09	T150	15:48	BM	38.98398	-119.82494	1.57
WFCR	18-Mar-09	T160	15:02		38.98298	-119.82518	1.75
WFCR	18-Mar-09	T180	13:48	BM	38.97956	-119.82447	2.01
WFCR	19-Mar-09	T185	14:46	BM	38.9744	-119.82176	2.58
WFCR	18-Mar-09	T190	12:40	BM	38.97284	-119.82166	2.74
WFCR	18-Mar-09	T200	11:45	BM	38.97902	-119.81902	3.00

Results

The study's transect locations were examined on the longitudinal temperature profiles for East and West Fork of the Carson River for August 2006. The thermal variation in space of the longitudinal profile in the vicinity of the transect was examined for evidence of groundwater influence. Examination of the longitudinal profile for the East Fork of the Carson (Figure 5 and Figure 6) demonstrates a localized (within a km) temperature variation of about ±1°. This variation lends a sawtooth-like appearance to the temperature trajectory for the East Fork which is less evident on the West Fork's temperature profile (Figure 7). Results of these observations are presented in Table 2. Only segments with downgradient cooling trends of 0.5 km or more were considered to be gaining.

Table 2. Streambed temperature sites and gaining conditions based on airborne thermal survey of August 2006. See Figures 8 and 9.

East Fork Carson River			West Fork Carson River		
Transect	**km**	**Type**	**Transect**	**km**	**Type**
T310	1.34		T40	0.03	
T320	1.99		T70	0.24	
T330	3.31	gaining	T90	0.74	
T340	3.46	gaining	T110	0.98	
T350	4.02	gaining	T120	1.09	
T360	5.09		T150	1.57	gaining
T370	5.59		T160	1.75	gaining
T380	6.69	losing-neutral	T180	2.01	gaining
T390	7.67	gaining	T185	2.58	
			T190	2.74	
			T200	3.00	

Of the 20 transects that were established, 13 yielded time series data sufficiently complete to be suitable for analysis. Time series plots of water column and bed temperature collected on the Carson River are presented in Figures 9-22. The thermal plots were analyzed for traits characteristic of upwelling (gaining) and downwelling (losing) relative to surface water. Table 3 summarizes results of this analysis, and includes features for temperature profiles of generalized gaining, losing, and neutral locations (see introductory section "Background on Qualitative Thermal Responses to Direction of Seepage Flux").

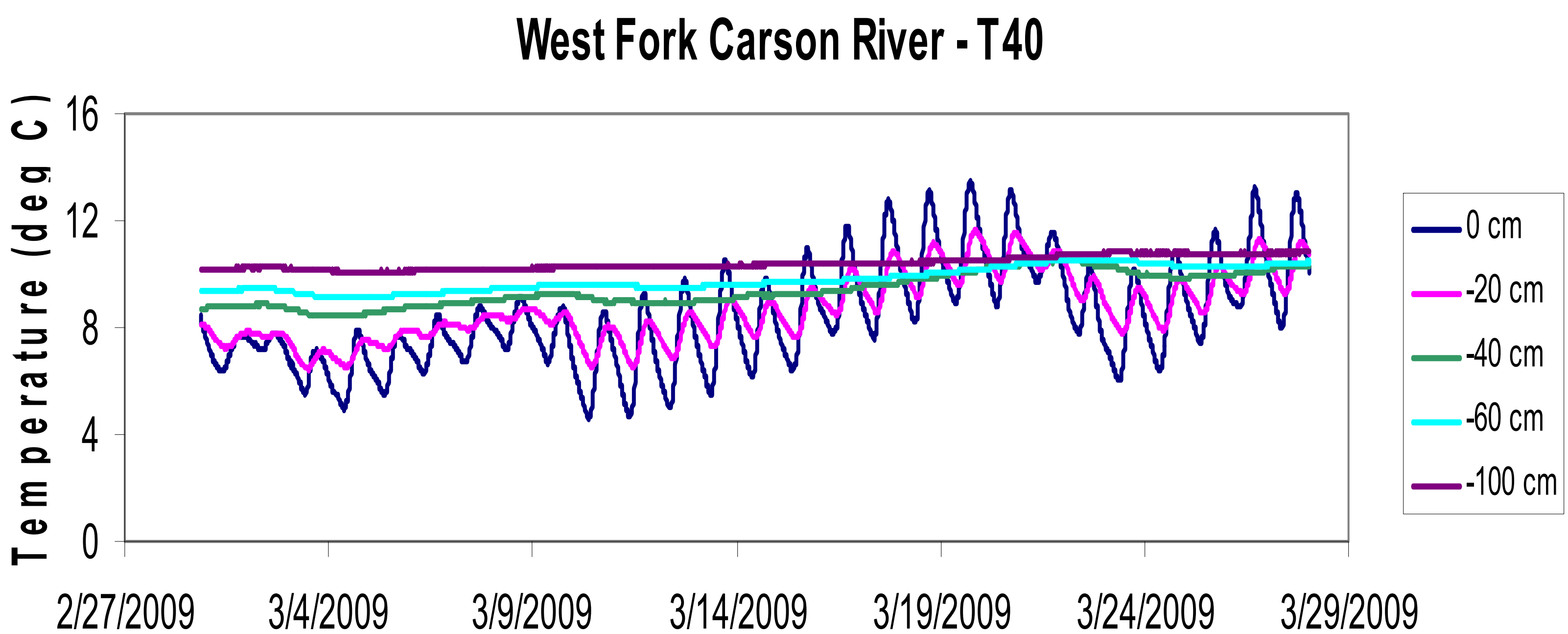


Figure 9. Vertical thermal profile of West Fork of Carson River at Site T40 during 28 February-28 March 2009.

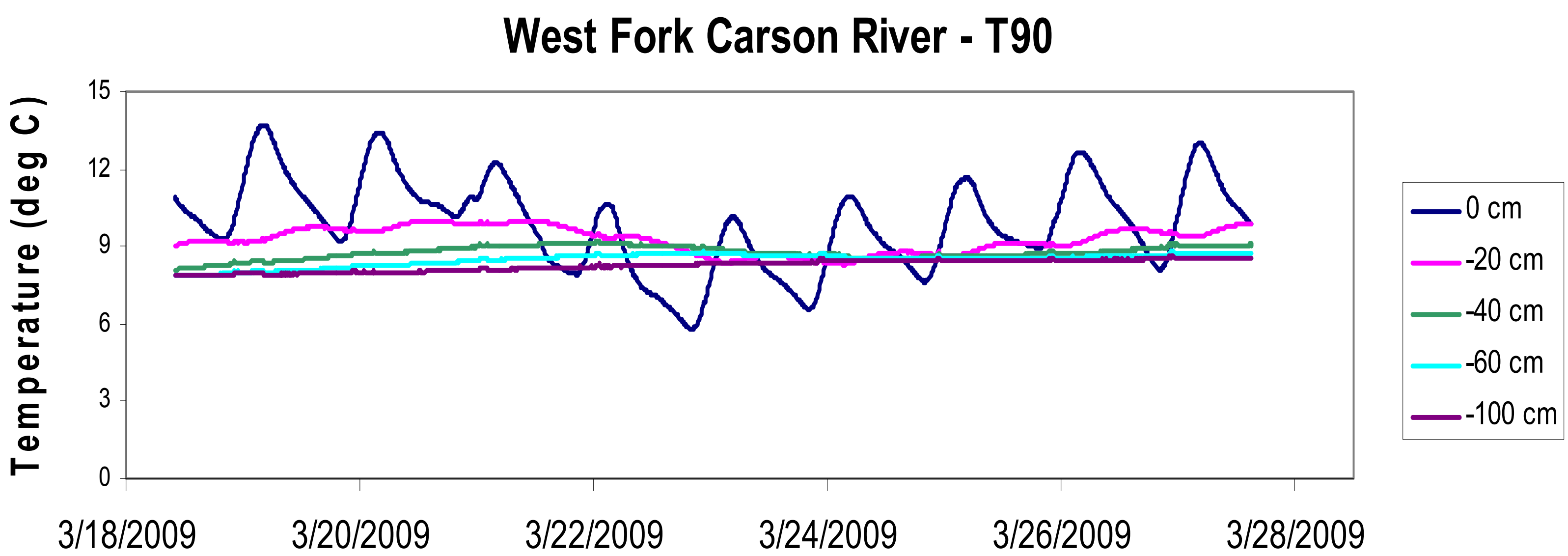


Figure 10. Vertical thermal profile of West Fork of Carson River at Site T90 during 18-28 March 2009.

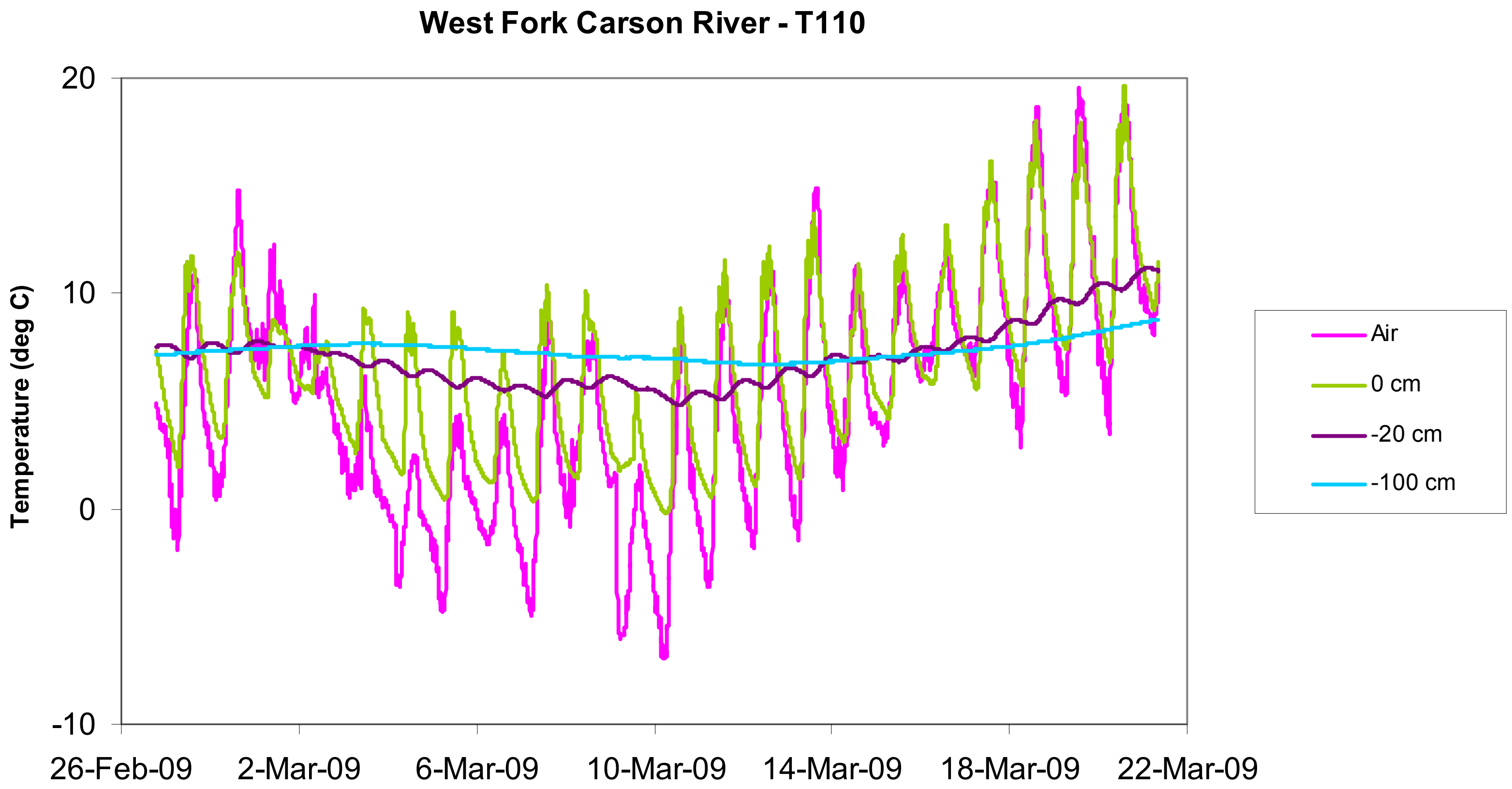


Figure 11. Vertical thermal profile of West Fork of Carson River at Site T110 during 28 February-21 March 2009.

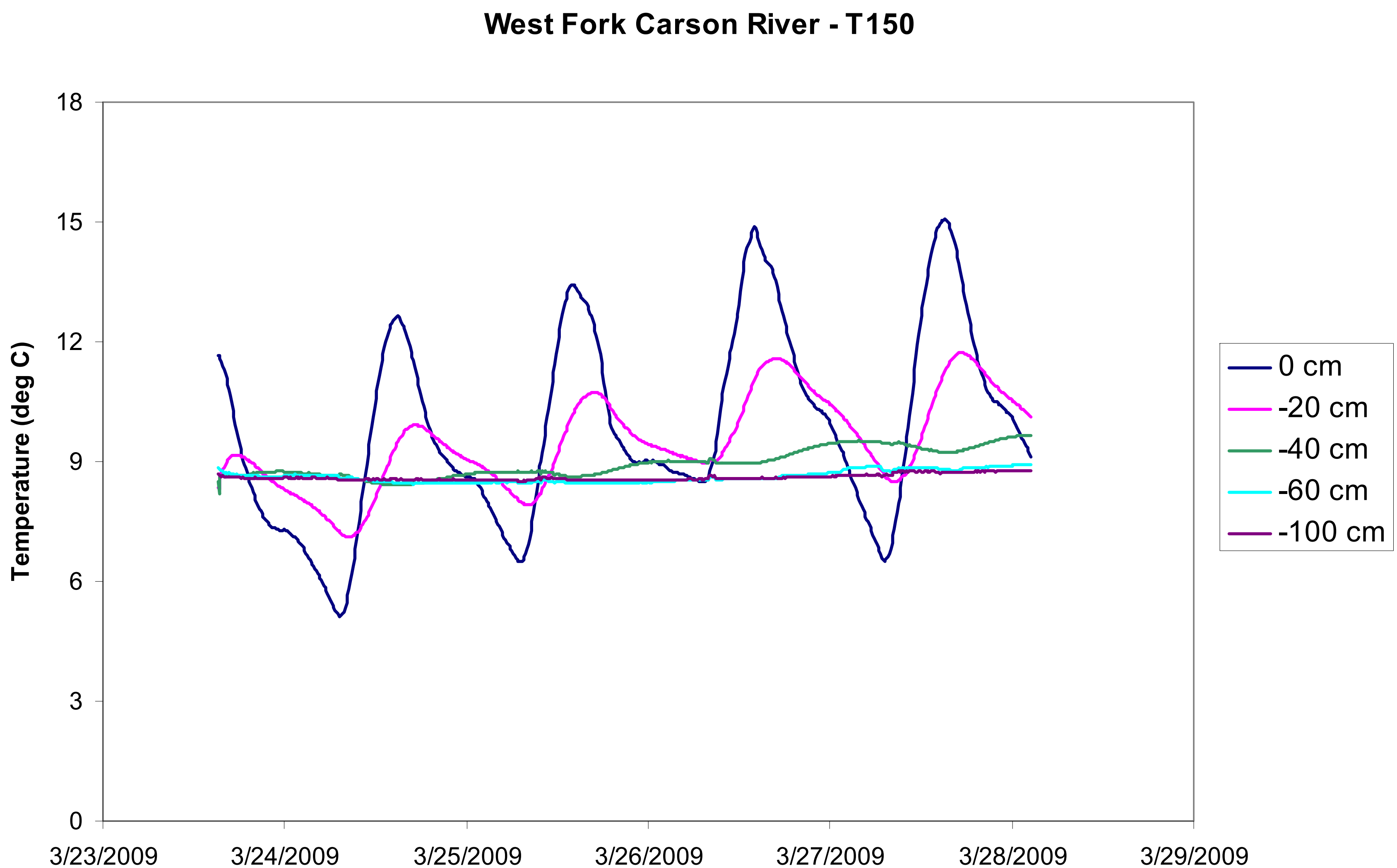


Figure 12. Vertical thermal profile of West Fork of Carson River at Site T150 during 23 February-28 March 2009.

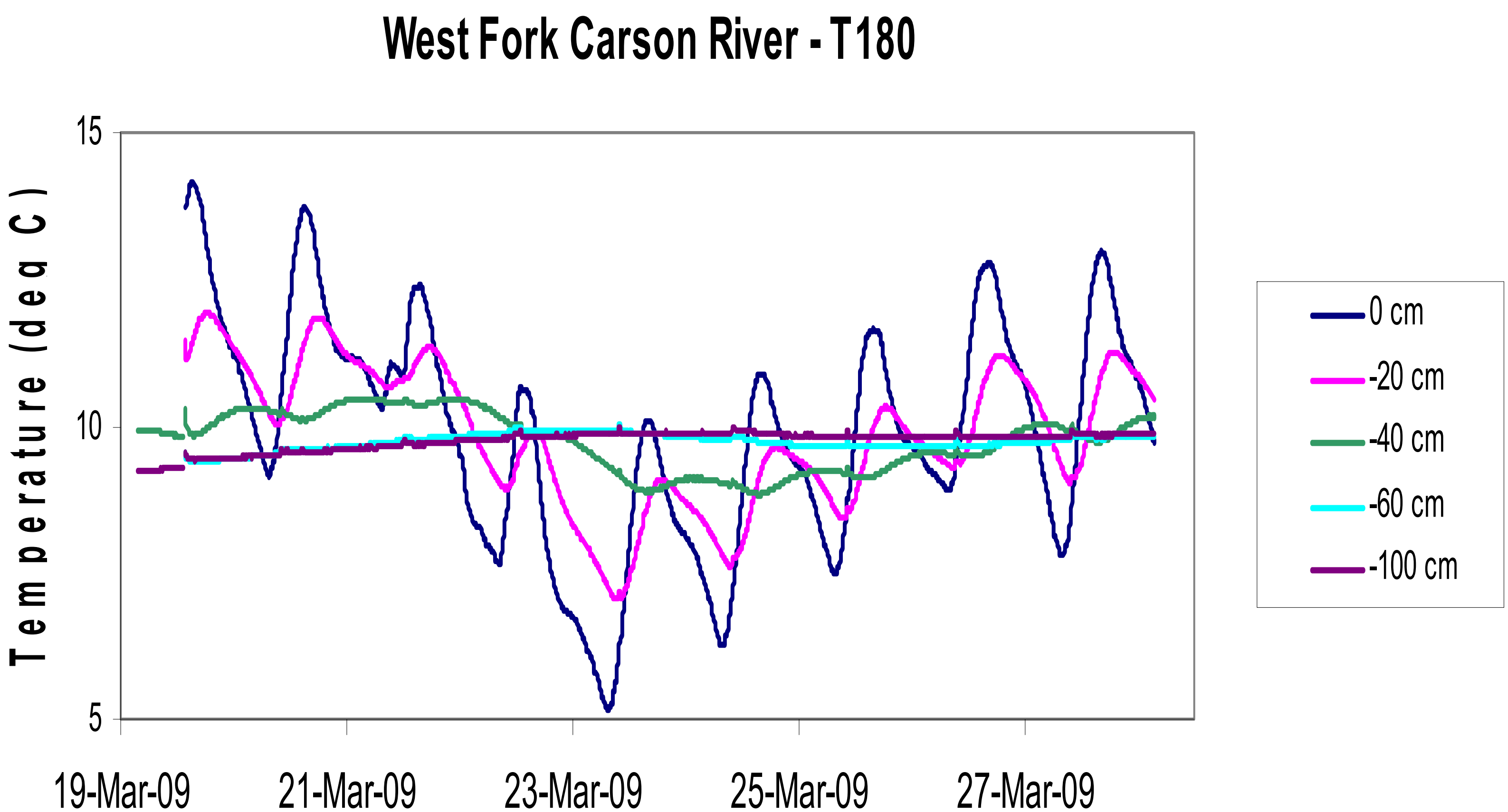


Figure 13. Vertical thermal profile of West Fork of Carson River at Site T180 during 19--28 March 2009.

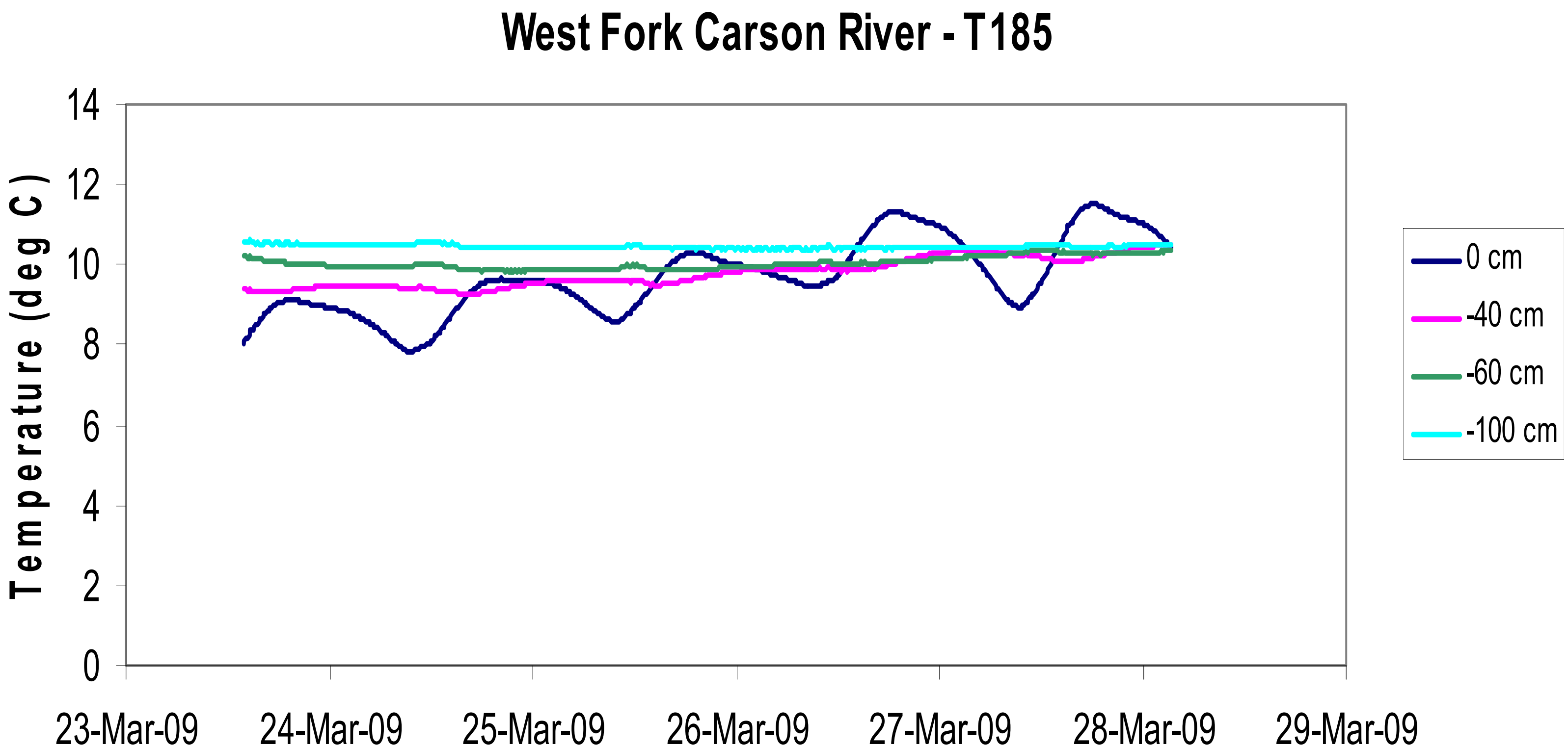


Figure 14. Vertical thermal profile of West Fork of Carson River at Site T185 during 24 -28 March 2009.

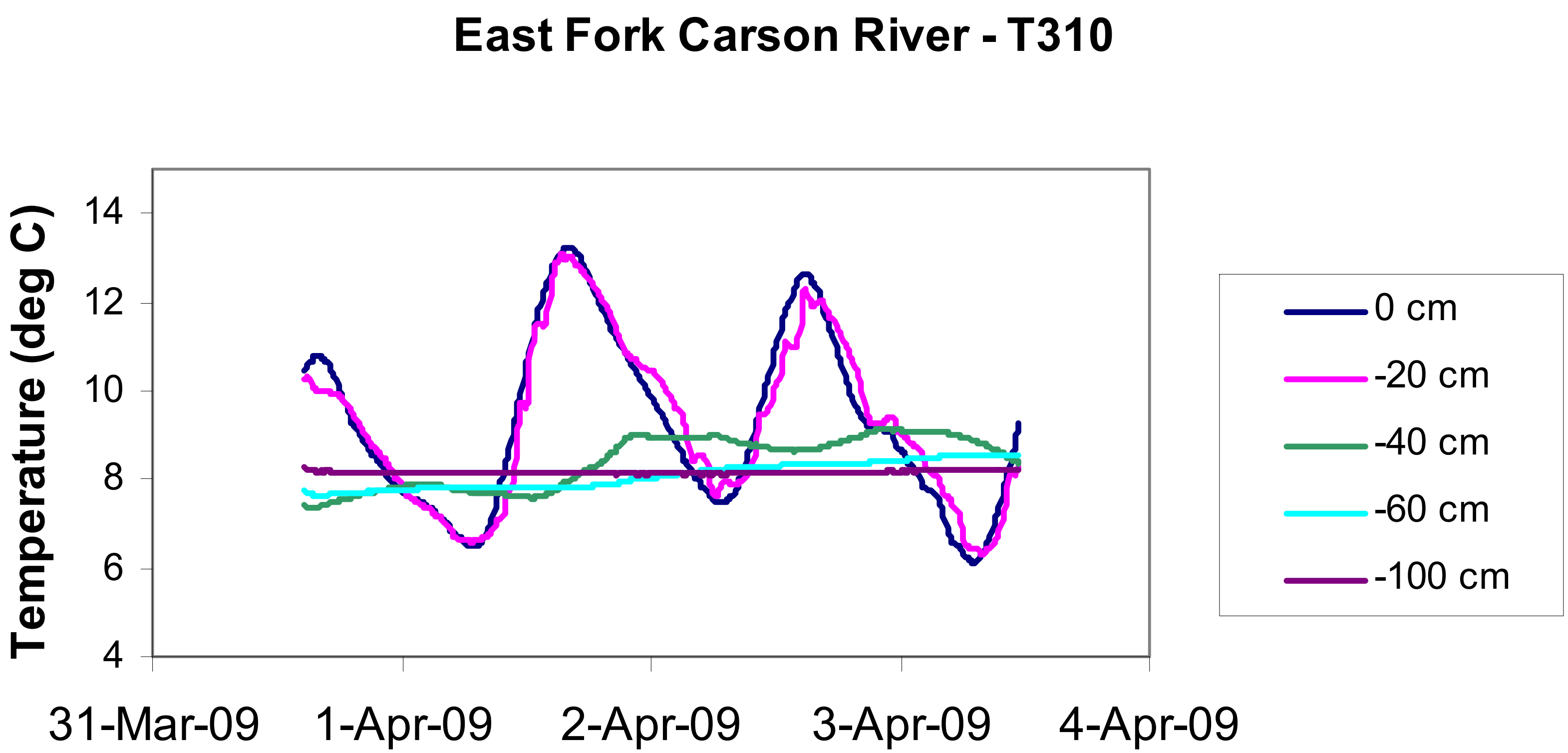
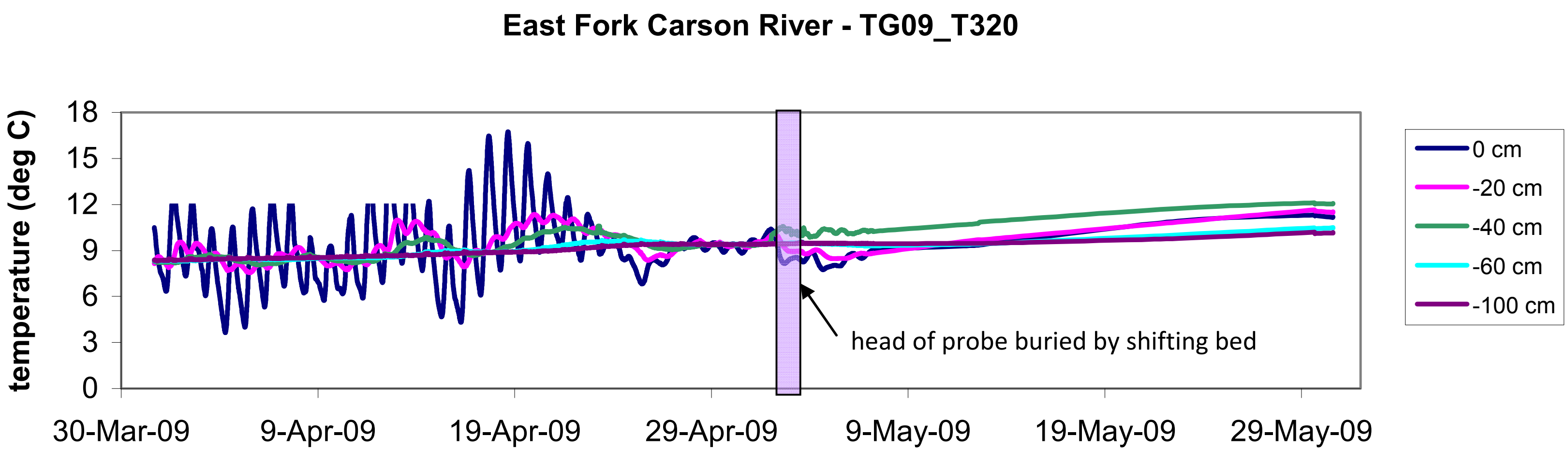


Figure 15. Vertical thermal profile of East Fork of Carson River at Site T310 during 1-3 April 2009.



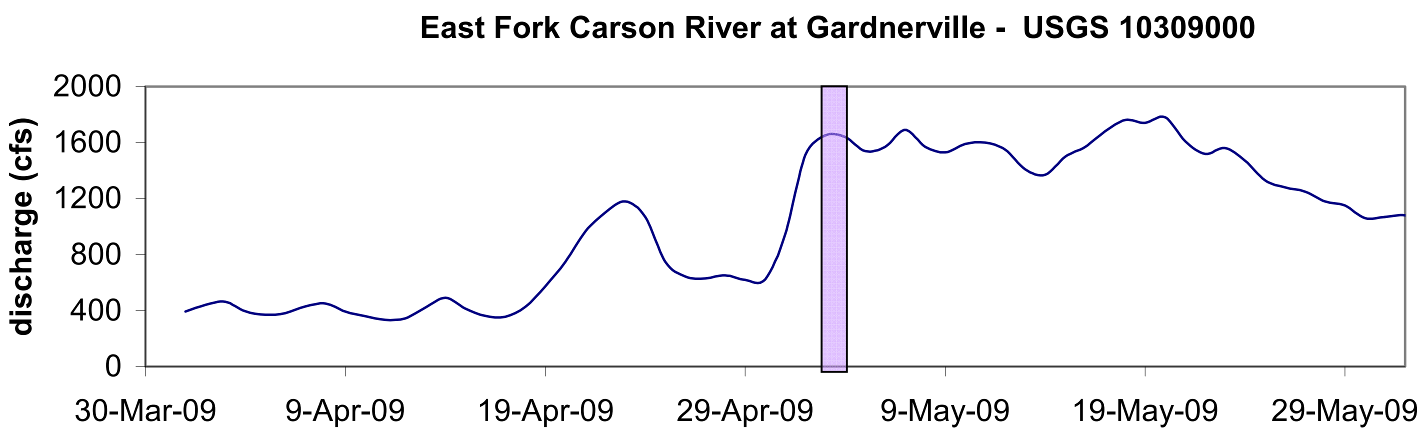


Figure 16. Vertical thermal profile of East Fork of Carson River at Site T320 (top) and discharge of East Fork at Gardnerville during 1 April – 29 May 2009 (bottom).

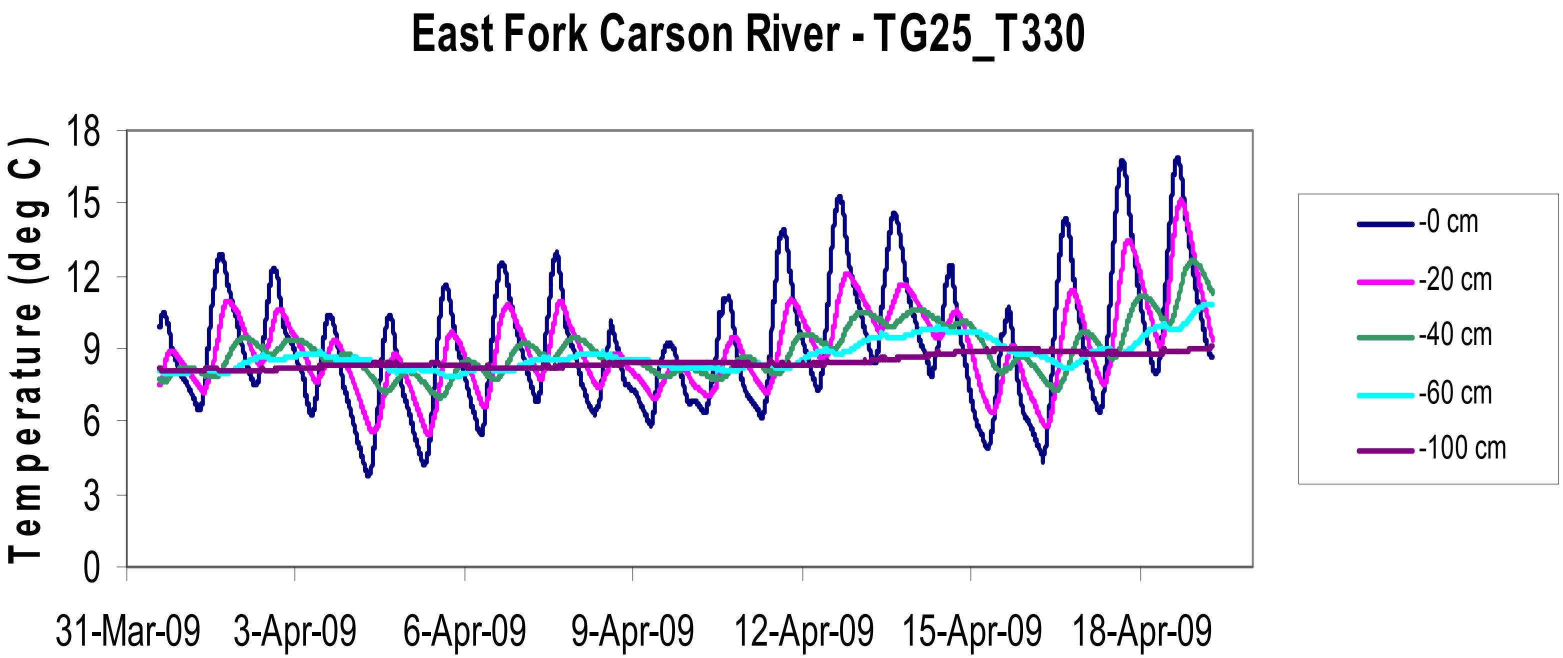


Figure 17. Vertical thermal profile of East Fork of Carson River at Site T330 during 31 March-18 April 2009.

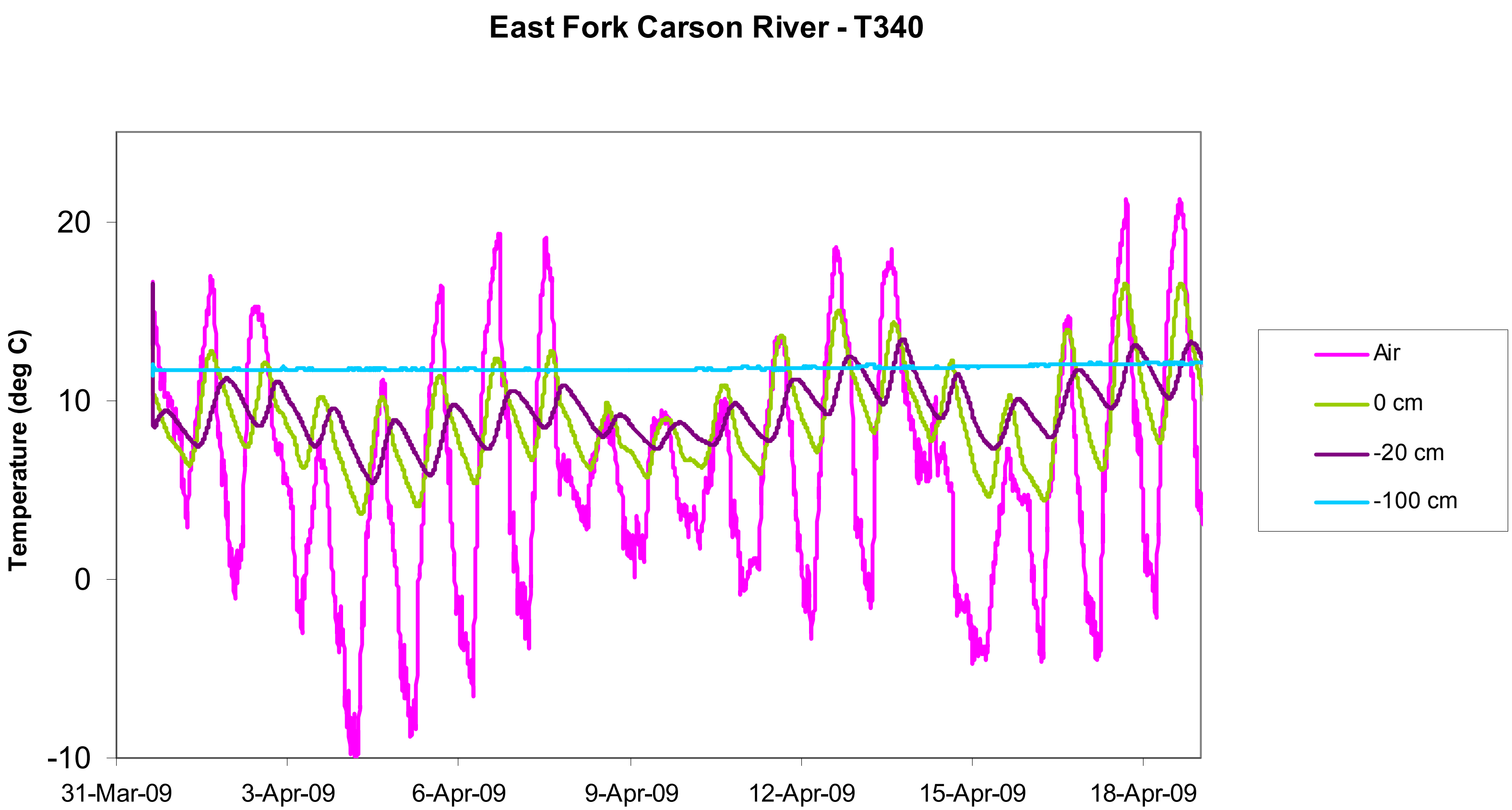


Figure 18. Vertical thermal profile of East Fork of Carson River at Site T340 during 31 March – 18 April 2009.

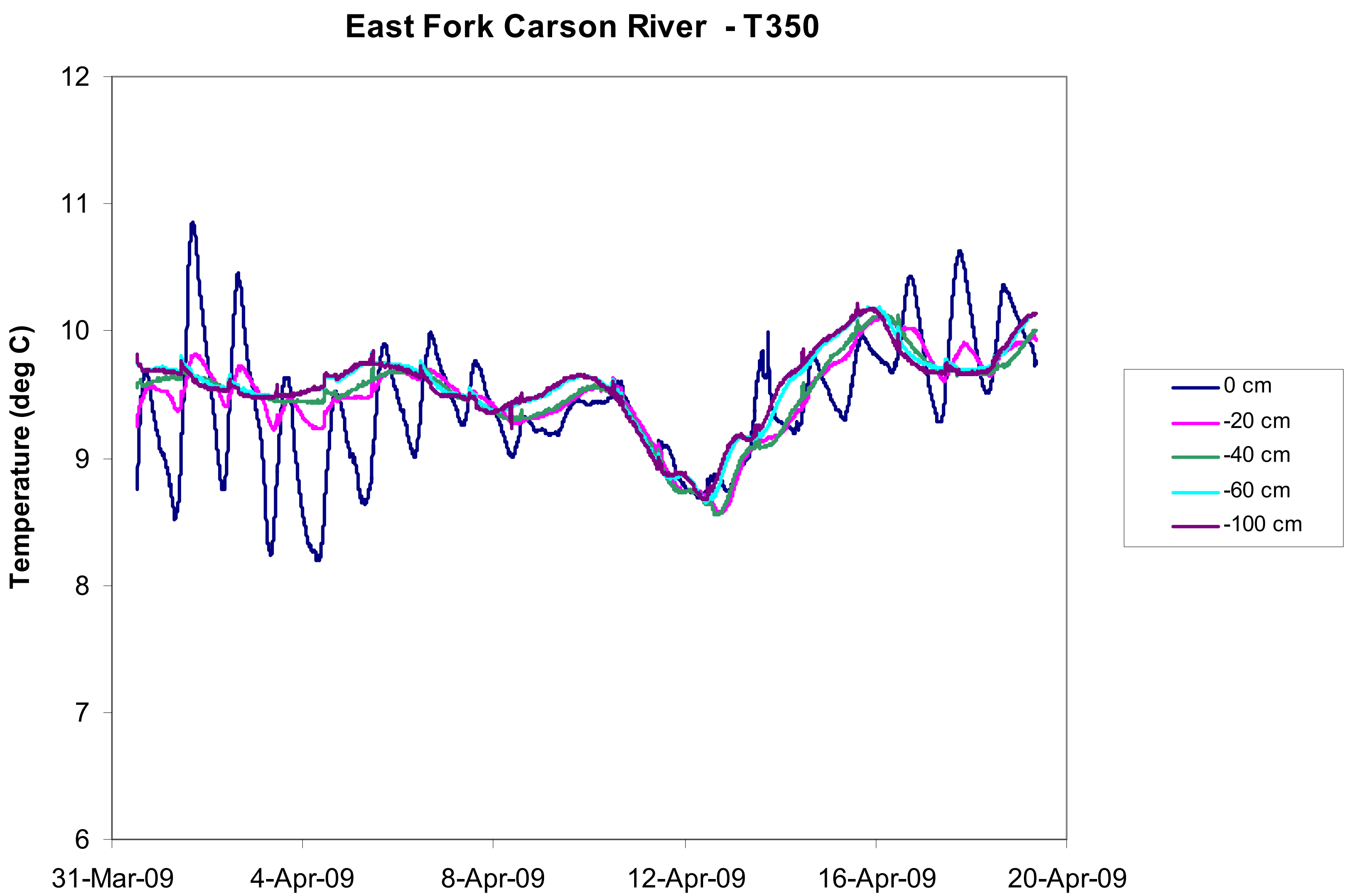


Figure 19. Vertical thermal profile of East Fork of Carson River at Site T350 during 31 March-20 April 2009.

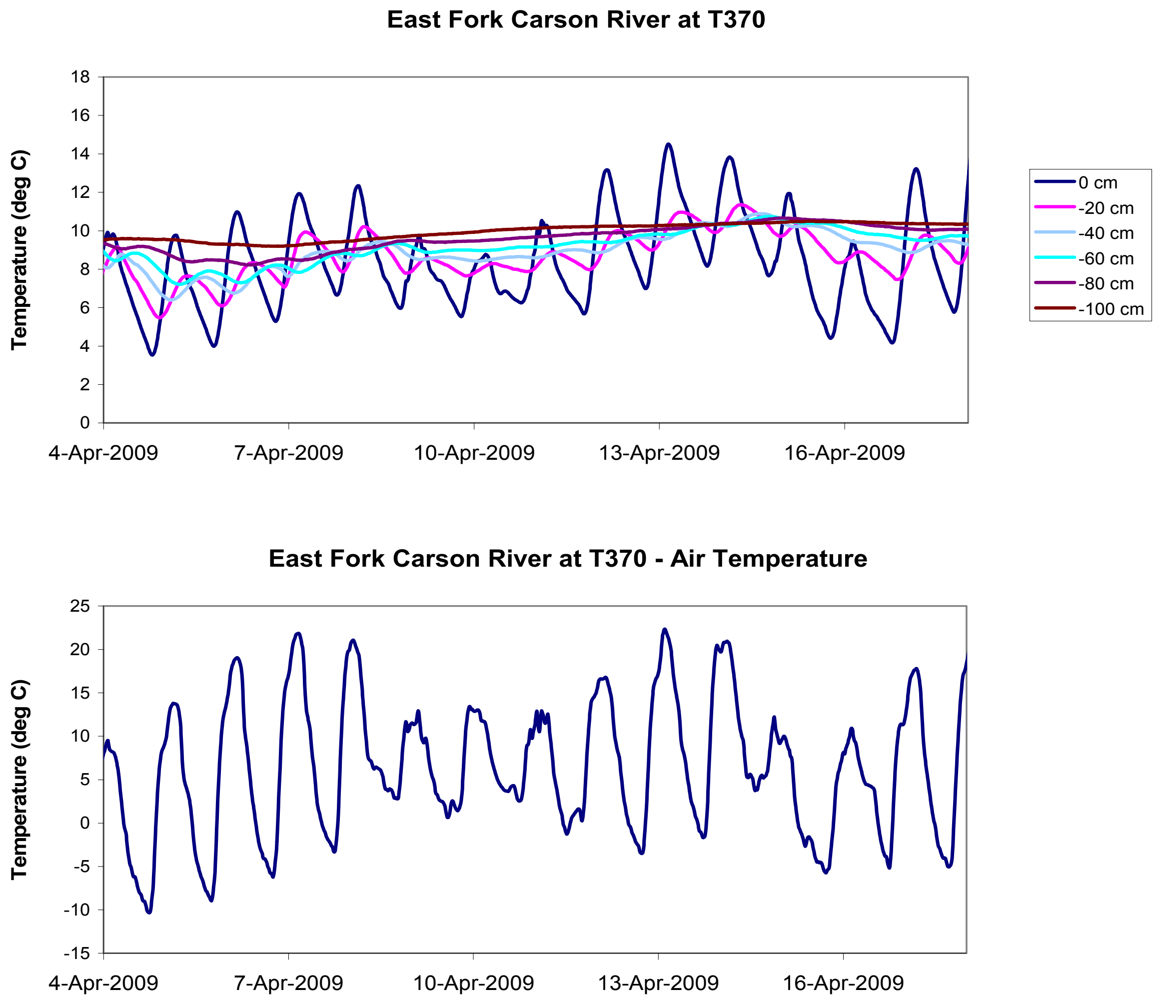


Figure 20. Vertical thermal bed profile of East Fork of Carson River at Site T370 during 4 – 19 April 2009 (top) and air temperature (bottom) during the same period.

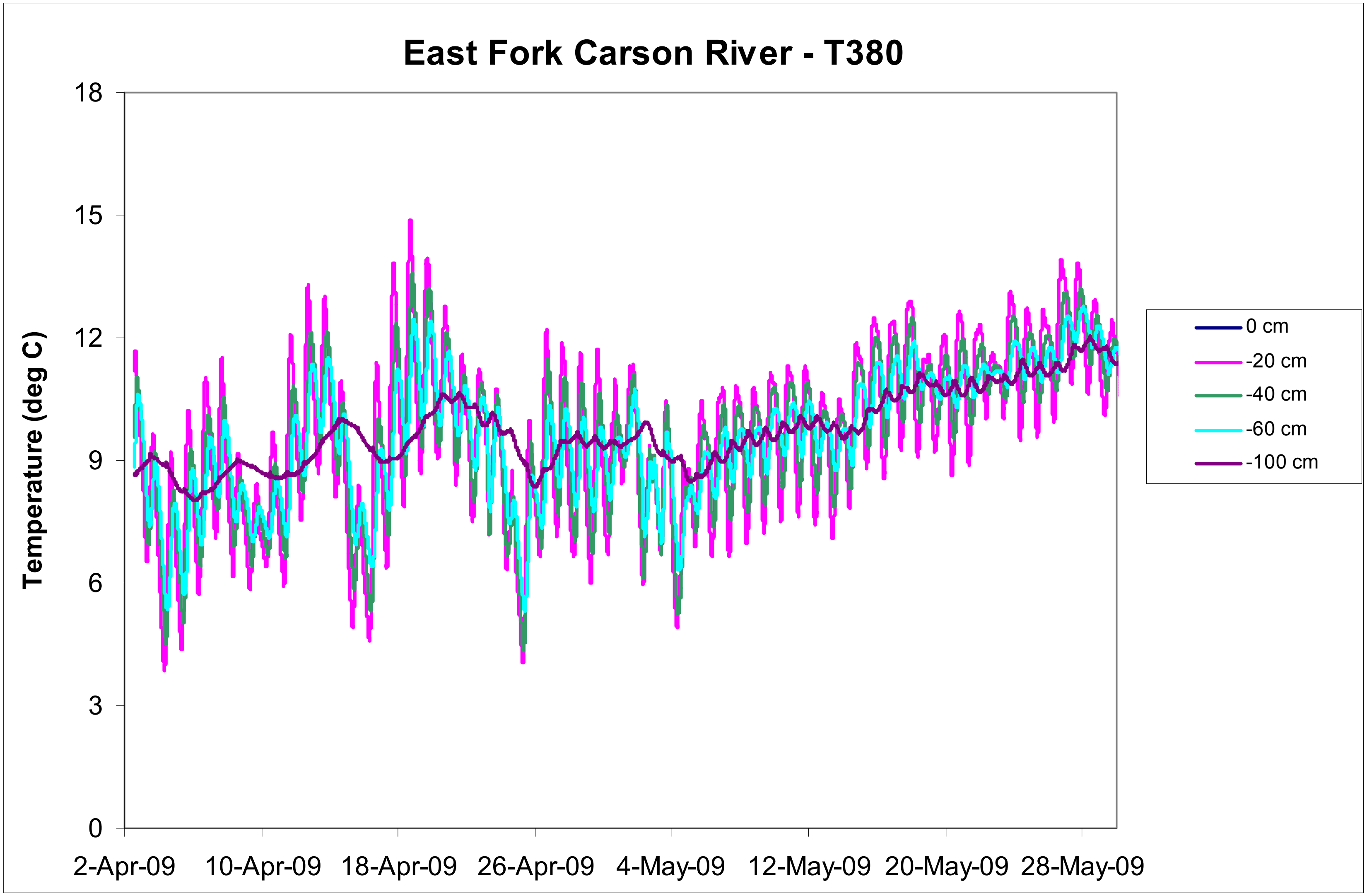


Figure 21. Vertical thermal bed profile of East Fork of Carson River at Site T380 during 2 April – 28 May 2009.

Table 3. Summary of features of temperature profile data for East and West Fork Carson River March-July 2009.

	Site	(1) Upper Positions in Bed Temperature Tracks Water Column	(2) Phase Lag of Temperatures Present with Depth from Bed	(3) Deepest Position in Bed with Constant Temperature	Number of Constant Temperature Plots at Deepest Portion of Bed	Hybrid Signature with Combined Gaining-Losing Features	Flux Direction Based on Bed Thermal Analysis	Flux Direction Based on TIR Long Profile Analysis	Agreement Between TIR and Bed Temperature Probe
Reach Type Characteristics	Generalized Gaining, upwellling, positive flux			■					
	Generalized Losing, downwelling, negative flux	■	■						
	Neutral	■							
Carson River Sites	WFCR - T40			■	1		gaining		
	WFCR - T90			■	1		gaining		
	WFCR - T110			■	1		gaining		
	WFCR - T150			■	2		gaining	gaining	yes
	WFCR - T180			■	2		gaining	gaining	yes
	WFCR - T185			■	2		gaining		
	EFCR - T310			■	2		gaining		
	EFCR - T320			■	2		gaining		
	EFCR - T330	■	■	■	1	■	losing	gaining	
	EFCR - T340	■	■	■	1		gaining	gaining	yes
	EFCR - T350	■					neutral	gaining	
	EFCR - T370	■	■				losing		
	EFCR - T380	■					neutral		

Notes: ■ = present

Reach Type Characteristics are generalized traits of the diel temperature pattern for gaining and losing reaches as described in Methods.

The pattern for characteristics in columns (1), (2) , (3) were observed for the sites indicated with blue shading.

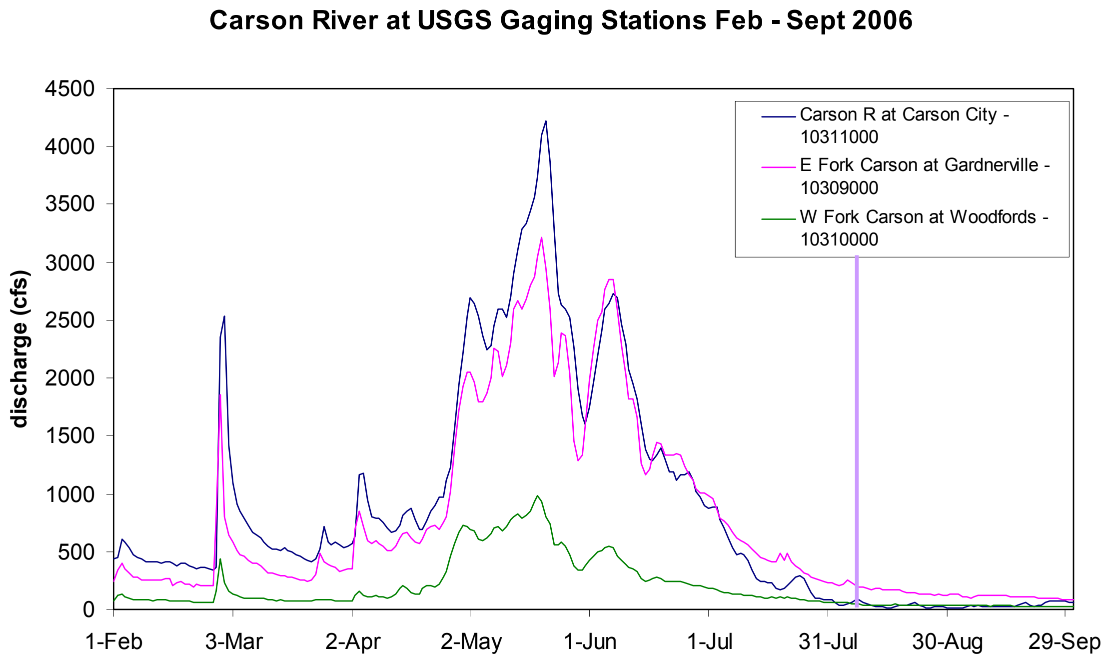


Figure 22. Discharge of mainstem Carson River and its East and West Forks during February through September 2006. August 8th, the date of the airborne survey is shown as a vertical line. (Data Source: USGS).

Discussion

The raised fluvial bedforms that create riffle-pool sequences in streams lead to a downward flow into the bed at the upper margin of the riffle and an upward flow at the downstream margin (Thibodeaux and Boyle 1987). In free-flowing alluvial channels this vertical wave through the hyporheic zone tends to have an overall cooling effect during summer, and a warming influence in winter. Thermal heterogeneity of fluvial habitats at the reach scale was described by Vaccaro and Maloy (2006), who use the term "structure" to describe the variability in a profile that represents areas of cooling or heating. The East Fork of the Carson River, which is for the most part unregulated during channel-forming flows, tends to have riffle-pool diversity that may be responsible for the sawtooth variation (structure) observed in its longitudinal thermal profile. The West Fork, on the other hand, has few riffles and the long thermal profile contains far less structure, consistent with it sluggish, homogenous appearance.

Analysis of the temperature profile data (Table 3) illustrates that conditions influencing the thermal regime in the stream bed are complex. The examples provided in the Introduction for thermal profiles of gaining and losing reaches represent clear-cut cases the likes of which were encountered only occasionally in this study. Some of the time series had characteristics that matched the type curves closely. For example Sites T90 (Figure 10) and T185 (Figure 14) possessed traits of constant temperature at depth in the bed and were clearly indicative of upwelling. Site T380 on the East Fork of the Carson (Figure 21) had a thermal signature that unambiguously indicated strong downwelling of surface water, with an attenuated signal of the diel surface temperature oscillation extending all the way down to 100 cm depth.

The thermal profiles at other locations, such as West Fork Carson at T150 showed mixed traits, with a surface oscillation that extended into the bed, but a constant temperature at 60- 100 cm depth. A similar pattern was observed at site T180 and T370, where the temperature at depth was flat from day to day but there was evidence of surface temperature emanating into the bed. Multi-dimensional transport of heat may contribute to what was referred to in Table 3 as a "hybrid signature" with combined gaining-losing features. Longitudinal transport occurs when heat is added from upstream to a point in the bed so the location is influenced by flux in two (X-Z) dimensions (Silver 2007). Such transport of heat along stream bed can lead to reduced diel fluctuation and a longer phase lag.

Availability of temperature gradient data for a stream bed provides information that can suggest dynamics of groundwater-surface water exchange, but additional data (e.g. hydraulic gradient information) is useful to assess flux at a site. For this study of the Carson River data were collected from piezometers co-located at the thermal profiling sites, which will enhance further analysis of the thermal data.

Surface-groundwater dynamics are directly linked to discharge and head conditions within the aquifer, and direction and rate of seepage flux for the Carson River were found to vary seasonally (Maurer et al 2005). The aerial TIR survey was done during August 2006 when the Carson Valley was being actively irrigated and discharge of the East Fork was about 200 cfs (Gardnerville USGS Gage) and 90 cfs at Carson USGS Gage (Figure 21). Higher discharge conditions predominated during this study's temperature profiling during March-May 2009. Discharge of the USGS East Fork Carson River Gage at Gardnerville was roughly 400 cfs through 18 April 18 2009 when runoff began and flows increased to ~1200 cfs. Discharge then dropped by about 50% for a few days and subsequently rose to 1600 cfs during the first few days of May 2009 (Figure 16).

Time series temperature profiles are available from two monitoring sites (Site T320 and T380) that recorded surface water and bed conditions during the April-May 2009 runoff period (Figure 16 and Figures 21). The thermal signature of these two stations responded quite differently from each other due to the increased head and discharge conditions present during runoff. Throughout the 8-week runoff period, Site T380 had a diel temperature oscillation that extended all the way down to 100 cm depth (Figure 21). This thermal pattern was indicative of strong downwelling (Table 3). While the amplitude (ΔT=daily maximum-daily minimum) of the diel temperature variation decreased with elevated discharge in early May, it is noteworthy that a surface ΔT of ~ 4°C persisted even after discharge increased three fold. Conversely, the thermal time series with depth of Site T320 displayed traits suggestive of downwelling conditions (compare Figure 16 and Figure 21). During the first 20 days of April, large temperature swings (ΔT of ~ 6°C) at the surface became dampened in the bed, with constant temperature conditions prevailing at -60 cm and deeper. As discharge rose above about 800 cfs, the ΔT at the surface was attenuated to the point where ΔT was < 1°C on May 1st. A dramatic change in thermal signature in the bed at T320 occurred for the remainder of the month of May as all five sensors had a linear trajectory that slightly increased through the month. We speculate that the head of the probe became buried by the shifting bed on about

May 1st, and remained buried until the probe was extracted from the channel in July. The constant (ΔT near 0.0 °C) temperature conditions indicates that the bed temperature up to the level of the highest sensor (which initially was positioned at +2-3 cm above the bed) was dominated by groundwater.

Summary and Conclusions

1. An airborne TIR survey of the Carson River during August 2006 provided a detailed longitudinal profile of surface water temperature conditions. The thermal profile data for the East and West Forks of the Carson within Nevada were analyzed for apparent zones of gaining groundwater.

2. Geomorphic structure associated with riffle-pool sequences was thought to be responsible for greater variability on a sub-kilometer scale on the East Fork Carson River compared to the West Fork.

3. Thermal profiling probes were used to quantify the thermal regime in the bed at 13 locations of the East and West Fork Carson River between Highway 88 and Genoa Lane during March-May 2009.

4. The bed temperature time series were evaluated to identify areas indicative of gaining and losing groundwater. These were compared against results from the airborne TIR survey.

5. Analysis of the bed temperature profile time series identified gaining reach locations that were similar to that obtained by the TIR survey, the correspondence was not exact.

6. Bed temperature time series during spring runoff 2009 revealed differences in thermal signature that appeared to be associated with movement of the bed. Thermal profiling results reinforced the desirability of collecting ancillary data on hydraulic head to reinforce conclusions on seepage dynamics.

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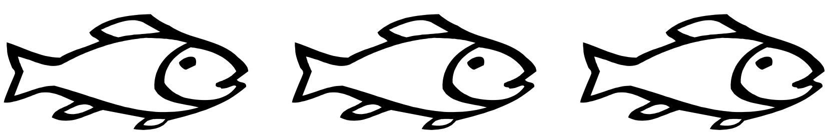
Photographs

Installing temperature monitoring equipment on West Fork Carson River March 2009.

Configuring CR206 data logger to select thermistors. Carson River March 2009.

Fish Habitat Study

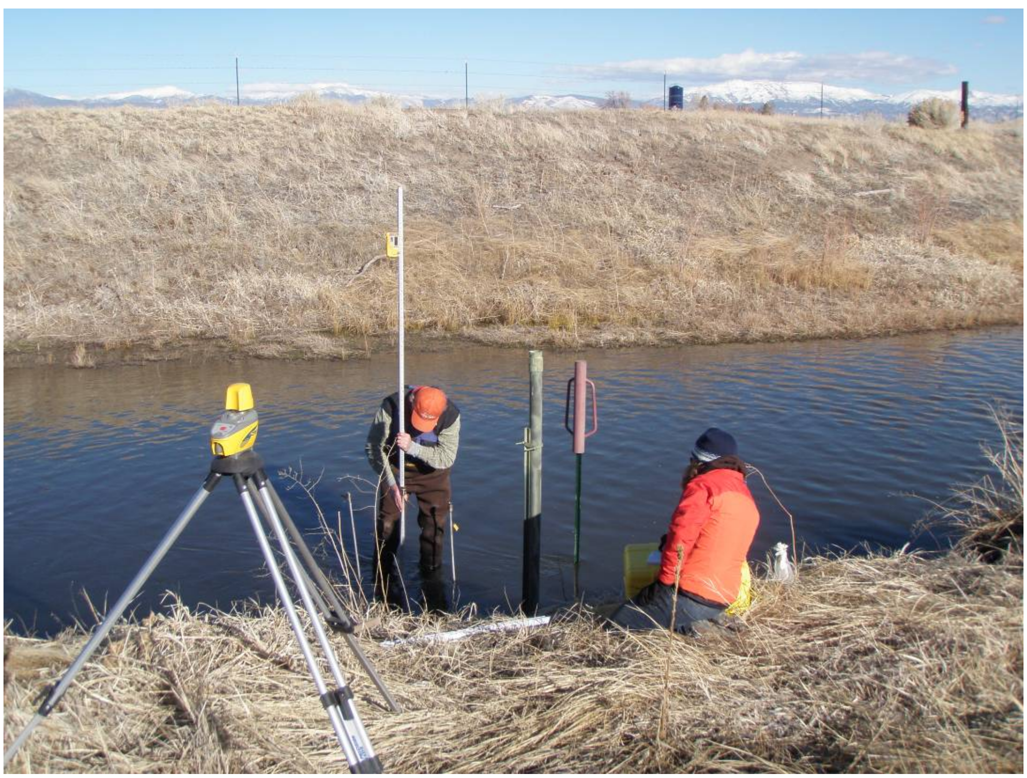
Please Do Not Disturb



This equipment is monitoring water and river bed temperature.

For information contact: **Desert Research Institute**
775-673-7407

Label used for identifying equipment.

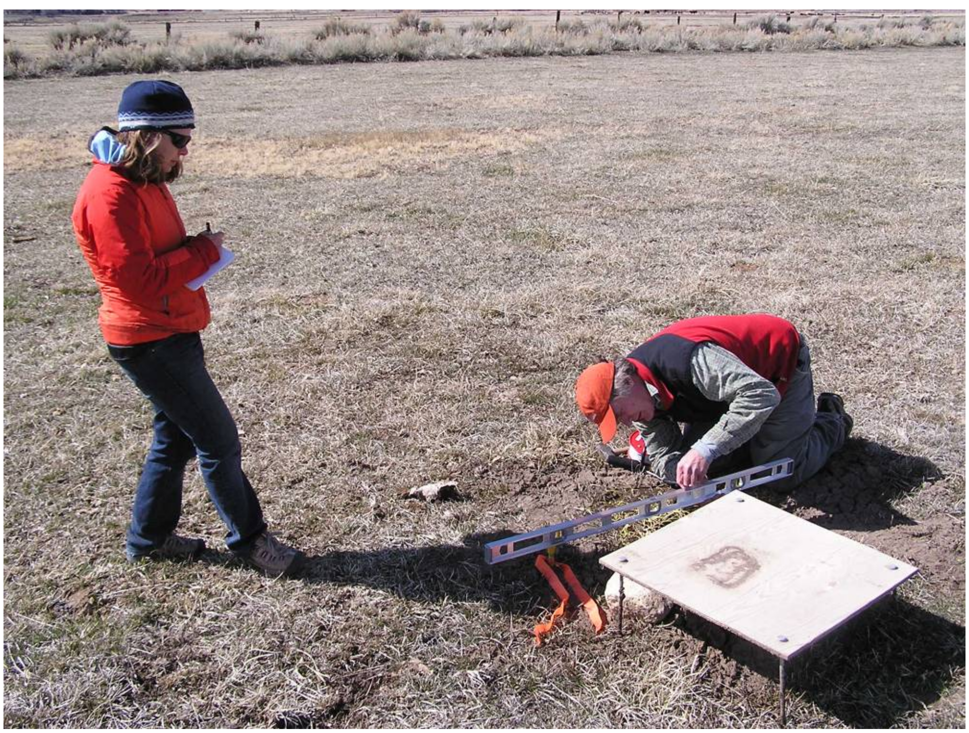


Laser level in use by John Cobourn, Megan Seifert, and Jim Brock on staff gage at T190 of River Ranch Restoration Design Study, March 2009

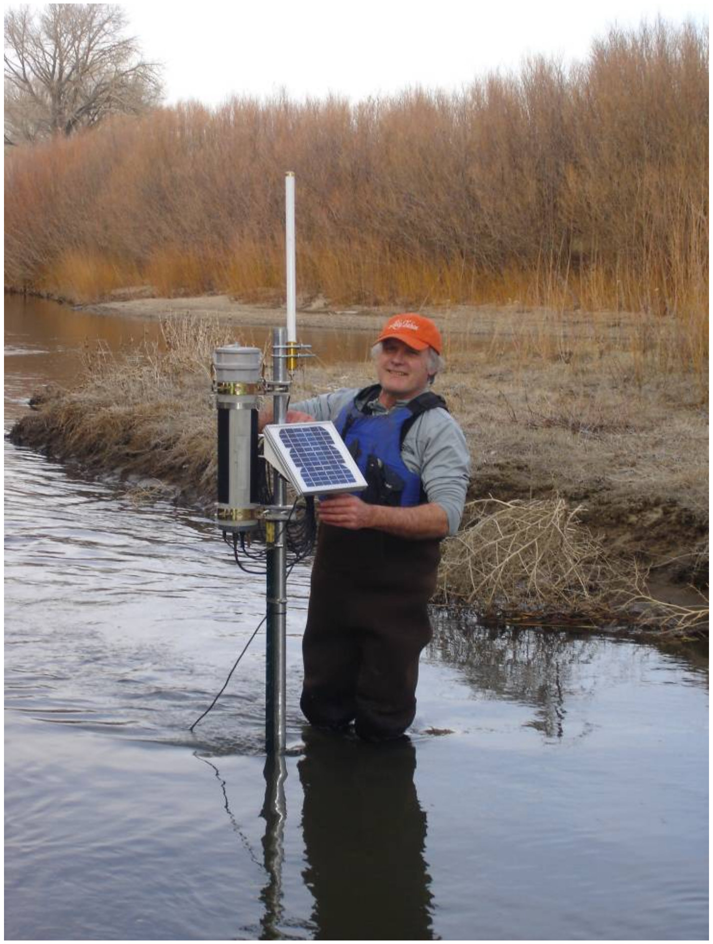
Measuring water level in piezometer with electric sounding tape. West Fork Carson River March 2009.

Megan Seifert determines elevation of reference bolt on staff gage, West Fork Carson River Site T40, March 2009

Groundwater monitoring well in floodplain of West Fork Carson River, March 2009



Megan Seifert and Jim Brock measuring water surface elevation relative to survey monument, West Fork Carson River, March 2009



Data logger enclosure at SiteT40 on West Fork Carson River March 2009 (left) and East Fork Carson River (T390) following peak runoff May 2009 (right).

Submersible Caretta vault used to protect data logger East Fork Carson River May 2009. Complete data records of bed temperature profile were collected during the runoff flows at these stations. The white mast is a radio antenna that allows data to be retrieved from shore.