To: Tom Elliott, Yakama Nation

From: Kevin Fetherston, PhD, PWS; Steve Winter, PH, PWS; Scott Katz, MS and Megan Whiteside

Date: September 4, 2020

Re: Wapato Reach Technical Memorandum #2

INTRODUCTION

In 2019, Natural Systems Design, Inc. (NSD) was contracted to support the Yakama Nation develop a forest management plan for the Yakima River Wapato Reach black cottonwood forest to be presented in three technical memorandums (TMs). NSD has previously delivered Technical Memorandum #1 *(TM#1) –Conceptual model of cottonwood forest development along the Wapato Reach of the Yakima River* to provide our analysis of current Wapato Reach cottonwood forest conditions and our characterization of ongoing processes that govern cottonwood forest establishment and loss. TM 1 documented both the long-term decline of the cottonwood forest and detailed the current negative trajectory as new forested areas are developing at a much slower rate than they are being lost.

NSD has prepared TM 2 to provide a series of approaches and actions to increase the rate of forest establishment. There are four stand-alone elements to TM 2, including:

1. Developing a spatial site selection decision tool that identifies locations where active silvicultural re-vegetation efforts are more likely to be successful
2. Identify a suite of process-based restoration actions
3. Provide recommendations to develop a flow regime that would better support cottonwood establishment
4. Provide a pilot restoration design for the West Pasture, which is attached in Appendix D.

SITE SELECTION DECISION TOOL

Site Selection

Key to designing Wapato Reach silvicultural treatments is selection of terrain sites that have physical characteristics that can support cottonwood forest stand recruitment. This is especially critical in the semi-arid climate of the Wapato Reach of the Yakima River. As identified in TM 1 (NSD 2020) Wapato Reach black cottonwood are facultative phreatophytes that utilize groundwater as their primary water source. The height of the surface elevation above groundwater capillary fringe is a limiting factor in selecting terrain specific cottonwood forest locations. Soil type characteristics were also found to be a limiting factor as aerated soil in the upper profile is necessary to support cottonwood. Soils in the Wierman and Zillah silt loam series were found to be the dominant Wapato cottonwood forest soil types. Given the spatial extent of these physical characteristics are available–from LiDAR digital elevation models and NRCS soil maps–a GIS–based decision tool was developed to identify Wapato Reach hydrologic, geomorphic, and soil type characteristics critical to the recruitment of cottonwood (Figure 1).

The next step in site selection was to use aerial photography to characterize existing vegetation found on these sites. Sites with either very low density cottonwood stands or with herbaceous or shrub groundcover are candidates for further on-the-ground reconnaissance surveys. Finally, an on-the-ground site rapid reconnaissance to confirm soil typing and to characterize groundwater depths is recommended. Together, GIS terrain analysis, vegetation remote sensing, field soils and groundwater assessment make up the *site selection decision tool* process (Table 1). In addition to the hydro geomorphic and vegetation assessment site ownership and access will need to be assessed.

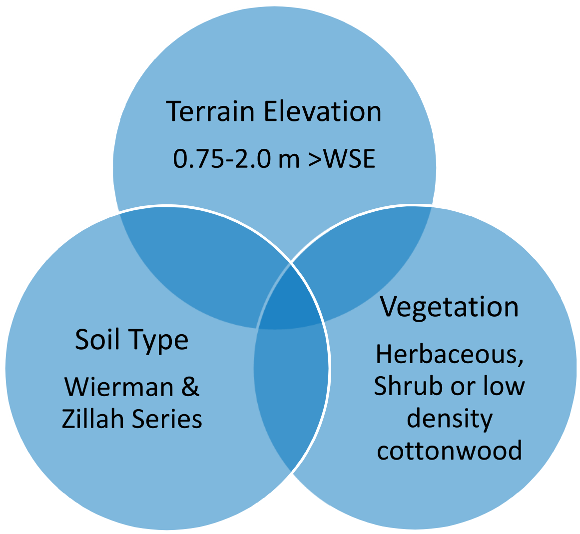


Figure 1. GIS Site Selection Decision Tool Analysis, intersect of existing cottonwood forest conditions: terrain elevation above water surface, soil type and existing vegetation.

Table 1. Site Selection Decision Tool

STEPS	SITE SELECTION DECISION TOOL
1	GIS Map REM Elevation range 0.75-2.0 meters > WSE
2	GIS Map Soils Type: Wierman and Zillah Silt Loam Series
3	GIS elevation & soils intersect mapping
4	GIS Map Landform Type: generic floodplain, abandoned channel, etc.[1]
5	GIS Remote sensing existing vegetation type: herbaceous, shrub, barren
6	Field survey: soil type verification
7	Field survey: groundwater depth measurement and GIS mapping

Notes: Landform types are–primary and secondary channels, perennial side channel, , ephemeral side channel, abandoned (active and non-active) channels, scroll bar, gravel bar, vegetated gravel bar, generic floodplain, terrace, generic floodplain terrace, agriculture.

Applying the site selection decision tool

Landform type and elevation, surface and groundwater hydrology, and soils type were previously identified as critical limiting factors in the establishment and recruitment of Wapato Reach cottonwood forests (Figure 2 & Figure 3; NSD 2020). Non-forested sites with these critically defined physical characteristics were mapped as a first order prioritization for the selection of potential silvicultural treatment areas (Potential planting Sites Map 1; Appendix A). Landform position results in a number of important cottonwood stand associated physical gradients including flood frequency and duration, exposure to shearing forces, sediment scour and deposition, sediment depositional characteristics, soil hydraulic conductivity and depth to ground water table (Merritt et al., 2010). Distinctive Wapato Reach alluvial patches were found to be generated by fluvial disturbance processes that are key to the landscape pattern of cottonwood recruitment (Figure 2 & 3). Specifically, Wapato Reach cottonwood forests were found to be growing predominantly on Wierman and Zillah soil series, at elevations 0.75-2.0 meters above summer low flow water surface elevations, and primarily on active floodplain flood deposits (Figure 3; NSD 2020).

Using these physical criteria potential silvicultural treatment sites were selected and mapped (Potential Planting Sites Maps 1-4; Appendix A), followed by examination of existing vegetation types using aerial photography and previous vegetation type maps (TM#1; NSD 2020). Potential silvicultural treatment sites currently have none or very low density of black cottonwood.

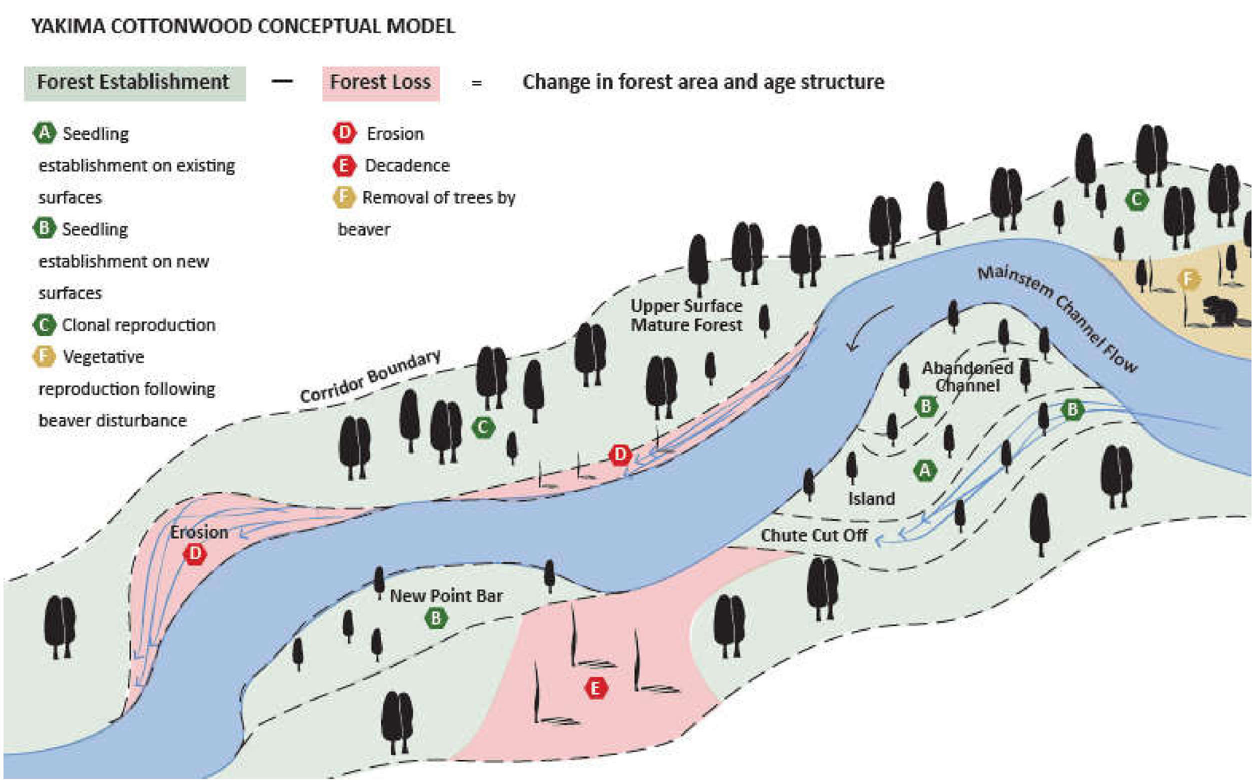


Figure 2. Wapato Reach cottonwood forest establishment, recruitment and loss by landform types.

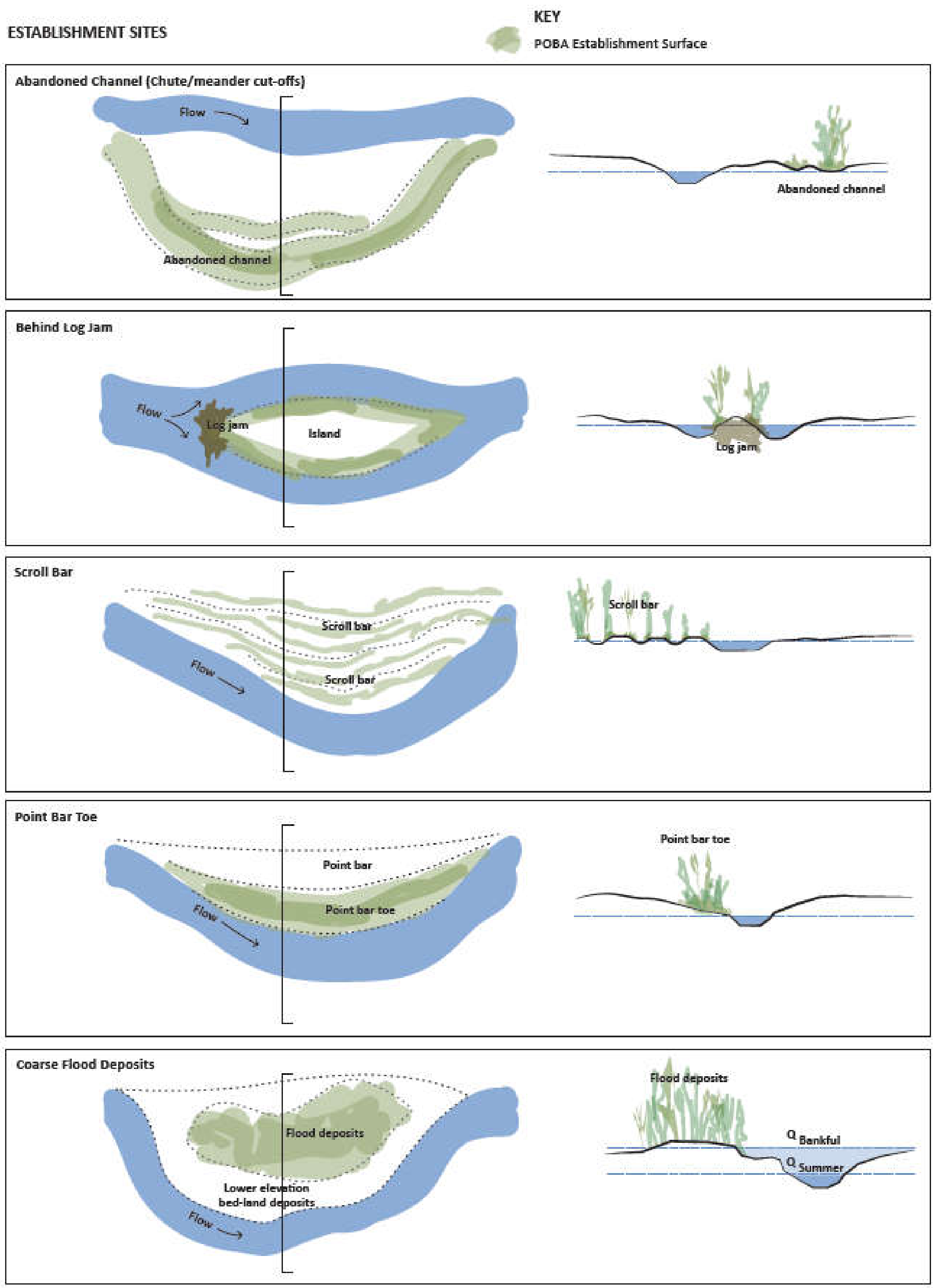


Figure 3. Wapato Reach cottonwood forest seedling establishment and forest stand recruitment sites.

Planting surface geomorphic landform types

The results of the decision tool GIS analysis indicate there are approximately 3,183 acres of area identified as having appropriate land surfaces suitable for cottonwood silviculture within the Wapato Reach (Figure 4; Potential Planting Sites Maps 1-4; Appendix A). Potential planting sites are dominated by agricultural land (37%), generic floodplain (30%), scroll bars (9%), abandoned channels (6%), ephemeral side channels (4%), vegetated gravel bars (3%), terraces (3%), gravel bars (1%).

It is interesting to note that the Upper Focus Area has significantly more potential planting sites that meet the cottonwood physical requirements (Potential Planting Sites Maps 1-4; Appendix A). The Lower Focus Area terrain is mostly greater than 2.0 meters in elevation above the water surface area–the upper elevation limit for cottonwood. The general lack of cottonwood forest cover in the Lower Focus Area is also reflective of the less dynamic wandering single threaded channel that does not generate large areas of barren erosional and depositional surfaces necessary for cottonwood seedling establishment and stand recruitment.

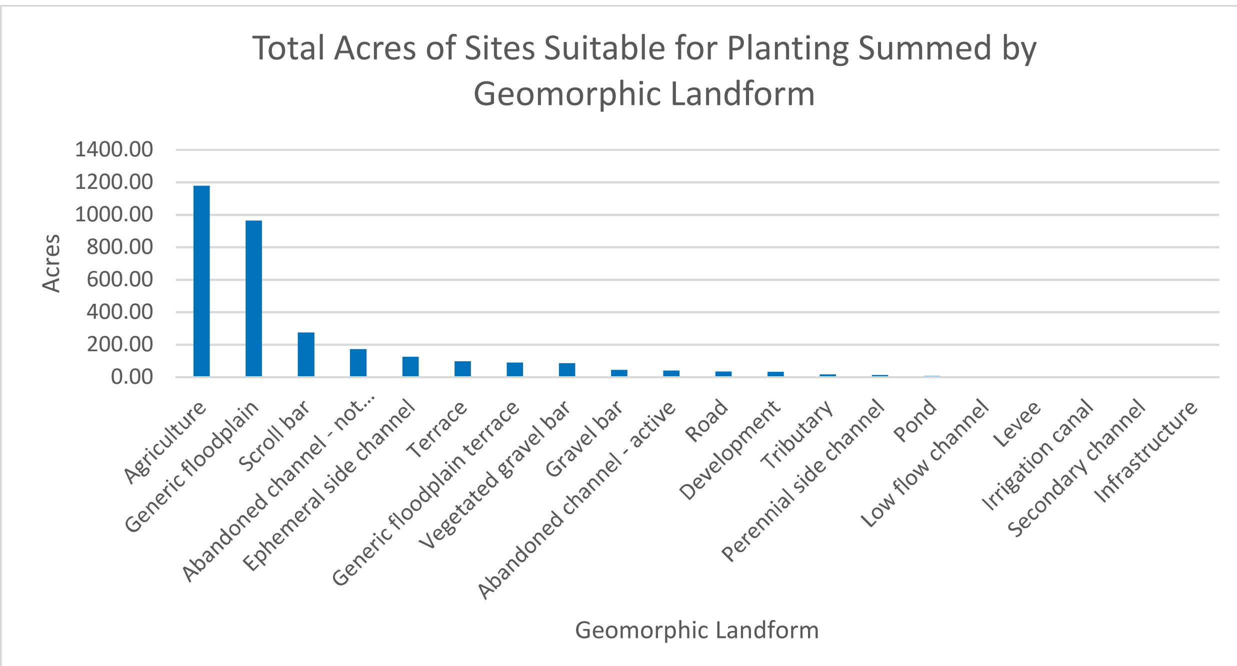


Figure 4. Total acres of suitable planting sites by landform type.

Field assessment

Following GIS analysis, and potential site selections are made, a field assessment should be conducted to ground truth GIS analysis selected locations. Site reconnaissance includes verification of soil types, groundwater characterization and vegetation assessment.

Additional Soils Characterization

Soil type is a critical element of potential cottonwood planting sites. Potential project area soils will be characterized by texture and color and compared with NRCS soils maps descriptions. If the site is an abandoned agricultural field soil salinity measurement (soil electrical conductivity (EC)) may be warranted before planting to rule out high soil salinity problem areas.

Groundwater characterization / measurement

Field assessment includes measurement and estimation of ground water depth by conducting a leveling survey of water body surface elevations and excavated soil pit water levels. If accessible, excavation will be conducted with either a back or track hoe, typically two to three trenches will be excavated to below the approximated water depth based on existing adjacent channel WSE. Once trenches are excavated water levels will be allowed to stabilize before surveying trench WSEs. A leveling survey will be conducted of the entire project site water, adjacent channel and other floodplain water surface bodies with either an RTK, total station or auto-level. Focus will be on surveying the WSE of the main channel, side channel, and other floodplain water bodies (e.g., emergent marsh, abandoned side channel, oxbow) WSE's. A site water surface elevation map will be generated from these points using ARCGIS Groundwater Tools. Using existing LiDAR DEM the generated ground and surface water field survey will be compared to a relative elevation model (REM) developed from the LiDAR. If further groundwater detail is deemed necessary, temporary static wells may be installed in the excavated trench sites for more in-depth monitoring of project area surface and ground WSE's.

COTTONWOOD FOREST SILVICULTURAL RESTORATION STRATEGIES AND DESIGNS

The focus of this technical memorandum is restoration of Yakima River Wapato Reach cottonwood forest stands, including willow species. The Site Assessment Decision Tool has been designed to physically characterize and locate those Wapato Reach alluvial terrain sites that will support cottonwood and willow forest stands. The Decision Tool is the first step in site selection and silvicultural design process. Once a site has been selected–and a field reconnaissance characterizing the site's soils, hydrology and vegetation conditions conducted–the next step is to develop a silvicultural treatment design that fits the unique site conditions.

Here we describe a suite of planting and natural seeding techniques appropriate for the Wapato Reach cottonwood forest. All of the silvicultural and horticultural techniques presented here have been developed and field tested by Mr. Chris Hoag, Hoag Riparian & Wetland Restoration LLC (see Appendix C). In addition to the silvicultural approaches, we introduce the design and application of engineered roughness elements that hydraulically support cottonwood seedlings and plantings within hydraulic high shear stress environments.

Using these proven planting and seeding techniques, riparian vegetation restoration design details and specifications may be developed on a project by project basis (see Appendix C for NRCS technical guidance for riparian revegetation, cluster plantings, and vertical bundles including designs, details and specifications). Here we present two silvicultural and river engineering approaches to several unique Wapato Reach terrain specific contexts. First, cottonwood nursery seed beds are presented. Second, approaches to designing channel roughness and planting elements for abandoned side channels, ephemeral side channels, scroll bars, vegetated gravel bar and gravel bar sites are discussed.

Cottonwood nursery seed beds

Given that natural cottonwood seed dispersal is the dominant strategy of cottonwood reproduction, that sexual reproduction provides population genetic diversity, and that seed germination and seedling establishment may occur on any open barren moist mineral substrate, the following approach is designed to utilize these natural cottonwood seed dispersal characteristics. Cottonwood need moist baren mineral soils with adequate oxygenation in the upper 50-100 cm of the soil profile to become established (Braatne et al., 1997). Cottonwood within the semi-arid Wapato Reach environment need access to groundwater during the growing season (May through October) to establish and recruit into a mature cottonwood forest.

Cottonwood seed dispersal

Cottonwood seed release occurs along the Wapato Reach during the months of May and June (Tom Elliott personal communication). Seed release timing is dependent upon cumulative daily antecedent temperatures which vary annually (Stella et al., 2006). Upon examination of the prevailing wind direction during the months of April through July it can be seen that west southwest to north northwest winds prevail within the Wapato Reach region during the period of seed dispersal (Figure 5). Using these black cottonwood life history characteristics, the Decision Tool analysis, current aerial photography, and local wind rose analysis, nursery seed bed sites were selected throughout the Wapato Reach (Figure 5 & Figure 6; Upper and Lower Focus Area Seed Bed Maps 1-4 Appendix A; Table 2).

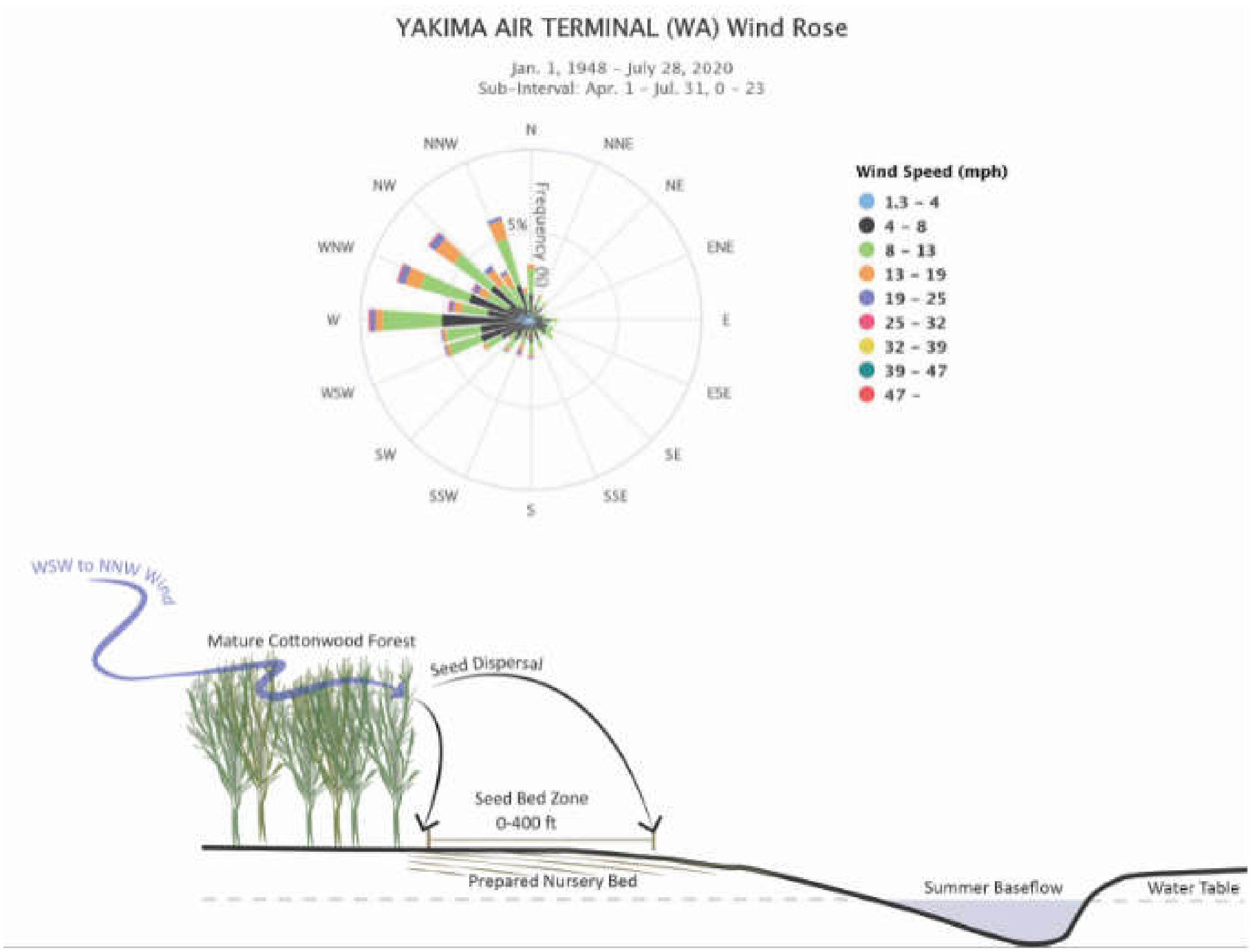


Figure 5. Cottonwood nursery seed bed and prevailing wind rose.

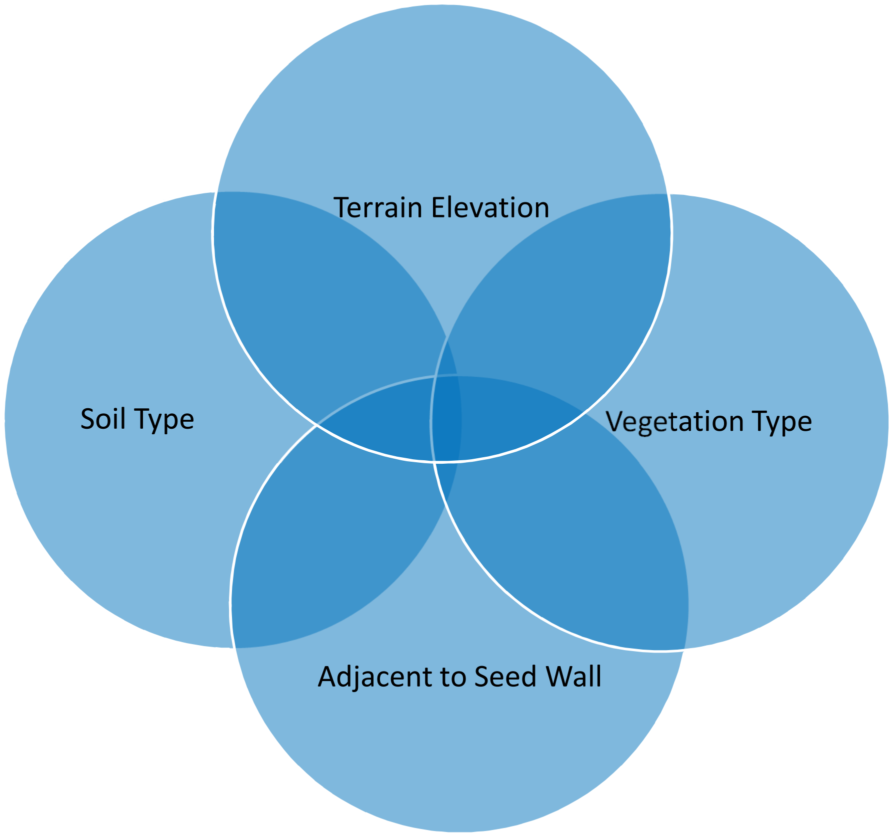


Figure 6. Site Selection Decision Tool, forest, and wind rose analysis

Cottonwood nursery seedbed preparation and irrigation

Upon selection of a nursery bed site using the Decision Tool (Figure 6) and Wind Rose analysis a field reconnaissance characterizing the site's soils and surface and groundwater should be undertaken. The nursery bed should be located within 200 to 400 feet of an adjacent forest seed wall (Figure 5). Nursery seedbed preparations include (1) removing all vegetation, and (2) disking, plowing or rototilling the area until smooth and level. Vegetation removal can be conducted using mechanical and chemical methods.

Once the site's soil is prepared a temporary irrigation system should be installed and maintained typically for two growing seasons. Irrigation systems include:

(1) Drip irrigation line with micro-sprinklers
(2) Irrigation handlines
(3) Wheel lines
(4) Flood irrigation (this approach may be touchy – as seed may wash way).

Irrigation of the seedbed should begin at the start of seed dispersal. An irrigation management schedule should be developed that maintains moist site conditions throughout the growing season (May through October) for two years. The degree of irrigation will depend on rooting depth and cottonwood development.

Select Nursery Seed Bed Sites

Based upon the Decision Tool analysis 50 potential nursery bed seed sites were mapped (Upper and Lower Focus Area Seed Bed Maps 1-4 Appendix A; Table 2 Appendix B). Of these 50 sites, 25 were selected based upon distance from adjacent cottonwood grove seed wall and adjacent water sources for temporary irrigation (primary or secondary channels) (Table 2). See Planting and Seed Bed Site Selection for Upper and Lower Focus Area Maps 1-4 (Appendix A) for select nursery seed bed sites. Additional analyses include ownership and access for site preparation and irrigation equipment installations.

Table 2. Select potential cottonwood nursery seed bed sites.

(Seed Bed Maps 1-4 Appendix A; See Appendix B for complete nursery seed bed analysis)

SEED BED SITE ID	FOCUS AREA[1]	TOTAL AREA (ACRES)
1	UFA	2.6
7	UFA	3.9
8	UFA	5.0
13	UFA	19.8
14	UFA	18.2
15	UFA	2.9
16	UFA	1.9
17	UFA	5.4
20	UFA	4.3
23	UFA	2.1
24	UFA	3.0
25	UFA	2.5
26	UFA	4.3
32	UFA	6.2
33	UFA	2.8
35	UFA	5.6
36	UFA	3.7
37	UFA	2.8
38	UFA	4.2
40	UFA	3.4
45	UFA	2.9
46	UFA	5.7
47	LFA	7.0
49	LFA	5.5
50	LFA	2.0

Notes: Upper Focus Area (UFA), Lower Focus Area (LFA)

Process Based Roughness Restoration Actions

Abandoned side channels, ephemeral side channels, scroll bars and vegetated gravel bars

Our observations of recently-established cottonwood forest indicate that successful establishment is focused on active fluvial landforms. Abandoned side channels, ephemeral side channels, scroll bars, vegetated gravel bar and gravel bar sites are often challenging to plant, naturally seed and establish cottonwood and willows due to both scour during high flows and the gravel and cobble coarse flood deposit substrates often found in these alluvial sites.

Abandoned side channels have been noted to create refugia for cottonwood recruitment and to provide safe sites for cottonwood silvicultural plantings (Stella 2011). Combined with installation of engineered wood structures, located at the head of abandoned channel and main channel confluence to reduce peak flooding velocities, relatively protected sites may be enhanced for planting cottonwood groves within the otherwise active channel environment. These sites, often dominated by gravels and cobbles, may be planted by using unique cottonwood/willow cluster plantings designs (See Appendix C for cluster planting details and specifications).

Abandoned channel mapping & planting site analysis

Abandoned channels were mapped as part of the landform typing. Overlaying abandoned channels with terrain elevation and soil type provides an additional landform specific approach to silvicultural site selection (Table 3; Potential Planting Sites and Geomorphic Landform Mapping Maps 1-4). Further examination of both aerial photography and the GIS maps allows for more detailed abandoned channel selection (Table 3; see Excel WorkBook: Table NF Metric English Appendix B for full details).

Upper and Lower Focus Areas contrast in the amount and prevalence of abandoned side channels. The Lower Focus Area has a prevalence of generic floodplains and terraces that are greater than the 2.0 meter, the upper threshold for cottonwood site selection. Potential Planting Sites and Geomorphic Landform Mapping Maps 4 & 5 show the total suitable planting area (Upper and Lower Focus Areas) by Abandoned channel NA (not active) and Abandoned Act (active).

Roughness Elements

Engineered Wood Structures

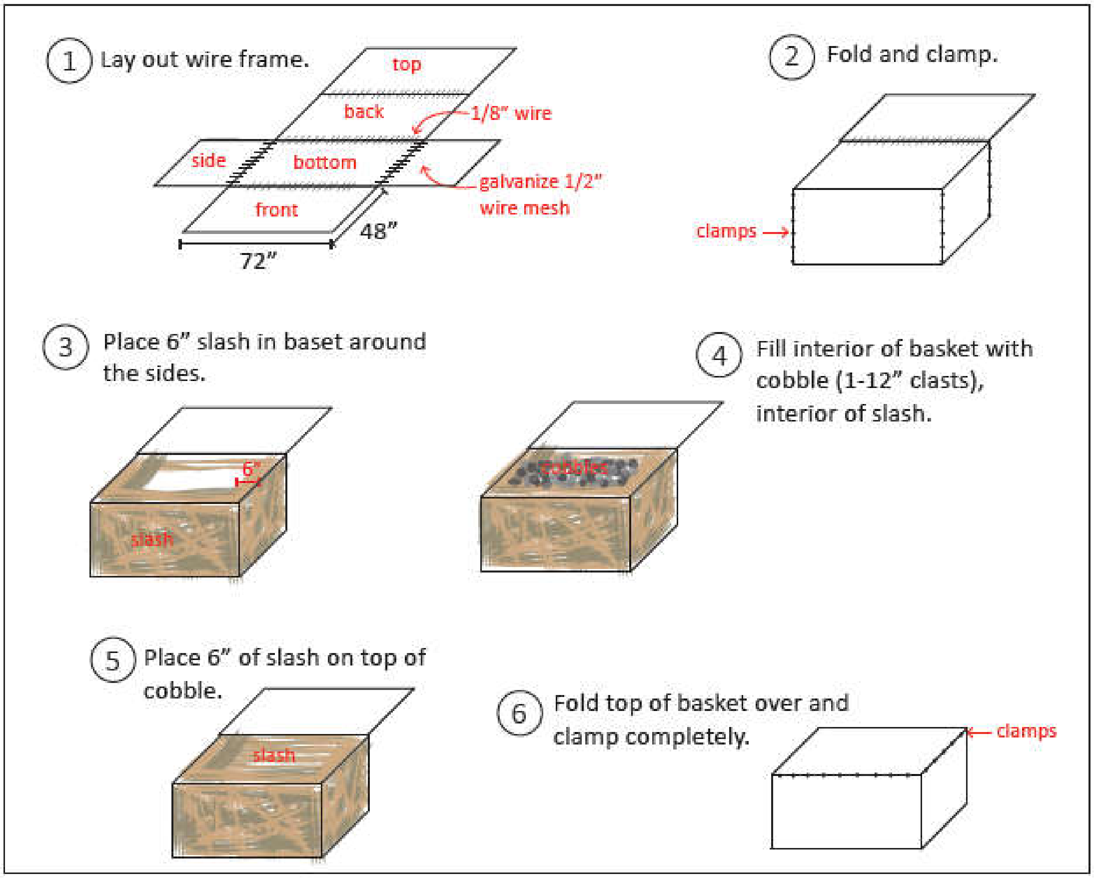
River restoration engineering actions can create lasting changes to the physical processes that cottonwood populations depend on without enacting changes to the existing flow regime. It is well established that valley and channel morphology, in-stream structure, and floodplain roughness alter the hydraulics in a river without any change to discharge (e.g. Knighton, 1998). Specific examples of variance in physical processes without changing discharge in an alluvial river include different channel morphologies such as single versus anabranching channels, the presence or absence of side channels, flow obstructions such as logjams, the elevations of floodplains relative to active channels, and floodplain plant communities (different stem sizes and densities). One of the most practical and well-established tools available for establishing these sub-reach changes in physical processes is through the construction of engineered log jams (ELJs). ELJ's come in a range of sizes, degrees of roughness and costs. ELJ's may be designed to provided hydraulic refugia, or hydraulic "safe sites," where cottonwood seedlings and plantings may establish and recruit into forest stands in an otherwise high shear channel environment.

ELJ's may be designed to fit a range and scale of hydraulic and habitat objectives. Here we are interested in introducing ELJ concepts that may be fully developed into hydraulic roughness designs in support of developing floodplain elements for cottonwood establishment and recruitment but could also support in-stream habitat complexity. ELJ's for the Wapato Reach may be used to provide both local hydraulic shadows, as well as, to raise water surface elevations through back water effects. Alluvial terrain features where ELJ roughness could be featured include: at the head of abandoned channels to deflect and reduce shear forces throughout the channel; at the head of point bars to create low shear and aggradational environments; mid-channel islands within braided reaches to stabilize islands providing safe sites for seedling establishment and plantings; as deflector jams to protect existing floodplain areas such as nursery seed bed sites.

Another roughness element we would like to propose is a simple and cost effective design we call the caddis basket (Figure 7).

Caddis Baskets

Caddis basket may be employed in many circumstances to locally reduce the degree of shearing forces by creating downstream hydraulic shadows (Figure 7, 8 & 9). They are simple, cost effective and relatively easy to construct on-site with a small track or back hoe (Figure 7). Caddis baskets are constructed out of galvanized wire mesh, local cobble and gravel and wood slash. Caddis basket arrays may be employed to protect either existing seedlings (Figure 8) or to create new safe sites where cottonwood groves may be planted (Figure 9). Common to both scenarios is the creation of low shear zones immediately downstream of the caddis basket array.



PLAN AND CROSS-SECTION

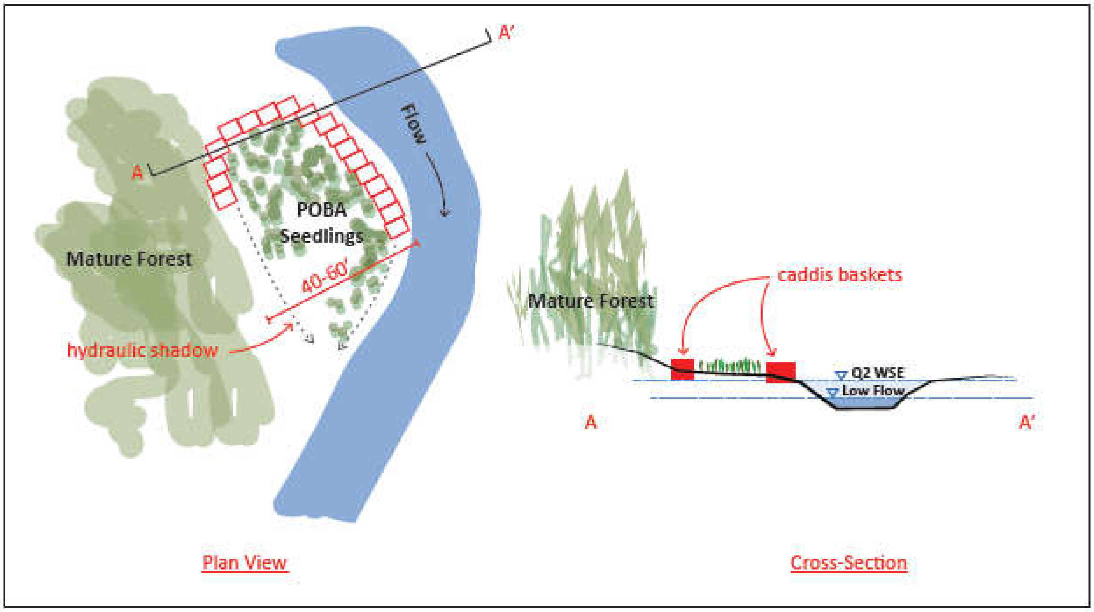


Figure 7. Caddis basket construction and design.

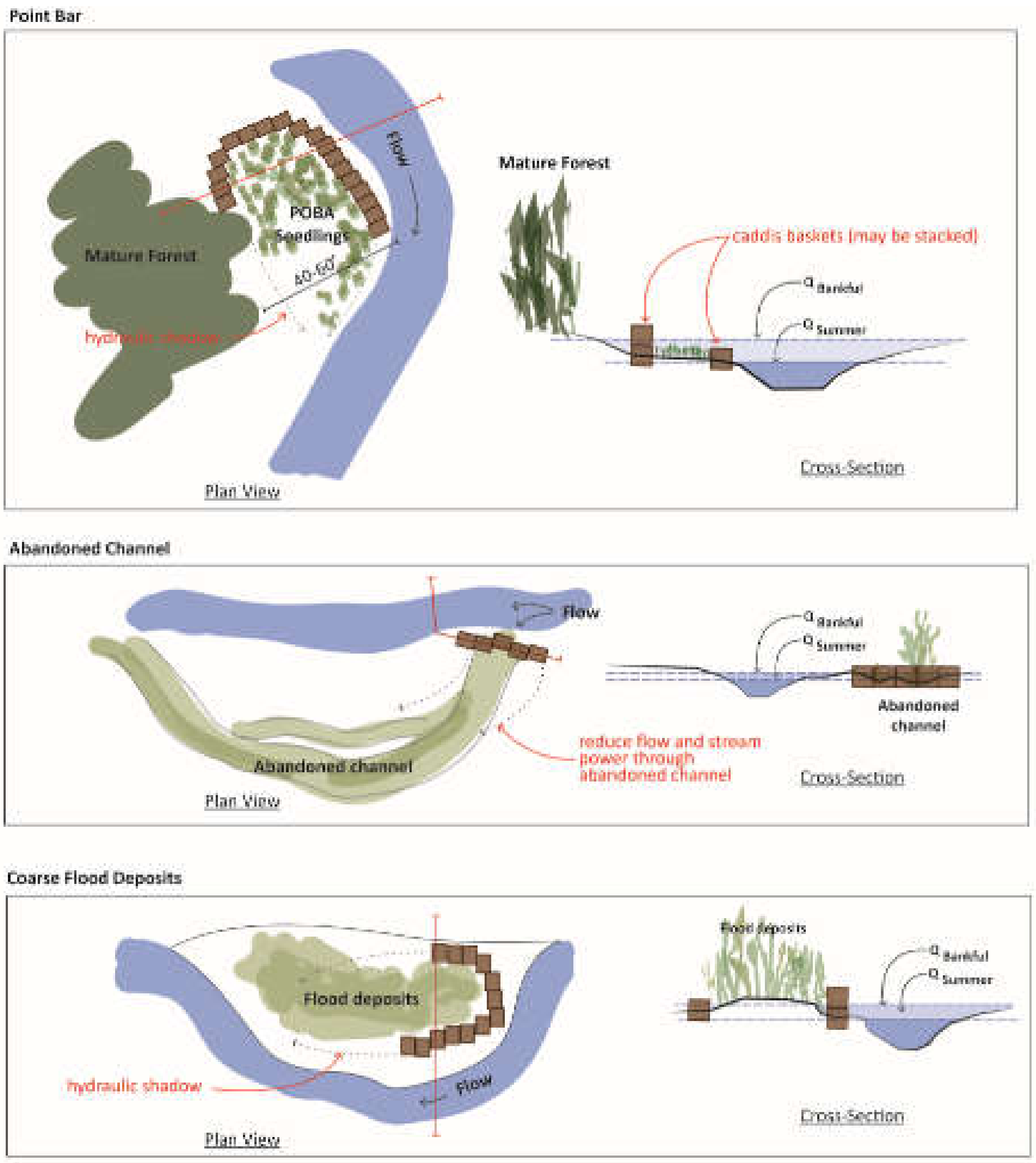


Figure 8. Caddis basket designs for point bar, abandoned channels and coarse flood deposits with existing cottonwood seedling and saplings.

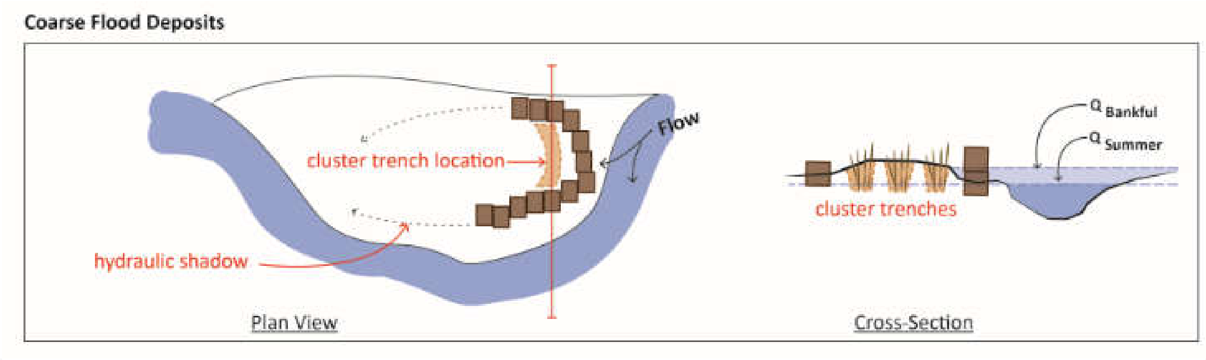


Figure 9. Caddis basket coarse flood deposit and cottonwood-willow cluster trench planting (see Section Appendix A for cluster planting details).

Engineered Wood Structures

As noted, under the current regulated flow regime, engineered wood structures may be utilized to create stable low shear alluvial surfaces at a number of Wapato Reach landform positions. Landform positions include: heads of abandoned (active and non-active) side channels, side channels, mid-channel islands in unstable braided reaches (Figure 10), and eroding floodplain surfaces. A range of engineered wood structures may be designed from simple piling stabilization of existing bartop wood, to flood fencing and engineered log jams (ELJs). Further engineering details are outside the scope of this contract.

Engineered log jams (ELJs)

Figure 10. An example of an unstable channel within the Wapato project reach (RM 92.5). The channel morphology indicates that channel migration and bedload transport rates are high throughout the reach and

could be prohibiting cottonwood establishment. The addition of engineered log jams to this reach would help stabilize the islands and provide areas of refugia from scour for cottonwoods to grow.

Planting techniques

Planting sites identified with the Decision Tool will vary as to terrain, soil and substrate conditions. Sites may range in conditions from an elevated floodplain flood deposit with sandy loam soil to gravel cobble conditions in an abandoned side channel. These variable conditions necessitate different planting techniques described below. All riparian planting designs, details and specifications may be found in Appendix C.

Collecting cottonwood seed and growing bare root and tall pot seedlings

Collecting cottonwood seed along the Wapato reach and growing them out in a local nursery to be used as 1-year bare root plants is a well established approach to generating cottonwood seedlings for planting in a range of sandy loam to silt loam floodplain conditions. Gravel and cobble substrate conditions are more suitable to live stakes and potted plants. For example, see below cluster planting technique for coarse sand, gravel and cobbles.

Willow clump plantings

Willow clump plantings are a streambank soil bioengineering technique for use in specific sites such as channel reconstruction projects where high energy and saturated soil conditions make using live stakes difficult to establish. (see Appendix C for details).

Cottonwood and willows

See Appendix C "*How to Plant Willows and Cottonwoods for Riparian Restoration*" (Hoag 2007) for a complete description of the following site assessments, plant materials, horticultural methods, and planting methods:

- Guiding principles for willow and cottonwood planting
- Site assessment protocols
- Species selection criteria
- Planting designs–species distributions
- Types of planting stock
    - Stem cuttings
    - Container stock
- Source of cuttings from commercial stock
- Source of cuttings from native stands
- Timing of harvest
- Cutting diameter
- Cutting length
- Harvesting cuttings
- Painting harvested cuttings
- Storage
- Treatment of cuttings
- Pre-soaking of cuttings
- Spacing considerations
- When to plant
- Planting methods and planting cuttings
- Clump planting

- Permits
- Management and maintenance

Cluster plantings in coarse sand, gravel and cobbles

Cluster planting unrooted cottonwood and willow dormant cuttings is a proven method for planting in coarse sands, gravels and cobbles (see *Cluster Plantings* (Hoag 2009; Appendix C).

RECOMMENDATIONS FOR A RIPARIAN FLOW REGIME

Background

Black cottonwood reproduction has been shown to be in decline within the Yakima River Wapato Reach over the past half a century since full implementation of hydroregulation in support of the Yakima River agriculture industry (Braatne et al. 2007; NSD 2020). The proximal cause of cottonwood decline is the alteration of the natural flow regime by hydroregulation. Under current regulated conditions, spring freshet flows are captured to fill the five dam reservoirs on the mainstem Yakima and tributary rivers.

Summer flows in the Wapato Reach are now lower during the critical seed release and seedling establishment phase of cottonwood reproduction. Lower flows directly relate to seedling establishment elevations that are lower than the historically and are now in portions of the active channel that are scoured during subsequent high flows (Braatne et al. 2007).

Recent research (NSD 2020) has confirmed Braatne et al (2007) results and further showed that small stands of cottonwood are reaching recruitment size (pole size >3 inches dbh) on slightly elevated flood deposit sites (0.75-2.0 meters above base flow water surface elevation (WSE)), compared to lower elevation seedling establishment elevations (<0.5 m above base flow WSE) (Braatne et al. 2007; NSD 2020). Successful establishment appears to be on deposits formed during peak flows such as in 1996 and 2011 (NSD 2020). Therefore, these events are used to establish elements a managed flow regime that could be adapted to favor successful and enduring seedling establishment that will accelerate the forest re-generation process.

Recommendations for adaptations to the managed flow regime are developed below, using our understanding of changes to the natural flow regime, the hydrologic and geomorphic requirements of cottonwood establishment, recent establishment patterns. From these lines of investigation, we provide the components of a managed flow regime along with our recommendations for next steps to refine the adaptations to the flow regime.

Changes in Flow Regime

Regulation of surface flows in the Yakima basin started as early as the 1890s with a canal at Sunnyside. After Sunnyside the water infrastructure in the Yakima basin was fully developed by six structures ending with installation of Roza dam in 1939 (Dick 1993). A schematic of the water infrastructure system is shown below on Figure 11.

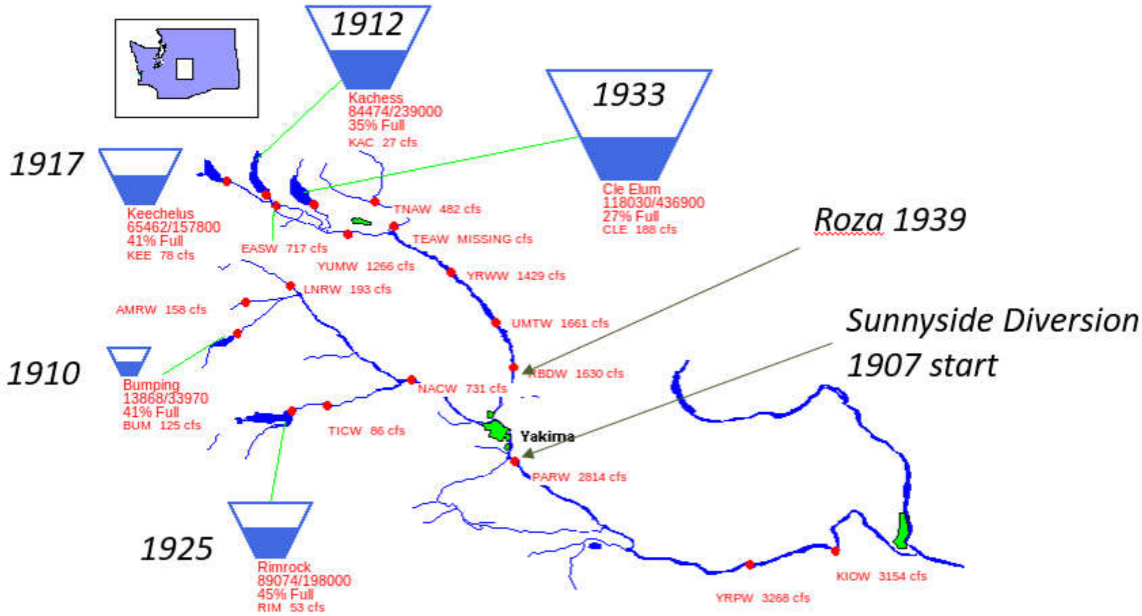


Figure 11. Schematic of major water infrastructure in the Yakima Basin with initial year of installation noted. Base graphic downloaded from US Bureau of Reclamation Hydromet. Note that elements have been altered and adjusted over time.

Accessible surface flow records extend back to 1898 with the USGS gauge 12503000 on the Yakima River at Union Gap extending to the present day. The US Bureau of Reclamation also maintains a database of flows that includes a “QU” dataset that provides an estimation of ‘natural flows’ (e.g. unregulated flows) in the basin.

These data sources allow us to document changes in the annual flow hydrograph that will influence how cottonwood seedlings can establish throughout the Wapato Reach. Figure 12 depicts a typical hydrograph using daily data from 1980 to 2019 compared to the BOR QU dataset.

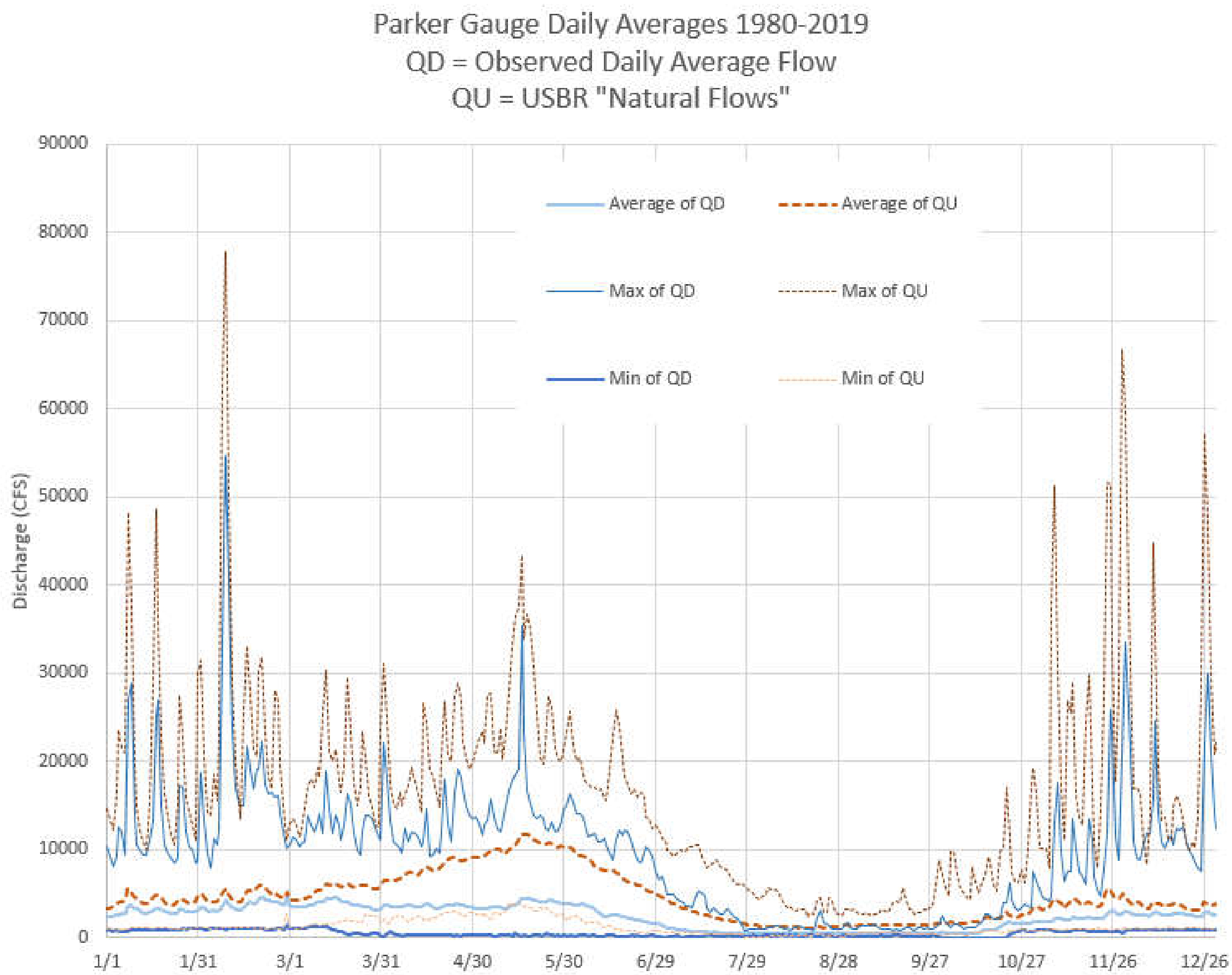


Figure 12. Current (solid lines) vs historical (dashed lines) trends in the annual hydrograph at the Parker gauge.

The trends depicted in Figure 12 show us four distinct patterns of today's flow regime compared to the pre-regulation era.

1. Today's average daily values are substantially below the natural average for the period from March to July, today displaying only a very minor snowmelt signal.
2. Today's average flows are strongly influenced by the minimum flows, which are very low due to the water managers actively storing water during the late winter and spring to provide sufficient water for agricultural use later in the year.
3. Base flow occurs from late July through October. Regulated baseflows are very low – roughly half of historical baseflows, and very similar to the minimum of historical flows based on the BOR QU dataset.
4. While the current average and minimum flows are strongly reduced, wet season peak flows (max of QD in Figure 12) still occur and are a significant influence on channel form. Peak flows are truncated from the historical condition, but today's peaks are still significant from a geomorphic perspective, driving sediment transport, deposition, and channel migration processes.

Regulation of surface flows in the Yakima River has therefore significantly reduced typical flows in the key cottonwood seedling establishment period in May and June. The reduction in flow magnitude and late snowmelt timing can be observed in the monthly average flows from 1898 to 2019 using combined data from the Union Gap and Parker gauges shown below in Figure 13.

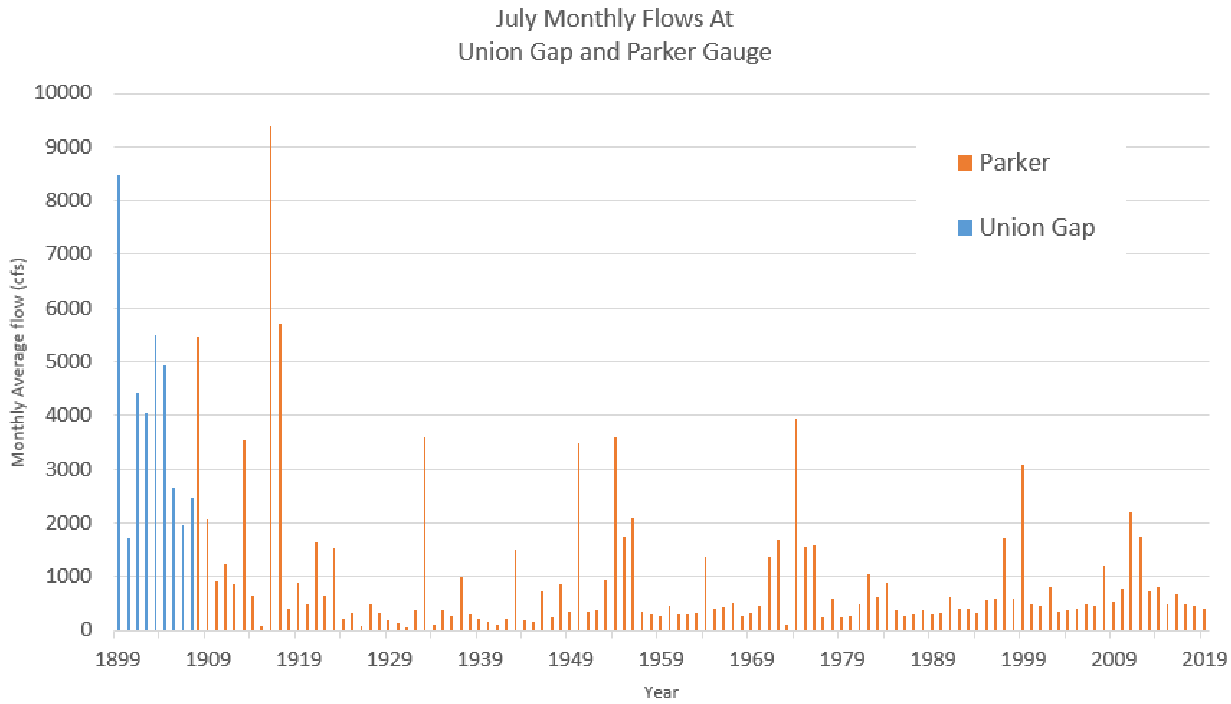


Figure 13. Monthly Average Flows in the Yakima River 1898 to 2019 using Union Gap (blue) and Parker (orange) gauges

Anthropogenic changes to flows began prior to the data displayed in Figure 13, however, as noted above, the water infrastructure system was progressively built out until the 1930s. Generally greater variance and higher monthly averages are evident prior to approximately 1917 when Keechelus and Kachess reservoirs were completed.

The recession from snowmelt to summer baseflow is highly altered, with today's average flows similar to the lowest natural flows in the QU dataset with the observed average for comparison (Figure 14). The recession rate during the historical period would have been a significant influence on cottonwood seedling establishment. Using the average flows from the QU dataset, the recession period occurs over a period of 49 days at a rate of -150 cfs/day (Figure 14). The natural flow dataset recession appears to be linear, rather than a power law function which is more typical of natural stream flow recession.

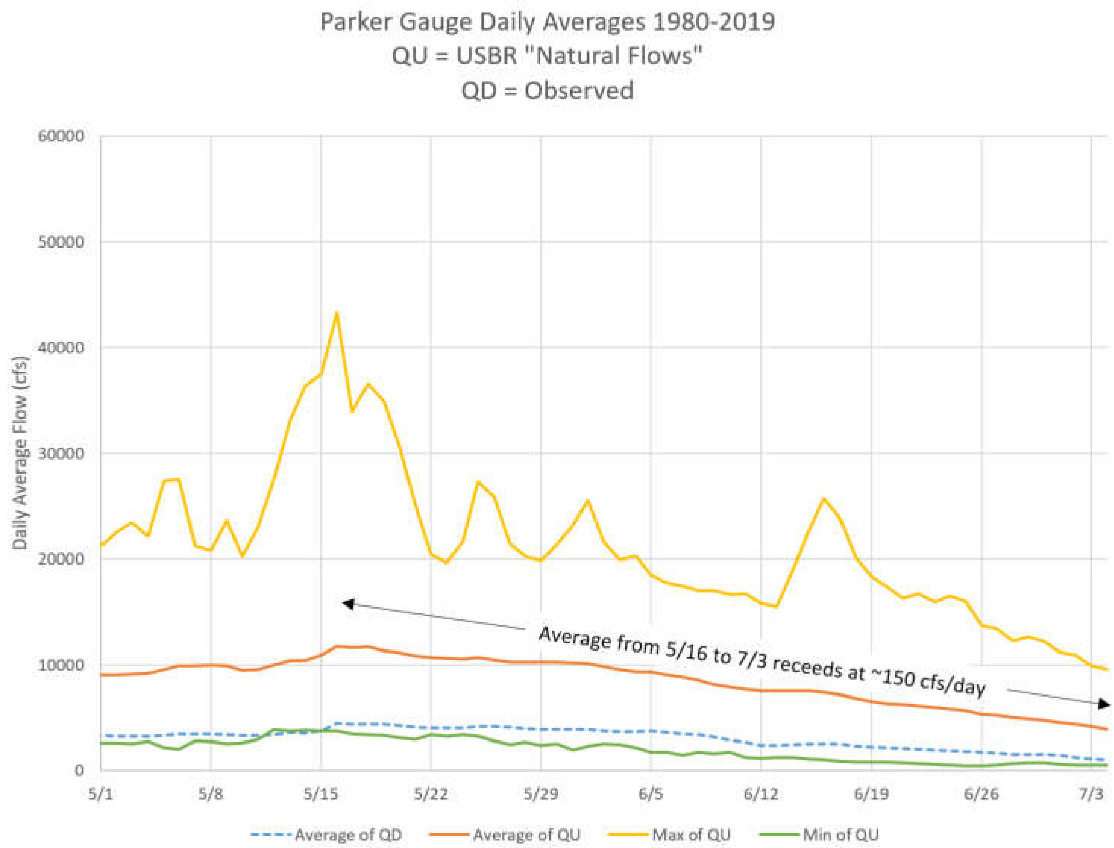


Figure 14. May to June average flows at Parker Gauge for the QU dataset

Despite the highly regulated flows, significant flow events still occur in the basin. In 1996 an approximately 1 percent annual chance flow event occurred with an instantaneous peak flow of 58,150 at the Parker Gauge. Peak flows are certainly truncated from the past, but the overall frequency and timing of large events (greater than 20,000 cfs) is likely similar to the past (Figure 15).

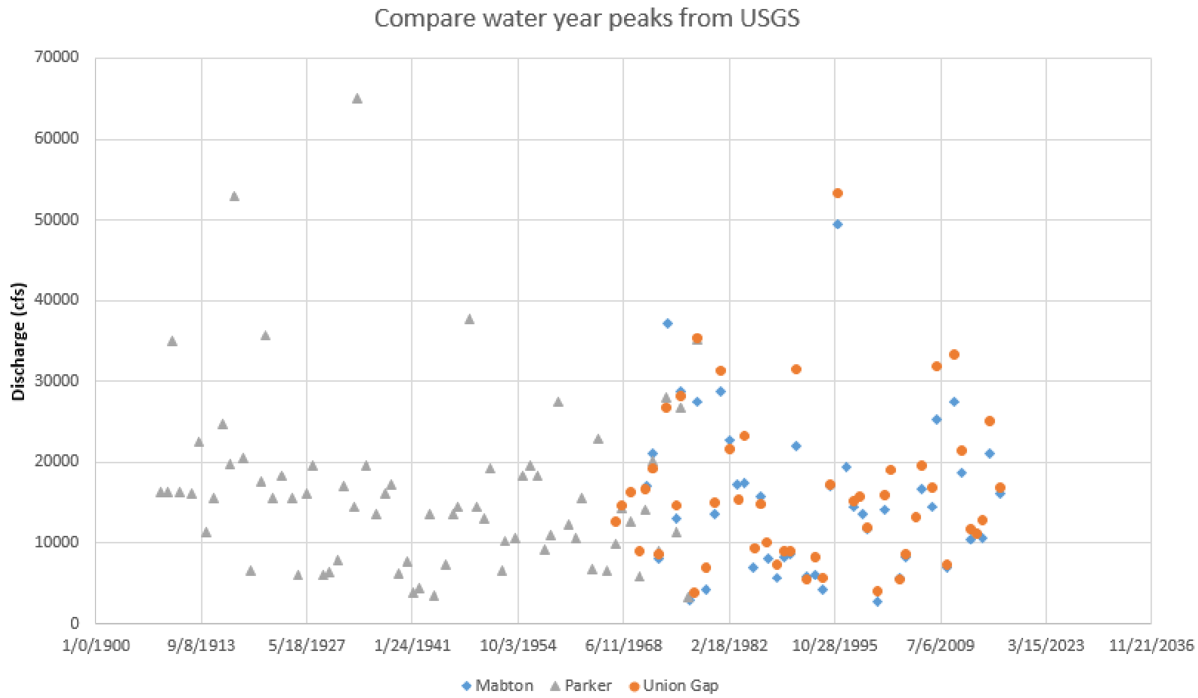


Figure 15. Annual peak flows from three gauges along the Wapato Reach

Hydrologic and Geomorphic Requirements

Changes to the Yakima River's annual flow regime have both: (1) reduced the opportunity for new cottonwood forest development, while (2) still allowing sufficient peak flows that drive channel migration processes that erode existing cottonwood forest. Under current conditions, the rate of forest loss is greater than forest regeneration (NSD 2020).

The *Conceptual Model of Cottonwood Forest Development* (NSD 2020) identifies the following hydrogeomorphic conditions that appear to support successful seedling establishment to pole size stands:

1. Creation of new bare mineral soil fluvial land surfaces (scoured floodplain, overbank deposits, and/or aggraded in channel bars) with elevations between 3.2 and 4.8 feet (1 to 1.5 meters) above baseflows.
2. Pair the creation of new fluvial landform surfaces with a flow recession curve that supplies a steady lowering of
3. Create hydraulic conditions that avoid scouring flows on newly exposed surfaces. In general, these are more complex areas with side channels and strong lateral flow patterns and protected areas in the lee of log jams.

Recent Peak Flows and Establishment Patterns

Within the last 25 years, significant peak flows of greater than 26,000 cfs (10 percent annual chance recurrence interval) have occurred, with different outcomes for cottonwood establishment. While 1996 generated more potential establishment area, the 2011 event appears to have generated more pole-sized stands, suggesting more enduring cottonwood establishment.

Table 3. Cottonwood forest establishment areas after 1996 and 2011 floods.

FOREST METRIC (FOCUS REACH)	1996 FLOOD	2011 FLOOD
Total potential establishment sites created *(acres of gravel bars)*	420	220
Total area of forest formed (acres) *1996 -2015 forest polygon (open/closed/woodland)* *2011 – Pole size digitation*	29	54
Establishment effectiveness % *(% of potential sites actually established)*	7%	25%

To provide context for adjustments to the managed flow regime, we offer a comparison between the 1996 and 2011 flood events (Figure 16).

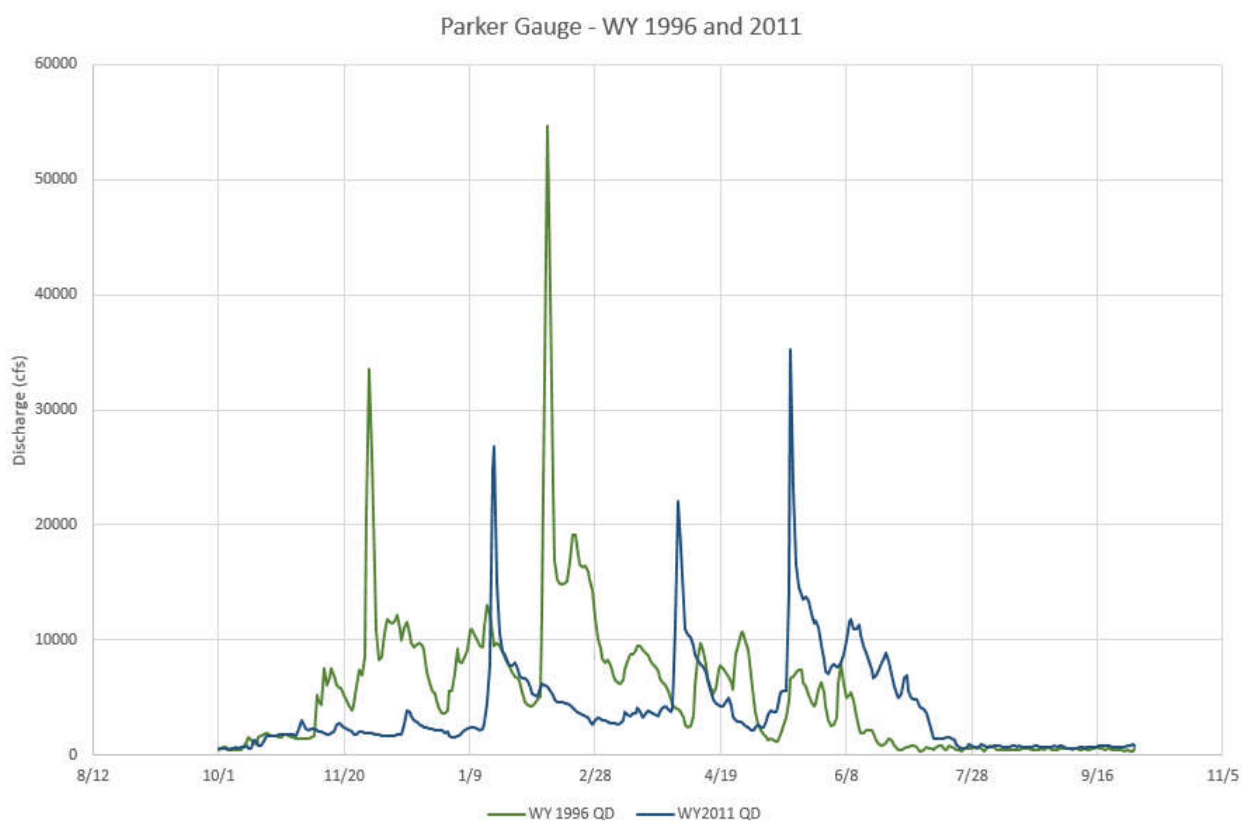


Figure 16. Observed daily average flows for 1996 and 2011

As noted on Figure 17 below, the 1996 event was truncated to approximately 75% of the BOR "QU" peak flow, but the event inundated much of the active floodplain and resulted in broad channel changes through the system. The 1996 event occurred as a single peak in February, with a rapid recession to less than 10,000 cfs by the end of that month. The snow melt period from March through June was less than 10,000 cfs and was highly variable during that period.

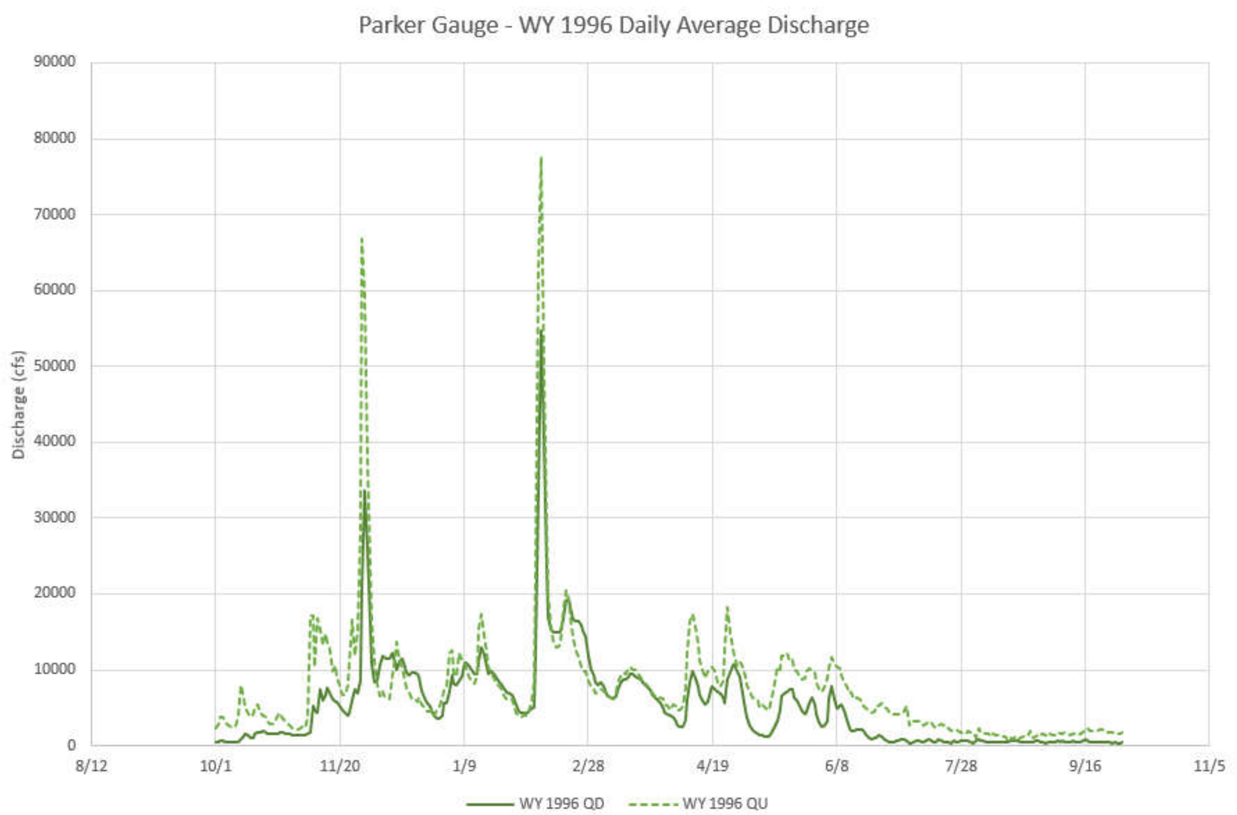


Figure 17. Comparison of observed 1996 flood event to BOR QU prediction of natural flow

In 2011, there three significant peaks over 20,000 cfs with the last relatively late in the year in May (Figure 18). After the last peak, the recessional curve occurred from mid-May to July, and displayed less variance than 1996.

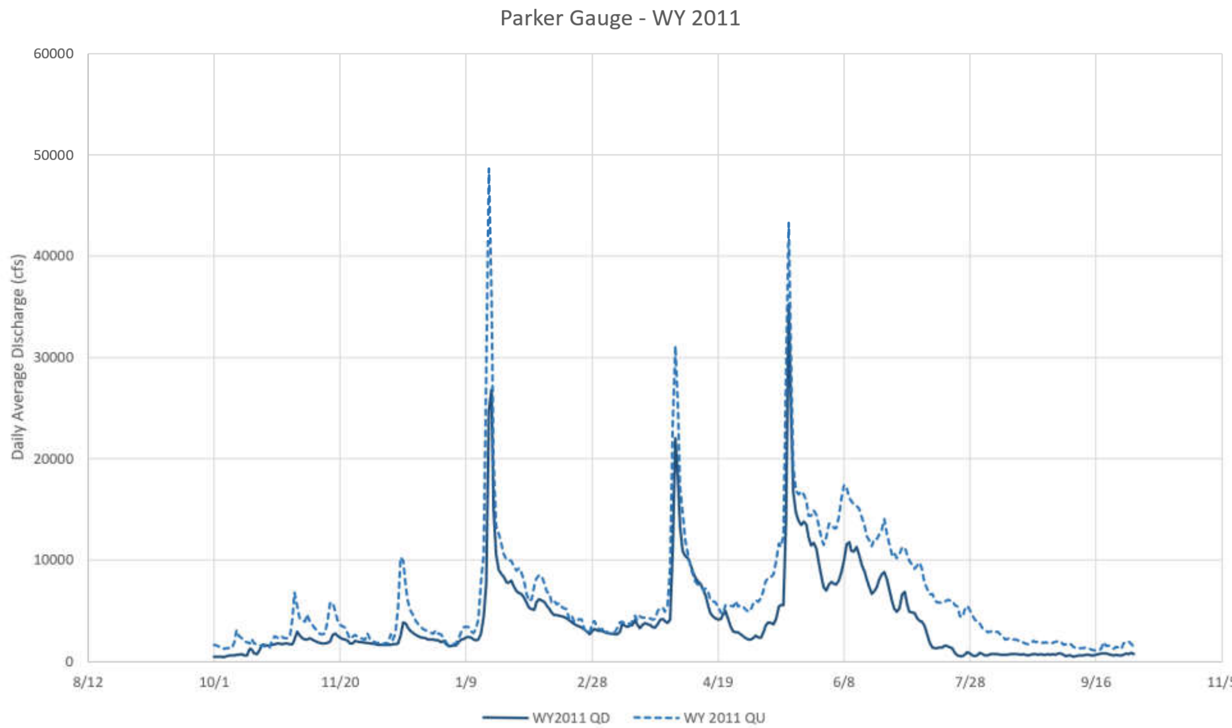


Figure 18. WY 2011 Daily Average Flows for Observed (QD) and Natural (QU)

A comparison of the recessional curves to baseflow (generally starting with the last drop below 10,000 cfs) between 1996 and 2001 is shown below in Figure 19.

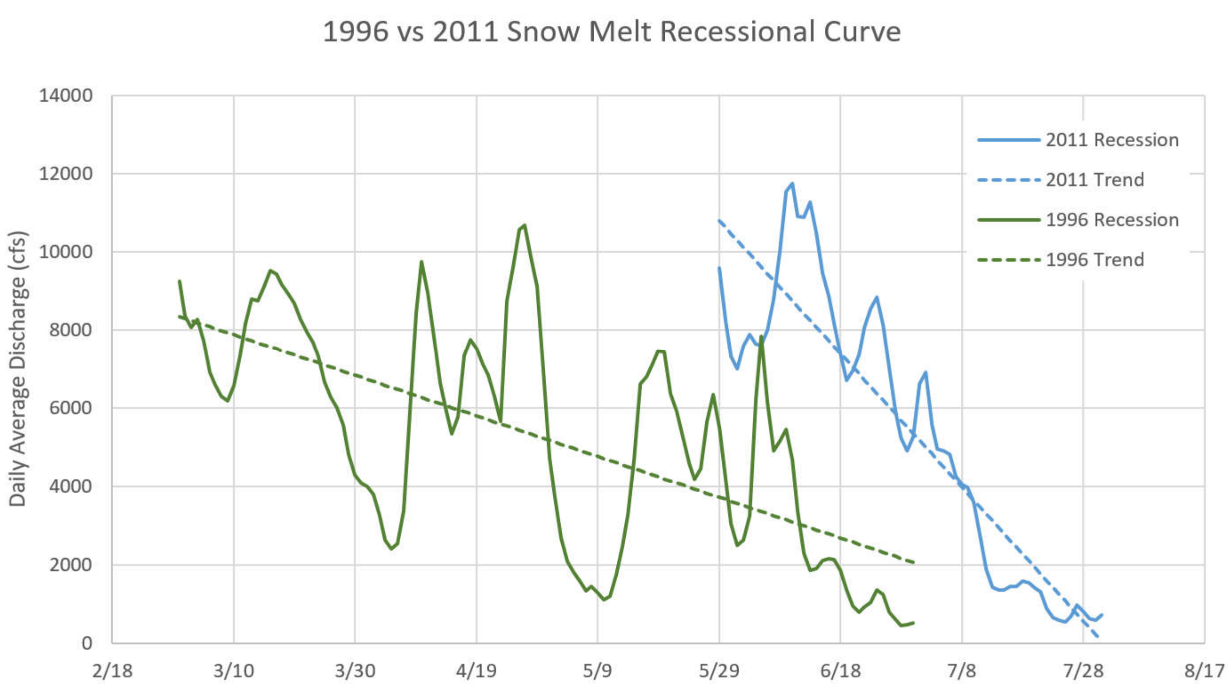


Figure 19. Comparison of snowmelt recessional curves (generally between 10,000 cfs and summer base flow) for WY 1996 and 2011 with least squares linear fits shown.

The 1996 curve starts sooner and drops to baseflow by mid June. The 1996 recession has significant variance above and below the linear trend, with an average deviation of 1,700 cfs. More significantly there are two longer duration negative excursions that represent times when the water level would have dropped significantly at establishment locations. From an establishment point of view, the low excursions have the potential to break hydrologic contact with developing roots.

The 2011 recessional curve occurs later and is shorter and steeper between 10,000 cfs and baseflow for summer 2001. The 2011 recession had less variance, and the variance had limited negative excursions below the trend line after an initial drop to below 8,000 cfs.

The timing of the recessional curve will also influence the degree and ultimate success of cottonwood establishment. While seed dispersal timing has not been established for the Wapato reach, similar efforts in other regions has tied timing to temperature patterns. For 2011, a general comparison of flow timing to minimum and maximum daily temperatures is shown in Figure 20.

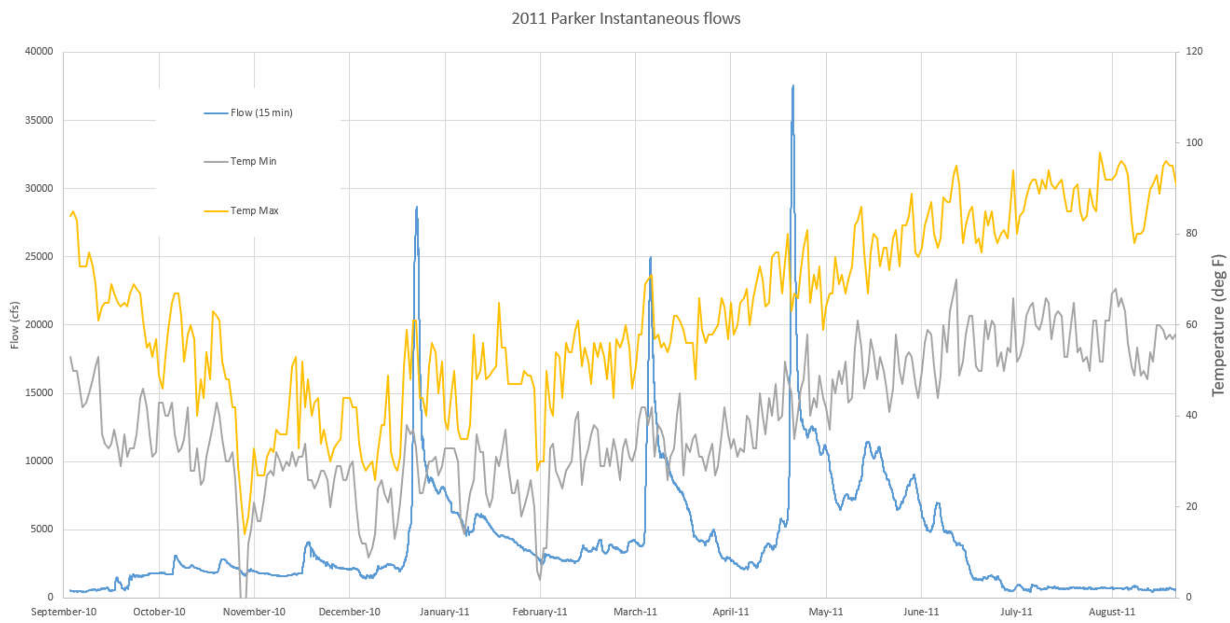


Figure 20. WY 2011 flow hydrograph with daily temperature minimums and maximums from nearby airport data.

With our observations that conditions in 2011 resulted in more cottonwood establishment than 1996, our comparisons suggest that these years differed most significantly with the timing of the peak, timing of the last peak over 10,000 cfs, and the shape and timing of the recessional curve.

In 1996:

1. The landscape resetting peak was early in the year, prior to seed dispersal.
2. The last peak in the likely seed dispersal window was relatively low (less than 10,000 cfs).
3. The recessional curve occurred earlier in the year and over a longer period but was highly variable with deep negative excursions from a smooth recession curve. These negative excursions appear to have the potential to drop water levels faster root establishment, in particular the abrupt drop in 1996 after a small peak to 10,000 cfs.
4. Baseflows were average in the summer of 1996.

In 2011:

1. There were three peaks over 25,000 cfs, each one had the potential to create establishment sites.
2. The last peak was the largest, and occurred closer to seed dispersal, so may have been more effective at delivering seeds to establishment sites.

3. The recessional curve was relatively short but had less overall variance than 1996 with limited negative excursions below a linear trendline.
4. Baseflows were above average in the summer of 2011.

Recommended Components of a Managed Flow Regime

The 2011 annual hydrograph appears to provide a template for a flow regime that is likely to establish more cottonwood than the loss rate for the Wapato Reach. Under current conditions, there is more loss than establishment, so increasing the frequency of 2011 type events would be necessary to change the ratio of establishment to loss.

Using the 2011 year and the conceptual models developed by Braatne and NSD, the following appear to be the key elements of a managed flow regime:

1. Geomorphically effective peak flows that develop appropriate establishment areas. Peak flows of over 20,000 cfs appear able to develop these areas. These events occur today, despite the high degree of regulation, so it is likely that the flow regime will need to be adaptive to respond to years after appropriate peak flow events.
2. A peak in the seed dispersal window. Some aerial dispersal can occur, but it is likely that a late peak sufficient to deliver seed to appropriate establishment locations. This peak needs to be sufficient to inundate the area between 3.2 and 4.6 feet above baseflows to match the most successful apparent establishment zone that is less likely to be scoured the following year.
3. Tie the last peak to a relatively smooth recessional curve that does not include significant drops in flow and stage

These elements are conceptually shown below over the range of recently observed daily average flows (Figure 21).

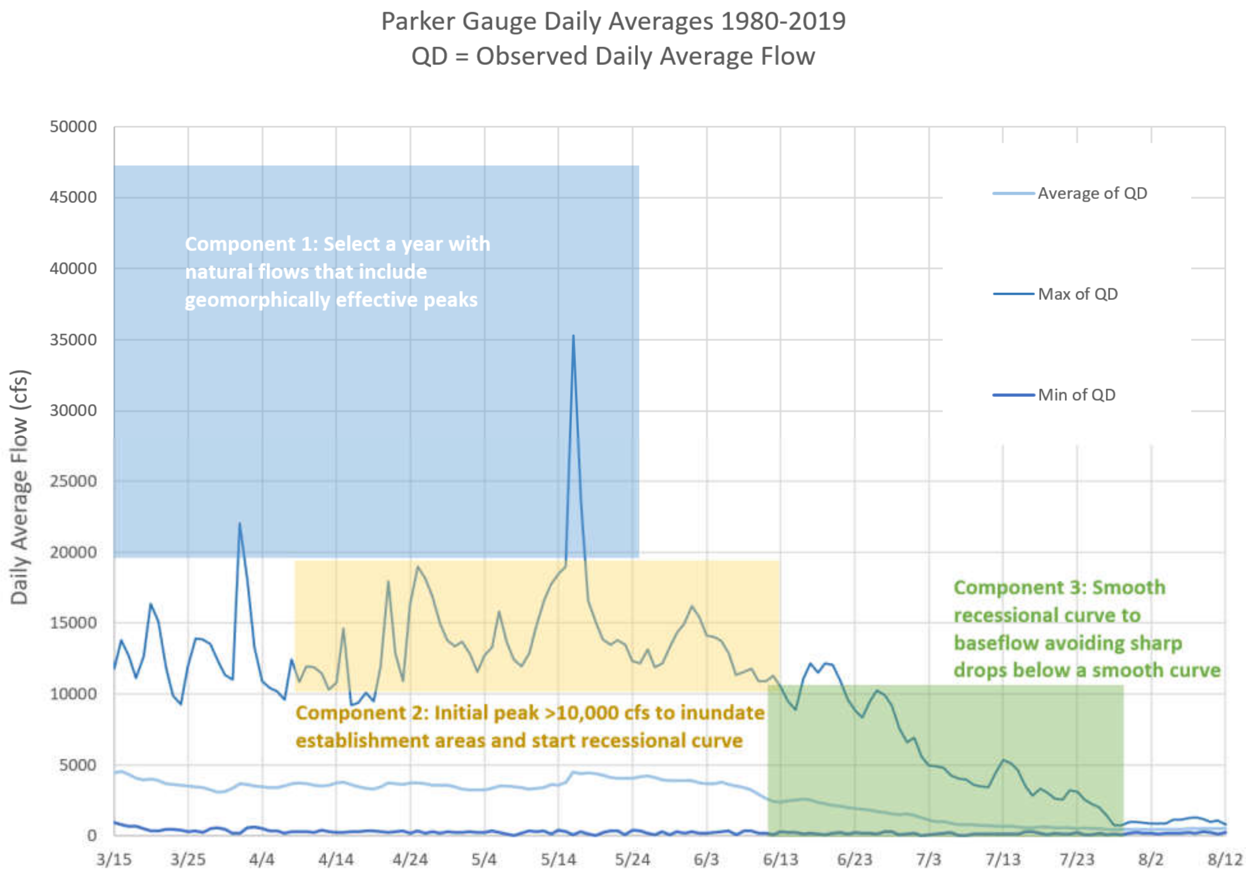


Figure 21. Conceptual Elements of a Managed Flow Regime for Cottonwood on the Wapato Reach

In addition to flow changes, there are physical changes to the system to alter local scale hydraulics that are discussed elsewhere.

Future Data Needs

To make the recommendations presented above into an actionable flow regime, it will be necessary to:

1. Refine our understanding of seed release in the existing forest by developing a cottonwood temperature seed release climate day model (Synchrony of Seed Dispersal, Hydrology and Local Climate Model Stella et al. 2006). Understanding seed release timing is necessary to most efficiently establish the timing of the start of the recessional curve.
2. Refine the existing 2D hydraulic model to be able to relate recessional flows to stage at lower flows. The Yakima County hydraulic model is a good base, but was built to be primarily a flood model, so was not resolved at lower flows that influence cottonwood establishment. More detailed bathymetry and calibration to lower flows (e.g. with stage within 6-8 feet above base flow. An unsteady flow model (varying flows in time) will be optimal to relate flow release to change in water elevation at potential establishment sites.
3. Review flow needs for other species. There may be trade-offs between flows likely to establish and sustain cottonwood and needs for other species, so these should be considered in identifying the details of the flow release (e.g. Tonkin et al 2020).
4. Review of multi-year trends after establishment events. We do not currently know how the years after an establishment event influence cottonwood survivorship. We also do not know how long establishment areas are viable after they are formed.

5. Assess dam operations to determine the feasibility of controlling releases to provide appropriate recessional rates. With the degree of regulation in the system and other water user needs, it will be necessary to establish a feasible set of actions to physically create the desired flow conditions.
6. Develop a decision tool to allow water managers to identify seasonal flow conditions that will allow the activation of the managed flow regime in response to natural runoff conditions that supply enough water to support the appropriate inundation flow and smooth recessional curve.

Wapato Reach - Meninick Wildlife Area/West Pasture Site

See Appendix D for complete DRAFT

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