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THE EFFECTS OF STREAM SEDIMENTATION ON TROUT EMBRYO SURVIVAL[1,2]

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ABSTRACT

Five sampling stations were established in Bluewater Creek to measure sediment concentrations and discharge. In the vicinity of the sediment-discharge stations, man-made redds were constructed with sorted gravel. Eyed rainbow trout eggs in hatching boxes were placed in the redds. Periodically, the Mark VI standpipe apparatus was used to measure intragravel dissolved oxygen and intragravel apparent velocity within the redds. The sampling stations with low sediment concentrations responded with high intragravel dissolved oxygen rates, high intragravel apparent velocities (seepage rates), and low trout embryo mortality. Conversely, the sampling stations with high sediment concentrations responded with low intragravel dissolved oxygen rates, low intragravel apparent velocities (seepage rates), and high trout embryo mortality.

INTRODUCTION

Small quantities of sediment are introduced constantly throughout the entire course of a stream by geological processes and have little effect on the aquatic communities occurring normally within the stream. The introduction of gross quantities of sediment into streams has changed the quality and quantity of lotic aquatic life. Agricultural practices responsible for the addition of gross quantities of sediment into streams are: (1) overgrazing range land; (2) brush and tree removal on the floodplain and along stream banks; (3) snag removal and channel realignment; (4) row crop production on steep sloping land; (5) overgrazing floodplain land; and (6) surface irrigation return water.

The addition of gross quantities of sediment will change the community of aquatic organisms within a stream and diminish the total productivity of the stream (Cordone and Kelley, 1961). Trout or other sport fishes disappear and less desirable fish replace them in the stream community complex. Bottom fauna and fish production are reduced in streams carrying high sediment concentrations throughout the entire year.

Clean, permeable gravels provide the nursery areas in the stream environment for trout embryos. In the process of redd construction, sediments are cleared from the gravels by the spawning female before the eggs are deposited. The fertilized eggs develop in an environment well protected from predators. Water seeps through the gravels into the redd delivering oxygen to the developing trout embryos and washing away metabolic waste products produced by the embryos.

The suspended sediment present during the incubation period can greatly affect the survival rate of developing trout embryos. In a stream with high sediment concentrations, sediments will be deposited in trout redds, clogging the pore spaces between the gravels. Consequently, the seepage rate will decrease and the supply of oxygen to the redd will diminish.

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[2]Presented at the Third Seminar on Biological Problems in Water Pollution at Cincinnati, Ohio, August 16, 1962.

Continuous high sediment concentrations in a stream, occurring during the trout egg incubation period, can determine the recruitment of young-of-the-year trout to the population. Without high yearly recruitment, the trout population can be replaced by a species whose needs are better supplied by the environment.

This investigation on Bluewater Creek, a stream greatly influenced by agricultural practices in its lower reaches, considers the relationships between stream discharge and sediment concentrations and their subsequent effects on the intragravel apparent velocity (seepage rate) and intragravel oxygen supply to the developing trout embryos.

METHODS

Sediment concentrations and discharge were measured at five sampling stations in Bluewater Creek by standard methods used by the Geological Survey. The Department has a cooperative agreement with the Quality of Water Division of the U. S. Geological Survey in Worland, Wyoming to collect these records. Methods used for sampling suspended sediment are found in reports by the Federal Inter-Agency River Committee (1940, 1941). Stream gauging procedure to measure discharge is summarized in Corbett (1943). Sediment concentration is defined as the weight of sediment in a water-sediment mixture to the total weight of the mixture and is ordinarily expressed in parts per million (ppm). Discharge is defined as the rate of flow at a given instant and is ordinarily expressed in cubic feet per second (cfs).

In the vicinity of the sediment-discharge sampling stations, man-made redds were constructed by excavating a hole in the streambed approximately 3 feet long, 2 feet wide, and 1 foot deep. The excavations were filled with 3/8-inch sorted gravel chips and allowed to stabilize for one week before eggs were placed in the redds.

Eyed rainbow trout eggs were counted, poured into Vibert boxes (Anon., 1959) partially filled with gravel chips, and placed in the redds. At each sampling station, two Vibert boxes with 200 eggs per box were placed 7 inches deep within the redd. The developing embryos were allowed to remain in the stream until one week after calculated hatching time.

Mortality is defined as the ratio of the number of dead embryos remaining in the Vibert boxes to the total number of eyed rainbow eggs placed in the egg hatching box.

The Mark VI standpipe apparatus was used to measure the intragravel dissolved oxygen and intragravel apparent velocities within the redds containing the developing rainbow trout embryos. The theory and application of this standpipe are found in Terhune (1958). Intragravel dissolved oxygen determinations were measured using a micro-technique of the Winkler method (Harper, 1953).

Description of the Study Area

Bluewater Creek is a spring-fed stream approximately 15 miles long, flowing in a northwesterly direction to its confluence with the Clarks Fork of the Yellowstone River near Fromberg, Montana. During the irrigation season, little water is diverted from the creek in the upper 6 miles. Irrigation demands, diverting water from the creek and irrigation surface and subsurface returns, greatly change the quality of water in the lower 9 miles of the stream. During the winter months (November through March), fluctuations in flows are small.

Experimental Design

Sampling sites in the study stream were chosen so that comparisons could be made between stations with low sediment concentrations and stations affected by progressively higher sediment concentrations.

The five sampling stations were located at intervals of about 3 miles and numbered consecutively I through V; with I denoted as the upstream station, V the downstream station.

FINDINGS

In the winter months, when no water is diverted from the stream for irrigation, the daily mean discharge at all five sampling stations showed little fluctuation (FIGURE 1). The greatest change between consecutive days in daily mean discharge was 2 cubic feet per second.

The monthly average sediment concentrations for the five sampling stations are shown in FIGURE 2. The monthly average sediment concentration was lowest at the upstream station (I) of Bluewater Creek. Proceeding downstream, the monthly average sediment concentration increased progressively at the next two sampling stations (II & III). At sampling Station V near the creek's confluence with the Clarks Fork of the Yellowstone River, during November and December, the monthly average concentration was less than at Station IV.

In January, starting at the upper station and proceeding downstream to the lower sampling area, the monthly average sediment concentrations increased progressively.

TABLE 1. Monthly average sediment concentrations and range of observed concentrations in Bluewater Creek

Month		Sediment Concentration (ppm) Station I	II	III	IV	V
November 1961	Monthly Average	20	97	174	328	254
	Range of Observed Concentrations	9 - 67	61 - 166	115 - 389	249 - 481	196 - 427
December 1961	Monthly Average	13	118	142	282	246
	Range of Observed Concentrations	8 - 26	59 - 203	69 - 199	55 - 884	79 - 511
January 1962	Monthly Average	16	147	276	343	386
	Range of Observed Concentrations	12 - 25	71 - 363	172 - 486	221 - 506	61 - 1240

Sediment concentrations at the upper station on Bluewater Creek were low, with 20 ppm as the highest monthly average concentration. This was roughly one fifth of that at the next station downstream (II). Comparing the monthly average sediment concentration at Station I with the other sampling stations, points out that the concentrations were, at most, for Station III - 17 times greater; Station IV - 22

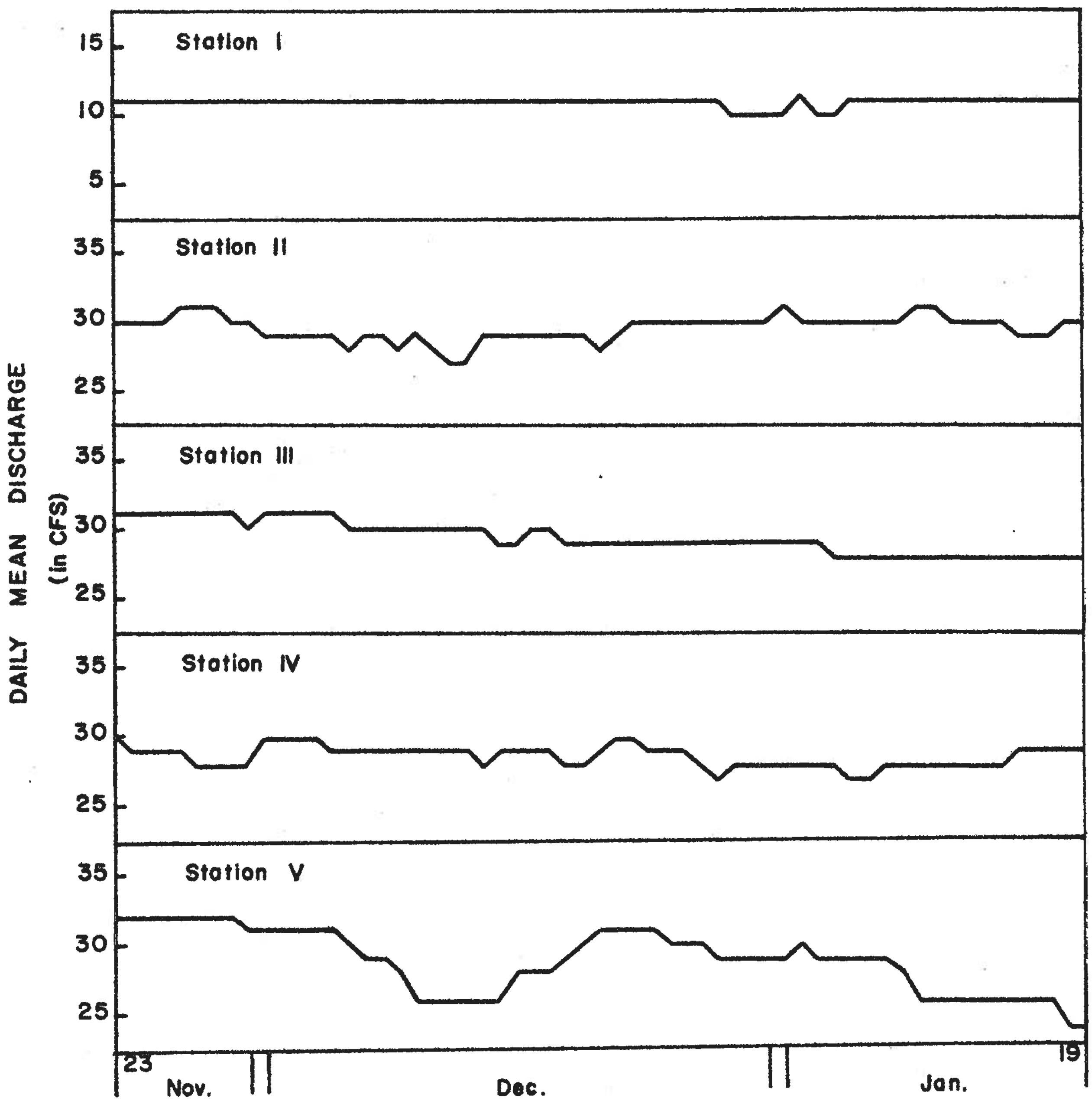

Fig. 1. Daily mean discharge (cubic feet per second) from five sampling stations in Bluewater Creek recorded from November 23, 1961 to January 19, 1962.

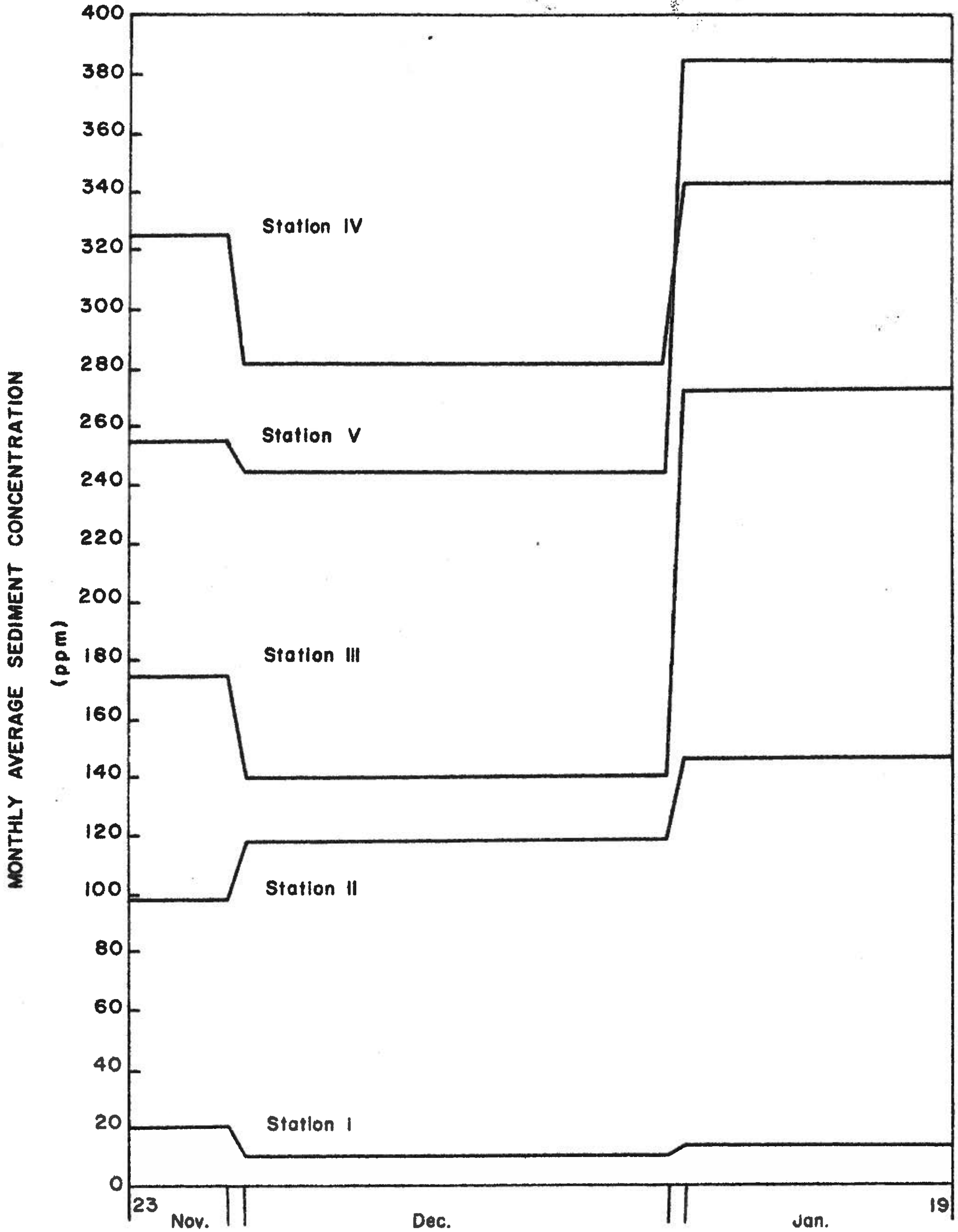

Fig. 2. Monthly average sediment concentrations (ppm) from five sampling stations in Bluewater Creek recorded from November, 1961 through January, 1962.

times greater; and Station V - 24 times greater. The sediment concentrations in Bluewater Creek can be characterized as increasing progressively downstream.

The great variation occurring in daily mean sediment concentrations (TABLE 1) further describes the deterioration in water quality in the downstream areas in the creek. The sources of sediment with relatively stable flows are thought to be: (1) runoff occurring on warm days; (2) lateral erosion of the streambanks; (3) ice gouging of the streambanks and streambed; and (4) degradation of the streambed. Little variation in daily mean sediment concentration implies that a stream in a steady state of operation would neither aggrade or degrade but transport the load supplied to it through the system without change in vertical position of the bed and without change in transverse form of the bed or the channel (Strahler, 1959). Bluewater Creek is relatively stable at the upper station (I) with concentrations ranging from 9 ppm to 67 ppm in November. In January, the sediment concentrations at the lower station (V), an unstable area of the stream, ranged from 61 ppm to 1,240 ppm. The progressive downstream deterioration in the creek, as indicated by great variation in daily sediment concentrations, points out relative stability in the upper areas compared to great unstability in the lower areas.

The Mark VI standpipe apparatus was used to measure intragravel apparent velocity and intragravel oxygen concentration in redds placed in the vicinity of the sediment sampling stations. A standpipe was driven into a redd constructed of 3/8-inch gravel chips and removed after each series of measurements.

The apparent velocity is laminar flow of water through the streambed gravel and is often called the seepage rate, the volume of liquid flowing per unit time through a unit area normal to the direction of flow. A high rate of seepage is required to deliver oxygen to the salmonid embryos and to carry away metabolic waste products (Coble, 1961).

In the stable upper area of the stream with low sediment concentrations, the apparent velocity through the man-made redds remained high during the entire study period (FIGURE 3). At the start of the study, the apparent velocities in each of the redds were within 5 cm/hr of each other. A marked progressive rate of decrease in apparent velocity was measured at each successive sampling site. After 12 days at the lower sampling station, the apparent velocity dropped from 85 cm/hr to 25 cm/hr. No change occurred in the apparent velocity at Station I during the same time period.

TABLE 2. Trout egg mortality compared with intragravel oxygen concentrations and intragravel apparent velocities

Station Number	Per Cent Mortality	Oxygen Concentration		Apparent Velocity	
		Average	Range	Average	Range
I	5%	7.8 ppm	7.4-8.1	82cm/hr	75-90
II	39%	7.8 ppm	7.3-8.1	61cm/hr	55-85
III	90%	7.6 ppm	7.1-8.1	43cm/hr	15-85
IV	100%	7.3 ppm	6.4-8.1	21cm/hr	5-90
V	100%	7.1 ppm	6.4-7.9	23cm/hr	10-85

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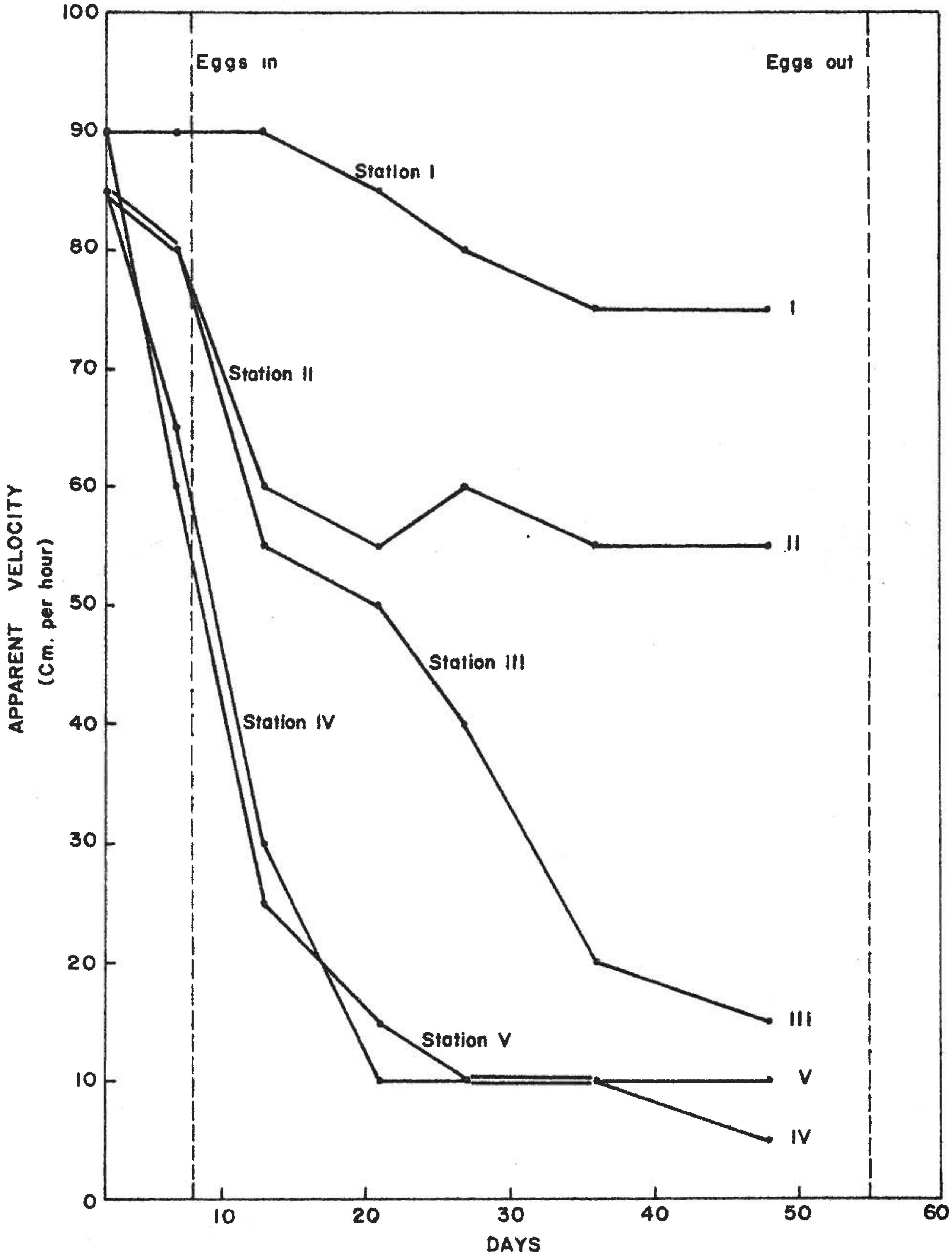

Fig. 3. Intragravel apparent velocity from five sampling stations in Bluewater Creek collected from November 23, 1961 to January 8, 1962.

High concentrations of intragravel dissolved oxygen are required for salmonid embryo survival (Wickett, 1954 and Coble, 1961). At the start of the study, the dissolved oxygen concentration in four of the five redds was 8.1 ppm; in the remaining redd at Station V, the dissolved oxygen concentration was 7.9 ppm. The rate of decrease in dissolved oxygen concentrations is shown in FIGURE 4 and illustrates progressive downstream deterioration in the redds. The smallest amount of dissolved oxygen deterioration occurred at Station I with a decrease of 0.7 ppm. At the lower two sampling stations the dissolved oxygen deterioration was the greatest with a 1.7 ppm decrease at Station IV and 1.5 ppm decrease at Station V.

The average dissolved oxygen concentrations also describe the progressive downstream deterioration in the creek (TABLE 2). The upper areas of the stream with relatively low sediment concentrations and high intragravel apparent velocities have high average intragravel dissolved oxygen concentrations. Low average intragravel dissolved oxygen concentrations are found in the downstream redds affected by high sedimentation rates and low intragravel apparent velocities.

The mortality of rainbow trout embryos is related to the average intragravel oxygen concentration and the average apparent velocity (TABLE 2). Only 5 per cent of the rainbow trout embryos failed to survive at Station I. Mortality increased progressively at the next two downstream sampling stations. No embryo survival was found at the two lower stations in the stream.

DISCUSSION

Bluewater Creek, during the study period, was characterized as a stream with little fluctuation in discharge. There was a progressive downstream increase in the sediment concentrations at the five sampling areas in the stream. Man-made redds filled with 3/8-inch gravel chips were placed in the vicinity of each sediment sampling station. Each redd, at the start of the study, had almost identical high intragravel dissolved oxygen concentrations and intragravel apparent velocities. The intragravel dissolved oxygen concentration rate and apparent velocity decreased progressively downstream in relation to the progressive downstream increase in sediment concentration. Accompanying the progressive downstream decrease in intragravel dissolved oxygen concentrations and intragravel apparent velocities was a progressive increase in trout embryo mortality.

Sediment passing a given area of a stream can greatly affect trout embryo survival. Low sediment concentrations with small fluctuations in discharge in a stable streambed environment would indicate an area of a stream with potential for good trout embryo survival.

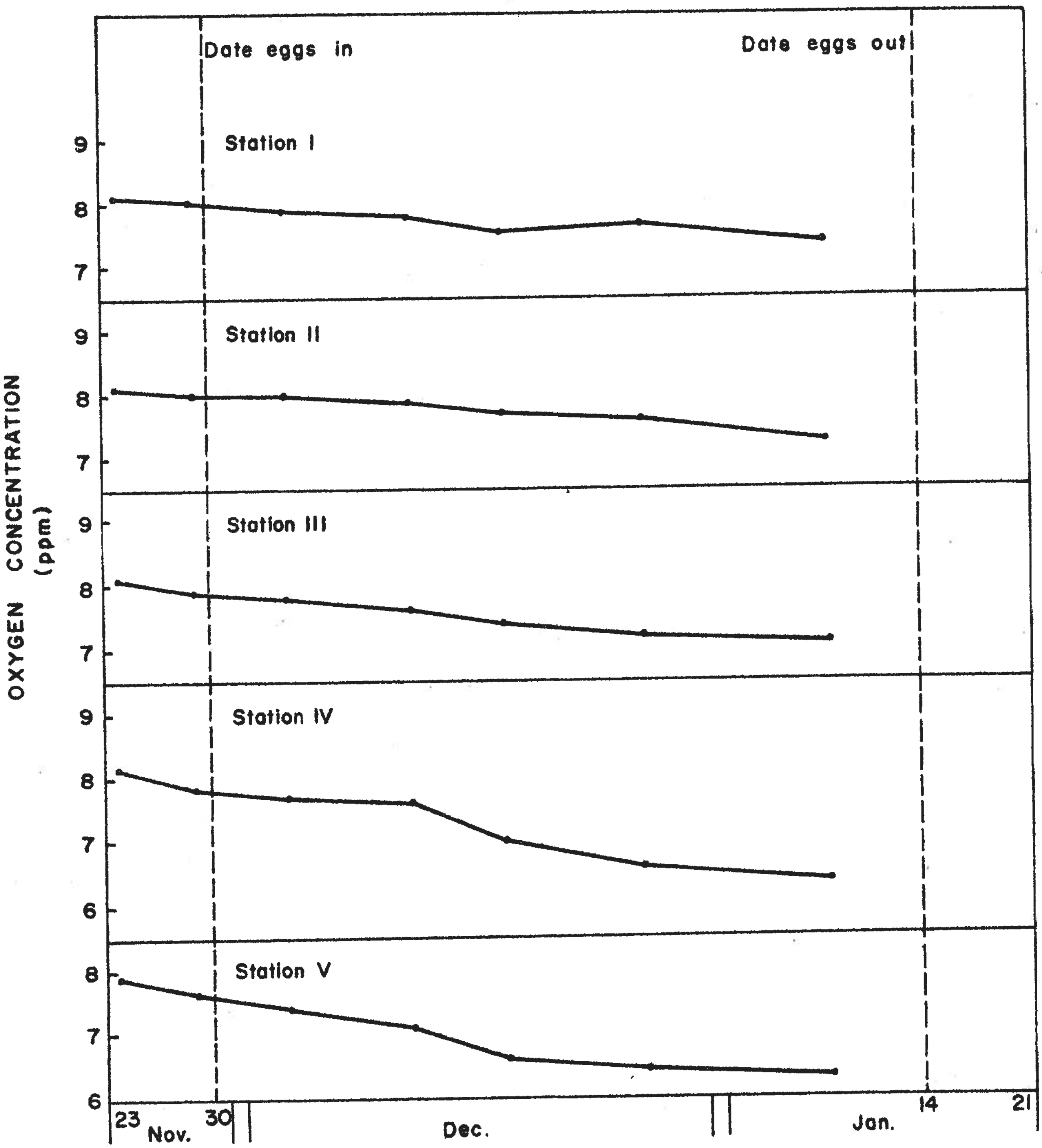

Fig. 4. Intragravel oxygen concentration from five sampling stations in Bluewater Creek collected from November 23, 1961 to January 8, 1962.

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