Bull Trout Performance During Passage Over a Horizontal Flat Plate Screen

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Final Report to:

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Executive Summary

This investigation was conducted to the describe effects of passage of bull trout Salvelinus confluentus over a horizontal flat plate screen. Experimental releases were conducted with three sizes of bull trout that averaged 28, 37, and 58 mm total length (TL). Fish were released individually and in batches to: (1) describe general behavior near and on the screen; (2) estimate physical condition and survival of fish after passage; and (3) estimate entrainment and impingement rates.

Consistent negative effects from passage of bull trout over a horizontal flat plate screen were not observed. Potential entrainment was ≤ 3.5% for 28-mm fish, and was never observed for larger fish. Impingement never occurred. Passage times increased with fish size and ranged from 4 sec to more than 10 min. Physical damage to eyes, fins, and integument was either rare (eyes) or less frequent in fish that passed over the screen than in control fish. Fish that passed over the screen did contact the bottom more frequently than control fish, but no immediate mortality occurred from screen passage. Survival at 24 h was ≤ 1.5% lower for fish that passed over the screen compared to controls. At 96 h after passage, survival was reduced, but was not consistently lower for fish that passed over the screen compared to controls. Thus, physical effects of screen passage were at, or near the level of background effects induced by fish culture, handling, transport, and testing.

Water depth and orientation of bull trout changed with fish size and age despite the use of a standardized release methodology. Larger fish were more frequently observed near the bottom and more frequently oriented upstream than smaller fish. The tendency to occupy deeper water

increased the likelihood that fish contacted the horizontal flat plate screen. It also increased the likelihood that fish discovered attractive hydraulic properties of the screen. We observed several 58-mm fish that appeared to be maintaining position by using downward pressure generated by water approaching the screen. This behavior was the main factor responsible for increased passage time for larger fish. Thus, we did observe that certain hydraulic conditions of the horizontal flat plate screen used in this investigation attracted fish and delayed their movement over the screen.

Introduction

Bull trout Salvelinus confluentus is an endangered char that occurs in cool-water streams in northwestern North America (Lee et al. 1980). Presence of water diversion structures for irrigation in that area have the potential to influence movement and survival of bull trout. Horizontal flat plate screens are potentially useful to reduce negative effects of diversion structures on bull trout because rate of horizontal movement of water across the screen (sweeping velocity) is higher than the rate of movement of water through the screen (approach velocity). This characteristic enhances self cleaning and reduces the likelihood of impingement and entrainment of organisms. An evaluation of hydraulic characteristics and operation of horizontal flat plate screens was conducted with a working model constructed at the U.S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado (Figure 1). A detailed description of the model is available (Frizell and Mefford 2001) and it is useful for establishing design criteria for horizontal flat plate screens deployed in the field.

Another important aspect of development of design criteria for horizontal flat plate screens is an evaluation of potential effects on resident fish. During passage through screened structures, fish may become impinged on the screen or entrained into diversions. Fish may also avoid or be attracted to physical or hydraulic characteristics of screened structures which can influence natural movement and migration. To investigate the potential effects of passage on

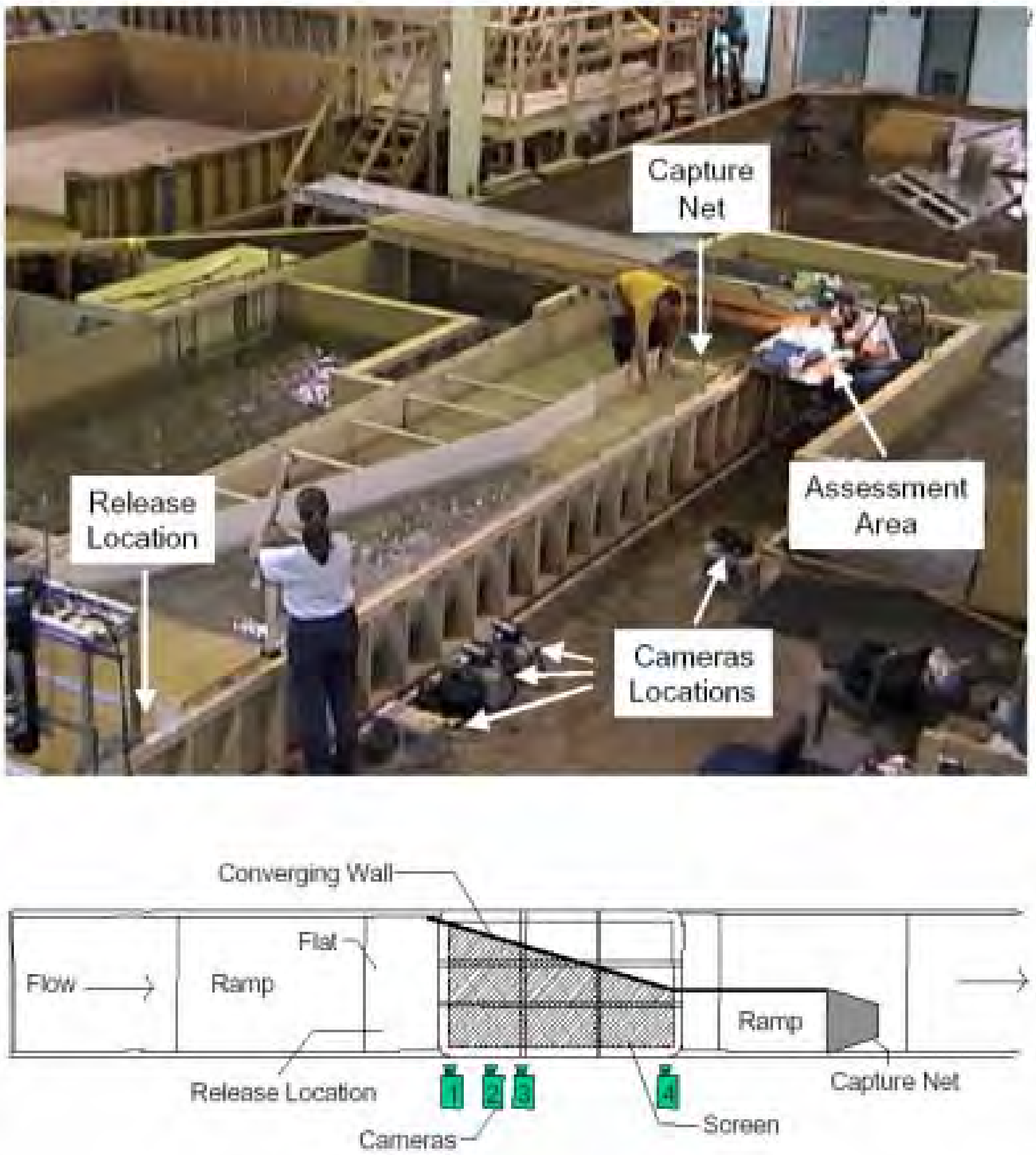

Figure 1. Picture and plan view of horizontal flat plate screen testing area.

bull trout, we conducted experimental releases with three early life stages of bull trout using the model horizontal flat plate screen at the Water Resources Research Laboratory. Fish were released individually and in batches to address three study objectives: (1) describe general behavior of fish near and on the screen; (2) estimate physical condition and survival of fish after passage over the screen; and (3) estimate entrainment and impingement rates of bull trout. Results describe bull trout behavior and effects of passage at two sweeping velocities.

Materials and Methods

Horizontal Flat Plate Screen and Testing Characteristics

The horizontal flat plate screen was 1.8×3.6-m-long with 2.4-mm (3/32 inch) perforations. The screen had a vertical 15° converging wall on one side and a vertical transparent plexiglass wall on the other side (Figure 1). The bypass entrance was 0.744-m-wide. Water for the screen was recirculated by a pump from an underground reservoir. Discharge rates were manipulated to produce the two sweeping velocities studied in this investigation: 0.6 m/s (2 ft/s) or 1.2 m/s (4 ft/s). Flow conditions over the screen were subcritical at 0.6 m/s and supercritical at 1.2 m/s. Water depth under both conditions was 13 cm. Descriptions of corresponding approach velocities and testing conditions are summarized in Table 1 and detailed elsewhere (Frizell and Mefford 2001).

Fish movements during passage over the screen were recorded using four video cameras (Figure 1). Cameras 1, 2, and 3 were positioned sequentially at the upstream end of the screen and camera 4 was positioned at the downstream end of the screen. Collectively, video cameras recorded fish passage over one-half (1.8 m) of the screen.

Fish were introduced onto the screen using release tubes constructed of 19- or 38-mm (inside diameter) PVC pipe. The 19-mm diameter release tube was used for the smallest life stage studied; the 38-mm, for the other two life stages. In preparation for a release, fish and holding water were transferred to a release tube and a rubber stopper prevented fish from escaping. The release tube was positioned on the floor of the screen structure, at the beginning of the flat, 1.2 m upstream of the screen and 0.3 m from the plexiglass wall. A release was accomplished by removing the rubber stopper and opening a valve that allowed water and fish to exit the tube. The release tube was designed so that fish emerged from the screen near the bottom of the water column, oriented in an upstream direction.

After a release, fish were recaptured using a drift net mounted 2.4 m downstream of the screen. Dimensions of the 363-μm mesh net were 40 × 80 × 86-cm long. The net sampled the entire bypass discharge from the screen. Following capture, the cod end of the net was opened and fish were rinsed into a pan for assessment.

Fish Culture, Acclimation, and Handling

Bull trout embryos were obtained from Creston National Fish Hatchery (Kalispell, Montana) and cultured at the Aquatic Research Laboratory, Colorado State University. Embryos were maintained at 4 to 6°C in a Heath incubator until hatching was complete. After hatching, larvae were transferred to fiberglass culture troughs for rearing at a water temperature of 10°C. Fish were fed a commercially prepared diet (BioDiet, Bio-Oregon, Inc., Warrenton, OR).

Table 1. Summary of discharge (m3/sec) and velocity (m/sec) conditions over a horizontal flat plate screen at two sweeping velocities.

Condition	Q_c	Q_d	Q_b	V_s	V_a	Depth (m)
0.6 m/sec treatment	0.19	0.11	0.08	0.6	0.15	0.13
0.6 m/sec control	0.06	0	0.06	0.6	NA	0.13
1.2 m/sec treatment	0.32	0.2	0.12	1.2	0.15	0.13
1.2 m/sec control	0.12	0	0.12	1.2	NA	0.13

NA = not applicable.
Q_c; channel discharge; Q_d; diversion discharge; Q_b; bypass discharge; V_s; sweeping velocity; V_a; approach velocity.

In preparation for testing at the Water Resources Research Laboratory, culture water temperature was increased to 14°C 10 days before the first fish release trials were conducted so that fish were acclimated to testing conditions. Throughout the investigation, water temperature at the Water Resources Research Laboratory ranged from 13.5 to 16.5°C and culture temperatures were manipulated to match test temperatures within ± 1°C.

During thermal acclimation, fish were also exposed to a constant water current by directing the flow of water into the culture trough. This provided a range of velocities within the culture trough and allowed fish to select preferred conditions. By positioning the automatic feeder near the water inlet, fish were forced to encounter relatively high velocities.

On the day of testing, 10 to 25 fish were placed in 4-L resealable bags containing about 1.5 L of water and oxygen-filled head space. Bags were transported to the Water Resources Research Laboratory and held in insulated coolers until selected for a test. Dissolved oxygen concentrations in bags were checked occasionally and were always > 6.0 mg/L.

Three bull trout life stages were investigated including: (1) swim-up larvae approximately the same age and size of young bull trout at the time they emerge from spawning redds in a stream, (2) a later larval stage, and (3) juveniles. Bull trout in each group were 67, 108, and 145 day old (after hatching) and had average total lengths of 28, 37, and 58 mm, respectively (Table 2).

Table 2. Summary of bull trout total lengths (mm) for three life stages studied.

Life Stage	Mean	Standard Error	Minimum	Maximum	*n*
First	27.8	0.204	23.9	32.2	98
Second	36.9	0.351	28.1	46.5	100
Third	58.0	0.409	49.8	69.1	100

Individual Releases

Releases of individual fish were used to estimate the effects of passage on physical condition, passage times, and impingement and entrainment. Twenty-five fish of each life stage were released at both sweeping velocities. Each fish was independently released and captured. Passage times were measured starting with release and ending when fish crossed the downstream edge of the screen. A maximum of 120 s was allowed for fish to exit the screen voluntarily. Fish that remained on the screen for longer than 120 sec were swept into the current and into the capture net by observers. Following capture, each fish was rinsed into a pan, anesthetized (200 mg/L tricaine methanesulfonate), and physical condition was assessed using a binocular microscope at 10X magnification. An *a priori* set of criteria were used to consistently evaluate evidence of physical damage to fish from passage. Measurements collected, and criteria used for each individual were: (1) elapsed time to pass over the screen; (2) survival: yes, no; (3) total length; (4) eyes: normal, abraded, exophthalmic, hemorrhagic, missing; (5) caudal, dorsal, right and left pectoral fins: normal, frayed, trace fin split (≤10%), fin split (.10%), broken fin rays, (one or more rays disrupted into fragments attached by intervening fin tissue), missing; (6) integument: normal, abraded, bruised, cut; and (7) scales: normal, scattered descaling (<20% per side of fish), severe descaling. After assessment, each fish was preserved in 10% formalin.

Because physical damage may arise from handling, transport, release, and capture, a control group of fish was similarly assessed. Control conditions were created by installing a transparent plexiglass sheet over the screen and releasing fish at both sweeping velocities using identical methodology. The plexiglass did not change the appearance of the screen which may be important for fish orientation but did remove turbulence and approach velocity effects due to the operation of the screen. Control batches allowed the effect of screen passage on survival to be separated from effects caused by other sources.

Batch Releases

Batch releases of fish were used to estimate immediate, 24-, and 96-h survival rates after passage, batch passage times, and potential for impingement and entrainment. Twenty batch releases of 10 fish from each life stage were studied at both sweeping velocities. Batches were released and captured using the same methods described for individuals. Following capture fish were rinsed into a pan where the number of survivors was counted. The live fish were placed into 4-L resealable bags containing about 1.5 L of water and oxygen-filled head space, and transported in insulated coolers to the Aquatic Research Laboratory at Colorado State University. Bags containing fish were transferred to a water bath for 1 hour to allow acclimation to culture conditions (14°C). Batches of fish were then released into separate flow-through aquaria and survival was monitored daily for 96 h. Aquaria were 20 × 40 × 25 cm high, and water depth was about 15 cm. Water temperature was 14°C. Fish were fed once daily during the monitoring period. Cool-white fluorescent lamps were the only source of illumination (530 lx), and a 12:12-h light:dark photoperiod was maintained.

Control batches of fish were also used to assess effects of handling, transport, release, and capture on survival. Control batches were treated similarly to fish released over the screen, except they were released at the downstream end of the screen about 2.4 m from the capture net.

Control fish were not removed from the net until an amount of time equal to the average time required for fish in treatment batches to traverse the screen had elapsed. Control batches allowed the effect of screen passage on survival to be separated from effects caused by other sources.

Video Interpretation

Video recordings of movement of individually release fish were interpreted to quantify several responses including: number of times a fish contacted the screen over the 1.8-m camera observation area; orientation (upstream or downstream) at cameras 1 and 4; and depth in the water column (bottom third, middle third, or top third) at cameras 1 and 4. Fish that were on the surface were difficult to detect during video interpretation, but because fish in the middle and bottom third were easily detected, a depth classification of "top third" was given when a fish was not observed.

Descriptive and Statistical Analysis

In general, descriptive statistics were calculated for the endpoints investigated and summary tables were constructed to facilitate inspection of the data. Because of the number of fins and categories involved in fin assessment, the data were re-classified as normal or non-normal, then the frequency of occurrence of fish with four, three, two, one or no normal fins was calculated.

Survival data were analyzed using the Genmod procedure (options link = logit, dist = binomial, and dscale; SAS Institute 1993). The procedure estimatee mean survival and associated 95% confidence intervals. In several cases, confidence intervals could not be estimated because no mortality was observed in most or all of the replicates. Lack of variation in treatments precluded useful statistical comparisons. Consequently, data were analyzed by inspection. It should be noted that the responses of the same batches of fish were used to estimate survival at 24 and 96 h. Because the same batches were used, there is a lack of independence between 24- and 96-h estimates (e.g., a replicate with 80% survival at 24 h can only have ≤ 80% survival at 96 h). We advocate that because little is known about effects of horizontal flat plate screens on bull trout, this violation of statistical assumptions is relatively unimportant and that the analysis provides valuable insight about the pattern of mortality that may occur after passage.

Results

Entrainment

No incidences of entrainment of fish through the screen were observed for 37- or 58-mm fish. Reliable estimates of entrainment for 28-mm fish were not obtained because unrecovered fish may have been lost via entrainment, through seams in the screen structure, or escaped the capture net. Data suggested that if entrainment occurred, the rate was low because 99.5% of control fish and 96.0% of treatment fish were recovered at the 1.2 m/s sweeping velocity, and 99.0% of control fish and 98% of treatment fish were recovered at the 0.6 m/s sweeping velocity. Thus, potential entrainment was not greater than 3.5% (maximum difference between recovery rates of control and treatment fish) for any of the conditions studied.

Impingement

No incidences of impingement of fish on the screen were observed for fish in the 28- or 37-mm size groups. Some fish in the 58-mm size group were observed on the screen, but observations suggested that the fish were maintaining desired positions by using downward pressure generated by water approaching the screen (Figure 2). Behaviors that suggested fish were attracted to these areas and were not involuntarily impinged included: (1) demonstration of volitional movement (upstream and downstream) at these locations; (2) demonstration of ability to control body position on the screen; and (3) returning to the locations after being disturbed by an observer. Preliminary observations showed that some fish continued this behavior for at least 10 min.

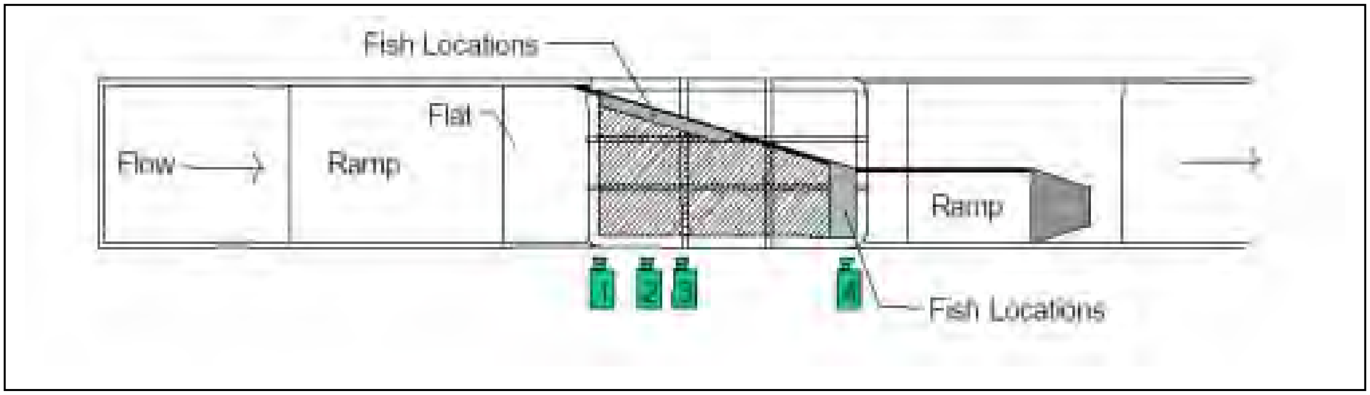

Figure 2. General areas (shaded) on a horizontal flat plate screen occupied by 58-mm bull trout for long periods of time. Downward pressure generated by the approach velocity of water passing through the screen in these areas allowed fish to hold position with relatively little swimming activity.

Passage Times

Average passage times for individual fish ranged from 4 to 17 sec at 1.2 m/sec sweeping velocity and 10 to 61 sec at 0.6 m/sec sweeping velocity (Table 3). Passage times increased with fish size at both sweeping velocities and were generally longer for control fish than for treatment fish.

Average batch passage times ranged from 7 to 45 sec at 1.2 m/sec sweeping velocity and 23 to 120 sec at 0.6 m/sec sweeping velocity (Table 4). Passage times generally increased with fish size at both sweeping velocities. At least one fish in every batch released for the 58-mm, 0.6 m/sec treatment remained over the screen for the maximum time allowed of 120 sec.

Physical Condition After Passage

In general, physical condition of bull trout did not appear to be affected by passage over the screen (Tables 5-10). The effect of passage on condition and coverage of scales was not assessed because the first two life stages did not have scales and very small scales were patchily distributed over the surface of fish in the 58-mm group. Other characteristics were measured as proposed.

Eyes - Only one occurrence of a non-normal (abraded) eye was observed out of 600 fish examined. The single occurrence was for a 58-mm fish (Table 9). Because eye damage was rare, and it was not observed in smaller fish, it is unlikely that the abrasion was caused by screen passage.

Table 3. Summary of elapsed times (sec) for passage of individual bull trout over a horizontal flat plate screen at two sweeping velocities.

Sweeping Velocity = 1.2 m/sec

Treatment	Mean	Standard Error	Minimum	Maximum	*n*
		Life Stage (28 mm)			
Control	10	1.1	5	29	22
Treatment	4	0.2	3	5	22
		Life Stage (37 mm)			
Control	10	0.8	29	46	25
Treatment	5	0.2	4	7.2	20
		Life Stage (58 mm)			
Control	17	2.3	5	54	25
Treatment	10	0.7	5	22	25

Sweeping Velocity = 0.6 m/sec

Treatment	Mean	Standard Error	Minimum	Maximum[a]	*n*
		Life Stage (28 mm)			
Control	13	1.1	5	27	25
Treatment	10	1.0	5	28	23
		Life Stage (37 mm)			
Control	20	1.8	11	54	25
Treatment	12	0.8	7	23	25
		Life Stage (58 mm)			
Control	61	10	9	120	25
Treatment	50	8.0	14	120	25

[a]120 sec was the maximum time allowed.

Table 4. Summary of elapsed times (sec) for passage of batches of 10 bull trout over a horizontal flat plate screen at two sweeping velocities.

Sweeping Velocity = 1.2 m/sec

Life Stage (mm)	Mean	Standard Error	Minimum	Maximum[a]	*n*[b]
28	7	0.2	6	9	20
37	7	0.4	4	12	20
58	45	6.2	20	120	20

Sweeping Velocity = 0.6 m/sec

Life Stage (mm)	Mean	Standard Error	Minimum	Maximum[a]	*n*[b]
28	26	1.4	18	47	20
37	23	2.0	17	56	20
58	120	0	120	120	20

[a]120 sec was the maximum time allowed.
[b]*n* = 20 is equivalent to 20 batches of 10 fish.

Table 5. Summary of condition of 25 28-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
Finsa	4 of 4 normal	2	6	8	24	8	24
	3 of 4 normal	9	5	36	20	44	44
	2 of 4 normal	8	8	32	32	76	76
	1 of 4 normal	4	6	16	24	92	100
	0 of 4 normal	2		8		100	
Integument	Normal	24	25	96	100	96	100
	Abrasion	1		4		100	
	Bruise						
	Cut						
Total contactsb	0	91	92	91	92	91	92
	1	8	8	8	8	99	100
	2	1		1		100	
	3						
	4						
	5						
Depth, camera 1	Bottom third	14	12	56	48	56	48
	Middle third	0	5	0	20	56	68
	Top third	11	8	44	32	100	100
Depth, camera 4	Bottom third	8	9	32	36	32	36
	Middle third	0	2	0	8	32	44
	Top third	17	14	68	56	100	100
Orientation, camera 1	Upstream	6	8	43	42	43	42
	Downstream	8	11	57	58	100	100
Orientation, camera 4	Upstream	11	7	79	54	79	54
	Downstream	3	6	21	46	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 6. Summary of condition of 25 28-mm individual bull trout assessed after handling C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	3	5	12	20	12	20
	3 of 4 normal	6	8	24	32	36	52
	2 of 4 normal	10	8	40	32	76	84
	1 of 4 normal	5	3	20	12	96	96
	0 of 4 normal	1	1	4	4	100	100
Integument	Normal	25	24	100	96	100	96
	Abrasion		1		4	100	100
	Bruise						
	Cut						
Total contacts[b]	0	81	82	81	82	81	82
	1	11	10	11	10	92	92
	2	8	6	8	6	100	98
	3		2		2		100
	4						
	5						
Depth, camera 1	Bottom third	6	13	24	52	24	52
	Middle third	1	2	4	8	28	60
	Top third	18	10	72	40	100	100
Depth, camera 4	Bottom third	12	14	48	56	48	56
	Middle third	1	1	4	4	52	60
	Top third	12	10	48	40	100	100
Orientation, camera 1	Upstream	7	10	78	59	78	59
	Downstream	2	7	22	41	100	100
Orientation, camera 4	Upstream	11	7	44	47	44	47
	Downstream	14	8	56	53	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral. [b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 7. Summary of condition of 25 37-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	1	0	4	0	4	0
	3 of 4 normal	2	1	8	4	12	4
	2 of 4 normal	7	2	28	8	40	12
	1 of 4 normal	9	8	36	32	76	44
	0 of 4 normal	6	14	24	56	100	100
Integument	Normal	23	24	92	96	92	96
	Abrasion	2	0	8	0	100	96
	Bruise		1		4		100
	Cut						
Total contacts[b]	0	98	94	98	94	98	94
	1	2	6	2	6	100	100
	2						
	3						
	4						
	5						
Depth, camera 1	Bottom third	13	3	52	3	52	3
	Middle third	0	0	0	0	52	3
	Top third	12	22	48	88	100	100
Depth, camera 4	Bottom third	13	13	52	52	52	52
	Middle third	0	0	0	0	52	52
	Top third	12	12	48	48	100	100
Orientation, camera 1	Upstream	12	3	92	100	92	100
	Downstream	1		8		100	
Orientation, camera 4	Upstream	14	10	67	71	67	71
	Downstream	7	4	33	29	100	100

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 8. Summary of condition of 25 37-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

		Frequency		Percent		Cumulative Percent	
Characteristic	Condition	C	T	C	T	C	T
Eyes	Normal	25	25	100	100	100	100
Fins[a]	4 of 4 normal	0	1	0	4	0	4
	3 of 4 normal	1	2	4	8	4	12
	2 of 4 normal	4	6	16	24	20	36
	1 of 4 normal	8	12	32	48	52	84
	0 of 4 normal	12	4	48	16	100	100
Integument	Normal	25	24	100	96	100	96
	Abrasion		1		4	100	100
	Bruise						
	Cut						
Total contacts[b]	0	94	90	94	90	94	90
	1	5	7	5	7	99	97
	2	1	3	1	3	100	100
	3						
	4						
	5						
Depth, camera 1	Bottom third	15	13	60	52	60	52
	Middle third	1	0	4	0	64	52
	Top third	9	12	36	48	100	100
Depth, camera 4	Bottom third	20	21	80	84	80	84
	Middle third	0	0	0	0	80	84
	Top third	5	4	20	16	100	100
Orientation, camera 1	Upstream	15	13	94	100	94	100
	Downstream	1		6		100	
Orientation, camera 4	Upstream	19	22	83	100	83	100
	Downstream	4		17		100	

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 9. Summary of condition of 25 58-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 1.2 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	24	100	96	100	96
	Abrasion		1		4		100
Fins[a]	4 of 4 normal	0	0	0	0	0	0
	3 of 4 normal	0	2	0	8	0	8
	2 of 4 normal	2	5	8	20	8	28
	1 of 4 normal	8	8	32	32	40	60
	0 of 4 normal	15	10	60	40	100	100
Integument	Normal	24	24	96	96	96	96
	Abrasion	0	0	0	0	96	96
	Bruise	1	0	4	0	100	96
	Cut		1		4		100
Total contacts[b]	0	82	78	82	78	82	78
	1	17	21	17	21	99	99
	2	0	1	0	1	99	100
	3	0		0		99	
	4	0		0		99	
	5	1		1		100	
Depth, camera 1	Bottom third	22	24	88	96	88	96
	Middle third	0	1	0	4	88	100
	Top third	3		12		100	
Depth, camera 4	Bottom third	25	24	100	96	100	96
	Middle third		0	0	0	80	96
	Top third		1	20	4	100	100
Orientation, camera 1	Upstream	20	23	91	92	91	92
	Downstream	2	2	9	8	100	100
Orientation, camera 4	Upstream	25	24	100	100	100	100
	Downstream						

[a]Number of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.
[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Table 10. Summary of condition of 25 58-mm individual bull trout assessed after handling (C) or after passage over a horizontal flat plate screen (T) at a sweeping velocity of 0.6 m/sec.

Characteristic	Condition	Frequency C	Frequency T	Percent C	Percent T	Cumulative Percent C	Cumulative Percent T
Eyes	Normal	25	25	100	100	100	100
	Abrasion						
Fins[a]	4 of 4 normal	0	0	0	0	0	0
	3 of 4 normal	0	2	0	8	0	8
	2 of 4 normal	4	7	16	28	16	36
	1 of 4 normal	5	10	20	40	36	76
	0 of 4 normal	16	6	64	24	100	100
Integument	Normal	20	24	80	96	80	96
	Abrasion	3	1	12	4	92	100
	Bruise	2		8		100	
	Cut						
Total contacts[b]	0	95	82	95	82	95	82
	1	3	11	3	11	98	93
	2	2	6	2	6	100	99
	3		1		1		100
	4						
	5						
Depth, camera 1	Bottom third	25	25	100	100	100	100
	Middle third						
	Top third						
Depth, camera 4	Bottom third	19	21	76	84	76	84
	Middle third	0	2	0	8	76	92
	Top third	6	2	24	8	100	100
Orientation, camera 1	Upstream	24	25	96	100	96	100
	Downstream	1		4		100	
Orientation, camera 4	Upstream	19	21	100	91	100	91
	Downstream		2		9		100

aNumber of fins assessed as normal; fins were caudal, dorsal, and right and left pectoral.

[b]A total of 100 observations were possible because four cameras were used for all 25 fish released. Collectively, video cameras recorded potential contacts over 1.8 m of the horizontal flat plate screen.

Fins - The frequency of fish in control and treatment groups with undamaged fins declined with fish size. The occurrence of fish with damage on all four fins ranged from 0 to 8% for 28-mm fish to 24 to 64% for 58-mm fish. In four cases, occurrence of fish with damage on all four fins was higher for controls than for treatments (Tables 5, 8, 9, 10), in one case the occurrence was equal (Table 6), and in the last case, the occurrence of damage on all fins was higher in treatment fish (Table 7). The types of fin damage most frequently observed were frayed, trace split, and split. Broken fins were observed only on one control and one treatment fish. Both fish had broken pectoral fins and were from the 28-mm size group.

Integument - A total of 9 abrasions were observed: six were on control fish and three were on treatment fish (Tables 5, 6, 7, 8, 10). Also, a total of 4 bruises were observed; three on control fish; one on a treatment fish (Tables 7, 9, 10). Only one occurrence of cut integument was detected (Table 9).

Screen Contacts

Video interpretation showed most fish never contacted the screen. Treatment fish contacted the screen more frequently than control fish. The percentage of one or more contacts was higher for treatment fish in four of the six size-velocity conditions studied (Tables 7, 8, 9, 10). The greatest number of screen contacts observed for a single fish was five. Fish that contacted the screen more than once tended to tumble and swim erratically after the first contact.

Depth in Water Column

Larger fish, especially the 58-mm size group, more frequently inhabited the bottom third of the water column. The percentages for 28-mm fish in the bottom third of the water column ranged from 24 to 56, whereas the percentages for 58-mm fish ranged from 76 to 100. The percentages of fish in the bottom, middle and top thirds for both cameras and treatments combined were: 44, 6, and 50% for 28-mm fish; 56, 0, and 44% for 37-mm fish; and 92, 2, and 6% for 58-mm fish.

Orientation

The percentage of fish oriented upstream increased with fish size. Forty-two to 79% of 28-mm fish were oriented upstream, compared to 91 to 100% for 58-mm fish. The frequencies of fish oriented upstream for both cameras and treatments combined were 53% for 28-mm fish; 86% for 37-mm fish; and 96% for 58-mm fish.

Survival

An initial assessment of survival was conducted at the time fish were removed from the capture net. The assessments showed that all fish were alive immediately after passage.

The 24-h survival estimates showed that effects of screen passage were small with survival rates ranging from 98.5 to 100% (Table 11). Survival rates were consistently lower for fish that passed over the screen compared to controls, but with a maximum difference of only 1.5%. Lack of variability in the data prevented calculation of 95% confidence intervals in every case. At least one fish died in every 28-mm control or screen treatment (Table 11). Survival was higher for other size classes with no mortalities in five treatments. Very low rates of mortality in some other treatments resulted in estimated 100% (with rounding error) survival rates (denoted by footnote “a”; Table 11). Consequently, values of “100%” in Table 11 should be interpreted with caution because mortality occurred in some treatments.

In general survival rates were lower at 96 h (Table 12) than at 24 h. At 96 h, only two treatments had 100% survival. Survival was lowest for 58 mm fish in the 0.6 m/sec sweeping velocity treatment. Most mortality for fish in this treatment occurred at 72 and 96 h, and was probably caused by a pathogen. The source of the pathogen was unknown, but water temperatures at the Water Resources Research Laboratory were higher for 58-mm fish (16 to 16.5°C) than for other trials (13.5 to 14°C) because the water cooling system failed. Evidence that some other factor may have influenced survival rates of 58-mm fish, suggested observed 96-h survival rates should be interpreted with caution, or even excluded from analyses intended to infer effects of screen passage. Alternatively, the observed survival rates can be used as worse-case estimates of effects if it is acknowledged that some other factor may have increased mortality. If the 58-mm size is excluded, survival rates were higher for controls in three of four passage conditions; if 58-mm fish are included, survival rates were higher for controls in four of six passage conditions. Lack of variability in the data prevented calculation of 95% confidence intervals in four cases.

Table 11. Summary of 24-h survival for batches of 10 bull trout after passage over a horizontal flat plate screen at two sweeping velocities.

1.2 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	100[a]	NE	NE	20
Treatment	98.9	NE	NE	20
		Life Stage (37 mm)		
Control	100	NE	NE	20
Treatment	100	NE	NE	19
		Life Stage (58 mm)		
Control	100	NE	NE	20
Treatment	100	NE	NE	19

0.6 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	100[a]	NE	NE	20
Treatment	98.5	NE	NE	20
		Life Stage (37 mm)		
Control	100[a]	NE	NE	20
Treatment	99.5	NE	NE	20
		Life Stage (58 mm)		
Control	100	NE	NE	20
Treatment	100[a]	NE	NE	20

NE = no estimate.
[a]Some mortality occurred in this treatment group, but estimated survival rates were 100% with rounding error.

Table 12. Summary of 96-h survival for batches of 10 bull trout after passage over a horizontal flat plate screen at two sweeping velocities.

1.2 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	98.0	95.8	99.2	20
Treatment	94.7	91.5	97.0	20
		Life Stage (37 mm)		
Control	100	NE	NE	20
Treatment	95.3	NE	NE	19[a]
		Life Stage (58 mm)		
Control	98.5	NE	NE	20
Treatment	100	NE	NE	19[a]

0.6 m/sec Sweeping Velocity

Treatment	Mean % Survival	Lower 95% CI	Upper 95% CI	*n*
		Life Stage (28 mm)		
Control	96.4	93.4	98.3	20
Treatment	97.9	95.4	99.3	20
		Life Stage (37 mm)		
Control	98.5	96.7	99.5	20
Treatment	98.0	96.0	99.2	20
		Life Stage (58 mm)		
Control	91.0	84.9	95.3	20
Treatment	81.8	74.1	88.1	20

NE = no estimate.
[a]One replicate lost.

Discussion

Consistent negative effects from passage of bull trout over a horizontal flat plate screen were not observed. Potential entrainment was ≤ 3.5% for 28-mm fish, and was never observed for larger fish. Impingement never occurred. Physical damage to eyes, fins, and integument was either rare (eyes) or less frequent in fish that passed over the screen than in control fish. Fish that passed over the screen did contact the bottom more frequently than control fish, but no immediate mortality occurred from screen passage. Survival at 24 h was consistently lower for fish that passed over the screen compared to controls, but the difference was small (≤ 1.5%). At 96 h after passage, overall survival was reduced, but was not consistently lower for fish that passed over the screen. Thus, the effects of screen passage were at, or near the level of background effects induced by fish culture, handling, transport, and testing.

Water depth and orientation of bull trout changed with fish size and age despite the use of a standardized release methodology. Larger fish were observed near the bottom and oriented upstream more frequently than smaller fish. This tendency to occupy deeper water increased the likelihood that fish contacted the horizontal flat plate screen. It also increased the likelihood that fish discovered attractive hydraulic properties of the screen. We observed several 58-mm fish that appeared to be maintaining position by using the downward pressure generated by the approach velocity of water passing through the screen. This behavior was the main factor responsible for increased passage time for larger fish. Thus, we did observe that certain hydraulic conditions of the horizontal flat plate screen used in this investigation attracted fish and delayed their movement.

Bottom-oriented behavior may have also contributed to the number of times that fish contacted the screen. Fish that contacted the screen more than once tended to tumble and swim erratically after the first contact. Loss of orientation combined with burst swimming to regain orientation resulted in fish colliding with the screen. Under normal conditions, this behavior would allow a fish to discover microhabitats on the bottom of a stream that offer refuge from water velocity. However, within the confines of a horizontal flat plate screen, the behavior results in multiple screen contacts.

The source of the pathogen presumed to have killed several 58-mm fish in the 0.6 m/sec sweeping velocity treatment was unknown. There was strong evidence that the mortality was caused by a pathogen because fish appeared healthy at 0, 24, and 48 h after passage, but then mortality began to occur at 72 and 96 h. Other evidence of a pathogen was that mortality was clustered within tanks suggesting that infected individuals transferred the disease within an aquarium. Two characteristics were different during 58-mm trials compared to previous trials: (1) the water temperature was 2 to 2.5°C warmer; and (2) passage times were longer which would have increased exposure to resident pathogens. Regardless of the cause(s), the presence of additional sources of mortality should be acknowledged when interpreting results for 58-mm fish.

References

Frizell, K., and B. Mefford. 2001. Hydraulic Performance of a Horizontal Flat Plate Screen. Final report. U.S. Bureau of Reclamation, Water Resources Research Laboratory, Denver, Colorado.

Lee, D.S, C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. Atlas of North American freshwater fishes. North Carolina State Museum, Raleigh, North Carolina.

SAS Institute. 1993. SAS Technical Report P-243, SAS/STAT Software: GENMOD procedure, release 6.09. Cary, North Carolina.