SIDE CHANNEL / OFF CHANNEL HABITAT RESTORATION

1 DESCRIPTION OF TECHNIQUE

Side channel habitats are generally small watered remnants of major river meanders across the floodplain. They are most common in those floodplains that have been strongly glacially influenced leaving a relatively flat valley floor. They include areas that may or may not be actively influenced at any one point in time by the main river. These sites include naturally abandoned river channels, oxbows, flood swales and sometimes the lower ends of terrace tributaries flowing out onto the floodplain. They also include constructed channels and connecting ponds that could have been built specifically for aquatic habitat or indirectly for some other purpose such as gravel mining. This technique includes construction, restoration and reconnection of side channels to the main channel and protection of these areas by controlling river and flood flow from the main river and capitalizing on availability of floodplain groundwater.

The focus of this technique is on restoration or creation of self-sustaining habitats. Self-sustaining is not synonymous with maintaining static conditions. Side channels may succeed into drier habitats as part of their natural evolution. Sustainability normally depends on channel processes including floods, channel migration, and aggradation. In some cases, sustainability will be more determined by fish activity than hydraulic conditions. Intense annual or biennial spawning by large numbers of salmon can keep some natural and/or created side channels active and functioning where without this natural activity they would soon succeed into ephemerally wetted swales.

There are also opportunities for restoration that are not self-sustaining that should not be foregone. For example, the only opportunities for side channel restoration in some areas might be to connect the river to relic side channels that have been isolated from the river by armored banks or levees that protects infrastructure or development. These sites may not be self-sustaining if the river is not allowed to flood through them. This type of side channel restoration might be a valuable exception to designing habitat restoration purely by restoration of natural processes. The types of side channel restoration discussed in this guide are the following:

- New side channel habitat. This focuses on the creation of self-sustaining side channels, which are maintained through natural processes.
- Reconnection of existing side channel habitat, which focuses on restoring fish access and habitat forming processes (hydrology, riparian vegetation).
- Restoration of side channels includes the restoration of habitat within an existing channel.
- Connection of side channels refers to restoration of hydraulic and hydrologic connection to the mainstem by restoring the relative elevation of the channel to the mainstem or removing flow blockages such as levees and sediment plugs.

The side channel technique is often used in conjunction with other techniques in this guideline such as *Levee Removal and Modification*, *Dedicating Land and Water to Stream Habitat*

Preservation and Restoration, and *Riparian Restoration and Management*. Removal of floodplain fill and bank protection, restoration of stream hydrology, and channel modifications may also be necessary to restore habitat forming processes to the side channel.

Restoration of fish access to side channels that have been blocked by roads, culverts, and dams can be a critical factor driving recovery of populations. Fish passage is mentioned in this guideline generally and discussed more thoroughly in *Fishway Design Guidelines* and *Design of Road Culverts for Fish Passage*[1] guidelines.

This side channel technique does not include artificial spawning channels, which generally include formal water supply structures, formal structures to supply upwelling water, and/or fish holding or segregation devices. Artificial spawning channels are generally not a self sustaining technique but are intended to provide a highly regulated and controlled spawning environment as an alternative to, or to supplement, hatchery production. Bell (1990)[2] includes a description and criteria for spawning channels.

1.1 Evolution of Natural Side Channels

In unconfined natural alluvial river systems, side channel habitat is constantly created and abandoned as the river migrates laterally and changes course. Naturally formed side channel habitat is usually associated with former stream channels abandoned through natural process, or the landward side of gravel bars formed during high flow events within the active channel area. Side channels generally evolve over time from being an active channel to a backwater, then perhaps to an isolated oxbow intermittently connected to the main flow during floods, and finally to a wet depression on the floodplain. This evolution might occur over decades. Interrupting the processes of channel evolution with activities such as bank protection can lead to loss of fish habitat over the long term (Roni et al. 2002)[3]. As long as the stream is creating new side channels, all successional stages of side channel development will occur within the stream corridor, providing a niche for all successive plant and animal communities.

Side channels often derive a major portion of their flow from either groundwater or seepage from the adjacent stream/river. The role of surface water in side channel habitats varies depending on mainstem and groundwater hydrologies, channel topography, and physical features. Peterson and Reid (1984) describe three types of side channel habitat within a river floodplain: overflow channels, percolation-fed channels and wall-based channels.[4] This technique also includes floodplain ponds.

> *Overflow channels* are flood swales, and often-relict mainstem channels, that are directly connected to the main river channel during high flows or at all times. They are often very dynamic as a result of the periodic influx of water, sediment, wood, nutrients, and organic material from the main channel. Fish habitat associated with overflow channels is often unstable and typically prone to flooding and channel shifting though possibly on an infrequent basis. Periodic floods through these channels can help maintain their productivity, cleaning and redistributing spawning material and creating new habitat as other habitat is destroyed. Restoration of overflow channels might include reconnection of the channel to the mainstem and placement of habitat features within the channel. Without the natural hydrology and disturbance regime, keeping habitat functional often requires a high maintenance effort. The level of utilization may depend on the frequency

of inundation by the mainstem. Entrapment of fish can occur if surface flow stops.

Perc channels are relict river and/or flood channels and are primarily supplied by groundwater of the hyporheic zone. The hyporheic zone is the area beneath and next to a river channel that contains some proportion of water from the surface channel. See **Figure 1**. Frequently, they are better protected from floods than overflow channels and so have relatively stable flows. Groundwater channels provide winter and summer refuge for juvenile fish, larval and adult amphibians, and a suite of invertebrates; spawning habitat for adult fish, some amphibians, and some invertebrates; and foraging habitat for many bird and mammal species.

Wall-based channels can be groundwater fed but are often fed from springs or surface water from an adjacent terrace. They are usually higher in elevation relative to percolation-fed channels. Habitat projects might include providing fish access to them and enhancing habitat within the channels.

F*loodplain ponds* are natural or constructed ponds in or above the floodplain such as abandoned gravel pits, mill ponds, ponds, and river oxbows. They might be supplied by groundwater or surface water from streams or springs and may or may not be connected to the river. Habitat projects might include providing fish access to them and enhancing habitat within the ponds. Though the origin and hydrology of floodplain ponds may be different than a wall-based channel, in this guideline they are described together.

The type of side channel (overflow, percolation-fed, wall-based, floodplain pond) has direct bearing on the approach to a restoration project and potential fisheries benefits. These general categories of side channels are used in this guideline for convenience. Although specifically defined, individual projects and work sites will likely include several of these channel types. For example a spring channel might be constructed as a tributary to a surface flow side channel and the spring channel may include connections to floodplain ponds or wall-based channels. The design of any side channel should consider using the attributes of all of these side channel concepts.

1.2 Side Channel Habitat

Side channel wetlands and ponds have been found to provide critical habitats for both juvenile salmonids (Peterson 1982; Cederholm and Scarlett 1982)[15, 42, 5] and a variety of wildlife species (Zarnowitz and Raedeke 1984)[6]. Species that frequent these areas and the attendant riparian community include amphibians, reptiles, birds, mammals, and mollusks (FEMAT 1993)[7].

The presence of side channels, especially a series of side channels in various stages of succession, increases the diversity of aquatic habitat available within a stream corridor. Also, during flood events, side channels frequently offer aquatic species refuge from adverse mainstem conditions. Juvenile coho are known to actively and preferentially migrate from mainstem rearing locations to side channel habitats in both fall and spring for protection from winter freshet activity and low summer flow stranding where they experience high survival rates. Though residence times vary, they migrate back to the mainstems generally in the spring. Side channel habitats have been constructed and studied by Swales and Levings (1989)[8] and

Cederholm and Peterson (1989)[9] to determine behavioral and physiological responses of coho salmon in these habitats.

Side channel wetlands and ponds have been found to provide critical habitats for juvenile salmonids (Peterson 1982; Cederholm and Scarlett 1982)[15, 42, 5] and a variety of wildlife species (Zarnowitz and Raedeke 1984). When these areas are more regularly and permanently available, as in larger stream basins, they can provide additional benefits such as high quality protected spawning habitat especially for coho and chum salmon that actively seek these areas. In many larger stream systems, side channels are important spawning areas, particularly for chum and coho salmon. They are also recognized for their value as summer and winter rearing habitat for coho salmon and cutthroat trout. Lister and Finnigan (1997)[10] provide a more thorough description of the use of natural and constructed side channels by various life stages of several species of salmonids.

Such projects also have significant benefits for a suite of wildlife species that either use or indirectly benefit from such habitats (e.g., amphibians as refuge and reproductive habitat, birds as foraging habitat). Bird and mammal scavenger species feed on spawned out salmon carcasses that tend not to be washed away as they might be in the mainstem. Use of side channels by fish and wildlife depends on connectivity (access) between the mainstem and side channel and the presence of suitable habitat characteristics.

Although side channel habitats may only be available intermittently or seasonally, they can still provide critical refuge for juvenile coho and other salmonids. Intermittent values can be reduced by losses to fish stranding depending on outlet escape conditions or the extent to which isolated pools area still can support fish life. For fish to survive in isolated pools there must be adequate shading cover and ground water exchange to keep temperatures low and sufficiently oxygenated.

The quantity, quality, and longevity of side channel habitat depend on the frequency, magnitude, timing, duration, and source of its flow. A channel that is fed primarily by groundwater provides a more stable environment for incubation and rearing than does a channel that relies solely on surface flow. Spawners of many species of salmon and trout select redd locations associated with groundwater (hyporheic) flow (Geist and Dauble, 1998)[11]. Additionally, groundwater specifically attracts spawners of some salmonids that prefer these conditions. As mentioned previously, the more stable conditions in these sites, reduced turbidity, warmer winter and cooler summer temperatures, limited scour and sediment deposition, and generally high invertebrate production for feeding juveniles make them very attractive to species adapted to this type of habitat. The most productive side channel sites are likely those with year-round fish access to allow rearing fish to benefit from optimal conditions whether in the main channel or side channel and to minimize likelihood of stranding if the outlet dries up.

Side channel habitats are commonly used by various salmonid species.

Blackwell et al (1999) summarize the use of side channels as follows:

> "Anadromous coho (Oncorhynchus kisutch; Sandercock 1991)[12], chum (O. keta; Bonnel 1991), sockeye salmon (O. nerka; Burgner 1991)[13], and resident salmonids (Brown and Mackay 1995)[14] often select off channel habitat to spawn. Resident species and

anadromous species with extended freshwater residency periods, rear in hydrologically stable off channel areas (Peterson 1982a; Nickelson et al. 1992; Richards et al. 1992)[15, 16, 17].

Lister and Finnigan (1997) continue the description of off-channel use as follows: Among the salmon species, chum and coho are most commonly associated with off-channel habitats. These species are apparently attracted to sites fed largely by groundwater. Late-run chum stocks, throughout their range, have been noted to spawn in groundwater-fed channels or seepage areas (Salo 1991)[18]. Coho spawn in groundwater channels to some extent (Sheng et al. 1990)[19], but most coho spawning occurs in relatively small surface-fed streams (Sandercock 1991). Coho juveniles, on the other hand, make widespread use of off-channel habitats, often gaining access to small stream and pond environments that are either inaccessible to adult coho or unsuitable for spawning (Peterson 1982a).

Chinook salmon do not spawn in off-channel habitat, but interior stocks make some use of off-channel ponds and side channels, often associated with tributaries, for juvenile rearing and overwintering (Anon. 1987; Swales and Levings 1989).

Of the trout species, coastal cutthroat (O. clarki clarki) are most likely to be found in off-channel environments. Adult and juvenile coastal cutthroat can be expected to cohabit many off-channel sites with juvenile coho (Cederholm and Scarlett 1982; Hartman and Brown 1987)[20].

Steelhead trout do not commonly spawn in side channels, and juvenile steelhead apparently use such habitats to a much smaller extent than coastal cutthroat. Steelhead are not abundant in off-channel ponds (Cederholm and Scarlett 1982; Swales and Levings 1989). In coastal stream steelhead underyearlings and parr prefer small surface-fed tributaries to groundwater environments for rearing and overwintering (Cederholm and Scarlett 1982). Some coastal groundwater channels do, however, overwinter significant number of parr and pre-smolt steelhead[21] and a groundwater channel at Deadman River, in the British Columbia interior, attracted significant numbers of underyearling steelhead for rearing and overwintering (Sheng et al. 1990). Adequate velocity and habitat diversity were likely requisites for juvenile steelhead use of these sites.

The stream-dwelling species of char, Dolly Varden, and bull trout, have not been commonly observed in off-channel habitats.

Though Lister and Finnigan (1997) report that sockeye use of side channels for spawning is not common in B.C., there is extensive use of overflow side channels and floodplain ponds by sockeye spawning in the Cedar River, Washington[22]. Sockeye spawn in the outlet channel of Newhalem Ponds side channel restoration project on the Skagit River.[23]

Use by chum salmon tends to be high. Large numbers of a mass spawner such as chum, can annually clean the gravel by suspending and flushing out accumulated debris and fines maintaining percolation inflow and flow through the gravel. Chum salmon tend to seek side channel habitats within the active floodplain.

The diversity of use is beneficial; for example chum carcasses can produce a high level of biomass and nutrients that are retained on the site because they aren't washed away during floods. Salmon carcasses are an important source of nutrients to the food chain supporting stream-rearing species such as coho, cutthroat and steelhead (Bilby et al. 1996)[24] and distributed through the hyporheic zone to benefit other ecological functions in the floodplain. Samuelson (1990)[25] showed coho and Chinook grew faster in Wynoochee River abandoned floodplain gravel pit ponds than in the river and fish grew faster in ponds that had been fertilized with salmon carcasses. Average lengths of coho and Chinook in the river were 30.38 and 41.25 mm respectively. In the unfertilized pond they were 46.38 and 56.61 mm. In the fertilized pond they were 49.60 and 66.52 mm. Body weights of Chinook improved with fertilization, coho did not. Egg-to-fry survival in groundwater channels has been three to five times greater than that of mainstem spawners.

Side channel projects have significant secondary benefits for a suite of wildlife species that either use or indirectly benefit from such habitats (e.g., amphibians as refuge and reproductive habitat, birds as foraging habitat). Side channels may function as spawning, rearing, and overwintering habitat for fish as well as providing a refuge from floods. In many larger river systems, side channels are important spawning areas, particularly for chum and coho salmon. They are also recognized for their value as summer and winter rearing habitat for coho salmon and cutthroat trout.

Restrictions and constraints imposed on the system, such as levees, dikes, bank protection, and channelization, often isolate existing side channels from the main stem and prevent or limit natural channel meander shifts that create new side channels. As a result, this valuable habitat has often been lost or has become inaccessible to the fish and wildlife that use it. These are lost opportunities and likely limit production of salmon on many large rivers systems in the Northwest. The best restoration is usually to remove such constraints. The value of some of the techniques within this section is the creation of habitat to replace lost opportunities where the constraints cannot be removed.

During the last few decades, habitat enhancement programs in British Columbia and Washington State have developed off-channel spawning and rearing habitat, primarily to benefit salmon.[26] Projects have included restoration and modifications to river floodplain swales, abandoned side channels, floodplain channels along steep terrace bluffs, and access to floodplain ponds, all in order to increase salmonid spawning and rearing habitat. Many of these projects rely on providing a mechanism for the introduction of additional ground and/or surface water to provide the desired fisheries benefit. Between 1986 and 2001, 92 off-channel sites in four watersheds in Washington State have been restored or enhanced. The projects are summarized by watershed in **Table 1** and specific projects are listed in **Table 2**.

Watershed	No of Project Sites	Area of habitat (sq. m.)	Estimated mean annual smolt production	Potential project contribution to total basin smolt

				production
Skagit	22	507,000	182,000	18%
Stillaguamish	25	382,000	68,000	24%
Hoh	19	74,000	16,000	20%
Quillayute	27	118,000	118,000	10%

Table 1. Project smolt production by watershed.

Estimates of the coho utilization and productivity of these sites are based on smolt outmigration trapping results at selected sites. The mean smolt production densities quantified at monitored sites are applied to the area of total restored habitat in each watershed, to estimate the potential coho smolt production of all restored sites. (Note: the Stillaguamish estimate does not include the production potential of four large, relatively open water sites, since this habitat is not likely being used at densities assumed at other, smaller-scale sites).

The project contribution is the ratio of the estimated mean annual smolt production to the total basin smolt production, which is estimated each year on the major coho producing rivers in Washington (D. Seiler, WDFW, Fish Management Program, unpublished data). An additional value is the contribution these sites make to the presmolt population. These are juveniles that either emigrate prior to smolting that do final rearing in downstream areas or juveniles that are recruited into the project from upstream spawning, rear temporarily and then leave before smoltification. In both cases, these fish benefit from the habitat, likely have higher survival and develop better condition, but have not been accounted for in the data because trapping only occurred during normal migration periods.

Side channel restoration may be detrimental to some species. Predation of juveniles may increase in sites with established populations of predators. It may allow non-native invasive species opportunity to disperse. Oregon chub, which is endemic to the Willamette Valley, prefers off-channel habitat but is threatened by predation by non-native spine rays. (Scherer et al, 1999)[27] Access of fish to side channels may also affect native amphibians[28].

2 Physical and Biological Effects

The physical effects of reconnecting or creating side channels likely include a short-term increase in turbidity at and downstream of the site, both during excavation of the connection with the main channel and following introduction of water to the side channel. Increased flow to side a channel may present an increased risk of aggradation of the mainstem. When flow is split, it reduces the competence of the flow remaining in the main channel to carry its sediment load. This may cause the sediment to deposit in the main channel. This effect can only occur if a substantial portion of the mainstem flow is diverted through the project, which is not the objective of the project and has not been experienced in Washington project history.

Excavation of a new side channel will likely result in removal of riparian vegetation in the vicinity of the new channel and displacement of flora and fauna adapted to the current setting. It may also result in lowering the local groundwater level, decreasing the amount of water available to nearby wetlands, ponds, wells, and vegetation. Project sites have a significant quick colonization by emergent wetland vegetation along the channel margins that is not only good habitat for juvenile fish but wetland associated wildlife as well. Usually, this wetland area did not exist in the pre-project site.

A side channel project might cause a redistribution of fish away from existing areas thus creating a situation in which there is more competition for limited resources. It might also cause fish to be more vulnerable to predation until riparian vegetation matures at a site.

3 Application of Technique

Roni et al (2002)[3] suggest that restoration of side channels may be more effective than other techniques for coho. Though it is not always restoration of natural process such as channel migration, this technique can be considered restoration in reaches that are confined by armoring or other measures to protect infrastructure and property. There are opportunities for creation of habitat where none exists now in upland and floodplain areas. Side channel habitats might be used as habitat restoration or as mitigation for other projects that confine a channel (e.g.; bank protection, bridges). Enhancement and restoration of existing side channel habitat and construction of off-channel spawning and rearing habitat may provide mitigation for the future loss of this habitat type, or lost opportunity.

Culverts and other road crossings of side channels often block access for juvenile fish and therefore may present restoration opportunities.

Channels downstream of dams and urbanized areas can become lowered by the change in sediment and/or hydrology regime. The channel degrading can potentially leave associated side channel habitats perched above the active channel elevation. Restoration of the grade of the main channel or lowering the side channel might be restore side channel function.

Side channels should be created where they will be self-sustained through natural processes. Created channels should mimic those locations to maximize longevity. Part of self-sustainability is the probability that a created channel will be naturally overtaken by erosion or avulsion from the mainstem. If that process leaves habitat in its wake, the habitat is self-sustaining.

Side channel habitat exists in nature on virtually all sizes of alluvial streams and can be up to thousands of feet in length. The scale of side channel reconnection or creation projects implemented however depends on the objectives of the project and available resources.

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4 Risk and Uncertainty

4.1 Risk to Habitat

Risks of disturbance to existing habitat associated with this technique are generally low, primarily because the majority of work is done outside the active channel and is not directly affected by the hydraulics of the mainstem. There is short term risk to adjacent and downstream habitat from increased turbidity during excavation of the connection to the main channel and following reintroduction of flow to the side channel (this risk is higher with creation of new channels than with reconnection of existing channels). Also, wildlife associated with vegetation and soil that is removed during construction will be displaced. If an excavated side channel lowers the local groundwater level, there is a potential that the water level in nearby wetlands and ponds will be lowered and the extent and that the type of riparian vegetation will change. There may be some risk of avulsion into the side channel during a large flood event.

If the hydraulics of the channel are not assessed and designed appropriately, fish can become stranded in isolated pools within the channel. Water quality within the pools may become unsuitable for aquatic life or the pools may dry up, killing any animals stranded there. Risk of this occurrence is highest where flow through the side channel is intermittent, highly variable, or inaccurately estimated and where side channel elevations were not properly designed or constructed. Design elements that manage these risks are discussed in section 5.2 *Design Considerations.*

There is a risk of the bed and banks of an overflow side channel shifting during the first few years following construction until the channel form has stabilized to accommodate high flows. Higher flows may cause bed and bank scour that destroys incubating eggs of fish or amphibians, or their fry or larvae. Habitat features installed in the channel (e.g., wood and spawning beds), as well as fish and wildlife, may be redistributed or forced out of the side channel by high velocities though new habitat may be created at the same time. Over time, leafy material from trees and fine and coarse sediment may accumulate in the side channel, possibly limiting productivity or fish passage and/or causing the channel to flood less frequently and gradually succeed to a depression on the floodplain.

4.2 Risk of Channel Change

There is some risk that creation or changes to a side channel could cause an avulsion. An avulsion is a significant and abrupt change of channel location into a new alignment resulting in a new channel across the floodplain. (see **Figure 2-17** from Integrated Streambank Protection Guidelines [29] An avulsion is caused by concentration of overland flow that scours or headcuts a new or enlarged channel. If the flow capacity of a side channel were greatly increased, it might cause enough water to flow through it that the upstream connection to the mainstem could scour during a flood, increase the flow to the side channel, and eventually divert the entire mainstem into the side channel alignment. Risks of avulsion include potential loss to property and infrastructure and habitat. On the other hand, side channel habitat is created by the natural process of avulsion and channel change.

There may also be an increased chance of avulsion into the side channel if large flow events that reach the side channel cause a headcut through to the main stem. The chance of avulsion increases if aggradation occurs in the mainstem. The presence of a side channel subject to overflow from the mainstem may reduce the flow and scour in the main channel. Managing risk of avulsion starts with understanding the factors that might cause it to occur. A channel site that is associated with a mainstem channel that is aggrading, a channel with levees that elevate flood flows to an elevation above the adjacent floodplain, or a channel susceptible to channel-spanning log jams is vulnerable to an avulsion. The fact that a channel exists parallel to the mainstem is a sign of avulsion potential. Separation of the constructed channel from the river channel by distance, elevation, or a maturely vegetated floodplain will reduce risk of avulsion. Control of high flow into the side channel will also limit the risk of an avulsion. Flow can be controlled by constrictions that limit the flow or spillways that protect against headcuts. See the section 5.2 *Design Considerations* for more details of these techniques. Risk of avulsions can also be managed with techniques such as floodplain roughness, floodplain drop structures, flow spreaders, and buffer management practices. See the Integrated Streambank Protection Guidelines for details of these techniques. If there is even a moderate risk of avulsion, a hydraulic analysis of avulsion should be conducted.

There may be some level of risk that of the mainstem shifting away from a side channel project leaving it disconnected from the mainstem or of shifting towards the project and overtaking it. Design elements that manage these risks are discussed in section 5.2 *Design Considerations*. Some projects might be considered transient with a high probability and expectation of being affected or overtaken by migration of the mainstem channel. Management of risk should also include the level and cost of construction. For example, side channel restoration work at Gorley Springs on the Grays River in Washington was done in the 1980's with the expectation that aggradation of the main channel would cause an avulsion within a decade or so that would jeopardize the project. The channel was built to not exacerbate that risk and at a cost that could still be realize a benefit in a short project life.

4.3 RISK TO INFRASTRUCTURE, PROPERTY, OR PUBLIC SAFETY

Reconnecting and creating side channels poses little threat to infrastructure, property or public safety unless the channel increases the likelihood of an avulsion. Channels with deep pools and high, steep banks can potentially trap people or wildlife. Generally channel and pond banks that are configured with slopes to optimize habitat benefits, such as shallow benches and gentle bank slopes for riparian structure and diversity, are least risky to people and wildlife.

4.4 Uncertainty of Technique

The certainty of habitat gain varies among the objectives and types of projects. Roni et al (2002) evaluated the variability and probability of success of common stream restoration techniques based on existing literature. Success was defined and evaluated as high, moderate, or low. They found that projects involving reconnection of existing off-channel habitats had a high probability of success; the variability of success among projects was low. Projects that involved creating off-channel habitat had a moderate probability of success; variability of success among projects was high. The high variability appears to be at least partially due to the wide variety of off-channel projects constructed and reported.

Monitoring of smolt production from side channels in British Columbia detected no difference in production from restored side channel habitats compared to natural side channels (Blackwell et al 1999). Because of this Blackwell et al suggest that the major benefits of coho production at off channel restoration projects comes as a result of an increase in the quantity of available habitat rather than from an increase in quality of habitat. Preliminary results of studies to evaluate constructed side channels in Northern Puget Sound region of Washington suggest that production of coho from constructed channels is greater than natural channels though they have less relative abundance of other species (evenness of species)[30].

The amount, type and longevity of habitat provided by the side channel depends greatly on the magnitude and frequency of flow and sediment delivered to the channel. If flows are lower than predicted, less habitat may be provided than anticipated, habitat may become isolated from the main channel, habitat may be unsuitable (shallow depth, poor water quality) to species targeted by the project, or the habitat may not be accessible to fish and wildlife when needed. Habitat longevity also depends on the regular use by spawners to regularly clean gravel and flush out fines. Side channels subjected to overflow from the main channel may accumulate coarse and/or fine sediment that reduces the quality of spawning habitat. Appropriate site assessment, as described in the following sections, is necessary to minimize uncertainty of project outcome. Side channels that rely on groundwater as their primary source of water tend to be more stable and are longer lasting than overflow channels. However, changes in land use should be kept in mind as they may alter groundwater dynamics.

5 METHODS AND DESIGN

5.1 Data and Assessment Requirements

5.1.1 Site Selection and Inventory

A key to successful side channel creation or restoration is site selection. Side channels should be created where they will be self-sustained through natural processes or where they have been lost because natural processes have been curtailed. An inventory of potential projects is valuable in order to optimize site selection. Such inventories should be conducted as part of watershed restoration planning or flood hazard management planning that may also contemplate actions that will confine the mainstem channel. Potential sites should be identified from aerial photos and USGS quad maps and then confirmed by field inspection. See **Figure 2**; aerial photos of abandoned gravel pits and pond site near Satsop River for an example. Things to look for at the scale of maps are geologic conditions that will create hyporheic upwelling, multiple river channels, oxbows, relict channels and evidence of them in vegetation patterns, wide undeveloped floodplains, wall-base channels, abandoned gravel pits, and areas of shallow groundwater. Just as many sites are identified by ground investigation. In the field, look for gravel in riverbanks that imply porous floodplain, flood swales, water sources, relative elevation of the floodplain to the river, levees that isolate the floodplain, road fills that either isolate the floodplain as a levee or that prevent floodplain flow such as a bridge approach fill, and existing side channels.

Hydrology of the mainstem should be considered. Potential sites associated with a mainstem that has a relative constant normal water level and high spring flows may be easier to develop and have less risk than sites with great water level fluctuations and low spring water levels. Sites below storage reservoirs might have hydrology that works well for these projects.

Fish utilization in the reach should be considered . Fish use of a specific project may depend on its physical location relative to the spawning distribution of the target species. If the site, for example, is located far above most spawning, juvenile recruitment into the project may not be adequate and it may take some time for fish to find it and build a loyal population through imprinting of its progeny.

Some side channel projects involve construction on large pieces of ground. Ownership of the land is a consideration. Projects are much easier to coordinate at sites in public ownership or in a single private ownership than multiple ownerships or land that is developed.

Search parameters depend on objectives of the project. For example, chum spawning objective may capitalize on hyporheic flow conditions; a coho rearing project may focus on wall-based channels and side channels that have low risk of flooding from the mainstem. The following describes the minimum effort required for a rough inventory-level assessment of side and off-channel habitat opportunities.

- Natural floodplain constrictions may be topographic and geologic evidence of hyporheic upwelling and downwelling and may also be depositional zones with multiple natural channels. See **Figure 3**.
- Meander scars, multiple channels, and oxbows may indicate natural side channel opportunities.
- Alluvial fans often force hyporheic upwelling as well as multiple side channels that may be opportunities for restoration.
- Channel junctions where a tributary carries bedload that a mainstem cannot transport might have associated side channels.
- Degraded channels may have associated side channels that are perched.
- Wall-based channels, ponds, and abandoned gravel pits may offer restoration opportunities.
- Look for railroads or highways that have truncated or confined channel meanders. There are often side channel opportunities on the landward side of these facilities that might be restored by reestablishing flow from the mainstem and/or restoring fish passage by replacing culverts or providing other fish passage improvements.
- Be aware of likely land use changes adjacent to sites that might affect water quality.
- Be aware of access needs for heavy construction equipment. The cost of access is an important consideration for project feasibility.
- If the prime objective is spawning habitat the inventory should cover the current range of spawning activity unless the intent is to increase the range of a species by supplementation.

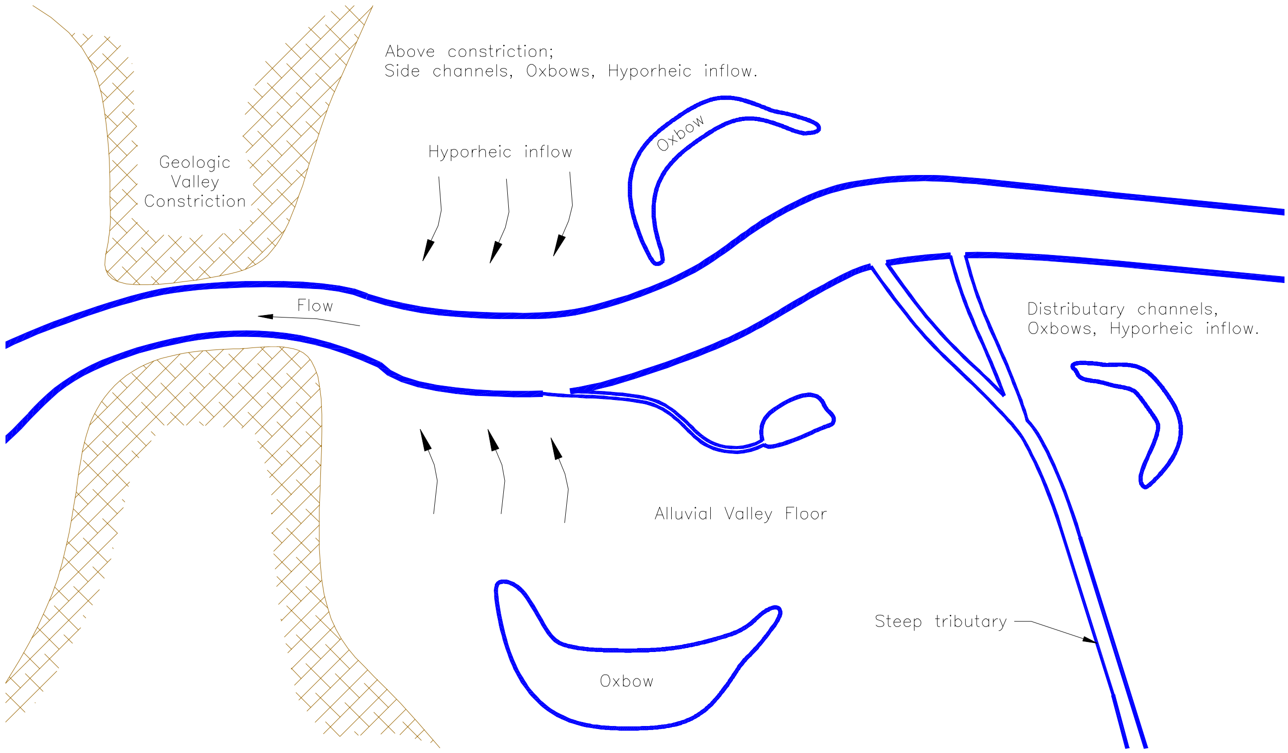


Figure 3. Natural floodplain constrictions may be topographic and geologic evidence of hyporheic upwelling and downwelling.

5.1.2 Project Data

Data collection and assessment for specific projects vary and depend on the intent and the scale 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 the full range of potential impacts and effects. The following data might be needed for specific projects. Monitoring of individual sites to evaluate site conditions and project effects should be done for several years before a project is built. More thorough explanation and application of some of these data are described in section 5.2 *Design Considerations*.

5.1.2.1 Data needs for all side channel projects

- Current fish use of the site.
- Topography and cross-sections of project area including river and floodplain.
- High and low flow hydraulic profile of the mainstem through the project reach and adjacent reaches. Recent high-water marks of the mainstem.
- Characteristics of the mainstem as evidence of aggrading or degrading
- Static water levels wherever available in the project site.
- Profile and representative cross-sections of likely and/or existing channel alignments.
- Sources and paths of overbank flow or additional surface flow during heavy runoff events.
- Characterization of floodplain roughness, woody vegetation, and large wood that will spread and moderate overbank flows.

- Vertical and lateral stability of mainstem; observe characteristics that may indicate rapid lateral movement or channel degrading or aggrading. Also look for evidence of a channel that has already degraded and left potential side channels perched.
- Calibrated water level rating curves of mainstem near upstream and downstream ends of project channel from low to high flow.
- Site constraints and project limits (e.g., existing infrastructure, preservation of floodplain conditions, property limits)
- Baseline monitoring data, which may include photo documentation of site from permanent benchmarks that will not be disturbed by the project
- Elevation reference points should be set at least at three locations near the channel alignment, and tied together in a survey that includes elevation reference points for other fieldwork on the project site.
- Flow measurements in flowing channels. A flow measuring weir can be installed but be aware that a slight change in water surface elevation caused by the weir can significantly change the volume of measured flow.
- Any evidence of standing water and/or wetlands in the project area.

5.1.2.2 Data needs for design of perc channels

- Groundwater
    - Profile of static water levels
    - Estimate of perc flow potential based on pump tests or calculated transmissivity
    - Assessment of quality of perc water
    - Topographic, geologic, and direct observations of evidence of hyporheic upwelling and downwelling in and near the project reach.
    - Perc water supply quantity.
    - Quality of perc water
- Soils
    - Potential loss of flow around drop structures.
    - Quality of bed material for use as project spawning material.
- Surface water
    - Quality and quantity of flow, sediment and pollutant risks.
    - Reliability of flow.
    - Assessment of flooding potential from the river mainstem

5.1.2.3 Data needs for restoration of wall-based channels

- Flow and reliability
    - Pond elevation relative to the access channel to determine the type and magnitude of channel modifications necessary to ensure fish passage.
    - Pond layout and bathymetry,
    - Profile and characteristics of outlet channel
    - Current fish utilization including likely predators
- Quality and quantity of surface water sources to the side channel and risks to water quality.
- Current aquatic and riparian habitat features and restoration opportunities.

5.1.2.4 Data needs for enhancement of floodplain ponds

- Topography and bathymetry of ponds
- Flows – springs and low flow stranding
- Water quality especially during low flow periods
- Flooding potential
- Current fish utilization including likely predators such as centrachids.
- Current aquatic and riparian habitat features and restoration opportunities.

5.1.2.5 Data needs for reconnection of side channels to mainstem

- Assessment of existing habitat for fish and other wildlife within the side channel including spawning gravel.
- Sediment
- Instream and riparian sources (mainstem and side channel) of large wood that will affect side channel point of diversion from mainstem.
- Stability of side channel considering increased flow and risk of high flows.
- Risk to infrastructure or other properties due to increased flow through side channel or on floodplain.
- Current aquatic and riparian habitat features and restoration opportunities.

5.2 Design Considerations

Design considerations are generally broken into four types of projects; 1) construction and restoration of groundwater channels, 2) reconnection of overflow channels to the mainstem, and restoration of 3) wall-based channels and 4) floodplain ponds. These general categories of side channels are used in this guideline for convenience. Most projects will actually include more than one if not all four of these concepts. The designer should refer to all channel types for attributes that might be included in a design regardless of the specific character of the intended project.

The primary objective of most side channel reconnection or creation projects that have been built to date is to provide habitat for salmonid spawning and/or rearing. The proportion of the site used to meet a particular life history requirement can vary and may depend on flow in the channel, channel gradient, amount of backwater and design of the channel. Some sites are allocated and designed solely to function as spawning sites, whereas other sites may incorporate juvenile rearing and adult holding habitat into the design. Though most side channel reconnection and creation projects have targeted salmonid habitat enhancement, they provide benefits to many other fish and wildlife species as well. The number of species and age classes benefited theoretically increase with the diversity of habitats built into the design. Rearing habitat projects can rely entirely on recruiting juvenile fish from the mainstem. To optimize benefit of rearing habitat, try to include some spawning habitat even in rearing habitat projects, especially at projects high in the range of spawning that may not recruit a large number of fry from upstream. It is recommended that perc channels be designed with diversity so they benefit a variety of organisms. Diversity might include water depths and velocities, bed complexity, habitat features, and substrate. As a criterion for diversity, constructed channels could be designed to mimic comparable naturally occurring side channels in the region.

5.2.1 Hydraulics

General considerations of water supply and reliability, risk of channel change, and channel and hydraulic grade apply to all projects. The supply of water to off-channel habitats may include surface water supply from the main channel, overbank flooding, groundwater upwelling, and/or isolated springs. Most sites are really a combination or several of these sources. A channel may have an overflow source from the river during high flow seasons, a perc source during low flow seasons, and be supplemented with flow from a wall-base source. The sources of water control the amount and type of sediments, nutrients, and organic matter supplied to the habitat, water temperature, flow and flow stability, and the diversity and longevity of physical features within the habitat. Upslope influences are much more likely to create water quality limitations. Be aware of potential source runoff from roads or agricultural practices that may affect the project.

The quantity, quality, and longevity of side channel habitat depend on the frequency, magnitude, timing, duration, and source of its flow. A channel that is fed primarily by groundwater provides a more stable environment for incubation and rearing than does a channel that relies solely on surface flow. Flow conditions and water temperatures are more consistent and predictable in channels fed by groundwater. Groundwater-fed channels run warmer and clearer in the high flow season than the main channel, providing better prey production and feeding opportunities, and a less harsh over-wintering habitat than the mainstem. Groundwater-fed side channels are also less subject to sediment deposition than those that are subject to overflow from the main stem, maximizing their longevity.

A potential site associated with a mainstem with a great range of normal water levels will be more difficult to develop than one associated with less variation. Excavation will have to be deeper and/or the site may be backwatered more frequently. A site associated with a mainstem with high spring flows during fry and smolt outmigration will have less risk of stranding fish in the spring due to low water.

Backwatering may affect the extent of spawning habitat in the channel. Backwater is the pooling of floodwater from the mainstem back up the side channel. It occurs when the mainstem water surface at the confluence of the side channel is higher than the normal water surface in the side channel. Backwatered portions of the channel will tend to become a pond instead of a channel during high flows. There may be increased deposition of fine sediment in the ponded area. The ponding and sediment together reduce the value of spawning habitat in the backwatered area. Adequate channel flow following the backwater condition may flush fines from the channel. Backwater effects should be estimated as part of the design. Effects are estimated by knowing the stage-discharge relationship of the river at the confluence with the side channel relative to the profile of the project where the channel enters the mainstem river relative to the project elevations.

The amount of flow can be a controlling factor for adult usage, juvenile recruitment, and objective of a project. Furthermore, the amount of inter-gravel flow is also closely related to egg-to-fry survival[31].

5.2.2 Channel Entrance and Fish Passage

Channel entrance conditions are important for attraction and access of fish into the side channel.

The desired situation is one that maximizes the opportunity of recruiting adult and/juvenile fish and is self-sustaining. Fish that strategically use side channels may have an innate ability to sense groundwater sources. Peterson (1985) stated that the point where the egress channel joins the stream is the most critical aspect of project design. Nickelson et al. (1992) stressed that extreme care must be taken to insure that the channel remains open at all flow levels and recommended locating alcoves at springs and tributary junctions.

If flow from a channel exits into a low-velocity area or eddy with habitat cover, the water is not rapidly diluted and fish have a better opportunity to find it than if it is rapidly dispersed and diluted in rapid turbulent flow. Channel outlets have been designed as a wide alcove in the bank of the mainstem. Large rocks and/or wood have been situated to maintain the alcove and provide physical and hydraulic cover for the fish. Beaver activity will also often benefit channel entrance conditions.

The location and alignment of natural side channel entrances depend on channel type. Entrances into side channels associated with braided channels are random and unpredictable. Natural side channel entrances associated with avulsions or laterally migrating channels are usually located near the outside of the downstream channel bend. See **Figure 1**. They may also follow the toe of a terrace. Channel entrances in these locations are helpful because they are less vulnerable to deposition that may block the entrance more than other locations.

Beavers that use side channels like to maintain a deep access to the mainstem. It may be just a few feet wide but backwatered by the mainstem even at low flows. Without the beaver pilot channel, sediment deposited in the alcove or eddy may result in wide, shallow sill at the channel junction.

Whether a project is intended for adult spawning or juvenile rearing, fish access into the site is obviously required. There are several situations that may block fish access. If a perc channel isn't low enough in any area, water may go subsurface leaving no surface flow for access. See the section on channel profile for perc channels.

Large wood and/or beaver dams can block fish passage at times. Before modifying a beaver dam to improve fish passage, evaluate whether it is in reality a barrier. Juvenile and adult salmonids often pass through beaver dams with drops of three feet or more that otherwise appear to be barriers; they are often passable at higher flows. There are often multiple paths within beaver dams for fish to move through. Fishways for juvenile and adult salmonids have been built into beaver dams to improve passage. They are described in Fishway Guidelines for Washington State and Powers[32]. These documents are available at http://www.wdfw.wa.gov/hab/ahg.

Road culverts or small dams can block passage. If a channel is perched above the low water level of the mainstem, there may be a drop that blocks access. These situations may necessitate the removal of the obstruction or modifying the channel to step it up over the barrier. Design of fishways and culverts for fish passage are described in other guidelines see http://www.wdfw.wa.gov/hab/ahg/

The depth of water may have to be controlled to provide fish passage, create habitat, and/or reduce the risk of breaking a seal in the bottom of a channel and losing flow. Drop structures are often required to create adequate depth; otherwise a project could become a long continuous riffle. Drop structures might be built to raise the hydraulic profile rather than excavating the channel into the groundwater. Drop structures must be very low, about a half of a foot, and they must be sealed deep into the bank and bed so flow is not lost around them through the permeable native soil. Drop structures are commonly made of logs so they can be well-sealed and so the water surface elevation can be precisely controlled; details for log controls and other drop structures are provided in the WDFW guideline Design of Road Culverts for Fish Passage . Drop structures should be notched or vee-shaped for fish passage at low flow. With a low flow or wide channel there will only be a thin film of water over a control structure. A hydraulic profile of the designed channel including high and low channel flow and backwater is prudent for design. Another benefit of control structures, assuming hydraulic conditions are appropriate for them, could be the reduced volume of excavation saving time, money, and space for disposal of spoils.

5.2.3 Managing Risk of Channel Change

Increasing the capacity of a side channel or removal of floodplain vegetation may increase the risk of an avulsion. A site that is associated with a mainstem channel that is aggrading is vulnerable to an avulsion. If there is even a moderate likelihood of increasing risk of avulsion, measures should be considered to manage the risk. Measures should include the consideration of the restoration project as a short-term project.

Separation of the constructed channel from the river channel by lateral distance, non-erodible soils, control of flow to side channel, control of flow entering the side channel, and/or mature floodplain vegetation, all reduce risk of avulsion. Constrictions made of boulders and/or wood within a constructed side channel can control how much flow it can pass and therefore the risk of avulsion. Constructed spillways in areas where floodwaters will first enter the channel can help lessen the risk of headcuts forming at those places. See the Integrated Streambank Protection Guidelines techniques on floodplain roughness, floodplain drop structures, flow spreaders, and buffer management for ideas that can supplement side channel construction to manage the risk of avulsion.

There may be some level of risk that shifts in the mainstem may capture the side channel or migrate away from it and leave it disconnected from the mainstem. Capture or disconnection may occur gradually and naturally due to lateral channel migration or capture may occur due to an avulsion exacerbated by the presence of the side channel.

5.2.4 Perc channels

Groundwater and spring-fed channels have year-round flow from springs or groundwater and may exist naturally, or may be created. Perc channels are constructed by excavating a channel in the floodplain to a depth that intercepts groundwater. Because of limitations of scale, land ownership, and flooding potential there are a limited number of opportunities for construction of perc channels. Those opportunities should be optimized with the best design. The success of perc channels especially depends on pre-design data, design considerations, and construction sequencing. It is recommended that anybody undertaking such a project consult with individuals with experience in such work and visit previous-constructed sites. A list of WDFW side channel projects is included with this technique.

Perc channel design is the most intensive because it usually entails the creation of a new channel so everything from location and alignment to design details of habitat structures is important. Many of the details in this section will apply to portions of other types of off-channel projects.

Excavation of an entirely new channel can be a large intrusion onto the floodplain landscape. Every feasible effort should be given to minimizing the effect by designing the alignment of the project, access and storage routes, disposition of spoils, processing of excavated materials and large wood, compaction of floodplain soils, and general restoration of the site. Clearing should be minimized by potentially working from one bank of the channel, alternating banks, or from the channel itself.

5.2.4.1 Water supply, quality, and reliability

Perc channels derive a major portion of their flow from groundwater, the source of which is usually the adjacent stream/river. Many abandoned natural channels exhibit year-round flow from groundwater or springs. The quantity and quality of side channel habitat depends on the volume and timing of groundwater and/or surface water flow delivered to these areas. A hydraulic gradient is created when a channel or pond is excavated into the water table with the channel outlet and water level control elevation below the static water level. This hydraulic gradient and permeability of floodplain soils control the amount of surface water flow and important parameters in the success of a project. Water source may also change between seasons. As water levels change from high water levels in the winter and spring to lower levels in the summer and fall, the dominant source of flow may change from hyporheic to groundwater.

Success of a perc side channel is much more likely if it is associated with hyporheic flow. The hyporheic zone is the area beneath and next to a river channel that contains some proportion of water from the surface channel. Hyporheic zones strongly influence sub-surface and surface water flow, temperature, dissolved oxygen, chemical composition and nutrients. All of these variables can affect spawning success. Channels with predominantly river-source water supplies are generally reliable when designed with the appropriate elevation and profile. They have water that is generally saturated with oxygen, nearly saturated with total gases, and experience mild seasonal temperature fluctuations making them excellent sites for restoration.

There are geologic, geomorphic, hydraulic, and biological indicators that can indicate presence, general rate, and direction of hyporheic flow. Edwards (1998)[33] describes several scales of hyporheic indicators; large-scale geological features, watershed and valley-segment scales, and channel unit scale.

Stanford and Ward (1988)[34] describe changes in channel constraint by bedrock or other soils that create basin or valley-scale distribution of hyporheic zones. Water is forced to flow to the surface at the transition between an unconstrained reach upstream and a constrained reach downstream. Types of bed material influence the channel reach scale. Alluvial reaches are more porous than colluvial or bedrock channels. Floodplains are usually a combination of seemingly random patterns of alluvium and colluvium often bounded by bedrock or consolidated sediments. The randomness is created as the floodplain evolves by the transport and sorting of alluvium in the active channel and gradual filling of relic channels with fine sediment and colluvium. The patterns of buried relic channels and colluvium deposits create locally variable hyporheic flow conditions. Reach-scale gradient and topography can greatly influence hyporheic flow.

5.2.4.1.1 Assessment of Flow Potential

Topographic, geologic, and direct observations of evidence of hyporheic upwelling and downwelling in and near the project reach.

The amount of water that will flow as surface water in a perc channel is proportional to the depth the design water surface is below the static water level, the porosity of the substrate and surrounding soils, and the area of contributing flow. A profile of static water levels through the length of project and across the floodplain at the project site and including the mainstem will show the direction and gradient of groundwater flow. River and groundwater levels and/or flows should be monitored during a wide range of river flows and seasons. Monitoring during low flow and dry seasons is especially important since water supply may be most limited during those periods. This usually requires a period of at least a year to cover seasonal groundwater levels. These measurements are used to determine hydraulic profile and flow of the channel.

A correlation of soils, static water surface profiles, and pump test results provide a best estimate of groundwater flow potential. An evaluation of soil characteristics and percolation capabilities is necessary for the design of perc channels. Test pits should be dug and percolation tests performed to determine soil types, the potential of groundwater flow, and water temperature and quality. Soil conditions will vary through the project site so a number of test pits should be dug. Test pit spacing of about 500 feet or at about quarter-points of the portion of the channel that will contribute perc flow near the project alignment is recommended to best estimate perc channel flow. The subsurface conditions can be highly variable as a result of sediment sorting and old channels being filled as the floodplain developed. Apparent strata of clean gravel or fine sand may be just pockets. In either case, added certainty is gained with additional test pits.

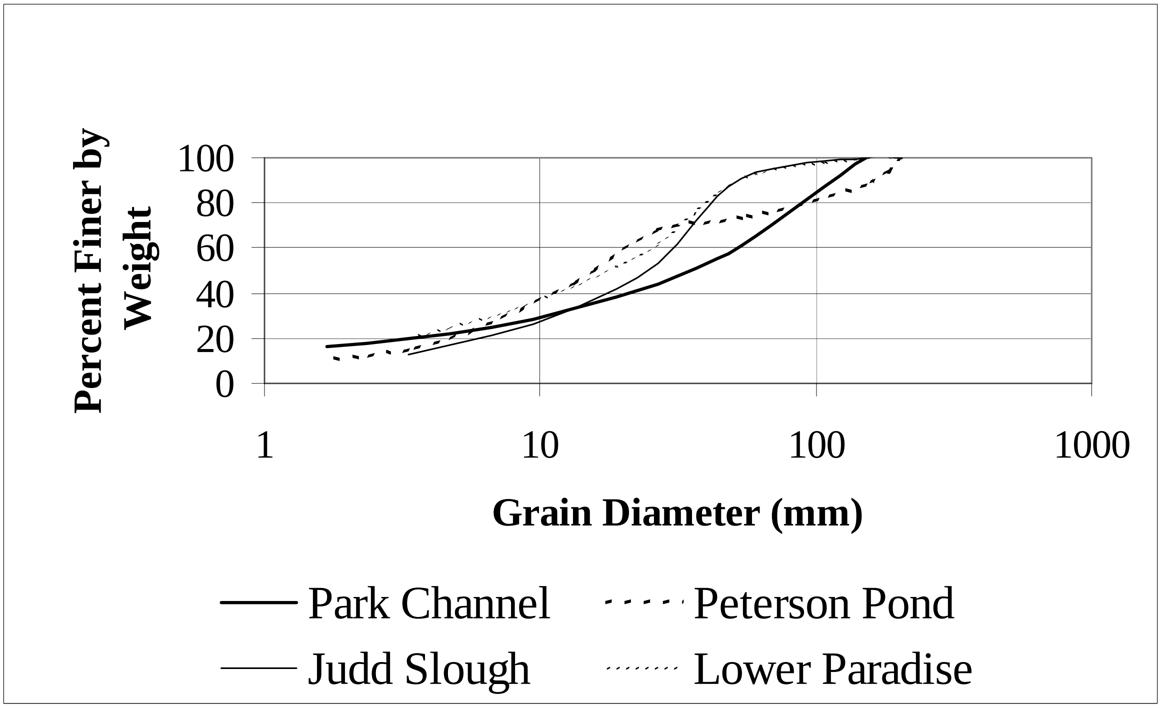


Figure 4. Four gravel samples associated with successful projects.

Descriptions of the soils should be recorded and elevations of soil strata in the test pits should be surveyed as the test pits are excavated. Soil samples should be collected to compare with those of other successful constructed side channels. **Figure 4** shows four typical gravel samples of in situ gravel associated with successful projects. The Park Channel and Peterson Pond are projects constructed by WDFW [23, 35], and the Judd Slough and Lower Paradise by Bonnell (1991).

Pump tests may be necessary to more accurately predict percolation rates. To accurately quantify groundwater-flow potential, an extensive aquifer test with several high-capacity wells and a long period, high-capacity pump test would be required. Such a test is not practical for this scale of project. As an alternative, the Washington Department of Fish and Wildlife has developed a simple pump-test method to calculate relative aquifer permeability and relative aquifer supply rates among sites[5]. This pump test procedure simplifies the description of the groundwater by making the assumption that the aquifer has no impermeable boundaries. Pump tests should be conducted during low flow season when river and groundwater levels are near their lowest levels. A description of the standard pump test is attached to this technique as *Appendix A.*

Water is pumped from a test pit excavated with a backhoe to about three feet deeper than the static water level. Two parameters are used to analyze the groundwater potential: drawdown index and apparent velocity. The drawdown index is the pump rate divided by the drawdown rate. The apparent velocity is the pump rate divided by the wetted area of the test pit. These parameters have been measured for 12 different projects, and comparative ratings have been developed with correlations to flow in the constructed channel.[36] Piezometers should be installed in the test pits as they are refilled to monitor static water levels during subsequent seasons. Piezometers can be PVC pipe buried in the backfill with a perforated section at the bottom and wrapped with filter fabric and capped.

There is some risk in excavating to expose or increase flow from groundwater. The groundwater can be perched on relatively impermeable strata of silt or clay that acts as a seal to contain the flow and keeps the level of groundwater relatively high. The seal has been broken at several sites during excavation of a channel or pond and flow has been lost through it to a deeper aquifer. Assessment of the risk may be difficult. Test pits might show water above consistent layers of silt or clay and loss of water may be directly observed. If monitoring of water levels in piezometers indicates the groundwater is very consistent regardless of changes of river flow and is at an elevation higher than expected relative to the mainstem or with an unusual direction of flow (other than downstream and/or towards the mainstem) the water might be perched.

5.2.4.1.2 Water Quality Assessment

Water quality should be evaluated. Water samples should be taken from test pits and evaluated for dissolved oxygen, total gases, and any other parameters that might affect fish health and egg incubation. Water chemistry tests should be performed if suspicious conditions are observed such as large amounts of iron precipitate, H_2S odor, evidence of petroleum products, or an unexplained absence of fish. Since salmonids do not always avoid low dissolved oxygen or high total gas environments, it is important to evaluate these parameters so a fish hazard is not created. Piper et al (1986)[37], Senn et al (1984)[38] provide water quality standards for salmonids aquaculture that have been used for assessment of perc channel quality. Lister and Finnigan (1997) recommend monitoring water quality monthly for at least one annual cycle. They recommend monitoring temperature, dissolved oxygen, and chemical constituents such as iron and hydrogen sulfide.

Water quality may vary with geologic conditions, over time and as a project is developed. WDFW experienced at least one situation in which the initial test pit had water with no dissolved oxygen but after a pilot channel flowed for five months had a dissolved oxygen level of 5.6 ppm[39]. Total gases have been observed to vary with seasons as water source naturally changes between hyporheic and groundwater sources but not enough to be a problem. Ultimately water quality hasn't been a driving issue in any of over forty perc channels constructed by WDFW in the last 20 years.

5.2.4.2 Channel and hydraulic grade

The design of a groundwater channel requires balancing the optimum water surface elevation for maximum groundwater flow against the potential that the channel will be backwatered too frequently from the river mainstem and the cost of excavation. For groundwater to flow as surface water, the design water surface of the channel has to be below the static water level. The amount and reliability of flow is directly related to the head differential of the hyporheic water level to the water level in the channel. The deeper the channel is into the groundwater, the more flow will be produced but the more frequently and extensively the channel will be backwatered from the mainstem. Head differential is much more important than surface area of the channel bed or deep pools within the channel. Pools might be effective in increasing flow if they connect the channel to more porous substrate. On the other hand, if a segment of a channel is too high, surface water will not flow or be present, especially during low flow and dry seasons. Deepening a pool within the channel will not increase flow through the channel though it may create flow through the pool itself. If the water infrequently becomes too low or the temperature high, deep pools distributed through the channel may provide refuge and year-round rearing.

Lister and Finnigan (1997) recommend that the designer avoid the temptation of maximizing the channel length to gain the largest possible habitat gain. Such a strategy may result in less than optimal slope and an increased risk of sediment deposition within the channel. They recommend that adequate slope or even slightly excessive slope be provided. Excess slope can often be mitigated by the addition of drop structures or constructed riffle section. Ultimately slope depends on flow potential, groundwater level, and excavation quantities.

The channel should be designed to not lose surface flow during low flow seasons. This is especially critical for perc channels because they are designed at or near the static water elevation. If there is a risk of breaking a seal in the bottom of a channel and losing flow, drop structures might be built to build the hydraulic profile up rather than excavating the channel into the groundwater. The depth of water in a perc channel can be controlled by drop structures but they must be very low; drop is commonly no more than 0.4 feet. They must be sealed deep into the bank and bed so flow is not lost around them through the permeable native soil. Seals should extend well into the bed and banks. Low porosity geotextiles are commonly used for sealing. The depth of the seal depends on the porosity of the native material; generally ten feet into the bank is appropriate. More than three feet into the bed is impractical. Portions of a perc channel intended for spawning habitat should normally operate without backwater effects from the river unless strong upwelling is expected to continue. Percolation flow, and therefore upwelling intergravel flow, is reduced when the channel is backwatered. Strong upwelling will maintain inter-gravel flow and prevent clogging with fines to aid egg incubation.

A water surface profile of the mainstem and designed channel including pump test elevations and high and low channel flow and backwater is prudent for design.

5.2.4.3 Special issues with construction of perc channels

Construction of a perc channel may require substantial excavation and handling and/or hauling of spoils, which can be a substantial project cost. Depths of excavation can be as much as ten feet. If the spoils are left on the site, careful consideration should be given to their effect on the constructed channel as well as the hydraulics of the floodplain. The spoils might be used to create a flow-spreader in the floodplain. Flow spreaders are explained in Integrated Streambank Protection Guidelines. A flow spreader might dissipate energy of overbank flows and clarify the water by spreading the water out across the floodplain. A flow diversion berm might be constructed to prevent floodwaters from directly entering the constructed channel. Containment berms might constrict the mainstem channel, relocate floodwaters to areas of the floodplain that were not naturally flooded, and/or ultimately increase the risk of flooding by increasing the head differential between the floodwater in the floodplain and the water level in the constructed channel. Any restoration plan should include an aggressive program of protecting existing vegetation and revegetation of the disturbed riparian area.

Various strategies have been used to enhance substrate of perc channels. If the channel is protected from floodwater intrusion, there may be no natural sorting of fines and gravel. Placing spawning gravel over filter blankets or layers of filter gravel has enhanced substrate; channel beds have been mechanically and/or hydraulically cleaned, and channels have been over-excavated and replaced with imported gravel. Replacement has been the most commonly effective and efficient strategy but the preferred strategy at any site depends wholly on local conditions of gravel availability and access. The economics of perc channel construction is benefited at large or multiple projects in a vicinity that make the acquisition and operation of mobile gravel screening operations practical. A common strategy is to screen large and small material out of pit run gravel supplied near the restoration site. Washing material may not be practical or necessary considering the logistics entailed. Screening and washing material excavated from the channel makes sense but may not be practical; moving and screening wet material is more complicated and has greater impact on riparian areas than screening dry material at another location. Logistics and sequencing are also complex if material has to be excavated, processed and then replaced in the channel. The depth of spawning gravel depends on what is beneath it. If the natural base is very unsuitable for spawning, at least eighteen inches of spawning substrate should be placed so it can be redistributed by spawning fish and still have a useful spawning bed. If the natural bed is marginal or better spawning habitat, less imported material may be needed. A veneer of rock may be placed over material that is marginally acceptable as spawning gravel so as the fish spawn it becomes mixed providing a suitable bed. Usually imported material is only needed for riffle sections of pool-riffle sequences.

Lister and Finnigan (1997) report the current custom in British Columbia is to use native in-situ bed material. “Comparison of chum salmon survival in channels with substrates of either native gravel, or artificially graded gravel, with smaller size fractions (<10 mm diameter) removed, has indicated that graded gravel offers no advantages in terms of egg-to-fry survival or density of fry production.”

Experience has shown that armoring the bank toe of an excavated perc channel is beneficial for several reasons (Lister and Finnigan, 1997)[10]. Spawning fish are very active in areas of upwelling flow, which is most concentrated at specific locations at the toe of the channel. Their spawning activity eventually excavates into the bank causing it to collapse and a loss of the focused upwelling and spawning area. A riprap toe will buttress and ballast the bank to prevent failure. Fractured rock is often used because it provides a better structural base. If the rock is placed irregularly and with a thickness of at least two layers, the interstices of the rock provide cover for juvenile salmonids (Lister and Finnigan, 1997)[10]. It is believed that the interstices allow greater density of fish rearing because fish are visually isolated from one another. Habitat features are further described later in this section. The rock toe can be placed into the bed and covered with large wood or logs from the site to support the bank and hide the rock. A bank can also be constructed with benches or terraces to minimize risk of bank sloughing due to spawning activity. A bench immediately behind the rocked toe can provide an ideal wet area for establishment of water-dependent vegetation.

Constructed banklines of perc channels are generally on slopes of 2:1; steeper slopes tend to slough especially when saturated with high groundwater. In areas with substantial spring flow and sandy soils, slopes of as much as 4:1 may be required. Flatter slopes may also be required in situations where there is rapid drawdown after high flow events and therefore rapid drainage from the banklines and thus bank sloughing. Access for efficient construction may necessitate clearing a substantial area around the channel. Considering the depth and width of the channel, slope of the banks and general need for access roads along the banks, the width of affected corridor is often as much as fifty or sixty feet.

The quantity of groundwater flow in perc channels is important, so it is desirable to make pre-project estimates of the flow potential. If channel flow is low (0.5 to 3.0 cfs), the optimum design might be to pond water to create rearing habitat. If flows are greater than about 3.0 cfs, pond and/or spawning habitat can be effective. Lower flows might be effective in projects built with special equipment or by hand. Channel bed width is based on constructability, equipment used, and desired total habitat. Drop structures are often used to create a nominal depth of 0.7 to one and a half feet; pools are also excavated in the bed. There generally is not enough perc flow available to maintain the hydraulics most desired for spawning conditions based on open channel flow so it is usually not practical to design channel width and slope for those characteristics. Flows in perc channels have commonly varied from 2.8 to 7.1 cfs creating average channel velocities of 0.2 to 0.5 fps (Sheng et al. 1990; Cowan 1991) [19, 40].

Large pools have been excavated at the very upstream of perc channels. Spawning fish often move as far upstream as they can and accumulate at the head end of the channel. The pool gives them a safe place to accumulate. A pool might be eight to ten feet deep. It should include cover and be designed as a holding area rather than spawning habitat. The intent is that fish will move back downstream when they are ready to spawn. Pools can also be excavated at other locations within or adjacent to the channel to serve as adult holding areas and add diversity to the channel. A good place to add pools in a channel is immediately downstream of any grade control weirs. The weirs create some aeration that acts as cover and fish may need a pool to help them negotiate passing the weir. As mentioned elsewhere, deep pools do not appreciably create additional surface flow unless they connect to more porous layers of substrate. Pools with large wood cover are useful in capturing and retaining spawned out carcasses keeping nutrients inside the project and sometimes providing forage for scavengers.

5.2.4.4 Manage the Risk of Avulson

The risk of avulsion was mentioned in the section on project risk and uncertainty. All types of side channels have some such risk. Spring channels can have a unique risk because a channel might be created where there was none before and substantial floodplain clearing and channel capacity might be necessary. Natural avulsions and channel changes are, on the other hand, important processes that create side channels.

Perc channels have been constructed commonly with the spoils used to construct a berm parallel to the side channel to marginally protect it from flood flows from the mainstem. Berms (or levees) can restrict natural processes and can have confining and constricting hydraulic effects on the mainstem (see the technique on *Levee Removal and Modification*); all such implications should be well understood if such a design is pursued.

There are several techniques that can be used to manage the risk of avulsion. Floodplain techniques, separation of the constructed channel from the river channel by distance, elevation, and control of high flow into the side channel will limit the risk of an avulsion. Floodplain techniques such as flow spreaders, drop structures, and avulsion sills are described in Integrated Streambank Protection Guidelines. Flow can be controlled by constrictions within the channel that limit the flow. Constrictions can be rock or wood structures that create headloss and thereby limit the flow in the channel to a safe discharge. To protect against a headcut as water spills from the floodplain into the channel, a spillway can be constructed in the banks of the channel at places where floodwaters will enter the channel. A spillway can be constructed of riprap, then buried and revegetated.

5.2.5 Reconnection of Side Channels to the Mainstem

The design components described in the following sections are important to the development of successful projects to reconnect existing side channels to the mainstem. The intent of this type of project is to restore surface water supply from a mainstem channel to a side channel. Surface flow may supply water at all river flows or at just high flows if perc flow water supply will continue at lower flows. Disconnection of a side channel often occurs at the upstream end due to several causes. If the side channel doesn't have the capacity to transport sediment delivered to it, sediment may block flow to the channel. Such deposition can be exacerbated by wood accumulation in the entry to the side channel. If the mainstem degrades, it may leave the side channel perched and therefore isolated from the mainstem at least at low flows. Mainstem channel patterns may result in the thalweg moving away from where the side channel feeds of the mainstem channel. The mainstem may also migrate towards the side channel and threaten to entirely divert into it. Artificial levees may also isolate a side channel from the river. Reconnection of the side channel is discussed here; the hydraulic effects of levee removal must be evaluated and are described in the Levee Removal technique.

Side channels with consistent surface water supply from the mainstem are the only side channel discussed here that are subjected to the hydraulics of surface water flow and floods. It is important to create processes within the side channel that will create and maintain habitat. Processes might be created or enhanced by combinations of channel layout, cross-section, elevation, and slope, structures, bed material, and large wood. Refer to the technique on *General Design And Selection Considerations For Instream Structures*.

5.2.5.1 Water supply, channel grade and elevation

Reconnection of water supply is all about water supply. A sediment deposition that plugs a side channel can be removed or modified but is only practical if it won't recur. The connection can be self-maintained in some situations by a constriction at the junction of the channels that maintains a scoured thalweg and therefore a low flow water supply. A constriction is only effective if the hydraulic profile of the side channel can create a head loss through the junction adequate to transport the sediment that is delivered to it. Part of a common evolution of side channels is for debris to accumulate at the junction and meter flow into the side channel. The constriction of the debris maintains low flow water supply by scouring a thalweg and controls high flow by restricting floodwater flow into the channel. The constriction might be created with rigid structures; a pair of large boulders has been used in some projects. Hydraulic conditions of the junction will certainly change over time with channel evolution and with sediment and debris accumulations. These changes should be anticipated to the point that risks to side channel habitat and success of the project are evaluated.

Large wood can be used to manage migration of the mainstem channel into the side channel. If there aren't naturally mature trees available in the right locations, logs can be placed across the side channel near the junction or downstream. The mainstem can then break into the side channel mimicking the trees that would have fallen as the mainstem migrates. See **Figure 5**.

There's not much practical recourse, so to speak, in the case of a mainstem channel that has migrated away from the side channel. Side channels are commonly created as a mainstem channel migrates or avulses across the floodplain; those processes shouldn't be interrupted. If a side channels is perched because the mainstem channel has degraded the solution may be to raise the mainstem channel back to its previous elevation. Such a project then becomes a channel modifications project; see the *Channel Modifications* technique.

Levees, road, and railroad fills often isolate side channels from the mainstem or confine channel meanders. Sites that will be protected from floods and channel migration by these infrastructures often have opportunities for restoration by reestablishing flow from the mainstem and/or restoring fish passage by replacing culverts or providing other fish passage improvements. Since natural processes of floods and channel migration won't occur, maintenance may be necessary.

Additional flow that is diverted into the side channel depletes the mainstem. Be aware of any habitat risk due to the depleted flow, especially in small streams.

Formal intakes have been constructed to enhance flow to side channels (Lister and Finnigan 1997) [10] provide siting and design detail for more formal control structures including slide gates mounted on culverts or concrete structures, settling ponds, and log curtain wall intakes. Surface water intakes should be located at the outside of bends, which are usually characterized by a deep thalweg channel and are less susceptible to sediment clogging or recruitment to the side channel. This location often works well at sites where there is a railroad or road fill that separates the side channel site from the mainstem.

Flow can also be controlled in a side channel with a simple culvert without a control gate. A culvert of an appropriate size will act as an orifice to meter flow to the side channel by creating increasing head differential as the mainstem water level rises and increasing flow passes through the culvert. Scour downstream of the culvert must be accommodated by the design of the culvert installation. Design of the control structure includes a trade-off of flow control and a risk associated with formal intakes and control culverts of blocking upstream passage of fish.

5.2.6 ENHANCEMENT OF FLOODPLAIN PONDS AND WALL-BASED CHANNELS

The difference between floodplain ponds and wall-based channels is that wall based channels and ponds are usually higher in elevation relative to percolation-fed channels. They are usually located along the base of higher terraces. Floodplain ponds are generally constructed ponds, often by extraction of gravel for commercial purposes; they may be located closer to the mainstem channel; they are likely flooded more frequently by overland flow from the mainstem; and they are more likely to have porous gravel substrate.

Water sources for both can either be hyporheic inflow similar to perc channels, groundwater sources similar to wall-based channels, provided artificially from the mainstem or a combination of these sources. For these reasons, they might be restored for both spawning and rearing functions.

Habitat might be gained in floodplain ponds and wall-based channels by increasing the water depth, increasing the water level to add area, excavating within or next to a channel or pond, or by improving fish access to the channel. Restoration of wall-based channels and floodplain ponds often entails providing fish passage for juvenile fish. Bates (1992)[41] describes fishways for juvenile and adult passage. Fishways for juvenile passage require precise flow control; too much flow in a fishway will block juvenile fish. Fishways within systems with spring-fed hydrology are practical for juvenile fish because flow is relatively constant and there is little or no bed material transport that might affect a fishway operation. Any fishway, however, requires continued inspection and maintenance effort.

The layout and bathymetry of the ponds can affect its productive capacity. There may be benefit also in reconfiguring a pond. Shaping the pond to optimize production is easiest if the gravel pit is shallow. Some pits are excavated only down to the groundwater level where the excavation is limited by excavation equipment. See **Figure 6**. Gravel mining operations within the floodplain could be reclaimed either as part of the gravel mining operation or subsequent to it. Lister and Finnigan (1997) [10] and their sources describe pond geometries.

> "Studies of juvenile coho utilization of off-channel ponds for overwintering have indicated that while shallow, less than 0.75 m deep, may be beneficial to coho in terms of benthic insect food production, the presence of deeper areas (to 3.5 m) tends to maximize survival for smolt emigration (Peterson 1982b; Cederholm et al. 1988)[42, 43]. Off-channel ponds that have both shallow areas or shoals for food production and deep areas for overwinter security are most likely to produce good numbers of large, viable smolts."

Peterson (1982) found greater survival of coho in deeper ponds (78%) than shallow ponds (28%). Swales and Levings (1989) suggest that shoreline perimeter and shallow areas are key to coho survival. Experience in Washington has been that the most efficient way to increase habitat in floodplain ponds has been to increase cover habitat within the pond or to improve fish access to it[35,39].

Predation is more likely a significant factor in floodplain ponds than other side channels. Zarnowitz and Raedeke (1984) attributed 43 percent of the mortality to coho in an over-wintering pond to bird and mammal predators. To minimize predation, they suggest a pond size less than 2.5 acres with steep sides that drop to greater than two feet in depth with two feet also the minimum pond depth and that 75 percent of the pond area should have depths in the four to eight-foot range. Ponds in Washington coastal rivers were constructed with minimum depth of three feet to limit access by herons but with a five-foot wide beach around the perimeter that slopes up to a foot of depth. The beaches were planted with plugs of slough sedge (Carex Obnupta) at eighteen-inch centers. The slough sedge spreads rapidly and has been observed to provide substantial cover for juvenile coho. Other aquatic plants common to floodplain ponds and that can be imported from other ponds in the vicinity include small-fruited bulrush (Scirpus microcarpus), and hardstem bulrush (Scirpus acutus). These plants also provide food and cover for small mammals and waterfowl.

Figure 6. Pond layout and bathymetry can affect its productive capacity.

Commercial gravel pit operations typically result in the loss of all riparian functions around the pits. Any restoration plan should include an aggressive program of revegetation of the shoreline of the pond. The revegetation could be started whenever a potential restoration site is identified and long before additional work is accomplished. Creating a bench around the pond at or near the water level is useful to establish a perennial wet area for establishment of shrubs such as willows that are fast growing, provide cover, and have strong root binding qualities.

Explosives can also be used to add diversity to existing ponds or wetlands. Additional depths in areas can create over-wintering or low flow refuge that might not otherwise be available and to provide the diversity suggested by Lister and Finnigan to optimize food production and rearing habitat. This type of project has obvious safety and potential implications to wetland functions that must be addressed. Explosive pressure waves kill fish so may not be suitable for areas that are already inundated or near them. Explosives may not be permitted.

Water quality of floodplain ponds may be different than other side channel habitats. Because of their size, surface exposure, and common lack of mature riparian vegetation, surface heating can be a concern. Warm surface water may reduce the rearing habitat available as fish are forced into deeper water and away from food production associated with the shallow edges of the pond. Warm water may also be more conducive to colonization of warm-water predator species. A combination of warming and depth may create supersaturated gas conditions. High gas levels should be estimated based on expected heating, mixing, and pond depths. Water quality problems will be less if there is significant perc inflow to the pond.

Water supply to wall-based channels is usually either groundwater other than hyporheic or surface water independent of the mainstem river stage. Those sources may have low dissolved oxygen levels and/or high total gas content.

Odors of hydrogen sulfide have been apparent in the winter at several floodplain pond sites implying there was stratification during summer months and anoxic conditions in the bottom of the pond. This could be due to lower quantity of inflow or no inflow into the bottom of the pond. It could be exacerbated by heating of the pond surface and excess pond depth.

Spawning often occurs in floodplain ponds especially along the upstream edge of the pond where upwelling is very conducive to spawning. Constructing a series of ponds, as shown in **Figure 6**, can maximize spawning habitat. If there is adequate head throughout the site and between each pair of ponds, upwelling at the upstream side of each pond can create additional spawning area. Connecting six abandoned gravel pits with surface water channels restored Countyline Pond on the Skagit River in Washington State. There is substantial risk of dewatering the surface water connections between the ponds and stranding fish if the ponds are too close together or the ground is too porous. Such a project should be done either in stages with a design that adapts to the hydrology or with a good understanding of groundwater hydrology to minimize the risk. A series of ponds can also help to manage risk of avulsion.

Additional shallow water can be provided along the upstream edge of ponds to increase spawning potential though spawning in gravel pits has been observed in water up to fifteen feet deep.

Additional water supply has been added to floodplain pits by culvert with a control gate that connects to the mainstem.

Public safety and the safety of wildlife are concerns at floodplain pits. If the banks are too steep, it is difficult for anybody or animal that falls into a pond to climb out. Shallow beaches, sloping banks at 2:1, and large wood reduce the risk.

A simple and common enhancement of floodplain ponds is to construct or lower a channel from the river to the pond to provide access for adult and juvenile fish. Access to provide spawning opportunity for adults, rearing habitat for juveniles, to prevent fish from being stranded in the pond, and to allow escape of fish stranded in the pond as a result of overbank floods from the river. Lowering the water level of a floodplain pond can add to the risk of avulsion. Though constructed floodplain ponds can be reclaimed as habitat, the practice of floodplain gravel mining may have risks that exceed these benefits at least in some cases. Bates (1992), Norman et al (1998)[44] and Kondolf (2002)[45] describe consequences and risks of floodplain pits including avulsion, entrapment of fish, and colonization by warm-water species and hydraulic effects on the floodplain.

5.2.7 Habitat features Common to all designs

A variety of habitat features can be included in side channels. These habitat features are described within other habitat restoration techniques in this guideline. These habitat features may not function the same as when they are built in mainstem channels. Relatively constant flow in perc channels and from floodplain ponds and wall-based channels may not scour under habitat structures, sort bed material, and carry large wood that will create log jams. Those features may have to be constructed where flood processes don't exist and they won't develop naturally.

5.2.7.1 Cover

Habitat cover features should be located throughout the channel to provide juvenile and adult fish with cover from predators and refuge from high velocities. Cover is vital to overwinter juvenile survival. Without adequate cover, predators such as diver ducks can literally consume the entire supply of wintering fish obviating any values of the project. Once diver ducks find easy prey, they will commonly take up residence until the food resource is gone. The more complex and submerged the cover the better to make it as difficult as possible for the ducks to swim into the areas where fish will hold in efforts to escape.

Intermittent deep pools should be provided with cover to add diversity and juvenile rearing and adult holding. Cover can be provided by log structures to support the toe of the channel and provide rearing/refuge habitat. Rock can also be used as described in the perc channel section.

Refuge alcoves are ponds excavated into the bank of a channel as refuge and rearing habitat. They are commonly dug deeper than the channel and loaded with large wood. Holding pools are also built into the upstream end of some channels and are described in the perc channel section.

If new large wood will not be replenished into a site, constructed wood structures might be anchored in place in portions of a channel that is backwatered. Otherwise, the backwater effect floats the wood out of the channel, either into the mainstem or up onto the floodplain. Anchoring might be done by use of appropriately sized wood that will form a natural jam or by mechanical means such as pins and cables. A site that is being cleared for a new channel may offer the opportunity to use material of the size that cannot normally be imported to another site.

5.2.7.2 Spawning substrate

Perc channels are generally constructed by excavation into the floodplain. If they are intended as spawning habitat, the spawning substrate may either be the native soil, cleaned native soil, or replaced with higher quality spawning gravel. Replacement of bed material with spawning gravel is described previously in section 5.2 *Design Considerations*.

If the channel sub-base material is sandy or clayey, a gravel filter may be required to support imported spawning gravel. Geotextile blankets have also been used, but are not recommended. The presence of a geotextile increases monitoring and maintenance requirements. Furthermore, the geotextile blanket will likely limit hyporheic flow and would create a physical barrier to movement into and out of the substrate for fish and wildlife species that spend any part of their life cycle in the substrate. Exposed geotextile decays and can become a hazard to spawning fish as their jaws and gills entangle in fragments of partially decayed fabric.

Substrate in a channel that periodically experiences flood flows from the mainstem may by rejuvenated by hydraulic sorting and recruitment from the river. Flood flows may also fill and scour to create diversity and specific habitats. These floods may be beneficial or they can potentially alter habitat conditions, scour the streambed and physically destroy incubating eggs.

Features such as spawning gravel should be incorporated into the design. Exposed gravel in the channel may be used or processed material may be imported into the site. Many channels have provided successful spawning habitat using existing substrate. An evaluation of the presence and quantity of potential spawning gravel can be conducted during excavation of the initial project test pits. It may be economically viable to screen gravel from the overburden for use as spawning bed material. Portable screens are available that can be brought to the site. To be economical, careful screening of a good sample is needed to be sure there is a high proportion of the desired size in the mix. Otherwise, the screening operation will extend the duration of the project since so much material will have to be sorted. Recent experience on a specific project found the desired fraction needed to be at least one third of the source material to be economical. The economics of processing substrate compared to importing it of course depends on the source and location of imported material. Using on-site materials, construction costs may range from as little as $6 to $8 per cubic yard of material excavated, which includes bed controls, habitat structures and revegetation. However, imported gravel may cost $40 to $60 per cubic yard installed. See the section on Special Considerations for Perc Channels.

Appropriately sized gravel is critical to the success of a groundwater fed spawning channel. Rounded rock provides ideal spawning habitat for many salmonids. For most species, 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). Angular or crushed gravels should never be imported to use as spawning substrate; they do not provide appropriate interstitial spaces for eggs and water flow, cannot be built into redds, and cause such abrasion of the spawning adults. Recommendations of spawning gravel sizes are summarized in literature reviews (Keeley and Slaney 1996)[46]. Substrate should not be homogenous. Variety in substrate features may be important for different life stages of salmonids as well as for invertebrates and other assemblages. See the spawning technique in this guideline for additional information on spawning gravel mixes.

6 PERMITTING

Permitting requirements for side channel restoration and creation projects will be very site- and project-specific. Channel and floodplain modification invariably involves physical disturbance, excavation and removal of material, haul in and placement of fill, etc. The work can disrupt habitat and water quality at the site and downstream. The work also can be very disruptive to wildlife. Special concern should be given to the potential for impacting threatened or listed species of birds. A general discussion of permitting requirements is included in the *Typical Permits Required For Work In And Around Water* appendix of this document.

7 Construction Considerations

Off-channel habitat is usually constructed out of the active flowing river channel and therefore may require less attention to factors that complicate construction in sites with moving water. Although, excavation is often done in deep water, and pumping down of the groundwater is sometimes needed to allow construction of some channel features. If a channel is to be constructed in a surface water channel or in a spring channel with substantial flow, a thorough plan for project sequencing and care of the water must be developed. It might include temporary closure berms to isolate work areas, pumping water onto the forest floor or settling basins, and substantial filter devices to clean water that will discharge to the main river. Factors such as access, materials availability, equipment and labor, and sediment control must be considered. Further discussion of these elements is provided in the *Construction Considerations* appendix.

Sequence the project so equipment doesn't have to be driven on the channel bed. Additionally, special low bearing pressure equipment may have to be used for at least part of the excavation. During construction of the channel, a layer of sand will likely accumulate on the gravel bed. It may have to be cleaned with a gravel-cleaning machine.

Excavation of perc channels may result in conditions not anticipated. The subsurface conditions can be highly variable as a result of sediment sorting and old channels being filled as the floodplain developed. Pockets of fine sand are often encountered during construction. It may be impossible to mechanically to excavate the fine, saturated material; it is essentially quicksand. Several strategies have worked in this case. If the channel realignment is flexible, investigate the lateral extent of the fine material to see if the alignment can be moved to miss the sand pocket. The material might be dredged by pumping it out leaving a pool for rearing habitat. It might just be left in place though if there is a strong upwelling current through the material that keeps it suspended, it might be washed downstream and contaminate spawning placed there. It might be left in place and protected with a layer of larger rock.

Topsoil and duff should be separated from gravel materials and clayey materials and stockpiled. Topsoil and duff can be spread back over the final project as part of the site restoration. Gravel might be sorted and/or screened for use as spawning material. Clayey material might be used as a hydraulic seal at drop structures within the project. Large wood, trees and rootwads should also be stockpiled for use in the project as habitat features.

Floodplain ponds were constructed in the 1980's by Washington Department of Fish and Wildlife to restore habitat lost by the mudflow associated with the eruption of Mt. St. Helens. Among other techniques, a series of ponds, or beaded ponds, were excavated by blasting. Blasting technique was used at sites that had no access for equipment. ANFO explosives were carried to the site. Explosives precluded much control of dimensions or geometry of the ponds. They initially had steep walls and depths of eight to ten feet that subsequently sloughed. Pond depths of just several feet ultimately resulted as fine sediment filled the deep ponds. This type of project has obvious safety and potential implications to wetland functions that must be addressed.

7.1 Timing Considerations

Timing considerations are less of an issue in the establishment of off-channel habitat because the projects are usually somewhat removed from nearby bodies of water. Construction should be conducted when potential impacts to migrating or spawning fish are minimized. Additionally, construction should occur during seasons of low groundwater levels.

8 Cost Estimation

Cost is highly variable in side channel restoration projects. Primary factors that may control project cost include the size of the project, land acquisition, volume of excavated material for perc channels, location of spoil piles, the need, availability and delivery of spawning gravel, large wood, and site access. The experience of the construction crew and the design team may also affect project costs. An economical option might be to sort gravels near the project site as describe previously.

9 Monitoring

Biological monitoring provides the ultimate measure of project success. Annual spawner counts and redd surveys are the most direct measures of salmonid spawning utilization. Trapping and counting adult and juvenile fish entering and leaving a site may be used to evaluate the total productivity including rearing use of a channel. If an estimate of project benefit is desired, this work should be done for several years prior and after the project and again after several generations of fish have used the site.

Smolt production is not always the total measure of success. Some sites are documented to have a great density of parr but with little smolt outmigration the next spring. It is expected that parr relocated to other habitats in the summer either due to competition or to a history strategy inherent in the stock of fish. This might be especially true at sites high in the watershed that, because of their headwater location and high energy conditions, have historically produced fry that relocated to downstream habitats and don’t recruit fry from upstream. Look at both parr and smolt production, especially if high in the area of spawning distribution. Parr and smolt evaluations are a big commitment that should only be undertaken with specific objectives and experienced personnel and supervision. Evaluations can be very intrusive and damaging. Significant mortality can occur. It is also very expensive and must be undertaken with specific objectives and an overall program goal. It is a big commitment.

Biological monitoring for non-fish wildlife will depend on the local fauna. A local habitat biologist should be consulted for determination of what may be important or feasible species to monitor to effectively measure project success. For a comprehensive review of habitat monitoring protocols, see *Inventory and Monitoring of Salmon Habitat in the Pacific Northwest – Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia*.[47]

In addition to biological monitoring, the monitoring of physical conditions is important to the documentation of project success. Periodic flow measurements in the channel will determine whether the flow is constant or diminishes over time. Analysis of sediment in the gravel bed can be used to evaluate its quality over time. An evaluation of headcut-prevention measures should be done after large floods occur that are high enough to enter the channel.

Effects of the project on groundwater and implications to wetlands should be monitored. Piezometers installed for the initial site assessment should be maintained and monitored for at least several years to see how the project affects groundwater levels and flows.

10 Maintenance

Maintenance should be minimal with this type of project, although fine sediment and organic material may gradually accumulate in the gravel bed. Succession and maintenance of natural side channel habitat occurs by flood velocities and scour, channel migration, spawning fish that clean and sort substrates, wood, and debris. If these natural conditions are not present at a site, maintenance operations may be needed to remove sediment, clean fishways, open beaver dams, replace wood, and other actions. Periodic cleaning of gravel and/or supplementation with new gravel may be required to maintain or restore full habitat potential. Regular inspection and maintenance is necessary for formal fishways. If sedimentation or channel migration risks indicate a need for a high level of maintenance, the project feasibility should be questioned.

11 Examples

The Washington Department of Fish and Wildlife has constructed a number of groundwater channels in recent years. Good example projects that incorporate the latest design information include Young’s Slough, Nolan Channel, and Peterson Pond on the Hoh River in Jefferson County; Rainier Channel on the Bogachiel River in Jefferson County; and Taylor Channel, Park Slough, Illabot Slough and Park Slough Extension on the Skagit River in Skagit County.

The following tables show most of the off-channel habitat projects constructed by WDFW in the last two decades.

Table 3. WDFW Off-channel project sites.

PROJECT SITE	RIVER BASIN	YEAR COMPLETED	HABITAT BENEFITTED	COST	PROPERTY OWNER
Airport Pond	Clearwater	1988/89	30,000 m5	$16,900	Rayonier
Rayonier Pond	Hoh	1988	4,048 m5	$19,000	Rayonier
Barlow Pond	Hoh	1988/89	8,100 m5	$26,600	Private
Anderson Ponds	Hoh	1988/89	10,150 m5	$45,900	Private
Pole Creek	Hoh	1988/90	6,100 m5	$45,300	Forest Service
Peterson Pond	Hoh	1989	2,000 m5	$22,500	Private
Dismal Pond	Hoh	1989	4,048 m5	$25,700	Rayonier
Anderson Cr. Channel	Hoh	1990	3,000 m5	$16,500	Rayonier
Nolan Pond	Hoh	1990	8,000 m5	$ 3,200	State
Wilson Springs	Bogachiel	1990	3,200 m5	$41,600	Private
Tall Timber	Bogachiel	1990	800 m5	$10,000	Rayonier
Smith Road Pond	Bogachiel	1990	2,000 m5	$15,600	Rayonier
Dahlgren Springs	Bogachiel	1990	600 m5	$ 7,300	Private
* Morganroth Springs	Bogachiel	1991	14,100 m5	$13,400	Forest Service
* W.F. Dickey	Dickey	1991	23,000 m5	$28,000	Rayonier
* Mosley Springs	S.F.Hoh	1991	4,048 m5	$21,000	State
* Lear Springs	S.F.Hoh	1991	800 m5	$18,100	State

PROJECT SITE	RIVER BASIN	YEAR COMPLETED	HABITAT BENEFITTED	COST	PROPERTY OWNER
* Upper Mosley	S.F.Hoh	1992	690 m5	$23,000	State
Bogey Pond	Bogachiel	1992	13,640 m5	$24,700	Rayonier
Falcon Walrus	Bogachiel	1992,1995	740 m5	$20,600	Rayonier
Calawah Springs	Calawah	1992	900 m5	$50,300	John Hancock Ins.
Colby Springs	Dickey	1992	9,200 m5	$13,500	Rayonier
Elkhorn Pond	Dickey	1992	5,400 m5	$ 9,100	State
W.F.Marsh Ck.	Dickey	1992	3,000 m5	$ 6,200	Rayonier
* Hoh Springs	Hoh	1993,1995	3,450 m5	$86,000	Rayonier
Soot Cr. Springs	E.Fk.Dickey	1993	2,100 m5	$64,000	Rayonier
T-Bone Springs	Dickey	1993	745 m5	$33,000	Rayonier
* Young Slough	Hoh	1994	3,000 m5	$158,000	John Hancock Ins.
* Lewis Channel	Hoh	1994	2,000 m5	$135,000	State
Tassel Springs	Sol Duc	1994	600 m5	$16,000	Private
Laforrest Pond	Bogachiel	1995/96	2,520 m5	$133,000	Private
*Nolan Channel	Hoh	1996	1,800 m5	$151,000	Rayonier
*Huelsdonk Creek	Hoh	1996	12,000 m5	$18,000	DOT
Manor Springs	Clearwater	1996	960 m5	$21,550	DNR
*Cascade Springs	W.Fk.Dickey	1996	3,000 m5	$42,000	Rayonier
*Powell Springs	Sol Duc	1997	2,000 m5	$76,000	Rayonier
Rootstock Springs (I)	Calawah	1997	200 m5	$12,000	Rayonier
Rayonier Channel	Bogachiel	1998	1,700m5	$135,000	Rayonier
Tyee Pond	Sol Duc	1998	2,800m5	$80,000	Rayonier
Rootstock Springs (II)	Calawah	1998	600m5	$22,000	Rayonier
*Eagle Creek Springs	Sol Duc	1999	2,200m5	$84,000	Private
Thomas Springs	Sol Duc	1999	2,800m5	$20,000	Private
Big Beaver Springs	E.Fk. Dickey	1999	7,400m5	$35,000	Rayonier
*Prairie Fall Creek	Sol Duc	2000	4,700m5	$148,400	Clallam County
*Labrador Creek	W.Fk.Dickey	2000	2,000m5	$37,800	Green Crow Timber
*M & R Springs	Sol Duc	2000	700m5	$59,900	Merril & Ring Timber
Mosley Springs Ext.	S.Fk.Hoh	2001	900m5	$68,000	DNR
Lear Ck. Springs II	S.Fk.Hoh	2001	700m5	$35,000	DNR

* Cost share projects with timber companies, DNR, DOT, Salmon Coalition, Counties and/or Tribes.

Case study – Nolan Channel
Nolan Channel is typical of a groundwater channel located within the floodplain of the Hoh River. The area selected for construction was actually a low swale within the flood plain, which seemed secure from active flooding. This was determined by observing recent high water marks relative to the proposed surrounding ground of the swale. Vertical survey control was established at the upper, middle and lower ends of the adjacent river reach. Pumps tests were performed in the proposed channel area to verify substrate, groundwater elevation and percolation potential relative to the river.

Tributary to:	Hoh River in Jefferson County, Washington State
Channel Length:	2400 ft
Groundwater fed length:	1600 ft
Total Excavation:	22,000 cubic yards
Pump Test Data:	
Drawdown Index: 1.0	
Apparent Velocity 0.04 fpm	
Project Construction Cost:	$160,000 (2001 Dollars)
	Cost per cubic yard: $7.30
Drop in river water surface:	8 feet (0.0029 ft/ft slope)
Drop in channel water surface:	2.5 feet (0.0010 ft/ft slope)
Design species:	Coho Salmon (juvenile and adult)
	Trout (juvenile and adult)
Project Features:	50 % pool/riffle channel design
	Refuge Bays
	Pool Cover Structures
	Shallow Wetland Habitat
	Large Rearing Pool at upper channel
	Channel Log Controls

12 PHOTOS

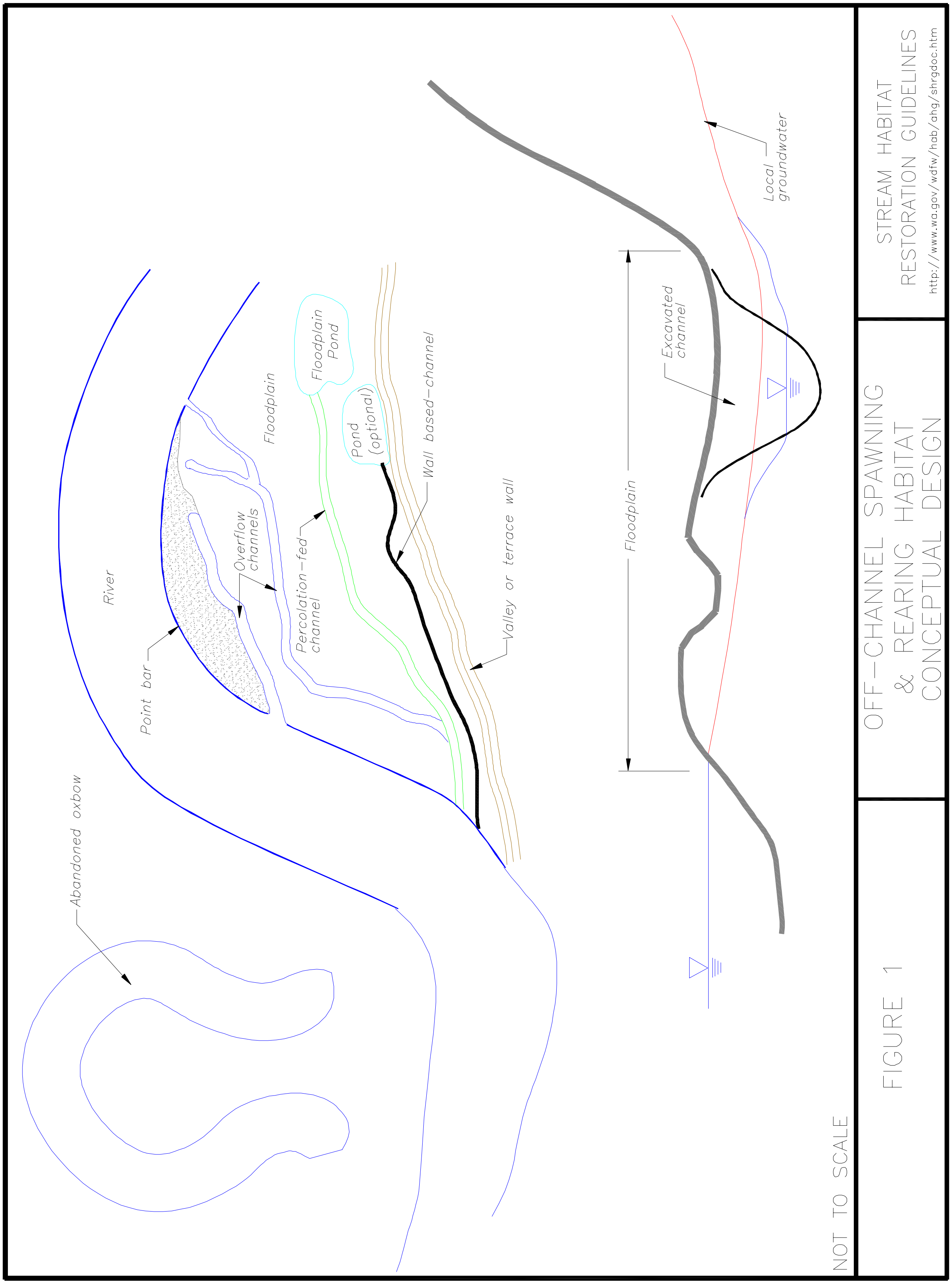
(d) **Figure 2.** Abandoned gravel pits and pond site near Satsop River.

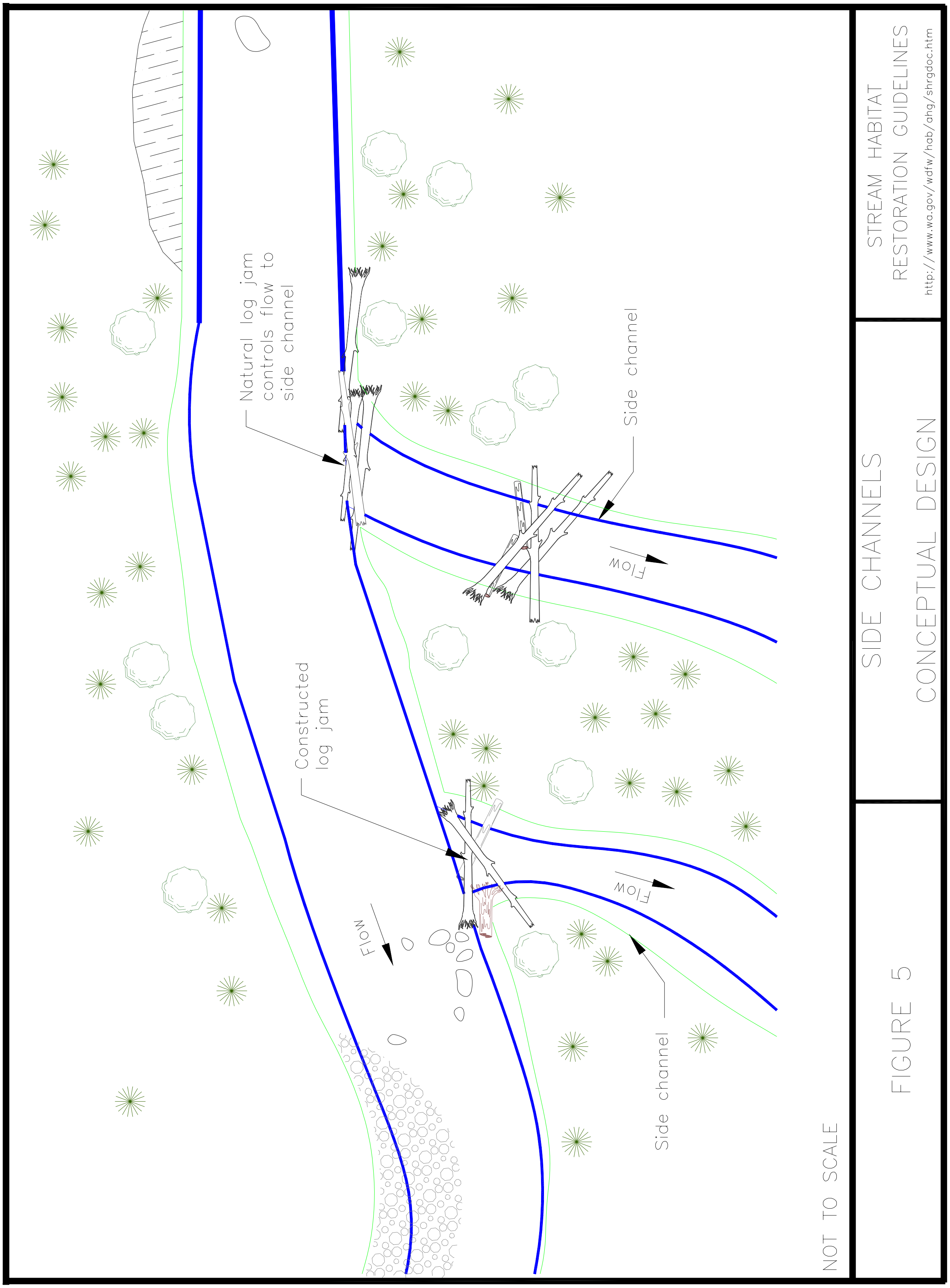
Figure 7. (a) Dismal Pond site prior to construction.

(b) Dismal Pond site during construction.

(c) Dismal Pond site after construction.

13 FIGURES


Abandoned oxbow
River
Point bar
Overflow channels
Floodplain
Percolation-fed channel
Floodplain Pond
Pond (optional)
Wall based-channel
Valley or terrace wall
Floodplain
Excavated channel
Local groundwater
NOT TO SCALE
FIGURE 1
OFF-CHANNEL SPAWNING & REARING HABITAT CONCEPTUAL DESIGN
STREAM HABITAT RESTORATION GUIDELINES
http://www.wa.gov/wdfw/hab/ahg/shrgdoc.htm


STREAM HABITAT
RESTORATION GUIDELINES
http://www.wa.gov/wdfw/hab/ahg/shrgdoc.htm
SIDE CHANNELS
CONCEPTUAL DESIGN
FIGURE 5
NOT TO SCALE
Natural log jam
controls flow to
side channel
Side channel
Flow
Constructed
log jam
Flow
Flow
Side channel

14 APPENDIX A

PUMP TEST PROCEDURES FOR DEVELOPMENT OF GROUNDWATER CHANNELS

1. Survey the site and set a project benchmark and temporary benchmarks (TBM), on the river at the proposed channel outlet and upstream adjacent to the upper end of the proposed channel location. Set TBMs near selected test pump sites. Sites should be near the proposed channel centerline, and at the middle, and upper ends of the channel. All elevations recorded during pump tests are tied to the project benchmark. To minimize required volume of excavation, select pit locations at a low ground elevation near the proposed project alignment. The pump site should be outside of the alignment in order to preserve it for studies following construction.

Equipment Needed: Excavator with 15 foot reach, 50 to 200 gpm portable pump, 100 feet hose, 20 ft intake hose, bucket for priming pump, stopwatch, 30 gal container of known volume, survey rod and level, 4 inch PVC standpipe 10 feet long with/cap (lower 6 feet with 3/8 inch holes, 4 inches on center and filter fabric to wrap lower 6 feet), 5 gallon bucket for soil sample and debris net.

2. Dig test pit about 3 feet below static water level. Select cleaner granular material while digging and store separately for backfill. Slope banks to prevent material from falling into the pit as it is pumped down.

3. Select a 5 lb soil sample representative of soil near static water surface level to develop a grain size distribution curve.

4. Record static water surface level relative to TBM. Record the radius of the hole at the water surface. Record the bottom elevation of the hole. Analysis of results requires the computation of contributing flow area, which can be estimated by a parabolic shape.

5. Record soil descriptions and strata through depth of cut. Record strata elevations relative to TBM.

6. Record river water surface elevations. Record time of measurement. If available, read nearby stream gauges.

7. Record the initial (static) water surface elevation.

8. Pump the test pit at a minimum 200 gpm.

9. Record the water surface elevation and time as the water surface drops. Record at 30-second intervals if there is a rapid water level response. If the drawdown exceeds 0.5 feet in one minute, stop pumping; allow the water level to recover to its initial static level and resume pumping at a rate about half the first pumping rate. Continue pumping for four hours or until the water elevation stabilizes for at least 30 minutes, whichever comes first. It is important to continue pumping for at least 30 minutes after the water surface has apparently stabilized.

10. Measure the radius of the hole at the drawn down stabilized water surface.

11. Stop pumping and record time. Record water surfaces and times as the hole refills at a frequency similar to the drawdown procedure described above.

12. Collect appropriate water samples if lab analysis is required.

Secure a 4-inch PVC standpipe with the lower portion covered with filter fabric. Backfill and cut off the pipe one foot above the ground surface. Record the elevation of the top of the standpipe for future measure downs.

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