SALMONID SPAWNING GRAVEL CLEANING AND PLACEMENT

1 DESCRIPTION

The health and reproductive success of naturally spawning salmonid populations are directly tied to the quantity and quality of spawning habitat. The quantity and quality of spawning habitat can limit the survival of eggs and fry, potentially limiting the size of the next generation. [1 2 3 4 5]. Favorable spawning sites tend to occur upstream of obstructions to flow (e.g., bedrock outcrops, boulders, large wood), and in the tailouts of scour pools associated with meander bends or structures in the channel. According to a literature search by Schuett-Hames and Pleus[6], the quality of salmonid spawning habitat is dictated by the size, permeability, and compaction of the substrate; velocity, depth, direction, and dissolved oxygen content of flow; and the proximity to cover and rearing habitat. Each of these factors may be impacted by a number of natural phenomena and human activities. Thus, the appropriate techniques for restoring salmonid spawning habitat will vary from stream to stream.

The scope of this section is limited to techniques and considerations for the addition and cleaning of spawning gravel for habitat restoration and enhancement. For other techniques that can be utilized to restore salmonid spawning habitat, including upland sediment control, water management, and restoring conditions that naturally retain and sort spawning gravel, refer to Chapter 4.5.7, *Restoring Salmonid Spawning Habitat*.

Land-use activities and catastrophic natural events may affect spawning habitat by changing the type or amount of sediment entering a stream system or by changing the patterns of sediment transport and storage within stream channel. Also, the supply of spawning gravel can be lost or reduced due to bank armoring and stabilization that restrict the natural recruitment of gravel to the stream, construction of dams that block downstream gravel movement, or gravel mining and stream channelization projects that remove gravel from channels [7 8].

Conversely, the supply of gravel may be increased by changes in land use (e.g., agriculture, urbanization, timber harvest) that may destabilize the soil, or increase the increase the rate at which water runs off. These effects can accelerate the rates of soil erosion and mass wasting events such as landslides or debris torrents. They may also increase peak flows in streams that may accelerate erosion of the channel bed, banks, and floodplain. This in turn may cause the sedimentation of downstream habitats. Similar impacts may occur where channels have been straightened, dredged, diked, narrowed, armored, or “cleaned” (removal of roughness elements such as large wood and boulders). These activities tend to deepen flow, or smooth or steepen the channel such that the velocity and sheer stress imparted on the bed and banks of the channel increase.

Fine sediments are a natural and necessary element of streambed gravel. However, large inputs of fine sediment into the stream can bury spawning gravel thereby precluding its use [9] or result in “cementing” of the substrates that impedes redd construction by the female salmonid.

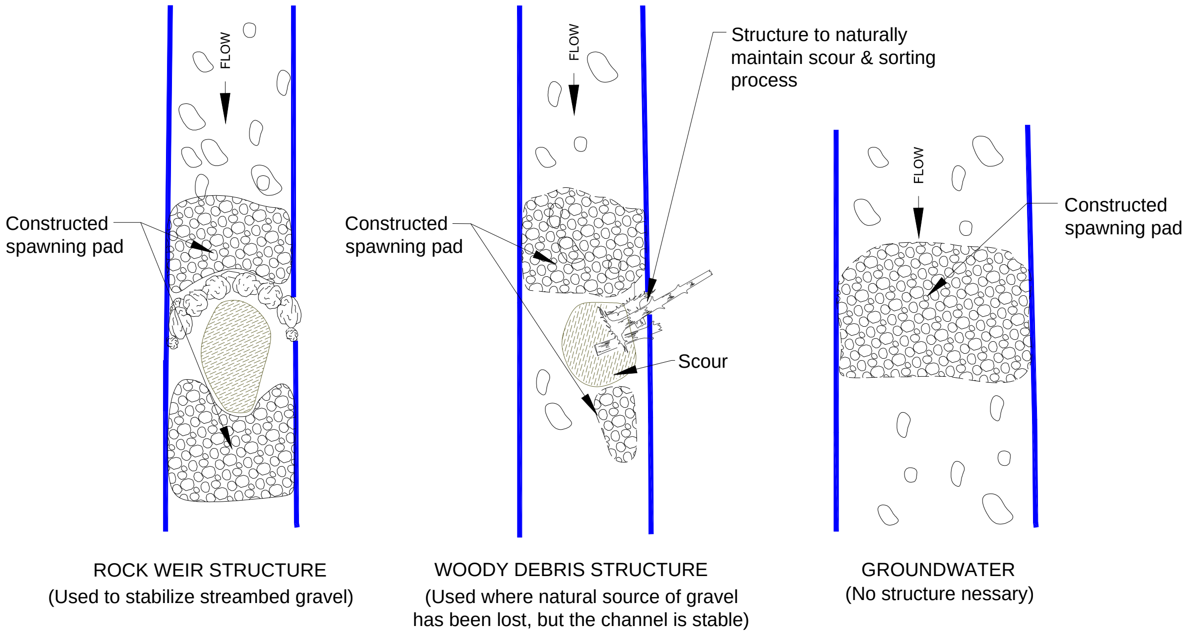
Fine sediments that settle out in spawning habitats can also cause decreased spawning success by filling the interstitial spaces between gravel partials. The presence of excessive fine sediments (<0.841 mm) within redds has been shown to reduce egg to fry survival due to a reduction of inter-gravel water flow. This reduces the availability of dissolved oxygen to eggs and fry as well as the rate at which metabolic wastes are removed from the redd [10] [11]. Excessive sediment may also physically prevent fry from emerging from the gravel in the spring [12] [13] [14] [15]. Several studies have verified that intra-gravel survival to emergence is reduced significantly when the percentage of fine sediments (<1.0. mm) in the gravel exceeds 12 to 14%. [16]. Also, when the space between the gravel partials becomes filled with fine sediment, aquatic invertebrates, the primary food sources for juvenile salmonids, are often displaced.

For close to 70 years, rehabilitation and enhancement techniques have been used to mitigate for the degradation and loss of salmonid spawning habitat [17]. In the early 1970's, declines in several Pacific salmonid stocks inspired a concerted effort to create new spawning habitat and rehabilitate degraded spawning gravels. Efforts were made to increase the quantity of spawning gravel by restoring the natural gravel supply, increasing the stability of gravel in the channel, and by mechanically adding gravel. Attempts were also made to improve the quality of spawning habitat by reducing the excessive supply of fines, encouraging the natural sorting and cleaning of gravel, and by removing excess fines by mechanical displacement.

<u>Gravel Cleaning</u>

Gravel cleaning refers to the mechanized removal of fine material (sand, silt, and clay) from gravel to increase interstitial flow and improve the quality of spawning habitat. Mechanized gravel cleaning (See **Salmonid Spawning Gravel Cleaning and Placement Figures 3, 4, and 5**) may produces immediate increases in egg to fry survival rates. However, unless the source of the fines has been identified and effectively treated (refer to Chapter 4.5.1, *Restoring Sediment Supply*), these benefits may temporary.

The long-term reduction of fine sediments in the streambed may be achieved by upland sediment control, revegetation, and water management. The control of fine sediment transport requires the restoration of stream meanders or roughness elements (e.g., wood, boulders) that create velocity gradients that naturally sort and clean spawning gravel. When possible the stream should also be reconnected to any historic areas of sediment deposition within the floodplain. Refer to Chapter 4.5.7, *Restoring Salmonid Spawning Habitat*, the *Introduction to Structural Techniques, Large Wood and Log Jams*, *Boulder Clusters, Channel Modification, and Levee Modification and Removal* techniques for more information.



Salmonid Spawning Gravel Cleaning and Placement Figure 1. Surface water dominated stream. Conceptual design.

<u>Spawning Gravel Placement</u>

In some cases, spawning gravel may be added to the stream to compensate for an identified loss of the natural gravel supply by constructing discrete spawning pads (See **Salmonid Spawning Gravel Cleaning and Placement Figure 1**) or through gravel supplementation. Depending on the specific conditions (flow, gradient and ambient substrate) both of these techniques may require maintenance and/or repeated application.

Construction of spawning pads is a direct habitat creation approach. Spawning pads are typically created by either building a channel constriction or installing streambed control structures across the channel. These structures may be designed to hold a specific mix of gravel that is placed mechanically or to trap the natural gravels that are mobile during high flows. With the exception of groundwater fed streams and channels, the benefits of these projects may be short lived if conditions are such that gravel is washed from the site over time and there is no compensating replacement from natural sources.

As an alternative to constructing discrete spawning pads, spawning gravel supplementation uses a managed inputs approach to create spawning habitat. In this technique appropriately sized spawning gravel is supplied to the stream and natural hydraulic processes redistribute the material downstream over time. Due to the unpredictability of high flow events capable of redistributing the material, it may take several years before the habitat benefits are realized. Benefits may be long-lived or short-lived, depending on design and on the magnitude and frequency of high flow events. In order to maintain the benefits in the long-term, gravel may need to be added periodically.

2 PHYSICAL AND BIOLOGICAL EFFECTS

2.1 Gravel Cleaning

Successful gravel cleaning may reduce the amount the fine material in spawning areas, enhance intra-gravel flow (permeability), enhance habitat for aquatic insects, and improve egg to fry survival rate of salmonids. However, gravel-cleaning operations are very intrusive as they employ the use of heavy equipment to physically disturb the streambed environment. As such, cleaning of spawning habitat, either mechanically or hydraulically, may temporally destabilize the spawning environment, alter water depths and velocities desired for spawning, and disrupt interstitial environment for aquatic insects. Also, unless the fines are removed from the stream channel during the cleaning operation, it may temporarily degrade water quality and redistribute fines into downstream habitats.

2.2 Salmonid Spawning Gravel Placement

Gravel placement techniques can increase the quantity and quality-spawning habitat when used under appropriate conditions. For example, spring-fed channels have a constant supply of high quality water and are often at least partially protected form high flow of events common to most surface streams. These conditions are ideal for salmonid egg incubation. Unfortunately, the lack of flushing flow events, which naturally recruit and distribute gravel, may also leave spring fed channel's lacking in adequate spawning gravel and dominated by fine materials. In these situations the placement of gravel pads and control structures may lead to a dramatic increase in spawning use and increase egg to fry survival rates as high as 30 to 60 percent. Conversely, constructing spawning pads comprised of spawning sized material in relatively high-energy sections of a surface-fed stream or channel, where gravel would not collect naturally, may lure salmonids to spawn there only to have their eggs and the gravel washed out during periods of high flow. Modifications to channel cross-section and profile by the addition of spawning gravel or creation of spawning pads (See **Salmonid Spawning Gravel Cleaning and Placement Figure 2**) can alter the hydraulics and energy distribution within the channel. These changes must be anticipated and planned for during project design to reduce the effects bank erosion and channel aggradation.

3 APPLICATION OF TECHNIQUE

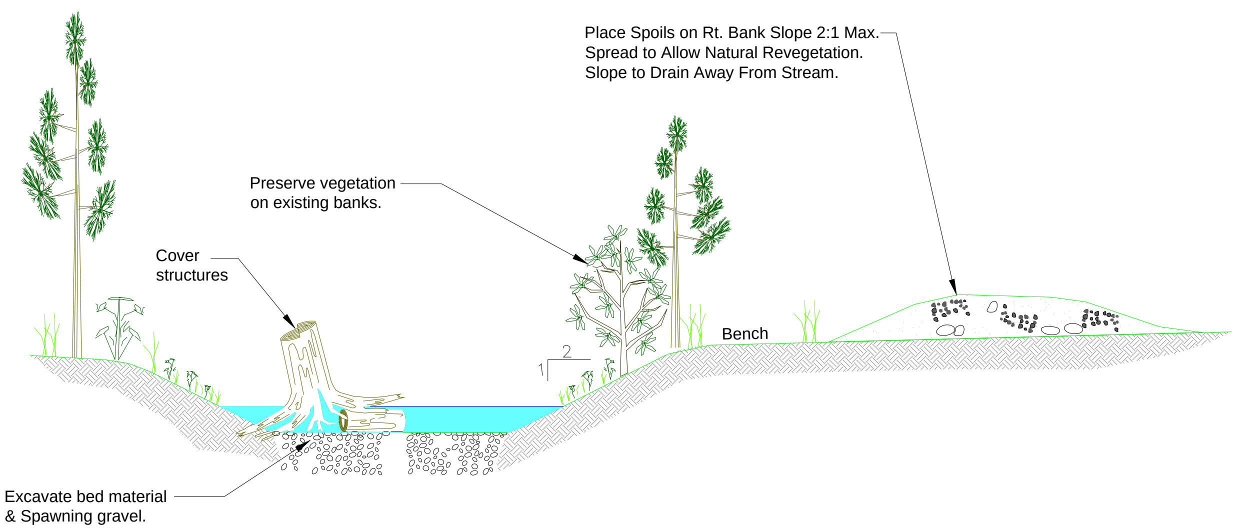
Potential rehabilitation sites must be assessed and projects carefully designed to ensure favorable results. Situations that should be avoided include channels that are laterally or vertically unstable, and streams that carry large volumes of fine sediment that can bury spawning gravels. Ideally, any rehabilitation of spawning areas would be located in areas of natural upwelling, which are typically dictated by variations in streambed elevation.

3.1 Gravel Cleaning

Mechanized methods of gravel cleaning should only be employed where excessive levels of fine sediment have been identified as a limiting factor for salmonids and in situations where the upstream source of fine sediment has been corrected so that rapid recontamination of the site will not occur. Streams with chronic, non-point-sources of excessive fine material are not good candidates for gravel cleaning, as it will provide only temporary benefits. Gravel cleaning operations are typically conducted in limited areas due to cost and logistic limitations and large-scale gravel cleaning operations are rare. Restoring natural stream processes and eliminating the sources of contamination will better correct system-wide siltation of spawning gravels.

3.2 Gravel Placement

Gravel supplementation and the construction of spawning pads are appropriate in situations where gravel has been a natural component of the sediment but its supply has been significantly reduced or interrupted. They can also be used as enhancement tools in streams that lack a natural source of material (e.g., spring-fed streams and the outlets of lakes, reservoirs, and wetlands). Gravel replacement is not appropriate as a stand-alone technique in very high-energy channel reaches where gravels may be washed out of the reach in a relatively short period of time (e.g., a single season). High-energy sites are typically dominated by cobbles and boulders where such material is available, or by bedrock or hardpan where it is not. It should be noted that some high-energy sites might have supported salmonid spawning habitat in the past, but the historic gravel deposits have been scoured out due to channel modifications that have increased the shear stress on the channel bed (e.g., dredging, steepening, narrowing, reductions in channel roughness by removing roughness elements or smoothing banks, floodplain fill, and levee construction), or watershed modifications that have increased surface runoff and peak flows. Where these activities have occurred, gravel replacement should only be conducted in conjunction with measures that restore the capacity of the reach to retain gravel. Gravel retention and project success has generally been greatest at sites downstream of lakes and reservoirs, and at groundwater-fed channels, where stream flow is relatively stable, but exhibits sufficient variability to promote sorting and moderate movement of gravel.



Salmonid Spawning Gravel Cleaning and Placement Figure 2. Constructed spawning pad at riffle. Conceptual design

Spawning pads may be constructed in channel reaches dominated by sand, silt, and/or organic material provided that there is no continuing source of fine materials entering the channel. However, they will likely be subject to a slow recruitment of these smaller sediments unless measures are taken such as installation of large wood or boulder clusters. (See **Salmonid Spawning Gravel Cleaning and Placement Figure 1**) to ensure the fines will be flushed out of the gravels rather than deposit within them. Spawning pads should not be constructed in pools or on meander bends where pools will naturally form.

Gravel supplementation involves the placement of appropriate sized gravel in or along the stream margin so that it can be naturally distributed in the reach downstream. Hence, it is applicable only in reaches capable of transporting the material being added. Gravel supplementation is not appropriate where the natural substrate is dominated by sand, silt, clay, and/or organic material. These conditions generally indicate a very low energy channel where flows will not be adequate to distribute added gravel. Gravel supplementation in general is more effective on a reach wide scale.

4 RISK AND UNCERTAINTY

4.1 Risk to Habitat

Many of the short and long-term risks to habitat are discussed in section 2 titled: *Physical and Biological Effects*. In addition to those, note that gravel cleaning and placement require in-stream work that may temporarily displace or disturb fish and wildlife species and degrade water quality. Restoration practitioners should also consider that targeting benefits toward a specific species of fish may have harmful effects on other species. For example, gravel placement techniques may create salmonid spawning habitat but result in the loss of salmonid rearing area such as pools.

4.2 Risk to Infrastructure

Gravel cleaning and placement pose minimal risk to existing infrastructure. The greatest risk to from these techniques is the possibility of aggradation resulting from gravel supplementation. If excessive gravel is added, or becomes entrained, it may accumulate in unwanted areas, such as culvert inlets and irrigation diversions.

Depending on the equipment and methodology used, gravel-cleaning operations may cause a short-term decline in water quality due to increased turbidity. This may adversely affect downstream water users (hatchery, irrigation, and potable users).

4.3 Uncertainty in Technique

There is a significant degree of uncertainty in both gravel cleaning and placement techniques. The duration and magnitude of project benefits is highly dependent on the flow and sediment transport regimes of the particular stream. Also, the spawning habitat needs of salmonids are species specific and seasonal and must be accounted for in project planning. Detailed pre-project observations and evaluation of the site can help guide the development of a project design and ensure it will be durable, effective and have a minimum of negative impacts.

Results from gravel cleaning studies are variable. Studies indicate that, while cleaning may result in a significant reduction in fine sediments in the treated areas, this does not guarantee increased reproductive success.

5 METHODS AND DESIGN

Streambed composition is a function of local and regional geologic, geomorphic, hydrologic, and hydraulic factors. Where spawning habitat exists naturally, these factors work in concert to provide and maintain the quantity and quality of gravel. Where degradation or loss of spawning habitat has occurred, the primary objective is to re-establish the conditions that provide for ideal spawning habitat. It may be necessary to precede instream restoration work with restoration of upland areas to minimize the sources of excessive levels of fine-grained sediment and to provide for a natural supply of spawning-sized gravels. This may include watershed and riparian restoration and implementation of best management practices to minimize surface erosion.

5.1 Data and Assessment Requirements

Before undertaking a spawning habitat enhancement project, it is important to understand the requirements of the particular species involved and the physical factors that effect the supply, transport, delivery, and deposition of fine sediment and gravel to the project site. For example, before initiating a gravel-cleaning project, the percent of fine sediments within the gravel should be determined. If excessive levels of fines are identified as a limiting factor effecting spawning success for salmonids, the source of fine sediment should be identified and treated.

Questions to be addressed include:

- Was the source of sediment caused by a single event or is it the result of chronic non-point source pollution or widespread mass wasting events?
- Has the supply of fine sediments increased due to land use activities within the watershed?
- If the sediment load is exacerbated by land use activities, can these be modified through watershed and riparian restoration to reduce the supply of fines to the stream?

Similarly, before adding gravel to a stream reach, the project proponent should consider why there is no suitable gravel present.

Questions to be addressed include:

- Is the supply of natural gravel lacking or is there a recruitment problem (e.g., the presence of an upstream dam or bank protection)?
- Do transport conditions in the stream channel limit gravel deposition (e.g., high gradient, confined channels with little wood or other roughness elements), or transport conditions that favor deposition of finer material (e.g. wide, low gradient, or backwatered reaches)?
- Are these conditions natural or caused by humans?
- If natural, should these conditions be altered to enhance salmonid spawning habitat (e.g., Do existing conditions provide critical habitat for salmonids during another life stage?)?
- Do existing conditions provide critical habitat for other fish and wildlife species?
- If these conditions are caused by humans, can their cause be addressed in order to restore

natural gravel deposition to the reach?

Assessment needs depend on the intent of the project, the nature of the channel, and the modifications to be implemented. Data collection and assessment must allow for careful consideration and analysis of all the potential impacts and effects. Field data collection should include the following:

- Documentation of site constraints and project limits (Site Scale)
- Documentation and mapping of existing habitat features (Site Scale)
- Evaluation of existing fish and wildlife use, habitat value and conditions (Reach Scale)
- Evaluation of the biological needs of the target fish species (Reach, Watershed Scale)
- Additional data necessary to complete baseline monitoring.

Characterization of hydrologic, hydraulic, and sediment transport conditions should included when considering supplementation projects:

- Characterization of the existing bed materials and of sediment sources, both gravel for spawning, and fine-grained material, which affects spawning. (Refer to *Sediment Transport* appendix for further discussion of sediment sources and transport mechanisms).
- Determination of channel forming discharge and flood discharges. (Refer to *Hydrology* appendix for further discussion of channel forming discharge)
- Flood and over bank flow profiles of existing hydrologic conditions (Refer to *Hydraulics* appendix for further discussion of modeling flow profiles)
- Hydraulics; including velocity, shear, and scour along the channel. (Refer to *Hydraulics* appendix for further discussion of shear and scour)
- Characterization of historic and current sediment transport dynamics

Preferred Characteristics of Salmonid Spawning Habitat

The characteristics of actual spawning sites vary greatly between species and among stocks of the same species (**Table 1**). Factors such as substrate size, water depth, and water velocity appear to limit where a female is physically able to construct a redd. Body size and stamina determine the size of particles that can be moved, the ability to work in fast water, and maneuverability in shallow water. If there is extensive variation in the size of individual members of a population, differences in velocity, minimum depth, and substrate preferences may be nearly as great between members of the populations as between different stocks or species [18]. Studies indicate that there is a relatively wide range of acceptable conditions for most species.

Table 1. Water depth, velocity, substrate size, and area required for spawning criteria for some salmonids [19]. (This identical table appears the Canadian Fish Habitat Enhancement Guide and is credited to Reiser and Bjornn[20].)

Species	Minimum Depth (m)	Velocity ($m*sec^{-1}$)	Substrate Mix Size Range (mm)	Mean Redd Area (m^2)	Req'd Area per Spawning Pair (m^2)
Fall chinook salmon	0.24	0.30 – 0.91	13 – 102	5.1	20.1
Spring chinook salmon	0.24	0.30 – 0.91	13 – 102	3.3	13.4
Summer chinook salmon	0.30	0.32 – 1.09	13 – 102	5.1	20.1
Chum salmon	0.18	0.46 – 1.01	13 – 102	2.3	9.2
Coho salmon	0.18	0.30 – 0.91	13 – 102	2.8	11.7
Pink salmon	0.15	0.21 – 1.01	13 – 102	0.6	0.6
Sockeye salmon	0.15	0.21 – 1.07	13 – 102	1.8	6.7
Kokanee	0.06	0.15 – 0.91	13 – 102	0.3	0.15
Steelhead	0.24	0.40 – 0.91	6 – 102	4.4 – 5.4	
Rainbow trout	0.18	0.48 – 0.91	6- 52	0.2	
Cutthroat trout	0.06	0.11 – 0.72	6 – 102	0.09 – 0.9	

The observed optimal sediment size distribution for three Pacific salmon species is provided in **Table 2**. For most species of salmonids, the general guideline is approximately 80% of 10 to 50 mm gravel with the remaining 20% made up of 100 mm gravel and a small portion of coarse sand (2 to 5 mm). More specific substrate mixes can be tailored to fish size. Small-bodied salmonids[1] spawn in gravel that is generally between 8 mm and 64 mm in size. Large bodied salmonids[2] spawn in gravel that is generally between 8 mm and 128 mm in size.

Table 2. Average size composition of gravel in redds of three Pacific salmon species (adapted from Andrew and Geen [21] and Burner [22]). Approximate average weight of each species shown in brackets.

Gravel Size (diameter)	Fall-run Chinook (9 kg)	Coho (4 kg)	Sockeye (1.5 kg)
	Percent		
Fines	10	8	12
3 – 12 mm	19	23	23

1 Small-bodied salmonids are defined as species that are typically less than 35 cm long when mature, including resident rainbow, resident cutthroat, anadromous cutthroat, bull trout (Dolly Varden), brown trout, brook trout, and kokanee.
2 Large-bodied salmonids are defined as species that are typically greater than 35 cm when mature, including pink, chum, coho, sockeye, steelhead, and chinook salmon.

13 – 50 mm	38	43	51
51 – 100 mm	21	23	12
101 – 150 mm	12	3	2

The selection of appropriately sized gravels is critical to the success of spawning gravel placement projects. The criteria provided in Tables 1 and 2 represent optimal conditions. But the specific gravel size selected for a gravel placement project should consider, not only the sizes and species of target fish, but also the hydraulic conditions. In some applications, it may be appropriate to augment spawning-sized gravels with larger materials to add stability. Angular or crushed gravels should not be used as spawning substrate. Washed, round gravel is preferred over pit run gravel that often contains considerable fine-grained sand and silt.

Gravels added should not be made up of one single size of material as this lacks the diversity needed by aquatic insects and contributes to streambed instability.

5.2 Gravel Cleaning

Gravel cleaning strategies have centered on the separation of fines from the streambed by physically agitating and disturbing the bed. This is accomplished by sifting fines from the spawning bed mechanically, or by flushing fines from spawning beds with hydraulic force, so that they can be washed downstream by flow or removed from the stream with a suction device.

5.2.1 Mechanical Removal of Fines

Cleaning of spawning gravels has usually been conducted on a relatively small scale in discrete reaches of a stream. The simpler methods of mechanically removing fines from spawning gravels used in the past involved the use of heavy equipment such as a bulldozer, backhoe, or front-end loader to physically disturb the substrate. Perhaps the most common method of cleaning gravels involves the use of a bulldozer (See **Salmonid Spawning Gravel Cleaning and Placement Figure 3**). The bulldozer moves up and across the stream at a 45-degree angle to the flow, angling its blade like a plow, so that gravels are turned to a depth of 10-14 inches and pushed up in the flow of the stream where fines can be washed downstream. After each pass, the bulldozer crosses the stream downstream and begins a new pass 6-7 feet downstream of the last pass. In this manner, the potential of recontamination of cleaned gravels by suspended fines in the immediate area is minimized.

R. J. Gerke[23] supervised the successful use of a bulldozer in cleaning spawning beds in several Washington streams that have suffered from heavy siltation caused by landslides. On the Cedar River, 29,000 square meters of gravels were cleaned using a bulldozer. About 3,000 sockeye salmon and 50 chinook salmon spawned following the cleaning operation.

A section of the Entiat River in Washington was also successfully cleaned using a bulldozer, according to D. A. Wilson.[24] J. R. West [25]reported that spawning by chinook salmon increased in Scott River in Northern California after gravels were cleaned there with a bulldozer.

Another mechanical method of cleaning gravel involves the use of a 5-foot wide digging bucket mounted on a G-600 Gradall to work the gravel and wash the fines using the stream’s flow. Moving downstream, the Gradall excavates the gravel to a depth of 1-2 feet. The excavated gravel is then slowly poured back into the streambed, allowing the stream to wash away the fines. Tests on the Nadina River by Andrew [26] resulted in a 32 to 44 percent reduction in the percentage of material less that 0.5 mm, and complete removal of fines 0.3 mm and smaller.

Due to environmental concerns associated with the presence of equipment in the stream, the release of sediment, and potential for contamination of downstream spawning areas, this method will have limited application. In some areas it may be prohibited by state and federal regulations.

In an attempt to minimize the release of fines into the stream flow, the International Pacific Salmon Fisheries Commission used a Gradall carrying a modified 7-foot digging bucket with a screened bottom constructed of 1/8-inch wire mesh, capable of separating fines from the gravel bed within the stream channel [27]. The machine works in a downstream direction, scooping up gravel to a depth of about two feet and hydraulically vibrating the bucket in the water so that fines within the gravel come out the screened bottom of the bucket and are deposited into the hole just created. When this has been accomplished, the cleaned gravel in the bucket is returned to the hole and the machine moves to the next spot to be cleaned. The resulting gravel bed is freed of fines for approximately the first 12 inches, under which there is a layer rich in fine sediments. It is not clear if such stratification of the gravel bed could be detrimental to spawning success.

Mechanical methods are most successful at reducing fine-sediment concentrations if conducted during relatively high stream flows.

Hydraulic Removal of Fines

Another approach to the cleaning of spawning gravels incorporates the use of a hydraulic flushing action to mobilize and collect fine sediments. The "Riffle Sifter," **(**See **Salmonid Spawning Gravel Cleaning and Placement Figure 4**) developed in 1963 by the U.S. Forest Service, was the first machine designed to hydraulically remove fines from choked spawning areas. The Riffle Sifter flushes fine sediments from the substrate by injecting a high-speed jet of water into the streambed through a series of pipes. The apparatus then collects the fine sediments through a suction system and jets them onto the floodplain. The Riffle Sifter has been shown to remove up to 65 percent of the particles smaller than 0.4 mm[28]. However, the Riffle Sifter was subject to mechanical problems in the course of cleaning in natural streambeds[29].

A prototype gravel-cleaning machine called "Gravel Gertie" (See **Salmonid Spawning Gravel Cleaning and Placement Figure 5**) was developed by Professor Walter Mih at Washington State University in 1979 for the Washington Department of Fisheries as a more advanced version of a hydraulic gravel-cleaning machine[30]. The Gravel Gertie is mounted on a low-bearing pressure tracked vehicle that drives through the riffle during operation. The hydraulic cleaning action of Gravel Gertie uses vertical jets of water, which are directed towards the streambed to flush out fine sediments. A suction system within three rectangular collection hoods removes fines from stream flow, ejects them via a high pressure nozzle, and deposits them above the Ordinary High Water (OHW) line. Gravel Gertie was field tested on the Palouse River in northern Idaho and on Kennedy Creek and several other streams in western Washington. Effective cleaning was accomplished to substrate depths of 12 inches. While variable, all of these streams showed a decrease in the percentage of fines after one pass, with reduction of fine sediments (<0.841 mm) ranging from 3 to 78 percent.

5.3 Salmonid Spawning Gravel Placement

5.3.1 Gravel Supplementation

This technique involves the deliberate placement of gravels in streamside locations where it will erode during high flow events and be deposited as salmonid spawning gravel in downstream reaches over time. Consequently, determination of the size, quantity, and location of gravel placement must take into account sediment transport processes and project objectives.
Gravel should be placed at locations within the channel such as along point bars, stream banks and the upstream end of mid-channel bars that are prone to erosion and scour.

Gravel should be sized so that the D_{50} of the gradation becomes mobile at the dominant discharge event (refer to *Hydrology* appendix). This can be accomplished using tractive force computations. Refer to the *Sediment Transport* appendix for a complete discussion of tractive force and other sediment transport analyses.

Determination of the volume of gravel to be added and the frequency of installation can be accomplished using Sediment Transport analyses detailed in the *Sediment Transport* appendix. Sediment transport and deposition within the channel is dependent on discharge, gradient, depth of flow, obstructions and channel morphology. The estimate of sediment transport is a complex science, and is often dependent upon data that is difficult to acquire and numerous assumptions. As such, sediment transport estimates should be conducted by persons with expertise in this area. The frequency of additions cannot be effectively predicted or estimated prior to installation, as transport rates are determined by unpredictable and variable natural events. Therefore, determination of the frequency, as well as the volume, will have to rely heavily on annual monitoring to determine gravel deficiencies on an annual basis.

5.3.2 Spawning Pads

Spawning pads are typically used in areas where stream flows and stream gradient are moderate such as ground water fed channels or wall based tributaries (that flow from the toe of the valley walls and across the valley floor). In low gradient areas where fine silt is prone to settle, spawning pads may be placed below channel constrictions or drop structures which provide a flushing affect that tends to keep the newly placed gravel relatively free of fine material. In areas with moderate to higher gradients, stream spanning structures such as log weirs or plank controls may be placed downstream of spawning pads to stabilize the streambed and slow the loss of new gravel during freshets. Channel constrictions and drop structures may also create a backwater upstream and a pool and tailout downstream that can collect gravel. The upstream gravel placement can also be designed to feed gravel to the tailout area. Though drop structures have been more commonly used in the past, channel constrictions can create more diversity and intra-gravel flow. Channel constrictions also have a much lower risk of creating a barrier to fish-passage. Structures that promote such constrictions include Boulder Clusters, Porous Weirs, and Large Wood and Logjams (see techniques in this guideline for design and construction details).

Spawning pads might be necessary where natural large wood has been removed, and no structure exists within the stream channel to retain gravel suitable spawning environments.

In small, low gradient streams that seldom experience flushing flows, spawning pads can become contaminated with sediment and organic material. In these cases, channel constrictions may be placed in association with spawning pads to increase the velocity of flow and flush sediment from the gravel located immediately downstream. The constrictions may be constructed of logs, lumber or rock and are designed to work over a range of low to moderate flows.

The spacing of channel constrictions is based on the channel gradient and the degree of backwatering desired. A common mistake is to place constrictors too close together, resulting in the backwatering of the upper constrictor, which, in turn reduces velocities through the upstream constriction, thereby reducing the effectiveness of the sediment flushing. Constriction design, including spacing and size, can be accomplished using either hydraulic models or through trial and error in the field.

Drop structures are commonly constructed out of logs, planks, or boulders, but other materials have also been utilized. Refer to the Drop Structures technique for details on design, material selection, minimum spacing, and passage requirements of drop structures. Note that constructing drop structures in a channel requires long-term monitoring and maintenance to ensure they do not become barriers to fish passage. This is less of a concern with channel constrictions.

6 PERMITTING

A general discussion of permitting requirements is included in *Typical Permits Required for Work In And Around Water* appendix. Permitting requirements for channel modification projects will be very site- and project-specific. Depending on the permits required and the local governments involved, securing the necessary permits may take months or even years. Because of this, permitting is a key element of project planning.

Gravel cleaning and replacement projects invariably involve physical disturbance of the channel, at least in the short term. Permits, such as the Hydraulic Project Approvals may require measures to avoid disrupting water quality and existing habitat. These measures could include isolating the project from the flowing stream, treatment of wastewater from the construction area, on-site erosion controls and replacement of native vegetation after construction is complete.

7 CONSTRUCTION CONSIDERATIONS

A general discussion of construction issues and considerations is provided in the *Construction Considerations* appendix. Key construction issues for these techniques include access for delivery of materials and equipment, in-channel disturbances, and the actual timing of construction.

Spawning gravel may be added to a channel in a variety of ways, including using a helicopter, conveyor belt, tracked excavator, dump truck, or even by hand carried bucket. Use of a conveyor belt operating from the back of a dump truck offers the advantage of controlled placement while minimizing disturbance to the stream bed and banks. Both gravel cleaning and gravel placement work should be timed to minimize disturbance, displacement, and disruption of individuals and populations of aquatic organisms, their behaviors and habitats. In-stream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, Washington Department of Fish & Wildlife Contact Information, in the Integrated Streambank Protection Guidelines showing Washington Department of Fish and Wildlife Regional Offices). Note that other timing restrictions may apply in order to minimize impacts to wildlife. Further discussion of construction timing and dewatering can also be found in the *Construction Considerations* appendix.

8 COST ESTIMATION

Cost is highly variable in spawning gravel enhancement projects. For gravel placement projects, the quantity, availability, and hauling distance of materials contribute to variability in costs. Sorted gravels may cost $20 to $40 per cubic yard.

Dewatering of a project site can also add significant cost to a project. Dewatering costs are greatly affected by the size of the channel and other site-specific factors.

Table 3. Approximate costs for selected spawning habitat rehabilitation projects.

Project Type	Approximate Costs	Comments / Assumptions
Gravel cleaning – mechanical scarification	\$5-20 per m^2	Bulldozer working instream Streams over 10m wide
Gravel cleaning – Hydraulic	\$20-50 per m^2	High pressure hose Small, shallow streams
Gravel placement	\$50-70 per m^3 gravel	Sorted gravel supplied Limited delivery distance Machine placed Does not include control structures

9 MONITORING

Biological monitoring provides the ultimate measures of project success. Annual spawner counts and redd surveys may provide a measure of spawning utilization but this does not necessarily reflect on the level of spawner success (i.e. survival from embryo to fry). Other measures such as redd capping, downstream migrant trapping, seining, and snorkeling can provide more direct information on egg to fry and fry to smolt survival rates.

Monitoring the physical conditions at a project site is also important to document project performance. Measurements of the degree of scour, distribution and abundance of gravel, gravel sorting, channel movement, fine sediment levels, and the condition of retention structures are recommended elements of a monitoring plan. Constructed spawning habitat, including bed forms and large wood, may be carefully surveyed immediately after construction and again after initial high flows to document changes that might affect spawning success. Scour chains or other devices intended for measurement of spawning gravel stability and scour can also be used. However, since the hydraulics around the structure will be quite varied, it may be very difficult to quantify impacts of bed instability.

The *Monitoring Considerations* appendix provides monitoring guidance and considerations for stream habitat restoration projects. For a comprehensive review of habitat monitoring protocols, refer to the Washington Department of Fish and Wildlife's Inventory and Monitoring of Salmon Habitat in the Pacific Northwest.[31] Monitoring the project for its integrity as a spawning site will likely require a more comprehensive schedule than that required for the integrity of the structures. Monitoring of physical characteristics and biological use should be conducted annually for both gravel cleaning and supplementation projects.

10 MAINTENANCE

Gravel cleaning should only be applied when a streambed has been adversely impacted by an isolated event, such as a landslide, or in a situation where the upstream source of fine sediment has been corrected so that recontamination of the site won't occur. Therefore, it should not require maintenance or frequent repeat treatments.

Because added gravel will slowly move downstream and will not be replenished by an upstream supply, gravel supplementation projects must be monitored regularly and periodically nourished with additional gravel to maintain long-term habitat benefits.

Spawning pads typically consist of structural components, which should be designed to withstand selected minimum flow requirements. These structures should be designed to be relatively maintenance-free. Refer to General Design and Selection Considerations for In-Stream Structures for further discussion of maintenance related to in-channel structures.

11 EXAMPLES

11.1.1 Gravel Cleaning

In 1980, WDFW conducted a study of the prototype gravel-cleaning machine known as "Gravel Gertie" (see section 5.2.1 *Mechanical Removal of Fines* for a description of the machine.) One of the sites selected for cleaning was Kennedy Creek, a small tributary (5 to 6 cubic feet per second of flow) of southern Puget Sound's Toten Inlet near Olympia, Washington. After two passes with the machine the level of fine sediment (<0.84 mm) in the streambed of the test reach was reduced from a pre-project level of about 10 per cent to 2 per cent.[32] Wither this actually lead to an increase in salmoind egg to fry survival at this site was never evaluated. However, this data suggests that "Gravel Gertie" could definitely remove fine sediments in the upper levels of the streambed.

11.1.2 Gravel Supplementation

In 1987, WDFW constructed and improved access to a tributary of the Suiattle River, North of the town of Darrington, WA. The site, know as "Suiattle Slough" was a spring fed channel which beavers had blocked off from the main river channel. In addition to providing access to several thousand square meters of off-channel over-wintering habitat for juvenile coho, a portion of the slough received substantial gravel supplementation. Gravel was placed on the bed of the channel and also stock piled in steep-sided piles at the waters edge. The energetic action of spawning coho slowly mined these gravel piles over time and the site has remained as preferred coho spawning habitat for 17 years.

11.1.3 Spawning Pad Construction

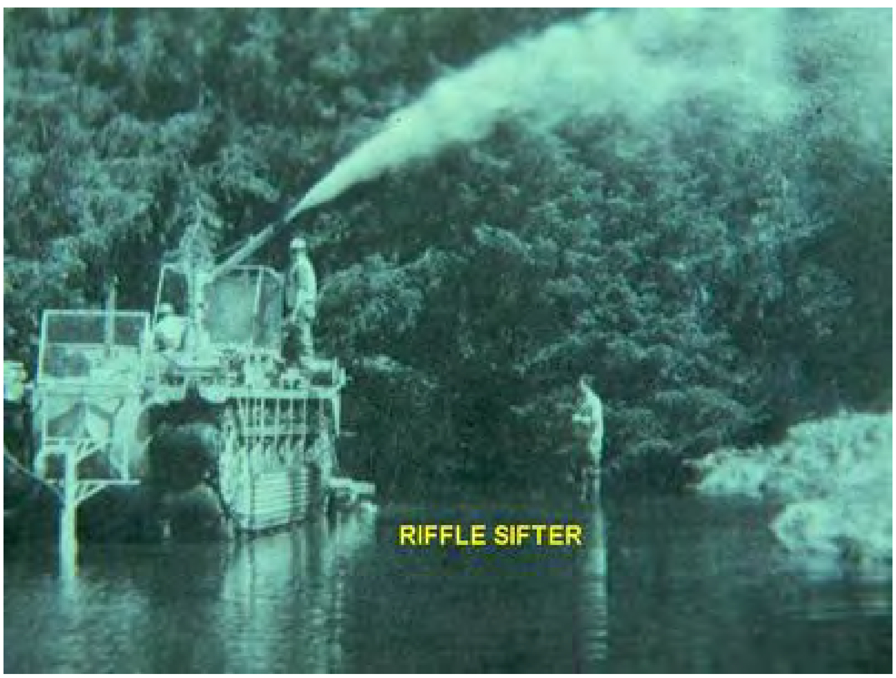
Perkins Creek

A gravel placement project was conducted on Perkins Creek, a small tributary to McClain Creek on Eld Inlet, near Olympia, WA. Prior to the project, spawning habitat in Perkins Creek was limited to a thin layer of somewhat angular gravel, which overlaid a clay sill. The project included the installation of a series of wooden plank drop structures and the placement of clean, round spawning gravel which was evenly graded from 0.75 inch to 2.75 inches in diameter. The adult escapement to the project and fry out-migrations was carefully monitored for seven years. During this time estimated egg to fry survival ranged from a low of 3 per cent to a high of 23.2 per cent. The largest adult chum salmon escapement documented during those years was in excess of 1,100 fish.[33]

Satsop River Side Channels

In 1985 the Washington Department of Fisheries (WDF) evaluated chum salmon production in four groundwater-fed side channels of the Satsop River, a tributary of the Chehalis River near Aberdeen Washington. All four channels had either limited or highly sedimented spawning habitat. In these projects the existing streambed materials were excavated and replaced with clean, round gravel (from 0.75 inch to 2.75 inches in diameter). The adult escapement to the project and fry out-migrations were carefully monitored. Egg to fry survival rates in these projects ranged from 20 to 73 percent. [34]

Salmonid Spawning Gravel Cleaning and Placement Figure 3.
Gravel cleaning with bulldozer.



Salmonid Spawning Gravel Cleaning and Placement Figure 4.
Riffle Sifter.

Salmonid Spawning Gravel Cleaning and Placement Figure 5.
“Gravel Gertie”

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