Twelvemile Creek Restoration Assessment of 2014 Flooding

USDA Forest Service, Craig Ranger District

&

TEAMS Enterprise Unit Watershed Restoration Division

February 25, 2015

Table of Contents

List of Figures

List of Tables

INTRODUCTION

Twelvemile Creek is located on Prince of Wales Island, approximately nine air miles southwest of Hollis and eight air miles northeast of Hydaburg, AK (Figure 1). Historically, Twelvemile Creek has provided high quality spawning and rearing habitat for coho (*Onchorhynchus kisutch*), pink (*O. gorbuscha*) and chum (*O. keta*) salmon, as well as steelhead (*O. mykiss*), cutthroat trout (*O. clarki*), and Dolly Varden char (*Salvelinus malma*).

Stream channel restoration, including large wood additions, occurred in Twelvemile Creek to accelerate the recovery of watershed processes, stream channel conditions and salmon, steelhead and cutthroat trout productivity. The restoration was conducted in the summers of 2012 and 2013. During the winter of 2014, two peak flow events occurred in Twelvemile Creek resulting in stream channel adjustment and habitat changes. Large volumes of wood and sediment moved during these events as the new addition of wood adjusted to the high flows. This report discusses the restoration design, the flood event, the channel response to that event, and lessons learned. This report will only briefly refer to habitat data that's been measured. For a full summary of habitat survey data collected to date, please refer to the Twelvemile Creek Mainstem Instream Restoration Monitoring Summary (USFS 2015).

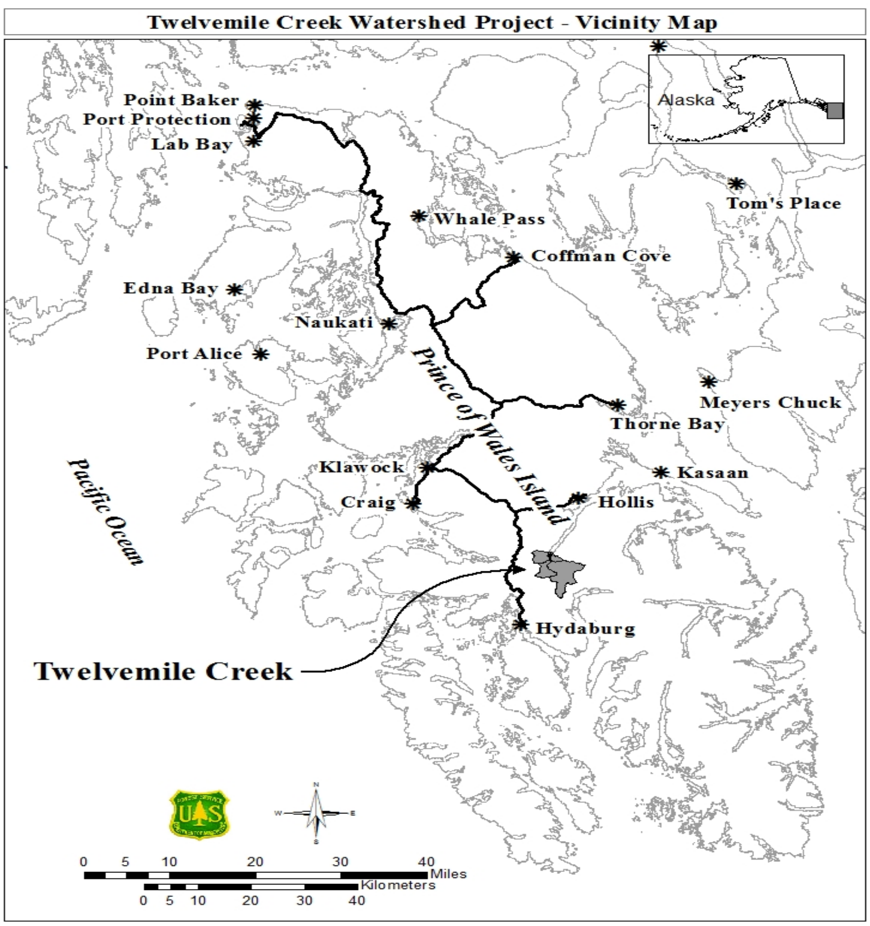

Figure 1. Locator map for the Twelvemile Creek Restoration Project Area. Prince of Wales Island, Tongass National Forest, Alaska.

BACKGROUND

In 2007, Prince of Wales Forest Service staff completed a Watershed Rehabilitation Plan for Twelvemile Creek which established goals and objectives to improve watershed conditions, including channel stability and habitats. With 92% of the watersheds riparian area harvested, the addition and supplementation of large wood was identified as a high priority project with the primary objectives to improve riparian function and aquatic habitats. Road decommissioning, culvert removals, and riparian thinning were also proposed and implemented to meet watershed restoration goals. While the high flows of 2014 affected all of Twelvemile watershed, this report is focused on the in-stream, large wood additions, and how the wood placement responded to the high flows.

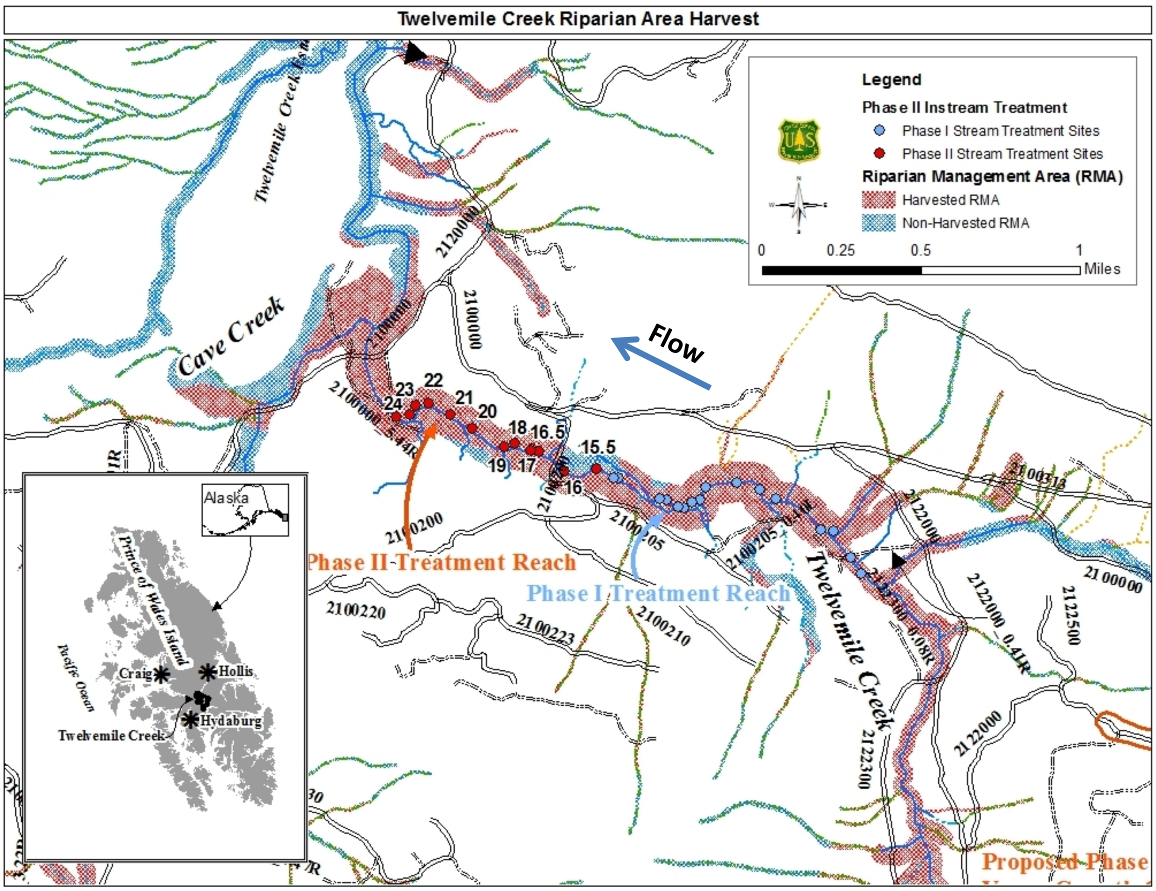

Figure 2. Past riparian harvest and approximate large wood treatment sites on Twelvemile Creek. Prince of Wales Island, Tongass National Forest, Alaska.

Restoration Design Criteria

Once identified as a priority, Forest Service specialists developed a site design to meet the stated instream restoration objectives.

A reference reach approach was used to design the restoration at Twelvemile Creek (TEAMS, 2012). There were no true reference reaches available in the immediate vicinity; therefore, seven ‘analog’ reference reaches were used. Disturbed reference reaches, or analogs, cannot only serve as surrogates but may in fact be better suited for design (TEAMS, 2012). Disturbed analogs are portions of the channel within an impacted area similar to a reach slated for restoration but they contain features that have allowed them to remain stable with the proper functioning stream channel characteristics, over time.

Both map and field data were collected from these analog sites and were used to determine discharge values and to develop restoration templates for channel parameters such as pool spacing, pool depths, and meander lengths and widths. Discharge was estimated using least squares regression model and Gauckler-Manning Formula. Channel parameters were measured using longitudinal and cross section surveys. The data used, and estimates developed for restoration, are in the design report (TEAMS, 2012) and are summarized below.

Discharge

During design, two methods were used to estimate flow in Twelvemile Creek and predict the annual and peak flow conditions to assist in development of design parameters. The methods included Least Square Regression Model and the Gauckler-Manning formula.

The least-squares regression model uses a set of predictive equations, specific to southeast AK, for estimating the 2, 5, 10, 25, 50, 100, 200, and 500 year recurrence intervals (Curren et. al., 2003). No field measurements are included in these calculations. Using these predictive equations, the estimate for an annual high water (Q2) at Twelvemile Creek is 580 cubic feet per second (cfs) and the 100-year estimate (Q100) is 1410 cfs (Table 1). Note the “standard error of prediction” percentage column of Table 1.

Table 1. Generalized least-squares regression for the 2, 5, 10, 25, 50, 100, 200, and 500 year discharge recurrence intervals for Twelvemile Creek.

[Q_T, T-year peak streamflow, in cubic feet per second; A, drainage area, in square miles; ST, area of lakes and ponds (storage), in percent; P, mean annual precipitation, in inches; J, mean minimum January temperature, in degrees Fahrenheit; E, elevation, in feet; F, area of forest, in percent]

	Constant	Exponent for A	Exponent for ST	Exponent for P	Exponent for J	Average standard error of prediction (log units)	Average standard error of prediction (percent)	Average equivalent years of record	Estimate of recurrence interval Q_T using user-supplied characteristics	
									User: Enter values in shaded area for this region (9999 indicates a dummy value that must be replaced)	
	Region 1, Region 3 (93 gaging stations)								**A=**	12
	Applicable range of variables:								**ST=**	26
	A: 0.720-571; ST: 0-26; P: 70-300; J: 0-32								**P=**	103
									J=	29.7
Q2	0.004119	0.8361	-0.3590	0.9110	1.635	0.158	38	0.88	580.827	
Q5	0.009024	0.8322	-0.3670	0.8128	1.640	0.156	37	1.3	794.850	
Q10	0.01450	0.8306	-0.3691	0.7655	1.622	0.157	37	1.8	942.083	
Q25	0.02522	0.8292	-0.3697	0.7165	1.588	0.161	38	2.4	1128.750	
Q50	0.03711	0.8286	-0.3693	0.6847	1.559	0.166	40	2.8	1271.575	
Q100	0.05364	0.8281	-0.3683	0.6556	1.527	0.171	41	3.1	1410.487	
Q200	0.07658	0.8276	-0.3669	0.6284	1.495	0.178	43	3.4	1561.067	
Q500	0.1209	0.8272	-0.3646	0.5948	1.449	0.188	45	3.6	1756.340	

The Gauckler-Manning Formula (referred to as Manning’s) is a way of estimating a streams velocity using field measured channel slope and a selected roughness coefficient. Using a surveyed channel cross-sectional area (A) and the Manning’s derived velocity (V), discharge can then be estimated using the equation Q=VA.

Using the disturbed analog reaches, channel slope and cross-sectional area were surveyed at 6 cross sections to estimate bankfull elevation and discharge (~Q2) and 7 cross-sections to estimate Q100 elevation and discharge. A roughness coefficient of 0.03 was used to estimate velocity (Arcement, 1989). Using these the annual flood for Twelvemile Creek is estimated at 545 cfs and 2259 cfs for the 100-year (Q100) (Table 2).

Table 2. Guackler-Mannings and regression model predicted discharge values for the Twelvemile Creek Phase II Project Area.

Calculated Flows for Twelvemile Creek Phase II Project	Discharge (cfs)	Source
Base flow Ref X-Section Mannings (n=0.03)	61-106	Ref X-Sections Mannings Calcs
Q1.2 Ref X-Section Mannings (n=0.03)	400,545,624	Ref X-Sections Mannings Calcs
Q100 Ref X-Section Mannings (n=0.03)	1188, 2259, 3305	Ref X-Sections Mannings Calcs
Q2 Extrapolated Regression Model	580	Curran et.al 2003
Q5 Extrapolated Regression Model	794	Curran et.al 2003
Q10 Extrapolated Regression Model	942	Curran et.al 2003
Q25 Extrapolated Regression Model	1128	Curran et.al 2003
Q50 Extrapolated Regression Model	1271	Curran et.al 2003
Q100 Extrapolated Regression Model	1410	Curran et.al 2003
	min,avg.,max*	

There were similar results for average annual bankfull discharge using both methods (Table 2). The regression model (Curran) estimate for the 2 year flood was 580 cfs and the average annual bankfull flow (1.2 year interval) using Mannings was 545 cfs.

The 100-year peak flow estimate for the regression model was nearly half the estimate using Mannings (Table 2). The regression model predicted an average 100-year flow at 1410 cfs. The Mannings predicted a 100-year flow at 2259cfs. The regression model results contain relatively high standard error values and as shown, the Q100 estimates were significantly lower than the Gauckler-Manning's method. Therefore, the more conservative (higher flow) average estimate of 2259cfs generated from Mannings was used to develop restoration design parameters for the Phase I reach originally and then later applied to the Phase II reach.

Design Channel Parameters

Reference sites used to determine channel parameters were selected on the basis of channel morphology. These sites included features such as stable banks, highly developed geomorphic features (e.g. pools, bars, glides), and floodplain connectivity (empirically derived entrenchment ratios – flood-prone width/bankfull width) often associated with remnant/relic large wood.

The development and maintenance of pool habitat was an objective of the project so measurements were taken at pools within the reference sites. Wetted widths at pool heads ranged between 31-38 and bankfull at 65-68 feet. Maximum residual pool depths ranged from 3.6-5.5 feet. Bankfull widths at the pool maximum depth cross-section were 68-80 feet. Average wetted width to depth ratios at the pool maximum cross-section was 29 feet (four pools). The average flood-prone widths measured in the field were greater than 107 feet.

The above data from the analog reference reaches was used to guide design parameters and wood placement. For example, tandem structures were designed to constrict channel widths at pool heads to develop or maintain a pool. The constrictions were designed to emulate reference sites and maintain the pool depth while allowing for sediment routing (Caamano et al. 2010). The designs also incorporated cross channel members (single logs) placed at thalweg elevation into at least 40 percent of the structures to replicate reference sites and increase stream channel topography, habitat diversity, and perhaps most importantly, restore or maintain floodplain connectivity.

Design indicated structure ballast pieces were to exceed the estimated Q100 elevation (typically 4 – 6 feet above the pool tail crest elevation based on field survey alone) to prevent buoyancy causing structure displacement. In addition, at least 70% of the length of the trees used for the frame of the structure was prescribed to be buried into the stream bank for structure stability.

An estimate for pool spacing and meander length was determined from field measurements and hydraulic equations. Using field measurements in Phase I (prior to treatment), pool spacing was 100 – 555 feet with an average of 260 feet. The hydraulic equations predicted a length of meander range of 308 – 778 with an average of 489 feet. Pool spacing is approximately half of the length of meander or two pools per meander; therefore, pool spacing estimated by hydraulic equations would range between 154 – 389 feet with an average of 245 feet. The two methods were relatively close (260 verses 245) hence a design pool spacing range of 150 – 390 feet was selected for the Phase II project area.

Table 3. Reference parameters for the Twelvemile Phase II project area RM 2.8-3.4.

Twelvemile Creek Phase II Project Design Parameters	**Design Parameters**	**Notes/Comments**
Valley Slope (Project Area)	0.0034%	Measured ARCmap elevations
Valley Slope (Reference Areas)	0.0041%	Measured ARCmap elevations
Sinuosity	1.20	Measured ARCmap
Low Flow Width (dist. reference)(ft)	31-38	Data from 5-2012 TEAMS survey
Bankfull Width (disturbed reference)(ft)	68-75	Data from 5-2012 TEAMS survey
Bankfull Width (regime equations)(ft)	51.2, 66, 101.1	Multiple Hydraulic Equations
Bankfull Average Depth (disturbed reference)(ft)	1.8, 2.3, 2.9	Data from 5-2012 TEAMS survey
BankfullAverage Depth (hydraulic equations)(ft)	2.2, 2.5, 2.8	Min, Average, Min from multiple hydraulic equations.
Residual Maximum Pool/Scour Depth (dist. Ref.)(ft)	3.5, 4.3, 5.2	Data from 5-2012 TEAMS survey
Glide Slope	0.2-0.5%	Data from 5-2012 TEAMS survey
Riffle Slope	0.6-1.5%	Data from 5-2012 TEAMS survey
Average Bank Full Width/Depth Ratio (Pool)	18.8	Data from 5-2012 TEAMS survey
Flood Prone Width (ft)	72, 106, 141	Data from 5-2012 TEAMS survey
Entrenchement Ratio	1.1, 1.6, 2.1	Data from 5-2012 TEAMS survey
Meander Beltwidth(ft)	331-723	Estimated from reference reach and remnant channels
Meander Beltwidth(ft)	207,553,620	Min, Average, Min from ARCmap & multiple hydraulic equations.
Meander Length(ft)	308,489,778	Min, Average, Min from ARCmap & multiple hydraulic equations.
	min,avg.,max*	

Large Wood Addition Methodology

Project objectives included increase large woody debris (LWD), increase or maintain number of pools, increase pool depths, increase off-channel habitats, increase bank stability, reconnect floodplain habitats, improve width-to-depth ratios, and overall promote the formation of quality instream habitat. Using the parameters defined above, large wood was placed in the channel as individual members, or structures (a cluster of wood), to achieve those objectives. The instream habitat goals and objectives are further defined in the Watershed Rehabilitation Plan (USFS, 2007b), the Twelvemile Creek Phase II Design document (TEAMS, 2012), and the Twelvemile Creek Mainstem Restoration Monitoring Summary (USFS, 2015).

Design did not specifically identify the placement of every piece of large wood. Instead, a typical structure type was designated for each site based on the site objectives. There were four typical structure types included in the design for Twelvemile Creek; Formidable Multifaceted (FMF) large wood scour structures, point bar depositional structures (Bar Buddies), cross-channel structures and floodplain wood placements. In addition to these structures, an 800 foot long side channel was planned in the lower part of the Phase I project area to reconnect wetlands and beaver complexes as off channel rearing habitat.

The relative stability of these wood additions, through time, under varying flood conditions, determines the outcome of the instream restoration. Stability of these structures through time depends upon the location of placement, the elevation at which they are placed, the weight or ballast of each structure, the extent in which they are tied into the streambank and the duration and magnitude of peak flood flow events. The Twelvemile Creek Phase II Design document (TEAMS, 2012) provided the individual structure types and the potential failure mechanisms per structure, included below as Table 4.

Failure Mechanisms and Risk

Failure of these structures is defined as the point at which the structure is degraded, eroded, or abandoned to the point of being ineffective. In the event of structure failure, wood would be lost downstream, while other pieces would be altered from their original placement or remain in place. Since there is a considerable amount of material in these structures, partial loss of wood may occur and not affect the structures ability to achieve the desired objective. (TEAMS, 2012)

During design, potential mechanisms or modes that could compromise the integrity or durability of a designed feature were identified. The design identified which mechanisms posed the highest potential for failure and prioritized design to abate those failure mechanisms (Table 4).

Stream channels are dynamic in their natural setting and present failure mechanisms that are beyond a designers control such as unpredicted high flows, influx of sediment or debris from natural disturbance, or later migration of the channel. Therefore, there is inherent risk of structure failure in designing any of these structures (TEAMS, 2012). Failure mechanisms within control include a lack of design, minimal construction oversight, or varying from design during implementation.

The Twelvemile Design report acknowledges the fact that structures can fail and wood can move downstream. The risk of failure to life or property is limited and was identified as only the bridge crossing along the 21200000 road downstream of the project. The bridge was determined to have adequate freeboard and was estimated to pass any large wood that may migrate downstream during the highest estimated peak flood flow events.

Table 4. The risks of failure, the failure mode, and potential consequences and effects to the system, lives and property associated with each component of the design.

Treatment	*Potential Failure Mode*	*Potential Effects of Failure*	*Potential Causes or Mechanisms*	**Risk Priority #, (1-10, 1-low, 10-high))*	*Design Checks*
FMF Structures - Barbs and Complexes	Burial by Incoming Sediment	Project Not Effective	Insufficient Design Considerations - Improper Placement / Catostrophic Event	3	Allowable Shear Stress Check, Meander Geometry & Pool Riffle Spacing Assessment
	Rapid Lateral Migration	Property or Infrastructure Damage	Improper Design, Structure Placement & Specifications	3	Reduces X-Sectional Area, Design Layout & Design Experience
	Erosion of opposite Bank	Minimal, some sediment input	Improper Design, Placement or Alignment	2	Reduces X-Sectional Area, Design Layout & Design Experience
	Structure Displacement	Minimal, reduce design effectiveness	Improper Material Sizing, Poor Construction Oversight or Design	2	Use Largest - Longest Cost Effective Materials – Provide Continuous Construction Oversight
	Excessive Scouring of Bed- BF Channel shear 1.71 lb/sq ft	Potential to cause structure failure	Improper Design	7	Follow Design Guidelines for Structures, scour/ shear stress check
Point Bar Structures	Burial by Incoming Sediment	Minimal	Insufficient Design Capacity	3	Allowable Shear Stress Check
	Rapid Lateral Migration	Property or Infrastructure Damage	Improper Design, Placement or Alignment	5	Reduces X-Sectional Area, Design Layout & Design Experience
	Erosion of opposite Bank	Minimal, some sediment input	Improper Design, Placement or Alignment	2	Reduces X-Sectional Area, Design Layout & Design Experience
	Structure Displacement	Potential to cause structure failure	Improper Material Sizing, Poor Construction Oversight or Design	3	Follow Design Guidelines for Structures. Use Largest Cost Effective Materials – Provide Continuous Construction Oversight
Constructed Side Channel	Burial by Incoming Sediment	Minimal	Design Capacity Too Large	5	Allowable Shear Stress Check
	Bed Degradation	Can Lead to Headcutting/ Channel Capture	Improper design	3	Follow Design Guidelines for Structures

Implementation

Phase I implemented structures at 20 sites in over 1 mile of stream. Seventy-seven old growth and 250 young growth logs were used (total of 327) in Phase 1. A portion of this wood met key wood size criteria for length and diameter or for rootwad diameter (>15 meters long & >0.6 meters diameter, or rootwad diameter > 3 meters). Many of the structures had logs trenched into the bank as designed and ballast material was placed on the banks. Pool head and bankfull widths were implemented as designed and structure elevations were determined during implementation using approximate pool tail crest and bank heights. Placed wood was added to existing legacy structures; however, no large residual wood was moved.

Phase II constructed structures at 12 sites in over nearly 0.75 miles of stream in about 8 machine days (2 machines for 4 days). Phase II was implemented with 279 pieces of young growth and 28 pieces of old growth (total of 307). None of the Phase II wood met the key wood criteria for length and diameter though the diameter of some rootwads qualified a number of pieces. To mitigate for a lack of key size pieces, additional pieces were included in design to increase total volume or mass of wood available to meet the objectives. There was less stream bank trenching of structures in Phase II than in Phase I with structure anchoring more dependent on interweaving wood into existing stands of trees. A higher percentage of Phase II structures were constructed as cross-channel, or full spanning, structures. Pool head and bankfull widths were implemented as designed with the exception of two meander bends where the channel was constricted beyond design parameters in an attempt to reconnect floodplains and off-channel habitats. Throughout the reach, structure ballast pieces were placed relative to pool tail crest elevations and bank heights. Placed wood was added to existing remnant wood and one large residual piece was moved into the low flow channel.

Winter 2014 Flood Events

Heavy rainfall and flooding occurred across southeast Alaska during the winter 2014, merely 6 months after Phase II of instream restoration in Twelvemile Creek. Continuous rainfall occurred between mid-December and mid-January which led to high antecedent soil conditions when the January 14 rainfall event occurred. Air temperatures were near 50 degrees at lower elevations on January 14 so rainfall reached into the higher elevations spurring rapid snow melt. The moist soil conditions and reduced storage potential, coupled with the high intensity rainfall and snowmelt led to immediate runoff and subsequent flooding. The staff gage at Twelvemile Creek reached the highest level in the period of record (2009-present) and nearby Staney Creek USGS Surface water station reached its highest recorded level (37 years of data). Over 60 landslides were recorded on the island attributed to the January 14 event. On March 11, another rainfall event registered the third highest recorded level at the Staney Creek station (Figure 3).

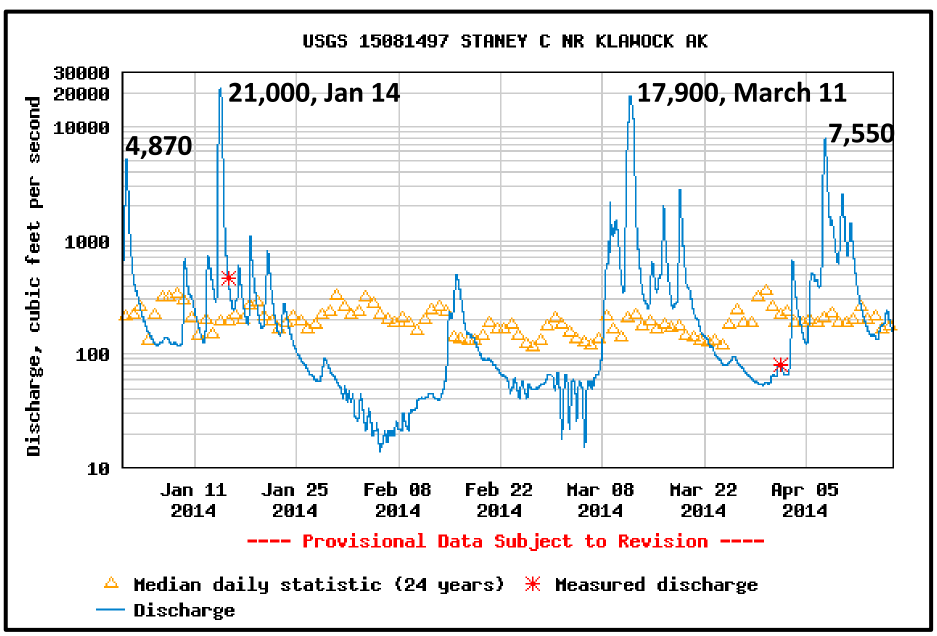

Figure 3. Discharge at Staney Creek, January-April 15.

Data from the USGS gaging station at nearby Staney Creek was used to evaluate the relative level of flooding. Log Pearson peak flow modelling was done to estimate the return intervals of the two floods. Using Staney Creek peak discharge data from 1969 to 1981 and 1990 to 2014 (37 years of data), the January 2014 flood of 21,000 cfs was estimated to be between a 65 (gage skew) and 75 (generalized skew) year return interval (Figure 4). The March flood, measured 17,900 cfs at Staney Creek, and was estimated a 29-37 year return interval (Figure 4). In any given year, there is a 1.3% chance of a flow similar to the January flood and a 2.7% chance of flow which occurred during March. The chance of both events occurring in the same year would be magnitudes less.

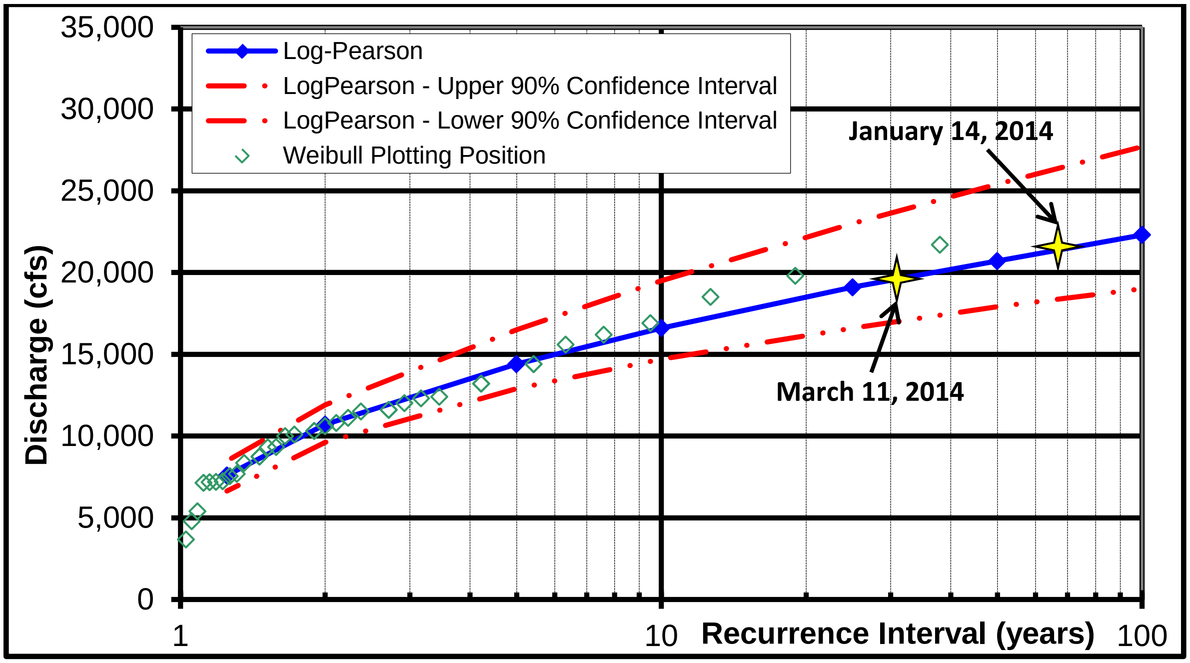

Figure 4. Discharge-Frequency, with Gage Skew – Staney Creek near Klawock, AK

To further highlight the relative magnitude of the flows experienced, Figure 5 shows the peak flows identified for Staney Creek Gage from 1964-1981 (15081500) and from 1990-2014 (15081497). It appears that peak flows are increasing through time. The highest 5 peaks have occurred in the last 15 years and 7 of the highest 10 peaks have occurred since 1993 (21 years). There was a gap in data collection between 1981 and 1990. The data collected post 1990 was from a station slightly downstream accounting for an additional 0.5mi^2 drainage area (<0.1% change).

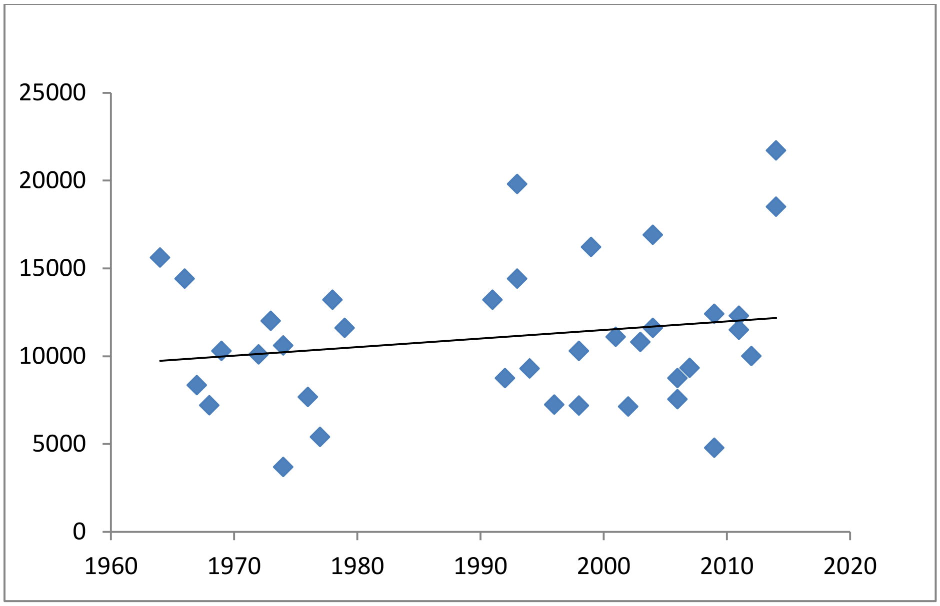

Figure 5. Peak Flow Values at Staney Creek Gage 1964-1981 and 1990-2014

Although rainfall and flooding can be somewhat inconsistent between Twelvemile and Staney Creek, the regional aspect of this storm across SE Alaska suggests a similar return interval at Twelvemile Creek.

As a result of both events, sediment and wood movement was observed in many streams on the island (author observation; communications with other island staff and residents). The Phase I and Phase II reaches of the Twelvemile Creek restoration were no exception. Both large residual pieces and placed individual logs and log structures moved during the January flood, again during the March event, and continues to move on smaller flows since then (wood count surveys and visual observations)(USFS, 2015). During the January and March events, no logs were observed outside the restoration reach; however, since that time wood has moved below the bridge and into the tidal area. An accurate count of individual trees moved below the bridge is not feasible due to the complexity of the structures but it is estimated at less than 5% of the placed wood moved (less than 30 pieces). Further movement of the wood is limited due to the collection potential of the downstream wood jams.

The project area was investigated and photos were taken immediately following the winter floods. Surveys were conducted in mid-April to estimate discharge during the flood, and evaluate the channel response relative to morphology and habitat conditions.

Post Flood Assessment

Surveys were performed after the flooding to capture as much flood related information as possible. Channel cross sections were surveyed, debris lines were identified and surveyed, and photos were taken. Structures were individually assessed to determine their stability and effectiveness following the flood and through time.

There were no flow estimates taken at Twelvemile Creek during the flood; however; surveys performed after the winter flows were used to estimate flood levels. The line of debris was used to determine the height of flooding and combined with cross section information was used to estimate discharge. These surveys were also used to determine elevation of flooding relative to the elevation of constructed log structures.

Debris line elevations relative to bank structures (such as FMF's) in the Phase I project area were typically near the top, or approximately one foot below, the majority of bank structures. Structures were designed to be a minimum of two feet above the peak flow water elevation to maintain ballast. Debris line elevations measured in the Phase I area ranged from 4.6 to 6.1 feet above the adjacent pool tail crest bed elevation. Debris line elevations in the upper Phase II area ranged from 5.9 to 7.5 feet above the respective pool tail crest bed elevations. Design parameters estimated Q100 only 4 to 6 feet above pool tail crest for the entire project therefore these data suggest the Q100 elevations in Phase II were underestimated by 1.5-2 feet.

Using the debris line elevation at surveyed cross-sections, the estimated peak flow for 2014 within the Phase I project area was 3,074 cfs, which is 36% greater in magnitude than the selected Q100 design estimate for Phase I. The average estimated discharge for the Phase II post flood cross-section, approximately ¾ of a mile downstream of the Phase I cross-sections, was 3,872 cfs. This estimate is 71% greater in magnitude than the Q100 design estimate for Phase II. Post flood assessment suggests the Q100 design discharge was underestimated.

Relative to the Phase I cross section, the increase in debris line height at the referenced cross section in the upper Phase II area may be associated with increased flow from tributaries or possibly caused by constriction at the location of cross section, a decommissioned road crossing (hanging-pipe). Another possibility could be the flood induced cross-channel spanning log jam (repositioned logs during the flood, Figure 6) which formed 220 feet below the crossing and could have backwatered the channel enough to increase flood flow elevation.

Figure 6. Photos Pre-Post Flood. Looking downstream at the jam downstream of the “hanging pipe” crossing. The large piece of residual wood in the upper photo was originally parallel to the channel on the channel edge prior to restoration. During restoration one end of this piece of wood was moved out into the channel in an effort to deflect flow, induce scour, and create habitat. Early fall flows moved (“spun”) the log to a cross channel location (upper photo) and the January flood resulted in additional wood accumulated on the log. A large, complex, cross channel, log jam has resulted.

Structure Durability Assessment and Discussion

Placed logs at every site have changed to some degree since initial placement even prior to the large 2014 events. Structures have simply shifted or settled, some have lost wood, some have gained wood (by capturing mobilized wood from upstream, both supplemented and natural), and many structures experienced both loss and gain of wood. Stream channels are dynamic and the added LWD is not meant to be static; therefore, shifting and movement of wood is expected during large peak flow events. With that said, these structures were placed in specific locations, with specific design intentions, with minor adjustment expected during flows less than Q25 return intervals.

The scale of the 2014 winter flood events and the visible structure response, particularly in the recently completed Phase II reach, presented an opportunity to evaluate structure performance. Habitat survey results including wood counts before and after the flood events are presented in the Twelvemile Creek Instream Restoration Monitoring Summary (USFS 2015, p.8-12).

Some sites were designed and implemented as single structures and some included multiple structures. From the 2014 events, one site within the Phase I reach had a structure completely displaced (displaced=all placed pieces of the structure have moved from original placement). Within the Phase II reach, five structures were completely displaced (Figures 6–9). In total, three of 32 **sites** experienced full displacement of wood and six total **structures** were displaced (Table 5). Consistent findings amongst these sites was deviation from design parameters during construction; four were not constructed as designed (not keyed into the banks or terrace); and two were either inappropriately placed relative to flow, or too aggressive (constricted the cross-sectional area beyond design parameters) (Table 5). The deviation from the original design was deliberate at some sites and inadvertent at others. Examples are depicted in Figures 6 through 9 and discussed below.

Table 5. Structures Displaced

Phase	Site #	Site Displacement	Structure Type Displaced	Failure Mode
II	16	partial	Bar	elevation to low
II	26	partial	Bar/Spanning	over constricted
II	19	FULL	Bar/Spanning	over constricted
I	6.5	partial	FMF	did not trench, elevation to low
II	15.5	FULL	FMF	did not trench, elevation to low
II	21	FULL	FMF	did not trench, elevation to low

Common of all the FMF structures that fully mobilized was the lack of trenching and burying into the bank. During construction, the decision was made not to trench and bury members at these sites with the thought that structure elevation and ballast alone would mitigate for structure durability. This approach may have worked if the elevations of the structures exceeded the peak flow water surface elevation. Another consistent finding was the lack of standing live trees near the banks at these sites. In other locations, where FMF structures persisted through the floods, there was also a lack of trenching; however, each had standing live trees that were incorporated into the structure functioning as vertical "pilings". These banks with the live "pilings" also rise more abruptly from the channel providing a higher bank elevation for structure ballast to tie into. Post flood surveys suggest that structure elevation was critical to the stability of the FMF structure and the available bank elevation typically determined the top of structure elevation.

Figure 7. Photos Pre and post flood of an FMF structure where only structure elevation could mitigate for durability, no burial and no live trees to incorporate. Large wood was placed on the floodplain and bank on the outside of the meander bend. Following the January flood the site was completely displaced and the vertical bank exposed.

For the overall project, the FMF structures were more stable than the point bar structures. There appeared to be three factors leading to the instability of point bar structures; 1) structures constructed too low relative to flood flow surface water elevations to accommodate large flood flow, 2) excessive reduction in cross-sectional area; bar structures constructed too far out into the channel resulting excessive flow constriction, or 3) not enough vertical support (pilings) or ballast to retain structures during large flows.

An example is Structure 26 (Figure 8) which was constructed in the lower part of the Phase II project area with a bank structure on the left outside bank and a large opposing structure on the right bank gravel bar. The intention of the large opposing structure was to backwater the channel enough to promote connectivity to existing beaver pond complexes on the left floodplain. During construction it was noted that the wetted width of channel constriction was aggressive (27 feet in width, ~30% less than design) and the flanks reduced the flood-prone width to approximately 80 feet (~20% less than design). The low risk at this site (due to the relatively low slope in the immediate vicinity) was considered in regards to the potential benefits of reconnecting the floodplain and beaver complex at multiple flows. It was decided (on-site) to proceed with the constriction. Due diligence was taken to secure the structure and multiple logs were driven into the gravel bar vertically and semi-vertically by the hydraulic excavator to secure the structure. The pilings were used because there were no live trees on the immediate bank. Some of the piling type members were driven into the gravel bar in excess of 20 feet in depth. The vertical members appeared to be penetrating a clay layer and were easily installed. Aside from the ease of the piling installment, the site appeared to be robust. Unfortunately, the opposing gravel bar complex was displaced during the first large peak flow event, likely due to the aggressiveness of the structure and incompetent pilings (installed in clay). The displaced wood floated downstream and deposited on a large natural (existed prior to restoration) cross-channel log jam. Subsequent visits to this site revealed additional movement and instability of the preexisting jam.

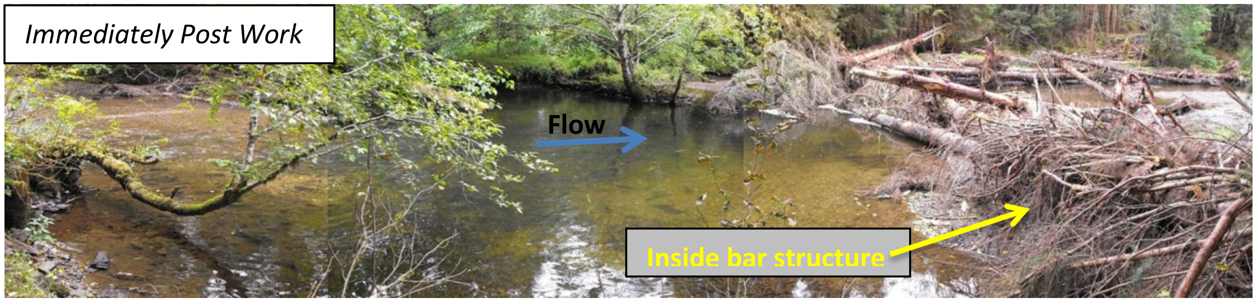

Figure 8. Photos Site 26. This bar structure exceeded the constriction parameters designed for this channel. Flood flows dislodged the vertical holding members of the bar structure and the bar and spanning members were moved downstream.

The 2012 Twelvemile design document stated that any movement of the large wood additions presented relatively low risk to areas downstream of the project site. Large wood is a natural component of flood debris in rivers, and the amount that could be generated from these structures was not expected to exceed what is normally observed in unmanaged streams at flood stage. The 2120000 road bridge was considered during the 2012 risk analysis. It was determined that the bridge contained the design capacity to allow the transport of large wood and had previously accommodated large wood transported by the stream without issues. In addition, it was also stated that if structures or members of structures did become dislodged during peak flows similar to the 2014 events, that it was likely that the wood would be transported downstream and either re-deposited or transported out of the system. To date the majority of wood mobilized by the event has in fact re-deposited on downstream structures or was collected by natural nick points in the stream forming new structure and habitat (Figure 9). A few of the structure members have mobilized downstream of the bridge and it is likely that additional pieces will migrate below the bridge during subsequent peak flow events. These pieces will either become lodged on existing natural large wood jams or will be deposited on the estuary floodplain. Again, it is estimated that the number of pieces that may move downstream of the bridge in the relative near future is 5% or less of the placed wood (professional judgment given current site conditions).

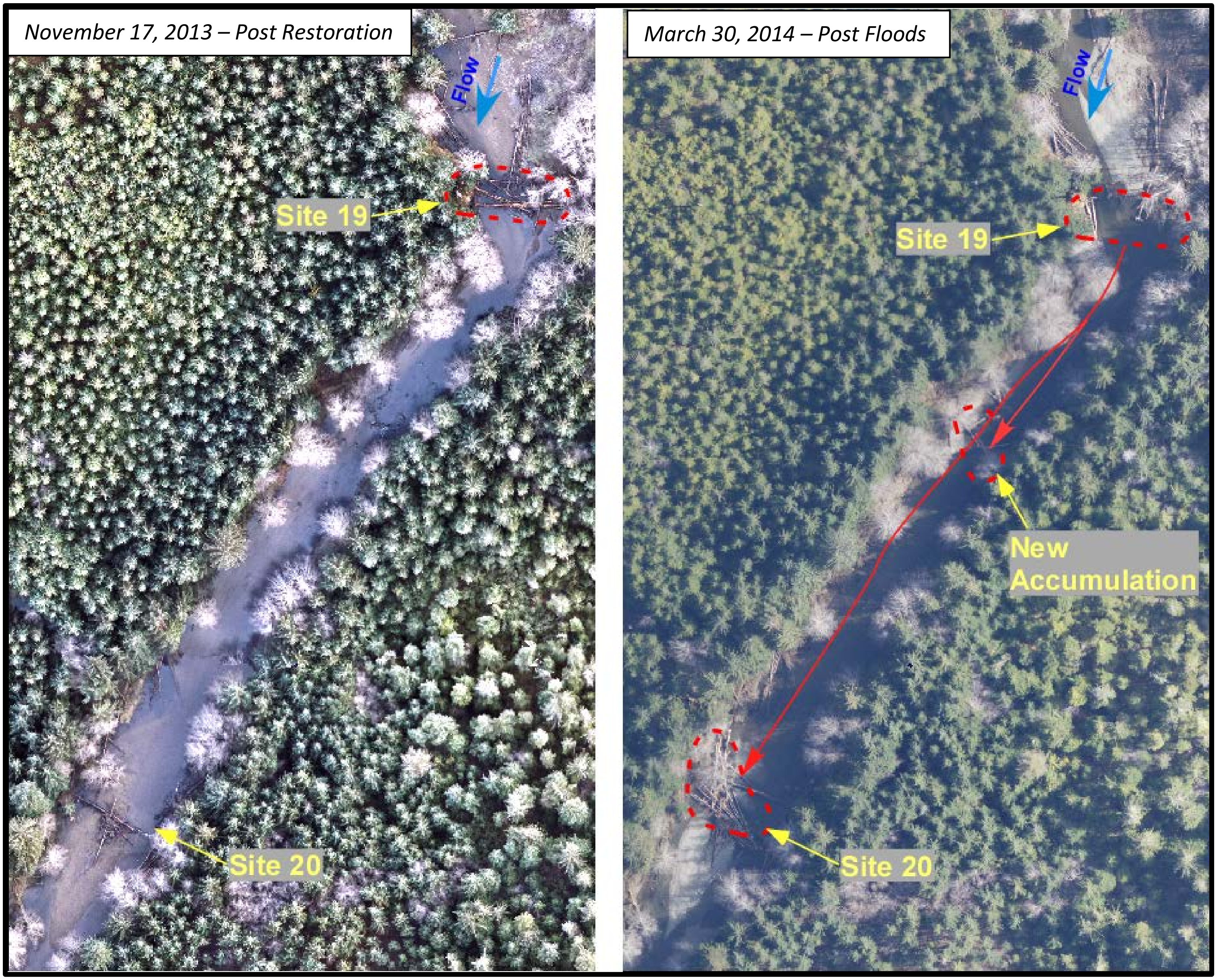

Figure 9. Aerial photos of Site 19-20 within Phase II. Site 19 was implemented with an aggressively reduced channel cross-sectional area (beyond design parameters). The 2014 winter flows moved this wood and re-deposited the wood downstream. Downstream, the mid-channel apex jam performed as expected and captured the passing wood.

Summary

A large flood flow occurred in Twelvemile Creek less than a year after restoration and resulted in the movement of sediment, and both placed and residual (older, remnant) large wood. While the restoration objectives for Twelvemile Creek restoration continue to be met (USFS, 2015), there was more wood movement than had been expected. Post flood assessments have provided insight to design and construction elements that may have contributed.

From a durability and functionality standpoint some structures (log jams) accommodated the flood flows, and functioned as designed, better than others. Post flood flow estimates suggest that the surveyed Q100 water surface elevations used for design were likely underestimated and contributed to the displacement of some structures. Findings suggest both natural and constructed site specific parameters, such as channel constriction, channel entrenchment, bank elevation, and channel shape, contributed to displacement of wood. On-site design modifications, in combination with reduced trenching also contributed to some wood movement. The modifications were deliberate decisions, made during construction, with known risk and evaluated outcomes. As predicted, the wood that was mobilized during these events has largely repositioned within the project area and continues to meet project objectives to provide improved stream function and fish habitat. Further movement of the wood and the overall effect of the project will be better evaluated over a longer timeframe.

The short term positive response of the Twelvemile Creek restoration is evident in the resiliency of this channel to relatively large flood events experienced. The addition of large wood has increased complexity, and although wood and sediment has moved since completion, most of the structures remain intact and function as designed to process sediment and maintain habitat for fish and other beneficial users. The Twelvemile Creek Mainstem Instream Restoration Monitoring Summary (USFS 2015) is available for more quantitative results to date.

Measures can be taken to increase structure durability. However structure durability and stability should always be commiserate and balanced with the accepted risk and overall objectives of the project. Rivers are dynamic and large wood structures constructed in wildlands with a low degree of risk to life and private property should also be designed to adjust with the stream corridor over time. Habitat restoration designers attempt to balance structure durability, site specific objectives and riverine/floodplain dynamics and resiliency. Over building can produce rigid structures incapable of adjusting with the stream corridor and often at high cost. On the other hand, lack of appropriate measures to ballast or anchor the structure and or overzealous desires to maximize habitat can lead to loss of the structure and failure to achieve habitat objectives. In summary, the lessons learned from this project will be considered in future restoration efforts and will help to improve the restoration program across the Tongass.

Lessons Learned

- Attaining key wood pieces for instream restoration is important. When key wood pieces are not available, all efforts to offset the smaller material, such as increased trenching or increased pieces, should be considered.
- Trenching of large wood 60-70% into the bank is essential to structure stability when adequate conifers are not available to interlock structure. Without trenching, appropriate ballast elevation, or competent trees along the bank, there is nothing to maintain a structure during large flows. Sites should always use at least 2 of these as mitigation against structure failure. If that’s not possible, the site may not be appropriate, reevaluate site.

- Design discharge elevations and channel design parameters are critical to the success of a project. Actual discharge measurements would have complimented the design at Twelvemile Creek and are recommended for large scale restoration projects.
- Channel constriction significantly affects stream power and can increase scour during flooding. Verify design widths and utilize design during implementation. Keep in mind that when width is decreased, either depth or velocity must increase to accommodate the same flow (Q=VA). Evaluate all potential outcomes when choosing to constrict beyond design width.
- When a project spans a large length of stream, take note of localized conditions such as channel entrenchment, change in slope, or the presence of obstruction that may cause significant backwater effect (e.g., road crossing) and adjust design parameters accordingly.
- FMF structures were the most durable at Twelvemile Creek. These structures accommodated flooding in most cases, and provide exceptional fish habitat.
- Point bar structures were the most vulnerable at Twelvemile Creek. Stream velocities may have been underestimated and the extent of depositional areas may have been overestimated.
- Cross-channel structures from both restoration, and as a result of mobilized wood, should be watched closely. These structures may most closely resemble natural accumulations pre-timber harvest? These structures also have the ability to either play a significant role in re-establishing floodplain connectivity, or possibly avulsing the channel.
- Inspection of the contract at all times during construction is essential. Any distractions, such as camera crews, or show-me-trips, should be coordinated by additional staff when construction is happening.
- The movement of large wood during a flood is natural and common; however, there is risk to large volumes of wood movement. Consider the risk and benefit of 'free' members of large wood and consider downstream effects such as infrastructure and property.
- Climate change predicts later snow and melt earlier which could translate to larger floods. When designing for annual and peak floods consider the potential for increased flow related to local climate trends.
- If top elevation of the ballast on a structure is the only possible mitigation for structure durability, reevaluate the site. If its decided to proceed, be conservative.
- If flood elevation is identified as a high failure mechanism, design should evaluate how placed jams that constrict or raise stream bed elevation will affect upstream water surface elevation.
- The channel roughness coefficient used in estimating discharges plays a significant role in channel capacity. Consider how the addition of large wood to a channel adds roughness – which may reduce velocity enough to affect stage height locally or upstream at another structure.

Contributors:

Sean Claffey, Craig Ranger District
KK Prussian, Tongass National Forest
Brian Bair, TEAMS Enterprise Unit Watershed Restoration Division

References

Arcement, G., and V. Schneider. 1989. Guide for selecting Manning's roughness coefficients for natural channels and flood plains. U.S. Geological Survey Water Supply Paper 2339.

TEAMS, 2012. B. Bair and G. Robertson. Twelvemile-Creek Phase II Design Narrative. River Mile 2.8-3.4. USDA Forest Service TEAMS Enterprise Unit

Caamano, D., P. Goodwon, J.M. Buffington. 2010. Flow structure through pool riffle sequences and a conceptual model for their sustainability in gravel-bed rivers. River Research and Applications 28: 377-389.

USFS 2007a. Twelvemile Arm Landscape Assessment. USDA Forest Service, Tongass National Forest, Craig Ranger District. March, 2007.

USFS 2007b. Twelvemile Creek Watershed Rehabilitation Plan. USDA Forest Service, Tongass National Forest, Craig Ranger District. 2007.

USFS 2011. Twelvemile Creek Restoration Environmental Assessment. USDA Forest Service, Tongass National Forest, Craig Ranger District. R10-MB-738. December 2011.

USFS 2012. Twelvemile Creek Restoration -Phase II Environmental Assessment. USDA Forest Serivce, Tongass National Forest, Craig Ranger District. R10-MB-755a. December 2012.

USFS 2015. Twelvemile Creek Mainstem Instream Restoration Monitoring Summary. USDA Forest Service. Tongass National Forest. Craig Ranger District. March 2015.