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A Simple and Effective Method of Cleaning the Gravel of Atlantic Salmon Spawning Habitat

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A SIMPLE AND EFFECTIVE METHOD OF CLEANING THE GRAVEL OF ATLANTIC SALMON SPAWNING HABITAT

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ABSTRACT

Semple, J.R. 1987. A simple and effective method of cleaning the gravel of Atlantic salmon spawning habitat. Can. MS Rep. Fish. Aquat. Sci. No. 1933. v + 6 p.

A simple, practical and effective method of cleaning the gravel of Atlantic salmon spawning habitat is described. The equipment employed is light, compact, readily obtainable, relatively inexpensive, and extremely portable. The equipment and cleaning method are simple and suitable for application by public-participation groups wishing some involvement in the Atlantic salmon enhancement process.

Mean (geometric) permeabilities after gravel cleaning at the two study sites were 144-288 percent greater than before treatment. The frequency of relatively high standard permeabilities (>3,000 cm/hr) increased from 33.4 percent before gravel cleaning to 50.1 percent after cleaning at the upper test site and from 20.9 to 70.8 percent at the lower test site. Mean standard permeabilities before (1,292 cm/hr) and after (3,726 cm/hr) gravel cleaning at the lower test site were significantly different (t-test, $P < 0.02$), but differences were not significant for the upper test site.

Key words: Atlantic salmon, spawning habitat improvement, gravel cleaning method, permeability.

RÉSUMÉ

Semple, J.R. 1987. A simple and effective method of cleaning the gravel of Atlantic salmon spawning habitat. Can. MS Rep. Fish. Aquat. Sci. No. 1933. v + 6 p.

Dans cet article, est décrite une méthode simple, pratique et efficace d'épuration du gravier dans l'aire de frai du saumon atlantique. On emploie du matériel léger, compact, facile à se procurer, relativement peu coûteux et d'une grande portabilité. Le matériel et la méthode d'épuration sont simples et conviennent à l'utilisation par des groupes désirant une participation publique au processus de mise en valeur du saumon atlantique.

Dans les deux site étudiés, la perméabilité moyenne (géométrique) après épuration du gravier était de 144% à 288% plus élevée qu'avant le traitement. La fréquence de perméabilités standard relativement élevées (>3 000 cm/heure) a augmenté de 33,4% avant l'épuration du gravier à 50,1 % après l'épuration dans le site expérimental d'amont, et de 20,9 % à 70,8 % dans le site expérimental d'aval. Les perméabilités standard moyennes avant (1 292 cm/heure) et après (3 726 cm/heure) l'épuration du gravier différaient nettement dans le site expérimental d'aval (essai t, $p < 0,02$), mais pas dans celui d'amont.

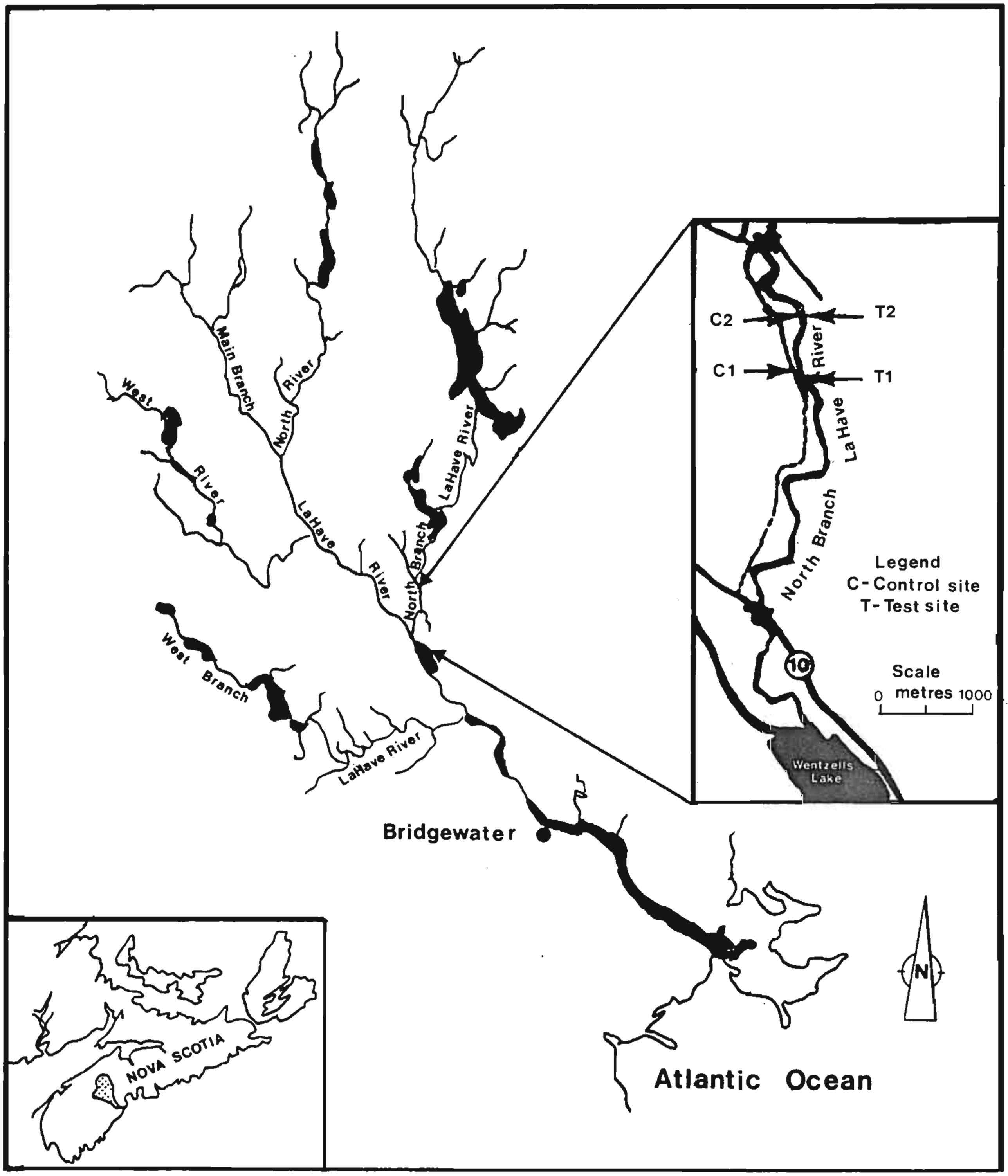

FIG. 1. Location of gravel-cleaning test sites, North Branch LaHave River, Nova Scotia, 1984.

INTRODUCTION

A continuing search to enhance the production of Atlantic salmon identified a need to improve salmon spawning habitat by flushing fine particulate matter out of the interstices of the gravel. Natural land erosion and erosion accelerated by road construction, logging, agricultural practices and land development have resulted in increased siltation in salmonid spawning areas (Saunders and Smith 1965; Phillips 1971; Narver 1971; Welch et al. 1977). The deleterious effects of sediment accumulation in salmonid spawning beds have been well documented, particularly for west coast salmonids (Wickett 1958; Cooper 1965; Phillips 1971; Narver 1971) and more recently for Atlantic salmon (Peterson 1978).

One way of measuring the amount of sediment in salmon spawning beds is to determine the permeability of the gravel. Permeability is a measure of the ability of the gravel to transmit water. When sediment concentrations are high, gravel permeabilities are low and vice versa (McNeil and Ahnell 1964; Peterson 1978).

When permeabilities of spawning gravel in four British Columbia streams were compared to survival rates of pink and chum salmon fry, streams having higher gravel permeability had higher survival than those with low permeability (Wickett 1958). Similarly, Peterson (1978) found higher mean percent emergence of Atlantic salmon fry at sites with higher mean gravel permeability.

In the present report, gravel permeability was the principal parameter used to assess the merits of the cleaning method employed. The report also documents the cleaning equipment and procedures used and their resultant effect on gravel permeability.

MATERIALS AND METHODS

Two Atlantic salmon spawning sites were selected on the North Branch LaHave River, Nova Scotia, for the experimental work on gravel cleaning. Site selection was based on stream flow, depth and substrate characteristics known to be conducive to Atlantic salmon spawning (Belding 1934; White 1942; Jones 1959; Peterson 1978; Beland et al. 1982).

Each test site was 30 m long and was staked off on both sides at 5-m intervals by steel rods in the stream bank above flood level. The rods provided a reference grid to ensure thorough gravel cleaning at each test site and provided reference transects along which stream width (wetted), water depth and surface-water velocity could be determined.

Stream width was measured with a steel tape across each of the seven transects at each test site. Water depths were measured with a metal metre stick at five equally spaced intervals along each transect. The mean depth at each transect was the sum of all measurements divided by n+1 to compensate for zero depth at the stream margins. The mean depth of the test site was the sum of all measurements divided by n+7. Surface-water velocity was measured by recording the average time (three measurements) the water current took to displace a fisherman's float two metres. The mean surface-water velocity at each test site was the mean of the mean velocities determined over each depth station.

Gravel permeabilities were measured with a Mark VI standpipe and pump assembly according to the method described by Terhune (1958). The standpipe was driven 20 cm into the gravel, followed by activation of the pump. Eggs of Atlantic salmon are normally found at a depth of 10cm-23cm below the gravel surface (Jordan and Beland 1981). Pumping continued for approximately 30 seconds to maintain a head difference of 2.5 cm between the water levels inside and outside the standpipe. The water temperature, amount of water abstracted and the duration of abstraction were recorded, and the permeability calibration curve reported by Terhune (1958) was used to determine the permeability at the observed water temperature. Twenty-five millilitres of water was subtracted from the amount of water abstracted before entering the calibration curve, because this volume was initially required to establish the 2.5-cm pressure head. Permeability measurements (cm/hr) were standardized to a water temperature of 10°C (Terhune 1958) to facilitate comparisons. Standard permeability is abbreviated as K_{10}, where the subscript "10" denotes the permeability at 10°C. The measurements were made at four equally spaced stations across the breadth of the stream within each 5-m-long segment at each test site.

RESULTS

GRAVEL CLEANING

A Wajax®, Mark 3, centrifugal pump was used to clean the gravel hydraulically within the two experimental sites. The pump, fabricated by Wajax Manufacturing Limited, Montreal, is the type commonly used to fight forest fires.

Pump and engine specifications were as follows:

Unit Dimensions

Length - 55 cm (22 inches)
Width - 30 cm (12 inches)
Height - 40 cm (16 inches)
Weight - 25 kg (55 pounds)

Unit Specifications

One-cylinder, 2-cycle, air-cooled gasoline motor

Bore diameter - 60 mm (2 3/8 inches)

Stroke - 60 mm (2 3/8 inches)

Displacement - 180 cm^3 (11 $in.^3$)

Horsepower - 9 (approx.)

Fuel consumption - 4.6 L/hr (1.0 imp. gal/hr)

Lubrication - oil in fuel mixture

Pumping capacity (max.) - 340 L/min (75 imp. gal/min)

The suction (intake) hose was 3 m long and 5 cm in diameter. It was constructed of woven linen fibre and contained a coupling for hookup to the pump at one end and a foot-valve strainer at the other. The discharge (outlet) hose was 30 m long, was 3.75 cm in diameter and had couplings at each end. During the cleaning operation a threaded polycarbonate nozzle having an inside diameter of 1.25 cm was used. The pump was mounted on the shoreline, midway between the end points of each 30-m-long test site.

Before cleaning commenced, two lengths of polyethylene rope were hung between opposite sets of the stream-bank metal rods to establish reference grids to facilitate thorough cleaning of each test site. Subsections were cleaned sequentially, in a downstream direction. The hose nozzle was normally held above the water surface, aimed downstream and angled slightly toward the stream bottom. Four or five sweeps with the high-pressure jet were made across the breadth of each subsection. This cleansing forced sediment and fines up into the river current where they were displaced downstream into stillwater settling areas. The engine was set at three-quarters throttle, which provided hose pressure sufficient to drive the water jet at least 30 m through the air.

Three people were required to perform the operation - a pump man, a nozzle man and a hose man. The pump man operated the pump, kept the foot-valve strainer free of debris and moved the grid ropes; the nozzle man directed the water jet and did the actual gravel cleaning; and the hose man carried the hose and kept it from becoming entangled or kinked.

The cleansing took three people 2.3 hours (6.9 man-hours) at the upper test site, T2 (Figs. 1 and 2). The area cleaned was 396 m^2 (Table 1). No rest stops were taken after the gravel-cleaning operation commenced. The cleaning rate was 172 m^2/hr. The lower test site, T1, had an area of 468 m^2 (Table 1) and required exactly two hours (6 man-hours) to clean. The cleaning rate was 234 m^2/hr. Less than 22.5 L (5 imp. gal) of premixed gasoline and oil was required to operate the pump to clean both experimental sites.

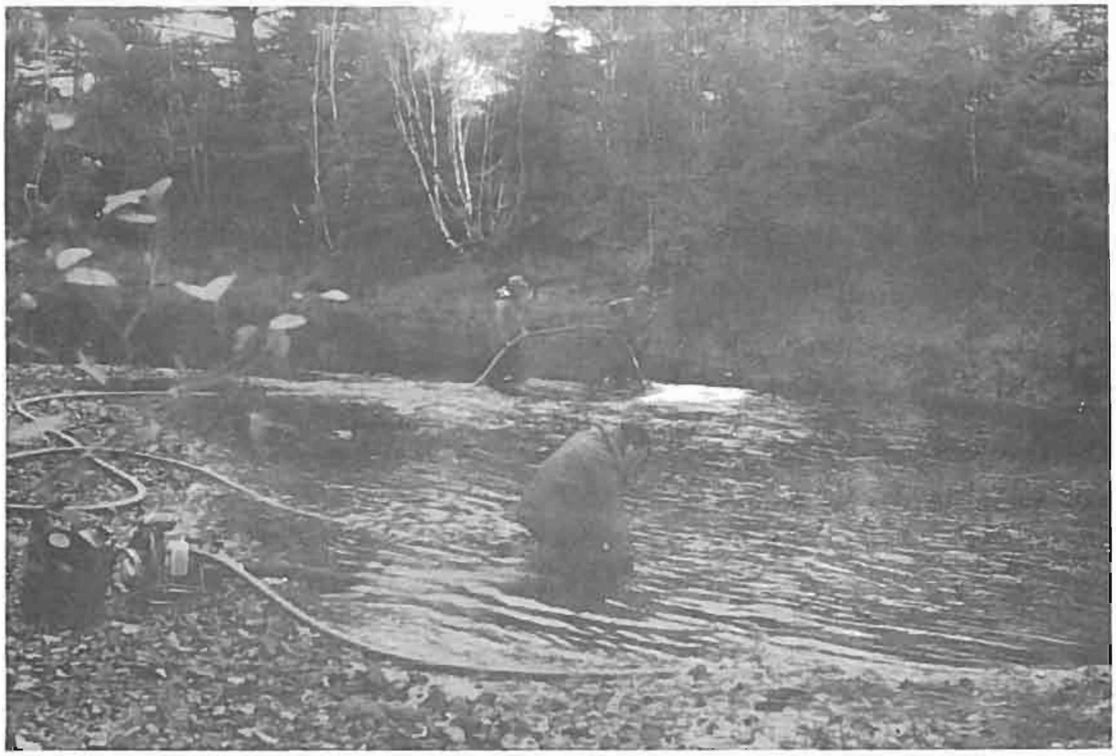

FIG. 2. The gravel-cleaning operation in progress at Site T2, 1984.

TABLE 1. Physical characteristics of gravel-cleaning test sites, 1984.

	Width (m)					Depth[2] (cm)			Surface-water velocity (cm/s)			Estimated bottom composition[3] (% of area)				
Site[1]	n	$\overline{x}$	SD	Length (m)	Area (m^2)	n	$\overline{x}$	SD	n	$\overline{x}$	SD	B	C	G	Sa	S
T1	7	15.6	1.5	30	468	42	32.9	20.8	35	0.38	0.15	15	42	31	10	2
T2	7	13.2	0.9	30	396	42	22.9	12.0	35	0.47	0.17	5	10	75	10	0

1. See Fig. 1.
2. At each test site, five actual measurements were made along each of seven transects, and one depth measurement was assumed to be zero to compensate for zero depth at the margins of the stream.
3. B = boulder (>25 cm diameter); C = cobble (6.4 cm-25.0 cm); G = gravel (0.6 cm-6.4 cm); Sa = sand (0.1 cm-0.6 cm); S = silt (< 0.1 cm).

SITE CHARACTERISTICS AND GRAVEL PERMEABILITY

Test sites were 30 m long and averaged between 15.6 m and 13.2 m wide (Table 1). Mean depths ranged from 32.9 cm at Site T1 to 22.9 cm at Site T2 (Fig. 1). Surface-water velocity averaged 0.38 cm/s at Site T1 and 0.47 cm/s at Site T2. Site T1 had more of its bottom area in large boulder and cobble (c.57%) than did Site T2, which had c.15% (Table 1).

Standard permeabilities (K_{10}s) were highly variable at each study location before and after cleaning. Standard deviations of the mean K_{10}s for the original (untransformed) permeability measurements were in each case greater than their respective means (Table 2). This result suggested that the untransformed permeability measurements for the before and after treatments were not normally distributed. A logarithmic transformation did normalize the T1 data, P = 0.05; hence, comparisons of statistical differences between treatment means (t-test) of each test site were done on transformed ($\log_e$) permeability measurements.

At both experimental sites, K_{10}s increased after gravel cleaning (Table 2), as did the frequency (%) of sampling stations that had relatively high (greater than 3,000 cm/hr) permeability (Table 3). After cleaning, the K_{10}s (geometric) at one of the two sites tested (T1) were significantly different, $p < 0.02$, from those measured before; but for the second site, K_{10}s were not significantly different, $p > 0.05$. The frequency of sampling stations with relatively high K_{10}s rose from 20.9% before cleaning to 70.8% after cleaning at Site T1. The increase in the frequency of these (greater than 3,000 cm/hr) stations at Site T2 was lower than at Site T1 after cleaning.

TABLE 2. Standard gravel permeabilities before and after gravel cleaning at the two test sites, 1984.

			Standard gravel permeability (cm/hr^{-1})			
			Arithmetic		Geometric	
Site[1]	Treatment[2] (cleaning)	n	$\overline{x}$	SD	$\overline{x}$	SD
T1	before	24	2,462	3,293	1,292	3.31
T1	after	24	7,921	6,793	3,726	5.48
T2	before	24	4,086	4,595	2,392	3.14
T2	after	24	9,222	13,081	3,450	5.47

1. See Fig. 1.
2. Sampling dates for before and after were October 18 and 25, respectively.

TABLE 3. K_{10} distributions (cm/hr) for gravels at the two test sites, before and after cleaning, 1984.

	Site T1		Site T1	
K10	Before treatment	After treatment	Before treatment	After treatment
>0 ≤1000	10 (41.7)	5 (20.8)	3 (12.5)	4 (16.7)
>1000 ≤2000	8 (33.3)	2 (8.3)	6 (25.0)	4 (16.7)
>2000 ≤3000	1 (4.2)		7 (29.2)	4 (16.7)
>3000 ≤4000	1 (4.2)	2 (8.3)	3 (12.5)	1 (4.2)
>4000 ≤5000	1 (4.2)	1 (4.2)	1 (4.2)	
>5000 ≤6000		2 (8.3)		1 (4.2)
>6000	3 (12.5)	12 (50.0)	4 (16.7)	10 (41.7)

1. Figures in parentheses are percentages.
2. See Fig. 1 for site locations.

DISCUSSION AND CONCLUSIONS

GRAVEL CLEANING

The gravel-cleaning equipment and procedures employed in the present study provided a simple but effective way of improving the permeability of gravels within stream reaches classified as Atlantic salmon spawning habitat. The equipment used was light, compact, readily obtainable and relatively inexpensive (c.$2,000 Can.).

In his literature search on the restoration of stream gravels for spawning and rearing salmonid species, Mih (1976) listed a number of alternative methods for mitigating the detrimental effects of fines in salmon spawning beds:

(1) Reduction of the source of fine material upstream from the stream reach in question.

(2) Replacement of existing spawning-bed material with new gravel.

(3) Mechanical disturbance to get the fine material into suspension or separate fines mechanically.

(4) Hydraulic disturbance by water-jet action or a combination of air- water-jet action.

(5) Hydraulic disturbance by water-jet action and removal of fine material by a suction system.

Mih (1978) concluded that the best alternative was to use a machine that travels the streambed and utilizes high-velocity water jets to dislodge fines and suction devices to remove them for out-of-stream disposal.

The method employed in the present study used the hydraulic flushing action of a high-velocity water jet and the carrying power of the natural stream flow to displace the fines into stillwater reaches of the stream. While this method may not be the most effective, it does appear to be one of the more practical, and was reasonably effective in increasing gravel permeability.

Tour (1980) discussed the pros and cons of different gravel-cleaning methods and provided information relative to the amount of effort required to clean the gravel in a standard 1,115-m^2 (12,000-ft^2) area of stream for each method (Table 4). He (op. cit.) assumed a 10-hour workday, which included one hour of travel time to and from the work site and 17.5% non-operating time for each method. On the same basis of calculation, it would take 2.5 man-days and nil machine-days to clean a comparable amount of streambed by employing the method used in the present study. Machine-days as inferred by Tour (1980) were for equipment used to haul gravel, spread gravel, mechanically disturb the stream bottom or to haul the cleaning equipment through the stream, and not for the actual cleaning operating except in the case of the mechanical-disturbance method.

TABLE 4. Effort required to clean a standard 1,115 m^2 of salmonid spawning gravel by various methods.

Cleaning method	Effort required Man-days	 Machine-days
Gravel replacement	48	32
Mechanical disturbance	4	4
Hydraulic disturbance with suction to remove fines	2-3	1-12
Hydraulic disturbance without suction to remove fines (Present study).	2.5	-

1. Table adapted from Tour (1980).

The reviews of Mih (1976, 1978) and Tour (1980) show that most gravel-cleaning equipment has been custom built, is expensive, and is not an off-the-shelf item that can be readily purchased. The only equipment of this type that is readily available, that the author is aware of, is manufactured by Timberline Reclamations Incorporated of Bozeman, Montana. This cleaning device uses high-velocity water jets, a vacuum hood, and suction apparatus to remove fines from the gravel rather than to displace them as in the present study. The cost of this equipment is $19,500-$27,500 U.S. (1983), depending on the model selected. In comparison, the equipment employed in the present study costs about $2,000 (Canadian)(1984) and is less cumbersome to use. Washington State University has developed a more elaborate device (Mih, personal communication)[1] which weighs 4.1 metric tons (not including the device used to move the machine) and costs approximately $60,000 U.S. (1983). It works on the same principle as the more compact and portable gravel-cleaning equipment manufactured by Timerline Reclamations Incorporated.

In addition to the large costs associated with purchase or development of gravel-cleaning equipment and to the actual conduct of cleaning operations associated with the different methods, there are other disadvantages. Heavy equipment used to spread gravel or to haul or move the cleaning equipment limits use in areas remote from roads. Heavy equipment can damage stream banks, promote erosion, and kill or damage salmonids seeking cover in the bottom substrate. All of the methods result in increased stream turbidity. Most available equipment is cumbersome, complicated to operate, and requires specialized training. Moreover, if the fines removed from the spawning gravel are discarded onto the neaby surrounding land, they may eventually be carried back into the stream by surface runoff.

GRAVEL-CLEANING EFFECTIVENESS

At both test sites, $\overline{K}_{10}$s (geometric) were greater after gravel cleaning than before, and the frequency of relatively high K_{10}s (>3,000 cm/hr) increased as well.

Proportion of fines (sand and smaller particles) has been shown to be inversely related to gravel permeability (McNeil and Ahnele 1964; Peterson, Fig 5, 1978). Furthermore, permeability is correlated with emergence survival of salmonid fry (Bjornn 1969; Phillips et al. 1975; Peterson, Fig. 6, 1978). Graphic depiction of the inverse relationship for salmonids between percent fry emergence and percent sand is shown in Hausle and Coble (1976).

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[1] Mih, Walter C. Professor of Civil Engineering and Hydraulic Engineer, Dept. Civ. Eng., Hydr. Eng. Sec., Wash. State Univ., Pullman, Wash.

Sediments act as physical barriers to the emergence of salmonid fry as well as reduce the permeability and exchange of interstitial water in the gravel surrounding the eggs and developing embryos. Hence, the delivery of oxygen and removal of waste metabolites is restricted. Coble (1961) found positive correlations between substrate permeability and dissolved oxygen, and between dissolved oxygen and embryonic survival of *Salmo gairdneri*. Hamor and Garside (1976) found that survival of *Salmo salar* embryos was regulated primarily by oxygen supply and secondarily, but significantly, by water exchange.

Phillips (1971) presented evidence that when other environmental stresses, including low dissolved oxygen, are added to the physical blocking effect of sediment, the combination is cumulative in reducing survival.

More directly, in the four British Columbia streams studied by Wickett (1958), the survival of pink and chum salmon fry was greater in those streams having higher gravel permeabilities. Peterson's (1978) data show a greater mean percent emergence of Atlantic salmon fry at sites with higher mean gravel permeability. He (op. cit.) concluded that at low, permeabilities (1,000 cm/hr) survival will be low and that at a permeability of 1,500 cm/hr mean fry emergence will be between 2% and 3% (underestimate due to trap efficiency). While the permeability versus percent-fry-emergence data that Peterson used to examine this relationship does not go beyond a K_{10} of about 1,700 cm/hr, it does suggest that even higher permeabilities will increase percent fry emergence even further.

Because of the linkages between gravel permeability and other factors - proportion of fines in the gravel, water exchange in the gravel (intragravel water velocity), dissolved oxygen in the gravel and subsequent fry emergence survival - permeability measurements are likely a relatively robust indicator of gravel-cleaning effectiveness and spawning habitat improvement.

Results of the present study indicate that the gravel-cleaning technique that was employed was an effective way of enhancing the quality of Atlantic salmon spawning habitat.

The life of the gravel-cleaning improvement for the present method is unknown but investigations in the state of Washington suggest that the average life of a cleaning operation is about three years (Gerke 1974, as reported by Mih 1979).

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