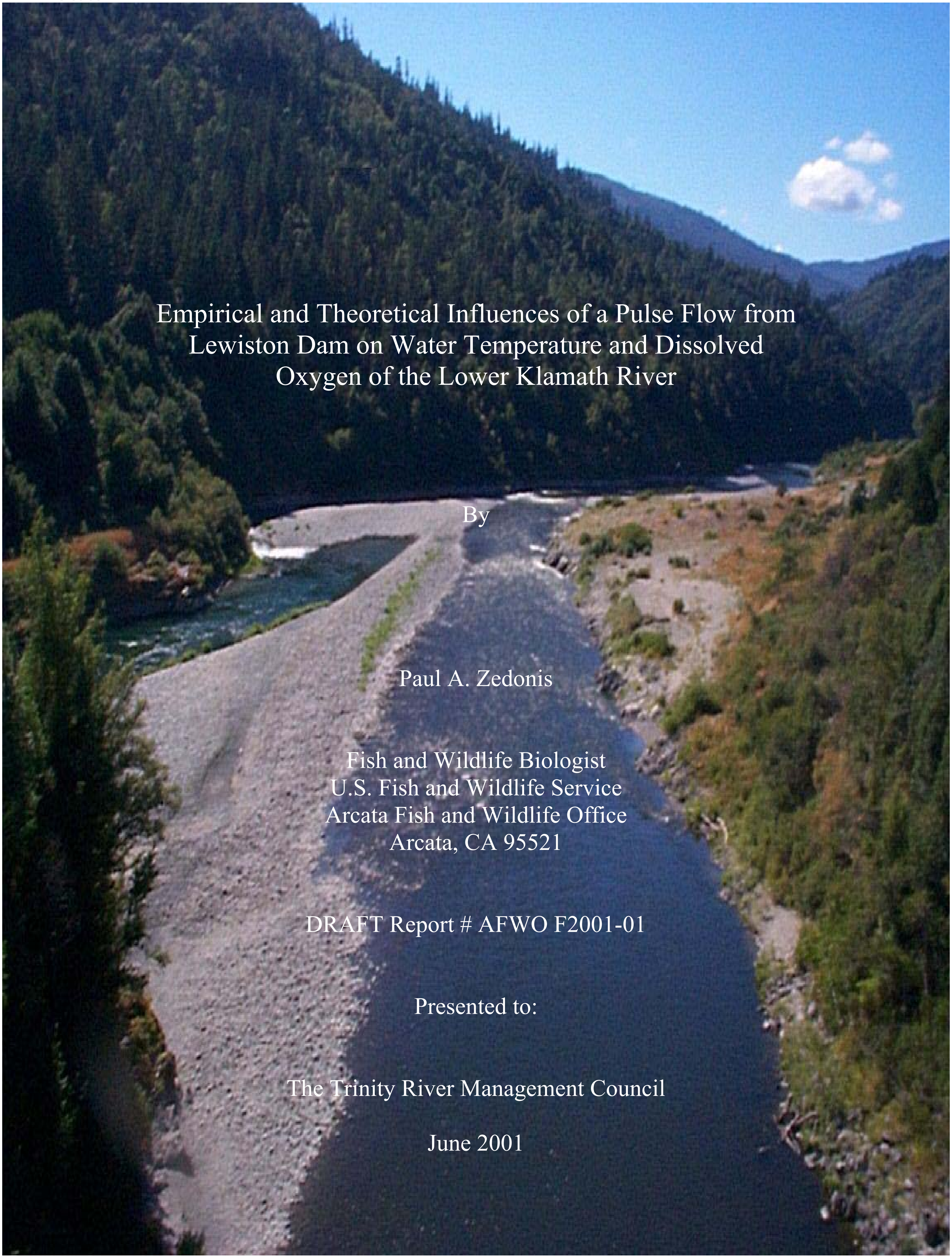

Empirical and Theoretical Influences of a Pulse Flow from Lewiston Dam on Water Temperature and Dissolved Oxygen of the Lower Klamath River

By

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DRAFT Report # AFWO F2001-01

Presented to:

The Trinity River Management Council

June 2001

Abstract

Field studies showed that a one-day pulse flow of 46.7 cms from Lewiston Dam, representing a 360% increase in dam release, decreased water temperatures of the entire mainstem Trinity River (180 kilometers) and resulted in markedly different thermal regime of the Trinity River at Weitchpec as compared to the Klamath River. It required approximately 47 hours for the pulse flow to influence the water temperatures of the Trinity River at Weitchpec. Water temperatures of the Trinity River were generally 2.8 ºC colder than the Klamath River and less than 17.2 º C.

A kinematic wave, generated by the one-day peak release, was observed at all stream gages along the Trinity River and lower Klamath River. The kinematic wave traveled at approximately 1.5 times that of the pulse flow water particles resulting in, for the most part, the wave reaching and passing the confluence area before the cold-water pulse. Because of this timing difference, the anticipated synergistic effect of a larger and colder flow from Trinity River did not materialize. The kinematic wave and the coldwater pulse both decreased water temperatures of the Klamath River below the confluence, although the later had the greatest effect (1 º C reduction)

A theoretical evaluation of the effects of the pulse flow on low dissolved oxygen concentrations of the Klamath River indicates a pulse flow from Lewiston Dam could substantially improve dissolved oxygen levels below the confluence. Dilution and lowered water temperatures are the two mechanisms that dissolved oxygen concentrations might increase.

Introduction

Water quality is an important factor to consider when evaluating the habitat quality of fishes. Two water quality factors that are very important to the well being of salmonids are high concentrations of dissolved oxygen (DO) and cool water temperatures. Elevated water temperatures and lower DO levels can stress salmonid fish and cause increased mortality due to increased susceptibility to disease and predation (U.S. EPA 1986).

Dissolved oxygen concentrations and warm water temperatures are potentially limiting salmonid production of the Klamath River (USFWS 1997, Bartholow 1995, Campbell 1995). Introduction of chemical compounds (nitrates and phosphates) from the upper Klamath River basin is the main reason for increased primary productivity and potentially poor water quality of the Klamath River, including periodic low DO levels (Campbell 1995).

Oxygen enters the water primarily as a result of two processes – gas exchange at the water's surface and oxygen production through photosynthesis by phytoplankton. During daylight hours oxygen production can be significant resulting in 100% saturation and even supersaturation (Wetzel 1983). During periods of low light, however, respiration by the same aquatic plants, fish, invertebrates, and microscopic animals (e.g. microbes that aerobically decompose organic matter) can deplete significant amounts of DO. In water bodies with high biomass and biological oxygen demands, DO concentrations may become low enough to be lethal to aquatic life. Prolonged exposure to low DO levels may not directly kill an organism, but will increase its susceptibility to other environmental stresses that may lead to mortality. In some instances, fish and aquatic invertebrates may be mobile enough to avoid harsh conditions. Less mobile creatures such as benthic invertebrates, may be more susceptible to low DO-induced stress. Warm water temperatures reduce the amount of DO further by increasing biochemical activity and reducing DO solubility.

Water quality of the mainstem Klamath River may become poor and result in fish kills and/or stressful rearing conditions despite dilution with tributary accretion, including typical 12.7 cms (450-cfs) releases from Lewiston Dam of the Trinity River (USFWS 1997). Surveys conducted during the summer of 1994 found dead juvenile chinook salmon along gravel bars in the lower most 56 kilometers of the Klamath River. We also received reports of mortality upstream of this area (USFWS 1997). The USFWS deducted that because there were no fish mortalities reported on the Trinity River when thermal regimes were similar to those of the Klamath that other water quality factors such as DO were the cause of fish mortality on the Klamath River.

In surveys conducted by the USFWS and California Department of Fish and Game, during early August 1997, salmonids and other fish were found dead or in a stressed state (USFWS 1997). Downstream migrant trapping data collected by the USFWS during this “mortality episode” had shown a high abundance of other fish species (suckers and dace) that were apparently avoiding poor water quality conditions by migrating downstream. Trap-captured fish included significant numbers of dead and stressed fish. DO levels (rkm 80.0) during the time of the surveys were as low as 3.1 ppm during the night and were likely the cause of mortality and stress. According to federal criteria, this level of DO is considered the lower limit to avoid acute mortality of salmonid fishes (USEPA 1986).

Flow conditions of the Trinity River are altered in odd years to accommodate ceremonial needs of the Hoopa Valley Tribe. Typically in late August or early September, the Bureau of Reclamation provides a one-day pulse-flow that is timed so as to arrive at the Reservation for a tribal dance ceremony.

While these pulse flows have occurred in subsequent years, little information has been collected on their effect to the physical environment. The purpose of this study was to assess the influences of a one-day 46.7-cms releasepulse flow from Lewiston Dam of the Trinity River on water temperature and DO concentrations of the Klamath River. Empirical and theoretical effects of the pulse flow are examined.

Study Area

The Klamath River Basin drains about 28,000 square kilometers in Oregon and California and is the second longest river in California (Figure 1). From Iron Gate Dam, the Klamath River flows for about 236 kilometers before reaching the confluence of the Trinity River at the small town of Weitchpec. From Weitchpec the Klamath River flows for another 70 kilometers before entering the Pacific Ocean near the town of Klamath. The Hoopa Valley Indian Reservation and Yurok Reservation reside along the lower 25.7 kilometers of the Trinity River and the lower 70 kilometers of the Klamath and River, respectively.

Water quality of the Klamath River and the Trinity River are substantially different and this is reflected in the intensity and type of land use activities within each basin/sub-basin and the size of the upstream water storage facilities. The Klamath Project of the upper Klamath River Basin (above Weitchpec) is typified by relatively small and shallow reservoirs, and land use activities include commercial agriculture, raising livestock, and logging. Return irrigation water is largely responsible for the increased concentrations of phosphates and nitrates in the Klamath River (Campbell 1995). In contrast, land use activities of the Trinity Basin are typified by logging and recreation.

The Trinity River basin, located immediately south of the Klamath Basin, contains the largest water storage facility in the Klamath River basin. Two reservoirs impounded by Trinity and Lewiston dams serve to regulate flow from the upper Trinity basin. Trinity Reservoir stores 2.45 million acre-feet and Lewiston Reservoir regulates Trinity Reservoir releases and serves as a point of diversion to the Sacramento River. From Lewiston Dam, the Trinity River flows for 180.2 kilometers before reaching the confluence of the Klamath River. Hypolimnetic releases from Trinity Reservoir typically assure cold-water releases occur year round. Water quality of the Trinity River is considered to be superior to that of the Klamath River (NCRWQCB 1994, Campbell 1995).

In 1999, the year in which this evaluation was conducted, Lewiston Dam releases were increased from 12.7 cms to 46.7 cms on September 12, maintained at 46.7 cms during September 13th, and decreased to 12.7 cms during September 14th.

Methods

Pulse Flow Travel Time

Stage height at stream gages was used to identify the timing of the influence of the pulse flow along the Trinity and lower Klamath Rivers. More aptly, the gage data represented estimates of the travel time of the kinematic wave that was propogated downstream at a rate much faster than that of actual travel time for water particles from the peak release (Linsley et al. 1982). An approximation of the actual travel time of the peak release was determined using a theoretical ratio between wave and water velocity for a wide rectangular channel or 1.5:1 (Linsley 1982). [(Note: As the kinematic wave travels downstream there are sequentially small blocks of water that are temporarily moving at a rate equivelent to that of the kinematic wave. As such, this kinematic wave that is identified by the gage data represents an estimate of flow (T.Waddle pers. comm)].

Flow gage data were attained from the California Data Exchange Center website (http://cdec.water.ca.gov/). Gage data used in the evaluations included: Lewiston (rkm 178.6), Douglas City (rkm 149.0), and Hoopa (rkm 20.0). Gage data used for the Klamath River included the Orleans gage (rkm 94.9), which served to identify flow estimates before the point of mixing at Weitchpec, and the Turwar gage, located at rkm 10.6 of the Klamath River.

Water Temperature

Hourly water temperature data were collected throughout the Trinity River and at select sites in the Klamath River. On the Trinity River, ten monitoring sites were chosen for the evaluation and they were located at: rkm 178.6, 148.5,127.5,117.8,94.3, 74.0, 50.5, 33.8, 20.0, 0.0. Of these ten sites, data for those located at rkm 178.6, 148.5, 117.8, 20.0 were attained through internet resources (http://cdec.water.ca.gov/). All other sites were monitored with calibrated temperature recorders accurate to within 0.1 Celsius. On the Klamath River, water temperature data was collected just above the confluence with the Trinity River (RKM 70.2).

During the field visit, periodic water temperature measurements (grab samples) were taken using a YSI Multiprobe (Model 85/25 FT; SN 97DO957AB). This instrument was calibrated against a NIST certified mercury thermometer earlier in the year (May 17th, 1999) and found to exactly match the NIST thermometer at temperatures ranging from 10 to 25 º C. This instrument can detect sensing changes of 0.1 º C.

Dissolved Oxygen Data

All attempts to collect DO information at the confluence area essentially failed. Both the Hydrolab ® that was deployed in the Klamath River (rkm 70.2) and the YSI dissolved oxygen probe failed during the time of the study. Therefore, the influence of the pulse flow on DO levels in the Trinity and Klamath Rivers could not be determined.

Because of the lack of real data, a theoretical evaluation of the influences of the pulse flow on DO concentrations was conducted. This evaluation was intended to provide an idea of the “sensitivity” of DO concentrations of the Klamath River below the confluence due to a pulse flow in the Trinity River. To conduct the analysis, hourly DO concentrations of the Trinity and Klamath Rivers were assumed or based upon historical data sets. The Trinity River, which typically runs clear, was assumed to have saturated conditions for the actual water temperature during the time of the study and assumed constant atmospheric pressure (740 mm Hg). Using these criteria, diurnal fluctuations of the Trinity River were relatively small (i.e, range = 9.0 to 9.5 ppm). In contrast, the DO profile used to represent the Klamath River was assumed to have large diurnal fluctuations and was developed from the DO profile attained by the USFWS during the time of a fish kill in 1997 (USFWS 1997). During this fish kill, the DO concentrations ranged from 3.1 to 7.6 ppm. For this study, this diurnal pattern was scaled upward (1.4 ppm) to represent actual water temperature conditions during the study. After scaling, the DO profile ranged from 4.5 to 9.0 ppm. For evaluation purposes and to represent near worse case conditions, this diurnal pattern was applied to days before, during, and after the pulse flows influence at the confluence. Resultant effects of the pulse flow on DO concentrations below the confluence were determined with Equation 1.

Equation 1:

$$\frac{A_{Trin} * Q_{Trin} + A_{Klam} * Q_{Klam}}{Q_{Mix}} = A_{Mix}$$

Where: $\mathbf{A}_{\mathbf{Trin}}$ is the water temperature or DO concentration of the Trinity River;

$\mathbf{A}_{\mathbf{Klam}}$ is the water temperature or DO concentration of the Klamath River;

$\mathbf{Q}_{\mathbf{Trin}}$ is the flow of the Trinity River;

$\mathbf{Q}_{\mathbf{Klam}}$ is the flow of the Klamath River;

$\mathbf{Q}_{\mathbf{Mix}}$ is the combined flow of the Trinity and Klamath Rivers;

And, $\mathbf{A}_{\mathbf{Mix}}$ is the resulting water temperature or DO concentration after mixing of the Trinity River with the Klamath River.

DO criteria from EPA (1986; www.epa.gov/cgi-bin/claritgw) were used to provide relative comparisons of conditions before, during, and after the influence of the pulse flow in relation to salmonid requirements. DO criteria for salmonids, as described in EPA (1986), are provided in Table 1.

Trinity River Mixing with the Klamath River

Field surveys were conducted prior to and during the high flow to identify the distance that mixing of Trinity and Klamath River water was complete. Evaluation of the spatial effects of mixing was considered important to be able to make inferences on the effects to aquatic life passing through these areas. In some steams, tributary flow may not become thoroughly mixed for a great distance (J.Bartholow pers. comm.).

Because water temperatures of the Trinity and Klamath Rivers were different (Trinity River was colder) during the time of the field study, water temperature was a useful parameter to identify the distance at which mixing of the two rivers was complete. Using a jet boat, a YSI hand-held multimeter, and working upstream to downstream, water temperatures were monitored laterally (perpendicular to the stream channel) and vertically in search of the point at which water temperatures were uniform (i.e., mixing was complete). When located, the distance to the junction of the Trinity to the Klamath Rivers was estimated with a lazer range finder. This procedure occurred before and during the time of the arrival of the kinematic wave.

Results

Kinematic Wave and Pulse Flow Travel Time

The influence of the pulse flow on river stage, or kinematic wave timing, was readily identified by stream gages along the Trinity River and lower Klamath River (Table 2, Figure 2). Evaluation of the gage data indicated the leading edge of the wave took 5 hours to travel from Lewiston (rkm 178.6) to Douglas City (rkm148.5), 21 hours from Douglas City to Hoopa (rkm 20.0), and 14 hours from Hoopa to Turwar (rkm 10.6 on Klamath River or 79.3 kilometers below the Hoopa gage). In total, it took approximately 40 hours for the kinematic wave to travel from Lewiston to Turwar (238.0 km).

Using the aforementioned information, estimates of kinematic wave velocities, and correspondingly pulse flow travel times were determined. The average kinematic wave velocities between gage sites ranged from 5.6 to 6.1 kilometers per hour (kph)(Table 3). Using the theoretical ratio of 1.5:1 between wave and water velocity identified by Linsley et al (1982), estimates of the velocity of the water of the peak release ranged from 3.7 to 4.0 kph. Using these water velocities, the estimates of travel time of the pulse flow (rather than the kinematic wave) from Lewiston gage to Douglas City, Hoopa, Weitchpec, and Turwar gages were 7.5, 39, 44, and 60 hours, respectively.

Examination of Figure 2 reveals that the timing of ramp-up, peak wave arrival and end, and ramp-down were clearly identified in the Lewiston and Douglas City gage data. Further downstream, however, some pulse flow features were not as readily identifiable. While the time of the peak wave arrival was readily identified at these lower river sites, the duration of the peak became less clear, and the ramp-down was more gradual than at upper river sites. As indicated in Table 2, however, the overall duration of the pulse (i.e., 59 to 64 hours), which includes ramp-up and ramp-down, was fairly similar at all gage stations.

The pulse flow raised the stage height at the Lewiston, Douglas City, and Hoopa gages by 0.43, 0.52, and 0.43 meters, respectively.

Water Temperatures

Water temperatures along the Trinity River were influenced by the pulse flow (Figure 3). Areas closest to the dam did not exhibit large changes in water temperature. Areas further downriver, however, did experience greater changes and the effect was delayed. The delayed effect is evident from Figure 3. The greatest effect to water temperatures of the lower Trinity River occurred on September 15 and 16, or 2 to 4 days after the start of the peak release at Lewiston Dam. Using the theoretical relationship of kinematic wave velocity to water velocity indicated the peak release from Lewiston Dam arrived at Weitchpec in 44 hours. This estimate is a close approximation of the time when water temperatures of the lower Trinity River were initially influenced by the pulse flow, or 47 hours.

Examination of temperature regimes before the pulse flow's influence provided baseline evidence from which to compare conditions during and after the pulse to reveal the influences of the pulse flow on water temperature of the lower Klamath River (Figure 4). From September 11 to 14, base flow conditions were generally 1 to 2 °C colder than the Klamath River. On September 15, the largest effect of the pulse flow was observed at approximately 3:00 pm (62 hours after the peak release), when the Trinity River was 16.8 °C and the Klamath River was 20.4 °C. Continued influence of the pulse flow was noted for several days after September 15, as well. From September 15 to 17 water temperatures of the Trinity River were generally 2.8 °C colder than the Klamath River and less than 17.2 °C. Beginning late on September 17, the effects of colder water temperatures of the Trinity River were diminishing and more closely resembled pre-pulse flow diurnal patterns.

The resultant effect of the one-day pulse flow on water temperatures at the confluence is interesting in that the duration of the pulse was short enough that the combined effect of decreased water temperatures and increased flow did not synergistically influence the water temperature of the Klamath River below the confluence. In essence, one can think of the kinematic wave as initially carrying a block of warmer water located in the lower river to the confluence area. Water temperatures started to decline after passage of the peak pulse flow (kinematic wave) late on September 14. During this time, a small reduction in water temperature occurred below the confluence (Figure 4). From September 15 to the middle part of September 16, down-ramping flows and markedly colder water of the Trinity River had the greatest overall influence on water temperatures below the confluence. The greatest effect occurred on September 15th when the water temperature of the Klamath River was reduced by about 1.0 °C.

Distance to Complete Mixing

Water temperature monitoring above, at, and below the confluence was adequate to identify and characterize the spatial effect of mixing under base-flow and pulse-flow conditions. The distances at which the Trinity and Klamath Rivers became completely mixed during base-flow and pulse-flow conditions were 69 and 124 meters, respectively. Factors suspected for the rapid mixing included: 1) substantial kinetic energy of Trinity and Klamath River water due to high gradients and increased river velocities before the confluence, 2) the relatively large angle (estimated at 45 degrees) that the Trinity River joins the Klamath River which caused increased turbulence, and 3) the river flow at the confluence is directed into a large bedrock outcrop and then into a deep pool with other bedrock projections that created additional turbulence.

Stream Gage Error

While the water temperatures determined from the YSI meter matched the water temperatures collected with the probes located above the confluence, the water temperature of the mixed zone, as determined by Equation 1, was within 0.2 °C less than the temperature identified by the YSI meter (Figure 4). As I trust the results of the YSI meter and believe that the water was thoroughly mixed at the identified locations, the most probable factor that may have caused these discrepancies is inaccurate flow gage data. If this is the case, the Orleans Gage on the Klamath River is over-predicting flow or the Hoopa Gage on the Trinity River is under-predicting flow or a combination of both occurred.

Theoretical Effects of the Pulse Flow on DO Concentrations in the Lower Klamath River

The possible influences of the pulse flow on low and widely fluctuating simulated DO concentrations in the lower Klamath River are illustrated in Figure 5. Prior to the pulse flow's influence (Sept 10th to 13th), the effect of the Trinity River water on Klamath River DO would be relatively small. The greatest effect occurs during the night when the DO of the Klamath River is lowest. During the early morning, the mixing of Trinity River water results in DO concentrations that are increased by approximately 0.5 ppm. Using EPA criteria (as identified on the secondary y-axis of Figure 5), this small increase improves conditions from "Severe Production Impairment" (Zone D) to "Moderate Production Impairment" (Zone C). In the afternoon, when DO is high and similar between rivers, the effect of the Trinty River water becomes negligible.

Upon arrival of the kinematic wave on the September 14th, the effectiveness of Trinity River water in increasing DO of the lower Klamath River increased. Similar to pre-pulse flow conditions, the greatest effect should occur during the morning hours when DO of the Klamath River is low. During the morning hours, DO of the Klamath River water increased from 4.5 to 5.9 ppm. Using criteria from EPA (1986), the wave further improved conditions for aquatic life. As is shown in Figure 5, production impairment was decreased from "Severe Production Impairment" (Zone D) to approximately "Light Production Impairment" (Zone B). Since water temperatures were not substantially affected on the September 14th, the improved DO can be attributed to the dilution from increased Trinity River water. On September 15, DO levels remained relatively high due relatively high flow as well as reduced water temperatures. After the September 15, DO profiles gradually returned to pre-pulse flow conditions.

Discussion

The pulse flow reduced the water temperature of the Klamath River. However, the short duration of the pulse resulted in the kinematic and cold-water components of the pulse flow having non-concomitant effects. The kinematic wave, which arrived earlier than the cold-water pulse, provided a larger volume of water to dilute the slightly warmer Klamath River. Due to the small differences in water temperature, the effectiveness of dilution was not that influential on water temperatures of the Klamath River. In contrast, the cold-water component of the pulse resulted in a larger effect on the water temperature of the Klamath River, reducing it by up to 1.0 °C. While each component was able to reduce the water temperature of the Klamath River, a pulse flow of longer duration would have allowed a greater period of overlap between the kinematic wave and coldwater pulse resulting in a synergistic effect and further reducing the water temperature of the Klamath River.

While it is known from empirical and modeling results that Lewiston Dam releases do influence water temperatures at Weitchpec (Zedonis 1997, USFWS and HVT 1999), overall the influence of reduced water temperatures on DO concentrations of the lower Klamath River do not appear to be the dominant factor when a short-duration pulse flow occurs. Rather, the effect of diluting the Klamath River (low DO) with Trinity River water (high DO) would likely have a greater effect. This would probably be most evident during the early morning hours when the differences in DO between the Trinity and Klamath rivers would be greatest. Water temperature reductions do increase the amount of DO that can be retained in water, but proportionally the effect of dilution is greater than relatively small reductions in water temperature. Again, however, this conclusion may only be supported when the DO concentrations of both rivers exhibit relatively large differences. If DO of the Trinity River experiences large fluctuations like the Klamath River, then the effect of reducing water temperature, as a means of improving DO, may become the dominant factor.

Meteorology largely influences water temperatures. Incidentally, the meteorology of lower Trinity River basin was affected by dense smoke from a series of fires, but most notably the Megram fire, the largest of fires. Smoke from these fires filled the valley floor for most of the summer and probably inhibited the heating effects of solar radiation on air temperature and water temperatures. In turn, water temperatures of the lower river may have been cooler than they would have been in the absence of smoke.

While I believe the effects of the pulse flow on river stage and water temperature are fairly well known, the effect of the pulse flow on DO concentrations is somewhat speculative due to the assumptions used in the evaluation. In particular, the DO profiles chosen for each of the rivers prior to mixing may not represent conditions that could occur. Is DO of the Trinity River always saturated? An answer to this type of question would certainly assist in our understanding on how a pulse flow effects the overall DO of the lower Klamath River. This is especially true when DO concentrations of the Klamath River are very low. If DO is lower than what I assumed, the overall effectiveness of dilution of the lower Klamath River with Trinity River water would be lessened. Because the DO profiles developed for the Klamath River were based upon empirical data collected in the field (USFWS 1997), I believe that these data can be representative of conditions that may occur in the future.

Summary

- This study revealed the temporal and spatial effects of a one-day dam release of 46.7 cms from Lewiston Dam of the Trinity River, which represented a 360% increase from base-flow conditions.

- The kinematic wave propogated from the peak release of the pulse flow required approximately 29.5 hours to travel from Lewiston Dam to the Klamath River, or 180 kilometers.

- The kinematic wave from the peak release increased the stage height at gages along the Trinity River by 0.43 to 0.52 meters.

- It required from 44 to 47 hours for the pulse flow (as opposed to the kinematic wave) to reach the Klamath River, and at this time a temperature effect occurred.

- The largest influence on water temperature occurred 62 hours after the peak release, when the Trinity River became 3.6 °C colder than the Klamath River. The influence of the pulse flow continued for two additional days, after which diurnal temperature patterns more closely resembled pre-pulse flow conditions.

- The one-day pulse flow from Lewiston Dam was not sufficient in duration to allow the kinematic wave (representing increased flow for increased dilution of Klamath River water) and the colder water of the pulse flow to have synergistic effects on improving the water quality of the Klamath River.

- Water temperatures of the Trinity River were 1 to 2 C colder than the Klamath River before the pulse flow and this may be attributed to reduced solar heating of the river and valley floor due to dense smoke from large forest fires that were occurring in the lower Trinity River basin.

- The channel morphology above and at the confluence of the Klamath and Trinity Rivers is diverse and resulted in almost instantaneous mixing of the Trinity River with the Klamath River.

- Stream gages located at Orleans and Hoopa may be inaccurate.

- Low dissolved oxygen concentrations of the Klamath River could be improved with a pulse flow from the Trinity River. Dilution appears to have the greatest effect, especially when DO concentrations of the Trinity River and Klamath River are very different, such as in the early morning. Reduced water temperatures are also likely to help.

Recommendations

- If and when pulse flow conditions are available, evaluate their effects and the potential effects on downstream water quality. On the Trinity River, the next opportunity is likely to occur in late August or early September of 2001 when the Hoopa Valley Tribe will again conducts it's White Deerskin Boat Dance.

- If evaluations of this sort continue, improve the accuracy of estimates of flow of the Trinity and Klamath Rivers before the confluence. Accurate estimates of flow contributions would allow for more accurate estimates of the Trinity River's influence on the water quality below the confluence.

- Collect accurate water temperature and DO data at the mouth of the Trinity River and along the Klamath River to determine the extent of poor water quality conditions over all water year types. Collection of this information is expensive, but in it's absence the problem cannot be thoroughly understood and nor can appropriate management actions be taken.

- Utilize accurate DO data to develop a water quality model of the Klamath that includes major tributaries such as the Trinity River. Through predictive modeling and monitoring, determine when, where and why dissolved oxygen levels decrease. Answers to these types of questions would provide water managers a better understanding of the problem and potential remedies, which could possibly include the use of a pulse flow from the Trinity River to temporarily improve conditions of the lower Klamath River.

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Personal Communications

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Table 1. Dissolved Oxygen Concentrations Versus Quantitative Level of Effect for Salmonid Waters (EPA 1986)[a].

Impairment Level	Threshold (ppm)
None	8
Light	6
Moderate	5
Severe	4
Limit to Avoid Acute Mortality[b]	3

a – Criteria are for salmonid lifestages other than embryo and larval stages.

b – Minimum should be considered as instantaneous concentrations to be achieved at all times

Table 2. Travel time of the kinematic wave propogated from the 46.7 cms pulse flow from Lewiston Dam.

Gage Site	**Ramp-up**	**Peak Arrival**	**Peak End**	**Ramp-down End**	**Pulse Duration in hours (peak)**
Lewiston	9/12 @ 15:00	9/13 @ 01:00	9/14 @ 00:00	9/15 @ 02:00	59 (23)
| 29.6 km ↓	| 6 hr ↓	| 5 hr ↓	| 4 hr ↓	| 8 hr ↓	
Douglas City	9/12 @ 21:00	9/13 @ 06:00	9/14 @ 04:00	9/15 @ 10:00	61 (22)
| 129.1 km ↓	| 25 hr ↓	| 21 hr ↓	| 19 hr ↓	| 28 hr ↓	
Hoopa	9/13 @ 22:00	9/14 @ 03:00	9/14 @ 23:00	9/16 @ 14:00	64 (20)
| 79.3 km ↓	| 12 hr ↓	| 14 hr ↓	| ND ↓	| 7 hr ↓	
Turwar	9/14 @ 10:00	9/14 @ 17:00	ND	9/16 @ 21:00	59 (ND)
Totals (hrs)	43	40	**NA**	43	-

ND – Not Discernible, NA – Not available due to uncertain duration at the Turwar Gage.

Table 3. Peak Flow Kinematic Wave and Water Velocities of a 46.7 cms Pulse-Flow from Lewiston Dam

Location	**Kinematic Wave**			**Peak Flow**		
	Peak Wave Arrival Time	**Cumulative Travel Time (hr)**	**Average Velocity (kph)**	**Arrival Time (hr)**	**Cumulative Travel Time (hr)**	**Average Velocity (kph)**
Lewiston Gage	**9/13 @ 01:00**			**9/13 @ 01:00**		
|	|	|			|	
29.6 km	**5 hr**	**5**	**5.9**	**7.5**	**7.5**	**3.9**
↓	↓	↓			↓	
Douglas City Gage	**9/13 @ 06:00**			**9/13 @ 8:30**		
|	|	|			|	
129.1 km	**21 hr**	**26**	**6.1**	**31.5**	**39**	**4.0**
↓	↓	↓			↓	
Hoopa Gage	**9/14 @ 03:00**			**9/14 @ 20:00**		
|	|	|			|	
20.0 km	**3.5 hr**	**29.5**	**5.6**	**5**	**44**	**3.7**
↓	↓	↓			↓	
Weitchpec	**9/14 @ 06:30**			**9/15 @ 02:00**		
|	|	|			|	
59.4 km	**10.5 hr**	**40**	**5.6**	**16**	**60**	**3.7**
↓	↓	↓			↓	
Turwar Gage	**9/14 @ 17:00**			**9/15 @ 20:00**		

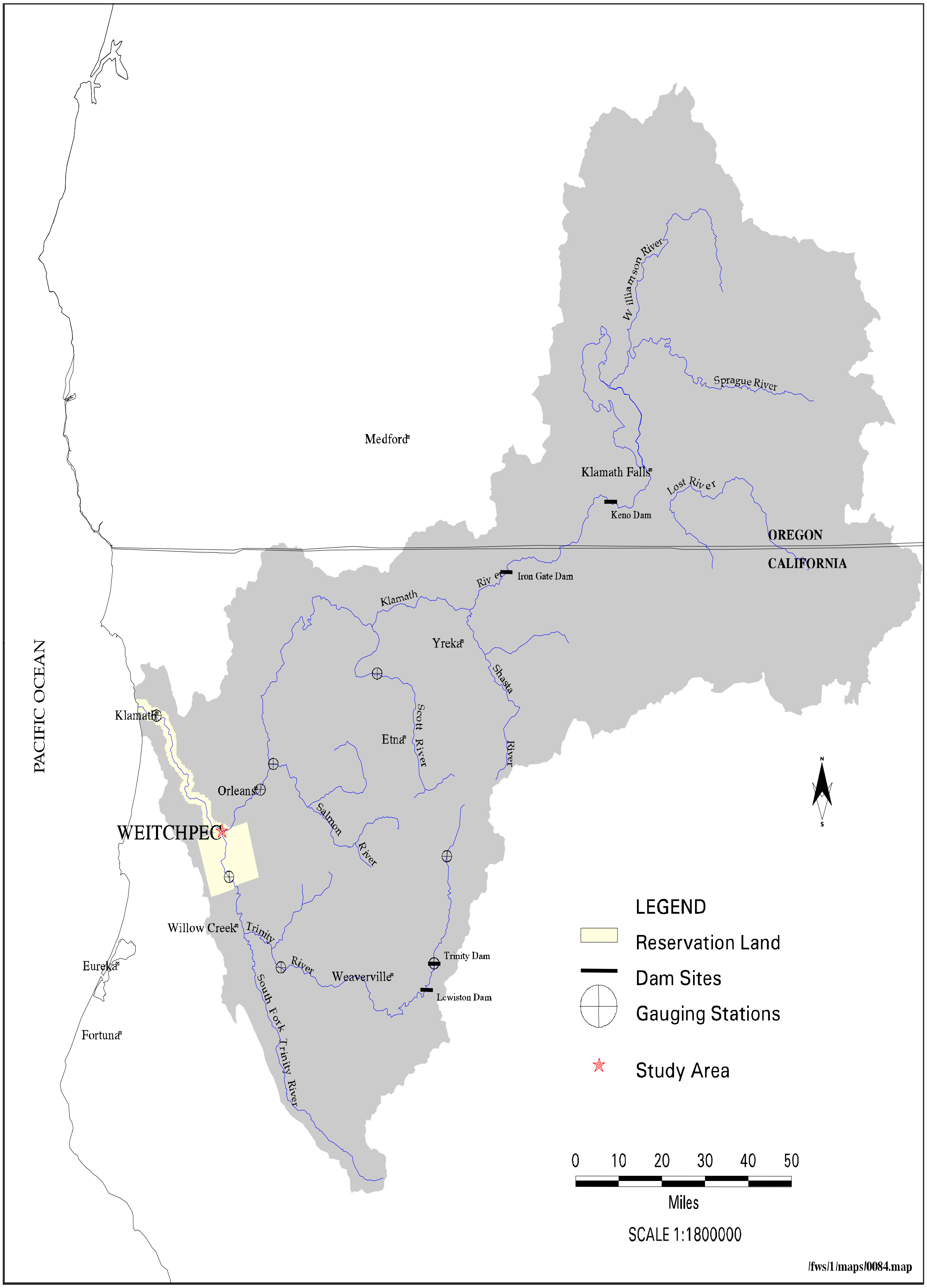

Figure 1. Klamath River Basin

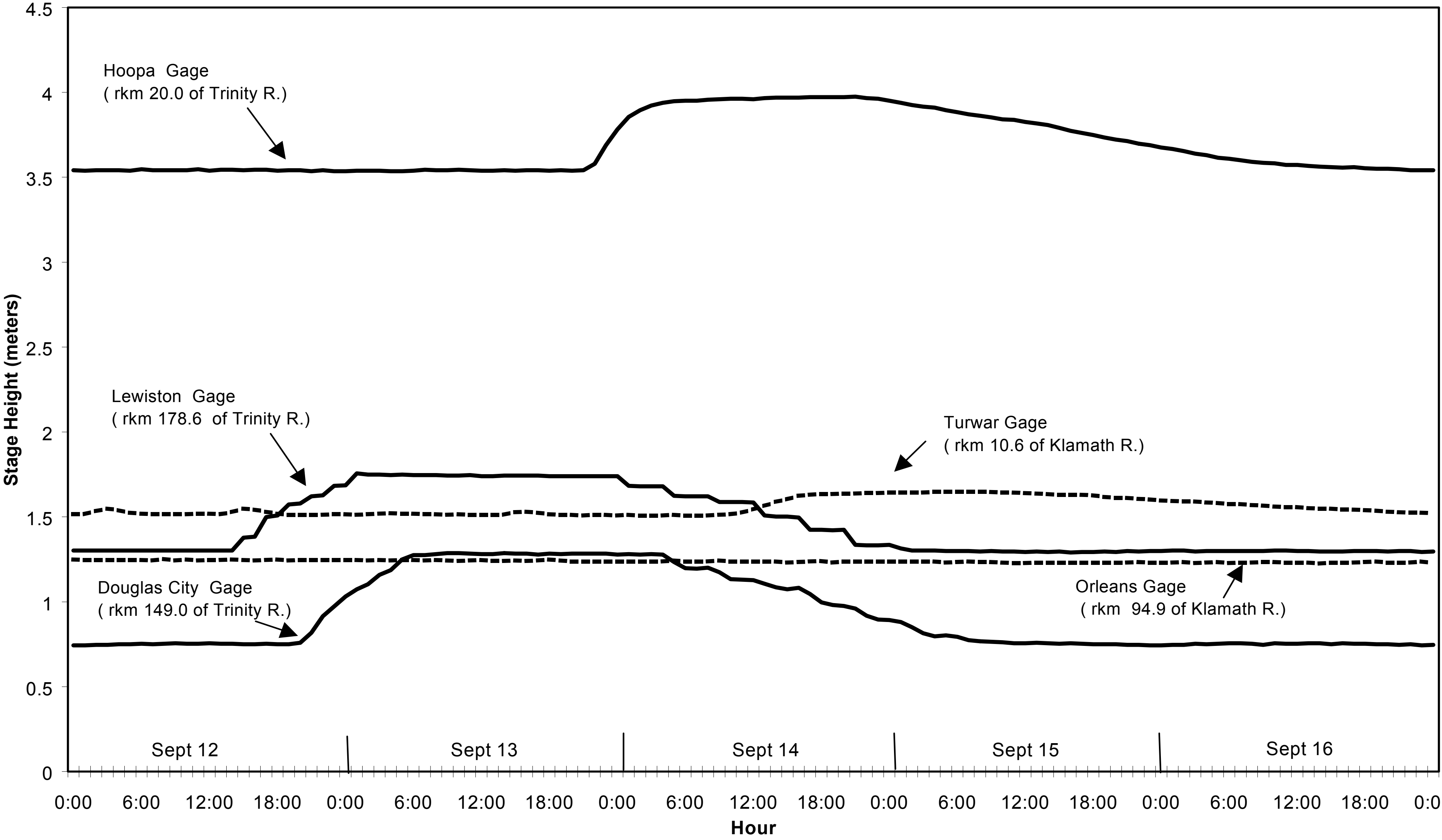

Figure 2. Temporal Influence of the 46.7 cms pulse-flow on staff gages along the Trinity River and lower Klamath River. Verticle lines represent approximate times of peak flow arrival.

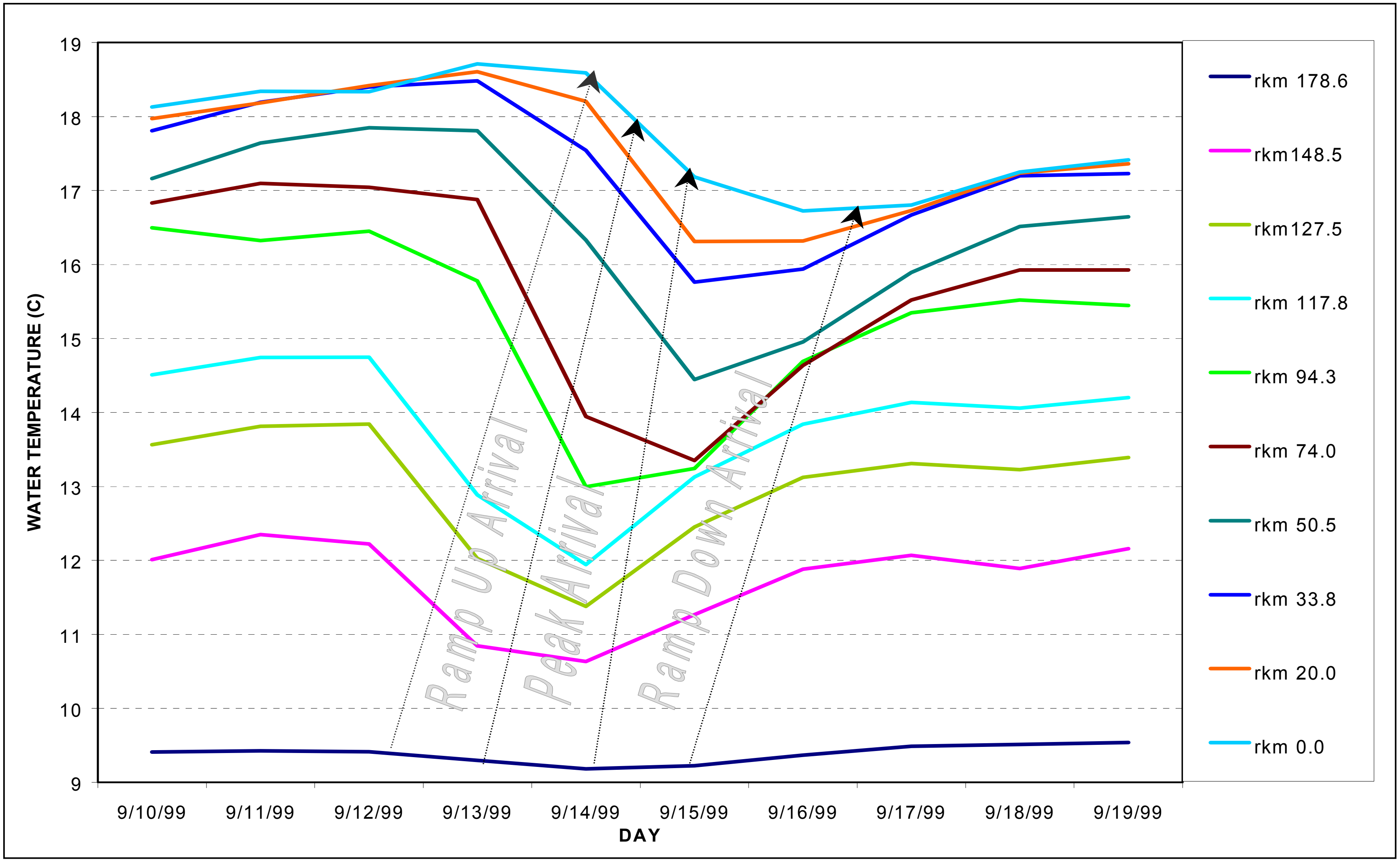

Figure 3. Spatial and temporal distribution of the kinematic wave propogated from the 46.7 cms pulse-flow and its effect on water temperature in the Trinity River, September 1999.

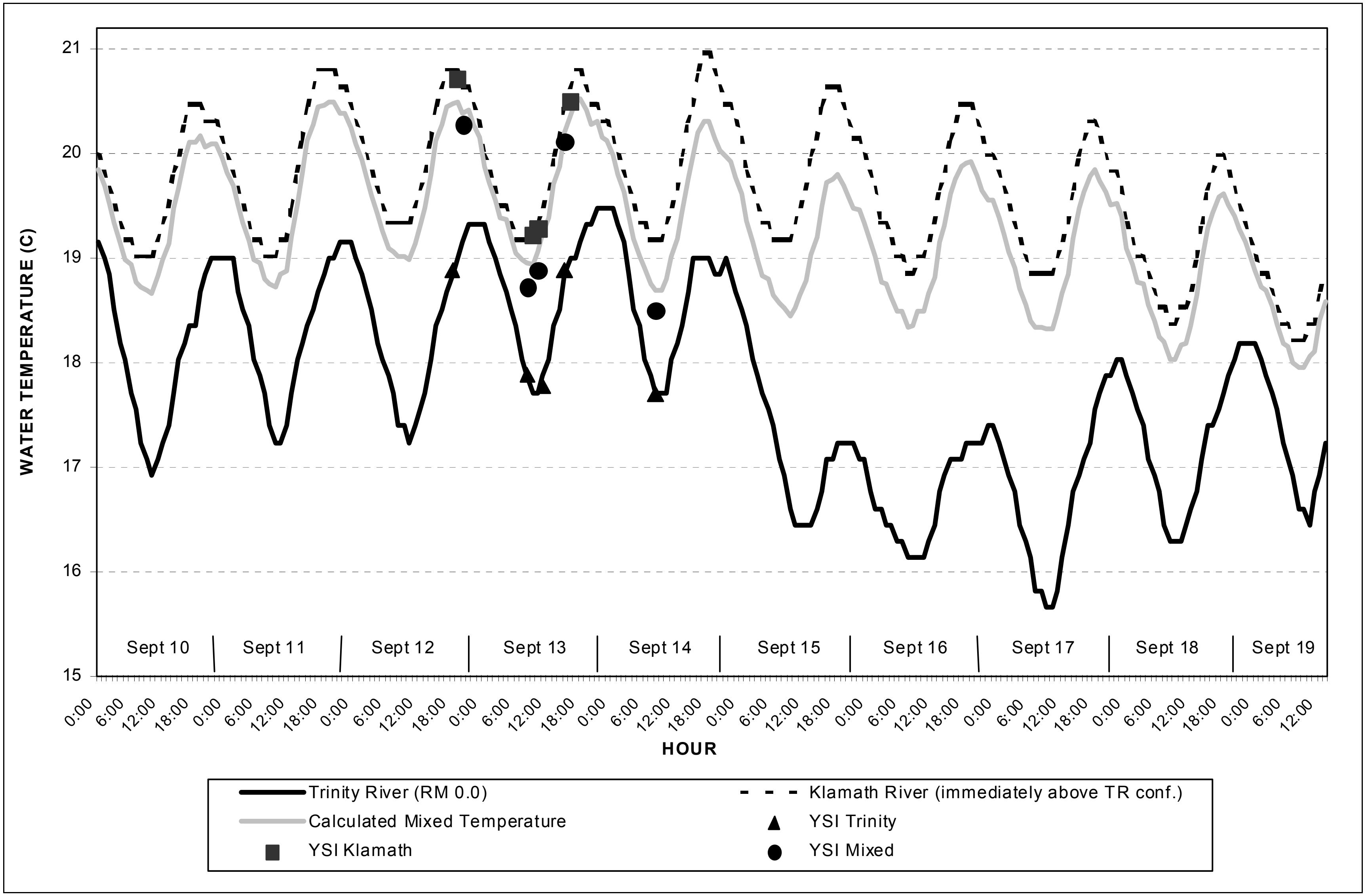

Figure 4. Comparison of hourly water temperatures of the Trinity River and Klamath River, predicted mixed water temperatures, and spot measurements of water temperature collected with a calibrated YSI multimeter, September 1999.

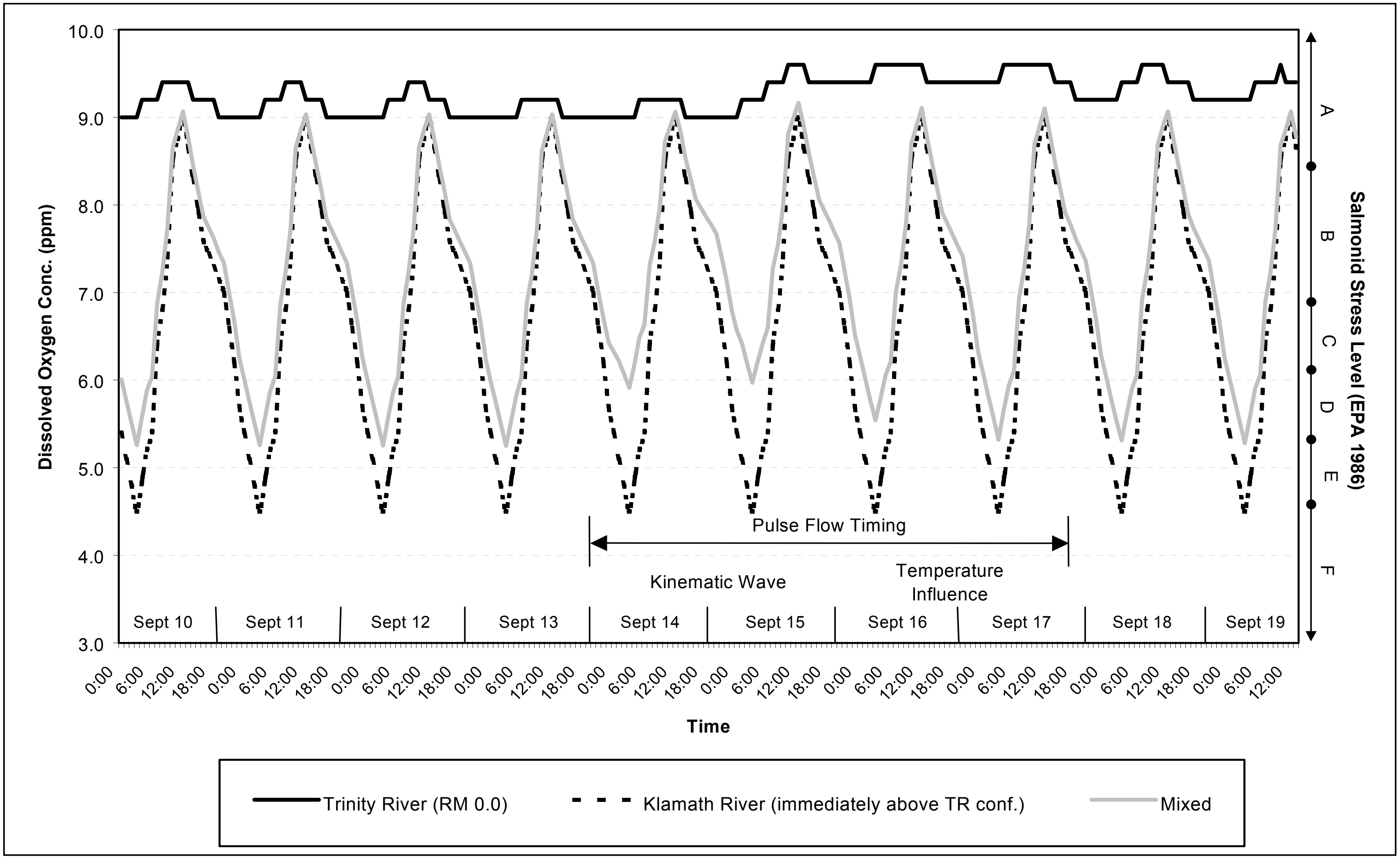

Figure 5. The influence of the 46.7 cms pulse-flow on dissolved oxygen (DO) concentrations below the confluence of the Klamath River. DO concentrations of the Trinity River are assumed 100% saturated, while those of the Klamath River represent a hypothetical data set based upon real data. Stress levels for salmonids are: A = no production impairment, B = light production impairment, C = moderate production impairment, D = severe production impairment, E = approximate threshold for acute mortality, and F = zone of acute mortality.