MONTANA FISH AND GAME DEPARTMENT
FISHERIES DIVISION
HELENA, MONTANA

THE EFFECTS OF SEDIMENTATION ON EGG SURVIVAL OF

RAINBOW TROUT AND CUTTHROAT TROUT

COMPLETION REPORT FOR JOB III , PROJECT NO. F-20-R-7

A FEDERAL AID TO FISH RESTORATION PROJECT

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by

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ABSTRACT

A study was conducted on Bluewater Creek during April, May and June, 1962, to determine the effects of various amounts of suspended sediment on egg survival of rainbow trout and cutthroat trout. Water temperature, stream discharge and suspended sediment data were collected. A particle size analysis of the original material placed in the redds was compared with materials removed after the egg incubation periods. The apparent velocity and dissolved oxygen concentration of the ground water within the redds were determined by means of a Mark VI groundwater standpipe. When sediment settled into a redd the permeability of the gravel and consequently the apparent velocity of the ground water was decreased. A total of 60 or more tons of suspended sediment passed the redds before apparent velocity showed a perceptible decrease. Apparent velocity decreased as the total suspended sediment load increased beyond this level. Redds exposed to 290 or more tons of suspended sediment had the highest egg mortality. Redds with the lowest suspended sediment load, highest apparent velocity and highest dissolved oxygen concentration had the greatest egg survival. Multiple regression analyses of the results showed apparent velocity, dissolved oxygen, suspended sediment load and stream discharge were the important factors in determining rainbow trout and cutthroat trout egg survival.

INTRODUCTION

The harmful effects of sedimentation on salmonid eggs have long been recognized. Hobbs (1937) was among the first to report such effects on natural reproduction of trout and salmon. He studied brown trout, rainbow trout and king salmon in several New Zealand streams and stated that, ". . where redds are clean losses are slight. Where redds are very dirty losses are heavy." Stuart (1953) conducted laboratory experiments which showed detrimental effects of sedimentation on brown trout eggs. He also observed high egg mortality in natural redds exposed to sedimentation. Campbell (1954) reported that sedimentation from gold dredging caused complete mortality of rainbow trout eggs, while Shapovalov (1937), Shapovalov and Berrian (1940) and Shapovalov and Taft (1954) concluded that siltation was probably the principal cause of pre-hatching losses in steelhead trout and silver salmon eggs. Harrison (1923) showed that eyed-egg survival of sockeye salmon was greatest in clean gravel. Neave (1947) reported that sedimentation was a major cause of chum salmon egg mortalities and Gangmark and Broad (1955 and 1956) concluded that floods and silt cause king salmon egg mortalities. Shaw and Maga (1943) demonstrated that mining sediment caused egg mortalities of silver salmon in hatchery troughs and Cooper (1956) determined that sediment from placer mining reduced the survival of sockeye salmon eggs. Cordone and Kelly (1961), after reviewing the entire subject of inorganic sediment in relation to aquatic life in streams, concluded that sediment deposition on the bottom of streams reduced the survival of salmonid eggs.

The present study was conducted on Bluewater Creek during April, May and June, 1962, in an effort to determine the effects of various amounts of suspended sediments on egg survival of rainbow trout (<u>Salmo gairdneri</u>) and cutthroat trout (<u>Salmo clarki</u>).

DESCRIPTION OF STREAM

Bluewater Creek is spring-fed and originates in the foothills of the Pryor Mountains. It is about 15 miles long and flows in a northwesterly direction to its confluence with the Clark Fork of the Yellowstone River drainage near Fromberg, Montana. The upper portion, which includes Stations 1 and 2 (Figure 1), lies in a narrow valley. Here, the banks are covered with a dense growth of birch (<u>Betula</u> spp.), willow (<u>Salix</u> spp.), and other deciduous vegetation. The lower portion, which includes Stations 3 - 5, meanders through cultivated fields and pastures and has very little or no deciduous stream-bank vegetation.

This stream had an overall gradient of approximately 18 feet per mile and an average width of about 9 feet in the upper 3 miles and 16 feet in the lower 12 miles. The stream-bottom materials in order of abundance were: upper portion - gravel, rubble and silt; lower portion - silt, gravel and rubble. A spring and an artesian well added 4.6 cfs and 8.3 cfs respectively to Bluewater Creek just above Station 2 and two springs added about 1 cfs between Stations 2 and 3. These and the springs at the headwaters were the only year-around water sources. Discharge in Bluewater Creek remained fairly constant throughout the year at Stations 1 and 2 and was fairly constant in the fall and winter at Stations 3 - 5. However, in

FROMBERG

CLARK FORK RIVER

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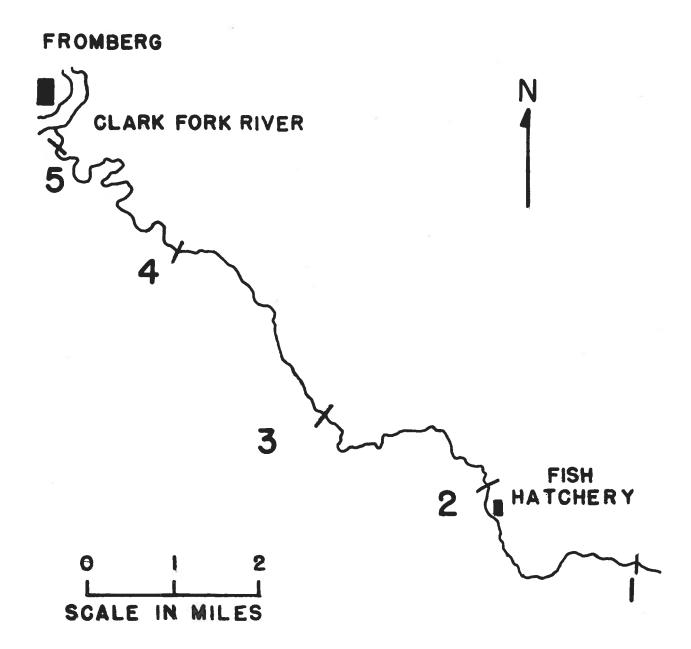FISH HATCHERY

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SCALE IN MILES

Figure 1. Bluewater Creek, showing sampling stations.

the spring and summer discharge measurements and sediment loads at Stations 3 - 5 showed drastic fluctuations due to irrigation diversion, irrigation surface and subsurface return and increased runoff.

Brown trout (Salmo trutta) and rainbow trout (Salmo gairdneri) were the only salmonids found in the stream. Other fish, in order of abundance, included the longnose dace (Rhinichthys cataractae), flathead chub (Hybopsis gracilis), mountain sucker (Pantosteous platyrhynchus), longnose sucker (Catostomus catostomus) and white sucker (Catostomus commersoni). Trout were most abundant in the upper portions (Stations 1 and 2), while other fish were more abundant in the lower portions (Stations 3 - 5).

MATERIALS AND METHODS

The sampling stations were approximately 3 miles apart and represented areas of Bluewater Creek with different suspended sediment loads. The suspended sediment load was smallest at Station 1 and increased progressively downstream. Suspended sediment samples were collected with a depth-integrated device with a one-pint capacity (DH-48 Hand Suspended Sediment Sampler; Federal Inter-Agency River Basin Committee, 1952). Stream gauging procedures used to measure discharge followed Corbett, et al. (1943).

Redds were constructed at each station by digging holes (36 x 36 x 20 inches) into the stream bed. These holes were filled with washed gravel (3/8 - 1 1/2 inches in diameter). Redds were located in riffles which maintained a water depth of at least 6 inches during periods of minimum discharge. Separate redds were constructed for each species except at Station 1 where one redd served both rainbow trout and cutthroat trout.
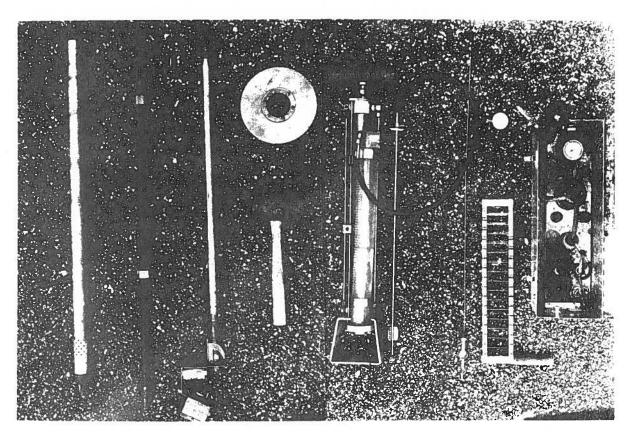
Figure 2. The Mark VI groundwater standpipe, driving bar, velocity liner with motor attached, disc, hammer, pump, syringe, comparator and oxygen analysis kit.

concentrations to be relatively stable at each station during his experiment. He collected suspended sediment samples and discharge data approximately twice a week. This was in contrast to the present investigation where large fluctuations in suspended sediment concentrations and discharges made it desirable to take samples at least once a day at each station. Suspended sediment concentrations are instantaneous measurements expressed in parts per million. Suspended sediment loads are estimations of the total pounds passing a station on a particular day and are expressed in tons per day. This is determined as follows: discharge (cfs) x suspended sediment concentrations (ppm) x 0.0027.

The monthly average suspended sediment concentrations and loads varied little during April, May and June, 1962, at Stations 1 and 2 (Table 1). They were lowest at Station 1 and increased progressively downstream (Stations 2 - 5) except during June when the average was higher at Station 3 than at Stations 4 and 5. Irrigation diversion from Bluewater Creek below Station 2 began on April 30 and continued throughout the remainder of the study period. Suspended sediment at Stations 3 - 5 increased in May and June as a result of irrigation return and increased rainfall. Rainfall had little effect on the amount of suspended sediment at Stations 1 and 2 because in this area less intensive land use and abundant stream bank vegetation retarded soil erosion.

The mean discharges (April through June) remained fairly constant at Stations 1 and 2 but varied at Stations 3 - 5 due to irrigation diversion and increased runoff (Table 2). The mean discharge at Stations 3 and 4

Table 1. Monthly ranges, mean suspended sediment concentrations (ppm) and loads (tons/day) on Bluewater Creek (1962).

Stations	1	2	3	4	5
April					
Sediment concentration					
range	15-112	54-215	80-176	83-269	125-899
mean	30	103	108	136	348
Sediment load					
range	0.4-3	5-18	6-13	6-21	10-172
mean	0.8	8	8	10	44
May					
Sediment concentration					
range	12-50	53-224	94-5057	16-11590	189-10000
mean	23	98	505	585	1084
Sediment load					
range	0.4-1	4-18	3-393	0.4-1293	10-4118
mean	0.6	8	29	53	260
June					
Sediment concentration					
range	14-177	49-468	119-19700	96-13020	168-3420
mean	32	126	1087	987	996
Sediment load					
range	0.4-5	4-45	6-4947	3-2508	9-1154
mean	0.9	10	219	133	206

Table 2. The monthly maximum, minimum and mean discharges (cfs) at each station on Bluewater Creek (1962).

Stations	1	2	3	4	5
April					
Maximum	12	32	29	31	71
Minimum	10	29	26	27	28
Mean	10	30	27	29	38
May					
Maximum	12	31	26	38	151
Minimum	10	26	13	10	19
Mean	10	29	17	16	50
June					
Maximum	11	36	93	56	127
Minimum	9	25	16	13	19
Mean	10	29	27	24	63

showed a decrease from April to May due to irrigation diversion. The mean decrease was less noticeable in June due to increased runoff from several rainstorms. On April 23 a large irrigation ditch (Wrangler) began adding water to Bluewater Creek between Stations 4 and 5. This water was diverted from the Clark Fork River and was the major cause of the high monthly mean discharges at Station 5.

Temperature data (Table 3) were collected with recording thermometers (Dickson Minicorder) placed at each station. The temperatures at the end of each three-hour period were averaged to obtain monthly means. Daily mean temperatures, obtained for these periods, were used to calculate temperature units (1 temperature unit equals 1° F above freezing for a 24-hour period) as a basis for determining the rate of egg development in each redd.

Table 3. The monthly maximum, minimum and mean temperatures ($^{\circ}$F) at each station on Bluewater Creek (1962).

Stations	1	2	3	4	5
April					
Maximum	64	66	67	64	60
Minimum	42	36	44	43	40
Mean	53	50	54	53	51
May					
Maximum	65	68	72	70	64
Minimum	45	38	41	47	40
Mean	54	53	57	58	53
June					
Maximum	64	73	73	78	72
Minimum	46	40	46	53	46
Mean	54	55	59	64	59

Rainbow Trout Eggs

Artificial redds for rainbow trout eggs were constructed at all stations on April 12. Apparent velocity and dissolved oxygen measurements were taken in each redd beginning 2 - 3 days after redd construction and continued until egg samples showed a total mortality at certain stations (May 9 - 15). Suspended sediment samples were generally secured 1 - 3 times a day from the time of redd construction to the end of the incubation period. Rainbow trout eggs were taken on April 28 from fish secured in Lake Mary Ronan. These were immediately fertilized, allowed to water harden, packed in quart jars surrounded by ice and then transported by airplane to the study area — a distance of about 400 miles. Upon arrival they were slowly tempered to the water temperature at the fish hatchery (60° F). Pea-sized gravel and eggs were than placed in vibrate boxes (Progressive Fish-Culturist, 1951) and 9 dram plastic vials (1 inch diameter x 2.75 inches high) each perforated by 27 holes (5/32 inch) to allow for water circulation. The eggs within the containers were then transported to the stations, tempered to the stream water temperature and buried 4 - 6 inches into the gravel of the artificial redds. The time required from spawn-taking to egg-burial varied from 6 - 11 hours. Each redd received a unit consisting of 13 plastic vials containing 25 eggs each and 2 vibrate boxes with 200 eggs each. Vibrate boxes were left in the redds during the entire incubation period. Vials were removed from each redd after being exposed to approximately 10, 20, 40, 100, 150, 200, 250, 300, 400, 500 and 550 temperature units. A five-foot piece of leader

tied to each vial permitted individual removal without disturbing the rest of the redd. Immediately after removal, the eggs from the vials and vibrate boxes were placed in 10 percent formalin. After several hours, they were removed from the formalin and mortality was determined by counting the white (dead) eggs.

The actual amount of sediment deposition in the redds from superimposed water and ground water was not measured. The effects of sedimentation were judged by determining the rate at which apparent velocity and dissolved oxygen of the ground water decreased in the redds. When sediment settled into the redd the permeability of the gravel and consequently the apparent velocity of the ground water decreased. Coble (1961) reported that low apparent velocities were generally accompanied by low dissolved oxygen concentrations and vice versa. Alderdice, Wickett and Brett (1958) showed that the critical dissolved oxygen levels for chum salmon eggs ranged from 1 ppm in early stages of development to over 7 ppm shortly before hatching. The measurements of apparent velocity and dissolved oxygen concentrations of the ground water are of similar value in appraising the quality of a redd: ground water with a low dissolved oxygen supply and a high apparent velocity may be as suitable to egg survival as ground water with a high dissolved oxygen supply and a low apparent velocity.

Rainbow trout egg mortality, accumulative suspended sediment load, apparent velocity, dissolved oxygen and stream discharge data for each station are presented in Table 4. The initial apparent velocity measurements were 70 cm/hr or more. These showed little decrease until a total

Table 4. Rainbow trout egg mortality in plastic vials in percent (EM) related to total accumulated suspended sediment load in tons (SSL), apparent velocity in cm/hr (V), dissolved oxygen in ppm (DO) and stream discharge in cfs (D) for redds.

Days[1]	1					2					3					4					5				
	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D
2		2	81	7	10		29	147	8	29		19	87	8	26		27	106	8	28					
3							38	100	8	30		25	106	9	27							57	70	9	30
4		4	83	8	10		49	132	8	30		32	90	9	27		44	105	10	28		71	72	8	31
8		7	89	7	10		80	142	8	30		59	66	8	28		82		8	30					
9																	91	29	9	30		149	39	5	30
10		8	87	8	10		91	37	7	31		73	36	7	28		101	18	10	30		162	5	7	31
11												80	34	7	27		113	7	9	31		176	36	7	29
13												96	83	8	27		135	37	8	30		343	24	7	71
14		9	62	8	10																				
15[2]		10			10		123			32		117			28		159			29		664			71
16	8	11			10	20	129	39	7	31	58	130			28	76	170			30	54	789	6	8	67
17	8	11	71	8	10	44	147			31	16	141	63	9	28	88	181	1	7	30	76	881			59
18	8	13			10	52	156			30	48	153			26	48	191			27	68	944			44
19							165	11	8	31															
20	8	14	65	8	10	24	171			30	64	179	30	7	26	92	205	1	7	24	72	1071	1	7	42
21							176	14	7	30							211	1	7	23		1104	1	3	29
22	16	15	58	8	10	36	181	20	8	30	100	206	30	7	25	100	217			23	72	1153			25
23	32	15			10	68	187			30	100	219			17	84	223	11	8	23	88	1176	2	5	25
25	32	16	90	8	10	52	196	10	7	30	100	230	8	4	13						96	1230			26
26																100	228	13	5	12					
27		17	99	7	10		206	9	7	29		237	7	4	13							1305	4	5	32
28							212			30	100	240			13										
29	28	18	120	8	10	96	217	14	7	30						96	231	6	6	11	100	1367	3	5	29
31											84	285			15										
33																	272	20	3	12	92	1931	2	3	45
34	88	21			10	96	271			27	100	348			14										
37											3/363				14										
39	3/100	24			10	100	306			26						3/100	289			11					
41	52	25			10	3/314				29						100	303			1	3/100	2435			60
42																									
44						90	468			31															

1/ After redd construction; 2/ Eggs planted; 3/ End of incubation period.

of 60 or more tons of suspended sediment had passed a redd. The total
suspended sediment load at the end of the incubation period was 25 tons at
Station 1 and ranged from 289 - 363 tons at Stations 2 - 4. The total
suspended sediment load was 2435 tons at Station 5 (Table 4). After 60
tons or more had passed a redd apparent velocity followed a general down-
ward trend to less than 10 cm/hr. Changes in discharge did not greatly
affect apparent velocity, although Wickett (1954) reported that apparent
velocity of the ground water was closely related to stream discharge. At
all stations except Number 2, dissolved oxygen concentrations tended to be
low when apparent velocities were low and vice versa but the relationship
between the two was not strictly proportional (Table 4). In 62 measure-
ments at Stations 1-- 5 there was no constant ratio between surface water
and ground water dissolved oxygen taken simultaneously.

Vials removed from redds at the end of the incubation period showed
egg mortality percentages of 52 at Station 1, 90 at Station 2 and 100 at
Stations 3 - 5. Eggs in the vibrate boxes had been exposed to 600 - 800
temperature units when they were removed from the redds at the end of the
incubation period. No living unhatched eggs were found at this time. Egg
mortalities in vibrate boxes were: 67 percent at Station 1, 92 percent at
Station 2, 97 percent at Station 3 and 99 percent at Stations 4 and 5.
High egg survival at Station 1 compared to Stations 2 - 5 was related to
low suspended sediment load, high apparent velocity and high dissolved
oxygen (Table 4). In the autumn of 1961, Peters (1962) buried vibrate
boxes, each containing 200 eyed rainbow trout eggs, in artificial redds at

Stations 1 - 5 in Bluewater Creek. He found an egg mortality of 5 percent
at Station 1, 39 percent at Station 2, 90 percent at Station 3 and 100
percent at Stations 4 and 5. He concluded that sediment greatly affected
trout egg survival.

A multiple regression analysis was made to test the significance of
the following independent factors on rainbow trout egg mortality (depend-
ent factor "y"):

x_1 - Accumulative suspended sediment load (tons)

x_2 - Apparent velocity of the ground water in redds (cm/hr)

x_3 - Dissolved oxygen concentration of the ground water in redds (ppm)

x_4 - Discharge of the stream (cfs).

A total of 23 observations were made at all stations during the rainbow
trout egg incubation period on these four independent factors and the one
dependent factor. The coefficient of multiple correlation (R) was 0.8505
for this analysis, which shows a high degree of linear dependence of mor-
tality on the other factors. The multiple linear regression model for
four independent factors is of the general form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4,$$

Where B_0, B_1, ..., B_4 are unknown parameters or constants.
In this analysis the model obtained was:

$$Y = 166.9128 - 0.0175X_1 - 0.6681X_2 - 11.2041X_3 - 0.2429X_4.$$

A minus sign on a term in this model means that as the factor associated
with this term decreases, egg mortality rate increases. This seems
reasonable for apparent velocity, dissolved oxygen and discharge, but not

for the suspended sediment load.

The "T" tests performed to determine the significance of each independent factor in estimating egg mortality showed that apparent velocity and dissolved oxygen were the most important. The "T" value for the ground water apparent velocity was -3.65 and was significant at the 99 percent level. The "T" value for dissolved oxygen concentrations of the ground water was -2.06 and should have been -2.10 in order to be significant at the 95 percent level. The "T" values for the suspended sediment load and stream discharge were too small to be significant. The accumulated suspended sediment load was highly correlated with the other factors (Table 5) and appeared to be the major cause of low apparent velocities of the ground water in the redds and therefore a major cause of egg mortalities.

Table 5. Simple correlations for the 4 factor rainbow trout egg analysis.

	Y	X_1	X_2	X_3	X_4
Y	1.0	0.4079	-0.7564	-0.6709	0.1968
X_1		1.0	-0.4068	-0.7115	0.4219
X_2			1.0	0.4785	-0.5220
X_3				1.0	-0.0484
X_4					1.0

A second multiple regression analysis was made to test the significance of only accumulative suspended sediment load (X_1) and stream discharge (X_2) in relation to rainbow trout egg mortality (Y). A total of 36

observations was made at all stations during the egg incubation period on these 3 factors. The coefficient of multiple correlation (R) was 0.3778 which does not show a high degree of linear dependence of mortality on the other factors. The multiple linear regression model for two independent factors is of the general form:

$$Y = B_0 + B_1X_1 + B_2X_2.$$

In this analysis the model obtained was:

$$Y = 64.6189 + 0.0407X_1 - 0.1586X_2.$$

The suspended sediment load had a positive sign which denotes that as the accumulative suspended sediment load increases, egg mortality increases. The "T" tests performed to determine the significance of each independent factor in estimating the rate of egg mortality showed that the suspended sediment load was more important than discharge. The "T" value for the accumulative suspended sediment load was 2.67 and was significant at the 95 percent level but the "T" value for stream discharge (-0.44) was again insignificant. The simple correlations for this analysis are presented in Table 6. The two multiple linear regression models presented in the

Table 6. Simple correlations for the 2 factor rainbow trout egg analysis.

	Y	X_1	X_2
Y	1.0	0.3733	0.1339
X_1		1.0	0.4951
X_2			1.0

analysis of the rainbow trout egg data apply only to this particular stream under the conditions present during the study but may serve as a guide in other streams.

A vertical sample of bottom material (6 inches long x 2 inches diameter) was taken from each redd 57 days after construction with a core sampler. This device did not adequately collect materials larger than 32 mm in diameter. The amount of sediment in the redds at this time was compared with samples from original redd materials. All size groups less than 32 mm were either as common or more abundant in the 57 day samples than in the original redds, except the 8 - 16 mm size group at Station 2 (Table 7). The small particles (less than 4 mm) probably were the major cause for a decrease in gravel permeability and apparent velocity. Station 2 had the smallest gain in material finer than 4 mm (1 percent) and Station 4 had the largest (36 percent). Particles finer than 0.125 mm were not found in the original materials but constituted 1 percent of the sample at Stations 1 - 3 and 3 percent at Stations 4 and 5. The rate of sedimentation in redds depends on the suspended sediment load, stream discharge and velocity as well as the position of the redd in the stream. An increase in stream discharge and velocity or a decrease in the suspended sediment load may cause some of the sediment to wash out of the redd. For this reason, the total amount of sediment that settled in the redds during the 57 days may or may not appear in samples taken at the end of the period.

Table 7. Particle size of materials used in rainbow trout redds compared with redd materials 57 days later and total accumulated suspended sediment loads.

Station	Total suspended sediment load (tons)	Percent finer than indicated size, in millimeters									
		.062	.125	.250	.500	1.0	2.0	4.0	8.0	16.0	32.0
		Original redd materials									
			0	0	1	1	1	1	3	26	73
		Redd materials after incubation period									
1	48		1	1	2	2	4	8	18	49	100
2	498		0	1	1	1	2	2	5	18	100
3	6139		1	1	2	2	2	6	18	52	100
4	4398	2	3	8	16	22	27	37	52	66	89
5	10364	2	3	4	6	7	8	10	13	33	100

Cutthroat Trout Eggs

Artificial redds used for cutthroat trout eggs were constructed at Stations 4 and 5 on May 9 and at Stations 2 and 3 on May 14. The redd at Station 1, constructed on April 12, was used for both cutthroat trout and rainbow trout eggs. On May 29 cutthroat trout eggs were taken from fish secured in Ashley Lake. These were transported about 400 miles to Bluewater Creek. The time required from spawn-taking to egg burial varied from 10 - 14 hours. The procedures used were the same as described for rainbow trout. Suspended sediment samples were generally taken 1 - 3 times a day during the egg incubation period. A large stream discharge (76 cfs) at Station 5 made it impossible to plant eggs on May 29 so the eggs that eyed in the meantime were buried on June 9. Vials were removed almost every day during the period these eyed-eggs were in the redd.

Cutthroat trout egg mortality, accumulative suspended sediment load, apparent velocity, dissolved oxygen and stream discharge data were determined for each station during the egg incubation period (Table 8). Apparent velocity and dissolved oxygen concentrations were taken initially 1 - 2 days after egg burial and were continued at intervals varying from 1 - 6 days during the incubation period. The first three apparent velocity determinations taken at Station 1 were lower (less than 100 cm/hr) than those taken later (150 cm/hr or more). This discrepancy probably resulted from a partially plugged standpipe. At the beginning of the egg incubation period apparent velocity was 182 cm/hr at Station 2 and decreased to 12 cm/hr near the end of the incubation period. At Stations 3 - 5 apparent

Table 8. Cutthroat trout egg mortality in plastic vials in percent (EM) related to total accumulated suspended sediment load in tons (SSL), apparent velocity in cm/hr (V), dissolved oxygen in ppm (DO) and stream discharge in cfs (D) for redds.

											Stations														
	1					2					3					4					5				
Days[1]	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D	EM	SSL	V	DO	D
1	2	1			10	6	10	182	7	29	2	9	20	6	16	6	17	45	5	18	4	101	10	7	65
2	8	2	30	7	10	56	23	45	8	29	56	17	28	5	16	32	31	8	5	17	4	242			73
3		3	60	7	10		29	52	7	26		24	25	5	14		45	7	6	17	8	438			80
4		4	96	8	10		41	110	7	27		36	35	6	17	96	62	36	6	18	0	644	10	7	83
5	16	5	200	8	10	20	48	108	7	27	44	46	45	7	16	100	78		7	17	16	785			60
6																100	91			18					
7	32	10			10	80	100			36	36	5000					2598			56	16	1369			75
8	32	11	200	7	10										93						32	2191			89
9						80	122	52	7	31						100	2694	27	4	24	32	2430	8	7	77
10										29	16	5154			29		2721	6	2	24	36	2634	5	6	74
11	24	13			10	76	139			29	64	5177	25	5	28						64	2907			74
12		13	200	7	10		143	84	7	30						100	2774	6	4	23	64	3090	6	7	73
13		14		7	10						60	5216	32	4	26						60	3192			66
14	52	15	200	8	10	96	156	29	7	28		5235			28		2837		3	23	68	3280	5	5	64
15							161	42	6	30		5256	33	4	26										
16		16	188	7	10		167	18	7	30		5273	26	4	26	100	2886	33	4	23					
17							172	11	7	30		5288			26	96	2905	9	4	26					
19	52	18			10	88	206			32	100	5301	17	3	25	2/	3080			25					
20		19	176	7	10		216	38	7	31						96	3122			26					
21							225	36	7	29	100	5409	15	6	27		3164	9	1	26					
22		20	183	8	10		235	88	7	27															
23	28	20	150	8	10	88	244	19	8	28	2/96	5454	10	5	28										
24			200	7	10		253	12	6	27		5471	7	4	27										
25	2/40	22	200	7	10	2/92	260	12	6	27	100	5503	26	5	27	100	3254	9	1	25					
28						90	292	36	6	25															

1/ After planting; 2/ End of incubation period.

velocity was 20, 45 and 10 cm/hr respectively at the time of initial measurements and decreased to less than 10 cm/hr by the end of the incubation period. As with the rainbow trout egg experiment, dissolved oxygen concentrations were low when apparent velocities were low, and vice versa. In 64 measurements at Stations 1 - 5 there was no constant ratio between surface water and ground water dissolved oxygen taken simultaneously. Increases and decreases in stream discharge did not greatly affect apparent velocity. A rainstorm greatly increased the suspended sediment load and stream discharge 7 days after cutthroat trout eggs were planted at Stations 1 - 4 (Table 8). The large suspended sediment load and stream discharge did not greatly decrease the apparent velocity in the redds or increase the egg mortality rate. The smaller sediment loads from irrigation returns and streambank erosion accompanied by a normal discharge was as detrimental to incubating trout eggs as this large discharge and suspended sediment load.

The vials removed from redds at the end of the incubation period had mortality percentages of 40 at Station 1, 90 at Station 2, 100 at Stations 3 and 4 and 68 at Station 5. Eggs in vibrate boxes were exposed to 600 - 700 temperature units at Stations 1 to 4 and 370 at Station 5 at the time of removal. No living unhatched eggs were found. Egg mortality percentages in vibrate boxes were: 43 at Station 1, 94 at Station 2, 98 at Station 3, 100 at Station 4 and 87 at Station 5. As with the rainbow trout experiment, high cutthroat trout egg survival at Station 1 compared to Stations 2 - 5 was related to a low suspended sediment load, high

apparent velocity and high dissolved oxygen (Table 8).

A multiple regression analysis was made to test the significance of the same independent factors to cutthroat trout egg mortality as used in the rainbow trout egg analysis. A total of 36 observations was made at all stations on the 4 independent factors and 1 dependent factor during the egg incubation period of cutthroat trout. The coefficient of multiple correlation (R) was 0.6905 for this analysis which shows a fairly high degree of linear dependence of mortality on the other factors. In this analysis the multiple linear regression model was:

$$y = 82.0968 + .0089X_1 - .1880X_2 - 1.0437X_3 - .7109X_4.$$

The "T" tests showed that accumulative suspended sediment load, stream discharge and apparent velocity were the significant factors in determining egg mortality. The "T" value for the accumulative suspended sediment load was 2.82 and was significant at the 99 percent level; the "T" value for stream discharge was -2.46 and was significant at the 95 percent level; and the "T" value for apparent velocity was -1.88 and was significant at the 90 percent level. The "T" value for dissolved oxygen was too small to be significant. These results differ from those on rainbow trout eggs where apparent velocity and dissolved oxygen were the significant factors. This is undoubtedly due, in part, to the high correlations that exist among pairs of independent variables. While the suspended sediment load and stream discharge were significant, apparent velocity and dissolved oxygen were correlated with egg mortality (Table 9) and are the environmental factors which probably determine egg mortality. The suspended sedi-

Table 9. Simple correlations for the 4 factor cutthroat trout egg analysis.

	Y	X_1	X_2	X_3	X_4
Y	1.0	0.5575	-0.3863	-0.5168	-0.1340
X_1		1.0	-0.4359	-0.5842	0.2446
X_2			1.0	0.4841	-0.4561
X_3				1.0	0.0642
X_4					1.0

ment load indirectly causes egg mortality by decreasing the apparent velocity of the ground water. When the apparent velocity is low the dissolved oxygen level is generally low and one or both of these factors cause egg mortalities. Stream discharge determines the amounts of sediment in suspension – a low discharge would deposit more sediment than a large discharge if the suspended sediment loads were equal. For this reason, discharge could also be indirectly related to egg mortalities.

Materials collected from redds after the end of the incubation period (June 28) were compared with original redd material (Table 10). These materials were collected 83 days after redd construction at Station 1, 50 days at Stations 2 and 3, and 45 days at Stations 4 and 5. All particle size groups smaller than 32 mm were more abundant in the samples taken June 28 then in the original materials. The minimum increase in materials smaller than 4 mm (8 percent) was at Station 2 and the maximum increase (39 percent) at Station 3. Particles finer than 0.125 mm were not found in the original gravel but ranged from 4 percent at Stations 1 and 3 to 10

Table 10. Particle size of materials used in cutthroat trout redds compared with total accumulated suspended sediment load and redd materials 83, 50, 50, 45, and 45 days later at Stations 1 - 5, respectively.

Percent finer than indicated size, in millimeters

Station	Total suspended sediment load (tons)	.062	.125	.250	.500	1.0	2.0	4.0	8.0	16.0	32.0
Original redd materials											
		0	0	1	1	1	1	1	3	26	73
Redd materials after incubation period											
1	61	3	4	7	9	11	13	17	28	76	100
2	437	4	5	6	6	7	8	9	11	62	100
3	6215	2	4	8	15	24	32	40	29	63	100
4	4687	4	7	15	20	24	26	30	36	51	100
5	12657	5	10	19	24	25	25	26	27	38	100

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percent at Station 5 (Table 10).

SUMMARY

1. A study was conducted on Bluewater Creek during April, May and June, 1962, to determine effects of suspended sediments on egg survival of rainbow trout and cutthroat trout.

2. Five sampling stations, approximately 3 miles apart, were selected to represent areas with different suspended sediment loads. Samples were generally collected 1 - 3 times per day.

3. Suspended sediment loads, stream discharges and water temperatures were fairly constant at Stations 1 and 2 but fluctuated drastically at Stations 3 - 5 due to irrigation diversions, irrigation surface and subsurface return and natural runoff.

4. Rainbow trout and cutthroat trout eggs were placed in plastic vials and vibrate boxes and buried 4 - 6 inches into the gravel of artificial redds. A standpipe aided in measuring the permeability of the gravel and the apparent velocity and dissolved oxygen of the ground water.

5. Apparent velocity was not greatly decreased until a total of 60 or more tons of suspended sediment passed a redd. After this, apparent velocity tended to decrease as the total suspended sediment load increased. Dissolved oxygen concentrations were generally low when apparent velocities were low and vice versa but the relationship between the two was not strictly proportional.

6. Rainbow trout egg mortalities in vibrate boxes were 67, 92, 97, 99 and 99 percent at stations 1 - 5, respectively and cutthroat trout egg

mortalities were 43, 94, 98, 100 and 87 percent at these same stations.

7. A multiple regression analysis of the results showed that the apparent velocity and dissolved oxygen of the ground water were important factors in determining rainbow trout egg survival while the accumulative suspended sediment load, stream discharge and apparent velocity were important for cutthroat trout egg survival.

8. A particle size analysis of the materials removed after the egg incubation periods showed that the greatest sediment deposition generally occurred where suspended sediment loads were highest.

9. High trout egg survival at Station 1 compared to Stations 2 - 5 was related to low suspended sediment loads, high apparent velocities and high dissolved oxygen levels.

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