Effect of Water Quality on Survival of Lahontan Cutthroat Trout Eggs in the Truckee River, West-Central Nevada and Eastern California

United States Geological Survey Water-Supply Paper 2319

Prepared in cooperation with the U.S. Fish and Wildlife Service and the U.S. Bureau of Indian Affairs

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U.S. GEOLOGICAL SURVEY

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U.S. FISH AND WILDLIFE SERVICE

Prepared in
cooperation with the
U.S. Fish and Wildlife
Service and the
U.S. Bureau of
Indian Affairs

A product of the River-Quality Assessment of the
Truckee and Carson River Basins, Nevada and California

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2319

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Conversion Factors and Abbreviations

International System (metric) units of measure used in this report may be converted to "inch-pound" units by using the following factors:

Multiply	By	To obtain
Centimeters (cm)	0.3937	Inches (in.)
Centimeters per second (cm/s)	0.03281	Feet per second (ft/s)
Cubic meters per second (m^3/s)	35.31	Cubic feet per second (ft^3/s)
Grams (g)	0.03527	Ounces (oz)
Kilometers (km)	0.6214	Miles (mi)
Liters (L)	0.2642	Gallons (gal)
Meters (m)	3.281	Feet (ft)
Millimeters (mm)	0.03937	Inches (in.)
Square meters (m^2)	0.000247	Acres
Square meters (m^2)	10.76	Square feet (ft^2)

Temperature may be converted from degrees Celsius (°C) to degrees Fahrenheit (°F) by using the following formula: $°F=[(1.8)(°C)+32]$.

Altitude Datum

The term "National Geodetic Vertical Datum of 1929" replaces the formerly used term "mean sea level" to describe the datum for altitude measurements. The geodetic datum is derived from a general adjustment of the first-order leveling networks of both the United States and Canada. For convenience in this report, the datum also is referred to as "sea level."

Effect of Water Quality on Survival of Lahontan Cutthroat Trout Eggs in the Truckee River, West-Central Nevada and Eastern California

By Ray J. Hoffman *and* G. Gary Scoppettone

Abstract

The U.S. Fish and Wildlife Service has an ongoing program to assess the feasibility of reestablishing naturally spawning populations of Lahontan cutthroat trout in the Truckee River-Pyramid Lake system in Nevada. Previous *in situ* egg-survival studies have documented a 100 percent mortality of cutthroat trout eggs artificially planted in potential spawning gravels in the Truckee River downstream from Reno. The relation between ambient river-quality conditions and the observed mortality of eggs, however, has not been adequately documented. This study was designed to monitor the quality of surface and intragravel water during a trout-egg incubation period that began March 10, 1980. Five sites were monitored: two upstream from Reno (background sites), one near Reno, and two downstream from Wadsworth.

After an incubation period of about 30 days, poor egg survival was recorded at all sites, including an unexpected high mortality at the upstream background sites. Analyses of the data indicated that the principal cause of egg mortality at the two downstream sites was low concentrations (less than 5 milligrams per liter) of intragravel dissolved oxygen. Low water temperatures, rather than degraded water-quality conditions, largely contributed to the poor survival at the upstream sites. Based on the results of this study, the following were considered unlikely to be mortality factors during the incubation period: (1) high water temperatures; (2) toxicity due to ammonia, nitrite, nitrate, arsenic, cadmium, copper, iron, lead, manganese, mercury, and zinc; and (3) decreasing intragravel dissolved oxygen caused by inflow of oxygen-poor ground water.

INTRODUCTION

Background

The Truckee River originates at the outlet of Lake Tahoe, Calif., at an altitude of about 1,900 m above sea level (fig. 1). Within a mixed coniferous forest, the river tumbles cool and clear through a steep canyon that trends generally northward. Near Verdi, Nev., the river flows eastward and begins its journey into the rain shadow of the Sierra Nevada. With reduced gradient and clarity, the river passes through the urban areas of Reno and Sparks. Downstream from Reno, the Truckee River continues eastward through a semidesert area of sand and sagebrush to Wadsworth, where it again turns northward and eventually empties into the mildly saline Pyramid Lake at an altitude of about 1,160 m above sea level. The length of the river from Lake Tahoe to Pyramid Lake is 183 km. Pyramid Lake is contained in a closed basin that has no outlet; water loss from the lake is primarily by evaporation.

The Truckee River is distinguished from other western streams in that it once was the spawning and nursery habitat for one of North America's largest inland trout, the Pyramid Lake strain of Lahontan cutthroat trout (*Salmo clarki henshawi*). These obligatory stream-spawning fish were once in such abundance that a sizable commercial fishery was supported until the turn of the century. In 1905, Derby Dam (fig. 1) was constructed on the lower river to provide agricultural water. With the resultant diversion of a substantial annual inflow through the Truckee Canal to the Carson River basin to the south, the level of Pyramid Lake underwent a dramatic decline. This lowering of the lake resulted in the formation of an extensive delta at the mouth of the river. The severe drought conditions of the 1930's, combined with water diverted for agriculture, did not permit sufficient flow for safe fish passage over the delta. Unable to reproduce, the famous Pyramid Lake population of cutthroat trout became extinct by 1940.

In the late 1950's, some semblance of the previous Pyramid Lake cutthroat trout fishery was restored by stocking other strains of Lahontan cutthroat trout. After partial rejuvenation through stocking, these cutthroat trout migrated up the river when sufficiently high spring flows allowed passage over the delta. However, they were stopped from proceeding farther upstream by Derby Dam. Although adult fish had 56 km of the lower river in which to spawn, there was some question whether natural reproduction had occurred. Water-quality problems associated with reduced flows, rechannelization, and increased input of treated domestic sewage from the Reno-Sparks urban area have all partly contributed to poor spawning conditions in the downstream reaches since the last of the original Pyramid Lake population swam the river in the 1930's (Sumner, 1939).

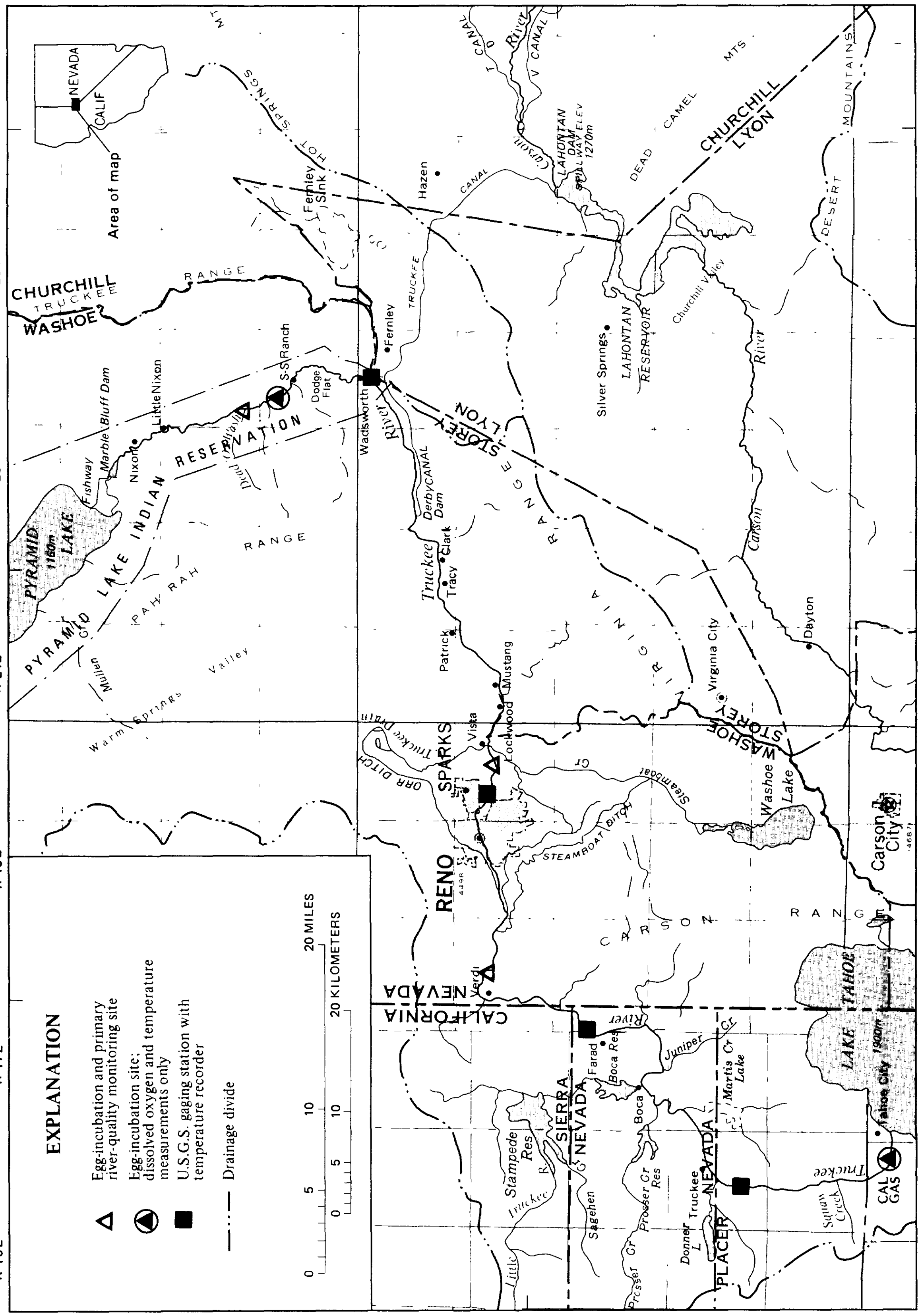

Figure 1. Egg incubation and water-data collection sites.

As part of an active program to determine the feasibility of restoring naturally spawning populations of Lahontan cutthroat trout to the Truckee River, the USFWS (U.S. Fish and Wildlife Service) has made several studies concerning the suitability of the river as a spawning habitat by observing the fate of cutthroat trout eggs artificially planted in the streambed. These studies (table 1) documented poor survival of eggs planted downstream from Reno. However, potential cause-and-effect relationships between river quality and egg mortality have not been documented; this information is needed to evaluate management alternatives for the lower Truckee River.

In the spring of 1980, the USFWS proposed a series of egg-survival studies of the river, in which the U.S. Geological Survey was requested to design and implement a water-quality monitoring program during the incubation period of the artificially planted eggs. The monitoring program, which included a report that summarized the results of the egg-survival study, was one of six planned study elements of the U.S. Geological Survey's ongoing river-quality assessment of the Truckee and Carson River basins (Nowlin and others, 1980).

Purpose and Scope

The purpose of this study was to evaluate the mortality of Lahontan cutthroat trout eggs at five sites in the Truckee River in terms of measured and observed conditions in the aquatic environment (fig. 1). The USFWS planted eggs in February and March 1980 in manmade redds (nests) at each of the five sites. Two sites were selected upstream from Reno where previous egg studies have shown that, in most instances, embryonic development proceeded normally; these sites were monitored as background sites. Three sites were in the reach downstream from Reno where, in every previous study, all, or nearly all, the eggs died prematurely.

Because of funding constraints, measured water-quality data were limited to temperature and dissolved oxygen at the Cal Gas and S-S Ranch sites (fig. 1). At the Verdi, Sparks, and Dead Ox Wash sites, a more comprehensive set of data was collected. The types of data collected and the frequency of collection are shown in table 2.

Acknowledgments

The authors gratefully acknowledge the assistance of the following individuals in various aspects of the investigation. Jon O. Nowlin, Project Chief, Truckee-Carson River-Quality Assessment, assisted in project planning and development of the intragravel sampler. Timothy G. Rowe and Howard L. Burge of the U.S. Fish and Wildlife Service, Reno, Nev., and Michael J. Crambes of the U.S. Geological Survey, Carson City, Nev., assisted with the field work. The authors especially want to thank Thomas R. Edwards of the U.S. Geological Survey, Boise, Idaho, for his substantial contribution to the data-collection activities.

Table 1. Summary of hatching studies (using Lahontan cutthroat trout eggs) in the Truckee River previous to the present study

Time of study	River reaches studied	Source of eggs	Results and suspected cause of mortality	Investigator
Spring 1971	1 site upstream (control) from Reno and 3 sites downstream from Reno.	Heenan Lake strain (non-hatchery eggs).	10 percent mortality at control site. Nearly 100 percent mortality at downstream sites. High water temperature and compacted gravels.	Johnson and others (1971).
Spring 1972	1 site upstream (control) from Reno and 2 sites downstream from Reno.	Summit Lake strain (non-hatchery eggs).	100 percent mortality at all sites. Poor quality eggs.	Ringo (1972).
Spring 1974	1 site upstream (control) from Reno and 2 sites downstream from Reno.	Summit Lake strain (non-hatchery eggs).	26 percent mortality at control and 100 percent mortality at downstream sites. High water temperature and low dissolved oxygen.	McBrayer and Ringo (1975).
Spring 1976 and 1977	3 sites upstream (control) from Reno and 4 sites downstream from Reno.	Summit Lake strain (non-hatchery eggs).	20, 40, and 100 percent mortality at control sites. 100 percent mortality at downstream sites. High water temperature and low dissolved oxygen.	Bailey and Scoppettone (1979).

METHODS AND MATERIALS

Measurement of Surface Water

Measurements of streamflow were made using standard methods (Rantz and others, 1982). Hourly water-temperature measurements were obtained by using an automatic recorder with a submerged probe. Periodic water-temperature, specific conductance, and pH measurements were made onsite with portable field instruments. Dissolved-oxygen (DO) concentration was determined with a portable meter calibrated in the field using the air-saturation method (Hines and others, 1977).

Water samples used to determine suspended-sediment concentration and for chemical analyses were collected with a DH–48 depth-integrating suspended-sediment sampler using the equal-transit-rate method (Guy and Norman, 1970; currently referred to as the method of equal-width increments). The individual samples collected at selected intervals across the stream were subsequently composited, mixed, and split into subsamples. Samples used to determine the concentration of dissolved trace elements were filtered onsite through a prerinsed 0.45-micrometer pore-size filter and acidified with 1.0 *N* nitric acid. Samples used to determine nitrogen species were chilled to 4 °C or less until analyzed. The concentration of un-ionized ammonia (NH_3) was calculated from analytically determined total ammonium (NH_4+ as N) as described by Thurston and others (1979). Water samples used to determine BOD_u (ultimate biochemical oxygen demand) were chilled in the dark while in transit to the laboratory at Carson City, Nev.

Table 2. Summary of water-quality data measured during Lahontan cutthroat trout incubation, March and April 1980

	Surface water (measured weekly)	Intragravel water (measured weekly)	Streambed (measured twice[1])
Field measurements			
Temperature[2,3,4]	x	x	--
Dissolved oxygen[3,4]	x	x	--
Specific conductance[3]	x	x	--
pH[3]	x	x	--
Laboratory measurements			
Total ammonium as N	x	x	--
Total nitrite as N	x	x	--
Total nitrate as N	x	x	--
Total organic carbon	x	x	--
Biochemical oxygen demand	x	x	--
Trace elements (arsenic, cadmium, copper, iron, lead mercury, manganese, and zinc)	x	x	x
Particle-size distribution	--	--	x
Suspended sediment	x	--	--

[1] At beginning and end of incubation period.
[2] Hourly recordings were made in addition to the weekly field measurements. See figure 1 for thermograph locations.
[3] One study was done over a 24-hour period at the Verdi, Sparks, and Dead Ox Wash sites (fig. 1).
[4] Only temperature and dissolved oxygen were measured at Cal Gas and S-S Ranch sites.

Determinations of suspended-sediment concentration were made by the U.S. Geological Survey Sediment Laboratory in Sacramento, Calif., using the methods described by Guy (1969). Analyses of chemical constituents in the water were made by the U.S. Geological Survey Central Laboratory, Denver, Colo., using the methods described by Skougstad and others (1979). Determinations for BOD_u were made by the staff of the U.S. Geological Survey in Carson City, Nev., over a 20-day incubation period at 20 °C using the methods described by Stamer and others (1979).

Measurement of Streambed Material

Samples of streambed materials for the determination of particle size and for chemical analyses were obtained with a stainless-steel version of the sampler described by McNeil and Ahnell (1964). Core samples, 15 cm in diameter and 15–20 cm deep, were first taken from an undisturbed area of about 3.4 m^2 that had been selected as an artificial redd and then sampled again about 3 weeks later. The samples were immediately transferred from the sampler to 19-liter plastic buckets and allowed to settle for about 30 minutes before the particle-size determination. Size analyses were done by the U.S. Geological Survey Sediment Laboratory in Sacramento, Calif., using dry-sieve techniques (Guy, 1969). Sieve mesh sizes range from 32 to 0.0625 mm. Standard U.S. Geological Survey sieves differ in mesh size from those commonly used by other investigators for particle-size determinations. The differences are slight, however, and valid comparisons can still be made.

Most potentially toxic trace elements (and many organic compounds) are adsorbed to fine-grained organic and inorganic alluvial particles. To quantify this occurrence and to provide a uniform comparison between sites, samples were prepared for chemical analyses of the clay- and fine silt-sized fraction (less than 0.020 mm) of the streambed materials. The preparation consisted of sieving the samples through a stainless-steel 2-mm sieve to exclude the coarse particles. Material less than 2 mm passing through the sieve was kept chilled to 4 °C or less until analysis. These samples were to be size-separated at the U.S. Geological Survey Central Laboratory to obtain splits that included only the clay- and fine silt-sized fractions and then apportioned for analysis of total organic carbon (Goerlitz and Brown, 1972) and trace elements (Skougstad and others, 1979). The March 11–13 samples submitted to the laboratory, however, contained insufficient quantities of fine-grained material for analysis; therefore, the whole sample (less than 2 mm) was analyzed.

Measurement of Intragravel Water

Intragravel water is defined as the fluid occupying the porous interior of the streambed. Specifically, in this study, it is considered to be the interstitial water collected from 15 to 20 cm below the streambed surface—the depth of buried eggs—for physical and chemical analyses. Sampling needs and the quest to obtain representative samples, to a large extent, dictated the design of equipment and the methods employed. The equipment and the procedure used in this study for obtaining intragravel water differed markedly from those traditionally used in fishery and intragravel research. A detailed discussion of the equipment used in this study, its development, and the test used to evaluate the reliability of the sampling procedures is presented in another report (Hoffman, 1986). Intragravel water was collected from four slotted polyvinyl-chloride pipes (hereafter called intragravel pipes, or pipe) that were buried horizontally in the streambed in proximity to the planted eggs. A limited, predetermined quantity of water was pumped from each pipe by a portable peristaltic pump through tygon tubing into a glass container at the surface. The procedures for sample preservation and the methods of chemical analyses of intragravel water were identical to those previously described for surface-water samples.

Hydrologic data obtained during this study were tabulated by La Camera and others (1985, p. 143–149).

Selection of Egg Sites and Egg-Handling Techniques

Specific sites at which eggs were planted were selected by USFWS biologists, using the techniques described by Bovee (1978). These techniques involved measuring the depth and velocity of the surface water and visually inspecting the composition of the streambed. Velocities of about 30 cm/s, depths of 0.5 m, and a streambed that consists mainly of gravel are believed to be preferred by spawning cutthroat trout. The manmade redds, dug with a shovel, measured about 2.4 m long, 1.4 m wide, and 15–20 cm deep.

Eggs for this study were taken from the Summit Lake strain of brood stock at a local fish hatchery. Brood-stock eggs were used instead of wild-stock eggs because of their availability early in the year, usually from January 1 through March 15. Wild-stock eggs are generally unavailable until April 15. The early availability of brood-stock eggs allowed sufficient lead time for planting to avoid the stressfully warm springtime temperatures that occurred in previous studies when wild-stock eggs were used.

Consistent egg-handling procedures were maintained from the time of egg collection at the hatchery through egg planting. For each station, eggs were removed from three to four females and sperm was obtained from an equal number of males. The resulting fertilized eggs were randomly mixed and split into two parts for hardening in either well water (standard procedure at the hatchery) or in Truckee River water[1], obtained from the vicinity of the redd site where the eggs were to be planted. The eggs were water-hardened for about 1 hour before the 1- to 2-hour trip to a given station. A portion of the fertilized eggs for each redd site was retained at the hatchery as a control to assess overall egg viability. These eggs were incubated at a constant 12.2 °C and intermittently treated with fungicide.

Eggs were planted at the five monitoring sites on five consecutive days from March 10 through March 14. One hundred eggs were placed in each of 40 plastic Vibert[2] boxes containing pea-size gravel (Whitlock, 1978). The boxes were arranged in the redd in four rows with five boxes per row. The rows were about 0.5 m apart; the boxes were separated by about 0.2 m in each row and were buried at a depth of 15–20 cm. Just before burial, the eggs were acclimated to within 0.5 °C of the ambient Truckee River temperature. A sketch of an artificial redd is shown in figure 2. Each row consisted of two Vibert boxes containing eggs hardened in well water and three boxes containing eggs hardened in Truckee River water. The boxes were randomly placed in each row, but were distinguishable by an attached color-coded ribbon exposed above the gravel.

To assess egg mortality resulting from handling, the row of boxes located farthest downstream at a particular site was removed 2 days after the eggs were planted. The average percentage of egg survival for these five boxes was used to estimate survival at day 3 for the remaining boxes in the redd. The three remaining rows were removed in an upstream sequence at major stages of embryonic development. To determine when the eggs had reached a certain life stage, a small secondary redd was constructed diagonally downstream from the main redd at three of the five sites. Each secondary redd held 16 Vibert boxes, each containing 100 eggs. Intermittent removal of one or two boxes from a secondary redd allowed determination of developmental stage without disturbing the main redd.

RESULTS AND DISCUSSION

In mid-January 1980, about 3 weeks before the field work was to begin, unseasonably high flows occurred in the Truckee River as a result of heavy rains on upper-basin snowpack. Peak discharge recorded in the reach downstream from Wadsworth was about 230 m^3/s, compared to the 3–8 m^3/s that normally occurs at this time. The action of this torrential flow cleansed the streambed of attached plants and fine-grained particles. The clean gravels throughout the river provided nearly uniform, albeit atypical, streambed conditions to begin the study.

[1]The purpose of using water from two different sources was to determine whether the quality of the water affected egg viability during the critical water-hardening phase. Examination of the egg-mortality data at the end of the study showed no important differences that could be attributed to the water used for hardening.

[2]The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

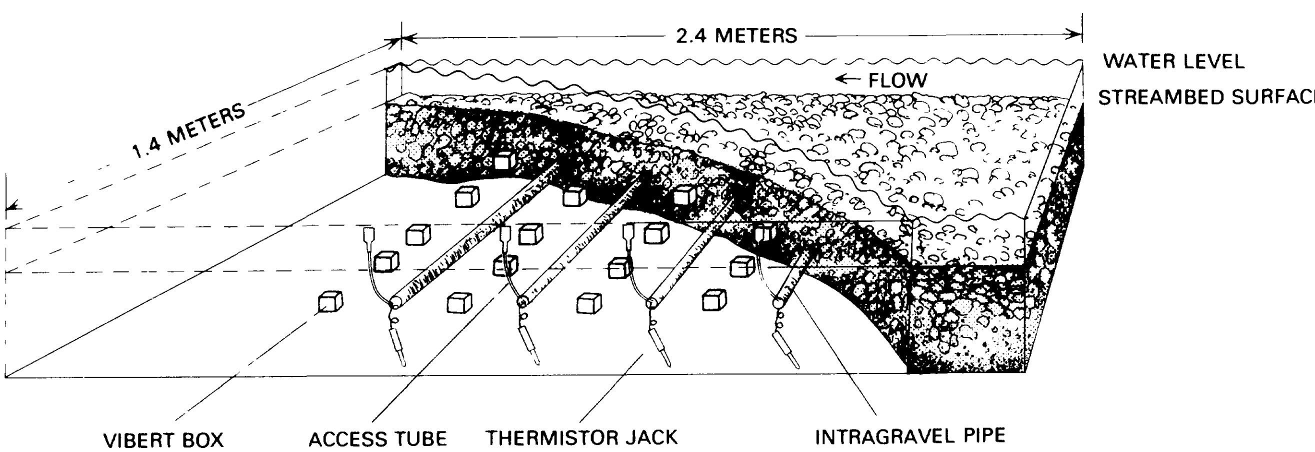

Figure 2. Sketch of an artificial redd showing arrangement of intragravel pipes and Vibert boxes.

During February 4–6, the artificial redds were prepared, the eggs in the Vibert boxes were planted, and the intragravel sampling equipment was installed. On February 19, unexpected high flows again occurred. As a result, the planted eggs and much of the installed equipment were lost.

During March 10–14, when mean daily flows ranged from 14 to 17 m^3/s (fig. 3), eggs and sampling equipment were again installed at the five sites. Mortality counts and water-quality measurements continued until April 16 (a period slightly more than 30 days), when virtually all eggs, including those at the background sites, had died prematurely.

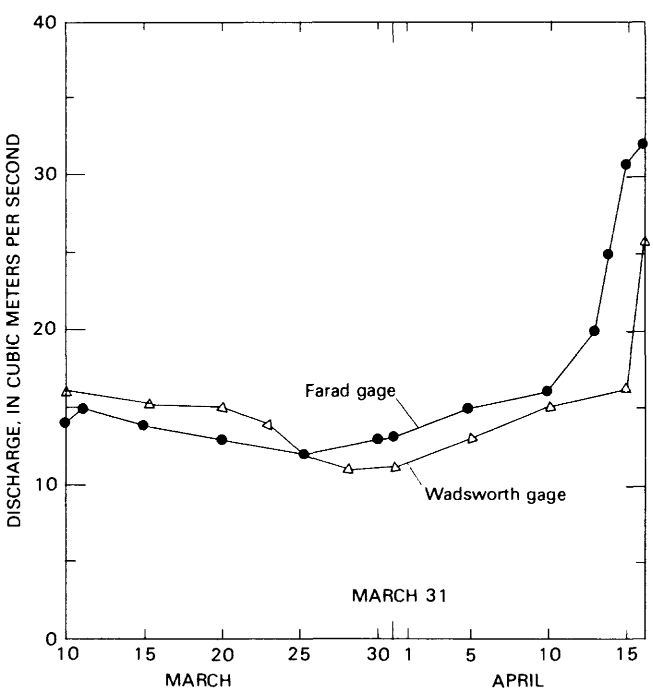

Figure 3. Mean daily streamflow at the Farad and Wadsworth gaging stations, March 10–April 16, 1980.

The remainder of this report is an attempt to glean as much knowledge as possible from these unexpected results.

Working Hypothesis

On the basis of results of previous egg-hatching (survival) studies and the present knowledge of Truckee River hydrology, four hypotheses were developed as to the most probable causes of observed egg mortality in the river downstream from Reno:

1. Low concentrations of intragravel dissolved oxygen attributed to clogging of gravel interstices by fine sediments and (or) high concentrations of oxygen-demanding substances.
2. Toxicity due to inorganic nitrogen compounds or trace elements.
3. Water temperatures exceeding the lethal threshold value of 13.3 °C.
4. Dilution of intragravel dissolved oxygen by inflow of oxygen-poor ground water, particularly in the reach downstream from Wadsworth.

Physical and Chemical Analyses of the Streambed

Fine-grained sediment deposited on the surface of spawning gravel can smother incubating eggs by filling the voids in the gravel bed. The filling of voids lowers the permeability of the gravel and effectively prevents the exchange of oxygen-rich surface water with intragravel water. Sufficient water velocity within the streambed is needed to maintain an adequate supply of oxygen and to remove potentially toxic metabolites from the developing embryos.

To characterize the size distribution of sediment particles composing the redds, samples of bed material were collected immediately before the redds were dug and again near the end of the study. Table 3 lists the results obtained from a limited number of samples. The data show no large differences in particle-size distribution among the three sites over the duration of the study. However, considerable differences of opinion exist among researchers as to the amounts and particle-size classes for bed materials that may adversely affect egg and fry survival. For example, McNeil and Ahnell (1964) consider the permeability of gravel to be low where bottom materials contain more than 15 percent by volume sand and silt that pass through a 0.83-mm sieve (comparable to the 1.0-mm mesh size in table 3). McCuddin (1977), using gravel-sand mixtures in the laboratory, related poor survival of salmonid embryos to sediments less than 6.4 mm in diameter (between the 8- and 4-mm mesh size in table 3) that compose more than about 25 percent of the substrate. A comparison of these findings with the data shown in table 3 might lead to the conclusion that the permeability of the gravel was borderline for egg survival at all three sites. Such a conclusion, however, is at variance with observations made at Verdi and Sparks, where dissolved-oxygen and temperature measurements strongly suggest that there was adequate exchange of surface water with intragravel water (figs. 4*B* and 4*C*). Bailey and Scoppettone (1979) found no significant differences in percentage of fine sediment along the Truckee River that correlated with egg mortality. In addition, the percentage of material smaller than 1.0 mm in this study was similar to that observed in Little Lost Man Creek, Calif. (Woods, 1980). Woods found that the exchange of surface water with intragravel water was good, judging from the measured high intragravel-DO concentrations. On the basis of the foregoing results, the relation of the particle-size data to egg mortality in this study is, at best, inconclusive.

The results of chemical analyses of bottom materials are given in table 4. The reader should be aware that the values for March are not directly comparable to those for April, because the total surface area presented by sediment particles in a smaller than 0.02-mm sample is much larger than that of an equivalent weight of a smaller than 2-mm sample. Consequently, the potential for higher concentrations of adsorbed constituents in a sample of finer material is increased. Nevertheless, it is noteworthy that the three sites have similar concentrations of most trace constituents during each sampling period. This is consistent with the similar particle-size distribution among the three sites (table 3).

The concentrations of arsenic, iron, and zinc in the April bottom-material samples are nearly the same as those obtained from river sediments in the Willamette River basin where chemical analyses were also performed on the smaller than 0.02-mm fraction (Rickert and others, 1977, p. F25). The concentrations of cadmium, copper, and lead in the present study, however, were much higher. The low concentrations of these three metals in samples of intragravel water (table 5) suggest that the adsorbed metals probably were not readily mobilized to an available solute form in concentrations that would have been detrimental to the incubating eggs.

The substantial increase in total organic carbon in the bottom materials in the reach from Sparks downstream to Dead Ox Wash in April (table 4) corresponds with the visibly

Table 3. Particle-size distribution of bed material in selected artificial redds, March and April 1980

[Values represent percentages by weight of material passing through indicated sieve mesh size]

Sampling site	Date	Gravel: 32	Gravel: 16	Gravel: 8	Gravel: 4	Sand: 2	Sand: 1	Sand: 0.5	Sand: 0.25	Sand: 0.125	Clay-silt: 0.0625
		Mesh size, in millimeters									
Verdi	3-13	84	57	38	31	24	14	6	2	0.3	0.0
	4-17	--------- No sample because of high flow ----------									
Sparks	3-12	86	41	33	26	21	14	6	2	.2	.0
	4-16	94	64	38	28	21	14	4	.9	.3	.1
Dead Ox Wash	3-11	34	30	27	23	21	18	9	2	.3	.1
	4-15	62	44	32	25	20	15	6	1	.2	.1

Table 4. Concentration of total organic carbon and trace elements in bottom materials from redds at Verdi, Sparks, and Dead Ox Wash, March and April 1980

[Concentration in parts per million which is equivalent to milligrams of total organic carbon or trace elements per kilogram of dry sediment]

Sampling site	Date	TOC	Arsenic	Cadmium	Copper	Iron	Lead	Zinc
		Material < 2 millimeters						
Verdi	3-13	500	4	0	16	14,000	0	33
Sparks	3-12	800	3	0	16	11,000	0	29
Dead Ox Wash	3-11	700	10	0	10	9,400	0	25
		Material < 0.02 millimeter						
Verdi	4-17	---------- No sample because of high flow ----------						
Sparks	4-16	12,000	11	40	300	28,000	200	140
Dead Ox Wash	4-15	51,000	15	25	370	24,000	200	180

Table 5. Range of trace-element concentrations of intragravel water in the Truckee River at the Verdi, Sparks, and Dead Ox Wash egg sites, March and April 1980

[Concentration in micrograms per liter]

Trace elements	Sampling site: Verdi	Sampling site: Sparks	Sampling site: Dead Ox Wash	Criteria for protection of freshwater life
Arsenic, total	0-3	1-3	9-13	50[a]
Cadmium, total	0-1	0-1	0-1	.4[a]
Copper, total	3-4	2-4	4-5	20[b]
Iron, total	120-270	90-150	120-220	1,000[a]
Manganese, dissolved	0-9	7-170	4-220	—
Mercury, total	0-0.3	0-0.1	0-0.2	.05[a] .20[c]
Lead, dissolved	0-1	0-1	0-2	8[a]
Zinc, total	0-40	10-40	10-30	Bioassay[a] (see text).

[a] U.S. Environmental Protection Agency (1977).
[b] McKee and Wolf (1963).
[c] U.S. Environmental Protection Agency (1972).

abundant organic detritus common in the lower river. Although limited in number, the data provide some indication of the high BOD potential on the streambed surface and within the gravel at Dead Ox Wash.

Potentially Toxic Chemicals in the Intragravel Water

Nitrogen Species

Bioassay tests have shown that concentrations of un-ionized ammonia (NH_3 as N) exceeding 0.02 milligrams per liter (mg/L), and nitrite (NO_2 as N) exceeding 0.04 mg/L are harmful to incubating eggs of Lahontan cutthroat trout (Koch and others, 1980). Because of the high total-ammonium (NH_4+ as N) concentration in the Reno-Sparks sewage-treatment-plant outfall, the potential exists for toxic concentrations of nitrogen species downstream in the Truckee River.

In this study, the concentrations of NH_3 (all values below the detection level of 0.01 mg/L) and NO_3 (0.02–0.85 mg/L) in intragravel water samples were well below the toxic threshold concentrations of 0.02 mg/L and 2.0 mg/L, respectively. Measured concentrations of intragravel NO_2 (<0.01–0.05 mg/L) exceeded the threshold concentration of 0.04 mg/L only once, and that value was 0.05 mg/L at the Dead Ox Wash site on the last day of sampling. The low concentrations of intragravel NH_3 reported in this study were due largely to the somewhat moderate and stable pH conditions within the streambed. At all sites, intragravel pH ranged from 0.3 to 1.4 units lower than that of surface water. At the Dead Ox Wash site, for example, the pH of the surface water ranged from 8.2 to 8.4, whereas the pH of the intragravel water was nearly a constant 7.5. Because the concentration of NH_3 increases with pH and temperature, lower intragravel pH and water temperatures would effectively reduce the concentration, and hence the toxicity, of un-ionized ammonia.

Trace Elements

In sufficiently high concentrations, many trace elements are stressful or lethal to incubating fish eggs. The degree of toxicity of certain trace elements depends on several factors, such as pH, temperature, hardness, DO, and synergism between metals. These factors can cause a change in trace-element toxicity and a concurrent, and perhaps unpredictable, response of the aquatic biota.

The metals cadmium, copper, iron, mercury, lead, zinc, and the nonmetal arsenic were selected for analyses in this study because they have been detected in the Truckee River in previous studies, and most are known to be potentially toxic to aquatic life if found in high enough concentrations. The range in concentrations of the selected trace elements in intragravel water is shown in table 5. Except for mercury and possibly zinc, the concentrations were below published criteria recommended for the protection of freshwater life. (Cadmium was not detected in most of the intragravel water samples at each site. The 1-μg/L [microgram per liter] cadmium values shown in table 5 were found at each site during the last round of sample collection.)

If 0.05 μg/L of mercury is used as the criterion for protection, then this value was exceeded twice at each site. If, on the other hand, 0.2 μg/L is used as the criterion, then this value was exceeded (0.3 μg/L) once and only at the Verdi egg site. The rationale in establishing the criterion of 0.05 μg/L of total mercury is based on the premise that bioaccumulation of mercury is an important consideration for the protection of life along the food chain. Hence, the U.S. Food and Drug Administration's provisional 500-μg/L tolerance value is divided by a 10,000-fold bioaccumulation factor, giving the value of 0.05 μg/L. It is doubtful whether occasional encounters with mercury concentrations ranging from 0.1 to 0.3 μg/L detected in this study were detrimental to the incubating eggs. Nine of twelve intragravel water samples had concentrations of mercury equal to or less than 0.1 μg/L.

Pacific Environmental Laboratory (1979) determined through bioassays using Lahontan cutthroat trout that the acute toxic concentration of zinc is 100 μg/L. Zinc concentrations, shown in table 5, were less than half this value. The recommended water-quality criterion, however, is determined by multiplying the bioassay concentration (100 μg/L) by 0.01, resulting in a value of 1 μg/L of zinc (U.S. Environmental Protection Agency, 1977). Historically, even those sites located farthest upstream on the Truckee River had values of zinc frequently exceeding 1 μg/L.

Trace-metal analyses of whole eggs that had been incubating in the Truckee River for nearly 30 days were compared to analyses of eggs that had not come in contact with any water following removal from the fish (table 6). The data show no important differences in cadmium, copper, lead, and zinc content. Iron and manganese, however, were substantially higher in the incubated eggs. Although not important toxicants by themselves, the increased levels of these two metals in egg tissue may be indicative of other processes. Manganese, for example, is readily mobilized to an available solute form in anoxic conditions. The nearly 20-fold increase in manganese in eggs from the Dead Ox Wash site correlates with observed low DO concentrations (fig. 4*E*) and with increasing levels of dissolved manganese (4, 20, 120, and 220 μg/L) in the intragravel water from mid-March to mid-April.

Polychlorinated Biphenyls

In January, 2 months before implantation of the test eggs, polychlorinated biphenyls (PCB's) were detected in the Truckee River by other investigators just upstream from the Verdi egg site. PCB's are industrial compounds that are more fat and oil soluble than water soluble, are strongly adsorbed to sediment particles, and have been related to fish egg mortality (U.S. Environmental Protection Agency, 1972).

In March, some eggs were removed from the streambed for PCB analysis after 3–10 days of incubation at the Cal Gas, Verdi, and Sparks sites. Eggs selected for analyses included those that had been water hardened with hatchery well water and those that had been hardened with Truckee River water. The results of the analyses showed concentrations of PCB's in egg tissue ranging from 0.15 to 0.52 micrograms per gram (μg/g). The highest concentration (0.52 μg/g), found in eggs from the Verdi site, slightly exceeded the threshold criteria for freshwater life of 0.5 μg/g (U.S. Environmental Protection Agency, 1972). The results are difficult to interpret because analyses of eggs maintained at the fish hatchery—eggs that were never introduced to the Truckee River—showed concentrations ranging from 0.09 to 0.58 μg/g, the highest PCB value recorded in this study. The source of PCB contamination has yet to be determined.

High and Low Water Temperature

Temperature tolerance of incubating salmonid eggs varies among species and strains (Embody, 1934). Leitritz and Lewis (1976) generalized that temperatures above 13.3 °C and lower than 5.0 °C can be harmful to incubating trout eggs. D. G. Kuntzelman (U.S. Fish and Wildlife Service, oral commun., 1981) observed that hatching success of brood-stock rainbow trout eggs dropped markedly at temperatures above 13.3 °C or below 7.8 °C. The temperature tolerance of Lahontan cutthroat trout brood eggs is unknown, but cultured eggs of Lahontan cutthroat trout are less hardy than those of rainbow trout. In this report, Kuntzelman's range for temperature tolerance of rainbow trout is used.

The periodic measurement of water temperatures during the study indicates that intragravel temperatures were below 13.3 °C at all sites (fig. 4). Hourly surface-water temperature data for the Cal Gas, Verdi, and Sparks sites also were available from recording thermographs. A summary of these hourly data (table 7) indicates that surface-water temperatures at these three sites also were below 13.3 °C throughout the study. Included in table 7 are estimates of the range in surface-water temperatures for the S-S Ranch and Dead Ox Wash sites. These estimates assumed a 1.0 °C increase in temperature between the thermograph at Wadsworth and the S-S Ranch site, 6.5 km downstream, and a 2.0 °C increase in temperature between the thermograph at Wadsworth and the Dead Ox Wash site, 16 km downstream. These temperature increases were based on regression analysis of instantaneous temperatures at the egg sites with the Wadsworth thermograph data, and on comparison of temperatures obtained during a 24-hour synoptic survey in June 1980 (LaCamera and others, 1985).

Using these estimated values, the maximum daily surface-water temperature at S-S Ranch would have exceeded 13.3 °C from April 8 to April 16, with daily maxima of 13.5 to 16.0 °C. At Dead Ox Wash, the estimated maximum daily surface-water temperature would have exceeded 13.3 °C

Table 6. Trace-metal concentrations of intact Lahontan cutthroat trout eggs from the fish hatchery and incubated in the Truckee River

[Analyses were done by Daniel J. Cain, U.S. Geological Survey Research Laboratory, Menlo Park, Calif., using atomic-absorption spectrophotometry. Concentrations expressed as parts per million by dry weight are equivalent to micrograms per gram of dry egg tissue. Background eggs were stripped from adult without contact with water and samples were immediately frozen and shipped to the laboratory in treated glass vials]

	Concentration at egg-incubation sites (parts per million, dry weight)					
	Cd	Cu	Fe	Mn	Pb	Zn
			Verdi			
Background	<0.02	5.0	36.6	11	< 1.3	6.0
River water, hardened	< .06	5.4	136	84	< 3.2	14.4
Well water, hardened	< .09	5.3	274	88	< 4.7	13.1
			Sparks			
Background	<0.03	6.3	44.2	15.0	< 1.6	15.0
River water, hardened	< .06	7.4	114	71.0	< 3.1	16.0
Well water, hardened	< .09	7.2	130	81.2	< 4.4	20.0
			Dead Ox Wash			
Background	<0.03	6.0	8.0	9.5	< 1.3	9.0
River water, hardened	< .04	6.5	142	--	< 2.0	14.7
Well water, hardened	< .07	6.4	171	215	< 3.5	17.5

Table 7. Summary of hourly temperature measurements of surface water during the egg-incubation period, March 10–April 16, 1980

	Surface-water temperature (degrees Celsius)	
Egg site	Maximum	Minimum
Cal Gas	10.5	0.0
Verdi[1]	10.5	3.0
Sparks	11.5	3.5
S-S Ranch[2]	16.0	5.5
Dead Ox Wash[3]	17.0	6.5

[1] Period of record March 27 - April 27.
[2] Values estimated from Wadsworth thermograph located 6.5 km upstream from S-S Ranch.
[3] Values estimated from Wadsworth thermograph located 16 km upstream from Dead Ox Wash.

from April 5 to April 16, with maxima of 13.5 to 17.0 °C. In general, the eggs may have been subjected to temperatures greater than 13.3 °C for about 4 hours on a particular day.

At the S-S Ranch site, the survival of eggs (fig. 4*D*) was greater than 90 percent until April 8 (28 days of incubation). Between April 8 and April 16, the time of an observed 4 to 5 °C rise in both intragravel and surface-water temperatures, the eggs suddenly died. At Dead Ox Wash (fig. 4*E*), there was no apparent correspondence of egg mortality with increased temperature; these eggs began dying sometime before temperature could be considered a mortality factor. Thus, considering the lack of any consistent correlation of

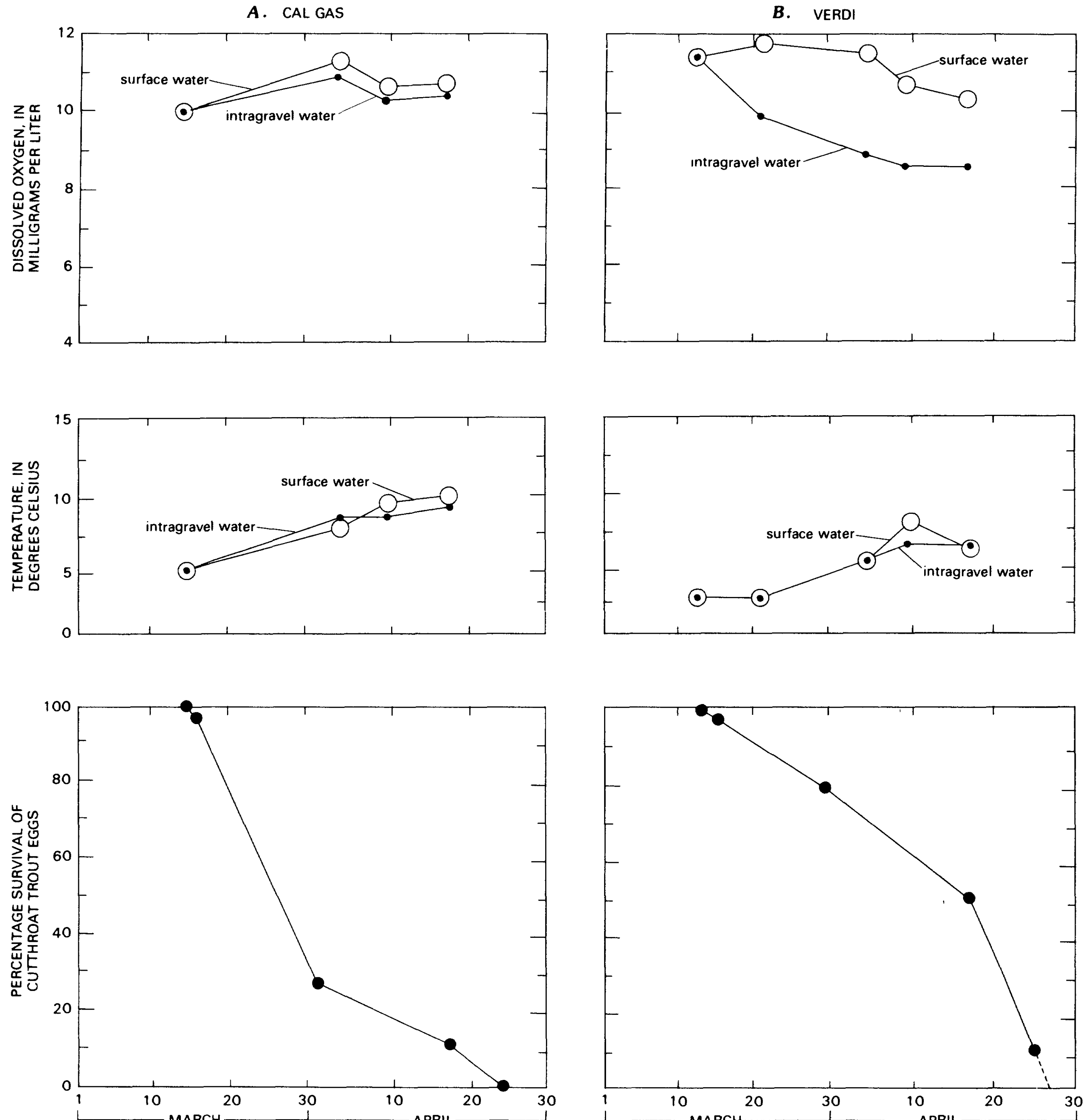

Figure 4. Results of periodic measurements of dissolved oxygen, temperature, and egg survival at the five study sites, March–April 1980. (Graphs are displayed in downstream order from A to E.) See figure 1 for location of study sites.

mortality with elevated temperatures, it is doubtful that elevated water temperature recorded late in the study was the principal cause of mortality.

As mentioned earlier, critically high water temperature was hypothesized as a possible environmental factor causing the high egg mortality observed in previous Truckee

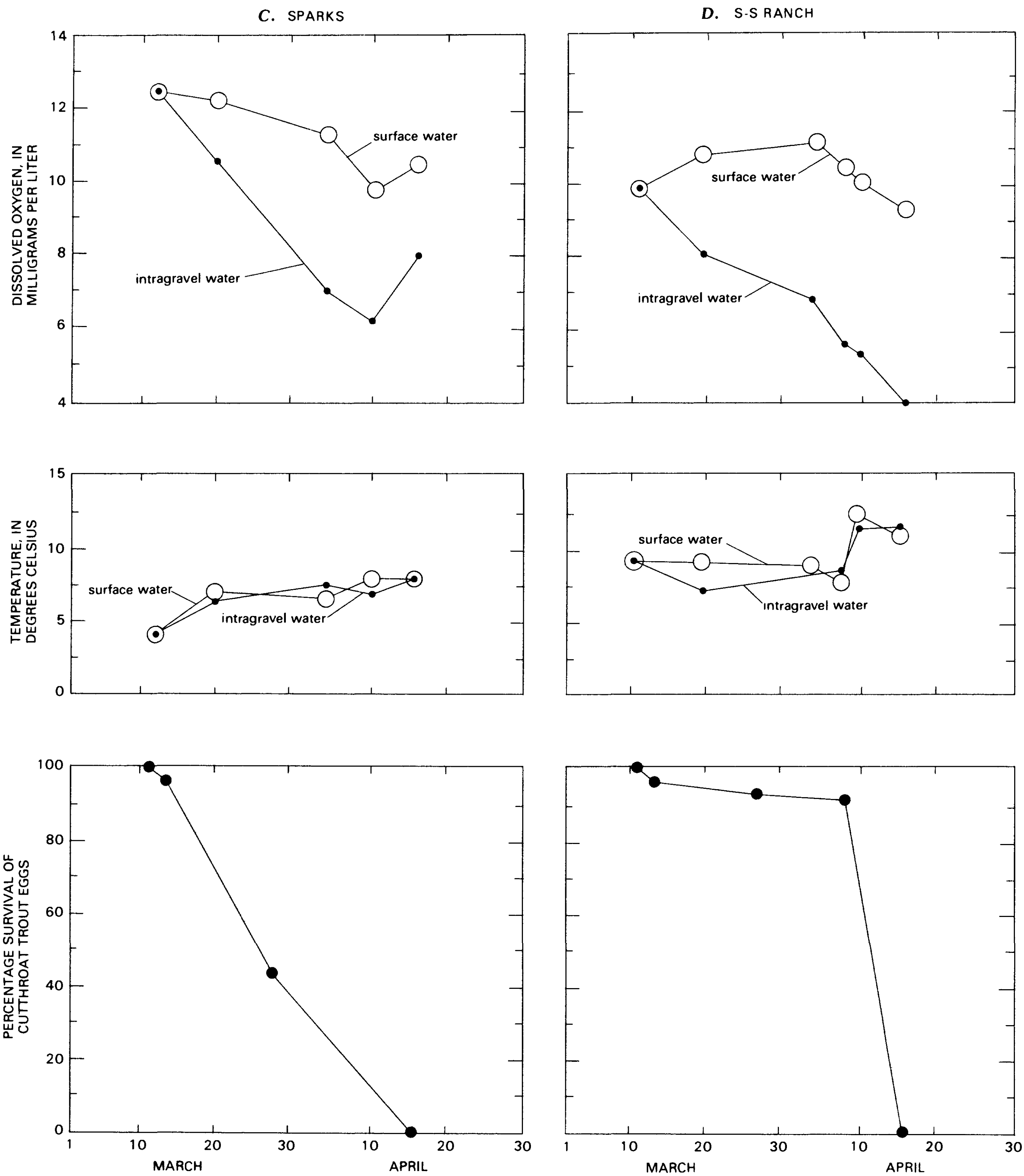

Figure 4. Continued.

River studies. What had not been considered during the planning stage of this study was the effect of stressfully low temperatures, especially on sensitive hatchery eggs suddenly subjected to temperatures below 7.8 °C. Sustained low water temperatures (figs. 4*A*–*C* and table 7) at Cal Gas, Verdi, and perhaps at Sparks were possibly responsible for

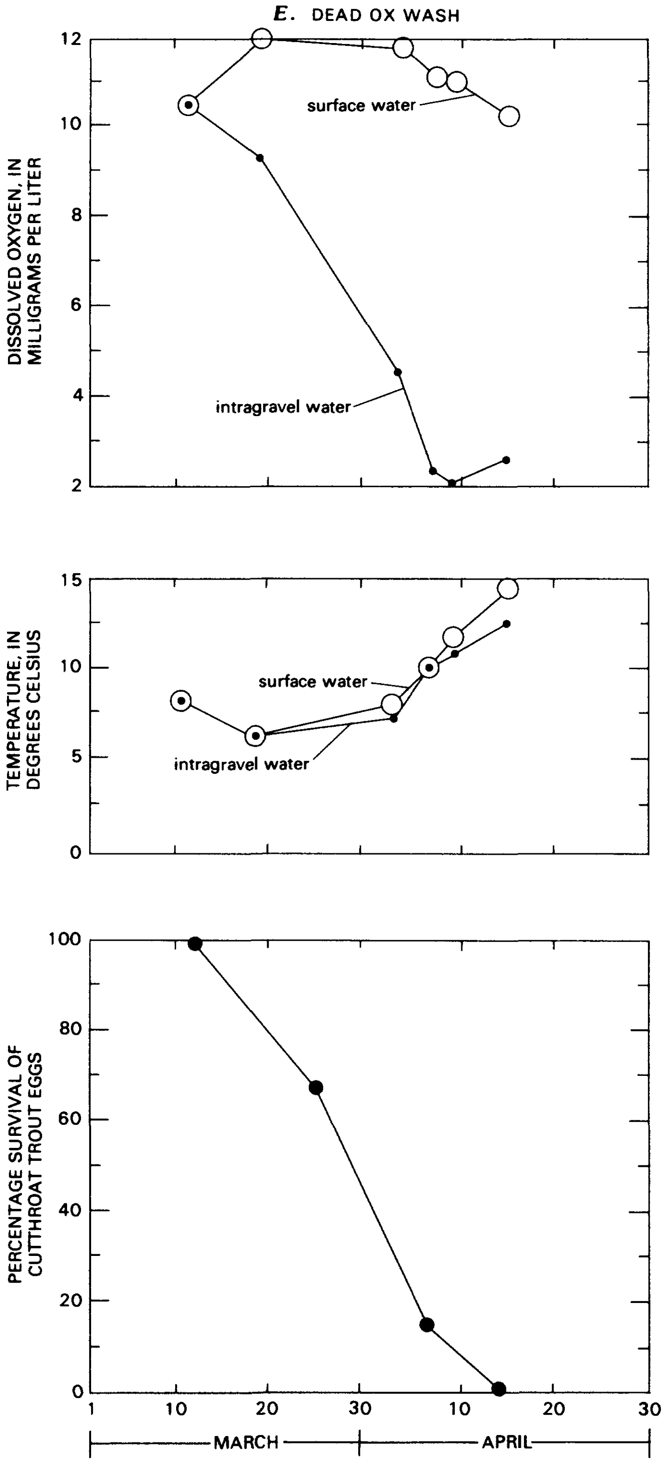

Figure 4. Continued.

the poor survival at these three sites. Also, mortality counts of the control eggs, concurrently maintained at the fish hatchery, indicated that the eggs used at Cal Gas and at Sparks were less viable than those used at the other sites; consequently, their ability to withstand harsh environmental conditions was low.

Based on thermograph records, the Cal Gas site had the lowest temperatures during the study; minimums were at or near freezing and mean daily temperatures considerably below 7.8 °C. Minimum and mean daily temperatures were slightly warmer at Verdi and Sparks but still were stressfully cool during most of the incubation period. Graphs of periodic measurements of temperature (figs. 4*A* and 4*B*) show lower values at the Verdi site than at the upstream Cal Gas site. This is explained by the timing of visits to the sites: periodic measurements at Verdi were taken in the cool early morning hours, whereas at Cal Gas, the measurements were taken in warmer afternoon hours.

Ultimate Biochemical Oxygen Demand of the Intragravel Water

The ultimate biochemical oxygen demand (BOD_u) is the total amount of oxygen consumed by heterotrophic bacteria to oxidize carbonaceous matter ($CBOD_u$) and (or) by chemoautotrophic bacteria to oxidize ammonium and nitrite ($NBOD_u$). Water samples for BOD_u analysis were collected only at the Verdi, Sparks, and Dead Ox Wash sites. No chemical inhibitor was added to BOD bottles to prevent potential nitrification. Instream $NBOD_u$ was assumed to be negligible, considering the low water temperatures (3.0–12.6 °C) at the time of sample collection. Nitrifying bacteria are not active below 10–15 °C (Rheinheimer, 1971). Examination of the BOD graphical analysis indicated that nitrification was either absent or insignificant in these samples. Thus, in this report, BOD_u is assumed to be equivalent to $CBOD_u$. The results of the limited number of laboratory BOD tests of intragravel water are given in table 8. The results of BOD tests of surface-water samples collected concurrently are included for comparison.

The concentrations of BOD_u in intragravel water were extremely low when compared, for example, to the average $CBOD_u$ (32 mg/L) reported for the Reno-Sparks sewage-treatment-plant outfall (LaCamera and others, 1985). In general, however, they were similar to those recorded at the respective surface-water sites. The results were both unexpected and puzzling. A valid explanation for the low intragravel BOD values, however, is that the data represent interstitial water only and not the water-sediment mixture. The wide difference in concentration of total organic carbon (TOC) in samples of the bed materials (table 4) compared to that measured in samples of intragravel water (table 8) substantiates this explanation, assuming that 1 mg of TOC in water has effects equivalent to 1 mg of TOC in sediment.

By design, the intragravel pipe effectively excluded particles having diameters greater than 0.15 mm. Consequently, the intragravel BOD values reported in this study are not a true estimate of the total oxygen demand within the streambed environment. The declining intragravel DO concentrations observed at Dead Ox Wash, for example (fig. 4*E*), probably reflect the integrated demand of oxygen by organic substances in the intragravel-water-sediment environment, rather than the demand exerted solely by intragravel water.

Influence of Ground Water on Intragravel Dissolved Oxygen

The working hypothesis that oxygen-poor ground water may be a contributing factor in egg mortality at sites downstream from Wadsworth was justified, because this reach is known to receive substantial ground-water inflow by seepage (Van Denburgh and others, 1973). Knowing that ground water in the reach generally has high specific-conductance values (800 to 3,500 microsiemens per centimeter at 25 °C), measurements of specific conductance of intragravel water were compared to concurrent measurements of the surface water, normally 100–300 microsiemens depending on spring streamflow, to determine ground-water inflow. If intragravel specific-conductance values were substantially higher than those recorded in the surface water, it would be reasonable to conclude that the increase was attributable to the influx of ground water. However, with the exception of the value recorded at the Sparks site on April 4, the results of the specific-conductance measurements at the Verdi, Sparks, and Dead Ox Wash sites (table 9) show no substantial differences between intragravel water and surface water. These data suggest that ground-water inflow and possible attendant low DO concentrations had not adversely affected intragravel water quality.

To test the assumption that a difference in specific conductance could be attributed to ground-water inflow, a short-term experiment was performed. About 4 months after the egg-study field work at the Dead Ox Wash site, a set of three intragravel pipes (fig. 5) was buried in the streambed 8, 15, and 23 cm below the surface water-streambed interface. Each pipe had its own access tube for withdrawing sample water for measurement of DO and specific conductance. A temperature probe was buried alongside the top and bottom pipes. The apparatus was installed in late August during low-

Table 9. Specific conductance of intragravel water and surface water at the Verdi, Sparks, and Dead Ox Wash egg sites, March and April 1980

Egg site	Date	Specific conductance (microsiemens/cm at 25°C): Intragravel water	Surface water	Difference (percent, rounded)
Verdi	3-21	118	125	-7
	4-3	--	118	--
	4-9	111	110	1
	4-17	93	89	5
Sparks	3-20	140	136	3
	4-4	165	129	28
	4-10	132	122	8
	4-16	110	100	10
Dead Ox Wash	3-19	194	245	-21
	4-3	264	282	6
	4-9	281	253	11
	4-15	211	193	9

Table 8. BOD_u concentrations, BOD bottle deoxygenation rates (K_1|base e), and TOC (total organic carbon) concentrations for samples of intragravel and surface water, March 11–April 17, 1980

[All BOD_u data calculated from 20-day, 20 °C BOD data. No chemical inhibitor was added to the BOD bottles to prevent nitrification. Numbers in parentheses indicate ranges]

Sampling site	Intragravel water: Number of samples	Average BOD_u concentration (mg/L)	Average K_1 (day^{-1})	Average TOC concentration (mg/L)	Surface water: Number of samples	Average BOD_u concentration (mg/L)	Average K_1 (day^{-1})	Average TOC concentration (mg/L)
Verdi	4	2.9 (2.4-3.4)	0.05 (.02-.07)	3.3 (2.3-3.8)	5	3.7 (2.8-4.4)	0.06 (.05-.09)	2.8 (1.4-3.8)
Sparks	4	2.7 (2.3-3.0)	0.04 (.02-.07)	2.8 (2.3-3.1)	4	4.7 (3.0-5.9)	0.05 (.03-.07)	2.8 (1.4-3.4)
Dead Ox Wash	3	8.4 (8.3-8.6)	0.02 (.02-.03)	5.1 (3.2-8.0)	5	7.3 (5.3-12.1)	0.05 (.04-.06)	4.0 (2.7-6.9)

flow conditions, when ground-water seepage into the river accounted for a greater percentage of the total flow than during the main study period. The results of the onsite measurements, made 20 and 30 days after installation, are shown in table 10. The data show a marked decrease in intragravel DO and a corresponding increase in specific conductance with depth and time. In addition, the temperature and DO data shown in table 10 indicate that eggs deposited by fall-spawning salmonids would not have survived at the test site.

The limited amount of data obtained during this short-term experiment seems to support the contention that the techniques employed during the egg-survival study were adequate for the detection of important differences in intragravel specific conductance. Further testing is desirable, however, to verify this preliminary conclusion.

Concentration of Intragravel Dissolved Oxygen

The recommended minimum intragravel-DO concentration for developing trout eggs is 5.0 mg/L (U.S. Environmental Protection Agency, 1977). Renewal of intragravel DO in most streams is largely the result of exchange of intragravel water with surface water (Sheridan, 1962; Vaux, 1962, 1968). Effective water exchange is dependent on several physical factors, such as the depth of surface water, the extent of compaction of streambed gravels, and channel morphology. The results of the near-weekly DO measurements of both intragravel and surface water during this study are shown in figure 4. Examination of the graphs of DO shows that (1) intragravel DO concentrations progressively declined downstream with an increasing diver-

Table 10. Dissolved oxygen, specific conductance, and temperature at the former Dead Ox Wash egg site, September 1980

		September 9			September 19		
	Depth below gravel surface (cm)	Dissolved-oxygen concentration (mg/L)	Specific conductance (microsiemens/cm at 25 °C)	Temperature (°C)	Dissolved-oxygen concentration (mg/L)	Specific conductance (microsiemens/cm at 25 °C)	Temperature (°C)
Surface water	—	10.4	350	20.5	9.0	418	15.0
Intragravel water	8	4.0	355	20.5	2.9	500	17.0
	15	1.0	417	—	.6	5,300	—
	23	.6	2,200	20.0	.4	5,700	18.0

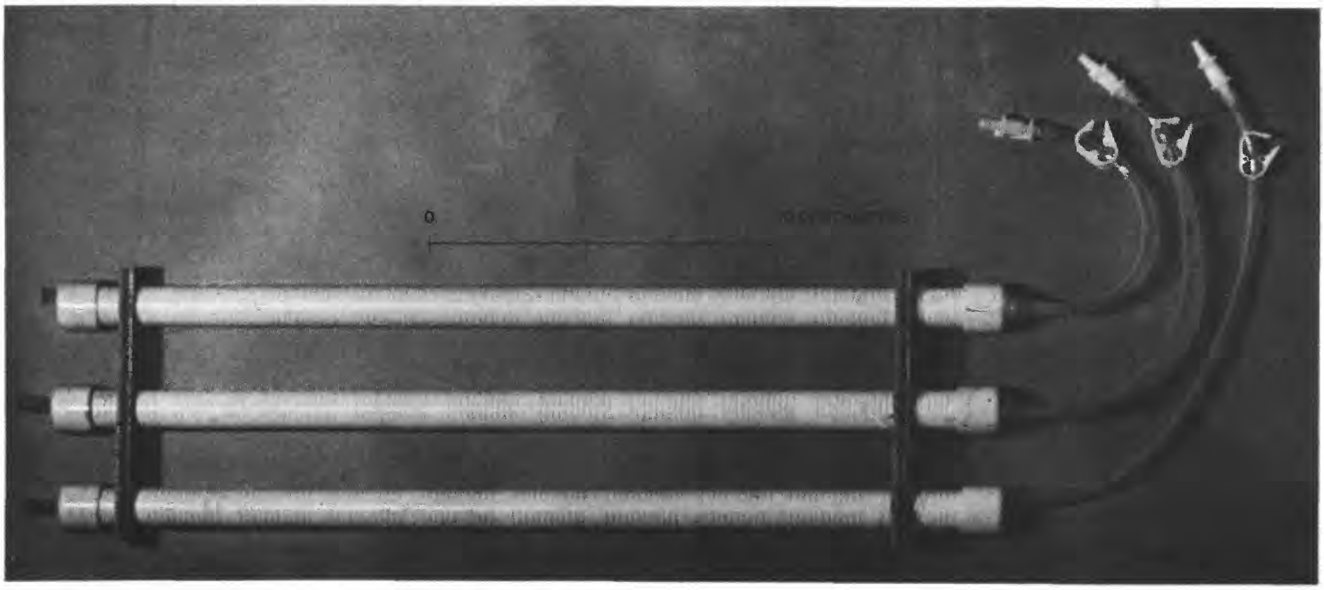

Figure 5. Rack of three intragravel pipes for obtaining measurements at discrete depths within the streambed.

gence between measured surface water and intragravel DO values at each site; (2) except for the Cal Gas site, intragravel DO in general decreased with time; and (3) intragravel-DO concentration decreased to a level below the recommended minimum of 5.0 mg/L at the two sites farthest downstream, S-S Ranch and Dead Ox Wash.

Temperature, as a factor affecting the solubility of oxygen in water, was not a major cause of the decrease of intragravel DO. For example, if the physical effects of temperature alone were considered, S-S Ranch and Dead Ox Wash intragravel water could have held, on the average, 38 and 56 percent more oxygen, respectively, than was actually recorded.

Single DO measurements taken at weekly intervals, however, are inadequate to show the daily oxygen cycle where there is appreciable metabolic activity of aquatic plants. To determine the variation in DO concentration over a 24-hour period, four measurements were taken about every 2 hours at the Verdi (background), Sparks, and Dead Ox Wash sites. The graphs of the plotted concentrations (fig. 6) for the Verdi and Sparks sites show a rise and fall of intragravel DO that closely parallels the surface-water DO cycle, with differences between the two cycles of about 1 mg/L. At Dead Ox Wash, however, the synchronized rise and fall is not so obvious, and intragravel DO was from 6 to 9 mg/L less than the surface-water DO, suggesting a lack of exchange of surface water with intragravel water at this site. High maximum concentrations were recorded at 1400 and 1600 hours on March 26 at Dead Ox Wash (fig. 6) and probably were the result of surface water mixing with intragravel water. A portion of the streambed was disturbed inadvertently just before 1400 hours when a box of eggs was removed for a mortality count. Previous tests in this study showed that localized disruption of the streambed by removal of a Vibert box resulted in a temporary increase in DO in the immediate vicinity.

Examination of the graphs of diel[3] DO percent saturation for Verdi and Sparks (fig. 7) shows intragravel water sometimes had DO saturation at or above 100 percent. These values occurred at the time of maximum oxygen production and corresponding supersaturated condition in the surface water caused by submerged aquatic plants. Supersaturated conditions within the gravels could occur only if (1) supersaturated surface water was "pulled" downward by too much pumping activity during the withdrawal of intragravel sample water, (2) one or more intragravel pipes was buried too close to the streambed surface, or (3) surface water infiltrated naturally into the streambed through highly permeable gravels. The possibility of either (1) or (2) occurring is remote, as careful sampling procedures were established at the outset, and extreme care was taken during installation of the intragravel pipes to ensure that they were placed at sufficient depth. Woods (1980) reported a similar occurrence of supersaturated intragravel DO and attributed it to interchange with supersaturated surface water.

In contrast, for the Dead Ox Wash site the synchronized rise and fall of intragravel DO percent saturation with respect to the surface water was not apparent. Intragravel DO percent saturation was always less than 80 percent at Dead Ox Wash, whereas it was usually greater than 80 percent at Verdi and Sparks. Moreover, intragravel water temperature at this site fluctuated little during the diel period (fig. 8). These observations, as well as the greater difference in DO concentration between surface and intragravel water at the downstream sites, suggest that surface water at S-S Ranch and Dead Ox Wash was infiltrating the streambed at a rate insufficient to keep pace with oxygen-demanding substances within the gravels.

Although it appears that the declining DO concentrations at the 15- to 20-cm depth were most directly responsible for egg mortality at the two sites farthest downstream, a fundamental question still remains: What environmental factor(s) caused the observed reduction of intragravel DO? The authors speculate that the following three factors probably were the most influential in affecting DO within the artificial redds downstream from Wadsworth:

1. *Oxygen uptake by microbes decomposing organic matter at the water-streambed interface.* Laboratory experiments by Hargrave (1972) have shown that oxygen uptake by bacteria on the surface of deposited sediments in freshwater lakes ranged from 1 to 10 milligrams of oxygen per square meter per hour [(mg O_2/m^2)/h]; bacteria consumed three orders of magnitude more oxygen on organic detrital matter than those on inorganic particles. Butts and Evans (1978) have documented that in some Illinois streams, oxygen uptake at the streambed surface was 11 (mg O_2/m^2)/h for a clean stream and 387 (mg O_2/m^2)/h for a polluted stream. Kreutzberger and others (1980) found that the oxygen demand of bottom sediments in a reach of the Milwaukee River affected by sewage overflows ranged from 116 to 279 (mg O_2/m^2)/h. In a reach of the Truckee River beginning at Reno and extending 8 km downstream, Thomas and O'Connell (1966) determined that the total benthic demand (bacteria and algae) in that study area was 11.4 grams of oxygen per square meter per day [(g O_2/m^2)/d], which is equivalent to 475 (mg O_2/m^2)/h. The Truckee River downstream from Wadsworth accumulates an abundance of detrital matter on the streambed surface remarkably fast. Instream conditions of this type provide the potential for a substantial (but yet to be quantified) oxygen uptake on the streambed surface in the lower Truckee.
2. *Oxygen uptake due to intragravel BOD_u.* In this study, the BOD_u of intragravel water at the 15- to

[3]Diel measurements are those involving a 24-hour period that includes a day and an adjoining night.

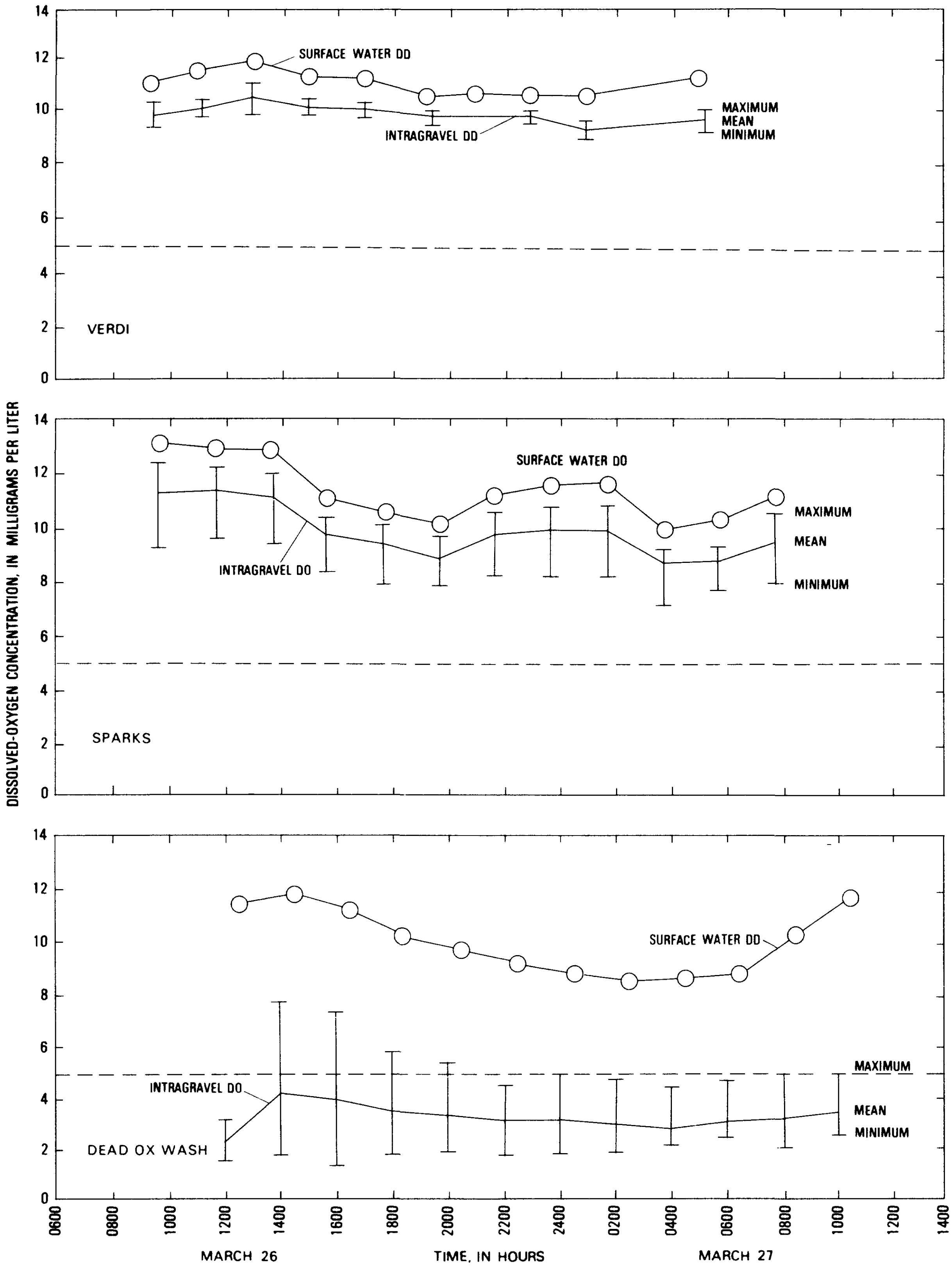

Figure 6. Dissolved-oxygen concentration of surface and intragravel water during March 26–27, 1980, diel measurements in the Truckee River. Dashed line at 5 mg/L represents the recommended minimum intragravel DO concentration for developing trout eggs.

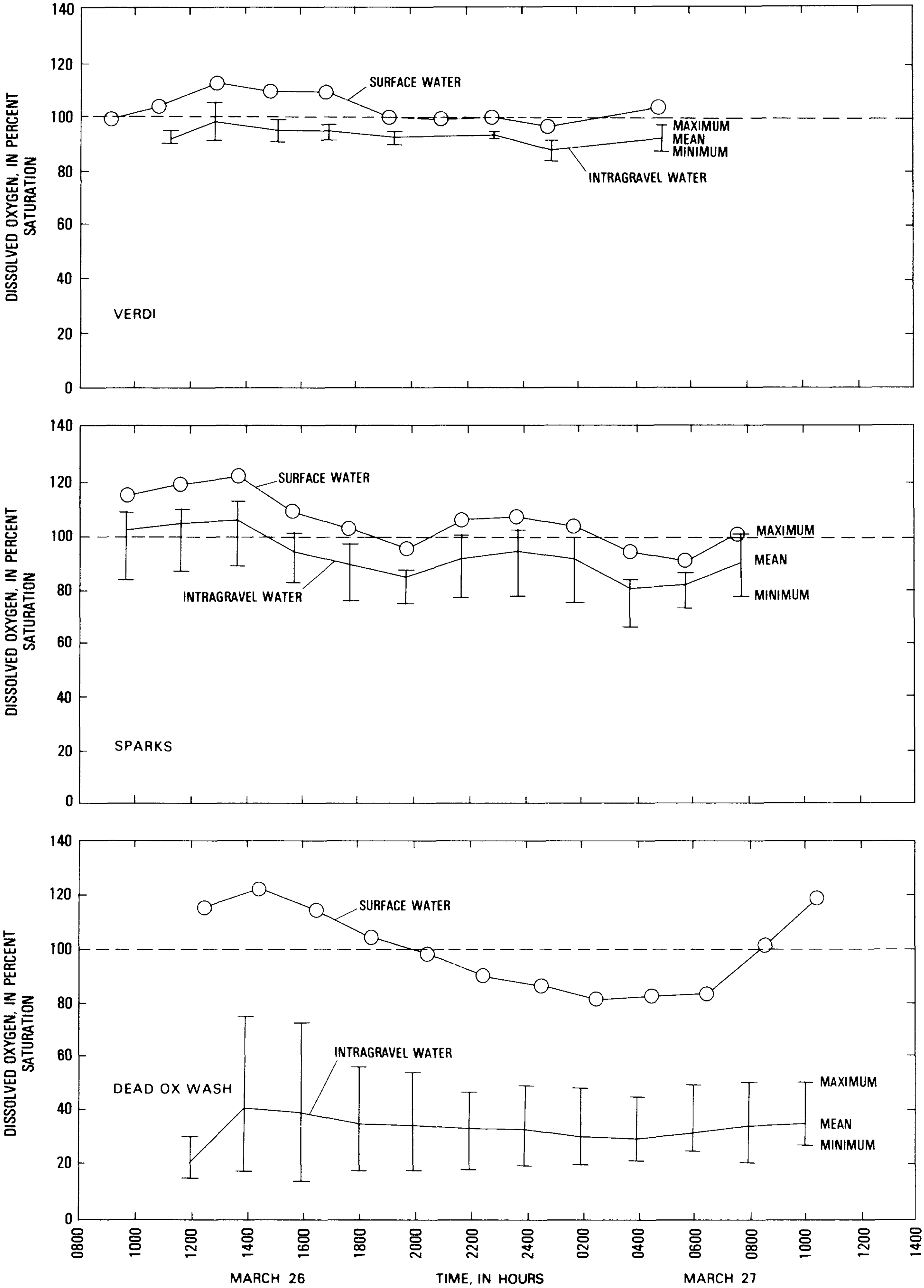

Figure 7. Dissolved-oxygen percentage saturation of surface and intragravel water in the Truckee River during March 26–27, 1980, diel measurements. Dashed line shows 100 percent saturation.

20-cm depth at Dead Ox Wash averaged 8.4 mg/L (table 8). But, as mentioned earlier, this value is believed to represent something less than the total intragravel oxygen demand. The value does, however, indicate an important BOD potential over time. If BOD conditions observed in the Dead Ox Wash redd are indicative of intragravel conditions some distance upstream, and if there is a reduced

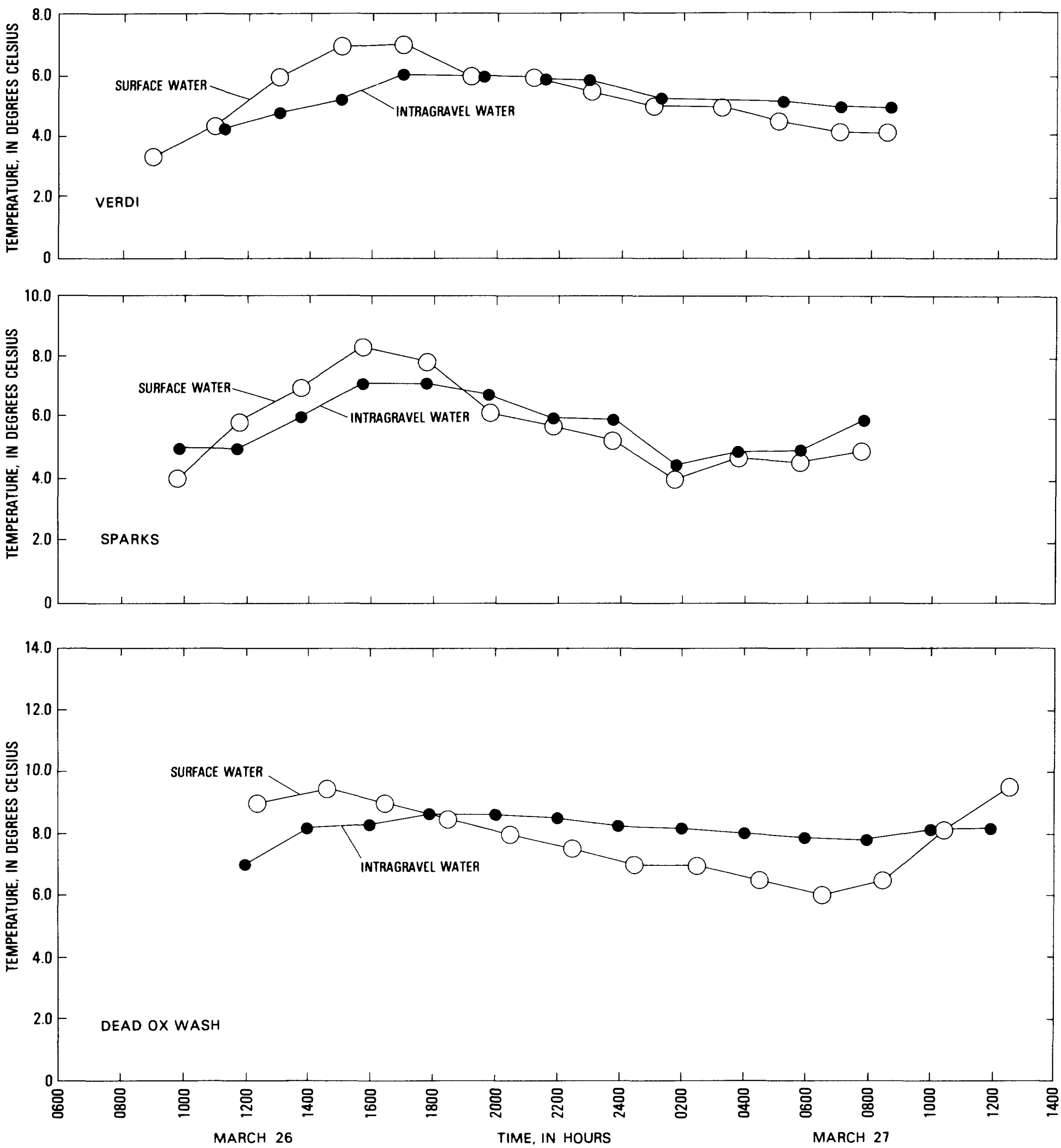

Figure 8. Temperature of surface and intragravel water in the Truckee River during March 26–27, 1980, diel measurements.

exchange of oxygen-rich surface water with intragravel water, then the pore water that is gradually moving downstream would eventually become devoid of DO.

3. *Oxygen uptake by incubating trout eggs in the artificial redds.* Hamor and Garside (1978) have shown that the rate of oxygen consumption by Atlantic salmon eggs is about 0.02 milligrams of oxygen per hour (mg O_2/h) per egg at 10 °C and 50 percent DO saturation (conditions that were similar to those at Dead Ox Wash). Assuming that the DO requirement of an incubating cutthroat egg is similar, then a Vibert box containing 100 eggs would theoretically consume 2 mg O_2/h or 48 mg O_2/d (milligrams of oxygen per day). When DO uptake by living eggs greatly exceeds the DO input from the external environment, the embryos would be adversely affected by the subsequent reduction in dissolved oxygen.

SUMMARY

The results of this study indicate that the principal cause of observed egg mortality in the lower Truckee River is the intolerably low concentration (less than 5 mg/L) of dissolved oxygen. Unexpected low water temperatures, rather than poor water-quality conditions, largely contributed to the observed high egg mortality at the background sites in the upstream reach of the river.

In this report, four hypotheses were advanced and investigated, including one that intragravel dissolved oxygen could have explained the high egg mortality. On the basis of the findings in this study, the following were considered not to be causal factors in egg mortality: (1) sustained high water temperatures (this study only); (2) toxicity due to un-ionized ammonia, nitrite, nitrate, arsenic, cadmium, copper, iron, lead, manganese, mercury, and zinc; and (3) decreasing intragravel dissolved oxygen caused by inflow of oxygen-poor ground water.

Future studies to assess the suitability of the lower Truckee River as a spawning habitat should focus on those environmental factors that affect intragravel dissolved oxygen.

Problems associated with the unavoidable use of sensitive hatchery eggs, the poor viability of some egg batches, and the occurrence of sustained low water temperatures at the upstream background sites compounded the difficulty in making a rational assessment of ambient water-quality conditions in relation to egg survival. In this regard, the use of wild-stock eggs in future investigations of *in situ* egg survival in the Truckee River is highly recommended. The effects of cold water temperatures should also be considered when studying fish egg survival in the upstream reaches of the river.

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