IRRIGATION AS A TOOL FOR STREAM TEMPERATURE MANAGEMENT

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INTRODUCTION

The impact of water quality, particularly the effect of stream temperature on salmonid populations, is currently a topic of interest in Oregon. As we know, fish are cold-blooded organisms and as such the temperature of the external environment governs their body temperatures. In recent history, numerous experiments have been conducted to quantify salmonid temperature tolerance limits. According to the Oregon Plan for Salmon and Watersheds (OPSW) Water Quality Monitoring Guidebook (1999), healthy growth of cold-water salmonids occurs between 4.4 and 18.9ºC (40 and 66ºF), but is hindered at temperatures outside of this range and considered lethal at temperatures greater than or equal to 25.0ºC (77º F). However, these tests usually occur within controlled laboratory environments and may not adequately reflect temperature regimes or other confounding variables, such as interspecific competition for limited food resources that affect the general health and survival of fish populations in nature.

The stream temperature standard maintained by the Oregon Department of Environmental Quality (ODEQ) is 17.8ºC (64ºF), a temperature they believe is necessary to allow for healthy growth and reproduction of cold-water fish species. Further, this organization uses the seven-day moving mean (SDMM) of daily maximum as the water quality standard for regulating stream temperature. The SDMM of daily maximum stream temperature for a given date reflects the average of the 24-hour maximum temperature for that date and the maximum temperatures for three days preceding and following that date (OPSW 1999). It is commonly agreed that this method provides an accurate account of seasonal trends in maximum stream temperature while reducing some of the observed extreme daily variation.

Thus from a management perspective, it is important to identify time periods when stream temperature rises to or above this level and to identify activities that may influence stream temperature during those periods. Beschta and Taylor (1988) reported diurnal fluctuations in stream temperature are minimal during winter and spring seasons in western Oregon streams, but increase rapidly following the end of the spring runoff period and as solar radiation increases, a trend that is also evident in eastern Oregon streams. Further, it is generally accepted that an inverse relationship exists between stream discharge and the magnitude of diurnal variation of stream temperature, since the thermal mass of a stream increases with increasing discharge (Constantz et al. 1994; Beschta and Taylor 1988). This is particularly true in Rosgen E-type channels with low width/depth ratios, since the surface area of stream exposed to solar energy is relatively small in proportion to the volume of water passing through that area at any given time

(Rosgen 1996). Any activities affecting channel morphology, presence of vegetation, and/or water availability during the season of low flow may all subsequently influence stream temperature.

In arid and semi-arid regions, however, irrigation is often applied to lengthen the green forage period or to increase production in riparian pastures. The contribution of relatively temperature constant groundwater, originating from irrigation, to stream discharge can be significant and has been shown to moderate stream temperature during summer months (Stringham et al. 1998). This case study was implemented to determine if the technique described by Stringham et al. (1998) could be used to promote subsurface return flows, derived from flood irrigation, to the creek in order to moderate stream temperature.

STUDY AREA

The study was conducted on a first order stream near the Steens Mountain range in south central Harney County, Oregon. Harney County lies between 42° and 44° north latitude and 118° and 120° west longitude. The surrounding meadow is approximately 300 acres in area and 1480 m (4856 ft) in elevation. The nearest weather station is located at Whitehorse Ranch (42.20° north latitude and 118.14° west longitude) at an elevation of 1335 m (4380 ft). The thirty-year average annual precipitation at this weather station is approximately 21.3 cm (8.4 in). Winter precipitation often falls in the form of snow. An average of 72% of the mean annual snowfall and 42% of the mean annual precipitation occurs from November through March. The thirty-year average winter temperature is –0.42°C (31.2°F) with a mean minimum temperature of –7.33°C (18.8°F) occurring in January. Summer precipitation is often in the form of rain via high intensity short duration localized thunderstorms. The thirty-year average summer temperature is 18.7°C (65.7°F) with a mean maximum temperature of 30.4°C (86.7°F) occurring in July. Temperature extremes range from -32.2°C (-26.0°F) in December to 39.4°C (102.9°F) in August (Oregon Climate Service 2003).

The segment of stream incorporated into this study flows from east to west and was relocated from the middle to the north end of the existing pasture in order to create a hay meadow in the 1950's or 1960's. The study reach is located mostly within a riparian pasture, which was excluded from livestock grazing from 1998-2000 and during the growing season in 2001. The stream was classified as a Rosgen E6-type channel in 2002. Current channel sinuosity ranges from 1.1 to 1.8; however, this is a recovering system with developing stream banks (Rosgen 1996). Three recent head-cut repairs have helped stabilize the channel, reduce erosion, and allow streamside vegetation to establish and aid in sediment capture. As the banks develop channel depth will increase, the width/depth ratio will decrease, and the channel will become more characteristic of an E-type.

METHODOLOGY

DEPTH TO GROUNDWATER

Depth to groundwater was monitored approximately every ten days at seventy-eight wells throughout the meadow system from May through September in 2000, 2001, and 2002. Seven meadow transects with seven to twelve wells each were located on the south side of the creek and oriented more or less perpendicular to it (Figure 1). Within each meadow transect, well placement was non-random. The first well was installed within one horizontal meter from the creek. The location of remaining wells within each meadow transect was determined primarily according to changes in vegetation communities, and secondarily by the width of the meadow.

The depth of each well was determined by the depth of the deepest point in the channel, with the location in the channel being consistent with the compass bearing of the well transect. Wells that did not consistently tap into groundwater throughout the growing season were deepened in August 2000. Standard survey methods were used to establish a difference in the ground surface elevation at each well relative to the creek-side well, and the difference in elevation from the creek-side well to the stream surface was recorded during each measurement cycle. This enabled us to adjust all depth to groundwater measurements relative to the creek surface level in order to determine if groundwater was flowing toward the creek or away from it (effluent/influent groundwater flow patterns) during the plant growing season.

TEMPERATURE

Two permanent stream stations, Stations 2 and 6, were established within the study meadow at the upper and lower ends during the 2000 field season. An additional station was located both directly upstream (Station 1) and downstream (Station 7) of the study meadow. Three additional stream stations, Stations 3, 4, and 5, were established in 2001 at locations where subsurface stream inputs originating from irrigation were anticipated (Figure 1).

Stowaway XTI Temp thermistors were placed in well-mixed sections and submerged to mid-channel depth to monitor stream temperature at hourly intervals from May to September of each year at each station. Additional thermistors enclosed in radiation shields and suspended from the fence in the vicinity of Stations 2 and 6 were used to monitor air temperature at identical intervals as the stream thermistors. Unidata Model 8007WDP Water Depth Recorders were used to monitor groundwater temperature at four wells at three-hour intervals throughout the plant growing season in 2001 and 2002. The seven-day moving means of daily maximum air, stream, and groundwater temperature were calculated at each station.

STREAM DISCHARGE

Permanent stream discharge stations are illustrated in Figure 1. Point-in-time flow measurements were taken approximately every ten days during the 2001 and 2002 growing seasons at four permanent stream stations, including one at both the upper and lower ends of the study reach.

Stream velocity and depth were recorded at hourly intervals in 2001 and 2002 at upstream and downstream ends of the study reach at Stations 2 and 7 by two Starflow Ultrasonic Doppler units. Both locations were selected to reflect irrigation influences, such as increases in stream discharge observed in response to groundwater inputs. Stream discharge at the upstream and downstream ends of the study reach were estimated from data obtained from these units, and seven-day moving means of daily maximum discharge were calculated at each station.

STATISTICAL ANALYSIS

A paired t-test was used to determine if a difference exists in seven-day moving means (SDMM) of daily maximum stream temperature between upstream and downstream stations each year. This test was also performed to determine if a difference exists in SDMM of daily average discharge between upstream and downstream stations each year. A standard two-sample t-test was used to determine if a difference in SDMM of daily maximum air temperatures exists between years.

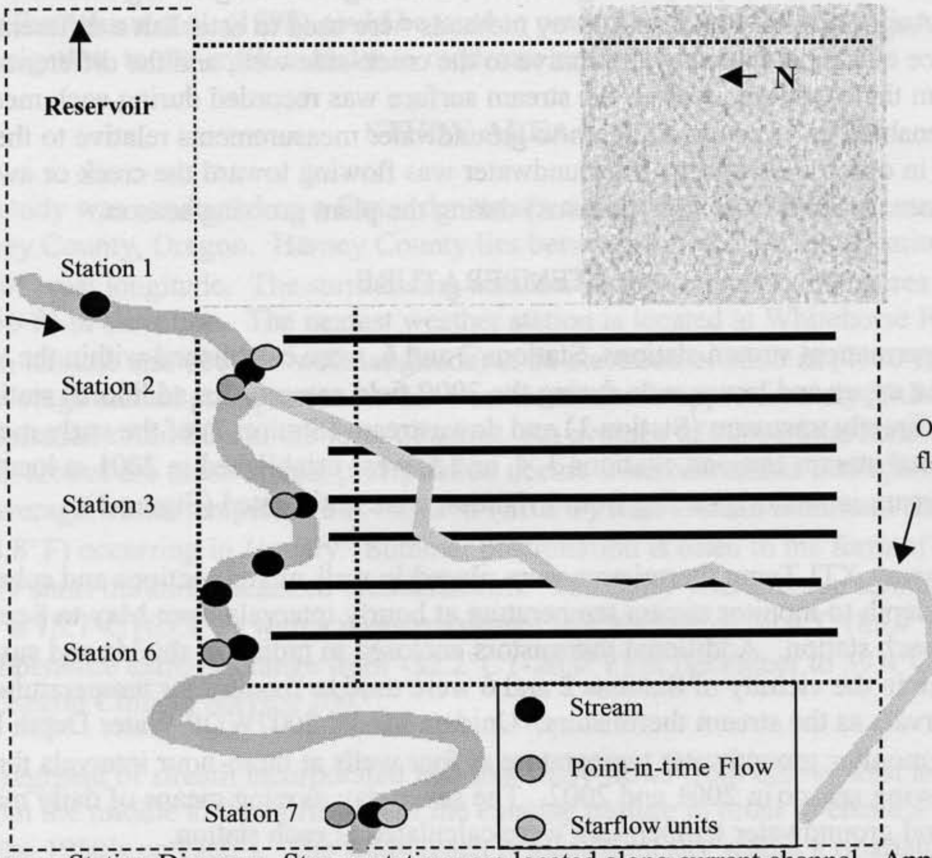

Figure 1. Stream Station Diagram. Stream stations are located along current channel. Approximate flow path of original channel is also illustrated. *Not to scale.

RESULTS AND DISCUSSION

AIR TEMPERATURE

The seven-day moving means of maximum air temperature early in the season of 2001 and 2002 were statistically similar to those observed in 2000 (t= -0.33, df=30, p=0.7561; t=0.92, df=30, p=0.3637) and remained similar throughout the growing season (t= -1.55, df=198, p=0.1219; t= -1.12, df=198, p=0.2634). Average daily maximum, absolute maximum, and maximum weekly air temperatures of each year are provided in Table 1. The maximum recordable temperature limit of the thermistors, however, is 37.8°C (100°F). It is conceivable that the absolute maximum air temperatures observed during any year within the study period actually exceeded this upper temperature limit.

Table 1. Air temperature summary.

Year	Ave. Daily Maximum in ºC (ºF in paren.)	Absolute Maximum in ºC (ºF in paren.)	Date of Occurrence	Maximum Weekly Maximum ºC (ºF in paren.)	Date of Occurrence
2000	27.8 (82.0)	37.2 (99.0)	July 31	35.0 (95.0)	July 31
2001	28.0 (82.4)	37.4 (99.3)	July 3	33.2 (91.8)	July 3
2002	28.0 (82.4)	37.6 (99.7)	July 11	33.5 (92.3)	July 13

TRENDS IN STREAM TEMPERATURE, DEPTH TO GROUNDWATER, AND DISCHARGE

Control Year: Non-irrigated

Stream temperature increased in the downstream direction from early June through early August 2000 (Figure 2). Since the meadow directly upstream of the study meadow, where Station 1 is located, was irrigated during the 2000 field season, comparisons of stream temperature are limited to stations within the non-irrigated study meadow. In particular, the seven-day moving mean (SDMM) of daily maximum stream temperature at Station 2 averaged 21.9ºC (71.4ºF), 3.2ºC warmer at Station 6, and 3.4ºC warmer at Station 7 ($t= -23.0$, $df=68$, $p<0.0001$; $t= -29.3$, $df=68$, $p<0.0001$). However, it is important to note that the thermistors used in this study are only accurate to 0.2ºC. The SDMM of daily maximum stream temperature at Stations 6 and 7 were similar early in the season ($t= -0.9$, $df=44$, $p=0.3996$), but began to diverge in late July 2000. Station 7 then averaged 0.5ºC warmer than Station 6 from late July through early August ($t= -10.9$, $df=17$, $p<0.0001$).

When relating trends in depth to groundwater to stream temperature, it is evident that historic management activities have affected the natural flow pattern of the meadow. As mentioned previously, the creek was moved from the middle to the north end of the meadow in the 1950's or 1960's to create a hay meadow (Figure 1). At this time, 13 large dikes were installed for the purpose of flood irrigating. In 1993, these dikes were breached and livestock grazing was reintroduced. However, the natural drainage pattern of this meadow remains toward the direction of the old creek. In other words, only the first few wells in each transect actually indicate groundwater flow toward the creek in its current location. The remaining wells tend indicate ground water flows in a direction towards the old creek bed. Years of historic irrigation, however, have created a secondary drainage pattern where the water table drains toward the old creek bed for a given length and later emerges downstream between Stations 6 and 7. This is evident by notable amounts of groundwater seeping through the streambank between these two locations.

For the purpose of this report, wells have been categorized into distance bands, denoting the distance of a given set of wells from the creek-side well. Only wells within the first two distance bands (0-10 m and 11-30 m) indicate drainage toward the creek in its current location. Wells within all other bands indicate groundwater flows toward the old channel and/or toward the west end of the meadow, later emerging either between Stations 6 and 7 or below Station 7. Trends in depth to groundwater indicate the water table remained above the creek surface early in the 2000 growing season in the 0-10 m and 11-30 m distance bands until early to mid-July (Figure 3). The water table in the remaining distance bands remained above the creek surface through mid-July and groundwater likely flowed from the soil into the creek between or below Stations 6 and 7 during this time period. This may suggest that maximum daily stream temperatures at Stations 6 and 7 began to diverge as groundwater inputs between these two stations became negligible (Figures 2 and 3).

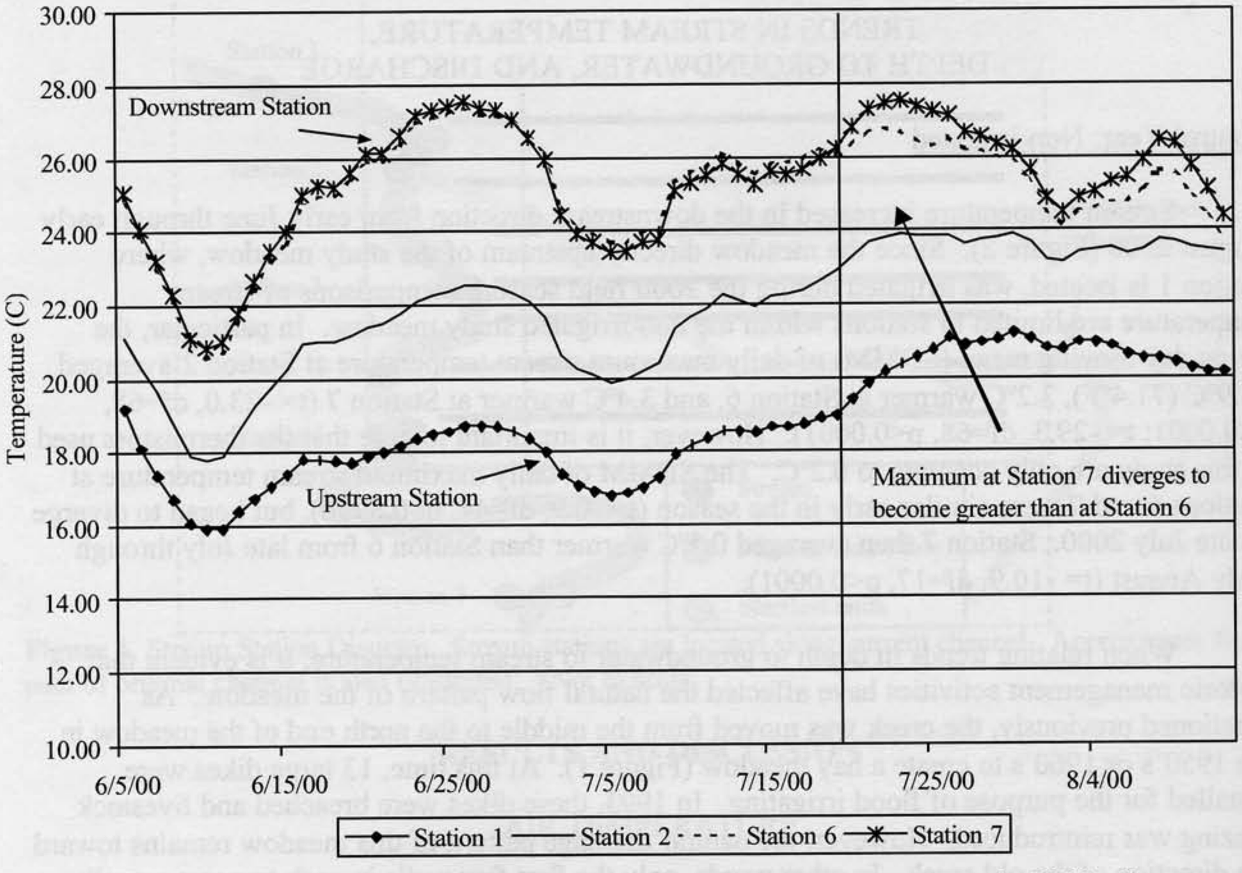

Figure 2. Seven-day moving means of daily maximum stream temperature in 2000. Stream heating is illustrated in the downstream direction. Station 1 was located within an irrigated meadow upstream; all remaining stations were located within the non-irrigated study meadow. (18ºC=64.4ºF, 22ºC=71.6ºF, 26ºC=78.8ºF)

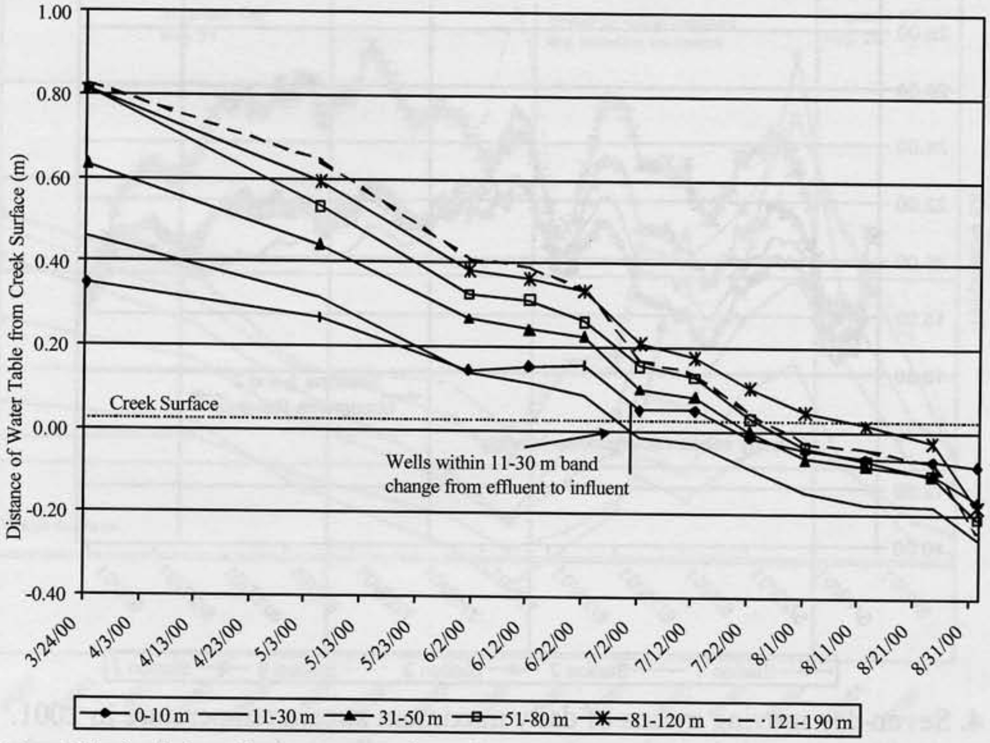

Figure 3. Water table height relative to creek surface under non-irrigated conditions. Wells were classified by horizontal distance from the creek-side well and mean depth to groundwater of wells within each distance band by date were reported.

Treatment Year 1: Response to Irrigation

Irrigation commenced on May 31, 2001 and continued through August 20, 2001; however, irrigation water did not reach the study meadow until early July (refer to the discussion below). For the purpose of this report, only results from stream stations that were established in 2000 are discussed in detail. Stream temperature data from stations located near the middle of the study reach are included in the figures for reference, but are not discussed.

Stream temperature increased in the downstream direction early in the 2001 field season (Figure 4). The seven-day moving mean (SDMM) of daily maximum stream temperature at Station 1, located within a non-irrigated meadow directly upstream of the irrigated study meadow, averaged 19.1ºC (66.4ºF), 1.0ºC warmer at Station 2, and 4.7ºC warmer at Station 7 through mid-June (t= -71.2, df=15, p<0.0001; t= -58.8, df=15, p<0.0001). The depth to groundwater increased steadily prior to irrigation water reaching the meadow in early July, but remained above the creek surface level in all distance bands except wells within 11-30 m from the creek side well (Figure 5).

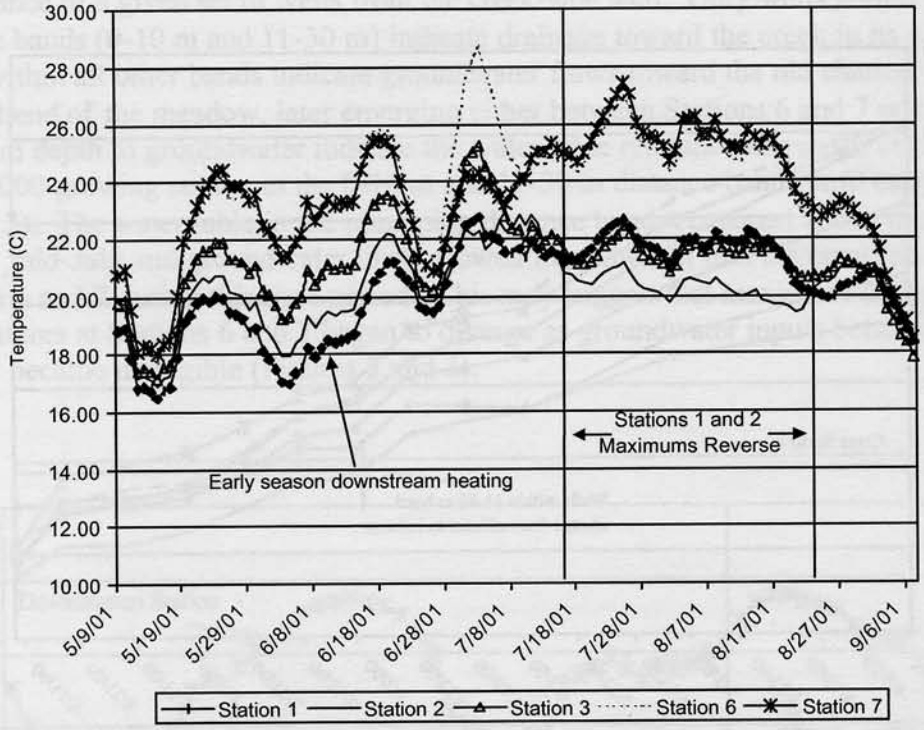

Figure 4. Seven-day moving means of daily maximum stream temperature in 2001. Station 1 was located within a non-irrigated meadow upstream; all remaining stations were located within the irrigated study meadow. Irrigation commenced May 31, but did not reach meadow transects until early July. (18ºC=64.4ºF, 22ºC=71.6ºF, 26ºC=78.8ºF)

When irrigated, water is released from a reservoir approximately 0.5 miles upstream from the northeast corner of the study meadow. Water then enters a head ditch and flows along the east end of the study meadow and must flow through several vegetated smaller ditches for approximately another 0.3 miles before reaching the first meadow well transect (Figure 1). This is a slow process above the soil surface and even slower subsurface. Therefore, the effects of irrigation on depth to groundwater were not evident until mid-July 2001, at which time the water table rose steadily above the creek surface level until irrigation ceased in mid-August (Figure 5). Although this rise in water table elevation did not result in maximum daily temperature mitigation between many stream stations within the study meadow, a notable reduction in the SDMM of daily maximum stream temperature occurred from Station 1, within the non-irrigated meadow upstream, to Station 2, within the irrigated study meadow (Figure 4). In particular, Station 2 averaged 20.3ºC (68.5ºF), 1.4ºC cooler than Station 1 from mid-July through mid-August (t=19.1, df=37, p<0.0001). In fact, with irrigation treatment we were able to maintain the average SDMM of daily maximum stream temperature at Station 2 from mid-July to mid-August within 0.2ºC of that observed at this station from early to mid-June. Whereas the average SDMM of daily maximum stream temperature at Station 1 increased from 19.1 to 21.7ºC (66.4 to 71.1ºF) from early (mid-June) to late season (mid-July through mid-August) in 2001. Further, during the non-irrigated treatment year (2000), the average of SDMM of daily maximum stream temperature at Station 2 increased from 19.8 to 23.5ºC (67.6 to 74.3ºF) from early to late season.

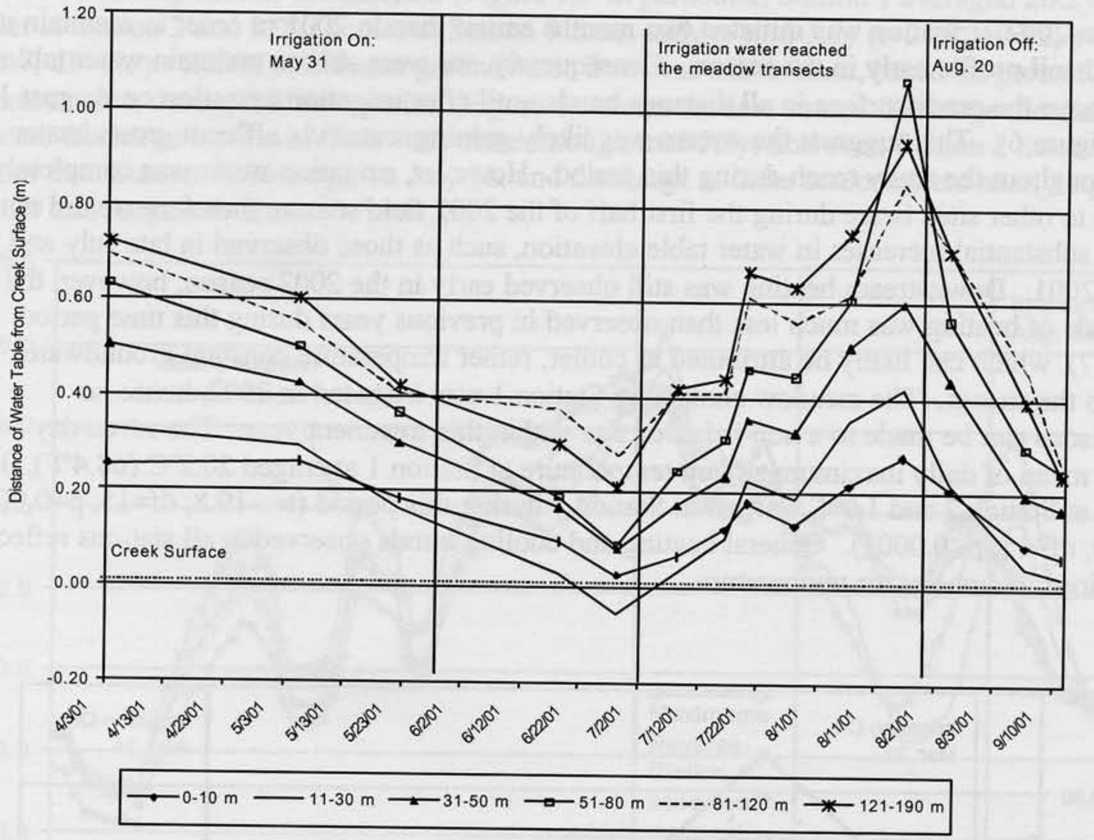

Figure 5. Water table height relative to creek surface under irrigated conditions. Wells were classified by horizontal distance from the creek-side well and mean depth to groundwater of wells within each distance band by date were reported.

Since seasonal discharge data from a non-irrigated year are not available, the end of the spring runoff period was estimated from the time period when the rate of change in stream discharge monitored by Starflow units leveled off in 2001, which was consistent with visual observations. Based on this information, we can only assume baseflow conditions typically occurred within the first week in June during the study period. Since we believe these units vastly overestimate discharge, however, only qualitative assessments are discussed. Estimates of stream discharge suggest discharge increased in the downstream direction from Station 2 to Station 7 throughout the 2001 irrigated season, which also suggests that the irrigated stream reach was gaining water via effluent groundwater flow through mid-August. Point-in-time discharge data obtained using a pygmy style flow meter also suggests discharge increased from Station 2 to Station 7 during the 2001 irrigated season on all measurement dates except July 9, 2001, when discharge at these two stations were relatively equal.

Treatment Year 2: Response to Irrigation

In 2002, irrigation was initiated two months earlier than in 2001 in order to maintain a saturated soil profile early in the season. Consequently, we were able to maintain water table levels above the creek surface in all distance bands until after irrigation cessation on August 14, 2002 (Figure 6). This suggests the stream was likely gaining water via effluent groundwater flow throughout the study reach during this period. However, irrigation water was completely diverted to other sites twice during the first half of the 2002 field season, therefore we did not observe substantial increases in water table elevation, such as those observed in late July and August 2001. Downstream heating was still observed early in the 2002 season, however, the magnitude of heating was much less than observed in previous years during this time period (Figure 7), which can likely be attributed to cooler, rather temperature constant groundwater inputs to the stream. The meadow containing Station 1 was irrigated in 2002, hence no comparisons can be made to a non-irrigated site within this treatment year. The seven-day moving mean of daily maximum stream temperature at Station 1 averaged 20.2ºC (68.4ºF), 0.5ºC warmer at Station 2 and 1.9ºC warmer at Station 7 during this period (t= -19.8, df=15, p=0.0001; t= -24.0, df=15, p<0.0001). General heating and cooling trends observed at all stations reflect fluctuations in ambient air temperature.

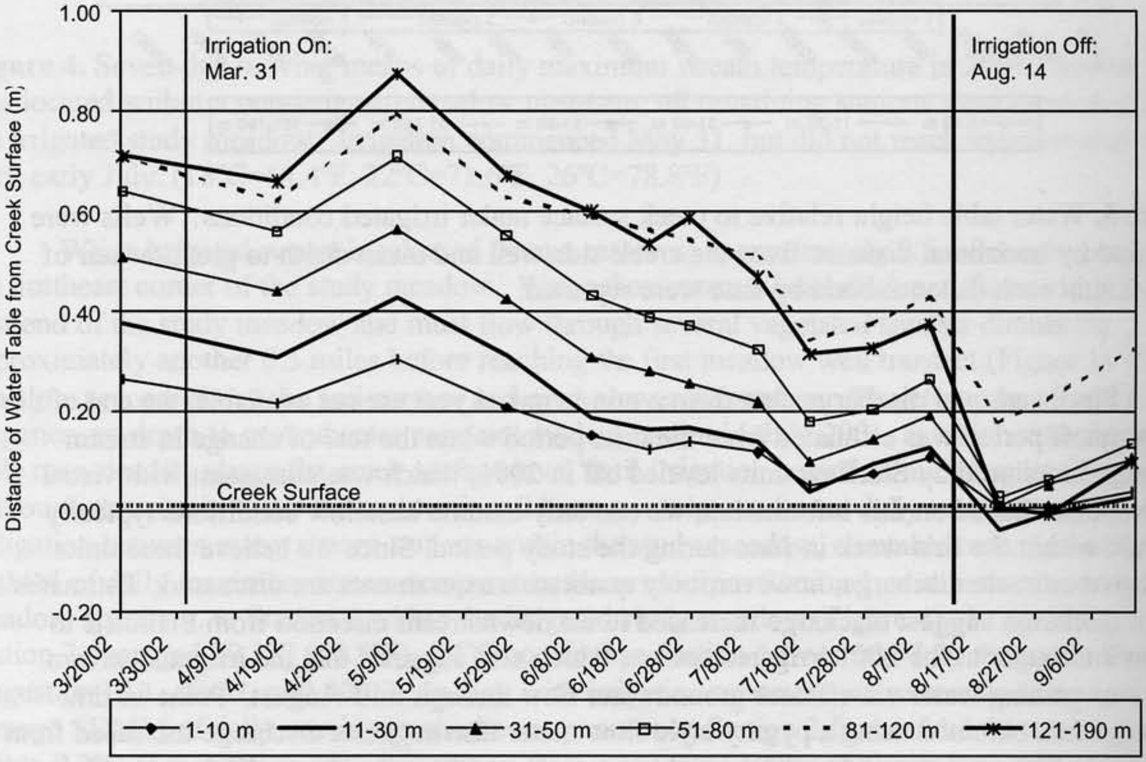

Figure 6. Water table height relative to creek surface under irrigated conditions. Wells were classified by horizontal distance from the creek-side well and mean depth to groundwater of wells within each distance band by date were reported.

By July 11, 2002, the SDMM of daily maximum stream temperature was greater at Station 1 than any station downstream (Figure 7). In particular, Station 1 averaged 26.2ºC, 0.6ºC cooler at Station 2 and 0.9ºC cooler at Station 7 from early to mid-July (t=21.8, df=12, p<0.0001; t=11.7, df=12, p<0.0001). Effluent groundwater flow was still evident, based on groundwater measurements, during this time period (Figure 6). Point-in-time stream discharge measurements indicate discharge increased from early June through mid-July; however, Station 2 discharge was greater than Station 7 discharge on July 18, and discharge at these stations were nearly equal on July 29 and August 8, 2001.

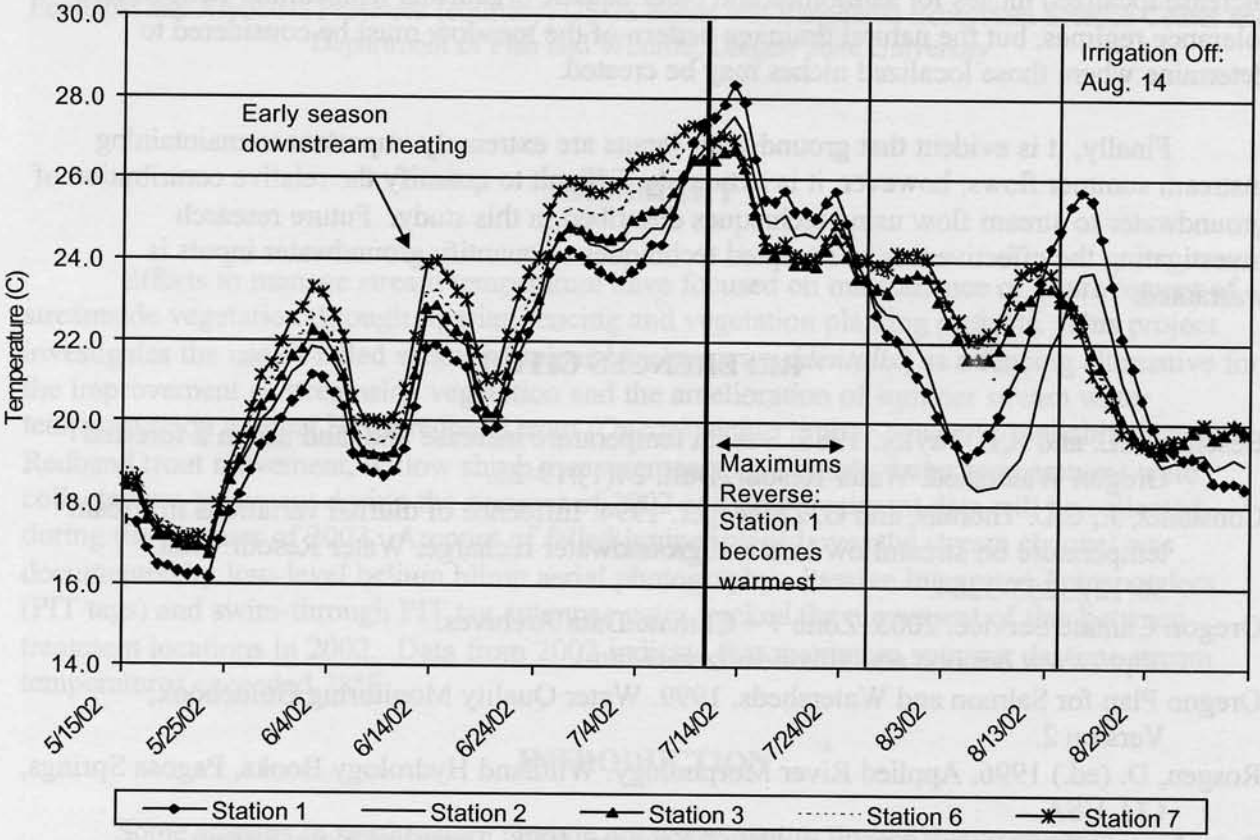

Figure 7. Seven-day moving means of daily maximum stream temperature in 2002. Station 1 was located within an irrigated meadow upstream; all remaining stations were located within the irrigated study meadow. Irrigation commenced March 31. (18ºC=64.4ºF, 22ºC=71.6ºF, 26ºC=78.8ºF)

CONCLUSIONS

The results of this study have illustrated that irrigation can be used to mitigate seven-day moving means of daily maximum stream temperature, primarily by maintaining effluent groundwater flow later in the season. Further, if irrigation is applied early in the season (i.e. March 31, 2002 in this study) and saturated or nearly saturated soil conditions are maintained the magnitude of early season downstream heating of maximum daily temperature may be reduced. By applying irrigation late in the season (i.e. May 31, 2001), the soil profile had already began to dry, and it took at least one month to see the effects of irrigation on the water table and stream temperature.

It is also important to conduct an initial site assessment prior to determining if subsurface flows, originating from irrigation, can be used to mitigate stream temperature within a desired stream reach. In the case of this study, the creek had been deliberately moved to the north side of the meadow and forced through a series of dikes. However, the drainage pattern of the majority of the meadow continues to follow the old creek bed. Although groundwater inputs were indeed observed returning to the creek through downstream banks, these inputs didn't begin to remerge until the final section of the study reach, which was beyond the extent of the study meadow. Thus irrigation could potentially be used to moderate stream temperature or to increase localized niches for salmonids and other aquatic organisms with similar temperature tolerance regimes, but the natural drainage pattern of the meadow must be considered to determine where those localized niches may be created.

Finally, it is evident that groundwater inputs are extremely important to maintaining instream summer flows; however, it is extremely difficult to quantify the relative contribution of groundwater to stream flow using techniques described in this study. Future research investigating the effectiveness of accepted techniques to quantify groundwater inputs is warranted.

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