Meacham Creek Watershed Analysis and Action Plan

Final Report

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Meacham Creek - downstream from cross section at river mile 3.30

Prepared for the Confederated Tribes of the
Umatilla Indian Reservation

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Watershed Assessment

Introduction

Meacham Creek is located 20 miles east of Pendleton and makes up about one-half of the flow of the Umatilla River where the two streams converge. Both streams support federally-listed steelhead trout and chinook salmon, with steelhead trout being the most common species in Meacham Creek. Each also supports the federally-listed bull trout within certain cool, headwater streams. The Confederated Tribes of the Umatilla Indian Reservation (hereafter referred to as the Tribes) have been actively involved in monitoring and managing these three species of fish in Meacham Creek and elsewhere in the Umatilla River basin.

The most downstream 4.5 miles of Meacham Creek flows through private and Bureau of Indian Affairs land within the reservation boundary. Upstream, Meacham Creek and its tributaries flow through a patchwork of private and Forest Service lands. Railroad tracks and a gravel access road now owned by the Union Pacific Railroad were constructed in the early 1880's and follow Meacham Creek throughout most of its length. The Union Pacific Railroad has a 50-foot right-away each side of the railroad track centerline. Some of the valley has double tracks while the remainder has single tracks, with narrow canyon portions of the valley being exclusively single-tracked. Heavy use of this route (about 35-50 freight trains per day) creates scheduling problems, especially with only one-way traffic in certain sections. Trains are sometimes subject to lengthy delays when the single track sections are damaged or blocked, since alternate routes are not available in northeast Oregon.

Private and Forest Service land along the stream is used mostly for grazing. Although some valley slopes support merchantable timber, little harvest has occurred in recent decades because some bridges and sections of the access road are not suitable for log trucks. Some of the flat, forested headwater plateaus of Meacham Creek watershed have been harvested extensively but most access roads originate from the top of the watershed and are not near stream channels. Additional recent timber harvest has occurred on a bench and slopes south of North Meacham Creek near its confluence with Meacham Creek. Here, timber harvest did not occur within 200 feet of the stream and the wide bench separated the stream from sloping ground. Access into the Meacham Creek valley is blocked by locked Union Pacific gates at the mouth and at the upper end near the town of Meacham. The few residents living in the valley have gate keys and unlimited access.

Study goals

One purpose of this study is to provide an assessment of past and current stream conditions for Meacham Creek and compare these with conditions for two reference streams that have had minimal disturbance. These conditions include channel and valley geometry, channel substrate, water temperature and quality, riparian vegetation, and specific fish habitat features such as deep pools and large wood. The other purpose of this study is to develop and prioritize recommendations for restoring and enhancing hydrologic processes, water quality, geomorphic stability, and salmonid habitat in Meacham Creek.

General methods

We conducted field surveys in July and August, 2002, in order to measure characteristics of Meacham Creek and of two reference reaches located within watersheds that are relatively undisturbed. Meacham Creek was initially divided into two sections, lower Meacham Creek and upper Meacham Creek, which were defined by the confluence of the North Fork Meacham Creek at river mile 14.90 (Map 1). At this junction, upper Meacham Creek has a watershed area that is 1.6 times that of North Fork Meacham Creek (Table 1). Upper Meacham Creek was further divided into two segments; reach 5, which extends from the North Fork Meacham Creek confluence to where the valley becomes narrow (river mile 24.2) and the upstream reach 6 which flows through a rocky gorge. The gorge extends upstream to about 1 mile downstream of the town of Meacham and from there the terrain becomes relatively flat. We ended reach 6 at river mile 28.18 which is about two-thirds of the way up the gorge.

Table 1. Location and drainage area of Meacham Creek and major tributaries.

Stream	River mile	Drainage area (sq. mi.)
Meacham Creek at confluence with the Umatilla River	0.00	178.6
Boston Canyon at confluence with Meacham Creek	2.24	5.3
Line Creek at confluence with Meacham Creek	4.95	2.5
Camp Creek at confluence with Meacham Creek	11.16	10.2
North Fork Meacham Creek at confluence with Meacham Creek	14.90	50.4
Bear Creek at confluence with North Fork Meacham Creek	3.45	13.6
North Fork Meacham Creek upstream of Bear Creek confluence	3.45	32.0
Meacham Creek upstream of North Fork Meacham Creek confluence	14.90	81.4
East Meacham Creek at confluence with Meacham Creek	18.48	19.5
Butcher Creek at confluence with Meacham Creek	21.35	9.5
Meacham Creek upstream of study area	28.18	29.3

Lower Meacham Creek was divided into two segments; reach 3 extends from the confluence with the Umatilla River to river mile 3.30 and is mostly a single channel. The remainder of lower Meacham Creek (reach 4) commonly has multiple channels. For purposes of analysis, reach 4 was further divided; reach 4a extends from river mile 3.30 to 7.08 and now flows predominantly along the west edge of the valley, frequently paralleling steep, bedrock slopes. The upstream remainder, reach 4b, is more centered in the valley.

The most downstream portion of North Fork Meacham Creek (reach 2) is relatively undisturbed and was chosen as a reference site to match reach 5 of upper Meacham Creek. A segment of the Wenaha River, a wilderness stream near the Oregon/Washington border, was chosen as a reference to match reach 4b of lower Meacham Creek. Both reference watersheds have had little disturbance along the streams, although North Fork Meacham Creek is grazed annually and some large wood was probably removed from the channel over the decades.

The reason we used reference reaches in this assessment is because there is little information on Meacham Creek prior to European settlement. The reference reaches are segments of stream where human disturbance has had little effect on stream channels or the surrounding vegetation. Comparing portions of Meacham Creek to reference reaches of similar size, channel confinement, gradient, and climate provides insight into the conditions of Meacham Creek prior to human disturbance.

A summary of inherent physical and hydrological characteristics for the various study reaches are provided in Table 2. Most characteristics of reach 4b in lower Meacham Creek and the Wenaha River reference reach are quite similar. The main difference is that the upper basin elevation is higher and precipitation is greater for the Wenaha River. This results in a significant snowpack that keeps flow high during the summer. Summer flow in the Wenaha River reach is about 60 cfs but only about 15 cfs for the Meacham Creek reach. Another difference is that the valley floor width is greater for Meacham Creek, although this has been reduced by the railroad grade built in the early 1880's.

Reach 5 in upper Meacham Creek and the North Fork Meacham Creek reference site are also very similar. Valley width of the reference site is somewhat greater than Meacham Creek and it also has greater summer flow. North Fork Meacham Creek has a summer flow of about 3.5 cfs while flow in reach 5 of Meacham Creek is only about 1.5 cfs, with some sections having subsurface flow. Detailed descriptions of physical and hydrological parameters and their derivation are provided in subsequent sections of this report.

Cross sections were established about every one-half mile along lower Meacham Creek, North Fork Meacham Creek, and the Wenaha River, while cross sections were spaced every one mile for upper Meacham Creek. At each cross section the following information was gathered:

- Topography of the channel and flood plain perpendicular to the stream

- Channel surface substrate size distribution within the bankfull width
- Upstream and downstream photographs

We also surveyed the position and elevation of the channel throughout the reaches. Other features that we mapped included:

- Deep pools
- Actively eroding banks
- Large wood
- Stream improvement structures
- Dikes

This later information was not gathered for the Wenaha River reach because the water was too deep, swift, and cold and the streamside vegetation too dense to conduct a 3.5-mile continuous survey along the channel.

A 1916 railroad map found at the Umatilla County Survey Office and 1956 aerial photographs of Meacham Creek provided information on past locations of the stream and dikes constructed to protect the railroad grade.

Our field surveys coincided with a prolonged heat wave so we measured water temperature within the main channel, tributaries, and cool water features between 2 and 6 PM. We supplemented this temperature information with gauging data from selected sites throughout the watershed and aerial thermal imagery collected in August, 2001.

We used current aerial photographs to map vegetation a distance at least 200 feet each side of the stream. We used information from the Oregon Department of Forestry and the U.S. Forest Service to map the boundary of fires that have occurred in Meacham Creek during the last decade. Aerial photographs and satellite imagery provided us with details on the acreage of timber burned or spared during each fire.

We used records from long-term stream gauging station records in northeast Oregon to develop regional predictive equations for the 1.5-year and 10-year flow at any location within the study reaches. These estimates of peak flow discharge, along with the cross section information, were used as input parameters for a computer software program (WinXSPRO) that calculated corresponding values for water elevation, surface width, velocity, and shear at each cross section location. Limited data from the Oregon Department of Environmental Quality and the Tribes provided information on water nutrients and suspended sediment loads.

Georeferenced black and white aerial satellite imagery (6-foot pixels) for the Meacham Creek watershed was obtained in August, 2002. This served as the base layer for a GIS product that includes coverages of the information described above.

Detailed descriptions of methods are provided for each parameter as it is introduced in the following sections.

Table 2. Summary of inherent physical and hydrological characteristics for various reaches in Meacham Creek and paired reference reaches in the Wenaha River and North Fork Meacham Creek.

Stream	Lower Meacham Creek			Wenaha River *reference*	Upper Meacham	North Fk Meacham *reference*	Upper Meacham gorge
Reach	3	4a	4b*	1*	5**	2**	6
Length of reach (mi.)	3.30	3.78	7.82	3.23	9.30	3.58	3.98
Reach boundaries (river mile)	0-3.30	3.30-7.08	7.08-14.90	13.93-17.16	14.90-24.20	0-3.58	24.20-28.18
# of cross sections measured	6	7	16	7	8	7	5
Cross section interval (mi.)	0.5	0.5	0.5	0.5	1.0	0.5	1.0
Stream elevation (ft)	1800	1950	2270	2990	2770	2640	3260
Upper basin elevation (ft)	4200	4200	**4200**	**6000**	**4200**	**5200**	4200
Drainage area (sq.mi.)	170-179	162-169	131-162	110-123	39-81	32-50	29-35
Avg. annual precipitation for drainage area (in.)***	35	35	**36**	**51**	34	39	35
1.5-year peak flow (cfs)	2108-2208	2023-2165	1644-2018	1663-1844	482-981	425-649	360-435
10-year peak flow (cfs)	4601-4826	4409-4585	3576-4399	3394-3780	1055-2156	903-1390	789-952
Channel gradient (%)	0.7	0.9	1.1	1.2	1.2	1.6	1.7
Stream power index for 1.5-year peak flow	12-19	15-24	15-22	16-30	6-12	8-11	6-7
Avg. valley width prior to railroad (ft.)	970	880	**1040**	**620**	**370**	**520**	180

* Paired reaches for lower Meacham Creek. ** Paired reaches for upper Meacham Creek.
Items in bold indicate substantial differences between Meacham Creek reaches and their corresponding reference reaches. *** Calculated as an area-weighted average throughout the basin upstream of the reach.

Channel characteristics

Channel sinuosity

Channel sinuosity is a measure of the lateral meandering of a stream as it flows through its valley. It is calculated as the length of channel between two points, as defined by the stream's main channel, divided by the length of the included valley. If the valley is straight, the valley length is simply the straight-line distance between the beginning and ending point. If the valley curves between two points, the valley length measurement incorporates these curves. Channel sinuosity of streams typically ranges from 1.1 to 1.8.

Under natural conditions, channel sinuosity is greater in wide valleys with few bedrock or vegetative constraints on lateral movement. Channel sinuosity is also greater in valleys with a low gradient and in valleys with an abundance of loose sediments (Dunne and Leopold 1978).

A natural stream channel will rarely flow straight down the center of its valley. Rather, the energy incorporated in the moving water will initiate bends, where the outside of the bend is scoured (faster water) and the inside of the bend receives deposits of sediment coming from upstream sources (slower water). Over time, a bend will either become so pronounced that the water cuts through to the next downstream bend or the stream will meander up against a harder substrate (commonly bedrock). Once against a hard surface, the meandering stops and the water energy is then dissipated downwards, usually resulting in a trench of deeper water. Pulses of sediment, often delivered during floods, and interactions with streamside trees along or logs in the stream, commonly truncate the meander process and keep the stream channel in constant change.

Road and railroad prisms can limit channel meandering due to the coarse material comprising the fill or by riprap later added to the base of the fill. Dikes and riprap along banks prevent channel meandering by diverting the direction of flow more to the center of the flood plain. Direct channel excavation and straightening with heavy machinery (such as occurred in Meacham Creek following the 1964 flood) forces a stream into a deep, single channel. Such human features and actions tend to create a more homogenous channel with less variability in water depth, current speed, and graded sediment deposits.

In this study we have quantified changes in channel sinuosity in Meacham Creek during the last 86 years by comparing the path of the channel today with its path in 1916 and 1956. The 1916 stream trace was transferred from a map found at the Umatilla County Survey Office and displays section corners, the railroad grade, the main stream channel, and dikes constructed to divert flow away from the railroad prism. While this map does not represent natural conditions for Meacham Creek, it does indicate conditions when the dikes were short, relatively scarce, and recently-installed. The 1956 channel locations were obtained from black and white aerial photographs and 2002 channels were obtained from digital satellite imagery (6 ft. pixel resolution).

We also compared the current sinuosity of the multi-channel portion of lower Meacham Creek (reach 4b) with that of the Wenaha River reference reach and the non-gorge portion of upper Meacham Creek (reach 5) with that of the North Fork Meacham Creek reference reach.

Methods

The 1916 railroad map was rectified to the 2002 satellite imagery by using the railroad grade location (mostly unchanged over the last 86 years) and section corners. The 1916 stream course, as indicated by a single line, and dikes were then digitized. The 1916 stream course aligned reasonably well within the current valley floor except at about a dozen wide bends where the digitized stream location coincided with steep basalt slopes in the satellite imagery, usually on the west side of the valley. It is likely that these bends were not actually surveyed in full but were sketched in, with the survey line cutting across the bends. Consequently, we modified the 1916 stream course at these bends so that the stream always fell within the bounds of the valley floor.

The main channel and major side channels were transferred from 1956 aerial photographs following using the railroad grade, patches of trees, draws, and other permanent features as common locations. The aerial photos were not actually rectified and so no error can be assigned to this process. Aerial photographs for 1956 were available only up to river mile 13.85 in lower Meacham Creek and upstream of Butcher Creek (river mile 21.35) in upper Meacham Creek.

The current location of the main channel and major side channels were digitized from the 2002 satellite imagery.

For each of the three time periods and for each of the 42 cross sections on Meacham Creek we determined channel length and valley length to the next upstream cross section and calculated a value for channel sinuosity (channel length divided by valley length). Channel and valley lengths were digitized from the computer screen following the stream and valley centerlines for each of the three time periods. We also determined the frequency and extent at which the channel flowed up against the railroad grade in lower Meacham Creek for each of the three time periods.

Results

Channel sinuosity throughout most of Meacham Creek was greater in 1916 than in 2002 (Table 3, Maps 2-5). The difference was greatest in the single-channel portion of lower Meacham Creek (reach 3), where average sinuosity decreased from 1.28 to 1.13. In the other portion of lower Meacham Creek (reach 4), that which is dominated by multiple channels, sinuosity decreased from 1.16 to 1.10. Channel sinuosity decreases were less in upper Meacham Creek where channel meandering is frequently truncated by the surrounding steep hill slopes.

Channel sinuosity decreased from 1916 to 2002 at a majority of the 42 cross sections throughout Meacham Creek (Figure 1). In lower Meacham Creek, sizable decreases (>0.1 ft./ft.) in sinuosity occurred at 12 of 29 cross sections (41%), while sizable increases in sinuosity occurred at only 2 of the 29 cross sections (7%).

In 1916, channel sinuosity of the non-gorge portion of upper Meacham Creek (reach 5) was the same as the North Fork Meacham Creek reference site but sinuosity was less than the reference site in 2002. Likewise, channel sinuosity of the Wenaha River reference site was more similar to 1916 conditions in the multiple-channel portion of lower Meacham Creek (reach 4b) than to 2002 conditions (Table 3).

Channel length of Meacham Creek within the study area decreased by 1.41 miles from 1916 to 2002, with most of the loss occurring in lower Meacham Creek (Table 3). Channel length decreased by 8.8% in the single channel portion of lower Meacham Creek (reach 3), 9.4% in the upstream multi-channel reach where the stream runs along the base of the west side of the valley (reach 4a), but only 4.8% in the remainder of reach 4 where the stream is more centered in its flood plain (reach 4b).

Much of the decline in channel sinuosity for lower Meacham Creek occurred prior to 1956, except in reach 4a (Table 4, Figure 1). The overall decline in channel length during the last 52 years was only 0.19 miles, with most of that occurring in reach 4a. Much of the diking in reach 4a occurred after 1956.

Table 3. Changes in stream length and sinuosity between 1916 and 2002 for Meacham Creek.

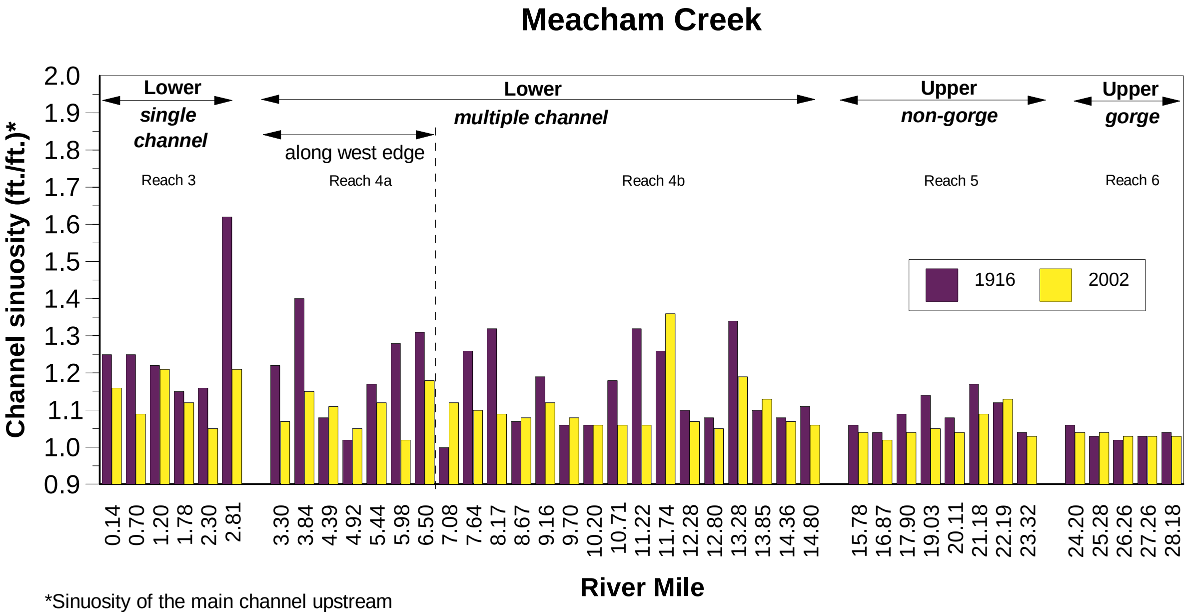
Stream reach	Channel length (mi.)		Change (mi.)	Change (%)	Average channel sinuosity (ft./ft.)	
	1916	2002			1916	2002
3. Lower Meacham; single channel	3.41	3.11	-0.30	-8.8	1.28	1.12
4a. Lower Meacham; multi-channel, west edge of flood plain	4.05	3.67	-0.38	-9.4	1.21	1.10
4b. Lower Meacham; multi-channel, center of flood plain*	9.18	8.74	-0.44	-4.8	1.16	1.11
5. Upper Meacham; non-gorge **	8.43	8.14	-0.29	-3.4	1.09	1.06
6. Upper Meacham; gorge	4.77	4.77	0.00	0.0	1.035	1.035
Overall	*29.84*	*28.43*	*-1.41*	*-4.7*	-	-
1. Wenaha River*	-	-	-	-	-	1.20
2. North Fork Meacham Cr **	-	-	-	-	-	1.09

* = paired reaches ** = paired reaches

Table 4. Changes in stream length and sinuosity between 1956 and 2002 for Meacham Creek.

Stream reach	Channel length (mi.) 1956	Channel length (mi.) 2002	Change (mi.)	Change (%)	Average channel sinuosity (ft./ft.) 1956	Average channel sinuosity (ft./ft.) 2002
3. Lower Meacham; single channel	3.12	3.11	-0.01	-0.3	1.12	1.12
4a. Lower Meacham; multi-channel, west edge of flood plain	3.93	3.67	-0.26	-6.6	1.17	1.10
4b. Lower Meacham; multi-channel, center of flood plain*	7.21	7.29	+0.08	+1.1	1.09	1.11
Overall	*14.26*	*14.07*	*-0.19*	*-1.3*	-	-

* only up to river mile 13.85



*Sinuosity of the main channel upstream of the indicated cross-section

Figure 1. Comparison of Meacham Creek sinuosity for 1916 and 2002.

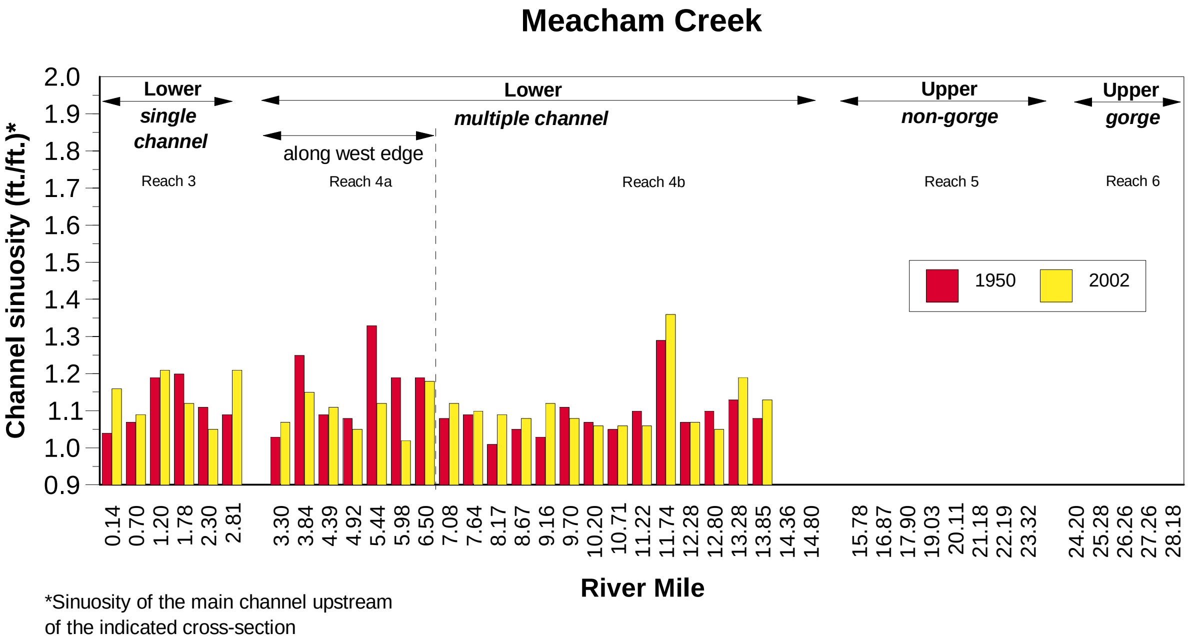


Figure 2. Comparison of Meacham Creek sinuosity for 1956 and 2002.

In spite of a general decline in sinuosity over time, a few reaches actually increased in sinuosity. These are probably just random adjustments of the stream as it continued to wander across its flood plain. The increases in sinuosity at these few reaches were not a result of boulders and trees added to the stream to improve fish habitat in the 1980's.

Lower Meacham Creek ran parallel along the base of the railroad fill more often and at a greater overall distance in 1916 than it did in 2002. The stream edged up against the railroad fill at 21 locations for a summed distance of 2.21 miles (13% of the total stream length) in 1916 but at only 6 locations and a summed distance of 1.01 miles (7%) in 2002 (Table 5, Maps 2-5). Stream encroachment upon the railroad grade was even greater in 1956 than in 1916, with 19% of the total channel length running along the railroad grade. A number of successive short sections of 1916 channel running against the railroad grade had merged into longer continuous sections by 1956.

At none of the 6 locations in 2002 was the stream actively eroding the prism of the railroad or access road.

Table 5. Number and extent of locations where the main channel of lower Meacham Creek ran parallel and up against the railroad fill or access road.

	1916	1956	2002
Number of locations	21	16	6
Summed length (miles)	2.21	2.98	1.01
% of total stream miles	13%	19%	7%

Dikes included in the 1916 railroad map were short (usually less than 100 feet long) and relatively scarce compared to dikes in 2002. The highest density of dikes in 1916 was in reach 3 at 1.8 per mile (Table 6). Dikes in 2002 were most common in reach 4a at 4.0 per mile. Densities were 3 times greater in 2002 than in 1916. Reach 6 had no dikes either period. Dikes in 2002 may be underestimated because they were too great a distance from the stream to observe during the field survey or vegetation obscured their presence in aerial photographs.

Table 6. Number and density of dikes along Meacham Creek in 1916 and 2002.

Reach	Year 1916		Year 2002	
	# dikes	Dike density (# per stream mile)	# dikes	Dike density (# per stream mile)
3	6	1.8	8	2.4
4a	3	0.8	15	4.0
4b	5	0.6	18	2.3
5	1	0.1	8	0.9
6	0	0.0	0	0.0
overall	*15*	*0.5*	*49*	*1.7*

Discussion

The 1916 railroad map provides strong evidence that channel sinuosity and length in Meacham Creek has decreased during the last 86 years. These decreases are most pronounced in lower Meacham Creek and are likely understated in this analysis, since the railroad prism frequently intercepted the meandering stream even in 1916. Prior to the railroad, Meacham Creek probably meandered more widely than it does now. Reference reaches in the two undisturbed watersheds have an average channel sinuosity that is more similar to 1916 conditions than to current conditions in Meacham Creek, suggesting further that channel sinuosity has decreased in Meacham Creek due to human activities.

Except within reach 4b, most of the loss in channel sinuosity occurred prior to 1956. Little is known about the history of channelizing and diking that went on during this period except for the dikes included in the 1916 railroad map.

The likely causes of decreased channel sinuosity and length are evident on the ground. Numerous dikes of river rock or pit rock have been constructed to divert flow away from the railroad grade and valley grazing land. Furthermore, stories from local landowners, pictures housed at the local Oregon Department of Fish and Wildlife office, and remaining berms of river rock paralleling the stream provide evidence that at least portions of the stream were channelized and straightened with bulldozers following the December, 1964 flood. According to these sources, the flood initiated many channel changes, left large deposits of cobbles and wood, and washed out portions of the railroad grade.

The consequences of channel straightening on fish habitat and their food supply has not been studied in detail for this region. Studies from other regions suggest that the following can occur following channel straightening:

- Reduced number and depth of pools used by fish for feeding and summer refuge.
- Less complex assemblage of overflow channels for slackwater refuge during high flows.
- Incised channels and consequent de-watering of surrounding low terraces that provide temporary subsurface storage and cooling of water.
- Less interaction with streamside trees that are a potential source of large wood in the channel.
- Fewer deep pools within gravel-rich areas and therefore fewer opportunities for cool, subsurface water to be intercepted by the stream during the summer.
- Less overall surface area for fish to rear and for food to develop.

Introducing greater channel sinuosity back into the stream for the purpose of improving fish habitat may be possible by creating breaks in some dikes and intentionally diverting water along alternative paths (see recommendations #2 and #8 in the Action Plan section). However, social and business concerns require consideration. First, the railroad company has a strong financial need to keep the railroad grade and access road intact during floods. Second, the residents of the valley depend solely on the railroad access road to reach their property. Also, a number of these landowners graze cattle in the valley bottom and would likely resist changes to the stream's location that would isolate or eliminate prime grazing areas. Those portions of the watershed where channel sinuosity losses have been the greatest are the areas where most of the property is privately-owned . Nevertheless, the Tribes have secured easements with a number of landowners in lower Meacham Creek and dikes could be breached under these agreements.

Channel gradient

Channel gradient is mostly a function of the underlying valley bedrock, although changes in channel sinuosity can also influence gradient. Deep layers of sand, gravel, and cobbles deposited during large floods can locally influence channel gradient by creating sediment wedges that temporarily elevate segments of the stream channel. These abrupt changes in channel elevation usually moderate over time as the stream slices downward through the sediment wedge.

In this study, we evaluated spatial changes in channel gradient for Meacham Creek and for the two reaches in the reference basins. We include only current conditions since no information exists for the past.

Methods

We mapped water surface elevation along the deepest channel of Meacham Creek from its confluence with the Umatilla River to river mile 28.18 in July, 2002. Where the channel was dry, the lowest portion of the stream bed defined the channel elevation. A GPS reading of elevation at the beginning of the survey provided for an assumed initial elevation. The survey was open-ended, however frequent GPS readings of elevation provided for a check on gross measurement errors.

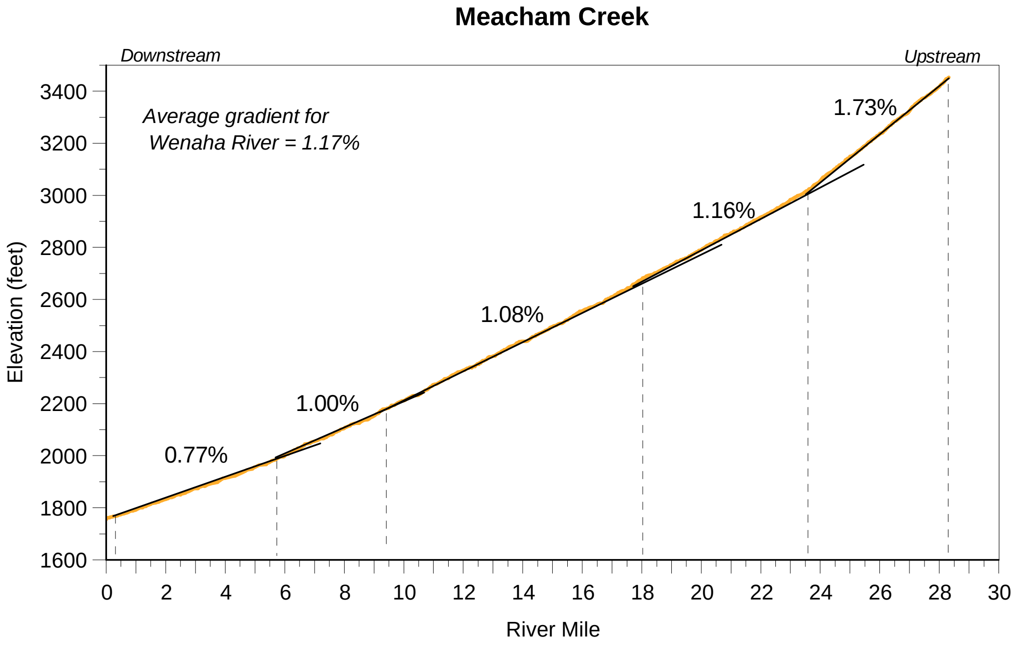
The same measurements were conducted for the lower 3.58 miles of North Fork Meacham Creek. High and swift summer flow prevented a continuous measure of the gradient of the Wenaha River reference reach. Instead, channel gradient was measured about 500 feet upstream and downstream of each of the seven cross sections.

Results

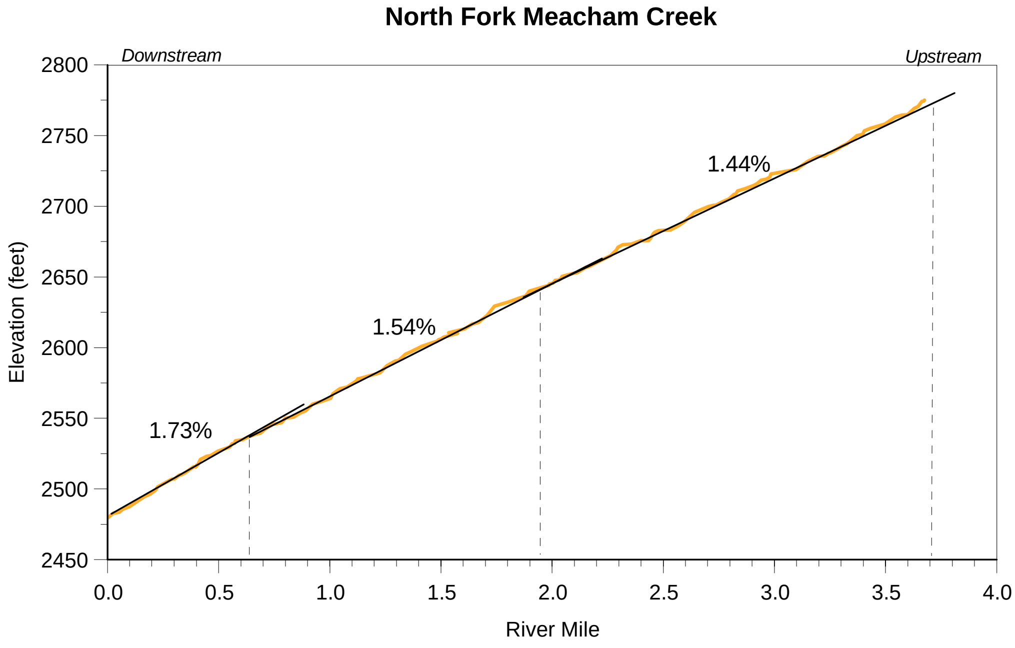
General channel gradient in the lower 28 miles of Meacham Creek changes at four distinct locations (Figure 3) and at two distinct locations in the lower 3.58 miles of North Fork Meacham Creek. These points of gradient change did not correspond to tributary junctions or any other obvious physical features of the valley, except for the most upstream segment of Meacham Creek (reach 6). Here, an abrupt increase from 1.16% to 1.73% occurs and corresponds to an upstream narrowing of the valley. North Fork Meacham Creek is steepest at its confluence with Meacham Creek and slackens in an upstream direction.

The gradient in the lowest section of North Fork Meacham Creek is 1.73% while the section of Meacham Creek into which it flows is 1.08% and may explain, in part, the extensive deposits of gravels in reach 4 of Meacham Creek. A decrease in channel gradient usually creates a depositional zone for coarse substrate.

The average gradient for the Wenaha River reference reach was 1.17%, while its counterpart reach in Meacham Creek (reach 4b) was 1.00 to 1.08%.



Meacham Creek



North Fork Meacham Creek

Figure 3. Water surface gradient (or channel bottom in dry sections) for Meacham Creek and North Fork Meacham Creek during July, 2002.

Channel gradient is only slightly increased by the shortening of channel length that has occurred from 1916 to 2002. The calculated channel gradient of reach 3 using the 1916 channel length is 0.70%, while the current gradient is 0.77%. Similarly, the calculated channel gradient of reach 4 using the 1916 channel length is 0.93%, compared to the current 1.00%.

Discussion

The relatively slack channel gradients (0.77 to 1.16%) throughout non-gorge portions of Meacham Creek explain the alluvial character of this valley. The flood plain of North Fork Meacham Creek is more confined by steep hillslopes than Meacham Creek and therefore has less sediment storage capacity. This, along with its steeper gradient and steep slopes throughout much of the drainage basin make it a major contributor of coarse substrate to downstream portions of Meacham Creek. Areas with slopes greater than 60% make up 31% of the basin in North Fork Meacham Creek. In contrast, large portions of upper Meacham Creek, (upstream of the gorge section) are relatively flat and are not capable of contributing coarse substrate. Slopes greater than 60% make up only 12% of the upper Meacham Creek basin. Nevertheless, the lower portion of reach 5 in upper Meacham Creek is a depositional area for sediment transported from the gorge portion of Meacham Creek and nearby steep tributaries.

Streamflow

The discharge of water during floods influences the movement of substrate and wood in a stream, while average annual flow and summer flow help define a stream’s ability to provide living space and cool water for fish. The ability to estimate the magnitude of flood flows for a given recurrent interval and at any location along a stream in a watershed allows for detailed analysis of water elevation, velocity, shear pressure along the stream bottom, and lateral extend of flooding.

Gauging information is often lacking for purposes of developing regional prediction equations of peak flows appropriate for estimates at specific sites. Or else, parameters easily obtained from maps or GIS coverages do not correlate well to variation in peak flows across the landscape. Fortunately, long-term stream gauging is relatively good for northeast Oregon and peak flow values correlate well with watershed area and average annual precipitation. Furthermore, long-term hydrological information is available for a gauging site in lower Meacham Creek (USGS gage station #14020300 at R.M. 1.4) and one in the Umatilla River immediately upstream of the confluence with Meacham Creek (USGS gage station #14020000 at R.M. 81.7), allowing for a check on the reliability of estimates for the study area.

Methods

We examined gauging records for Meacham Creek (26 years of record) and the nearby Umatilla River (67 years of record) to evaluate the history of average annual flows and flood flows in the region. We also examined peak flow records for 12 other streams in northeast Oregon and developed regression equations for predicting peak flow of various recurrence intervals that we could use for any location in the Meacham Creek and Wenaha River watersheds. This analysis is outlined in Appendix A. Accurate predictions were possible with these equations, with about a 10% average error among all gauging stations used in the analysis and only a 1% difference between actual and predicted values for the Meacham Creek gauge. Independent variables in the equation are watershed area and average annual precipitation, both easily obtained using GIS. Average annual precipitation upstream of a point along a stream was evaluated using an area-weighted mean of average annual precipitation polygons provided by the Oregon Climate Center at Oregon State University.

We determined 1.5-year (bankfull flow) and 10-year peak flows at each cross section location in Meacham Creek and Wenaha River using the surveyed topography at each cross section and the computer program WinXSPRO (latest version at www.westconsultants.com/desktopdefault.aspx?tabindex=11&tabid=28). We determined an elevation and surface water width associated with the bankfull and 10-year flow. From this we could determine water depth during the bankfull flow. We then determined an index of stream power by multiplying the bankfull discharge (cfs) by the channel gradient (ft/ft), which has direct influence on the downstream movement of substrate of various size classes and large wood in a stream, as well as bank erosion. Output from the computer program also provided estimated values of shear load along the channel/water interface and of average water velocity.

Information on summer water width and reaches with subsurface flow were obtained from the field measurements in July and August, 2002.

Results

Mean value of average annual flow from 1976 to 2000 water years for Meacham Creek (205 cfs) was about the same as for the Umatilla River immediately upstream of the Meacham Creek confluence (227 cfs). Nevertheless, summer flows are quite smaller in Meacham Creek. Mean monthly flow in August for the Umatilla River is 47 cfs but only 13 cfs for Meacham Creek. A higher upper basin elevation and greater annual precipitation results in a greater snowpack for the Umatilla River and therefore more flow during the summer. Neither stream has significant water withdrawals upstream of their gauging stations. Low flows for Meacham Creek typically extend into late fall while the most runoff occurs in April during the height of snowmelt (Figure 4).

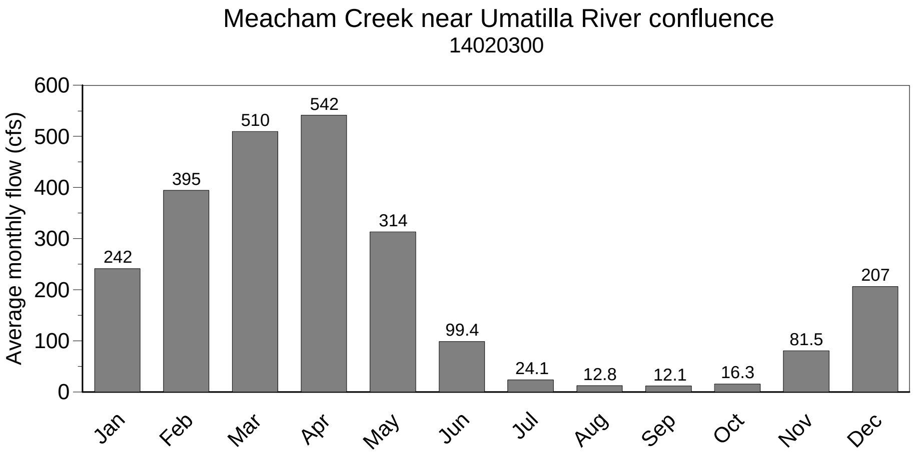


Figure 4. Average monthly flows for Meacham Creek.

Average annual flow in Meacham Creek varied widely from year-to-year yet certain cyclic patterns are evident, especially when the long-term for Umatilla River records are included. A 5-year smoothing of the annual series of flow for the Umatilla River indicates that four periods of unusually low water yield have occurred since 1966, ending with the current drought period (Figure 5). These periods of low water yield have occurred every 13 years, on average. Prior to 1966, a period of drought had not occurred since the 1930's.

The annual peak flow in Meacham Creek can occur any month from November through May (Figure 6). However, the largest peak flows occur exclusively from November through February. These peak flows are caused by rain-on-snow events where a prolonged and high-intensity, warm rainfall melts a snow pack that covers much of the basin. Those peak flows that occur from March through May are usually the result of a melting snow pack without concurrent heavy rainfall.

An analysis of flow values associated with various recurrence intervals (Table 7, Figure 6.1) indicates that Meacham Creek contributes 54% of the 1.5-year and 56% of the 10-year flow at the Meacham Creek and Umatilla River confluence.

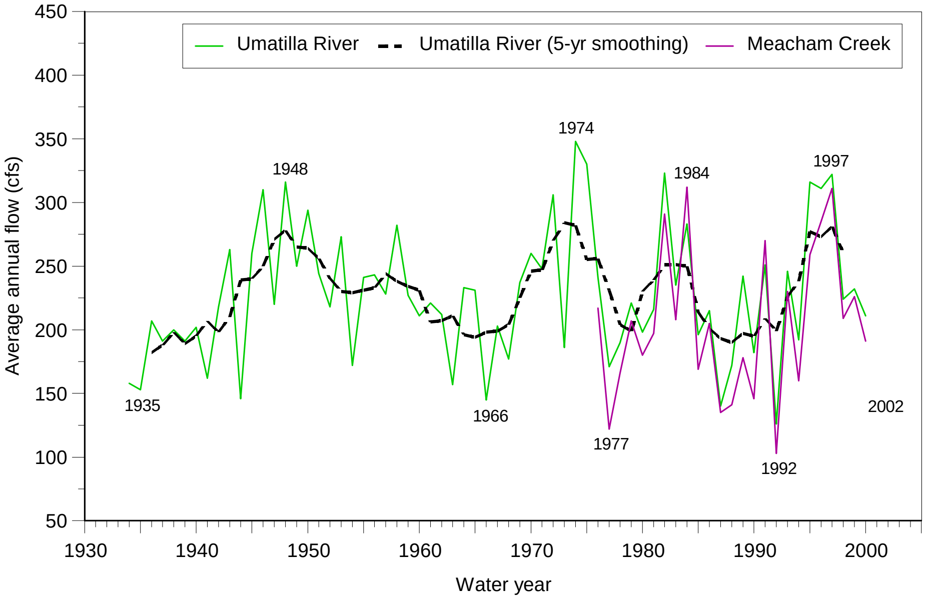


Figure 5. Average annual flow for the Umatilla River immediately upstream of Meacham Creek and for Meacham Creek. Smoothed line shows extended periods of unusually high and low flows.

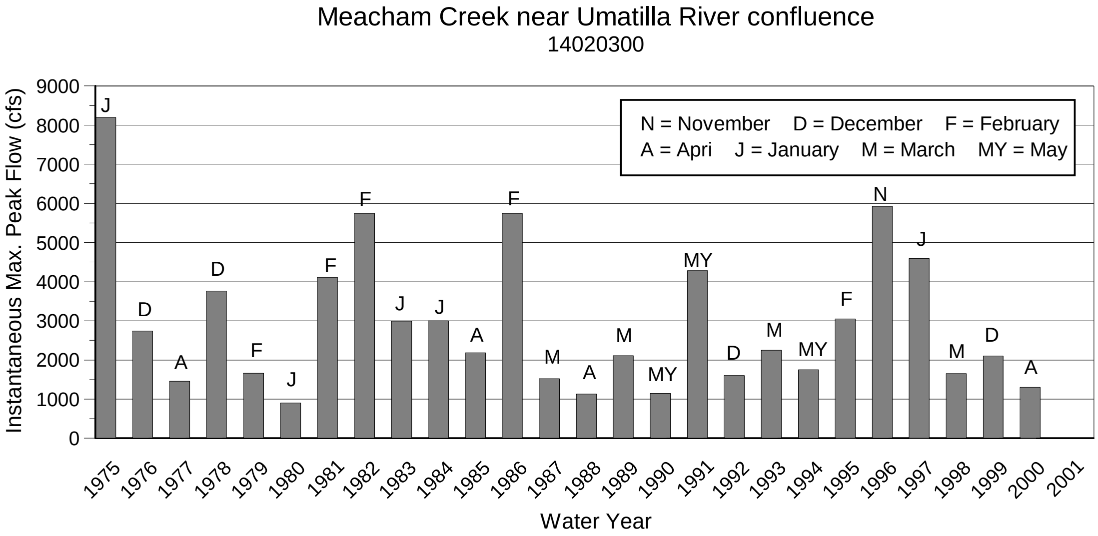


Figure 6. Maximum peak flow (cfs) by water year for Meacham Creek, with the month of occurrence indicated.

Table 7. Instantaneous peak flow values (cfs) for various recurrence intervals for the Umatilla River upstream of Meacham Creek and Meacham Creek near the Umatilla River confluence.

Recurrence interval (years)	Umatilla River upstream of Meacham Creek 1402000 1933 to 2000 drainage area = 135.1 sq. mi.	Meacham Creek near Umatilla River confluence 14020300 1976 to 2000 drainage area = 177.4 sq. mi
1.5*	1850	2160
2	2170	2630
5	3030	3780
10	3780	4830
25	4860	6260
50	5760	7430
100	6710	8840

* Often considered bankfull flow.

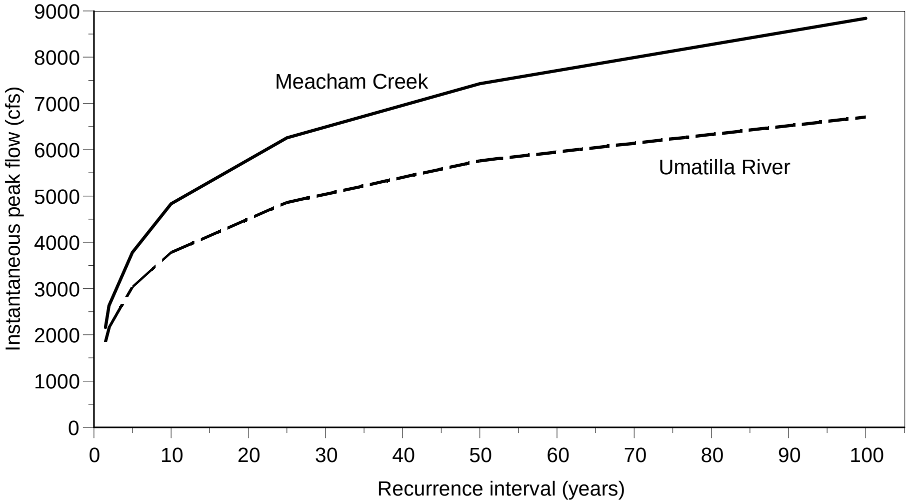


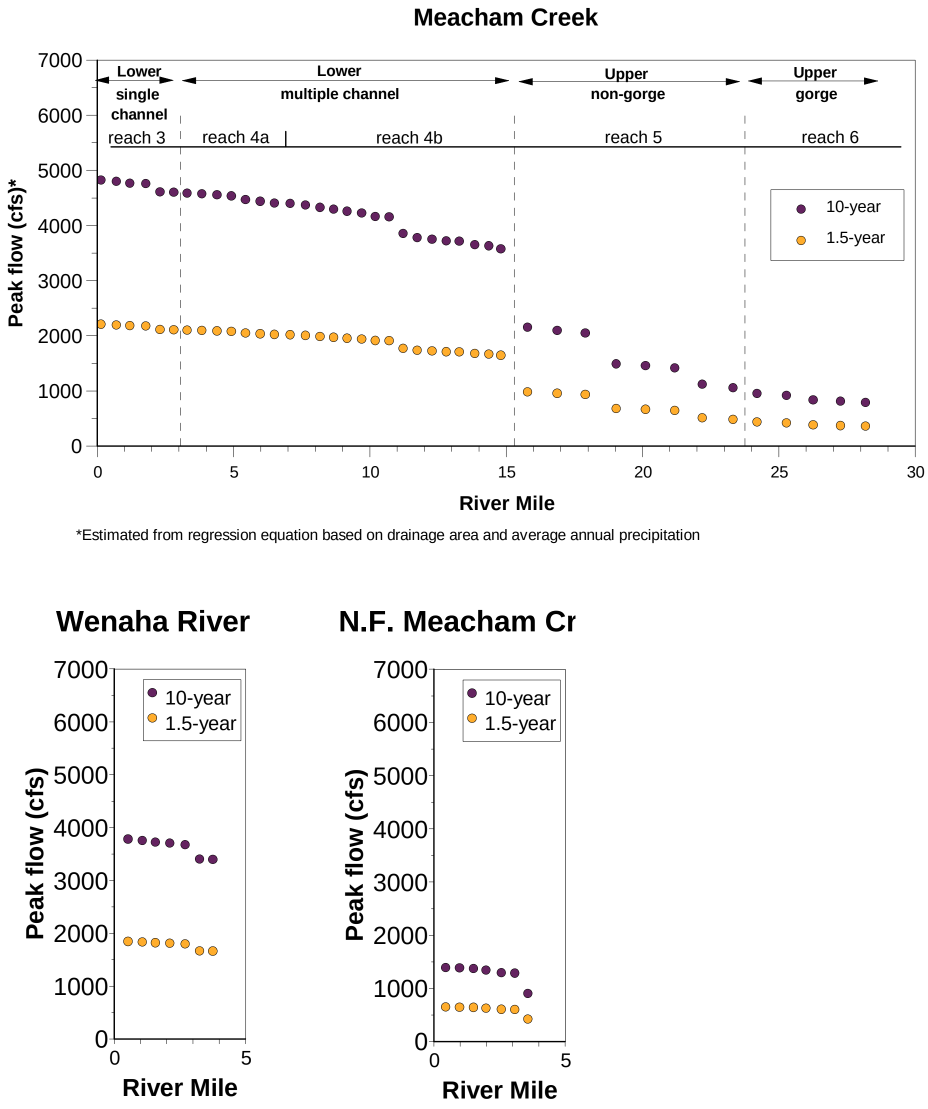
Figure 6.1. Changes in instantaneous peak flow with increasing recurrence interval for Meacham Creek and the Umatilla River.

Using estimated peak flows for each river (Table 7), we determined the recurrence interval of the largest floods that were recorded at the Meacham Creek gauge (Table 8). The largest flood occurred in January, 1975 and is estimated to have a recurrence interval of nearly 100 years. Floods of smaller size occurred in February, 1982 and February, 1985 and were 10- to 25-year events. The November, 1995 flood was a 50- to 100-year event in the Umatilla River and the largest of record, but was only a 10 to 25-year event for Meacham Creek. The January, 1965 flood was a 25-year event in the Umatilla River but its magnitude is unknown for Meacham Creek since the gauge was not yet installed.

Table 8. Unusually high flows for the Umatilla River (since 1933 water year) and Meacham Creek (since 1976 water year) with the estimated recurrence interval.

Umatilla River upstream of Meacham Creek 1402000 1933 to 2000			Meacham Creek near Umatilla River confluence 14020300 1976 to 2000		
Date	Peak flow (cfs)	Recurrence interval	Date	Peak flow (cfs)	Recurrence interval
12/12/46	4320	10-25 year	-	-	
1/29/65	4910	25 year	-	-	
1/25/75	5930	50 year	1/25/75	8200	50-100 year
2/20/82	3090	5 year	2/20/82	5750	10-25 year
2/23/95	4560	10-25 year	2/23/95	5750	10-25 year
11/28/95	6220	50-100 year	11/28/95	5930	10-25 year
1/1/97	5230	25-50 year	1/1/97	4600	5-10 year

The 1.5-year and 10-year peak flows for each of the cross sections established in this study are displayed in Figure 7. Starting at the base of the drainage, peak flow decreased only slightly in the upstream direction since the lower basin width is narrow and there are few tributaries. Where Meacham Creek and North Fork Meacham Creek converge, peak flows in Meacham Creek are about 1.6 times that of North Fork Meacham Creek.



*Estimated from regression equation based on drainage area and average annual precipitation

Figure 7. Calculated 1.5-year and 10-year peak flow for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.

Much of the sediment movement and shaping of stream channels occurs when the flow in a stream equals or exceeds bankfull discharge. Days where flow is equal to or greater than bankfull flow in Meacham Creek have occurred in only about one-half of the years (Figure 8) since records have been kept. Bankfull flows occurring for more than 3 days have happened in only water years 1981, 1982, 1996, and 1997. A bankfull flow has not occurred in Meacham Creek since water year 1997.

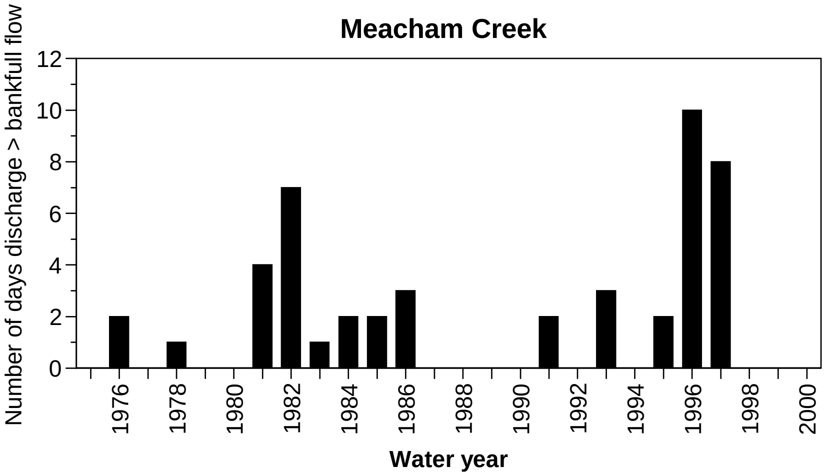


Figure 8. Number of days by water year that discharge exceeded the bankfull discharge near the mouth of Meacham Creek.

Average water depth during a bankfull flow varies widely throughout the Meacham Creek study area, ranging from 1.0 to 3.5 feet (Figure 9). Average water depth generally declines in an upstream direction for lower Meacham Creek but site-to-site variability is high.

A stream power index associated with the bankfull flow was calculated by multiplying bankflow discharge (cfs) by stream channel gradient (ft/ft). The downstream movement of coarse sediment and logs and the propensity for a stream to meander is related to the stream power index. Stream power in Meacham Creek generally increased in an upstream direction until river mile 7 (the upstream extent of reach 4a) and then remained relatively steady until the North Fork Meacham Creek confluence (Figure 10). Upstream of the confluence, stream power increased slightly and then remained steady throughout the gorge portion (reach 6) of upper Meacham Creek.

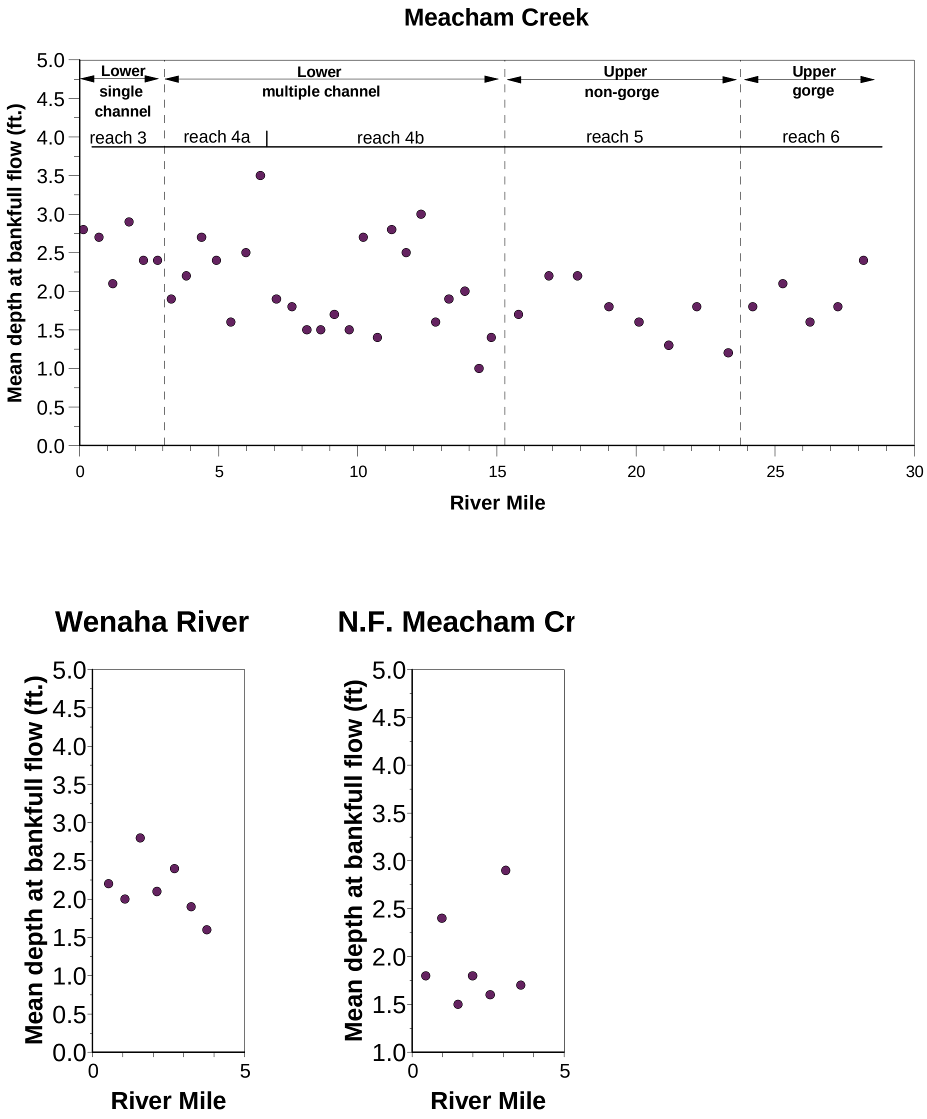
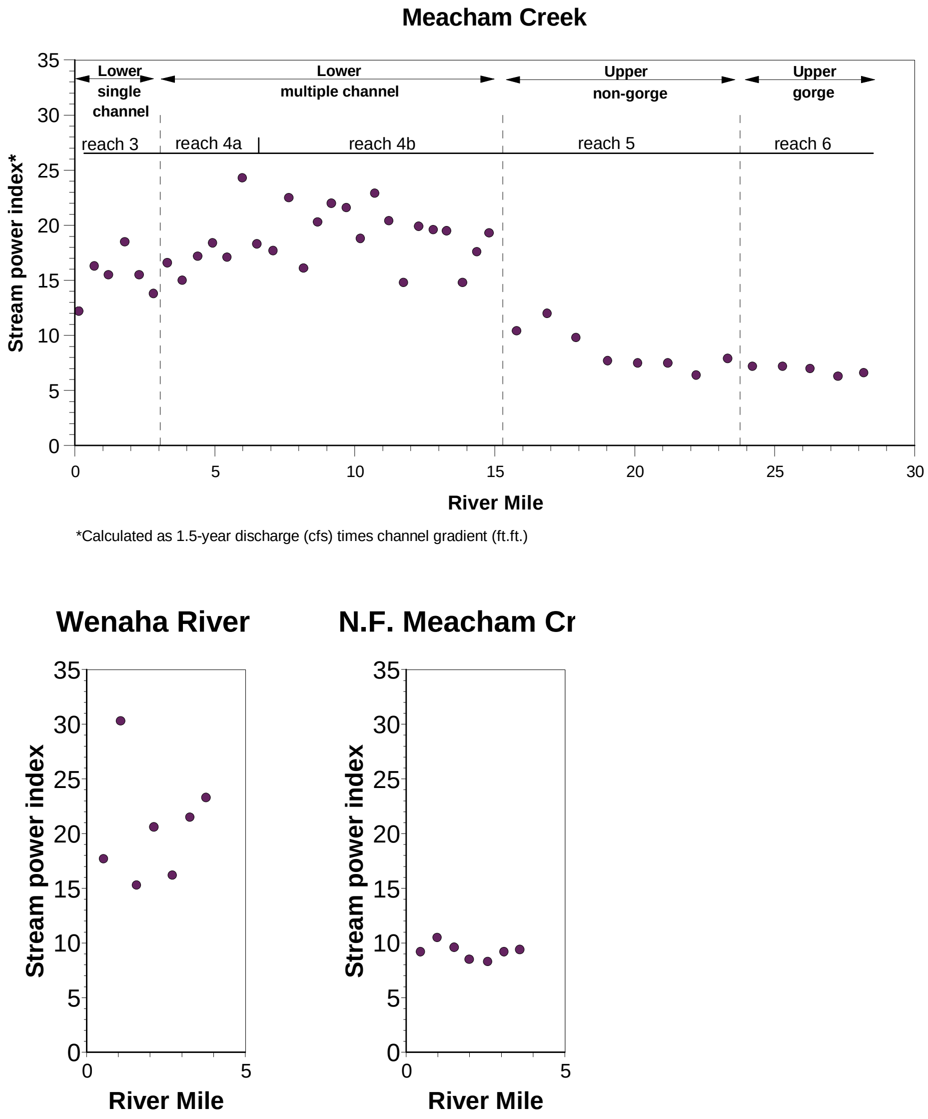


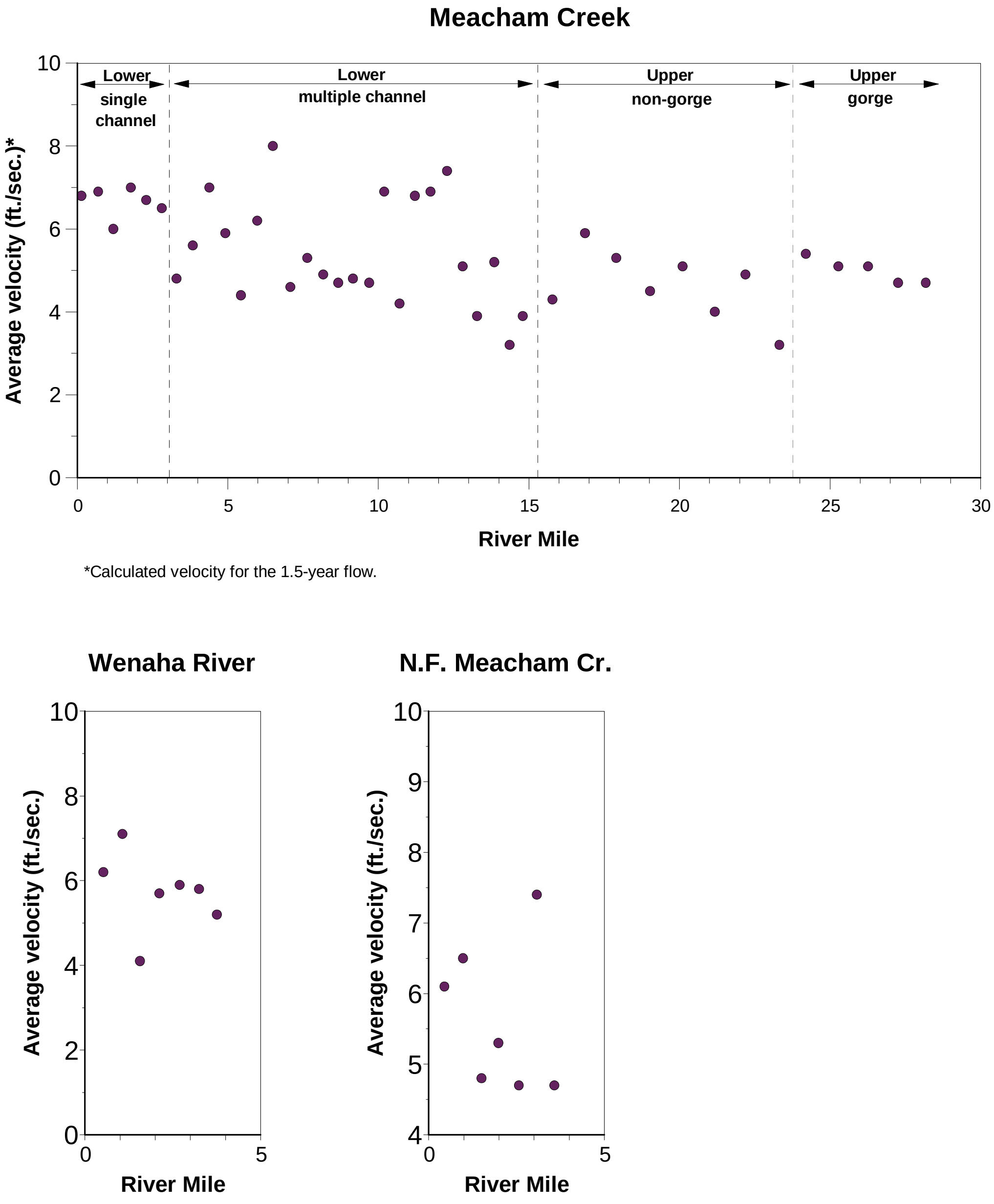
Figure 9. Mean water depth during bankfull flow for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.



*Calculated as 1.5-year discharge (cfs) times channel gradient (ft.ft.)

Figure 10. Calculated stream power index for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.

Average stream velocity at bankfull flow also ranged widely (3.5-8.2 ft/s) throughout the Meacham Creek study area. Values were highest in reach 3, parts of reach 4a, and a segment centered on river mile 11.5 (Figure 11). At these locations, the stream occupies a single channel during bankfull flow. As expected, stream velocity was lowest at those cross sections where the bankfull flow was spread out over a broad channel or multiple channels.



*Calculated velocity for the 1.5-year flow.

Figure 11. Calculated average water velocity for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.

Water levels within Meacham Creek during our field surveys were unusually low and so measured water surface widths are less than they would be during normal summers. Meacham Creek has three sections where summer flow is subsurface. One location is centered on river mile 12.5, downstream of the North Fork Meacham Creek confluence (Figure 12). Another dry section occurs immediately upstream of the North Fork Meacham Creek confluence. Both of these dry sections occur in areas with extensive accumulations of coarse sediments. Finally, an extended reach of subsurface flow occurs from river mile 21 to 27 in upper Meacham Creek. We examined notes kept during the original land survey in the fall of 1887 for comments on whether or not Meacham Creek was dry or flowing where a section line crossed the stream. Those reaches which were noted as dry in 1887 were also dry in 2002. The railroad grade had been constructed prior to the 1887 survey so there was no way to determine whether or not the subsurface reaches were a result of rock filling the channel during railroad construction. The railroad grading within the bedrock gorge portion of upper Meacham Creek was probably constructed using dynamite. The steep slopes probably caused much of the blasted material to end up in the valley bottom. However, when we examined the angularity of rock in the gorge portion of Meacham Creek, we could see no difference between this substrate and that found throughout other portions of the Meacham Creek channel. Either the blasted rock quickly became rounded by being tumbled in the stream, was buried by natural stream substrate, or was transported out of the basin during floods.

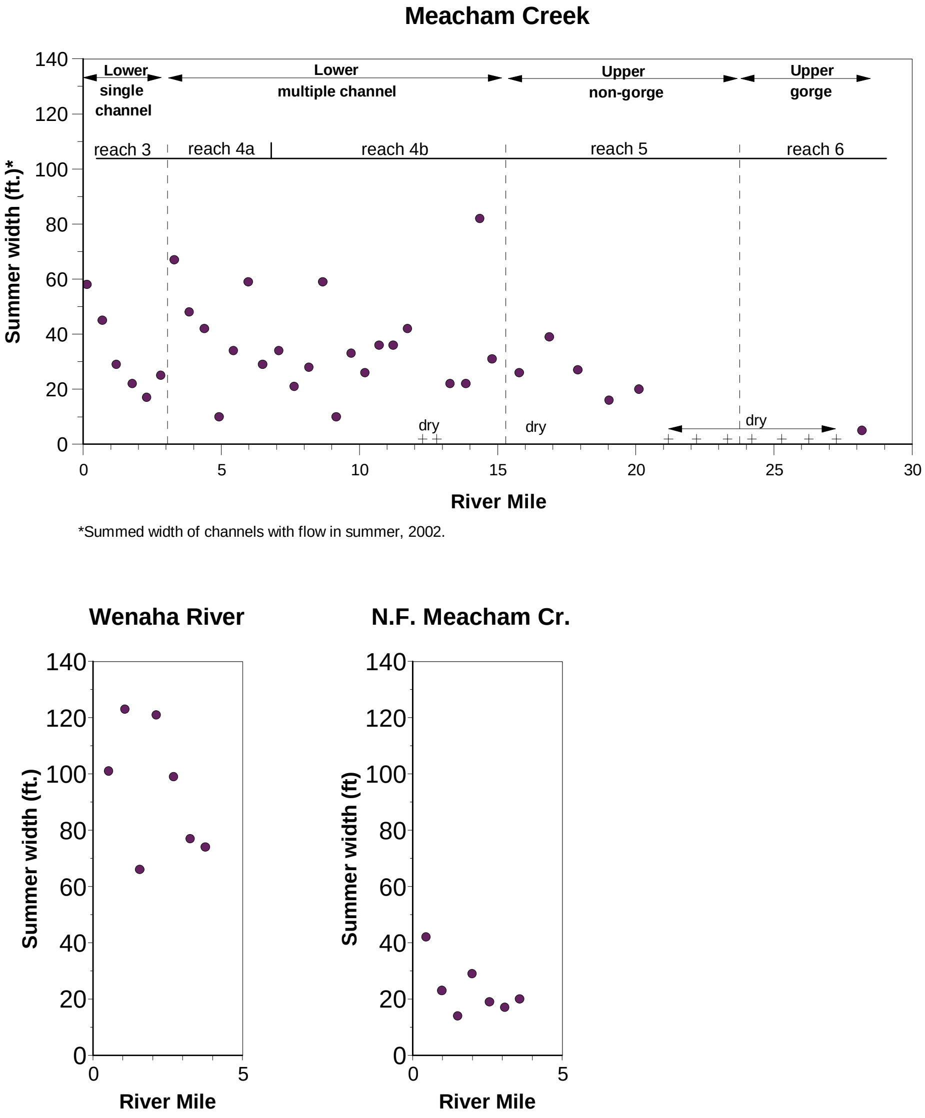
Summer wetted width varied widely from 10 to 80 feet with no longitudinal trends. The Wenaha River had an average summer width of 94 feet compared to its Meacham Creek counterpart (reach 4b) which had an average width of 37 feet. These differences in summer width do not reflect differences in channelization but are merely a reflection that flow is greater in the Wenaha River.

Discussion

Flood flows and average annual flows in Meacham Creek have decreased considerably since 1997. Historic flow records indicate that since 1966 the Umatilla basin has undergone cycles of dry and then wet years with the periodicity of about 13 years. It has been 5 years since a channel-forming flow (equal to or greater than bankfull) has occurred in Meacham Creek, suggesting that we are currently near the bottom of the trough within the current cycle. Correspondingly, channel changes, wood movement, and sediment movement have probably been minimal during the last 5 years.

The technique we used to accurately predict (within 10%) bankfull and 10-year peak flow for any location in Meacham Creek and the Wenaha River using easily-obtained information on drainage area and average annual precipitation allows for an accurate determination of flow parameters, such as discharge and velocity, at each cross section. An extension of this evaluation with focus on channel geometry and flood plain width is provided in a following section.

We could find no evidence that the three sections of Meacham Creek that go subsurface during the summer are a result of the railroad construction in the early 1880’s. The presence of these dry reaches has a profound affect on summer fish habitat. The dry reaches keep juvenile fish from moving upstream to find zones of cool water during the summer. However, as discussed later, the dry sections create downstream zones of cool water. The high variability in summer wetted width throughout Meacham Creek reflects the spatial variability in the ratio of surface flow to subsurface flow.



*Summed width of channels with flow in summer, 2002.

Figure 12. Summer widths for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.

Channel substrate

At first glance, alluvial deposits within Meacham Creek seemed unnaturally abundant and coarse compared to the reference reaches. The general scarcity of streamside brush and trees along the stream and the low summer surface flows further enhanced the perception that the stream is choked by coarse substrate. Causes of accelerated delivery of large substrate to the channel or a reduced ability of the stream to hold back finer sediments were not obvious. To help resolve this issue, we examined basin-wide patterns in the size distribution of channel surface substrate and compared sediment size in Meacham Creek to the reference reaches.

Methods

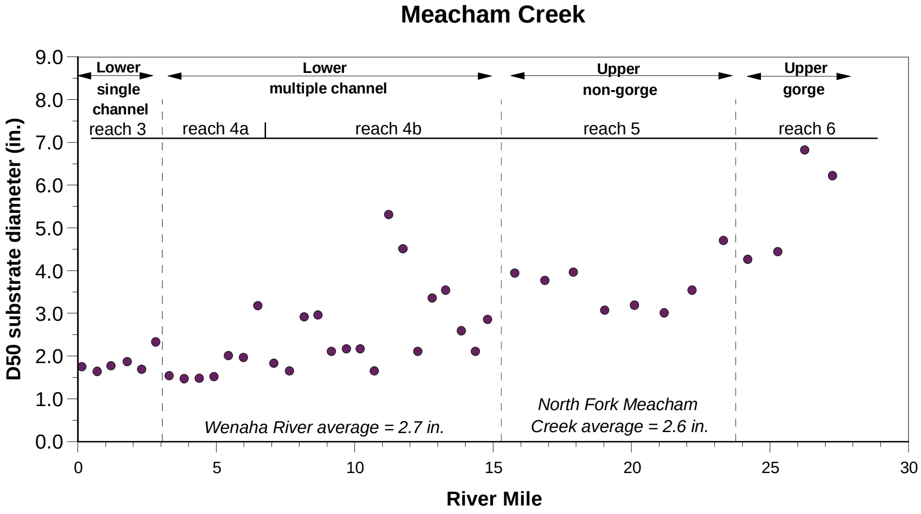
We sampled the surface channel substrate within the bankfull width upstream and downstream of each cross section. One hundred pebbles were sampled at a cross section with 10 pebbles gathered at each of 10 transects. Transects were spaced 50 feet apart with 5 upstream and 5 downstream of the cross section. Transects included riffles, glides, and pools, but since pools are rare in these streams, most transects were from riffles and glides. Since transects were established at fixed intervals, riffles and pools were sampled in proportion to their occurrence. The 10 pebbles from each transect were selected at random distances across the bankfull width. The selection was done blindly (a pencil poke off the toe of the boot) in order to not bias pebble selection. The diameter of each pebble was measured and the samples pooled to create a size frequency distribution at each cross section. The diameter associated with the 50% finer threshold of the frequency distribution was calculated, as well as diameters for the 15%, 34%, 84%, and 95% finer thresholds. A size frequency distribution constructed from a sample of only 100 pebbles can sometimes result in anomalous values in predicted diameter for 84% and 95% thresholds. Where predicted diameters were clearly erroneous, these values were not used.

Results

The mean diameter size (50% finer threshold or D50) of the channel substrate was relatively consistent from the mouth of Meacham Creek to river mile 6 (Figure 13), averaging 1.8 inches. Here, the flow is often confined to a single channel or runs parallel to steep, rock cliffs on the west side of the valley. From river mile 6 to the North Fork Meacham Creek confluence the mean diameter varied widely from cross section to cross section (range of 1.7 to 5.3 inches) but generally coarsened in an upstream direction. The stream here meanders across a wide flood plain and multiple channels are common.

Mean diameter size in Meacham Creek was greater upstream of the North Fork Meacham Creek confluence than downstream. Diameter size was even greater for the gorge section and increased in an upstream direction.

Longitudinal patterns in the D15 substrate size class (diameter for which 15% of the pebbles are smaller) are generally the same as for the D50 size class except for wider variability among cross sections throughout the study area (Figure 13).



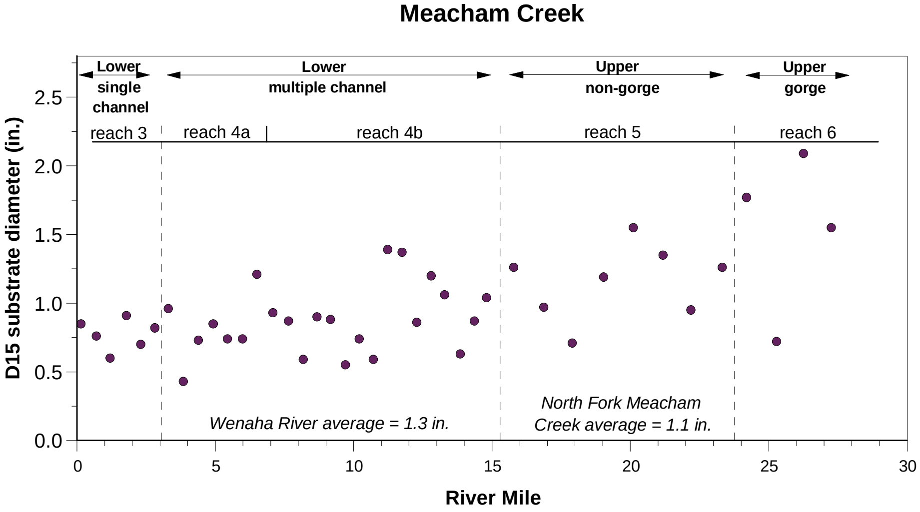


Figure 13. D50 and D15 surface substrate diameters for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham reference reaches.

The D50 diameter for channel substrate in reach 4b of lower Meacham Creek was the same as that for the Wenaha River reference reach (Table 9). The D15 diameter was slightly higher for lower Meacham Creek. Variability among cross sections was greater for lower Meacham Creek.

Reach 5 of upper Meacham Creek had a mean D50 diameter that was 1 inch greater than the North Fork Meacham Creek reference site, although mean D15 diameters were about the same. Variability among cross sections was the same for the two reaches.

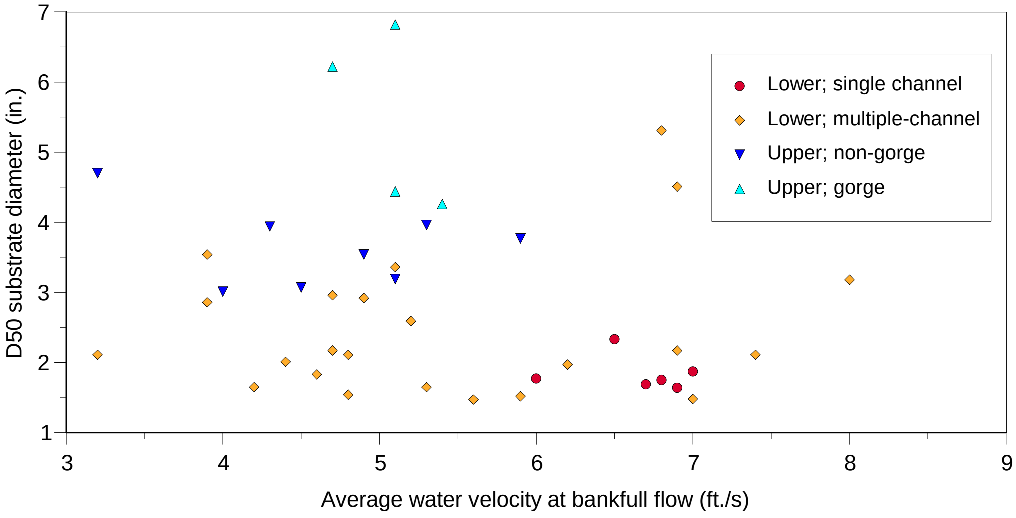
Table 9. Comparison of the D50 and D15 diameter between the two reference reaches and counterpart reaches in lower and upper Meacham Creek.

	Lower Meacham reach 4b	Wenaha River reference reach 1	Upper Meacham reach 5	North Fork Meacham reference reach 2
D50 diameter (in.)				
mean	2.7	2.7	3.6	2.6
standard deviation	*1.0*	*0.3*	*0.6*	*0.6*
D15 diameter (in.)				
mean	0.9	1.3	1.2	1.1
standard deviation	*0.3*	*0.1*	*0.3*	*0.3*

Theoretically, channel substrate should be the coarsest where water velocity is the highest, assuming that the stream is not scoured down to bedrock. However, when the D50 substrate diameter was plotted against average water velocity (during a bankfull flow) for cross sections evaluated in this study, such a relationship is missing (Figure 14).

The size distribution of stream substrate and evidence of layering can be observed at a number of locations throughout the study area where the stream has recently meandered into old alluvial terraces, leaving a vertical face. These areas had non-graded substrate deposits with a wide range of pebble sizes, as illustrated in Figure 15. Layering was uncommon. The random arrangement of particles in the terrace deposits and the wide range of pebble sizes suggest that the alluvium was deposited during very large floods that were perhaps accompanied by slope failures, debris torrents, and rapid movement of sediment down the valley. We did not do any sampling of aggregate directly below the surface of the streambed, but we assume that, like most streams, Meacham Creek has a surface layer of larger-sized aggregate over deposits of smaller-sized aggregate.

Meacham Creek



Wenaha River and North Fork Meacham Creek

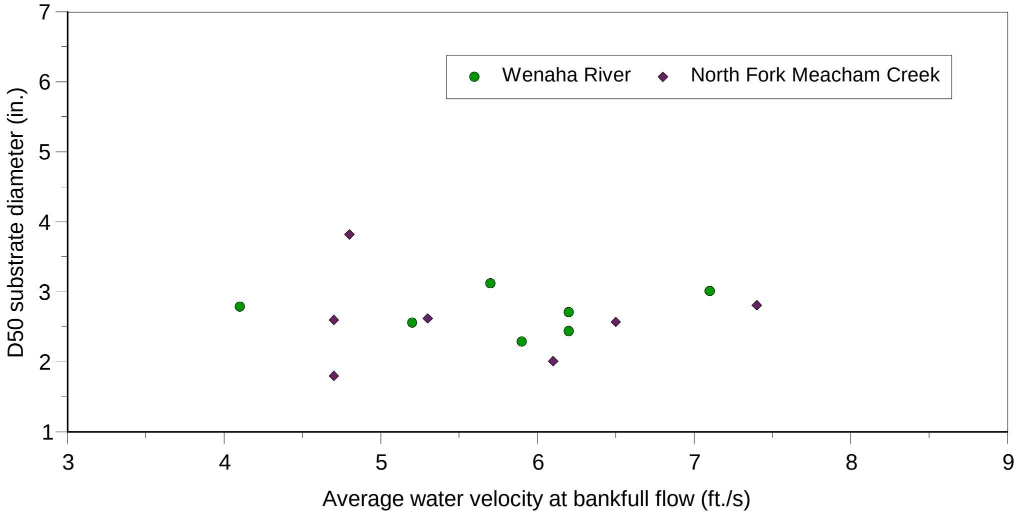


Figure 14. Association between the D50 channel substrate diameter and average water velocity at bankfull flow for cross sections throughout Meacham Creek and for the Wenaha River and North Fork Meacham reference reaches.

Figure 15. Substrate at the bare surface of a vertical streamside bank in lower Meacham Creek. The largest rock in the photograph is about 7 inches across.

Discussion

Our initial impression that Meacham Creek had unusually coarse channel substrate did not prove true upon examining field evidence. Channel coarseness was not greater in Meacham Creek than it was in the paired reference reaches.

The lack of correlation between mean substrate diameter and average water velocity during bankfull flow is puzzling. The re-working of gravel deposits during minor high flows over a period of years may be disguising this relationship; it has been five years since the last bankfull flow occurred. Alternatively, the lack of correlation may be due to the use of average velocity rather than localized maximum velocity in the analysis. Considering the wide, irregular flood plains common to these streams, water velocities high enough to move larger substrate may be limited to only a portion of the stream cross section. We had no way of estimating localized maximum water velocity.

Alluvial deposits recently exposed by stream meandering are not stratified or graded. The deposition seems to be similar to that which occurs during extreme floods or following debris torrents. The surface substrate currently seen within the bankfull width of Meacham Creek and the two reference streams may be a product of a previous climate regime when extreme floods were greater than they are now. This could occur if the climate was colder and created deeper and more extensive snow packs. When warm and intense winter rain storms arrived there would be a greater amount of melted snow contributing to streamflow. A climate regime typified by extreme floods would leave behind a deep substrate of larger size that would not be as easily transported downstream during a subsequent climate regime which had dampened peak flows.

Since individual stones are not angular, these deposits are probably not a result of filling of the upper Meacham Creek canyon with sidecast material during railroad construction, followed by downstream movement of the material during floods. There is no information for Meacham Creek or any other northeast Oregon streams on bedload movement. Such a study would involve several decades of measurements at permanent cross-sections and results would need to be interpreted in terms of when the last major flood had occurred. With existing information, nothing can be concluded about whether or not the total load of aggregate in Meacham Creek is in equilibrium.

Channel and flood plain geometry

The geometry of the stream channel(s) and the adjacent flood plain can be a product of multiple natural and human influences. The frequency and magnitude of floods, size and source of sediments, channel confinement, and density and size of vegetation growing next to the stream each leave a mark on geometry. Spatial variation in channel shape can help understand natural channel-forming patterns within a basin and human influences on these processes.

Channel geometry can have a strong influence on fish habitat. Wide floodplains with multiple channels provide zones of slow-water refuge for fish when streamflow is high and allow fish to access additional sources of food. These wide floodplain reaches also have a higher component of the flow beneath the surface during the summer. This can benefit fish by allowing some of the water to cool as it flows through deep gravel deposits. However, these sections may also provide little living space for fish during low flows. Confined floodplains with single channels tend to intercept the cool, subsurface flow from upstream reaches and provide abundant living space for fish in summer. Nevertheless, the swift water common to confined reaches during high flows can make these areas inhospitable for fish.

In this section, we present detailed information on channel and flood plain geometry, as measured at 56 cross sections throughout the study area. We also include the Rosgen Level II classification at each cross section; this classification system is commonly used by the Forest Service to describe channel shape and surface substrate composition (Rosgen 1996). We examine longitudinal variation in channel geometry throughout Meacham Creek and provide comparisons with the reference reaches.

Methods

We measured valley floor width throughout the Meacham Creek and the two reference reaches using a digital elevation model. The valley floor was defined by selecting a low-gradient subset of grid values that bordered the general stream course and corresponded to the historic flood plain of the stream. The break between valley floor to steep hillslope was usually abrupt within the study area. The downstream end of those tributaries that have low-gradient, alluvial fans were not included in the valley floor width determination. Measurements were made for two scenarios; without the railroad grade and with the railroad grade in place.

Channel cross sections were surveyed every one-half mile along lower Meacham Creek and along the reference reaches. Cross sections were surveyed every mile along upper Meacham Creek. Cross sections began and ended at the elevation that roughly corresponded to the 10-year flow and extended across the flood plain to include all overflow channels.

We plotted the channel cross sections and used the computer software, WinXSPRO, to determine water elevation corresponding to the 1.5-year flow (bankfull flow) and the 10-year flow. The following parameters were then determined (and illustrated in Figure 16):

- Combined widths of the water surface during the summer (July, 2002)
- Combined widths of the water surface at the 1.5-year (Q1.5) and 10-year (Q10) flow
- Number of discrete channels at the 1.5-year and 10-year flow
- The active channel width at the 10-year flow (includes the width of any incorporated islands)
- The floodprone width (elevation determined by taking the maximum channel depth at a bankfull flow and multiplying by two; floodprone width has no hydrological significance other than being a parameter for defining entrenchment and channel shape under the Rosgen Level II classification method).

We classified stream segments (from one cross section to the next) using the Rosgen Level II classification system. Under this classification, channel geometry (designated by a letter) is followed by a dominate substrate size (designated by a number), as illustrated in Figure 17. For this rating system, entrenchment ratio is defined as the floodprone width divided by the bankfull width. The width/depth ratio is defined as the bankfull width divided by the mean water depth during bankfull flow. Appendix B provides a summary of all hydrological and physical parameters evaluated for each cross section.

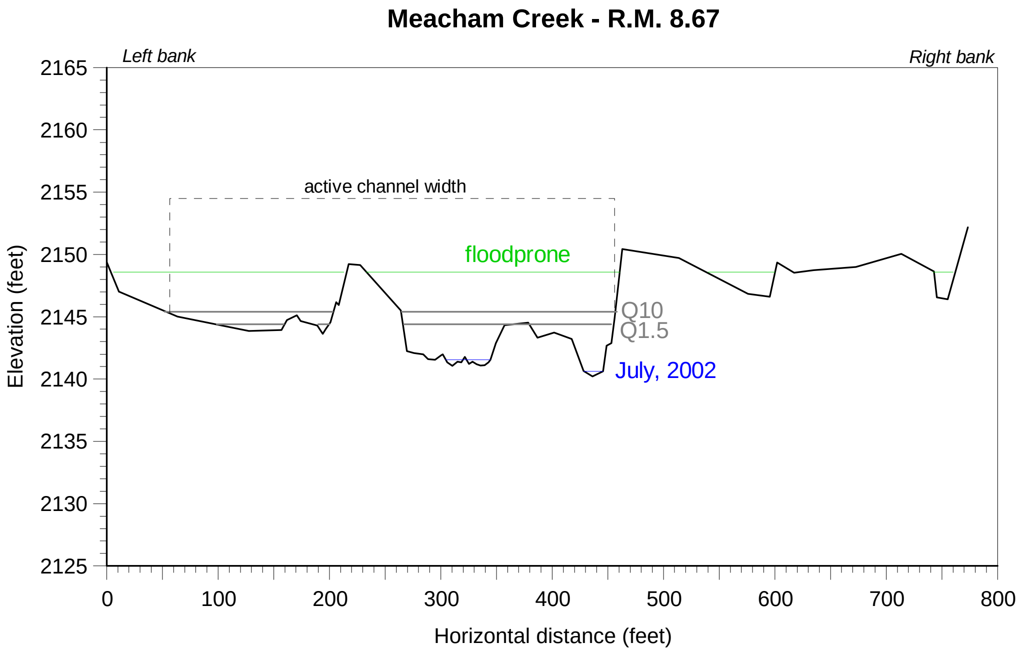


Figure 16. Example showing elevations of the surface of summer channels in blue, bankfull channels (Q1.5), and channels during a 10-year flow (Q10) in grey. Also shown is active channel width during a 10-year flow and the Rosgen floodprone elevation (green).

Results

Valley floor width

The railroad grade has narrowed the valley floor available for future stream meandering by 16 to 24% in lower Meacham Creek and 7 to 19% in upper Meacham Creek (Table 10). Losses in valley floor width were greatest from river mile 1.5 to 3.5 and from river mile 10 to 12 (Figure 18). The railroad crosses the stream twice in lower Meacham Creek and coincides with these locations of greatest valley floor width loss. In spite of the sizable losses in valley floor width in lower Meacham Creek, these altered reaches are still wider than the Wenaha River reference reach.

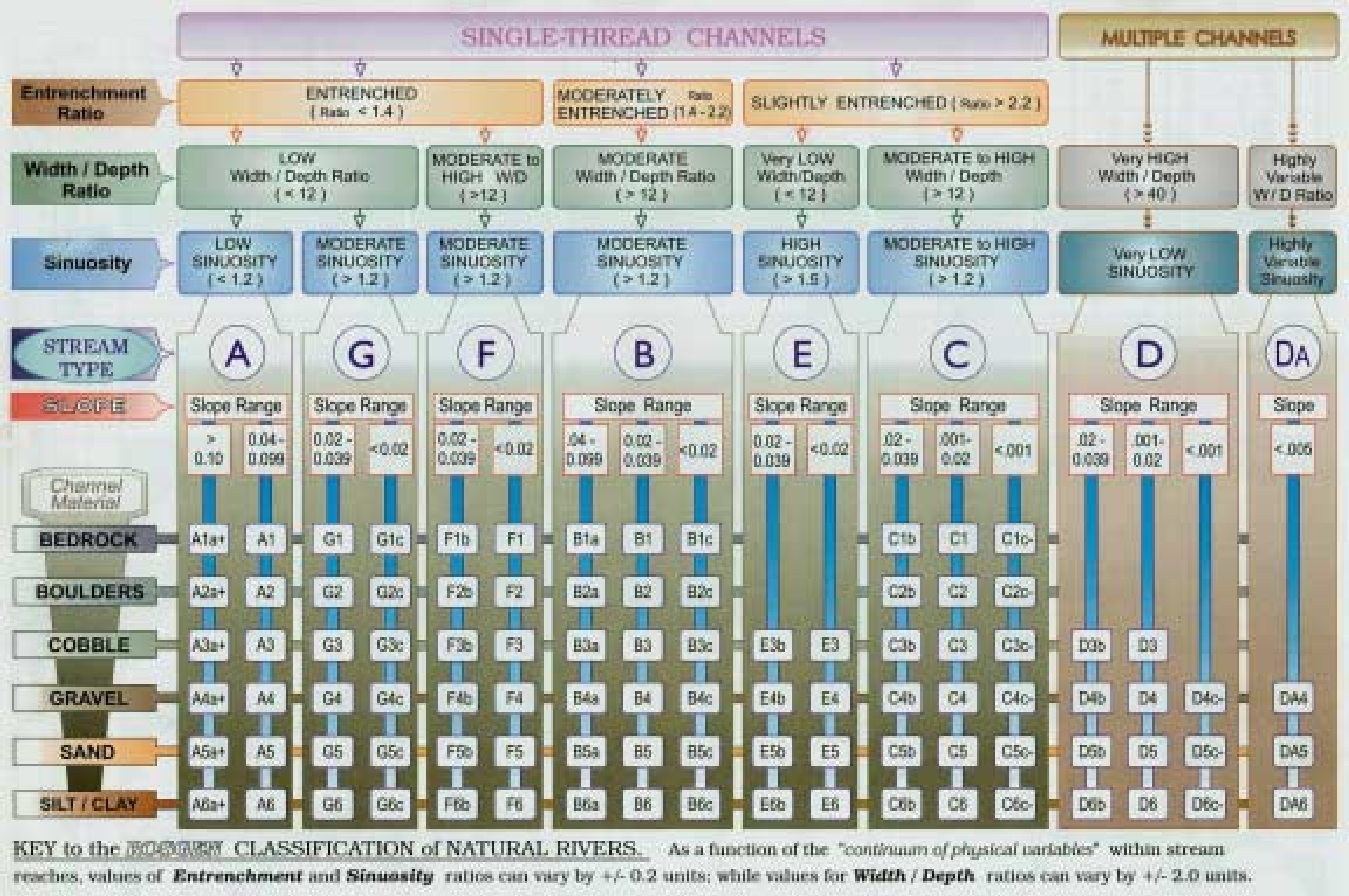


Figure 17. Rosgen Level II classification of stream channels.

Table 10. Summary of average valley floor widths by reach before and after railroad construction.

	Average valley floor width (feet) without railroad	with railroad	Percent difference
Lower Meacham			
Reach 3	970	740	-24%
Reach 4a	880	730	-16%
Reach 4b*	1040	800	-23%
Upper Meacham			
Reach 5**	370	300	-19%
Reach 6	190	170	-7%
Wenaha River			
Reach 1*	620	-	-
North Fork Meacham			
Reach 2**	520	-	-

* paired reaches ** paired reaches

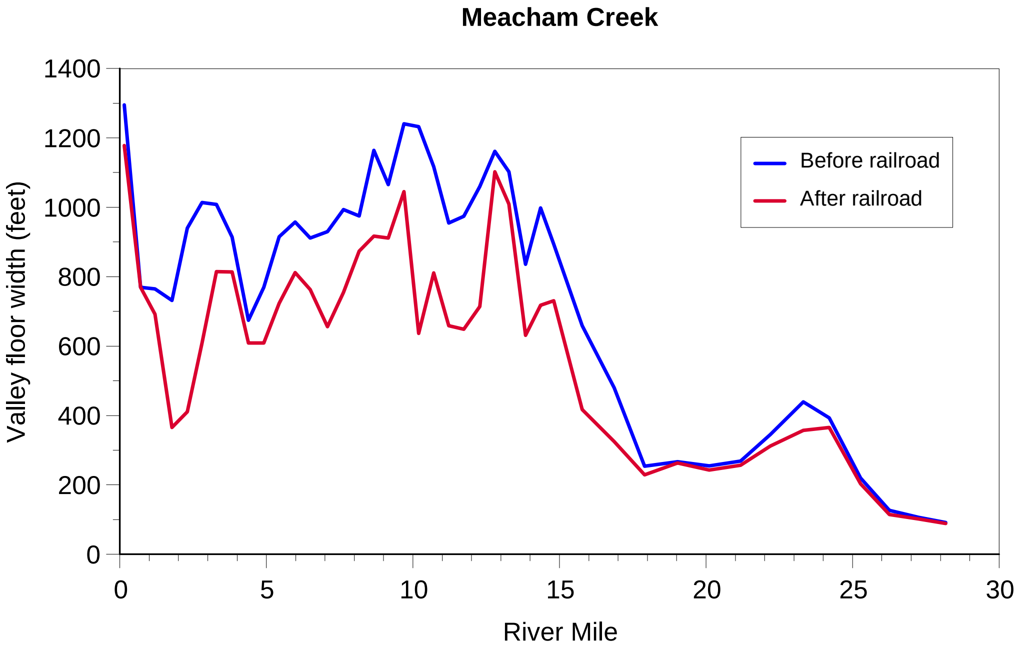


Figure 18. Valley floor width of Meacham Creek before and after the railroad was constructed. Reach 3 is from R.M. 0.00 to 3.30, Reach 4a is from R.M. 3.30 to 7.08, Reach 4b is from R.M. 7.08 to 14.90, Reach 5 is from R.M. 14.90 to 24.20, Reach 6 is from R.M. 24.2 to 28.18.

Bankfull width

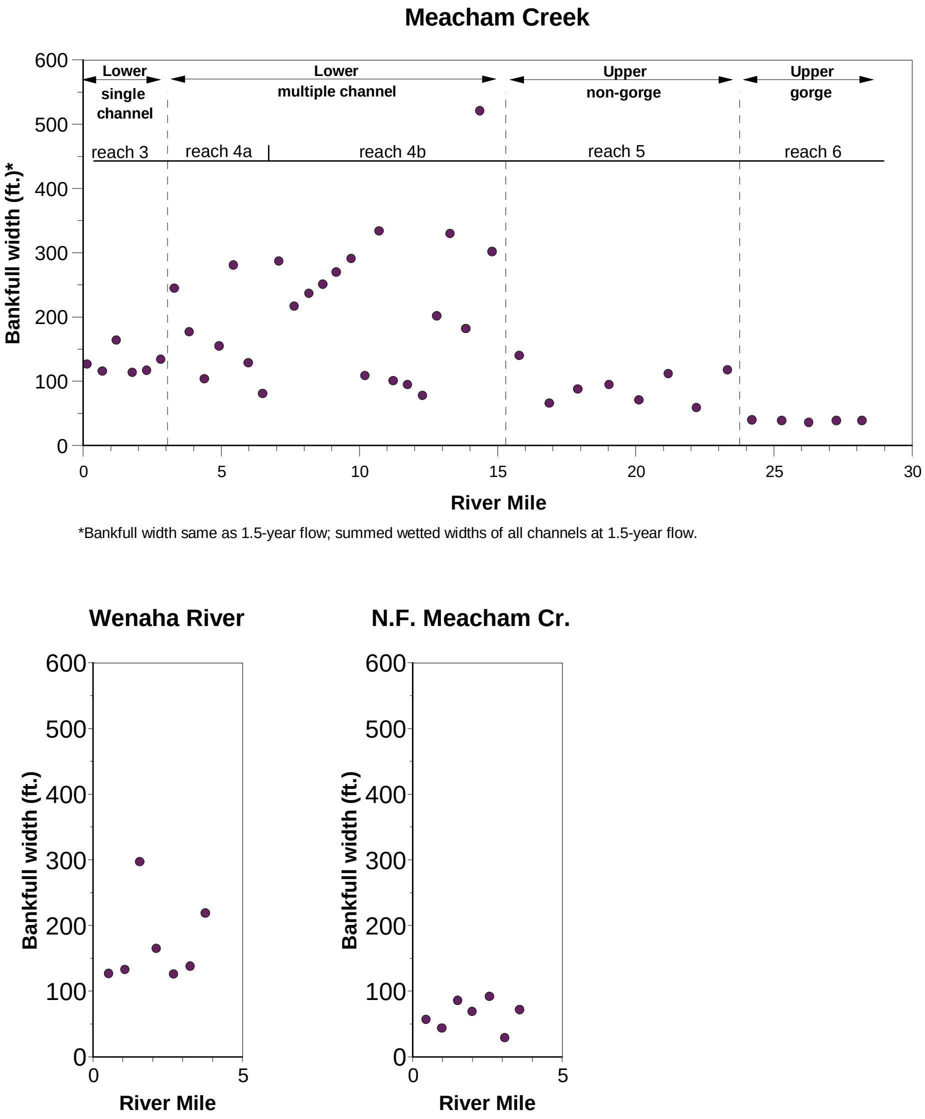
The derivation of bankful width at cross sections is discussed in the methods section. Bankfull width, as derived from the WinXSPRO model, varied considerably <u>among</u> reaches but did not exhibit longitudinal trends <u>within</u> reaches (Table 11, Figure 19). In lower Meacham Creek, bankfull width averaged nearly twice as much in the multi-channel Reach 4b than it did in the single-channel Reach 3. Variability from station to station was high in Reach 4b. The bankfull width of Meacham Creek was markedly less (by over one-half) upstream of the North Fork Meacham Creek confluence (reach 5) and then again for upper Meacham Creek where flow is through a rocky gorge (reach 6).

Average bankfull width in reach 4b of lower Meacham Creek was over 25% greater than its paired reference reach in the Wenaha River. Similarly, reach 5 of upper Meacham Creek was 33% wider than its paired reference reach in North Fork Meacham Creek.

Table 11. Summary of bankfull (1.5-year flow) widths.

		Bankfull width (feet)
Lower Meacham		
	Reach 3	129
	Reach 4a	167
	Reach 4b*	238
Upper Meacham		
	Reach 5**	97
	Reach 6	39
Wenaha River		
	Reach 1*	172
North Fork Meacham		
	Reach 2**	64

* paired reaches ** paired reaches



*Bankfull width same as 1.5-year flow; summed wetted widths of all channels at 1.5-year flow.

Figure 19. Bankfull width for Meacham Creek and for the Wenaha River and North Fork Meacham Creek reference sites.

Active channel width

The active channel width associated with a 10-year flow increased in an upstream direction within reaches 4a and 4b (Table 12, Figure 20). Reach 3 had an average active channel width that was only about 30% of that for reach 4b. Variability among sites was very high throughout reach 4b and also throughout the Wenaha River, its reference reach. Within upper Meacham Creek, the active channel width in the non-gorge portion (reach 5) was over 2.5 times that of the gorge portion (reach 6).

The active channel width of reach 4b in lower Meacham Creek was about 1.4 times that of the Wenaha River reference reach. In contrast, the active channel width of reach 5 in upper Meacham Creek was 76% of the North Fork Meacham Creek reference reach.

Table 12. Summary of active channel width associated with the 10-year flow.

		Active channel width (feet)
Lower Meacham		
	Reach 3	143
	Reach 4a	266
	Reach 4b*	473
Upper Meacham		
	Reach 5**	133
	Reach 6	50
Wenaha River		
	Reach 1*	331
North Fork Meacham		
	Reach 2**	175

* paired reaches   ** paired reaches

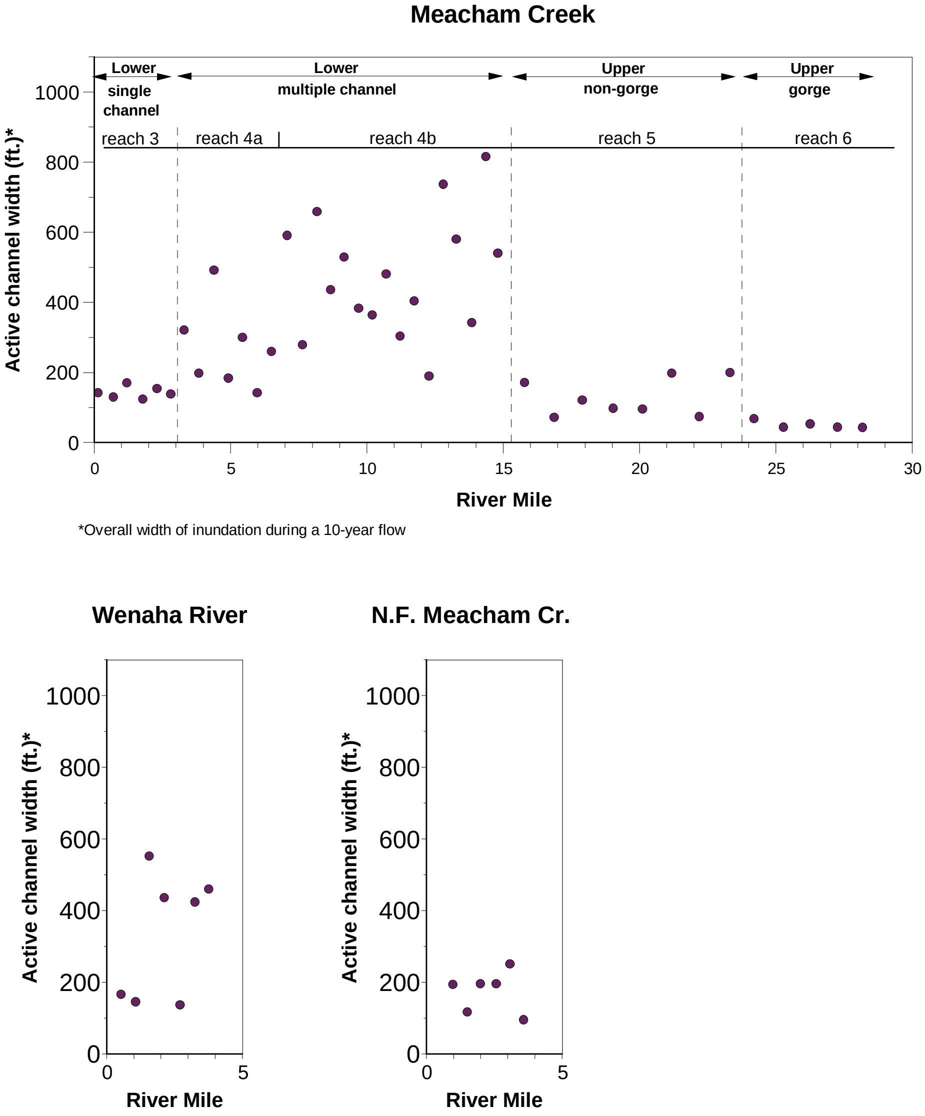


Figure 20. Active channel width during a 10-year flow for Meacham Creek and for the Wenaha River and North Fork Meacham Creek reference sites.

Number of channels

The number of channels with flowing water at lower Meacham Creek cross sections generally increased in an upstream direction (Table 13, Figures 21-23), especially for the 1.5-year flow. Multi-channel reaches were uncommon in upper Meacham Creek.

Reach 4b of lower Meacham Creek and the Wenaha River reference reach had a similar number of channels during the 1.5- and 10-year flows but fewer during summer flow. Reach 5 of upper Meacham Creek had far fewer channels during 1.5- and 10-year flows than did its reference reach (North Fork Meacham Creek).

Table 13. Summary of the number of channels associated with the summer, 1.5-year, and 10-year flow.

	Average number of discrete channels		
	Summer flow	1.5-year flow	10-year flow
Lower Meacham			
Reach 3	1.2	1.2	1.0
Reach 4a	1.1	1.4	1.3
Reach 4b*	1.4	2.8	2.9
Upper Meacham			
Reach 5**	-	1.4	1.3
Reach 6	-	1.0	1.0
Wenaha River			
Reach 1*	2.1	2.6	2.3
North Fork Meacham			
Reach 2**	1.0	1.6	2.3

* paired reaches ** paired reaches

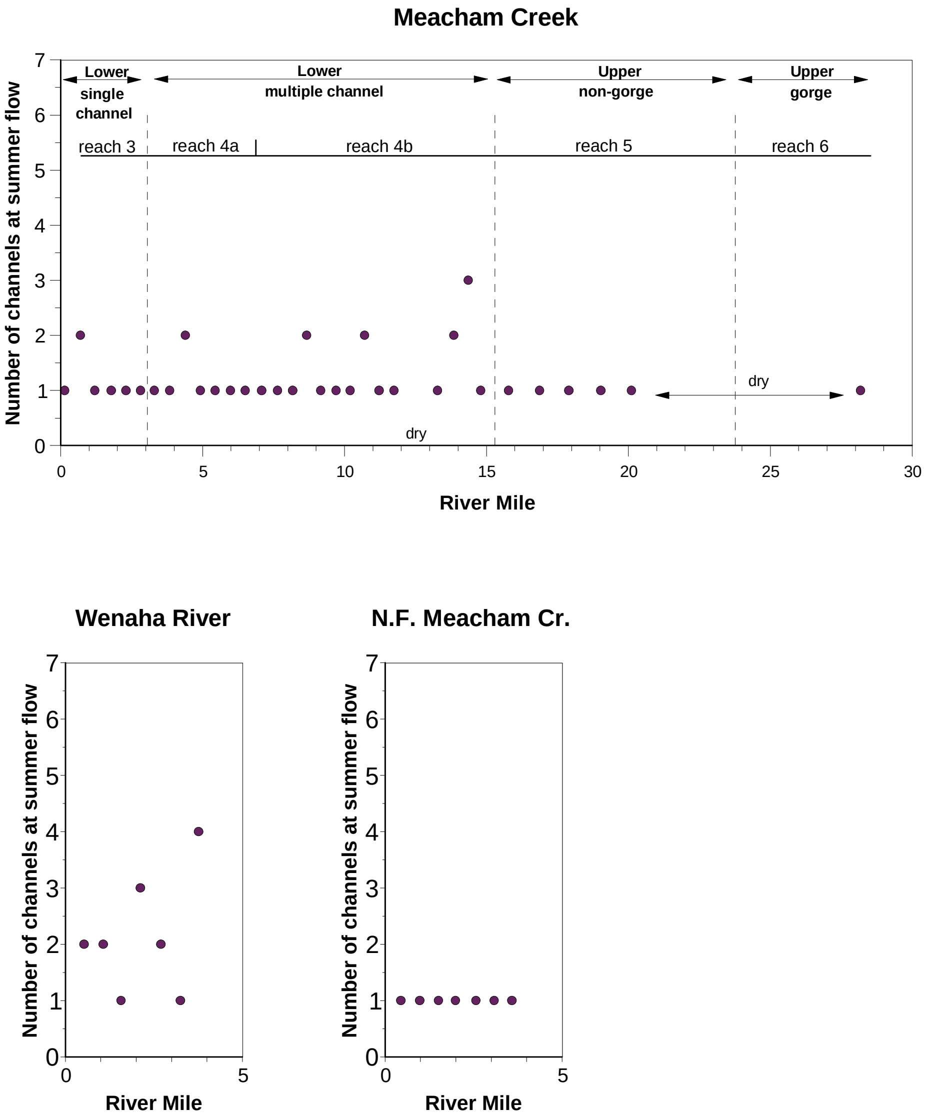
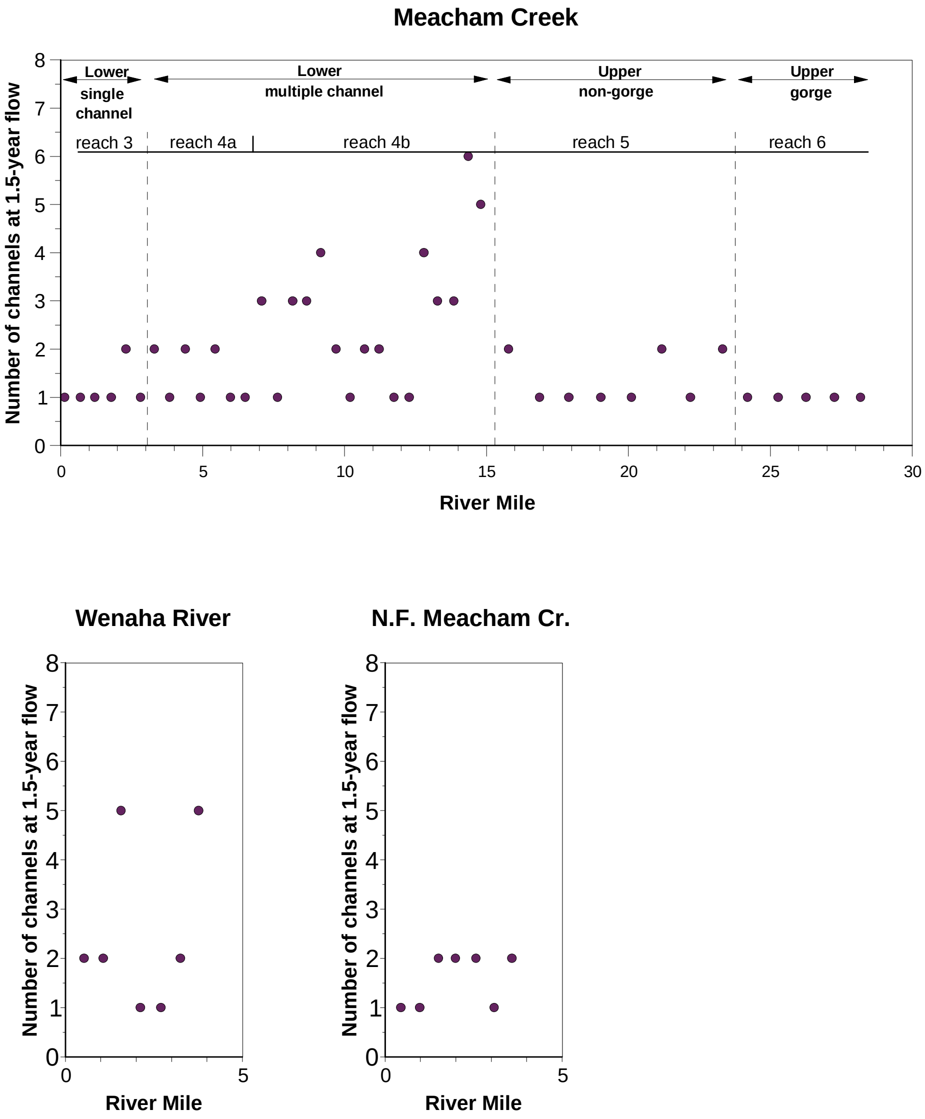


Figure 21. Number of discrete channels for Meacham Creek and for the Wenaha River and North Fork Meacham Creek reference sites during summer flow.


Meacham Creek

Wenaha River

N.F. Meacham Cr.

Figure 22. Number of discrete channels for Meacham Creek and for the Wenaha River and North Fork Meacham Creek reference sites during a bankfull flow.

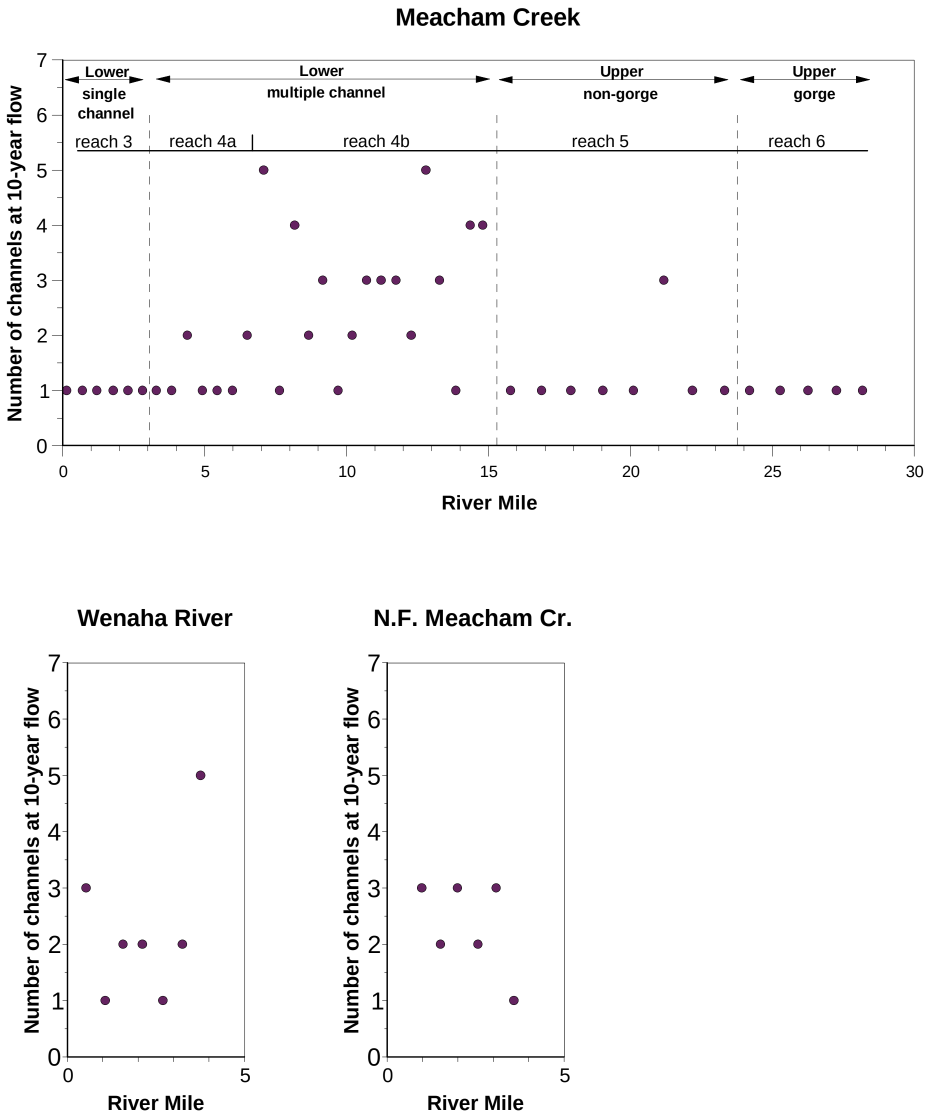


Figure 23. Number of discrete channels for Meacham Creek and for the Wenaha River and North Fork Meacham Creek reference sites during a 10-year flow.

Rosgen channel classification

The Rosgen Level II channel classification (see Figure 17 for details) is one or several methods designed to categorize differences in channel geometry and channel substrate size among stream reaches. In our study, the general reach breaks we initially observed throughout Meacham Creek (reach 3 through reach 6) were confirmed by the Rosgen channel classification. Reach 3 was dominated by Type C channels, while Reach 4a was a mix of Type C, D, and F channels (Table 14 and Table 15). Further upstream, reach 4 was dominated by multi-thread Type D channels. Upstream of the North Fork Meacham Creek confluence, reach 5 included a wide range of channel types including Bc, D, F, and C. Reach 6, a rocky gorge, was exclusively Bc and F types.

Reach 4b in lower Meacham Creek and the Wenaha River reference reach consisted mostly of Type C and D channels, but Meacham Creek had a higher proportion of the multi-thread Type D channels. The majority of cross sections in North Fork Meacham Creek were Type C channel types while its Meacham Creek counterpart included more Bc and F Types, signifying a more-confined stream channel.

Table 14. Rosgen Type II channel classification for cross sections in Meacham Creek and in the Wenaha River and North Fork Meacham Creek reference sites. R.M. means river mile.

Meacham Creek										Wenaha River		North Fork Meacham	
Reach 3		Reach 4a		Reach 4b*		Reach 5**		Reach 6		Reach 1*		Reach 2**	
R.M.	Type	R.M.	Type	R.M.	Type	R.M.	Type	R.M.	Type	R.M.	Type	R.M.	Type
0.14	C4	3.30	D4	7.08	D4	15.78	F3	24.20	B3c	0.53	D3	0.45	C4
0.70	C4	3.84	C4	7.64	C4	16.87	B3c	25.28	B3c	1.07	C3	0.98	C3
1.20	F4	4.39	D4	8.17	D3	17.90	B3c	26.26	B3c	1.57	D3	1.51	C3
1.78	C4	4.92	F4	8.67	D3	19.03	F3	27.26	F3	2.12	C3	1.99	D3
2.30	C4	5.44	D4	9.16	D4	20.11	C3	28.18	F2	2.70	F4	2.57	C4
2.81	C4	5.98	F4	9.70	D4	21.18	D3			3.25	C4	3.08	E3
		6.50	C3	10.20	C4	22.19	B3c			3.76	D3	3.58	B3c
				10.71	D4	23.32	D3						
				11.22	D3								
				11.74	C3								
				12.28	C4								
				12.80	D3								
				13.28	D3								
				13.85	D3								
				14.36	D4								
				14.80	D3								

* = paired reaches   ** = paired reaches

Dominant substrate classes assigned to each cross section were either gravel (4) or cobble (3), except for the most upstream cross section in reach 6 which was classified as boulder (2). The dominant substrate within Reach 3 at the lowest end of Meacham Creek was exclusively gravel (Table 15). The percentage of cross sections with substrate dominated by gravel decreased in an upstream direction. The Wenaha River reference reach had a greater percentage of cobble-dominated cross sections than reach 4b of Meacham Creek. In contrast, the North Fork reference reach had a mix of gravel and cobble cross sections while reach 5 of Meacham Creek was exclusively cobble.

Table 15. Summary of Rosgen channel geometry types and channel substrate classes for cross sections in Meacham Creek and in Wenaha River and North Fork Meacham Creek reference sites.

	Meacham Creek					Wenaha	North Fk.
	Reach 3	Reach 4a	Reach 4b*	Reach 5**	Reach 6	Reach 1*	Reach 2**
Channel geometry (% by type)							
C	86%	29%	25%	12%	0%	43%	57%
D	0	43	75	25	0	43	14
E	0	0	0	0	0	0	14
Bc	0	0	0	38	60	0	14
F	14	29	0	25	40	14	0
Channel substrate (% by size class)							
Gravel (4)	100%	86	50	0	0	29	29
Cobble (3)	0	14	50	100	80	71	71
Boulder (2)	0	0	0	0	20	0	0

* = paired reaches ** = paired reaches

Discussion

The channel and flood plain geometry of Meacham Creek can be separated into distinct reaches that conform to large-scale features of the watershed. North Fork Meacham Creek has an overwhelming influence on downstream portions of Meacham Creek. The wide and multi-channel portion of lower Meacham Creek (reach 4b) seems to be a creation of the disproportionate amounts of coarse sediments coming from North Fork Meacham Creek. Steep slopes throughout much of the North Fork basin, a relatively steep channel gradient, and a limited ability to store sediments in its own flood plain, points towards it as the source of the abundant deposits of coarse sediments seen throughout lower Meacham Creek. Areas in the upper Meacham Creek basin that are steep enough to contribute coarse sediments are limited and there was no evidence that channel filling of the gorge section (reach 6) during railroad construction has persisted. The high coarse sediment load coming from the North Fork Meacham Creek watershed is mostly natural since roads are few and located away from stream courses.

When compared to the Wenaha River reference reach, there is nothing particularly unusual about reach 4b of lower Meacham Creek; both have numerous multi-channel segments, a coarse surface substrate, and a wide active channel width. The overall valley floor width of reach 4b has been narrowed by the railroad grade but it is still wider than the Wenaha River. The obvious difference between the two reaches is that the Wenaha

River has much more surface flow during the summer. The higher water table resulting from abundant summer flow and the lack of grazing results in a dense understory that veils the multiple channels and coarse substrate of the Wenaha River.

Dikes along the railroad grade of lower Meacham Creek have generally pushed the stream towards the west side of the valley. The Meacham Creek channel, beginning downstream of river mile 6.7, has probably become more entrenched due to the dikes. The dikes periodically force the channel up against the bedrock slopes along the west side of the valley. As flow runs parallel along the relatively smooth bedrock banks much of the stream's energy is expended downwards, resulting in channel downcutting and isolation of the channel from its flood plain. The downcutting may also be contributing to lower soil moisture on streamside terraces during the summer and a resultant change in streamside vegetation.

The pronounced nick point at river mile 6.7 occurs where a dike forces the stream to the west. Upstream the stream is wide with multi-channeled channel (Figure 24); downstream, the channel is more entrenched (Figure 25). Upstream movement of this nick point over time is a possibility. The gradient change at river mile 6.7 is abrupt and there is no reason that the stream will not continue to carve downward through the deep sediments immediately upstream of river mile 6.7. A possible solution to preventing this and restoring some downstream segments to their original geometry is to create a break in the dike and allow some or all of the flow to spread out over the stream's former channels. A similar opportunity to restore the stream's geometry exists downstream of river mile 3.3. Details are included in the action plan section of this document.

The substrate in reach 5 is coarser than substrate in reference reach 2. This could be a result of encroachment of the railroad prism into the active channel width of reach 5. A more confined channel would result in higher water velocity during bankfull flows, and consequently, greater shear stress along the channel bottom and a higher propensity to move smaller-sized substrate downstream. However, the calculated shear stress at reach 5 cross sections is actually lower than values for reach 2 (1.2 versus 1.7 psf, significantly different at the $P=0.01$ level using a t-test). This suggests that the coarseness of substrate in reach 5 is either due to the remnants of a historic pulse of unusually coarse rock (such as that which would be produced by blasting of canyon walls to construct the railroad) or a lack of smaller, gravel-sized material entering into reach 5. The former explanation seems more plausible. However, angular rock in the channel is uncommon in reach 5 and does not support the idea of a distinct source for the larger cobbles and boulders. Nevertheless, railroad construction occurred over one hundred years ago and this may have been enough time for the angular edges of rocks to become rounded.

Opportunities to create more room for the stream in reach 5 by moving the access road or railroad grade are limited due to the narrowness of the valley. Solutions for improving fish habitat in this reach will probably involve adding channel complexity to the existing stream channel via placement of large wood.

As an aside, classifying channels using the Rosgen Type II system was frustrated by inconsistency associated with the channel sinuosity parameter. The other parameters, such as single vs. multiple channels, entrenchment ratio, width/depth ratio, channel gradient, and substrate lead to an obvious choice of channel type for particular segments. However, in nearly every case, the sinuosity class was inconsistent with the channel type. Thus, we ended up not using sinuosity as a parameter to classify channels.

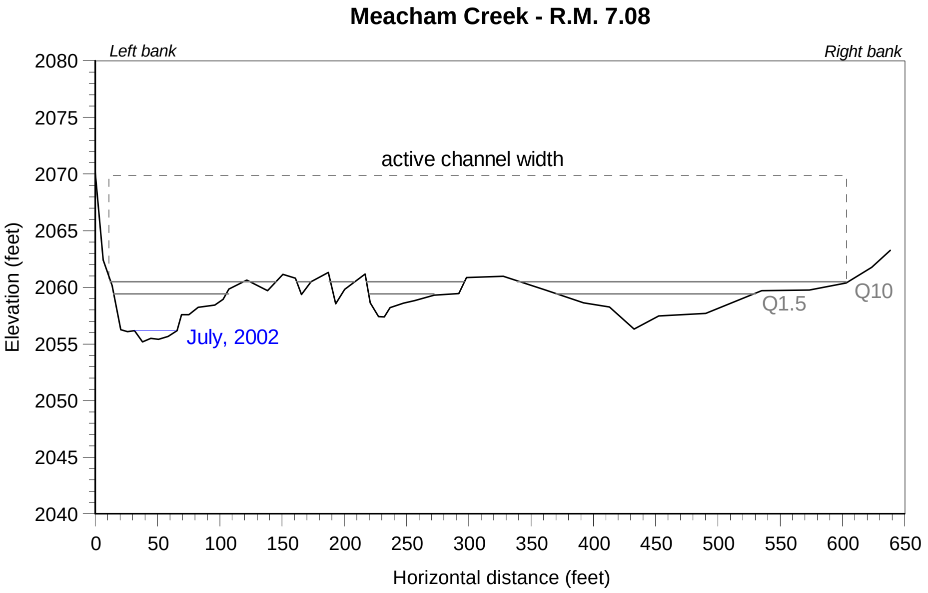


Figure 24. Channel cross section upstream of nick point at river mile 7.08.

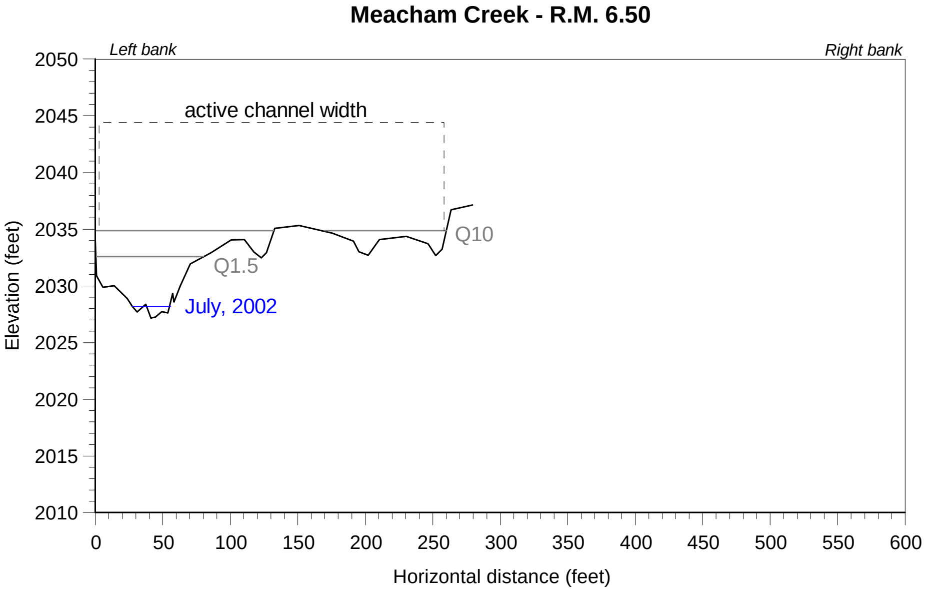


Figure 25. Channel cross section downstream of nick point at river mile 6.50.

Eroding banks

Steep, eroding faces along a stream are a result of the stream meandering into the bank during high flows and undercutting supporting material at the base. Commonly, this scouring away of material along the outside of a bend is accompanied by sediment deposition on the inside of the bend. The rate of bank scour is moderated to some extent by the roots and trunks of vegetation growing along the bank. The web of roots and the bulkhead provided by the trunks of trees can often resist the channel's energy better than a bank with no trees or brush. Dikes and riprap also moderate bank scour by diverting fast water towards the center of the channel or providing a surface that is resistant to erosion.

The frequency and extent of eroding banks can provide some indication of the rate of channel migration and downstream transfer of stored sediments.

Methods

We surveyed the beginning and ending points of eroding banks that were at least 5 feet higher than the summer water elevation in all reaches except for the Wenaha River (reach 1). The locations of these segments of eroding bank were included in the GIS and their frequency and longitudinal extent were then calculated.

Results

The frequency and extent of eroding banks increased in an upstream direction throughout lower Meacham Creek (Table 16, Maps 6-9). The percent stream length with an eroding bank on at least one side was nearly 17% in reach 4b but only 8% in reach 3. Stream segments with eroding banks were relatively uncommon in upper Meacham Creek. Overall, 8% of the length of Meacham Creek had eroding banks.

The North Fork Meacham Creek reference reach had eroding banks along 9.1% of its length, while reach 5 of Meacham Creek had only 3.6%. The frequency of eroding banks in reach 5 was only half that of the reference reach.

Discussion

Eroding banks are a common feature in the North Fork Meacham reference reach and throughout lower Meacham Creek. In these reaches, the percent of stream length with an eroding bank on at least one side varied from 8.2 to 16.8%. The eroding banks usually occurred on the outside of bends where the stream had meandered into a higher terrace. Scoured outside banks along bends were usually accompanied by depositional areas on the inside of the bends. The higher incidence of eroding banks in reach 4b of lower Meacham Creek is probably due to its aggregate-rich and multi-channel nature. Here, the channel freely meanders across most of its flood plain.

Table 16. Actively eroding banks (5 feet or more in height) next to the channel for Meacham Creek and North Fork Meacham Creek.

	N. F. Meacham 2*	Meacham Creek Reach 3	Reach 4a	Reach 4b	Reach 5*	Reach 6	Total
# Segments with eroding banks	12	9	14	32	13	1	69
Total channel length (mi.)	3.58	3.30	3.78	7.82	9.30	3.96	28.16
# Eroding bank segments per mile	3.3	2.7	3.7	4.1	1.4	0.2	3.96
Summed length of eroding bank (ft.)	1765	1424	2332	6927	1761	95	12539
% of stream length with eroding bank on at least one side	9.1%	8.2%	14.0%	16.8%	3.6%	0.5%	8.4%

* = paired reaches

Eroding banks in upper Meacham Creek were relatively rare due to intrusion of the railroad grade in the flood plain. Course boulders that accumulated along the banks of the stream due to railroad construction on steep slopes now provide an armoring of the stream channel bank. Also, eroding banks are probably less common because bedrock is a major component of the stream banks in upper Meacham Creek.

The density of eroding banks seen along study area streams is probably within the range of natural variability and not caused by human actions. Bank erosion may once have been more common in reaches 3 and 4a prior to intentional channelization of the stream.

Deep pools

Deep pools provide unique habitat for fish, especially within Meacham Creek where adult chinook salmon need to find safe spots to pass the time in the summer before spawning in early fall. Deep pools provide living space, cover, and safety from predators. A stream with hardly any deep pools forces the spawners to congregate in the few existing pools, thereby increasing chances of spreading disease or early death by large predators. Deep pools are also preferred habitat for juvenile anadromous salmonids and resident trout during portions of the day. Deep pools often intercept cool water that remains stratified in the pool bottom thereby providing a cool-water refuge during the summer. At the upstream end of these pools are energy-efficient feeding stations for fish.

Methods

We surveyed all pools with a maximum depth of 4 feet or more during July, 2002. We also mapped stream segments with bedrock banks since we had initially noted a correlation between channel depth and rock banks. We also noted the length, maximum depth, and width of each pool.

Results

Deep pools were uncommon throughout Meacham Creek except in reach 3 where they averaged 4.6 per mile (Table 17). Deep pools in the North Fork Meacham Creek reference reach averaged 2.7 per mile which was considerably greater than its Meacham Creek counterpart (reach 5) at 1.0 per mile.

Overall, two-thirds of deep pools were associated with the stream flowing against a bedrock bank. Within the North Fork Meacham Creek reference reach, 80% of deep pools were associated with a section of bedrock bank. The percentage of all bedrock bank stream segments that created a deep pool ranged from 3% in reach 6 to 80% in reach 4a (Table 17).

Deep pools were relatively short so only a small percentage of the total stream length consisted of deep pools. Reach 4a had the highest percentage of channel length consisting of deep pools (3.6%). The North Fork Meacham Creek reference reach had 1.3% of its length in deep pools, which is nearly three times that of reach 5 in upper Meacham Creek. The two reaches had about the same percentage of channel length bordered by bedrock banks.

Only a few pools in the study area were associated with large wood, which was scarce, or with stream improvement projects. Deep pools throughout the study area tended to lack any cover characteristics other than the deep water. Boulders and large wood were uncommon within these pools. Because a majority of the pools were associated with the stream flowing along bedrock banks, water velocity is expected to be high during flood flows and therefore be of limited use by fish at that time.

Average pool dimensions (maximum depth, width, length) were not consistently different between pools formed by bedrock banks and those not formed by bedrock banks when examined by reach (Table 17).

Table 17. Deep pools (maximum depth 4 feet or more) bedrock banks for Meacham Creek and North Fork Meacham Creek.

	N. F. Meacham 2*	Meacham Creek					
		Reach 3	Reach 4a	Reach 4b	Reach 5*	Reach 6	Total
# pools	10	15	6	13	9	1	44
Total channel length (mi.)	3.58	3.30	3.78	7.82	9.30	3.96	28.16
# pools per mile	2.7	4.6	1.6	1.7	1.0	0.2	1.6
# pools associated with bedrock bank	8	7	4	5	4	1	29
Bedrock-associated pools per mile	2.2	2.1	1.1	0.6	0.4	0.2	1.0
% pools associated with bedrock	80%	47%	67%	38%	44%	(100%)	66%
Channel length with pools (ft.)	253	628	314	400	247	14	-
% channel length with pools	1.3%	3.6%	1.6%	1.0%	0.5%	0.1%	-
Channel length with bedrock (ft)	2404	1847	2420	3647	5662	9515	-
% of total channel length with bedrock	8.4%	10.6%	12.1%	8.8%	11.5%	45.5%	-
% of bedrock bank reaches that form pools	38%	78%	80%	56%	15%	3%	-
Pools associated with bedrock							
Max. pool depth (ft)	4.6	5.3	6.2	4.6	4.8	(3.9)	-
Avg. pool width (ft)	14	23	19	16	21	(10)	-
Avg. pool length (ft)	28	28	42	19	38	(54)	-
Pools <u>not</u> associated with bedrock							
Max. pool depth (ft)	3.6	5.5	5.4	6.4	4.7	-	-
Avg. pool width (ft)	20	15	18	14	14	-	-
Avg. pool length (ft)	14	54	73	19	19	-	-

* = paired reaches

Discussion

Deep pools are an essential component of habitat for adult chinook salmon and steelhead in the Meacham Creek watershed. The deep pools provide holding areas for chinook salmon during the summer and for steelhead during the spring. The deep pools can also be preferred habitat for juvenile salmonids and adult resident trout. However, a majority of deep pools now found in Meacham Creek do not have much cover or complexity and offer little protection from predators nor do they provide slackwater zones during high flows. In addition, deep pools are scarce throughout most of lower and upper Meacham Creek.

Most existing deep pools in Meacham Creek are created by downward scouring of the channel as it flows against bedrock banks. These pools have high velocity water during higher flows which readily flushes out any large wood that is moving downstream. Large wood in a deep pool can readily increase the pool's use by fish; the wood provides cover and zones of slow moving water. Large wood, a major sculptor of pools in smaller, undisturbed eastern Oregon streams is scarce in Meacham Creek and so creates few pools.

Deep pools with favorable habitat could be created in Meacham Creek through the addition of large wood to the channel. However, as illustrated in a following section, the design of large wood structures must take into account stream power and be able to withstand both lateral and longitudinal displacement during floods.

Vegetation and channel structure

Natural large wood

Large wood in a stream obstructs the flow of water in a channel thereby creating unique features that can benefit fish. Deep pools can scour immediately downstream of a rootwad or bole, slow water zones can exist within and downstream of wood jams, and the many partitions created by a jam of wood provide protected feeding and hiding sites for individual fish. An evaluation of 19 streams in coastal Oregon indicated that 80% of pool-forming elements were large wood and boulders (Stack, 1988). A study of small streams in northeast Oregon (Carlson et al. 1990) indicated that large wood and stream gradient were the two most important factors associated with pool formation (Figure 26). Streams with the most wood combined with a gentle channel gradient had the greatest volume of pools during the summer. Large wood can also influence larger features in a stream. Log jams at the head of shallow gravel bars can initiate islands that then divide the flow into two or more channels. A log jam blocking an existing channel can lead to the creation of a new adjacent channel.

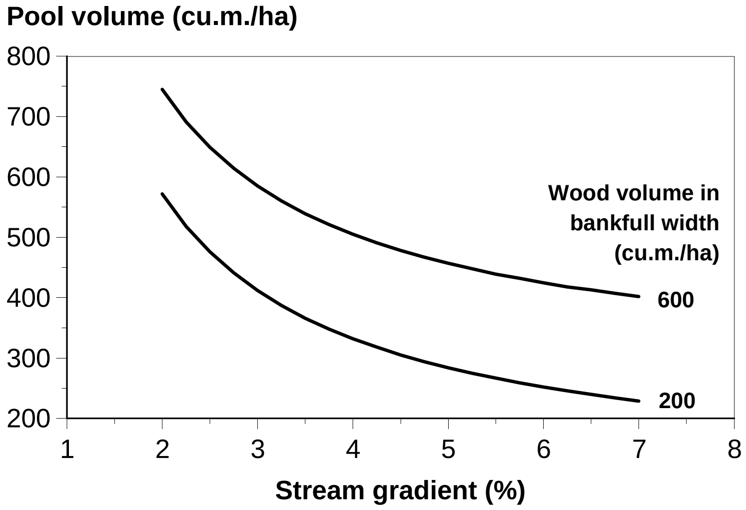


Figure 26. Pool volume in streams and relationship to large wood loading and channel gradient. Shown are results from a regression equation derived from measurements of 16 streams in far northeast Oregon. Pool volume = 268 + 959 / stream gradient + 0.432 * wood volume – 410 * ratio of summer stream width to bankfull width; adjusted R-squared = 0.74.

In a large stream such as Meacham Creek, tree trunks must be quite long and attached to a large rootwad to withstand downstream movement during high flows. Smaller wood in large streams typically gets rafted to the stream edges during high flows and consequently does not interact with the stream during lower flows. Jams of many logs resist downstream movement better than single logs (Braudrick and Grant 2000, Abbe and Montgomery 1996).

Most logs in a stream originate from the streamside forest, except in unusual cases where steep, tributary channels are capable of delivering wood during debris torrents. Common pathways for streamside trees to enter the stream channel include bank undercutting, windthrow, and the falling of dead trees killed by disease, fire, beaver, or competition for space with other trees.

In the following, we present results from a survey of large wood (excluding those logs intentionally placed in the stream as part of a stream improvement project) that we tallied in the July, 2002, survey of Meacham Creek and North Fork Meacham Creek.

Methods

We surveyed the location of all large pieces of wood that were within the bankfull width. The large end diameter of the piece needed to be 20 inches or greater, the length 30 feet or greater, and more than one-third of the bole within the bankfull width to be included. During the survey we kept track of which trees did and did not have an attached rootwad. Wood volume for the trunk of a piece was calculated using the following equation:

V = 3.14*D^2/4*L

where, V = volume in cubic feet, D = diameter in feet at mid-span, L = length in feet.

No attempt was made to estimate the volume of wood associated with attached rootwads so actual wood loading is underestimated in the following discussion.

Results

Large wood was relatively uncommon in Meacham Creek, ranging from 1.2 pieces per mile in reach 3 to 4.3 pieces per mile in reach 4b (Table 18). Large wood was also uncommon (2.7 pieces per mile) within the North Fork Meacham Creek reference site. The volume associated with the boles of the large wood ranged from 302 cu.ft./mile in reach 6 to 968 cu.ft./mile in reach 4b. The per unit volume of wood in North Fork Meacham Creek was only about one-half of that found in reach 4b. Although not measured, wood volume in the other reference reach, the Wenaha River, seemed no greater than that inventoried in reach 4b of Meacham Creek.

The average mid-span diameter of the wood varied from 25 to 32 inches among reaches while the average length varied from 44 to 75 feet. Except in reach 6, a majority of pieces had an attached rootwad, ranging from 60 to 97% among reaches. North Fork Meacham Creek (reach 2) had 60% of pieces with rootwads which was similar to its Meacham Creek counterpart (reach 5) at 69%. Wood volume per mile and piece size characteristics were similar between reach 2 and reach 5, except that the average piece volume was considerably greater in reach 5.

Discussion

The scarcity of large wood in Meacham Creek and in the North Fork Meacham Creek reference reach is likely a result of intentional removal. During early railroad days, wood in the stream and trees along the stream were probably used to fuel steam locomotives. Early settlement in North Fork Meacham Creek, along with a sawmill located at the lower end, also likely contributed to early removal of trees from the stream and those growing along the stream. Furthermore, jams of wood were commonly removed from the stream following large floods.

Large trees growing along most segments of Meacham Creek are uncommon and so the future supply of large wood in streams is limited. The scarcity of large wood within the Wenaha River reference reach was unexpected. The well-stocked stands of large-diameter conifers growing along this reach are an obvious source of large wood. Furthermore, there is no reason that large logs would have ever have been removed from the Wenaha River, owing to its isolation and lack of homesteads. One possible explanation for the current lack of wood in the Wenaha River is that the streamside stand is healthy and few trees have died during the last century. Individual trees are older than

200 years but show few signs of disease and trees are spaced far enough apart to avoid mortality through competition. Plentiful water during the summer probably promotes stand health. During the next two centuries, these trees will probably decline in health and then contribute significantly to wood loading in the Wenaha River.

Table 18. Characteristics of natural large wood in channel. Large wood limited to trees with a large end diameter of 20 inches or greater, length of 30 feet or greater, and more than one-third of the bole within the bankfull width.

	North Fk. Meacham 2*	Meacham Creek Reach 3	Reach 4a	Reach 4b	Reach 5*	Reach 6	Total
# of logs	10	4	10	34	13	9	70
Channel length (mi.)	3.58	3.30	3.78	7.82	9.30	3.96	28.16
Logs per mile	2.7	1.2	2.7	4.3	1.4	2.3	2.5
Wood volume (cu.ft.)	1911	1596	2416	7566	4088	1197	16863
Wood volume (cu. ft.) per mile	519	483	639	968	440	302	599
Average diameter (in.)	25	31	30	28	32	24	-
Average length (ft.)	50	75	48	44	52	43	-
Average bole volume (cu.ft.)	191	399	242	223	314	133	-
Percentage of logs with rootwads	60	75	90	97	69	11	-

* = paired reaches

Vegetation

Vegetation along the two references reaches and their Meacham Creek counterparts are visually different. The Meacham Creek reaches have a sparser tree density and brush layer. Furthermore, the tree species composition is different between Meacham Creek and reference reaches. We attempted to quantify these and other vegetation patterns by mapping polygons of similar vegetation in streamside areas throughout the study areas using 1997 aerial photographs and field notes. Our goal was to derive information on both overstory and understory characteristics.

Methods

Polygons enclosing similar vegetative communities were marked on 1997 color aerial photographs and transferred to the satellite imagery that formed the base layer of our GIS product. Only areas between the stream and railroad tracks or up to 200 feet from the stream were included. Notes on vegetation growing within many of these polygons had been gathered during the field survey of stream channels and this information was used to verify what was observed in the stereoscope. Vegetation mapping methods were those used by the Malheur National Forest and are explained in Appendix C.

Results

As we surveyed Meacham Creek, we looked for evidence of the stand that existed prior to the current stands. We could find no evidence of a previous stand within the valley or on the lower slopes. All live trees seemed to be less than 100 years old and there were no snags or relic trees from a previous stand. Neither were there any large ponderosa pine stumps that would signify a previous stand.

Trees growing in streamside areas along reach 4b of lower Meacham Creek were mostly younger ponderosa pine with some patches of cottonwood nearest the river and within low depressions a distance from the river. The understory was patchy. In contrast, trees along the Wenaha River were mostly older Douglas-fir and grand fir with a dense, and nearly continuous understory (Table 19, Maps 10-13, 19). Conifer dominated stands with moderate to dense canopy cover covered 74% of the area along the Wenaha River but only 58% along reach 4b of Meacham Creek. The differences are probably due, in part, to the amount of water near the soil surface during the summer. In the Wenaha River, ample summer flow keeps the water table near the surface while summer water in Meacham Creek is relatively scarce. Also, the Wenaha River drainage basin upstream of reach 1 receives more average annual precipitation than the Meacham Creek drainage basin upstream of reach 4b (51 versus 36 inches, Table 2) . Furthermore, cattle grazing is now non-existent along the Wenaha River while most streamside areas along Meacham Creek are still heavily grazed.

Streamside areas in both North Fork Meacham Creek and reach 5 of upper Meacham Creek are both dominated by conifer forest but reach 5 had more areas with shrubs (Table 19). Ponderosa trees growing along lower Meacham Creek were older than we initially estimated. We measured the age of 10 dominant ponderosa trees using an increment borer and found that most were 85 to 105 years old (Figure 27), even though their diameters at breast height were only 15 to 28 inches. These pine trees regenerated from the years 1917 to 1937 and may be the result of decreased grazing pressure by sheep following World War I. The demand for wool decreased sharply once the war ended and sheep pastures were often abandoned, which allowed conifers to regenerate.

Many of the dikes along lower Meacham Creek that were installed in the 1970's and 1980's now support dense stands of ponderosa pine. The dikes were constructed of coarse basalt boulders and cobbles that were blasted from nearby pits. The original land surface between the dikes has spotty ponderosa pine regeneration.

Table 19. Percent vegetative cover along stream by reach.

Dominance type and canopy cover class	Meacham *Reach 3*	Meacham *Reach 4a*	Meacham *Reach 4b**	Wenaha *Reach 1**	Meacham *Reach 5***	N. Fork *Reach 2***	Meacham *Reach 6*
Conifer							
Sparse ***	0.0%	7.2%	15.3%	11.4%	20.2%	14.9%	19.5%
Moderate	39.3	40.8	24.2	28.8	38.9	44.2	14.0
Dense	16.6	21.1	33.4	45.6	26.4	35.5	52.9
Hardwood							
Sparse	1.7	0.6	0.0	0.0	0.0	0.0	0.0
Moderate	11.6	3.9	6.2	2.0	0.0	0.0	0.0
Dense	14.1	7.5	5.1	0.0	0.1	0.9	0.0
Grass	10.3	15.6	10.3	4.2	0.7	2.4	6.0
Shrubs	6.5	3.2	5.4	8.0	13.7	2.0	7.5
Total	100%	100%	100%	100%	100%	100%	100%
Most common conifers	*P. pine*	*P. pine* *D. fir*	*P. pine* *D. fir* *G. fir*	*D. fir* *G. fir*	*P. pine* *D. fir* *Larch*	*P. pine* *D. fir*	*P. pine* *L. pine* *D. fir*

* Paired reaches.

** Paired reaches.

*** Canopy cover of trees: 10-30% = sparse, 31-50% = moderate, 51-100% = dense.

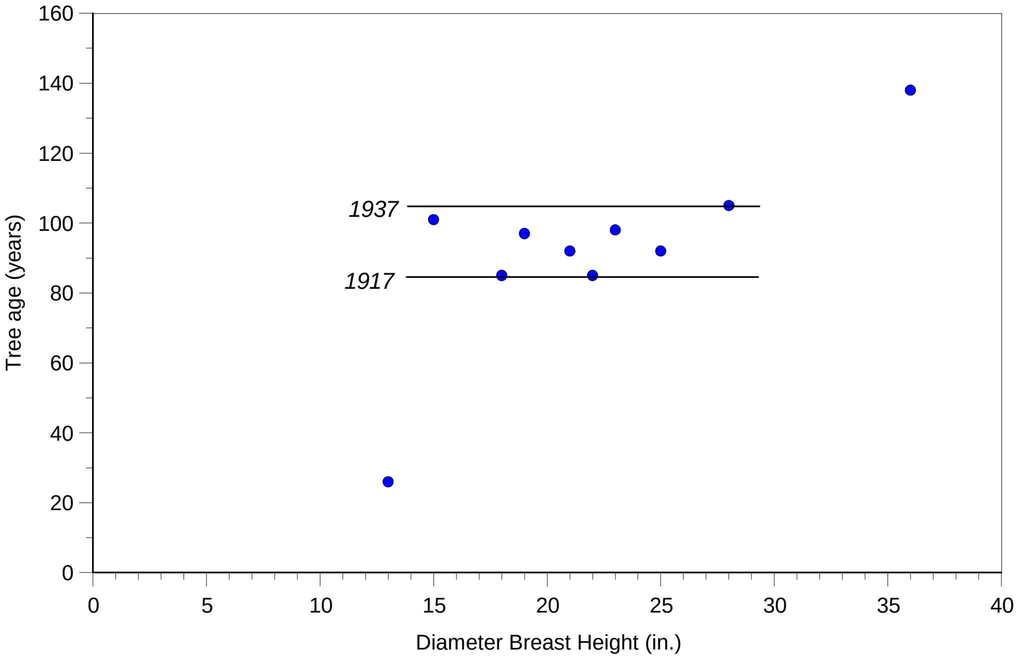


Figure 27. Tree age and diameter for dominant ponderosa pine trees growing along lower Meacham. Oldest and youngest year of origin for 8 out of 10 trees indicated by horizontal lines.

Discussion

Trees and other vegetation growing along the edge of a stream can influence the geometry of the channel by buttressing the bank and binding together non-cohesive sands and gravels. A study of 10 streams in northeast Missouri indicated that unforested bends in the river moved laterally at a rate 3 times that of paired forested bends (Burckhardt and Todd 1998). In our study, we demonstrated that channel and floodplain geometry for reach 4b of Meacham Creek was not much different than the Wenaha River reference reach. However, we had no means to measure the rate which each stream meandered across its floodplain. The heavily vegetated banks of the Wenaha River may help mute channel shifts and the sparsely vegetated banks of Meacham Creek may promote more rapid channel shifts. The wide and bare cobble surface of the active channel zone of Meacham certainly suggests a more active channel. It is possible that a positive feedback loop sets up wherever streamside vegetation is sparse; the lack of vegetation makes the stream more prone to move while the skeletal substrate created by a rapidly-meandering stream becomes a poor medium for plant establishment and growth.

Most puzzling in this case is why there is no sign of a previous forest along Meacham Creek. If all trees were cut in the valley during construction of the railroad and to fuel the boilers of the early steam trains, there should be at least a few stumps remaining. Large, ponderosa stumps are not likely to have decayed completely during the last 120 years. It is probable that the valley bottom was frequently burned by Native Americans prior to the railroad in order to improve vegetation for horses or elk. Prior to burning, the valley may have been more similar to how the Wenaha River valley appears today. An alternative hypothesis is that wood necessary to fuel early stream trains was so scarce that all stumps and trees were harvested from the valley.

Tree regeneration is occurring on its own throughout much of the Meacham Creek valley bottom, most of which is ponderosa pine. Natural regeneration seems to be most successful where trees can escape trampling by cattle. This includes cobble bars with little grass and the tops and surfaces of dikes. Because of slow growth of riparian trees in this region, the benefit of young trees to the stream will be several centuries in the future.

Wildfire

Wildfire has historically been a strong influence on watersheds in northeast Oregon. The average recurrence interval of fire within a portion of the nearby Tucannon River watershed was estimated to be 35 years between 1687 and 1900 (Heyerdahl et al. 2001). Fire frequency and size declined dramatically after 1900 probably due to a period of higher summer precipitation and reduction of fine fuels because of cattle grazing, and from effective fire suppression that began after the 1940's (Pyne 1982). Fires prior to 1900 tended to be low intensity and many older fire-tolerant trees such as ponderosa pine survived. The fires following 1900 tended to be intense and fueled by a dense understory of young grand fir and Douglas-fir (Heyerdahl et al. 2001). Under natural wildfire regimes, streamside areas have burned at about the same frequency as upslope areas in this region (Olson, 2000).

For the study, we examined the frequency and extent of fire in the Meacham Creek watershed during the last decade. We also examined the likely causes of fires and what burned during the fires.

Methods

We obtained paper maps from the Oregon Department of Forestry and a GIS coverage from the U.S. Forest Service that showed the perimeters of wildfires that have occurred in the Meacham Creek watershed during the last decade. These sources also included the year and name of the fire. We did not examine wildfires prior to the last decade because of incomplete records and a need to capture recent railroad practices and firefighting effort.

The detailed aerial photographs available to us during this project were flown in the summer of 1997, so we could evaluate burned vegetation in detail only for the Milepost 248 fire and the Short Canyon fire. We roughly evaluated burned vegetation for the other fires using the 2002 black and white satellite imagery. Areas that support grass and brush quickly recover following wildfire and so little information can be gleaned from aerial photographs or satellite imagery about which of these areas burned and which were skipped over. Salvage logging of fire-killed trees was either spotty or non-existent and so it was possible to discern live and dead trees using the photographs and satelite imagery, even years after the fire.

Results

Six fires have occurred in the Meacham Creek watershed during the last decade, ranging from 3 to 4040 acres in size (Table 20). Five of the six fires and nearly all of the acres burned during a 4-year period from 1997 to 2000.

Overall, 5342 acres burned during the last decade or 4.7% of the watershed. Averaged over the entire basin this corresponds to a fire recurrence interval of 212 years. However, the fires were not randomly located throughout the watershed. All of the six fires bordered the railroad tracks. The Oregon Department of Forestry believes that each of the fires was ignited by a train and then burned upslope (John Buckman, personal communication). Fire fighting efforts by the U.S. Forest Service and the Oregon Department of Forestry helped control the size of most of these fires. It was unclear how many fires had been extinguished next to the tracks by railroad crews before they could spread.

Detailed measurements of the Milepost 248 fire (Table 20) indicate that only 19% of the burn area (189 acres) had fire-killed trees. The remainder was either burned grass and brush (45%) or conifers that survived the fire (35%). Combining the acreage of all fires, two-thirds of the area within fire perimeters was grass and brush and only 11% (608 acres) was fire-killed trees. The timber on the burned slopes tended to be young (less than 100 years) and consisted mostly of ponderosa pine with some grand fir and Douglas-fir on north-facing slopes.

Table 20. Fire acreage and resultant tree condition in the Meacham Creek watershed for the last decade.

Fire Name	Year	Acres within fire perimeter	Vegetation within fire perimeter
Short Canyon	1993	3	100% grass/brush**
Milepost 248	1997	996	45% grass/brush, 19% burned timber, 35% live trees**
Duncan	1998	53	90% grass/brush, 5% burned trees, 5% live trees*
Tie Creek	1999	127	90% grass/brush, 10% live trees*
Milepost 225	2000	121	95% grass/brush, 10% burned trees.*
Milepost 224	2000	4040	70% grass/brush, 10% burned trees, 20% live trees. Occurred several weeks after Milepost 225 fire*
Sum		5342	

* Estimated using satellite imagery ** Measured using aerial photographs

Discussion

Wildfires in Meacham Creek during the last decade have killed only relatively small areas of trees. These trees had limited value due to their small size and the difficult access. All fires seem to have originated at the railroad grade and would have probably spread to a larger area if they had not been contained by fire crews.

The prospect of a wildfire beginning in North Fork Meacham Creek seems most ominous for the future. The north-facing slopes and riparian corridor of this basin support a nearly-continuous belt of timber; a fire starting at the mouth of the basin could readily spread to the east through these stands of dense pine, Douglas-fir, and grand fir. Elimination of streamside trees throughout the basin would likely lead to a rise in water temperature. North Fork Meacham Creek provides the best habitat for bull trout spawning and rearing and for chinook salmon holding and spawning in the Meacham Creek watershed. Both of these species require cool water in the summer.

Considering the consequences, efforts to eliminate wheel sparking and the ignition of vegetation growing along the railroad, would be best focused on the stretch of tracks nearest the North Fork Meacham Creek confluence.

Past stream improvement efforts

Efforts to add structural features to improve fish habitat and retard stream meandering have occurred in Meacham Creek during the last decade. Much of the work was done prior to 1991, before the high flow on November 28, 1995, (10-25 year recurrence interval) during which, some of these features were washed out or rearranged by the high flow.

Structural features that have been added to Meacham Creek include:

- Log-boulder structures; usually consisting of one or two logs anchored to boulders using cable.
- Rock barbs; usually consisting of both large and small shot rock extending from the bank and placed at an angle to the bank (either upstream or downstream).
- Boulder berms; usually a linear series of large boulders connected by cable.
- Boulder clumps; usually a clump of large boulders connected by cable.

Rock barbs are designed to deflect flow away from the outer bank on a bend to truncate localized stream meandering. Upstream-facing barbs also create a zone of slower water immediately downstream of the barb which is favored habitat for fish. The other structures are intended to create pools, zones of slower water, and cover for fish.

Nearly all of the improvement projects are downstream of river mile 5, although a few Forest Service log/boulder structures exist in upper Meacham Creek.

Methods

We documented the position (using GPS coordinates) and characteristics of single or groups of improvement structures we encountered along the main channel of Meacham Creek from the mouth to the North Fork Meacham Creek confluence. All improvement structures we could see as we surveyed the channel were included. We noted the type of structure and its influence on fish habitat. Influence categories and their description are:

- *Very good*; creates complex cover and pools that are available to fish at both low and high flows.
- *Good*; creates cover and pools but may be used by fish only part of the year.
- *Some*; creates some alteration to the stream channel that may benefit fish at least during part of the year.
- *Minimal*; has minimal influence on the stream channel and does not appear to produce fish habitat features.
- *Harmful*; creates a barrier to the movement of young fish during low flows.

Detailed information on each structure or group of structures is provided in Appendix D.

Results

We did not have information on the number of structures that existed prior to the November, 1995, high flow, although observations by those familiar with the projects indicate that some of the log/boulder structures were washed out of the Meacham Creek watershed. Many of the remaining log/boulder structures have been altered since their introduction; many are now found perched on the lower streamside terraces (Figure 28). In contrast, most of the boulder berms and clusters seem to be intact and in their original locations. Most of the rock barbs are recent and did not experience the 1995 high flow and are intact.

We encountered 91 stream improvement structures, of which over one-half were log/boulder structures (Table 21, Map 14). Most of the others were rock barbs or boulder berms. Overall, only 9% of the structures created good or very good fish habitat. Nearly 60% created only minimal habitat or were harmful to fish. The single structure that was harmful consisted of a series of large boulders added to the top of a bedrock cascade near the gauging station (river mile 1.7). These boulders create a barrier to the upstream movement of juvenile fish during the summer. Water in lower Meacham Creek becomes too warm for fish (discussed in a later section), requiring them to move upstream of this point to find zones of cooler water.

Figure 28. Log/boulder structures near river mile 3.6 rafted onto a low terrace during a high flow.

The most common problem with the log/boulder structures was their small size compared to the size of the stream. Logs were usually less than 50 feet long and were too small in diameter to have rootwads large enough to provide much stability during high flows. Structures usually consisted of only single logs which further promoted downstream movement. Many of these log/boulder structures are now found perched on the lower streamside terraces and have little interaction with the stream except during high flows.

Table 21. Summary of the influence of stream improvement structures on fish habitat within Meacham Creek.

		Influence on fish habitat					
		Very good	*Good*	*Some*	*Minimal*	*Harmful*	Total
Log / boulder	#	2	2	10	38	0	52
	%	4%	4%	19%	73%	0%	100%
Rock barb	#	0	0	13	10	0	23
	%	0%	0%	57%	43%	0%	100%
Boulder berm	#	0	3	6	4	1	14
	%	0%	21%	43%	29%	7%	100%
Boulder clump	#	0	1	0	1	0	2
	%	0%	50%	0%	50%	0%	100%
Total	#	2	6	29	53	1	91
	%	2%	7%	32%	58%	1%	100%

Where the log/boulder structures created good or very good habitat, the structures consisted of two or more very large logs with rootwads. Some had trapped floating large wood and had become even more effective.

Boulder berms and clumps were usually stable in the channel but did not seem to create much usable fish habitat. Pools adjacent to boulders were small and probably too turbulent for fish to use during high flows. Some of the boulder berms were barely visible in the streambed. They had either locally elevated the streambed by trapping substrate or had sunk into the existing substrate as a result of localized scouring. Most of the boulder berms that created good habitat were full-spanning structures constructed of very large boulders. Deep plunge pools were created immediately downstream of these structures and created useful habitat for fish during lower flows. However, these pools are probably too turbulent for fish to use during higher flows.

None of the rock barbs created good or very good habitat, although we may have underestimated their value since we were examining them at low flows rather than at high flows. The zone of slack water commonly created immediately downstream of upstream-facing barbs during high flows can be an important refuge for fish (especially chinook salmon).

Discussion

The well-intentioned and intensive efforts to improve fish habitat in lower Meacham Creek have not lead to the improvements in fish habitat that was probably envisioned by the designers of these structures. Some structures, especially those made of materials large enough to withstand lateral or longitudinal displacement by the stream, provide good examples of what is feasible (Figure 29) in Meacham Creek, but the majority of structures have not provided the kind of habitat that is currently limiting fish production in Meacham Creek. Limiting habitat in Meacham Creek includes year-round, deep pools with complex structure and overhead cover.

Most fish habitat improvement structures have been constructed in the downstream section of Meacham Creek (reaches 3 and 4a). While this section lacked channel complexity and cooperative landowners provided an impetus to concentrate on this section, high water temperature limits fish use of this section during the summer (discussed below). Future efforts to improve stream structure would benefit fish more if structures were located upstream of Line Creek (river mile 4.95) where water temperatures are low enough to support fish year-round. A major consideration for improving stream structures in this area is gaining the cooperation of landowners.

Figure 29. Well-designed log/boulder structure (# 26 at river mile 2.25) that creates year-round cover and pools.

Results from these past improvement efforts point to a need for re-examining the design of structures installed in Meacham Creek. Recent studies elsewhere point to large, complex jams of stable logs as an effective design in wide streams with active flood plains (Abbe 1999, Abbe and Montgomery 1996). Design features that promote stability and fish habitat creation include the use of long logs with large attached rootwads and limited cabling to ensure that the jam acts as a single but flexible unit. The National Marine Fisheries Service, through their participation in permit approvals conducted by the U.S. Corps of Engineers, has not been particularly supportive of using cable in the design of created log jams in streams over the last decade. However, recently they have modified this stance and will entertain designs that use cable simply to hold large logs together, rather than rigidly attach them to bedrock or to banks. This is particularly important for large streams where logs long enough to remain stable in the channel on their own are no longer available.

Obtaining and moving large-diameter logs with rootwads is challenging in Meacham Creek where older trees are not plentiful and the road bridges may not be strong enough to handle over-loaded log trucks. However, there may be opportunities to use train cars for transporting suitable logs to sites. The largest trees growing along the lower slopes of the basin (Douglas-fir, ponderosa pine, and western larch) are found on high terraces in lower North Fork Meacham Creek. Very large grand fir can be found in headwater areas of upper Meacham Creek.

Boulder berms installed in lower Meacham Creek have not resulted in much high quality fish habitat and this design should probably be abandoned. Boulders may be re-used for cabling to log structures for the purpose of increasing log jam stability.

Rock barbs have been used in the portion of lower Meacham Creek upstream of the county bridge to limit channel migration into streamside terraces used for pasture and to align flow upstream of the county bridge. Low-profile rock barbs were installed in 1998, in conjunction with planting of streamside vegetation, to prevent further erosion of the outside bank of the stream. Little bank migration has occurred since installation of the rock barbs.

Although rock barbs can provide some incidental habitat immediately downstream of the barb, these features should probably not be viewed as fish habitat enhancement features. Their main function is to limit stream meandering and, as demonstrated in previous sections of this document, reducing channel migration can lead to further downcutting of the channel and increased disconnection between the channel and its flood plain. The use of rock barbs elsewhere in the basin should be limited to segments where the railroad grade or access road is being actively undercut by the stream.

Portions of lower Meacham Creek (4.5 miles) and lower Boston Canyon Creek have been fenced to exclude cattle from streamside areas. The project began in 1989 and was accompanied by long-term leases with participating landowners. The high-tensile wire fence has withstood collapse by elk and fallen trees over the years.

Sprouting of hardwoods and shrubs from long-grazed root stock along the stream began immediately after fences were installed and was rapid until the 1996 flood. The flood scoured out some of this vegetation but re-growth has continued to occur. Most notable has been dense patches of alder and willow along the channel fringe (Figure 29.1). Many trees planted along the channel terraces located further from the stream did not survive the hot summer conditions.

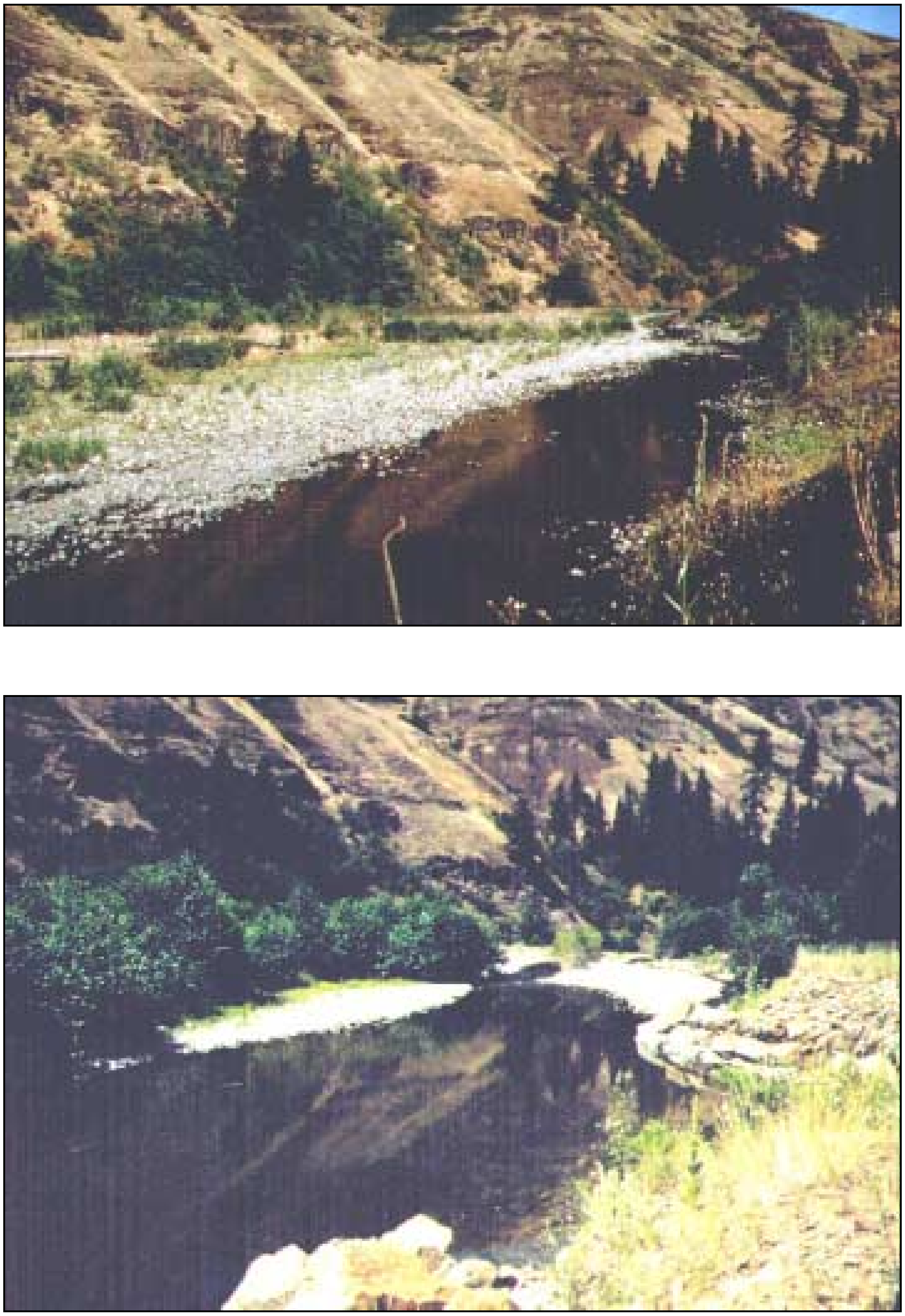


Figure 29.1. Regeneration of alder on gravel bar following 4 years of grazing exclusion (1988 to 1992).

Water quality

Water temperature

The climate of the Umatilla River basin makes water temperature an important aspect of overall fish habitat during the summer. The low elevation of Meacham Creek (1800 feet at the mouth) combined with sustained hot spells with maximum air temperatures over 95 deg F and only moderate nighttime cooling, results in water temperatures that can reach or exceed that which can be tolerated by native fish. Low summer streamflow in Meacham Creek complicates the situation for native fish because the water becomes so shallow (or goes subsurface) that fish are unable move upstream into cool water zones.

Water temperatures in streams flowing through the bedded basalt geology of northeast Oregon are spatially influenced by the non-homogenous entry of cool groundwater. Some of the basalt layers are less porous than others and so groundwater is intercepted at the impervious layers and shuttled into streams at discrete points. An example of this is shown for a section of Phillips Creek, located 14 miles east of Meacham Creek (Figure 30). Contrary to conventional wisdom, a section of the stream that was fully exposed to sunlight due to clearcut harvest of streamside trees, cooled 8 deg F as it flowed through the section. Here, the entry of cool groundwater overwhelmed the warming of water due to exposure to sunlight.

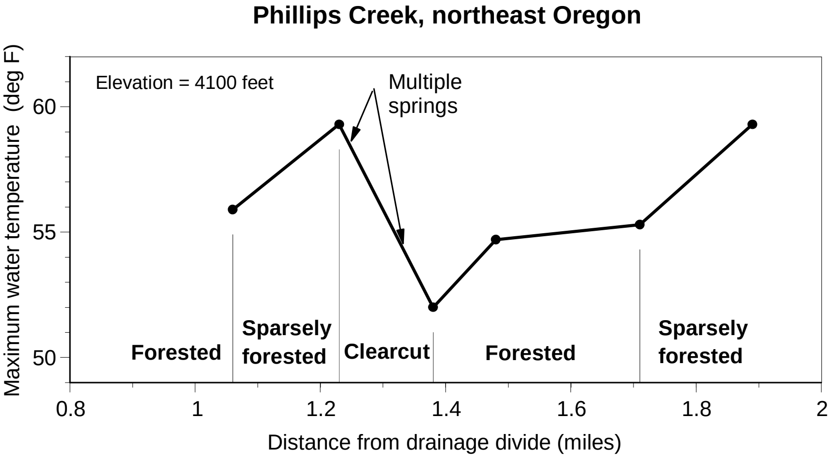


Figure 30. Interactions between stream shading and groundwater inputs for a stream 14 miles east of Meacham Creek. Data provided by the Oregon Department of Forestry.

Similarly, streams will undergo rapid changes in temperature as the ratio of surface flow to subsurface flow is altered by deep alluvial deposits.

The current use of state water temperature standards to define the suitability of streams to support fish has created considerable confusion. By establishing a region-wide goal of 64 deg F for those streams that support salmonids, some have interpreted this to mean that streams exceeding the standard (expressed as the maximum 7-day average of daily maximum temperatures) are that way because of human actions. By ignoring the universal trend that streams warm in a downstream direction and by over-estimating the capability of streamside trees to provide effective shade to wide streams, the influence of human activities on water temperature are often overestimated. Most of the computer models designed to predict water temperature lack important algorithms that are needed to account for variability in surface water temperature, such as the cooling effects associated with some of the flow going subsurface and re-surfacing downstream or the entry of groundwater in the form of springs.

Adding to the confusion is a lack of understanding of how native fish have evolved to minimize their exposure to warm water. Fish will commonly search out cool water pockets during the hottest part of the day or migrate upstream to cooler portions of the stream system to conserve energy and reduce their need for food (Matthews and Berg 1997). Juvenile steelhead are commonly found rearing in northeast Oregon streams that have a 7-day average maximum exceeding 70 deg F.

For these reasons, we do not include an analysis of water temperature in Meacham Creek based on state water quality standards and modeling. Instead, we examine the spatial patterns of temperature that were measured throughout the basin, coupled with our observations of the behavior of juvenile fish during a hot spell in July, 2002.

Methods

We used three sources of information to evaluate maximum water temperature in Meacham Creek. One source was the temperature information gathered at 6 sites in Meacham Creek and selected tributaries using recording gauges. Years of record were 1988 and from 1992 to 2001, although no single site included all years of record. Only during 1999 and 2000 did the six sites have a common period of record. From the raw temperature records, we determined the greatest 7-day running average of maximum temperatures for each year.

The second source of information was thermal imaging collected in August, 2001. A thermal imagining camera housed in a helicopter was used to capture reflected heat from the surface of the stream throughout the Meacham Creek study area. Recording temperature gauges placed at four sites prior to the flight provided a means to conduct a calibration check. We did not have enough funds to rectify the thermal images to the landscape in order to examine fine-scale patterns in surface water temperature. Instead, information was extracted from single frames at selected spots spaced at quarter-mile intervals. We assigned the location of the spots to the GPS coordinates defining the helicopters path. Usually, the helicopter was not directly over the stream so these locations show up as offsets in the GIS coverage. The temperature at each spot was an average of about 10 values, with each value selected to avoid areas with half-submerged rocks, shaded areas, and other anomalies that would cause an erroneous surface water temperature value. Thermal imagery measures only the temperature of the very surface of the stream so where the surface water is not mixed with the cooler water underneath, the overall water temperature can be greatly over-estimated.

The third source of temperature information we used in this study was that which we gathered in the field during a hot spell in mid-July, 2002. Maximum daily air temperatures directly above the water were 95 to 101 deg F and water levels were unusually low for mid-July. We used a digital thermometer to measure the water at selected sites, including the main stem of Meacham Creek, tributaries, and zones of unusually cool water (usually alcoves). Alcoves are like side channels but have no upstream connection with the main channel of the stream during low flows. For this analysis, we used only those readings taken between 2 and 6 pm. During this hot spell streams approached their daily maximum by 2 pm and did not cool off much until after 6 pm.

Results

The recording gauges in the lowest portion of Meacham Creek (R.M. 1.4 and 5.0) indicated that the greatest 7-day running average of daily maximum temperature routinely exceeded 75 deg F each year. Water temperature was more moderate at river mile 13.0, averaging about 70 deg F (Table 22). The two lower gauges are separated from the upper gauge by a section of subsurface flow centered on river mile 12.

Examining only those years where the lower and upper gauges on North Fork of Meacham Creek were both operating, water at the upper gauge was 1.0 deg F cooler than the lower gauge near the Meacham Creek confluence (70.2 deg F). Water at the lower gauge in North Fork Meacham Creek is nearly the same temperature as that measured in Meacham Creek at river mile 13. East Meacham Creek is considerably cooler than either Meacham Creek or North Fork Meacham Creek with maximum 7-day averages ranging from 64.5 to 68.8 deg F each year. Variation of maximum temperature among years was relatively high at all gauges with standard deviations ranging from 1.0 to 1.8 deg F.

The rate of heating for Meacham Creek between R.M. 5.2 and 2.00 (1999-2000) was 0.1 deg F per mile, while the rate of heating for North Fork Meacham Creek between R.M. 3.5 and 0.5 (1999-2000) was 0.5 deg F per mile. The rating of heating was less within lower Meacham Creek probably because it had reached equilibrium where cooling forces (groundwater, heat loss to the channel substrate, evaporation) counteracted warming forces (solar radiation and heat transfer from air to water).

Combined information from field measurements and thermal imaging revealed a complex longitudinal pattern in maximum water temperature throughout the study area (Figure 31). Starting at river mile 28 in Meacham Creek, water temperature increased rapidly in a downstream direction. The thermal imagery shows high variability in temperature among adjacent sites while the field data indicates a more steady increase.

Table 22. Greatest 7-day running average of daily maximum temperatures by year for Meacham Creek and selected tributaries. Data gathered by the Tribes and the Forest Service using recording gauges.

Year	Meacham Cr R.M. 1.4	Meacham Cr R.M. 5.2	Meacham Cr R.M. 13.0	North Fork Meacham Cr R.M. 0.5	North Fork Meacham Cr R.M. 3.5	East Meacham Cr R.M. 0.1
2001	76.7	77.3	-	68.2	69.4	-
2000	76.7	76.6	70.9	72.3	69.9	66.0
1999	74.8	74.4	69.7	69.2	68.5	67.5
1998	-	76.4	71.2	71.9	70.3	68.8
1997	76.2	-	69.0	69.2	67.9	
1996	74.7	-	-	68.6	-	66.8
1995	74.8	-	-	-	-	65.5
1994	-	-	-	-	-	
1993	74.2	-	72.5	-	-	64.5
1992	78.7	-	-	-	-	
1988	77.4	-	-	-	-	
All years mean	76.0	76.2	70.7	69.9	69.2	66.5
std. dev.*	1.5	1.2	1.4	1.8	1.0	1.5
1999-2000 mean	75.8	75.5	70.3	70.8	69.2	66.8
1997-2001 mean	-	-	-	70.2	69.2	-
std. dev.*	-	-	-	1.8	1.0	-

* standard deviation of a sample

The narrow width of Meacham Creek and vegetative shading creates problems with determining the stream's temperature using thermal imagery. Field data for this reach probably better reflects spatial variation than the thermal imagery. A sharp increase in water temperature as the stream approached the first dry section (between river mile 24.9 and 20.7) was probably due to declining surface water flow. By the time the stream approached river mile 25 most of the water was subsurface leaving only a shallow layer of water at the surface that was easily warmed by exposure to solar radiation (Figure 31).

In areas where they overlapped, the field data water temperature was considerably higher than the thermal imagery temperatures. This difference is probably real since weather and streamflow conditions were moderate when the thermal imagery was flown in 2001 and exceptionally warm (with abnormally low flows) in 2002 when the field measurements occurred.

By the time the stream surfaced downstream of river mile 24.9 the temperature of the water had dropped to below 65 deg F. It then warmed into the mid-70's before again going subsurface. East Meacham Creek provided cool water to moderate temperature increases in Meacham Creek within this section. The water surfaced again upstream of the North Fork Meacham Creek confluence and was warmed to the temperature of the

North Fork where they combine. The water stayed below 70 deg F until it approached the last segment of subsurface flow and increased to about 80 deg F as the surface water became shallow. Meacham Creek exited gravels from this subsurface reach at a cool 59 deg F and then warmed steadily in a downstream direction. The warm water (72 deg F) of Camp Creek at river mile 11.16 contributed to this increase. The Milepost 224 fire in 2000 burned through much of the Camp Creek watershed and may have reduced shade along the stream. Furthermore, the Camp Creek watershed faces west and receives direct sunlight throughout the afternoon.

Meacham Creek continued its increase in temperature until river mile 5 and then maintained a relatively steady temperature (73 to 75 deg F, 2001 values) until its confluence with the Umatilla River. The values in 2002 approached 80 deg F in this lowest section. Line Creek is cool, owing to a series of springs that enter the channel between the railroad and Meacham Creek but the volume of flow is only a small portion of the flow in Meacham Creek during the summer so its influence on Meacham Creek was small.

At the upstream end of the North Fork Meacham Creek reach, Bear Creek contributes exceptionally cool water (58 deg F) (Figure 31). It flows from a north-facing slope, while North Fork Meacham Creek drainage faces mainly west. The temperature of Bear Creek obtained with the thermal imagery is erroneous.

Throughout lower Meacham Creek and North Fork Meacham Creek we found alcoves and side channels with water that were much cooler than the main channel (Figure 31). The water temperature within these features was commonly 55 to 60 deg F. We could see juvenile steelhead congregating in these cool off-channel areas during the heat of the day, as long as the water was deep enough. During morning hours when the water was still cool, we observed juvenile steelhead throughout most of the Meacham Creek study area in mid-July, 2002. Only in the lowest 2 miles did we not see fish in the main channel during the morning.

We wore porous boots as we surveyed Meacham Creek and so could detect pockets of cool water within the main channel as we moved upstream. Cool water pockets were common at the bottom of deep pools and at the downstream end of large gravel bars. During a previous trip on June 12, 2002, we measured the temperature of water upstream and downstream of a gravel bar at river mile 7.19. Although the water was much cooler in June than it was in July, these measurements demonstrate a phenomenon that seems to persist throughout the summer.

The water temperature in the main channel at the upstream and downstream end of the gravel bar was about 57 deg F (Figure 32). However, along the downstream edge of the gravel bar were pockets of water that were 4 to 7 degrees cooler. The coolest water was that closest to the edge of the gravel bar. The exit of subsurface water at the downstream end of the gravel bar was further confirmed by abundant growths of algae. Studies elsewhere in the Pacific Northwest indicate that the subsurface water picks up phosphorus from fine sediments as it flows through gravel deposits (Fernald, et al. 2001) and is quickly exploited by algae once exposed to sunlight.

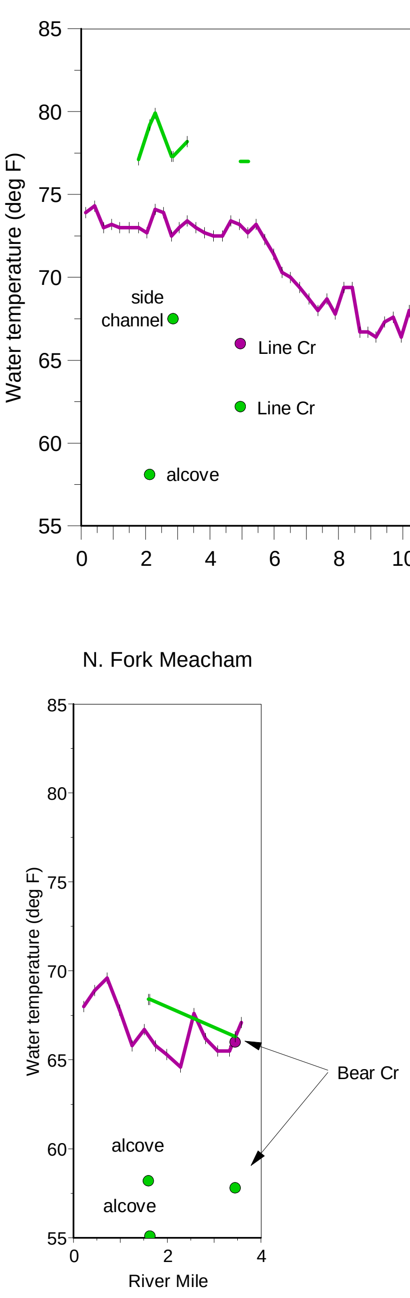


Figure 31. Water temperature as determined from thermal imagery (August, 2001) and field measurements taken between 2 and 6 pm on very hot days in mid-July, 2002.

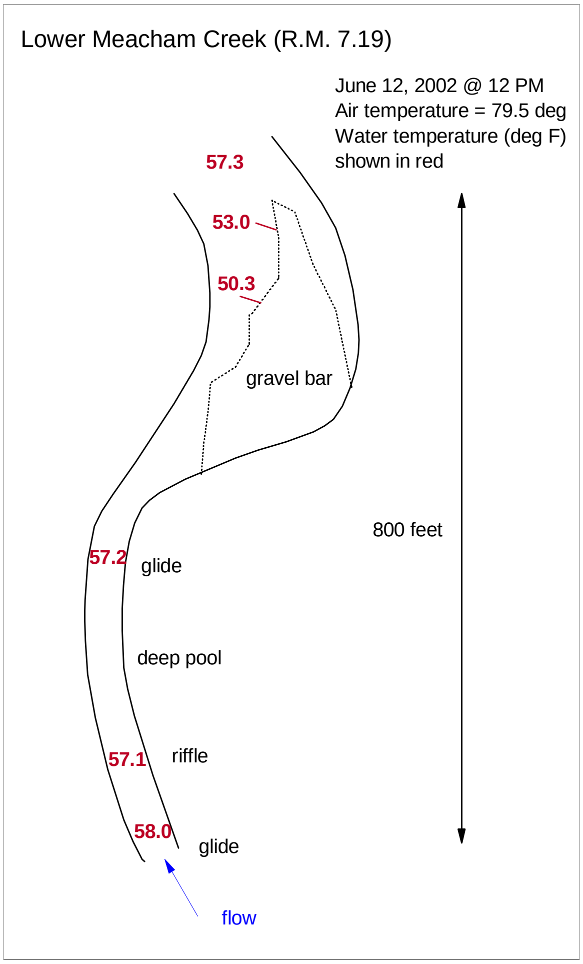


Figure 32. Changes in water temperature as Meacham Creek flows over and through a deposit of gravel and cobbles in mid-June, 2002.

Most of the streams in the study area were too wide for the surrounding trees to provide shade over the channel during the hottest part of the day. An inspection of aerial photographs and observations in the field indicated that even the tall and relatively well-stocked conifer stands along the Wenaha River and North Fork Meacham Creek reference reaches failed to provide much shade to the channel. Certain tributaries and springs (Boston Canyon, Bonifer Pond spring, Line Creek, R.M. 9.79 spring, East Meacham Creek, and Butcher Creek) currently provide cold water to Meacham Creek and create zones of thermal refuge for fish. Streamside vegetation along these narrow streams can greatly influence maximum water temperature.

Discussion

Maximum water temperature found in reaches 3 and 4a of lower Meacham Creek routinely exceed the upper incipient lethal level for adult chinook salmon (77 deg F) and limits the ability of juvenile fish to rear in these reaches in the summer. Juvenile salmonids have some access to thermal refuges such as the downstream ends of gravel bars, alcoves, side channels, and tributary confluences, to escape high temperatures in the main channel. Spring chinook spawners in the upper John Day River survive water temperatures that frequently exceeded their upper tolerance level of 77 deg F by congregating in pools with cool water (Torgersen et al. 1999). Nevertheless, such survival technique compromises their ability to feed, avoid predators, and resist disease.

Favorable temperature conditions exist in reach 4b, especially immediately downstream of river mile 12 where the stream exits a subsurface reach at a very cold temperature. These temperature patterns in lower Meacham Creek are probably natural since the channel is much too wide for streamside trees to cast a shadow on the water and summer flows are not diminished by water withdrawals (discussed later). Camp Creek, the tributary with the largest flow in lower Meacham Creek, may now be somewhat warmer than normal due to a fire in 2000.

Water temperatures within North Fork Meacham Creek and a section of Meacham Creek immediately downstream of the North Fork confluence are favorable for supporting salmonids year-round. On the other hand, thermal conditions in upper Meacham Creek alternate between favorable and unfavorable; water entering two subsurface reaches warms considerably as surface flow becomes shallow, while cool water exiting the subsurface reaches and cool water from tributaries provides excellent thermal refuge.

The multi-channel and aggregate-rich nature of reach 4b promotes alternate subsurface routes for portions of the flow. Within these subsurface routes water is cooled as it exchanges heat with the aggregate and is sheltered from the heating influence of solar radiation. When this water surfaces downstream it is much cooler than when it entered. Structural features in the channel such as pools created by log jams or scour pools on the outside of bends are places where this subsurface water is commonly intercepted and incorporated into the surface flow. A stream with little large wood or a stream that is not allowed to meander freely will not have as many opportunities to intercept the cool, subsurface flow.

It is not possible to estimate the temperature regime of Meacham Creek prior to European settlement since the type of vegetation bordering the stream at that time is unknown. Current measurements of temperature along the stream suggest that water temperature is greatly controlled by the presence of zones with subsurface flow. Where the stream surfaces after cooling off within an upstream subsurface reach, the streams loses all “memory” of the warming that had occurred further upstream in the watershed. We found nothing to suggest that the pattern of surface and subsurface reaches in most of the basin have changed since European settlement. However, one could speculate that some subsurface flow sections may have once existed downstream of river mile 7 but became surface flow after the dikes were installed.

Nutrients

Typically, nitrogen and phosphorus are cycled tightly in natural streams flowing through mountainous regions of the Intermountain West since both nutrients are in short supply. The geology yields only scant amounts of phosphorous as rocks weather and the alternating cold and dry climate does not promote quick decay of organic material and the release of nitrogen from this material or from the by-products of bacteria feeding on organic material. Bioavailable forms of nitrogen and phosphorus that reach the stream are quickly taken up by algae, some of which becomes food for aquatic macroinvertebrates, and then later, food for fish.

High levels of nutrients can be found in the water column of streams that have large and chronic sources of organic pollution. Typically, large loads of nutrients come from fertilizer, manure, sewage treatment or industrial plants, septic tanks, or stormwater draining from urban areas.

In this study, we examined nutrients in water from Meacham Creek from the limited sampling done in the spring and summer of 1998.

Methods

Information was provided by the Oregon Department of Environmental Quality on nitrogen and phosphorus compounds within Meacham Creek during April and August, 1998. Parameters included combined nitrate/nitrite, ammonia, Kjeldahl nitrogen, orthophosphate, and total phosphorus. Detection limits were not included with the data but detection limits usually used by the Department for these parameters are 0.02 mg/L as N for nitrate/nitrite, ammonia, and Kjeldahl, 16 *u*g/L for orthophosphate, and 30 *u*g/L for total phosphorus.

Results

Values for nitrogen and phosphorus were at or below detection limits for all samples, indicating that Meacham Creek has a very low nutrient status (Table 23). Samples taken in April (when nutrient uptake by algae is low) were no greater than those taken in August (when nutrient uptake is high) which suggests that there are no chronic sources of nutrients attributable to human activities.

Cow manure is abundant along heavily grazed portions of Meacham Creek but it is dispersed and the land is flat. There are no confined animal feeding areas. The pathways for this manure to enter Meacham Creek are limited to overland transport during high-intensity runoff and the cows doing their business while standing in the stream. Cow manure flushed into the stream during high flows is not likely to cause problems with water quality in Meacham Creek since little nutrient uptake occurs in winter and early spring and it is rapidly transported downstream.

Table 23. Nitrogen and phosphorus data for Meacham Creek in 1998. Data provided by the Oregon Department of Environmental Quality.

	Nitrate/ Nitrite (mg/L as N)	Ammonia (mg/L as N)	Kjeldahl nitrogen (mg/L as N)	Ortho-phosphate (*u*g/L)	Total phosphorus (*u*g/L)
Meacham Cr at mouth 8/25/98	0.02	-	<0.02	16	30
Meacham Cr at R.M. 0.5 4/29/98	<0.02	< detection	<0.02	-	30
Meacham Cr at R.M. 1.4 4/29/98	<0.02	0.02	<0.02	-	30
Meacham Cr at R.M. 11.2 4/29/98	<0.02	< detection	< 0.02	-	30
Meacham Cr near I84 8/25/98	<0.02	-	<0.02	16	30

Discussion

The limited nutrient information available for Meacham Creek suggests that nutrients are both scarce and tightly cycled within its aquatic environment. Obvious sources of nutrient enrichment are lacking in the watershed. Nutrients resulting from moderate to heavy grazing along Meacham Creek are not showing up in the water column.

Potential episodic increases in nutrients include that associated with train derailments or fire-fighting. Nitrogen in the form of liquid ammonia or granular fertilizer could be introduced into Meacham Creek during a train derailment. Phosphorus in the form of granular fertilizer could be added to the stream during a train derailment or in the form of fire retardant while trying to control a wildfire.

Suspended sediment and turbidity

Human-caused increases in suspended sediment and turbidity can influence habitat quality for fish. Most fish feed by sight and so chronic turbidity can make feeding less efficient. A layer of fine sediments deposited over gravels and cobbles in a stream can make the stream bottom less productive by occluding algae and some aquatic organisms on which fish depend for food. In some cases, fine sediment deposits can fill in the spaces between gravels and prevent oxygen-rich water from flowing around eggs that have been deposited by fish. Without enough oxygen, the eggs do not develop. Many fish have evolved to address this problem by using their tails to swish the fine sediments out of gravels before laying their eggs and building redds of porous gravels that favor water exchange.

In this section, we evaluate limited information available for understanding natural and human-caused sources of sediment in Meacham Creek.

Methods

Average daily turbidity and suspended sediment loads were extracted from a monitoring summary report prepared by the Umatilla County Soil and Water Conservation District (King 2002). The report contained information on suspended sediment loads from the 1998 to the 2001 water year and turbidity data from 2000 and 2001 water years. Automated water samplers (Isco) were used in all years to extract water samples . Daily composite samples were taken from November 1 to June 5 in 2001. Samples were successfully gathered during 65% of the days at the Umatilla River site upstream of Meacham Creek and 71% of the days at the Umatilla River site near Hermiston. Missed sampling days during periods of high runoff can greatly skew average values of sediment load. Gaps in the record for the Umatilla River site upstream of Meacham Creek and the Umatilla River site near Hermiston did not occur during peak runoff periods. However, for the Meacham Creek site a portion of samples were missed during the peak runoff period. Few sizable peak flows have occurred in the Umatilla River basin since suspended sediment sampling began in the 1998 water year, so sediment load estimates from this period are probably much less than during periods of normal or abnormally high runoff.

Suspended sediment loads presented below are expressed as pounds of sediment per day per square mile of drainage area.

Results

Meacham Creek had an average daily unit load of suspended sediment that was only 70% of the unit load recorded in the Umatilla River upstream of Meacham Creek and 37% of the unit load in the Umatilla River near Hermiston (Table 24). The average daily load from 1998 to 2001 water years in Meacham Creek had a mean value of 70 lbs/sq.mi./day and is very low compared to other Pacific Northwest rivers. The McKenzie River, a western Cascade Mountains river noted for its unusual clarity, has a long-term suspended sediment load of 470 lbs/sq.mi./day. Longer-term monitoring that includes periods of unusually high flow will likely show that the suspended sediment load is considerably greater than 70 lbs/sq.mi./day for Meacham Creek.

Table 24. Total suspended sediment load and turbidity measured at the mouth of Meacham Creek and the Umatilla River upstream of Meacham Creek from Nov. 1 to June 5 (adapted from King 2002).

	Meacham Creek	Umatilla River upstream of Meacham Creek	Umatilla River near Hermiston
Average daily suspended unit load (lbs/sq.mi./day:			
1997-1998	60	100	-
1998-1999	120	120	240
1999-2000	60	100	240
2000-2001	40	80	100
average	70	100	190
Average turbidity (NTU)			
1999-2000	5.3	5.4	29.3
2000-2001	6.3	5.1	43.2

The lower suspended sediment load in Meacham Creek when compared to the upper Umatilla River was not expected since the Meacham Creek valley is more arid and grazed heavily. In addition, wildfires next to Meacham Creek from 1997 to 2000 are a potential source of accelerated sedimentation. Field observations confirmed that Meacham Creek has a low suspended sediment load. Deposits of fine sediment within the active channel width were rare except where overbank flow allowed deposition on higher terraces. The surface substrate of the channel was skeletal and included very few fines. Nevertheless, fine materials were a sizable component of the bank matrix observed where the stream had recently scoured the faces of older terraces.

We could find few sources of accelerated sedimentation along Meacham Creek. The railroad grade and most of the access road were well-drained and do not concentrate flow and cause erosion. An exception is a section of the access road in upper Meacham Creek where the road does not follow the railroad grade. Here, the road concentrates water within a rutted surface and funnels sediment-laden water to the stream.

Heavily grazed pastures next to Meacham Creek showed no sign of rill erosion and bank sloughing due to cattle trampling was not obvious. The few roads that follow tributaries (North Fork Meacham Creek and East Meacham Creek) are usually located away from the channel. Where roads do approach the channel, vulnerable sections were washed out decades ago.

Although not quantified, fine sediment deposition on streamside terraces seemed to be deeper in the reference reaches than in Meacham Creek. A dense growth of shrubs and trees along the reference reaches probably slows the water flowing across terraces during high flows better than does the sparse vegetation growing on terraces next to Meacham Creek. This allows more of the suspended sediment load to settle out of the water column.

Discussion

Turbidity values and suspended sediment loads measured in Meacham Creek from 1998 to 2001 water years are surprisingly low. These low values are partly a result of the lack of high flows in Meacham Creek during the last 5 years. Suspended sediment concentration and turbidity in a stream usually increases exponentially with flow as the stream rises. During periods without high flows, the long-term average suspended sediment load can be greatly underestimated.

The velocity and geometry of Meacham Creek, combined with a limited source of fine sediments throughout the basin, has resulted in few fines among the gravel and cobble surface substrate. Obvious sources of fine soil particles entering Meacham Creek are few. Most roads are located away from stream channels and where heavy grazing occurs along streams the ground is level. A surge of fine sediments must have occurred during construction of the railroad and access road, but this material seems to have moved out of the system during the last 120 years.

Other topics

Recreation

Extensive private ownership in lower Meacham Creek and locked gates has prevented recreational development in the study area. The Forest Service portion of the upper basin is used for big game hunting in fall and some snowmobiling in winter. Lower Meacham Creek becomes warm enough for swimming during summer hot spells. A favorite swimming area with deep pools is located upstream of the first railroad bridge at about river mile 1.8. This area was heavily used by local people in 2002 because Union Pacific Railroad kept the gate open for the summer. Use of the swimming area is probably less during summers when the gate is locked since the walk from the gate to the swimming area is about 1.5 miles.

Recreational development in the upper Meacham basin seems unlikely since existing water rights would disallow much additional appropriation of water for storage. The 102 cfs instream water right for upper Meacham Creek, held by the Oregon Department of Fish and Wildlife, would prevent any future diversion of water out of streams except during high runoff periods in the winter and spring. A reservoir would probably have to receive some year-round flow to keep it full and attractive if it were to serve as the center of a developed recreational facility, such as a recreational vehicle campground.

The deep pools in lower Meacham Creek that are used for swimming are structurally favorable for holding chinook salmon spawners from early summer to fall. And, the use of these pools by swimmers could potentially disturb the salmon. Nevertheless, water temperatures in this reach are too warm for the spawners to survive except during the coolest of summers, so we do not consider disruption by swimmers to be an issue.

Water use

Water withdrawals from streams have affected the quality of fish habitat throughout much of eastern Oregon. Diverting water from streams during the summer can decrease living space for fish or may result in dewatered reaches. Reduced flow can also cause the water temperature to increase since shallow streams are more readily warmed by solar radiation than deeper streams.

In this section, we examine surface water withdrawals throughout the Meacham Creek watershed. We limited our investigation to surface water rights that are consumptive or those that are instream water rights. Numerous water rights have been obtained within the Meacham Creek basin by the U.S. Forest Service and Pendleton Ranches for springs or for the filling of small ponds that are used to water stock. They are not included here since they do not involve much consumption of water. We also did not investigate how senior water rights in the lower Umatilla River would influence any further appropriation of water in the Meacham Creek basin.

Methods

We used an online service provided by the Oregon Water Resources Department to examine existing water rights in the Meacham Creek watershed. This easy-to-use web site provides detailed information on individual water rights, although in-progress applications for water appropriations are not shown. We did not think there are any water rights in-progress since no surface water rights have been granted for Meacham Creek since instream water rights were granted to the Oregon Department of Fish and Wildlife in 1990. The internet address for the web site is:

http://stamp.wrd.state.or.us/apps/wr/wrinfo/wrinfo.php?search_type=FindStream.

Results

Little consumptive water use occurs within the Meacham Creek basin. Surface water rights with priority dates of 1888 and 1897 were granted to the Oregon Railroad and Navigation Co. (now Union Pacific Railroad) for railroad camps at 5 locations along Meacham Creek (Table 25). However, these rights have not been used for many years and would probably be cancelled if they were ever challenged. No maximum rates of usage are indicated in the water right certificates but they can be interpreted to be small since the stated diversion pipe sizes were small (4 to 6 inches) and probably gravity-fed.

The largest water use in the basin is a diversion from lower Camp Creek to irrigate 23 acres and to supply water for domestic use and to water stock. This water right has a priority date of 1891 and a maximum diversion rate of 0.29 cfs. All other consumptive surface water rights in the basin are very small (less than 0.02 cfs).

The Oregon Department of Fish and Wildlife was granted instream water rights to support fish rearing with priority dates of 1988 and 1990. The water rights are large (225 cfs for lower Meacham Creek, 100 cfs for North Fork Meacham Creek, and 102 cfs for upper Meacham Creek) and will probably prevent any further allocation of water, except during periods of very high flow in the winter and spring.

Table 25. Surface water rights (consumptive and instream uses) for the Meacham Creek watershed.

Stream	Priority date	Rate	Point of use	Use	Likely status	Right holder at time of issuance
Tie Cr, tributary of lower Meacham Creek (Duncan Station)	1888	-	SE1/4,NW1/4, Sec. 16, T.1N, R. 36E	Railroad, 6 in. pipe	Inactive*	Oregon Railroad and Navigation Co.
Beaver Cr, tributary of upper Meacham Creek (Meacham Station)	1888	-	SW1/4, NE/4, Sec. 9, T.1S, R.36E	Railroad, 6 in. pipe	Inactive*	Oregon Railroad and Navigation Co.
Upper Meacham Creek (Huron Station)	1888	-	NW1/4, NW1/4, Sec. 8, T.1S, R.36E	Railroad, 3 in. pipe	Inactive*	Oregon Railroad and Navigation Co.
Lower Meacham Creek (Gibbon Station)	1897	-	NE1/4, SE1/4, Sec. 31, T.3N, R.36E	Railroad, 6 in. pipe	Inactive*	Oregon Railroad and Navigation Co.
Lower Meacham Creek (Camp Station)	1897	-	NE1/4, SE1/4, Sec. 15, T.1S, R.36E	Railroad, 4 in. pipe	Inactive*	Oregon Railroad and Navigation Co.
Camp Cr, tributary of lower Meacham Cr	1891	0.29 cfs	NW1/4 and SW1/4, Sec. 9, T.1N, R.36E	Irrigation of 23 ac., domestic and stock use	Active	Ephriam Wilbur
Lower Meacham Cr	1904	0.02 cfs	SE1/4, Sec.30, T.2N, R.36E	Irrigation of 1 ac., domestic and stock use	Active	Ben Brown
North Fork Meacham Creek (spring)	1970	0.01 cfs	NE1/4, NE1/4, Sec. 12, T.1S, R.36E	Domestic	Active	Robert and Fred Hoskins Jr.
East Meacham Creek (spring)	1970	0.007 cfs	NE1/4, SW1/4, Sec. 30, T.1S, R.37E	Domestic	Active	Robert and Fred Hoskins
Upper Meacham Creek (spring)	1973	0.005	NW1/4, SE1/4, Sec. 27, T.1N, R.35E	Domestic	Active	Floyd Harris
Upper Meacham Creek (spring)	1973	0.01	NE1/4, SE1/4, Sec. 35, T.1S, R.35E	Domestic	Active	John Doherty
Camp Creek	1988	11 cfs	At Mouth	Instream, supporting aquatic life	Active	Oregon Dept. Fish & Wildlife
North Fork Meacham Creek	1988	40 cfs	Bear Creek to mouth	Instream, supporting aquatic life	Active	Oregon Dept. Fish & Wildlife
North Fork Meacham Creek	1990	100 cfs	Mouth to headwaters	Instream, for fish rearing	Active	Oregon Dept. Fish & Wildlife
Upper Meacham Creek	1990	102 cfs	North Fork to R.M. 35	Instream, for fish rearing	Active	Oregon Dept. Fish & Wildlife
Lower Meacham Creek	1990	225 cfs	Mouth to North Fork	Instream, for fish rearing	Active	Oregon Dept. Fish & Wildlife
Camp Creek	1990	11 cfs	Mouth to R.M. 2.8	Instream, for fish rearing	Active	Oregon Dept. Fish & Wildlife

* probably has expired due to non-use over the last 5 years.

Senior water rights in the lower Umatilla River basin may have already disallowed further allocation of water from Meacham Creek, even prior to granting of the instream flows.

Discussion

Flows in Meacham Creek and its tributaries are essentially natural flows. Exercised water rights result in only minor reductions in streamflow. Further allocation of water from Meacham Creek is unlikely due either to senior water rights in the lower Umatilla River or the large instream water rights that were granted for fish rearing in 1998 and 1990. Water surface permits with small water use rates are usually granted for domestic use, in spite of a general closure of a basin to further water allocation. In the future, houses may be built on plots of private land along Meacham Creek and water rights would probably be granted for domestic use but not for irrigation.

Fish passage

At least four species of adult fish seasonally migrate in the Meacham Creek watershed. Steelhead migrate into Meacham Creek during the winter and spawn in many tributaries of the basin in the spring. Chinook salmon move into the watershed during early summer and most migrate into lower Meacham Creek and North Fork Meacham Creek where they find deep pools to over-summer and then spawn in the fall. Adult bull trout roam during higher water in search of food and then retreat into areas with cool water for the summer. Pacific lamprey move upstream into Meacham Creek in early summer to immediately spawn, although their spawning areas are not well known within the watershed.

In addition, juvenile anadromous salmonids, resident rainbow trout, and mountain whitefish will move upstream at various times of the year. Fish can get displaced downstream during higher flows or elect to move downstream in search of early sources of food in the spring and then later move upstream to favored feeding areas that develop later in the season. In addition, fish will abandon downstream portions of the watershed when the water becomes too warm in the summer.

Adult fish have evolved to jump (salmonids) or suck (lamprey) their way over obstacles. Steelhead are known to scale water falls as high as 11 feet (Salmonberry River in northwest Oregon) and lamprey routinely scale water falls (50-feet-high Willamette Falls on the Willamette River) by inching up the bedrock face with their mouths.

Obstacles are much more a problem for juvenile fish and resident trout, for which even a 12- to 18-inch drop can block upstream passage. Fish passage obstacles are often seasonal. Stair-stepped drops in bedrock- or boulder-dominated channels can become obstacles to fish when flows are low. Low flows can also result in sections of subsurface flow, which creates an obvious fish passage problem.

In this section, we evaluate the obstacles to fish passage that we and others have noted in the study area.

Methods

The Oregon Department of Fish and Wildlife provided us with a table of known obstacles to fish passage in the northern Blue Mountains. Two records in the table pertained to the Meacham Creek watershed. In addition, we noted obstacles that we encountered as we surveyed the study area.

Results

The Meacham Creek study area has few fish barriers that are human-caused. An effort to improve fish habitat at river mile 1.7 of Meacham Creek has resulted in a barrier to the upstream movement of juvenile fish during the summer (Table 26, Figure 33). Old concrete dams in lower Camp Creek (R.M. 0.3) and upper Meacham Creek (R.M. 20.2) are obstacles to juvenile fish and resident trout. All other obstacles are natural features. Camp Creek has a 40-foot-high falls at river mile 3.1 and is a blockage to all fish although isolated resident fish may live upstream of the falls. Segments of subsurface flow in lower Meacham Creek (R.M. 12.0 to 13.2) and in upper Meacham Creek (R.M. 15.2 to 15.6 and 20.8 to 24.9) are barriers to all fish by the middle of summer.

Barriers to fish movement in smaller tributaries and Meacham Creek upstream of the study area, especially at road crossings, may exist but we are not aware of any surveys to determine this in these smaller streams.

Table 26. Listing of barriers to fish passage within the Meacham Creek basin.

Description	Location	Season	Human-caused	Fish blocked
Cabled boulders at rim of bedrock cascade (2 ft high)	Meacham Cr R.M. 1.7	summer	yes	juvenile
Concrete dam (4.3 ft high)	Camp Cr R.M. 0.3	year-round	yes	juvenile and resident trout
Falls (40 ft high)	Camp Cr R.M. 3.1	year-round	no	all
Subsurface flow	Meacham Cr R.M. 12.0-13.2	summer	no	all
Subsurface flow	Meacham Cr R.M. 15.2-15.6	summer	no	all
Subsurface flow	Meacham Cr R.M. 20.8-24.9	summer	no	all
Concrete dam (2.5 ft high)	Meacham Cr R.M. 20.2	year-round	yes	juvenile and resident trout

Figure 33. Cabled boulders added to the top of a bedrock cascade now prevent upstream passage of juvenile fish during summer low flow. Site number #7 in Appendix D.

Discussion

Meacham Creek has few human-caused obstacles to fish passage. Those that exist can probably be remedied without much cost. The concrete dam in upper Meacham Creek (river mile 20.2) is a relic from the steam locomotive days and is no longer used. It could be easily broken down using explosives or a crawler tractor winch. The obstacle created by the boulders placed in lower Meacham Creek (river mile 1.7) could be easily modified to allow fish passage using a crawler tractor winch or excavator. We did not see the concrete dam in lower Camp Creek nor do know if it has any current use. Therefore, we cannot make a recommendation about improving fish passage at this site.

Synthesis of conditions

Overall, Meacham Creek provides important habitat for steelhead trout, chinook salmon, and other native fishes. Where fish habitat is less than ideal, both human and natural forces are accountable. The most influential human disruption of fish habitat has been the channelization of reaches 3 and 4a in lower Meacham Creek, a result of diking to keep the stream from meandering into the railroad prism. Natural features with strong influence on fish habitat include the three sections of subsurface flow that keep juvenile fish from migrating upstream to cool water portions of the basin such as North Fork Meacham Creek and East Meacham Creek during the summer. On the other hand, cool water refuges exists downstream of the subsurface flow sections and these greatly benefit fish.

Large wood is scarce throughout the study area. The flood plain of lower Meacham Creek is wide and probably retained only the largest pieces of wood following floods, even prior to disturbance by humans. A scarcity of large trees growing along the stream now does not indicate that natural delivery of large wood will improve conditions much during the next century. The lack of evidence of older stands growing in the valley bottom prior to construction of the railroad (no stumps, snags, or residual trees) is puzzling and may be a result of repeated burning by native Americans to promote pasture for horses. An alternative theory is that wood for the steam trains was once in such high demand that even stumps and snags were removed to feed the boilers.

The ***original condition*** of Meacham Creek, based on our current understanding of how the stream once operated to support populations of fish, is detailed below:

A. Stream temperatures alternated between warm and cool in a downstream direction. Fish were able to access zones of thermal refuge downstream of subsurface reaches and where tributaries and springs entered.

B. The meandering channel accessed the entire valley bottom with no propensity to run along the steep valley walls to the west or along the railroad grade. It created complex channel features that provided fish options for feeding and refuge from fast water. The channel form was only slightly entrenched allowing flood flows to overtop the streambanks without constrictions.

C. The stream was bordered by diverse and abundant streamside forests, including areas of older trees that were large enough to be stable in the stream when eventually undercut by the stream. Large trees in the channel provided jams of wood that sculpted the channel and provided holding pools for spawners, high-quality feeding areas for juvenile fish, and refuge from high-velocity water and predation.

D. Diverse and dense vegetation among streamside trees filtered out finer sediments during high flows, thereby creating a fertile top soil that promoted vigorous vegetation along the stream.

E. Channels were unobstructed to the passage of fish (except in subsurface reaches during the summer), allowing them to access their traditional spawning and rearing areas.

F. Wildfires resulted in cool burns that crept along the ground, leaving riparian areas relatively intact, and sparing most of the older, green trees.

Summer flows were undiminished by water withdrawals. Water was low in fine sediments and nutrients were tightly recycled by aquatic biota with little excess to support nuisance growths of algae.

Fish habitat in Meacham Creek today is fashioned, to some extent, by all of the parameters discussed above, including:

- Channel sinuosity*
- Channel gradient
- Streamflow*
- Channel surface substrate
- Channel and floodplain geometry*
- Bank erosion
- Large wood*
- Riparian vegetation*
- Fire
- Stream improvement efforts
- Water temperature*
- Nutrients
- Suspended sediments
- Recreational use
- Water withdrawals
- Fish passage*

Of these 16 parameters, we have selected 7 that seem to influence aquatic habitat the most in Meacham Creek (marked by an asterisk in the list above). We evaluated the influence of each parameter on the relative quality of fish habitat within each reach. We have done this for three conditions. They are:

Initial	Conditions prior to European settlement.
Current	Current conditions and infrastructure (railroad, road, dikes) and land uses (transportation, grazing, residential).
Modified	Future conditions assuming reasonable investments in stream improvement are made and some land uses are modified.

For the modified condition we assumed that the effort made to improve conditions or modify land uses were limited to reasonable investments. Reasonable investments to restore initial conditions include activities such as removing some dikes, adding logs to the channel, restoring streamside vegetation, or fencing streamside areas. Investments not considered reasonable include activities such as relocating the railroad grade, removing all dikes, or banning all cattle grazing and tree harvest within the basin. In reality, all investments in future stream improvement of Meacham Creek are dependent on the goodwill of landowners in the basin. The Tribes and federal agencies have direct control over only a small portion of the streamside area within the study area.

We assigned each combination of fish habitat parameter and condition a subjective rating of fish habitat quality class, using the categories defined below:

Good	Fish habitat promotes high densities of fish for multiple life stages and species.

Moderately good	Fish habitat somewhat limited; promotes moderate densities of fish.
Fair	Fish habitat is limited, does not promote high or moderate densities of fish or certain life stages.
Poor	Fish habitat is very limited, fish may be absent during the summer or fish densities are very low.

We assigned scores to fish habitat quality classes such that, 4 = good, 3 = moderately good, 2 = fair, 1 = poor. For an overall fish habitat score, values for the 7 parameters were averaged with equal weighting given to each parameter, except for water temperature which received twice the weighting of other parameters.

Discussions of criteria of fish habitat quality classes for each of the 7 parameters are provided below:

> *Channel sinuosity*. We assumed that a stream channel capable of meandering across its flood plain without encountering human-placed features such as dikes and railroad grades had “good” habitat. “Moderately good” habitat was assigned to channels that were free to meander across a flood plain with only occasional interactions with human-place features. Channels rated as “fair” were those that had compromised fish habitat due to channelization or the channel was naturally and moderately confined by steep, canyon walls. “Poor” habitat was assigned to situations where extreme channelization had resulted in mostly unusable habitat by fish for parts of the year.
>
> *Summer flow*. We assumed that a reach with abundant year-round summer flow with no obstacles to upstream movement provided “good” fish habitat. “Moderately good” habitat was assigned to conditions where living space for fish was somewhat limited by natural low flows or by minor water withdrawals or some limitations to upstream fish (such as subsurface) movement existed. Channels were categorized as “fair” if living space was substantially limited by lack of surface flow and/or by substantial barriers to upstream fish movement. “Poor” habitat was assigned to those reaches with little to no living space for fish and had few opportunities for fish to migrate into areas with water.
>
> *Channel geometry*. We assumed that reaches with the capacity of forming multiple channels during flood flows and had a lesser average velocity were “good” fish habitat. These streams typically form a variety of water depths when large wood or boulders are present. “Moderately good” habitat was assigned to conditions where natural or human influences constrained the channel to some extent, thereby reducing refuge areas during high flows. Channels were categorized as “fair” if natural or human influences caused a majority of the area to have only a single channel and offered some refuge areas for fish. “Poor” habitat was assigned to reaches with an entrenched single channel with no refuge areas for fish.

Large wood. We assumed that "good" habitat was that where large wood was abundant enough to create pools and complex habitat and that the stream was narrow enough to readily retain both small and large pieces. "Moderately good" habitat was assigned to reaches where inputs of large wood were abundant but flood flows were too large to retain much of the smaller size classes of wood. Channels were characterized as "fair" if the supply of wood to the stream was not sufficient to create pools and other cover features or few stable pieces are present. "Poor" habitat was assigned to reaches with hardly any large wood with most existing pieces being too small to withstand downstream movement during high flows.

Riparian vegetation. We assumed that "good" habitat existed where well-stocked stands of large trees were continuous and had an intact understory outside of the active flood plain and abundant brush and young trees were regenerating within the active flood plain. "Moderately good" habitat was assigned to reaches where the stocking of large trees was patchier, and the brush and young trees were occasionally missing due to grazing. Reaches were characterized as "fair" habitat if most stands of streamside trees were understocked and brush was spotty along the stream. "Poor" habitat was assigned to reaches with few large trees or little brush growing next to the stream.

Summer water temperature. We assumed that "good" habitat existed where maximum temperatures were routinely less than 65 deg F. "Moderately good" habitat was assigned to reaches where maximum temperatures routinely reached 70 deg F and fish had access to thermal refuge areas (springs, alcoves, deep pools). Reaches were characterized as "fair" habitat if maximum temperatures routinely exceeded 70 deg F, but fish had access to thermal refuge areas. "Poor" habitat was assigned to reaches that typically exceeded 75 deg F, and fish had few thermal refuges.

Summer passage for fish. We assumed that "good" conditions existed where fish had no natural or human obstacles to summer movement. "Moderately good" conditions were typified by only limited obstructions to movement. Reaches were characterized as "fair" where significant obstacles to upstream movement existed. "Poor" condition was assigned to reaches where numerous passage obstacles exist, including shallow flow, high jumps, dewatered sections.

For all parameters, the quality of fish habitat was rated less or the same today than it was prior to European settlement (Table 27). Differences were greatest for channel geometry, large wood, and riparian vegetation. Overall fish habitat rated as moderately good prior to European settlement and fair for current conditions (Figure 34). Reach 4b in lower Meacham Creek had the least difference and was rated as moderately good for both periods.

Table 27. Rating of fish habitat quality (by reach) for initial, current, and modified conditions.

Parameter	Condition	Rating of fish habitat quality by reach				
		Reach 3	Reach 4a	Reach 4b	Reach 5	Reach 6
Sinuosity	Initial	Mod. good	Mod. good	Good	Mod. good	Fair
	Current	Fair	Fair	Good	Fair	Fair
	Modified	Mod. good	Mod. good	Good	Mod. good	Fair
Summer flow	Initial	Mod. good	Mod. good	Mod. good	Fair	Poor
	Current	Mod. good	Mod. good	Mod. good	Fair	Poor
	Modified	Mod. good	Mod. good	Mod. good	Fair	Poor
Channel geometry	Initial	Mod. good	Mod. good	Good	Mod. good	Mod. good
	Current	Fair	Fair	Mod. good	Fair	Fair
	Modified	Mod. good	Mod. good	Mod. good	Fair	Fair
Large wood	Initial	Mod. good*	Mod. good*	Mod. good*	Good*	Good*
	Current	Poor	Poor	Poor	Poor	Poor
	Modified	Mod. good	Mod. good	Mod. good	Good	Good
Riparian vegetation	Initial	Good*	Good*	Mod. good*	Good*	Good*
	Current	Fair	Fair	Poor	Fair	Fair
	Modified	Mod. good	Good	Mod. good	Good	Good
Summer water temperature	Initial	Fair	Fair	Mod. good	Fair	Mod. good
	Current	Poor	Poor	Mod. good	Poor	Mod. good
	Modified	Fair	Fair	Mod. good	Fair	Mod. good
Summer passage for fish	Initial	Good	Good	Fair	Poor	Fair
	Current	Mod. good	Good	Fair	Poor	Fair
	Modified	Good	Good	Fair	Poor	Fair
Overall fish habitat score **	Initial	3.0 Mod. good	3.0 Mod. good	3.1 Mod. good	2.6 Mod. good	2.8 Mod. good
	Current	1.9 Fair	2.0 Fair	2.5 Mod. good	1.5 Fair	2.0 Fair
	Modified	2.9 Mod. good	3.0 Mod. good	3.0 Mod. good	2.5 Mod. good	2.6 Mod. good

Condition:

Initial = Conditions prior to European settlement.
Current = Current infrastructure (railroad, road, dikes) and land uses (transport, grazing, residential).
Modified = Future conditions assuming reasonable investments in stream improvement made and continuing the current land uses.

Fish habitat quality:

Good = Fish habitat promotes high densities of fish for multiple life stages and species.
Moderately good = Fish habitat only somewhat limited; promotes moderate densities of fish.
Fair = Fish habitat is somewhat limited, does not promote high densities of fish or certain life stages.
Poor = Fish habitat is very limited, fish may be absent during the summer or fish densities very low.

* Prior to any regular burning of the valley by native Americans.

** Scores assigned to fish habitat quality classes are: 4 = good, 3 = moderately good, 2 = fair, 1 = poor. For the overall fish habitat score, values for the 7 parameters were averaged with equal weighting given to each parameter, except for water temperature which received twice the weighting of other parameters.

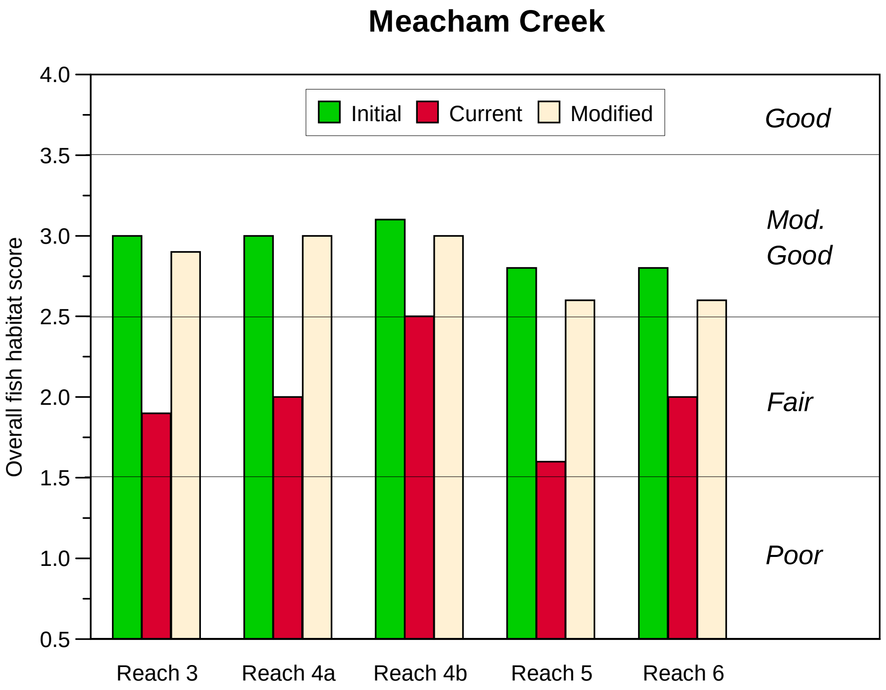


Figure 34. Overall fish habitat scores (see description above) for reaches 3 through 6 in Meacham Creek for initial, current and modified conditions.

The rating system indicates that much of the loss in fish habitat during the last 120 years could probably be recovered through reasonable stream improvement efforts and modifying some current land use practices. Some characteristics of Meacham Creek (sections of sub-surface flow, low summer flow, high temperature) greatly influence fish use during the summer, but are not a result of human activities. There is little that can be changed to improve fish habitat that is linked to these characteristics.

While most of Meacham Creek offers good habitat for fish at least during a portion of the year, the North Fork Meacham Creek is the most important component of the basin. Moderate water temperature, relatively abundant flow with no subsurface reaches, mostly intact riparian vegetation, and a channel not constricted by human infrastructure provides good overall habitat for fish. It is not surprising that those species with the most specialized habitat needs (bull trout that need spawning and juvenile rearing areas and chinook salmon spawners that require summer holding areas) are still found in this drainage. A current deficiency in at least the lower portion of North Fork Meacham Creek is large, stable wood. Wood was probably intentionally removed during the last 120 years. Wildfire is a particular threat to this basin since a source of ignition (the railroad) is at its downstream and windward boundary, and abundant timber along the riparian corridor and north-facing slopes could easily move a fire throughout the basin. A major wildfire would decrease channel shading and truncate the current stand rotation (about 100 years old), which is only beginning to provide wood that is large enough to be stable in the channel.

A central question of this study was whether or not the channel substrate of Meacham Creek was unnaturally coarse or the active flood plain unnaturally wide due to the railroad, grazing, and other human influences. When compared to the relatively undisturbed reference reaches, Meacham Creek turned out not to be different. There was little evidence that filling of the gorge with blasted rock during construction of the railroad grade has persisted to this day. In fact, the extensive alluvial deposits in Meacham Creek downstream of the North Fork Meacham Creek confluence and the limited alluvial deposits upstream of the confluence within Meacham Creek suggest that North Fork Meacham Creek is the major donor of coarse sediments to lower Meacham Creek. Physical features of the North Fork basin such as extensive areas with steep slopes, a steeper channel gradient compared to Meacham Creek, and a more extensive higher-elevation zone that is reactive during rain-on-snow events make it conducive to higher inputs of bedload. Human sources of coarse sediment are lacking in North Fork Meacham Creek since nearly all logging roads are near ridge tops or flat plateaus.

Camp Creek is the only other tributary of Meacham Creek that is large enough to provide much year-round habitat for fish. Fish have limited access into the Camp Creek basin due to a concrete dam near its mouth and an impassible falls at river mile 3.1. Unlike other tributaries, Camp Creek does not have cool water, and this may be a result of a large fire that occurred within its basin boundary in 2000.

The other tributaries provide zones of cool water refuge where they flow into Meacham Creek, but do not have enough flow to significantly change the temperature of Meacham Creek. Only at Bonifer Pond have cool water sources been intentionally altered to enhance summer fish habitat. Here, a large pond fed by cool springs provides an acclimatization area for juvenile hatchery fish prior to their release. The use of cool water zones by fish is often limited by shallow water and lack of overhead cover.

Currently, the railroad is only an indirect influence on lower Meacham Creek. Except where the railroad crosses the stream at two locations, the railroad is at the far edge of the stream's meander zone. The stream flows against the railroad grade at 6 places and little undercutting of the grade is occurring. The major influence of the railroad on Meacham Creek has been the extensive systems of dikes built to keep the stream away from the railroad grade.

In reach 3 and 4a, the dikes appear to have caused portions of the stream to incise within its flood plain and abandon its side channels, resulting in a deep, single channel that has fast water during high flows. This channelization process has the potential to move upstream over time. Removing all of the dikes along Meacham Creek would probably lead to a situation illustrated in the 1956 aerial photographs where nearly 20% of the total stream length was along the base of the railroad grade; streams tend to align themselves along hard surfaces that reside in their flood plain (USFW 2001),. Nevertheless, the current system of dikes could probably be modified to allow for both protection of the railroad grade and restoration of the stream channel. Rock barbs installed recently along lower portions of reach 3 demonstrate that short dikes are effective at curtailing channel meandering. The long dikes (up to 1000 feet long) installed several decades ago to protect the railroad grade, are probably overkill and some could be breached to provide more room for the stream to move, while still protecting the railroad grade.

The railroad grade upstream of the North Fork Meacham Creek also influences Meacham Creek by crowding its flood plain. But here, shallow or subsurface flow during the summer is also significant at limiting fish habitat. Within reach 5 of upper Meacham Creek, the stream channel alternates between wide segments that have limited crowding and narrow segments with the adjacent railroad tracks.

Problems that plague many other eastern Oregon streams do not occur in Meacham Creek. Accelerated sedimentation, high nutrient status, water withdrawals, and barriers to fish passage are either absent or minor. This makes the task of improving habitat within Meacham Creek a much more straightforward task. Further development within the basin will probably be minor since numerous trains in the study area detract from the valleys use for year-round or vacation homes and future water withdrawals are limited to small amounts for domestic use.

Private ownership of land along most of lower Meacham Creek will be one of the greatest challenges to improving conditions for fish. When we approached each landowner to request access for conducting the field survey, we also asked about their views on improving fish habitat in the basin. Nearly all landowners were in favor of improving fish habitat as long as it did not disrupt their current use of the land. A common concern among those who grazed cattle in the valley was that productivity of high quality summer pasture near the stream not be reduced.

Action plan

Restoring and enhancing original conditions

Natural and human-related limitations to stream health and fish productivity in Meacham Creek were highlighted in the previous Watershed Assessment section. These limitations include:

- Constriction of the flood plain by dikes that were constructed to keep the stream from meandering into the railroad tracks. The resultant channelization of the stream is most serious in lower Meacham Creek; reaches 3 and 4a.

- A lack of large wood in the channel and of older trees bordering the stream as a future source of large wood (throughout Meacham Creek and North Fork Meacham Creek). A scarcity of dense understory vegetation on floodplain surfaces that is effective at trapping finer sediments and creating favorable soils for further growth of shrubs and trees near the stream (most serious in lower Meacham Creek; reach 4b where cattle grazing is intense).

- The presence of deep and coarse stream substrate, broad flood plain, and low summer flows (all natural features) that cause subsurface flow to occur in some sections (reaches 4b and 5). The subsurface sections eliminate living space for fish and create an obstacle to fish attempting to move upstream into cooler waters during the summer. On the other hand, the cool water exiting subsurface reaches cools the stream and is a thermal refuge for fish. More subsurface sections (and downstream cool-water zones) may have existed prior to the diking and channelization in reaches 3 and 4a. Cool water refuges within alcoves and at tributary junctions may have once been more accessible to fish and contained more useful habitat prior to human-caused changes.

- Tributary streams are vulnerable to warming following hot wildfires which consume understory vegetation and trees next to stream channels. The North Fork Meacham Creek is most vulnerable to wildfire due to a continuous band of vegetation along the valley and north-facing slopes and a source of ignition (the railroad) at its upwind end.

- Physical obstructions to fish passage that prevent fish from searching out cool water in the summer and favorable feeding areas year-round. Included are a concrete dam in reach 5 of Meacham Creek, a fish improvement project in reach 3, and a concrete dam in lower Camp Creek.

Opportunities to improve stream health and fish habitat in Meacham Creek are present throughout the study area. Nevertheless, the unique natural features of Meacham Creek indicate that certain improvement efforts will be highly effective in some areas and less effective in other areas. For example, the distinct water temperature patterns of Meacham Creek dictate where fish are able to make the most of complex physical habitat during the summer.

In this section, we present a plan that specifies actions that would be effective at improving fish habitat in the Meacham Creek study area and in which reaches such activities would be most beneficial. These recommendations are summarized in Table 28, displayed in Figures 35 and 36, and later explained in detail. The first five recommendations are closely associated with the railroad and could be initiated in the next year or two. Land ownership throughout the study area, a critical factor in designing and implementing improvement projects, is provided in Maps 15-18.

Table 28. Summary of activities to improve fish habitat in the Meacham Creek study area.

Id	Priority	Reaches	Cost	Description
1*	Highest	3, 4a, 4b	High	Place multiple large wood structures along banks at 5 locations where the stream flows along the base of the railroad prism in order to create complex habitat and reduce the risk of railroad and road washout.
2*	High	3	High	Pilot project: re-route stream across its original flood plain starting at R.M. 3.3 by creating break in dike and constructing massive log jam in order to restore channel sinuosity and complex habitat for fish.
3*	Highest	3	High	Replace road bridge at furthest downstream railroad crossing in order to eliminate potential for large wood accumulating at piers and washing out bridge. Would allow for the use of creative designs for improving fish habitat with logs in upstream areas.
4*	High	5	Mod.	Fire-proof a swath of land east of the railroad from the North Fork Meacham Cr confluence upstream 1.5 miles in order to keep any railroad-sparked fires from spreading into the North Fork basin.
5*	Lower	5	Low	Remove concrete dam in stream at river mile 20.2 in order to allow juvenile and resident fish to move upstream.
6	Highest	4b, 2	High	Create large, stable log structures in the channel capable of scouring deep pools and providing complex habitat. Focus on areas that have cool water during the summer.
7	Lower	3, 4a, 4b, 5	Mod.	Excavate deep pools where cool water sources enter Meacham Creek at tributary junctions or springs in order to create cool water refugia. Add large wood to pools to create cover. Modify Bonifer Pond ladder so juvenile fish can access in summer.
8	High	4a	Mod.	Re-route stream across its original flood plain starting at R.M. 6.7 by creating break in dike and constructing massive log jam in order to restore channel sinuosity and complex habitat for fish. Similar to #2.
9	High	Camp Cr.	Low	Modify or remove concrete dam at R.M. 0.3 in Camp Creek in order to allow upstream migration of juvenile and resident fish.
10	High	3	Low	Modify stream improvement structure at bedrock cascade (RM 1.7) so juvenile and resident fish can move upstream during the summer.
11	Lowest	4a, 4b	Mod.	Plant conifer trees near stream and protect from trampling by cattle.

* closely associated with the railroad and could be initiated in a year or two.

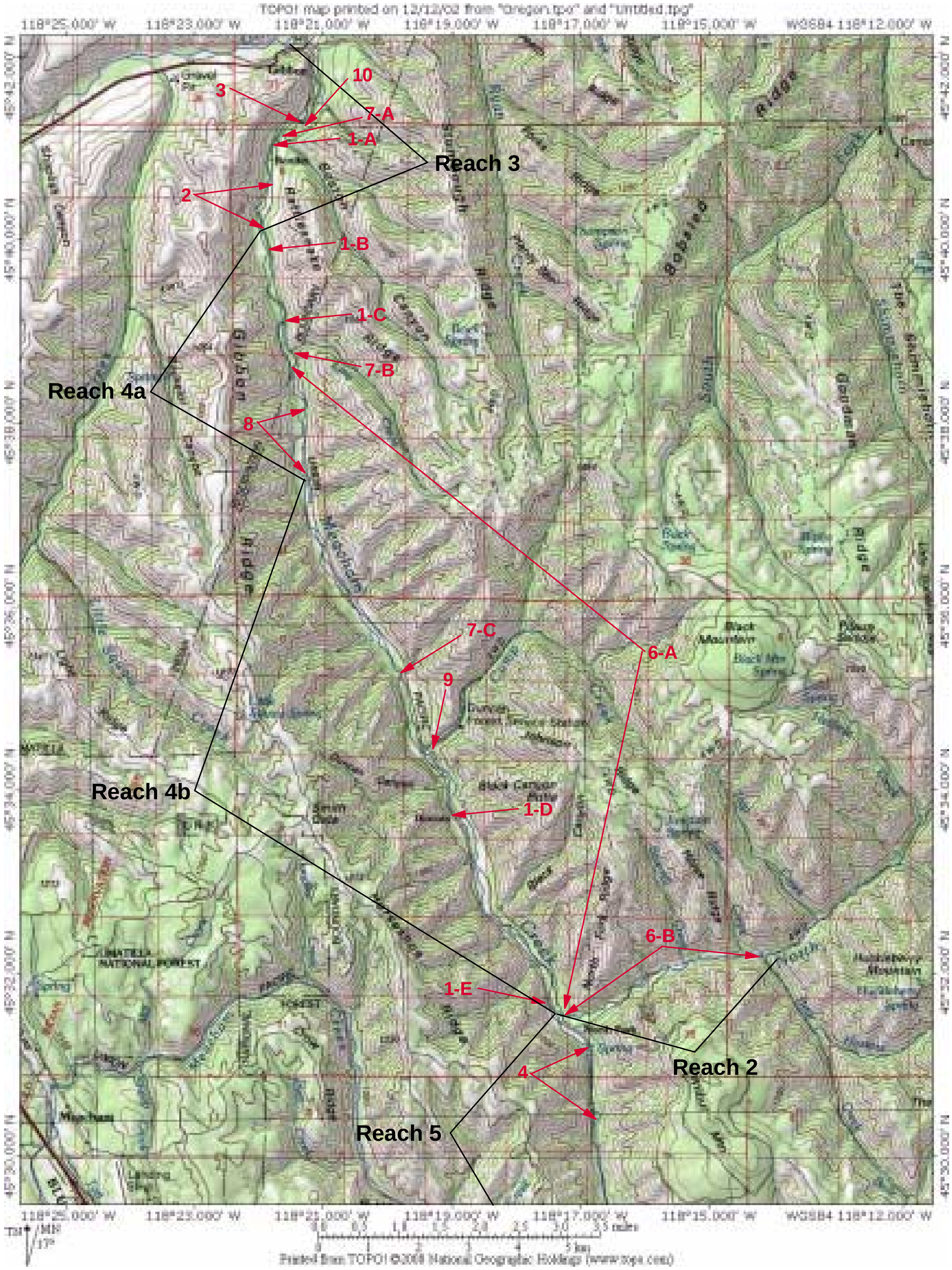


Figure 35. Location of suggested fish habitat improvement projects, lower Meacham Creek. Identification numbers correspond to those in Table 28.

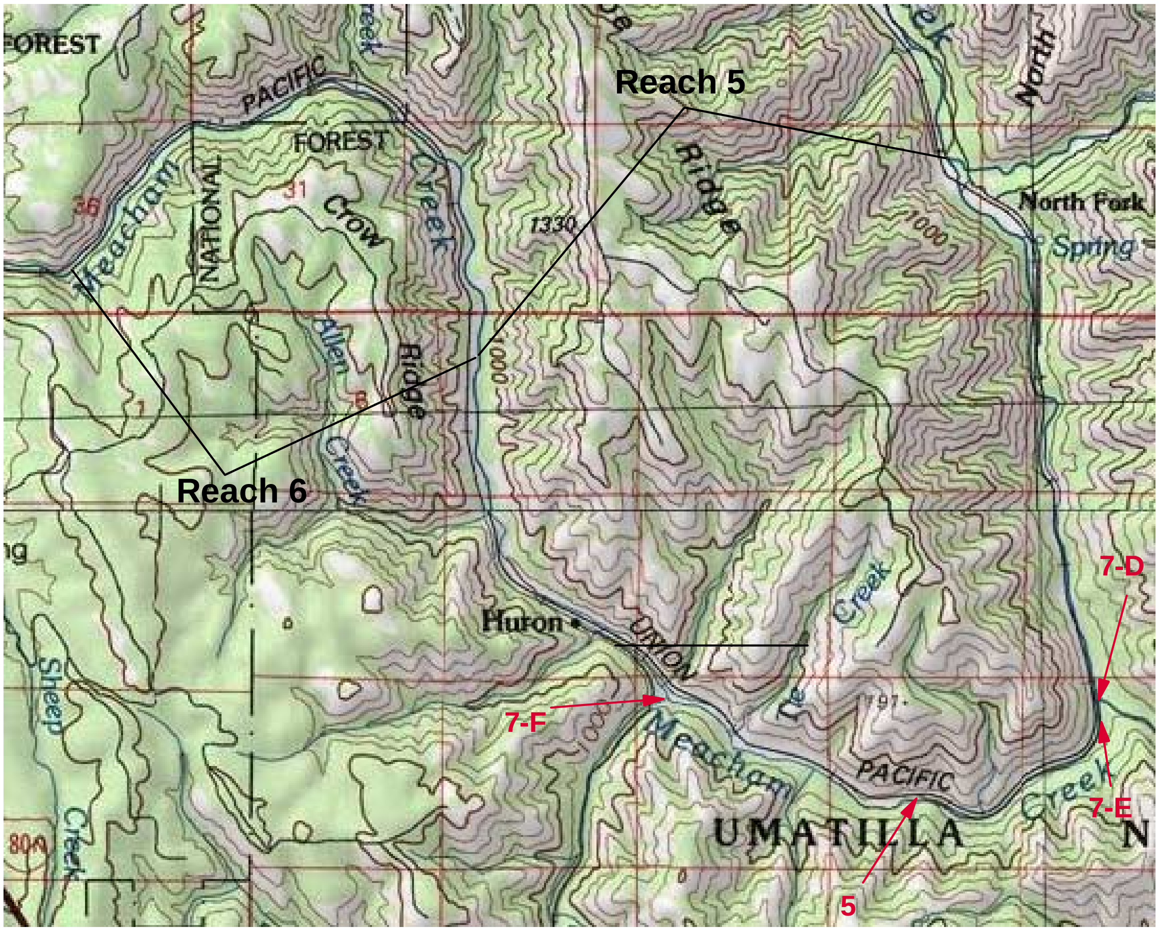


Figure 36. Location of suggested fish habitat improvement projects in upper Meacham Creek. Identification numbers correspond to those in Table 28.

Recommendation 1 – Logs where stream flows along railroad

Background

The main channel of Meacham Creek runs parallel and along the base of the railroad prism at 6 locations in lower Meacham Creek (downstream of the North Fork Meacham Creek confluence). The summed length of stream channel in this condition is 1.01 miles or 7% of the total length of lower Meacham Creek. At none of these 6 locations is the stream actively eroding the railroad prism, although there is potential for erosion during very large floods.

Lower Meacham Creek and portions of upper Meacham Creek meander widely across a cobble and gravel dominated stream bed that has few limits to lateral movement except for the bedrock cliffs on one side of the valley and the railroad grade on the other side. Where the stream meanders into bedrock or the railroad grade, the channel becomes deeper as the stream's energy is expended downward rather than laterally. Nearly all deep pools (greater than 4 feet) inventoried in 2002 were associated with the stream flowing along such features. Although these pools provide potentially good holding and rearing habitat due to the deep water and interception of cooler subsurface flow, the lack of complex structure limits their use. Without cover from above, crevasses and eddies to escape high-velocity water, and segregation of feeding sites, use of these pools by steelhead and chinook salmon is marginal.

Proposed action and expected benefits

The deep pools associated with the stream running along the base of the railroad prism can be altered so that they not only provide high quality habitat for fish but also provide a means to protect the railroad prism from future erosion. This action would be a partial response to the current lack of complex pool habitat throughout Meacham Creek, owing to a scarcity of large wood in channels.

Placing groups of 3 to 4 conifer logs with their rootwads attached and bundled with cable at the large end (Figure 37) would provide a substantive hard surface for the stream to flow against while providing cover, zones of slow water, and feeding stations for fish. By using large logs (> 28 inches DBH, > 50 feet long) with attached rootwads and bundling them in groups, these log structures would be resistant to downstream movement during high flows. Extra stability, where needed, could be ensured by cabling one structure to the other or by cabling large boulders to the rootwad end of the structure.

The National Marine Fisheries Service, through their participation in permit approvals conducted by the U.S. Corps of Engineers, has not been particularly supportive of using cable in the design of created log jams in streams over the last decade. However, recently they have modified this stance and will entertain designs that use cable simply to hold large logs together, rather than rigidly attach them to bedrock or to banks. This is particularly important for large streams where logs long enough to remain stable in the channel on their own are no longer available.

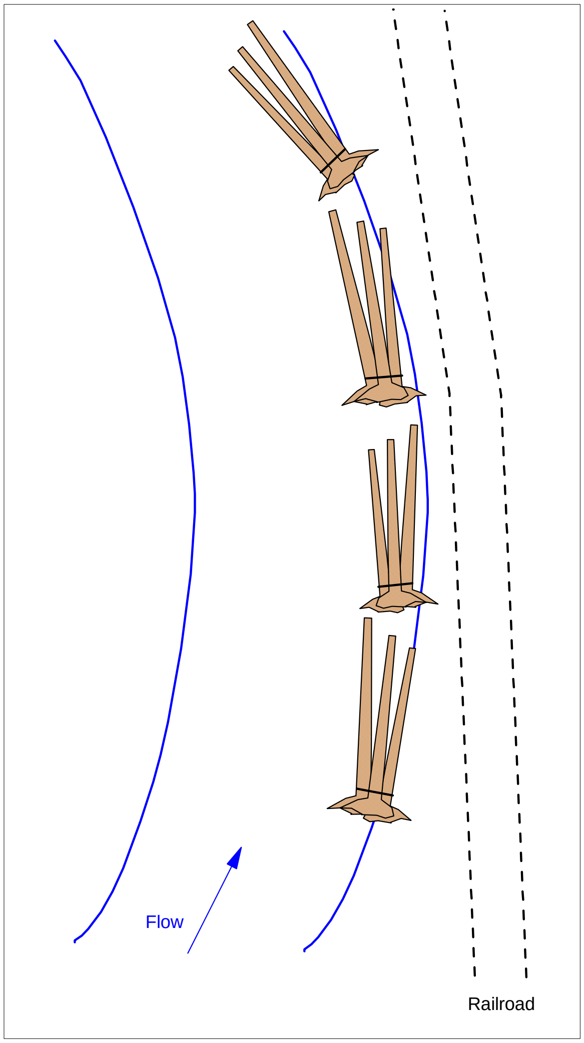


Figure 37. Diagram of log structures placed between railroad grade and stream on the outer edge of a bend.

Other landowners would not need to be involved in this activity since the placement sites fall within the railroad right-of-way. Neighboring landowners would probably have a favorable perception of the project since the log structures would help preserve the integrity of the access road, which is usually located between the railroad grade and the stream. A source of large conifer logs with attached rootwads would be needed for the project and could possibly be purchased from forest landowners in the Meacham Creek valley. Either trucks or railroad cars could be used transport logs to individual sites, although weak road bridges upstream of the North Fork confluence may not support a heavily-loaded truck. A very large log loader would be needed to load and unload these heavy logs with rootwads and place them into the stream.

Five reaches are recommended for this type of enhancement. Their locations and lengths to be treated are shown in Table 29 and Figure 36. Segment 1-A is probably the most important site since substantial amounts of cool groundwater enter the stream from Bonifer Pond on the east side.

Table 29. Segments of lower Meacham Creek flowing against the railroad grade that are suitable for the placement of log bundles at the base of the railroad prism.

Segment	Rive mile	Reach length (feet)	Comments
1-A	2.09	250	Highest priority because of cool water seep
1-B	3.58	300	
1-C	4.58	700	
1-D	11.98	350	Low surface flow by late summer in drought years
1-E	14.50	650	No surface flow by late summer in drought years

Recommendation 2 – Put stream into original course at R.M. 3.3

Background

Lower Meacham Creek experienced a 7% loss in main channel length from 1916 to 2002. Correspondingly, overall channel sinuosity has declined from 1.20 to 1.11. Channel straightening has been a result of diking and channel bulldozing for the purpose keeping the stream from encroaching upon the railroad and high-quality riparian pasture. Most of the loss in channel sinuosity occurred between 1916 and 1956, except in reach 4a (river mile 3.30 to 7.08) where most occurred after 1956. In a number of locations, especially downstream of river mile 7, the dikes have forced the stream to the west side of the valley where the stream now runs parallel to the bedrock banks. Here, the stream has become incised in its flood plain and lacks many secondary channels. The stream, as displayed in a 1916 railroad map and 1956 aerial photographs, once meandered widely across the flood plain (Figure 38).

Channel straightening and entrenchment creates faster water during high flows and a lowering of the water table on adjacent terraces during the dry season. Fish are more likely to be displaced in a downstream direction when faced with high-velocity water. Also, vegetation establishment on surrounding terraces becomes more difficult with a lower water table.

Proposed action and expected benefits

An opportunity to determine the effectiveness of reversing channel straightening and entrenchment exists at river mile 3.3, 1.1 miles upstream of Bonifer Pond (Figure 38). Here, the stream is diverted abruptly to the west by a dike and then flows against the steep, bedrock banks for about a mile. The drop in water elevation immediately downstream of the diversion point is about 5 feet.

Immediately upstream of the diversion point is an extensive gravel and cobble deposit with multiple high water channels.

The combination of creating a break in the diversion dike and constructing a large, stable log jam just downstream of the diversion point would allow the stream to occupy its original channels across the wide terrace east of the stream's current location. Here, the stream would not be incised and not confined to a single straight and deep channel.

The excavated break in the dike would provide a low spot for the stream to enter the terrace and the full-spanning log jam located immediately downstream would trap gravel and elevate the stream height so that it flows through the break in the dike even during the summer.

Fish would benefit from the channel re-establishment since water velocity would be less during high flows, habitat features in the channel would be more variable, and the elevated water table would support a higher density of streamside vegetation that could eventually provide some shade and streamside cover.

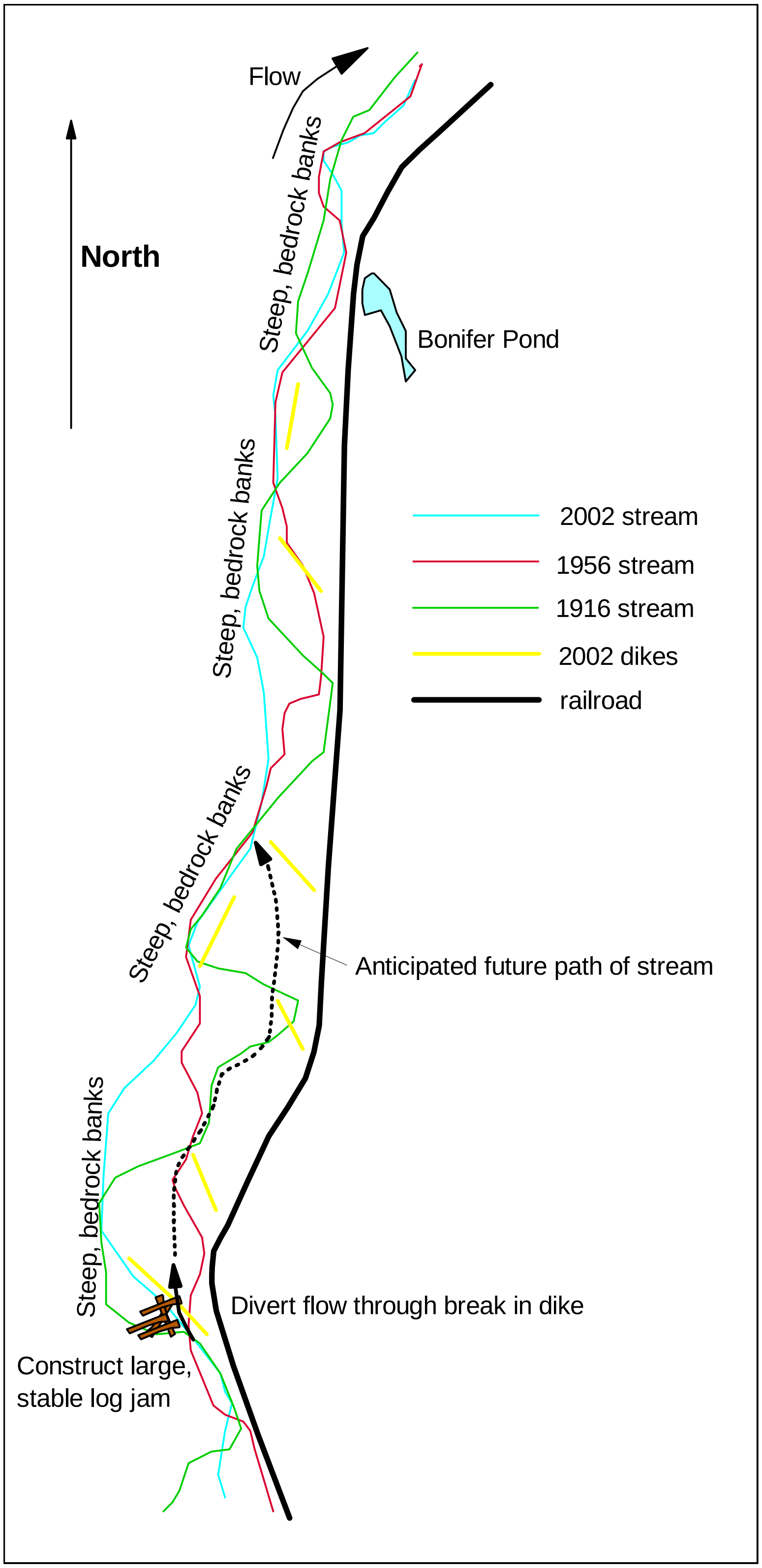


Figure 38. Location of the main channel of Meacham Creek in 2002, 1956, and 1916, along with current location of dikes.

Recommendation 3 – Replace access road bridge

Background

Adjacent to the first railroad bridge on Meacham Creek approaching from the Cayuse Road along the Umatilla River (Figure 35) is a road bridge of dubious design. The road bridge is old, has an overall span of about 70 feet, and was constructed using two sets of steel support pillars located in the stream channel. Wood floating downstream during high flows commonly catches on the pillars and is either removed by the maintenance crew or floats away during subsequent high flows. None of the other bridges in lower Meacham Creek or downstream of this point have this problem. Considering its fragile design and propensity to trap wood, the bridge is at risk of failure during flood flows.

The bridge presents a problem for the planning of upstream stream improvement projects. While any log structures added to Meacham Creek would be designed to minimize their downstream movement flood flows, the certainty of non-movement becomes risky when a vulnerable bridge is downstream. Log structures would need to be more expensive and design options more limited to ensure stability and prevent damage to the bridge. Without a vulnerable downstream bridge, a wider range of restoration activities could be explored.

The road bridge is important to railroad crews and landowners in the valley. Its failure during a large flood could prevent any access into the valley since the only other option is taking the access road upstream to the town of Meacham. A number of vulnerable road bridges exist upstream of the North Fork Meacham Creek confluence, and they too would likely suffer damage during a large flood. Furthermore, slope failures in the upper canyon often plug the access road following heavy rainfall.

Proposed action and expected benefits

The proposal to replace the access road bridge with one that is capable of readily passing large wood would solve two problems. Upstream habitat improvement projects could proceed with a wider range of options knowing that large wood movement during floods would not be fatal to a downstream bridge. In addition, railroad crews and valley landowners would be assured safer access out of the valley during and after flooding. A possible added benefit of bridge replacement is that heavy machinery could be moved in and out of the valley by truck without fear of collapsing the bridge.

Recommendation 4 – Fireproof corridor near North Fork

Background

Five wildfires burned over 5300 acres in lower Meacham Creek between 1997 and 2000. All seem to have originated at the railroad tracks. These fires burned mostly grass and brush with only 11% of the area within the fire perimeter being burned trees. These burned trees were of relatively low value due to their small diameter and the high expense of harvesting trees on the steep slopes. Nevertheless, if a wildfire began at the base of the North Fork Meacham Creek watershed it could be easily spread throughout the basin by a nearly-continuous belt of dense timber growing along the stream and north-facing slopes.

Widespread mortality of brush and trees along North Fork Meacham Creek and its tributaries would probably increase summer water temperatures and degrade conditions for bull trout and adult chinook salmon that rely on cold water. The relatively warm Camp Creek (72 deg F) was subject to a wildfire in 2000; all other tributaries in the Meacham Creek basin are cooler than Camp Creek.

Assuming that sparks from trains are the major mechanism by which fires ignite in the Meacham Creek valley, one strategy to reduce the risk of catastrophic fire in North Fork Meacham Creek is to reduce the propensity of fire to spread east of the railroad tracks near the confluence.

Proposed action and expected benefits

The proposed action is to reduce the amount of fine fuels and pathways for fire to be carried into the forest canopy near the lower end of North Fork Meacham Creek. Past fires have not jumped Meacham Creek, so only the 1.5-mile segment of railroad where the tracks are on the east side of the stream upstream of the North Fork confluence (between the two railroad bridges) would need to be treated (Figure 36). Options for reducing fire hazard along this section include:

- Remove brush and small trees capable of transporting a ground fire into the forest canopy. Remove the lower limbs of larger trees. Do this within a corridor up to 300 feet east of the railroad tracks.

- Pile and burn all fine woody material and brush within a corridor 300 feet east of the railroad tracks. Alternatively, conduct a controlled broadcast burn in this zone during the fall. Repeat every 5 years.

- Every year in early summer, eliminate grass growing within a corridor 50 feet east of the tracks with an herbicide containing glyphosate.

- Regularly inspect tracks in this stretch to detect defects that might lead to sparking.

- Locate a deep spot in the channel near this 1.5-mile stretch of stream where a ramp could be developed so that a pumper truck could efficiently obtain water for fighting a fire (a water use permit may be needed).

The benefit of this action is to reduce the risk of wildfire entering the North Fork Meacham Creek basin. Reducing the threat of catastrophic wildfire in this basin would help protect critical habitat for bull trout and chinook salmon.

Recommendation 5 – Remove concrete dam in upper Meacham

Background

A concrete dam in upper Meacham Creek (river mile 20.2, see Figure 36) appears to be a relic from the steam locomotive days and is no longer used. The dam creates a 2.5-foot-high jump that is a barrier to upstream movement of juvenile steelhead and resident fish during the summer.

Proposed action and expected benefits

The proposed action is to remove the concrete dam using explosives or a crawler tractor winch. Removing the structure with a crawler tractor winch is preferable because unsightly concrete could be removed from the stream and disposed of off-site, and the fish living within the pool downstream of the dam would survive the demolition.

Removal of the dam would allow juvenile steelhead and resident fish the opportunity to move upstream in search of better food supplies or to escape warm water.

Recommendation 6 – Create large wood structures

Background

Previous attempts to add large wood to Meacham Creek have generally not resulted in much habitat for fish (deep pools, cover, and protected feeding areas). Logs have been too short or the rootwads have been too small. More importantly, logs have been placed individually or in only groups of two. Even with attached boulders, many have been rafted onto terraces or moved downstream. Boulder structures in Meacham Creek, while stable during flood flows, also have not produced much useful habitat. Furthermore, the location of both log and boulder structures in the Meacham Creek watershed coincide with water that is too warm for fish during the hottest part of the summer.

Log structures designed to be effective in large, alluvial stream channels have been tried elsewhere in the Pacific Northwest with favorable results (Abbe 1999). Their success is linked to using long logs with large rootwads and the use of many logs within a single structure (Abbe and Montgomery 1996). Where water temperature is favorable, this kind of log structure can provide year-round habitat with little worry about their stability during high flows.

Proposed action and expected benefits

The proposal is to add stable log structures to portions of Meacham Creek and lower North Fork Meacham Creek that have year-round flow and summer water temperatures that are favorable for fish. Reach 4b of Meacham Creek and North Fork Meacham Creek downstream of Bear Creek provide these conditions (Figure 35). Both have maximum water temperatures below 70 deg F and, except for a one mile-long segment of Meacham Creek (centered on river mile 12.5), they each have ample surface flow in the summer.

Candidate sites and log structures would have the following features:

- Access from the road to the stream by a crawler tractor and large log loader. North Fork Meacham Creek has an intact albeit, rough, road along the lower 1.5 miles; thereafter access would be along streamside terraces alternating from bank to bank.
- Structure constructed of conifer logs greater than 24” at the large end with rootwads attached and over 50 feet in length.
- Structure comprised of many logs (5 to 6) and cabled loosely to act as a single but flexible unit (Figure 39); in special situations large boulders added to increase stability.
- Structure placed in the center of the main channel where water is relatively deep, so the stream does not meander away from the structure over time.

These large and stable log structures would benefit fish by creating deep pools with low velocity during high flows (Abbe and Montgomery 1996) and deep enough to intercept cool, subsurface water during the summer. The abundant cover provided by logs and their rootwads would provide protection from predators and multiple feeding areas for juvenile salmonids or resident fish.

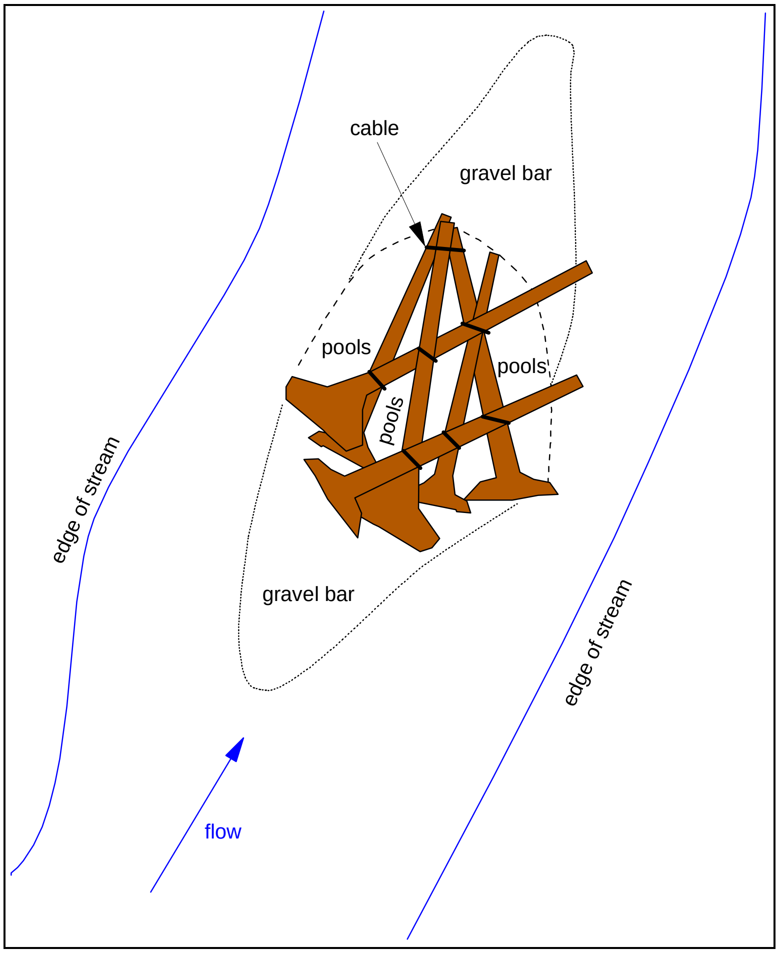


Figure 39. Example of log structure designed to be stable during flood flows in a large stream.

Recommendation 7 – Create pools where cool water enters

Background

Areas of cool water are found at selected locations throughout Meacham Creek, providing thermal refuge for fish during the hottest part of the summer. Reaches 3 and 4a of lower Meacham Creek and portions of reach 5 in upper Meacham Creek have summer temperatures that are too high for fish during the daytime. Cool water can be found at a number of tributary junctions, springs, and within alcoves (Table 30). However, in only a few of these areas is the water deep enough for juvenile fish to migrate into during the day and be safe from predators. Also, living space and cover is limited at these cool-water zones.

Table 30. List of sites where excavation of cool water pools near confluence with Meacham Creek would provide thermal refuge for fish.

Site	Reach	Description
7-A	3	Boston Canyon / Bonifer Pond
7-B	4a	Line Creek
7-C	4b	Spring
7-D	5	East Meacham Creek, downstream connection
7-E	5	East Meacham Creek, upstream connection
7-F	5	Butcher Creek

Proposed action and expected benefits

The proposed action is to excavate pools adjacent to the cool water sources near Meacham Creek in places where fish could move easily from Meacham Creek into the pool during warm days. Seven possible sites have already been identified (Table 30, Figures 35 and 36). The pools would be excavated 6 to 8 feet deep where they would not readily fill with bedload moving down Meacham Creek or from the specific cool water tributary. Small trees added to the pools would provide fish protection from overhead predators (Figure 40).

The proposed action would provide large pools of cool water accessible to fish during hot days when Meacham Creek is too warm.

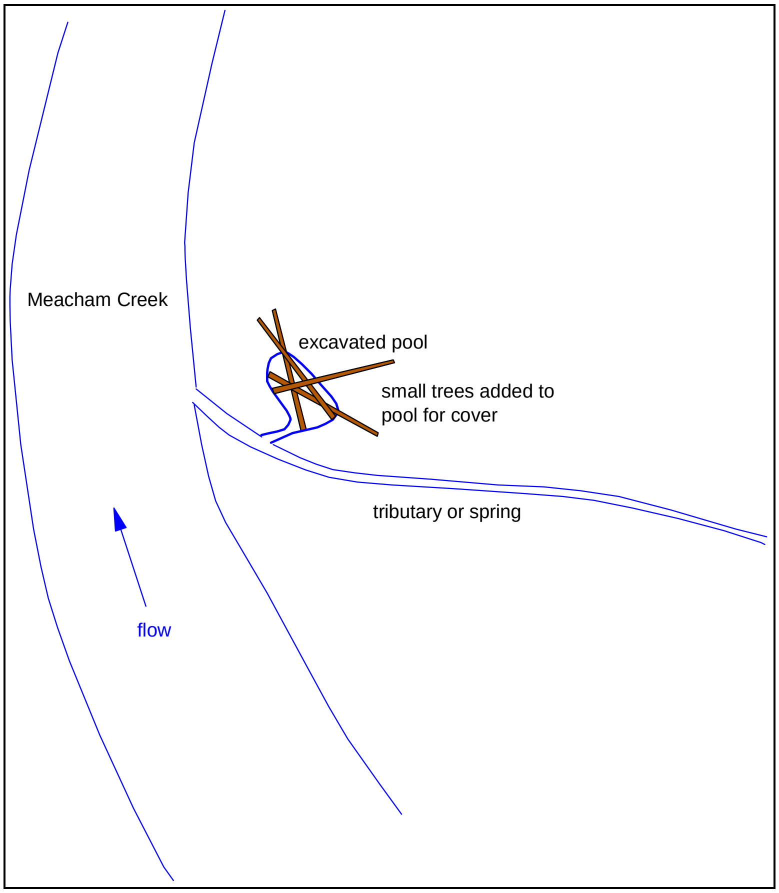


Figure 40. Example of a pool excavated at the mouth of a cool tributary or spring channel designed to provide thermal refuge from Meacham Creek during hot days.

Recommendation 8 – Put stream into original course at R.M. 7

Background

Immediately downstream of river mile 7 (Figure 35) is a situation similar to that described under recommendation 2. A series of dikes force Meacham Creek to the west side of the valley and the stream becomes entrenched as it flows parallel to the bedrock bank. The channel no longer meanders much, water velocity is high, and the water table is probably lower than when it meandered across the flood plain. The entrenched section has the potential of extending upstream into reach 4b where the stream now meanders with fewer obstacles. While deep pools are created where the stream runs along the bedrock bank, these pools have little cover and water is too swift during high flows to provide much habitat for fish.

Proposed action and expected benefits

Depending on the success of recommendation 2 as a pilot project, the proposed action at this site is to create a break in the first dike and create a large log jam downstream to force most of the flow down its previous channels. Other downstream dikes would be shortened, as needed, to provide both protection to the railroad grade and enough room for the stream to meander.

This action would provide higher quality habitat for fish in the rehabilitated channel, including slower water, more complex structural features, and a higher water table to support riparian vegetation.

Recommendation 9 – Remove concrete dam in Camp Creek

Background

A concrete dam within Camp Creek exists 0.3 miles upstream of its confluence with Meacham Creek (Figure 35). It has been reported by the Oregon Department of Fish and Wildlife to be a partial barrier to fish passage (4.3 feet high). We did not know about this dam during the field season, so we have not examined the site for possible remedies that would allow juvenile and resident fish to move into upstream portions of Camp Creek. This may be the site of a water withdrawal from which 23 acres are irrigated.

Proposed action and expected benefits

The proposed action is to work with the landowner to modify the dam so that all fish can move upstream into Camp Creek.

Recommendation 10 – Modify structure for fish passage

Background

A stream improvement structure consisting of large boulders cabled together across the top of a bedrock ledge in lower Meacham Creek (Figure 35)) is a barrier to juvenile and resident fish in the summer. Downstream of this site, the water becomes so warm that fish evacuate this segment during hot spells. Without the ability to search out cool water in upstream reaches of Meacham Creek, fish are forced to move downstream into the warm Umatilla River to find thermal refuge. The boulders do not enhance fish habitat at this site. The deep pool immediately downstream of the boulders is created by the bedrock ledge, not the boulders.

Proposed action and expected benefits

The proposed action is to remove some or all of the boulders so that juvenile and resident fish can move upstream.

Recommendation 11 – Plant and protect conifers

Background

Conifers are generally scarce along portions of reach 4 in lower Meacham Creek, and it is unclear what grew in the streamside area prior to disturbance by Native Americans and European settlement. Well-stocked conifer forests with an abundant understory grow along the Wenaha River reference, but this site benefits from abundant water during the summer and no grazing. North Fork Meacham Creek also has a well-stocked forest within the stream corridor and along the lower north-facing slopes but is different than lower Meacham Creek since high topography to the south provides vegetation with more protection from the sun. The lack of stumps and old snags along lower Meacham Creek further complicates efforts to define initial stand conditions.

Dense ponderosa pine stands have grown on the top and sides of the rock dikes installed 20 to 30 years ago to keep the stream away from the railroad. The difficulty of trees regenerating on these arid micro-sites is probably offset by the protection dikes provide trees from trampling cows. Elsewhere, young ponderosa pine trees are encroaching upon cobble areas near the stream that probably previously supported sparse grass. Nevertheless, along some sections of lower Meacham Creek few trees are present.

Even mature trees are probably not capable of providing much shade to reach 4 of Meacham Creek because of its significant channel width. Yet, mature streamside trees do provide the large wood that helps shape the channel and provide unique fish habitat. Trees must be centuries old to grow large enough to provide this function.

Proposed action and expected benefits

The proposed action is to plant ponderosa pine in those areas next to the stream within in reach 4 where trees are not regenerating on their own. In order to avoid mortality during high flows, candidate planting areas should be above the bankfull width elevation. Trampling by cows may be a hindrance to tree survival. A fence suitable for keeping cows out of this wide alluvial flood plain with its frequent stream meandering would be difficult to maintain. The fence would probably need to be set back from the active channel width. In many areas of lower Meacham Creek, the active channel width extends from the railroad prism to the steep slopes on the other side of the valley.

The expected benefit from this action is to enhance the supply of large wood to the channel of lower Meacham Creek for centuries in the future.

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